FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

DEPARTAMENTO DE ENGENHARIA MECÂNICA E GESTÃO INDUSTRIAL

VISHAY

SPRAGUE

SANFORD, MAINE
USA

# RELATÓRIO DE ESTÁGIO

## LICENCIATURA EM GESTÃO E ENGENHARIA INDUSTRIAL

DEMEGI-FEUP
*006300*

# 'OPENS' IN TANTALUM CAPACITORS

621(047) SIL/OPE
0037595
UNIVERSIDADE DO PORTO
Faculdade de Engenharia
BIBLIOTECA
N.º 42467
CDU
Data / / 19

João Manuel Mourão Dias da Silva

**Supervisors**

Prof. Alcibíades Paulo Soares Guedes
Daniel W. Johnson, Process Engineering Manager

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# SUMMARY

This document reports a six-month internship program at Vishay-Sprague, in Sanford, Maine, USA, which started in March and ended in September 1998.

This company produces a type of electronic passive components named 'tantalum capacitors', making use of a rather long and complex process, which has got its virtues as well as its problems. One of those drawbacks is a failure that occurs during the assembly line, in the molded-chip components, that is hardly detected by the standard quality control procedures: poor weld of the anode wire to the lead-frame.

Efforts have been made to correct or, at least, minimize this problem but it seems that only a structural change in the current welding process will be able to significantly reduce this failure. Meanwhile, due to market conditions and the increasingly higher quality levels required by customers, the detection of units with deficient anode attachment became a priority.

Two main criteria were considered in order to distinguish between good and bad units: 'force vs. deflection' and 'weld height'. Both produced very good results, concerning that distinction; both generated several ideas, regarding their correspondent practical approaches.

In the end, laser technology seemed to be the best solution and an off-line prototype was built in order to test its feasibility. The debugging period was rather long, bringing in a lot of doubts and, therefore, leading to very solid conclusions, concerning both the features of laser-based dimensional measurements and the original premise of the weld heights.

Due to urgently scheduled customer demands, the laser experiments could not be conducted to the end and gave place to a short-run approach, making use of the same prototype machine and a SMAC Moving Coil Actuator, regarding the implementation of a Statistical Process Control (SPC) station.

It has been generally accepted that laser technology can be the answer, in the medium-run, if a 100% inspection is to be installed along the assembly line. For the moment, the off-line SPC tool can be very useful, not only to assure the process stability, but also to help solve the problem on its root, which must always be the ultimate goal.

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# 1. INTRODUCTION

The 'opens' failure is not new. As a matter of fact, it is as old as the molded chip product and its occurrence has actually been reduced in recent years, as a result of several corrective actions involving the welding parameters. The reasons why it became so visible now are related not only to internal quality policies but also, and fundamentally, to customer service commitments. What used to be a reasonable "percentage of defectives" can no longer be accepted by the current market standards of the electronic industry. Ten years ago we would comfortably deal with 1% of defective product; nowadays, it is common to find customers requiring ratios in the order of 0.1 ppm (parts per million), meaning that only *one* unit out of *ten million* (1/10,000,000) 'is allowed' to be defective!!! Definitely, we are in zero-defect era.

Of course 'opens' are not the only failure in tantalum capacitors, but they have originated the most recent and strong complaints from important customers, who are not willing to accept any more palliative actions towards this issue. [see sample complaints from a customer in **Annex 1**] A project that centers its attention in the detection of bad units, for consequent rejection, may seem another palliative approach. Nevertheless, being able to *efficiently* distinguish between good and bad welds is the first step to a safe monitoring of the results of any attempt (whatever it is) to minimize the failures resulting from this stage of the process.

One of the main purposes of this project is, thus, the definition of consistent and absolute criteria of discrimination between good and bad parts coming out of the assembly line, concerning the anode wire attachment. These criteria should be easily translated into a single parameter or a combination of parameters, based on which binary values (*1/0* meaning *good/bad*) can be determined for each unit and permit an automatic decision followed by an automated action, free of any human intervention.

This leads us to a second general purpose of the project, which is the selection of the appropriate technology to execute this evaluation in the production line. Many aspects have to be taken in consideration, such as: reliability and repeatability of the collected data, maintenance of the sub-system in the assembly line, type of software, speed (product cycle time must be respected) and destructibility of the testing method.

Another purpose of this project is the study of the behavior of the chosen technology under conditions similar to the production line environment. This leads to the development of a semi-automatic prototype, which is supposed to receive the units manually, collect the correspondent data, treat it through programming and display the output on a screen. Of course, in production line this output would be transferred to a following station, where the identified 'bad units' would be automatically eliminated.

Only one case size of the molded chip product is object of our study. The smallest and, therefore, most difficult one was chosen; it is called 'A case'. Once this case size is solved, all the others can only be easier.

All the costs associated to this project belong to the item 'costs of quality', and can be fully justified based on market positioning and customer satisfaction. In the future, if any automation is really added to all the assembly machines (in a total of 26) as a result of the present study, then a proper project appraisal is recommended.

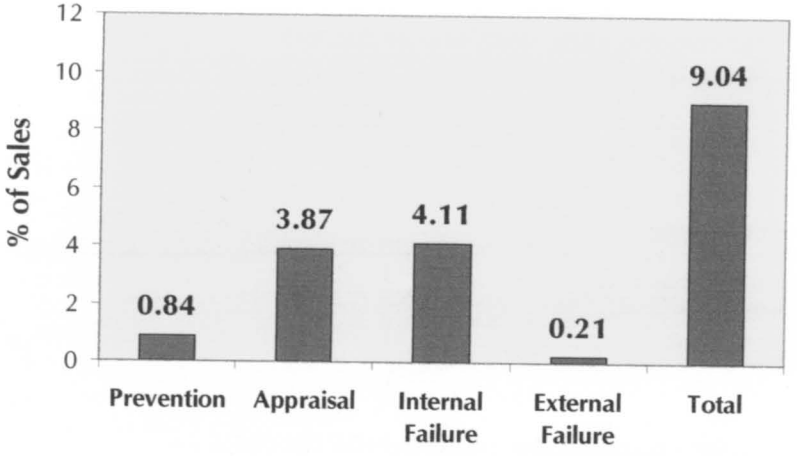



**Chart 1** – Costs of Quality at Vishay Sprague

Coming up next, this report continues with a brief description of the company, the factory and its annex buildings, some basic concepts related to tantalum capacitors, the molded chip product and, finally, the most important steps of the manufacturing process.

The following chapter explains with some detail the welding process and all the causes that can be behind the 'opens' failure.

Afterwards, two chapters are fully dedicated to the analysis of two criteria of distinction between good and bad welds: "force vs. deflection" and "weld height/thickness". In each of these two chapters, the general idea is described, the correspondent collected data is properly analyzed and, finally, several alternatives for a practical implementation are described.

Then, a discrimination criterion is chosen and the available practical applications are compared in their advantages and weaknesses, leading to a decision concerning the technology to be further evaluated by a prototype.

All the features of the prototype are described in the pursuing chapter, including references to some mechanical, electronic, hardware and software options. Special emphasis is given to the NI-DAQ card and to the Visual Basic application.

In the subsequent chapter, all major improvements and tests performed during the debugging period are described. It includes references to mechanical adjustments, software reprogramming and technology reassessment.

Finally, the conclusions and some recommendations are contained in a chapter that puts an end to the main body and text of this report, being followed by the bibliographic references and annexes.



**Figure 1** – Sprague Plant in Sanford, Maine

# 2. VISHAY-SPRAGUE OVERVIEW

## 2.1. Vishay Intertechnology, Inc.

Vishay Intertechnology is a global manufacturer of a broad line of passive (capacitors, resistors and inductors) and active discrete semiconducter (diodes and transistors) electronic components. These components are used in all electronic and electrical applications, from a simple toaster, TV, telephone or PC to sophisticated local area networks or even the latest design for a lunar space module!

As products such as computers, telephones, pagers and printers become more and more sophisticated, they require more and more discrete components (passive and active). An example of this increase is shown in the next chart, which about the number of discrete components necessary to assembly three consecutive Intel microprocessors.

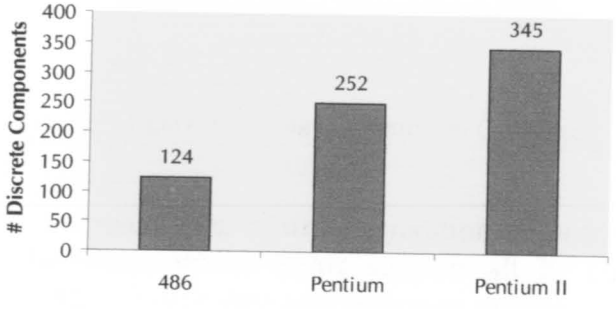



**Chart 2** – Discrete Components in Intel Microprocessors

Some major customers of Vishay are AT&T, Acer, Alcatel, Bosch, Compaq, Delco, Ericsson, Ford, GM, Hewlett-Packard, IBM, Matsushita, Motorola, Seagate, Siemens, Sony, etc.

The major brands of Vishay are the Measurements Group (strain gages), Vishay Foil Resistors, Vishay Thin Film, Dale, Draloric, Sfernice, Sprague, Roederstein, Vitramon, Lite-On Power Semiconducter, Telefunken and Siliconix.

## 2.2. Sprague Electric

Sprague Electric is a leading manufacturer of tantalum capacitors in the U.S. and Europe, holding the original patents for tantalum capacitors and being the first to offer surface mount tantalum chip capacitors. These capacitors are the smallest and most stable in their category and are used extensively in computers, telecommunications and the automotive industry.

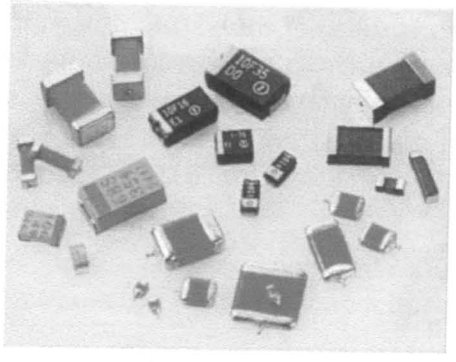


**Figure 2** – Sprague's Tantalum Capacitors

Furthermore, this company has a strong tradition of internal R&D and original equipment manufacturing, which helps support all its commitments to quality (ISO 9000 and QS 9000 certificates) and customer service.

This internship took place in Sprague's headquarters in Sanford, Maine, USA, whose facilities include a Main Plant and two Annexes. In the Main Plant we have the following major departments/functions:

| | | |
|---|---|---|
| General Management | Shipping & Receiving | Product Development |
| Finance & Accountancy | Marketing | Production |
| Human Resources | Customer Service | **Process Engineering** |
| Safety & Environment | Quality | Maintenance |

The Annex Buildings are exclusively dedicated to equipment designing and manufacturing, counting on an experienced engineering team as well as a highly skilled group of drafters, mechanics, electricians and other technicians.

[See **Annex 2**, the Sanford plant map]

## 2.3. Tantalum Capacitors

Tantalum, symbol Ta, atomic number 73, is the heaviest element in Group 5 (VA) of the Periodic Table. In nature, tantalum occurs not in the free state, but in several complex oxidic minerals, often in solid solution with a variety of other elements such as tin, titanium, thorium and uranium. The main source of tantalum is an isomorphous series of minerals containing oxides of tantalum, niobium, iron and manganese.

The first commercial use of tantalum was as filaments in incandescent lamps, but it was soon displaced by tungsten. Tantalum is used in chemical industry equipment for reaction vessels and heat exchangers in corrosive environments. It is usually the metal of choice for heating elements and shields in high temperature vacuum sintering furnaces. In 1994, over 72% of the tantalum produced in the world went into the manufacturing of over 10 $x10^9$ solid tantalum capacitors (STC) for use in the most demanding electronic applications.

The primary ***Ta powder*** produced by a sodium reduction process is treated to convert the metal to a form suitable for use as capacitor-grade powder and feedstock for wire and sheet.

***Ta wire*** is used primarily as the anode lead wire in STC. Since the 1970s, the average weight of Ta in a STC has dropped from several hundred milligrams to less than 50 mg; but the consumption of Ta powder for capacitors has remained relatively constant because of the dramatic increase in the number of capacitors manufactured. The weight of wire per capacitor has remained relatively constant and thus wire consumption has increased steadily.

The principal steps in the STC manufacturing process are as follows:

**1. PELLETING**

Ta powder is pressed into a pellet weighting from one to several hundred milligrams.

**2. SINTERING**

The pellet is sintered in vacuum at a temperature above 1300°C to produce a porous compact.

**3. FORMATION**

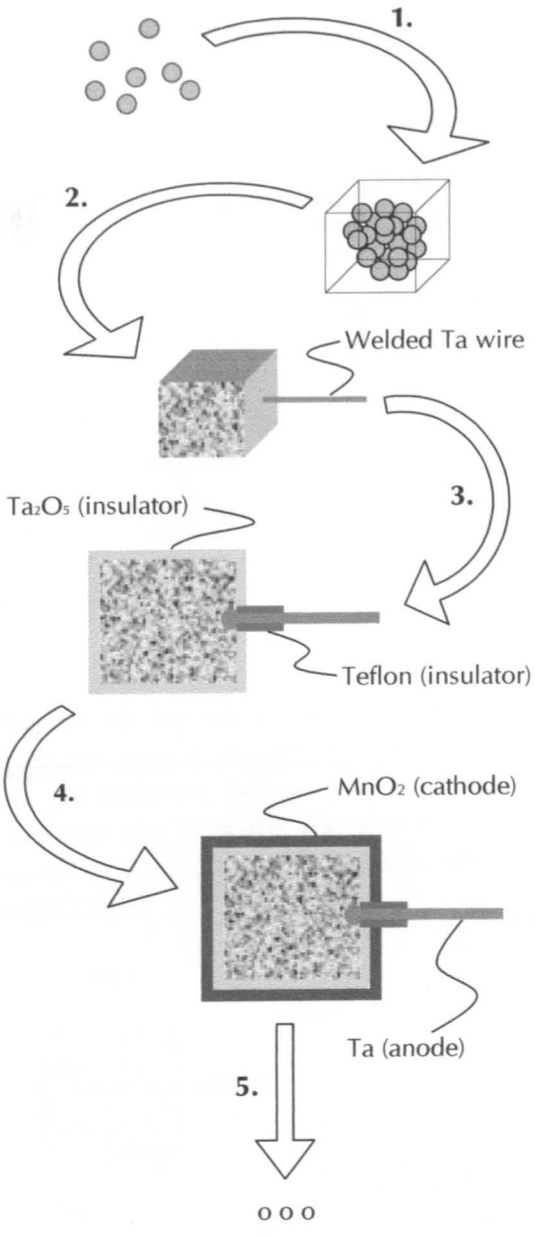
The Ta pellet is formed or anodized by making it the anode of an electrochemical cell containing a dilute aqueous solution of a certain acid.
Upon application of a voltage, anodic Ta oxide grows on the surface of the Ta, to a thickness proportional to the applied voltage.
The resulting oxide film is an excellent electrical insulator and can serve as the dielectric in the conductor-insulator-conductor configuration of the capacitor.

**4. DEPOSITION**

One conductor is the Ta and the other conducting electrode is $MnO_2$, a semiconductor, which is deposited on the anodic oxide by the pyrolysis of manganese nitrate.

**5. ENCAPSULATION...**

The basic unit is almost ready to be assembled in one of the available surface mount chip configurations.




STC was invented about 40 years ago and since then it has been occupying a good position in capacitor market. The major advantages of the STC over other capacitors are

- high specific charge (product of capacitance C and voltage V per unit of volume or mass)
- high reliability
- low equivalent series resistance (ESR)

As a physical subject, the STC is one of the most complicated and interesting passive components of all electronic devices, and the following table contains a good example of that. It shows that the basic layers of the STC involve all types of solid body structures (monocrystal, polycrystal, amorphous) and all types of solid body electrical conductivity (conductor, semiconductor, insulator)!

| Layer | Function | Structure | Conductivity |
|---|---|---|---|
| Ta | Anode (+) | Monocrystal | Conductor |
| $Ta_2O_5$ | Dielectric | Amorphous | Insulator |
| $MnO_2$ | Cathode (–) | Polycrystal | Semiconductor |

**Table 1** – STC as a physical subject

## 2.4. Molded Chip Product

*Chip products* are components that are designed to be very small, perfectly functional and easily handled by automation. They are usually designated as surface mounted devices (SMDs) because their terminals are wireless, being used soldered paddles or metal coatings instead. In **Figure 3** we can see how the introduction of SMD technology contributed to the miniaturization of modern electronic circuitry, by permitting the use of both sides of the electronic cards.




**Figure 3** – SMD Technology

Although Sprague produces the two main types of SMDs, molded and coated chip products, our attention will be centered on the ***molded*** chip product, which is the major production at Sanford's Main Plant. The process goes on as follows:

**5.a. COUNTERELECTRODES**

After the "heart" of the STC is completed, additional layers of graphite and silver are applied over the manganese dioxide surface of the pellet.

**5.b. ASSEMBLY**

The units are mounted on a lead-frame: the anode Ta wire is welded and the cathode surface is glued with a silver epoxy.

**5.c. MOLDING**

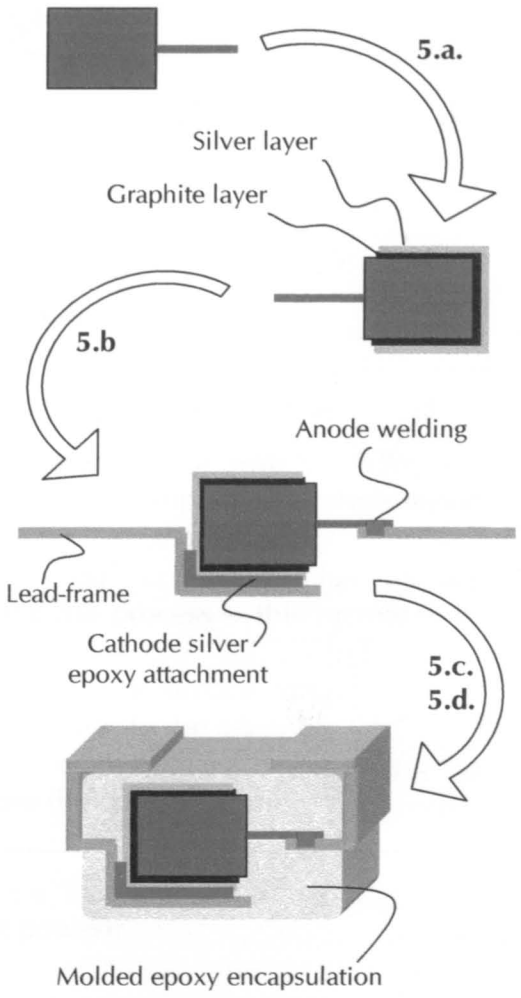
Each unit in the lead-frame is molded in a parallelepiped-shape epoxy capsule.

**5.d. FINISHING**

Several operations are performed, such as: trimming & forming, stamping, temperature cycling and visual inspection.

**6. TESTING**

Electric tests for Capacity and ESR are performed redundantly to each single unit, before packing and shipping.




One lead-frame includes 152 units in two rows of 76 units each.

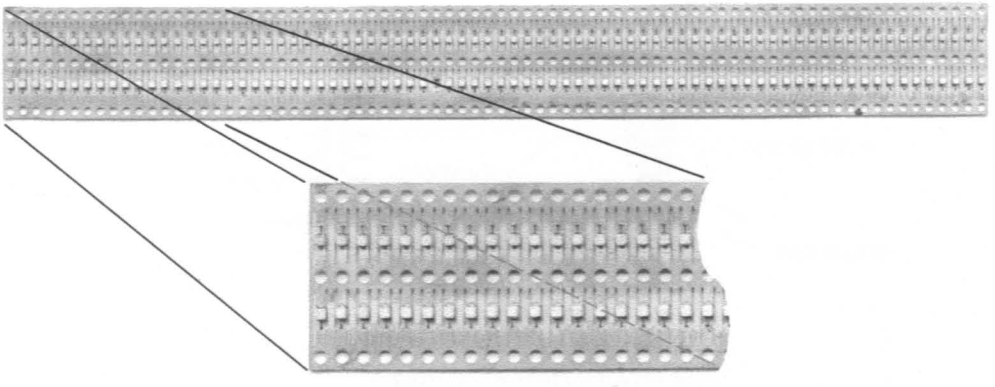


**Figure 4** – Lead-frame

# 3. INTRODUCTION TO 'OPENS'

## 3.1. The Welding Process

There are two steps of the process that involve the use of welding technology:

- in the beginning, attaching the Ta wire to the pellet
- in the assembly line, attaching the anode terminal to the lead-frame

The latter is the most susceptible to failure due to several reasons, such as:

- the materials involved are of totally different natures – *Ta wire* vs. *'alloy 42' solder-plated lead-frame (60/40 tin-lead solder)* [see a competitive analysis report in **Annex 3**, for more details]
- the Ta anode wire is in an "almost quenched" condition, after all the temperature cycles to which it is subject along the process – this increases its superficial tension
- there may be some remaining oxide over the Ta wire surface, despite a laser cleaning operation (to remove the teflon coating) prior to the assembly line
- the weld head of the upper electrode has an extraordinary big diameter (to prevent missing wires that might be shifted from the correct location) – this often leads to shunts and shorts around the wire

The welding operation in the assembly machine is a 'Resistance Welding', based on the famous 'Joule Effect' (electrical resistance heat power):

$$P = I^2 . R$$

The following picture shows a simplified scheme of the operation:

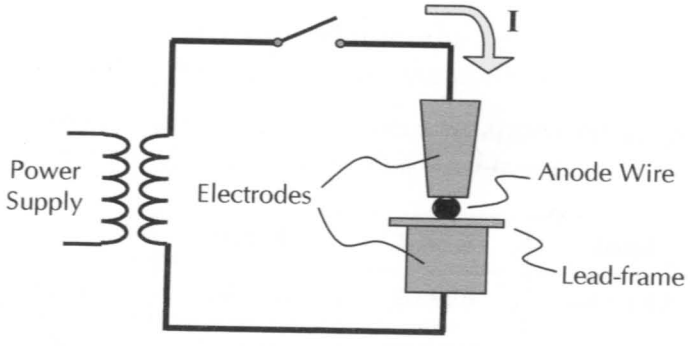



**Figure 5** – Resistance Welding

The anode wire represents the resistance **R** to be crossed by current **I**. If, for any reason, only a small part of the current passes through the Ta wire, then not enough heat can be generated and the weld does not succeed. Presently, the welder controller **can only detect some** of these occurrences, and their rejection is performed manually. All the *marginal* or *no* welds that are **not detected** by the machine go through production and originate components that react in an unpredictable way to the electrical tests. In the next section, the causes and consequences of this behavior will be analyzed.

## 3.2. Difficult Detection

All the units coming out of the assembly machine (including the ones with weak or non-existent anode attachment that were not detected) are molded and are very likely to reach the chip testers without being rejected. And if that happens, it can only be due to any physical unconformity detected by visual inspection.

The chip testers are designed to assess certain electrical properties of each single unit and compare them with the respective product specifications. These tests are performed in a 100% basis and redundantly.

Can we expect this procedure to eliminate all our 'bad weld' units? Clearly "No!" Previous studies had revealed that the ratio "undetected units / all bad units" is close to 30%! An experiment that was conducted later, during the internship, also confirmed this value.

**Experiment**:

*An entire lead-frame (152 units) containing **'only bad welds'** was sent through production and monitored until it reached the chip testers.*

*At that stage, all the units were removed from the production line and were tested for their electrical properties individually and manually at the laboratory.*

*The table below shows the proportion of units that appeared as **'good'**, out of each side and out of the total number of units in that lead-frame.*

| | ***Side A*** | ***Side B*** | ***Total*** |
|---|---|---|---|
| ***n / N*** | *14 / 76* | *30 / 76* | *44 / 152* |
| ***%*** | *18.4211* | *39.4737* | ***28.9474*** |

**Table 2** – 'Bad Welds' appearing as 'Good Welds'

Why do we have such a large number of 'known bad-weld units' (re-)acting as 'perfectly normal units'?

The answer to this question is rather simple: **"In spite of not being welded, the anode wire and the lead-frame are in physical contact and there is good electrical conductivity through them."**

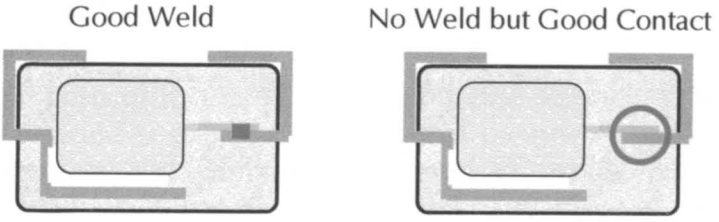



**Figure 5** – Electrical Contact in No Welds

If the "heart" of our capacitor is functioning properly and both the anode and the cathode are in good contact with their respective paddles, then there is no reason for the unit to be rejected by the electrical tests.

Units with this kind of defect can behave perfectly well for a long period of time, even during all their expected lifetime, but they are much more susceptible to become ineffective than normal units because of their weakness. Under customer conditions, various factors may easily cause anode detachment:

- vibration
- shock
- mishandling
- temperature

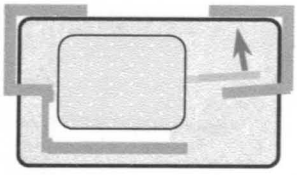


**Figure 6** – Anode Detachment

If that happens, the conductivity between the anode wire and its paddle can no longer be assured and one of two consequences may take place:

- marginal contact, usually causing high ESR
- no contact at all, equivalent to an "**OPEN**" circuit

The designation "open" has been used to refer to units with a defective anode attachment, whether it is weak or non-existent, whether it is detected by the chip testers or only later, by customers.

Our goal is the detection of this failure on the earliest stage possible, so that it does not reach the chip testers (which may not detect it) and, most important of all, does not arrive to customers. Obviously, the best stage of the process to do that is the moment immediately after the welding operation and before molding.

# 4. FORCE VS. DEFLECTION

## 4.1. Basic Principles

We want to evaluate the quality of a supposedly permanent mechanical bond between two elements: a weld between a Ta wire and a lead-frame.

The ultimate purpose of this exercise is to be able to decide, based on a certain parameter, if our weld is good or bad. Yet that parameter, whatever it represents, must be an accurate and continuous measure of reality and must, in fact, be proportional to the weld condition. Only this way can we monitor any effects resulting from mere adjustments or radical changes in the welding process.

"The objective of a weld is to join permanently two bodies."

So is the objective of a simple super-glue operation. The question is now:

"What would we normally do after trying to join two elements with super-glue? How would we make sure that the operation succeeded?"

We would certainly pull the two elements apart. We would act against the new joint. That is exactly what was done towards our weld in this first approach!

If we consider the configuration of the units on the lead-frame immediately after the welding station we tend to think of the following scenario:

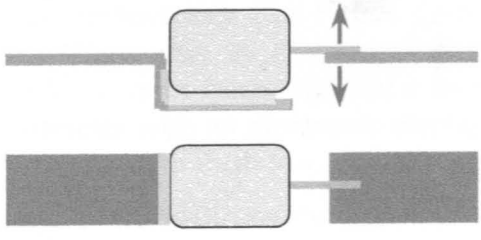



**Figure 7** – Units coming from the welding station

How can we put this in practice, dealing with such small dimensions?

- Ø0.008 in. (=0.2032 mm) cylindrical wire
- 0.055 in. (=1.397 mm) wide flat surface

As it was said before, all we want for now is to perform intensive measurements that can provide us with useful and statistically significant data. The most adequate way to do it turned out to be a **push-test instead of a pull-test**. In fact, we can:

- hold one of the two bodies
- push the other one in a an attempt to separate it from the held body
- measure the deflection caused by the push
- measure the reaction to that push

A small machine including a Micrometer and a Force-Gage [see **Annex 4** for specifications of the Force Gage] was built in the Annex. That machine reproduces the following conditions:

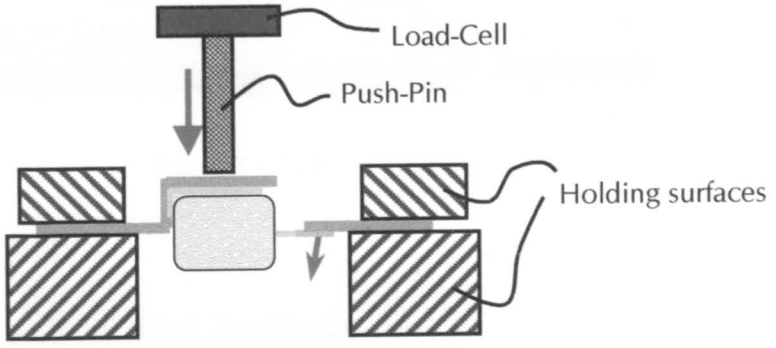



**Figure 8** – Push test setup

The Push-Pin (that could also behave as a Pull-Pin) is permanently in contact with the Load-Cell, in the Force-Gage, due to a screwed connection. An electronic display in the force-gage allows us to know the force to which our pin is being subject, and a manual Micrometer with an electronic display gives us full control of the deflection applied to our units with Push-Pin.

The lead-frame slides under the testing-pin by the action of a manual rotary control, so that every single unit of that lead-frame can be measured.

The forces measured by this method will actually be a function of many variables:

- the position where the pin is pushing
- the material of the lead-frame (its mechanical properties of flexion)
- the cathode attachment condition (silver epoxy connection)
- the position of the holding surfaces' edges
- the deflection applied to the units by the pin
- the weld condition

As we will see in the next section, and despite all this variability and apparent uncertainty, the results are rather conclusive.

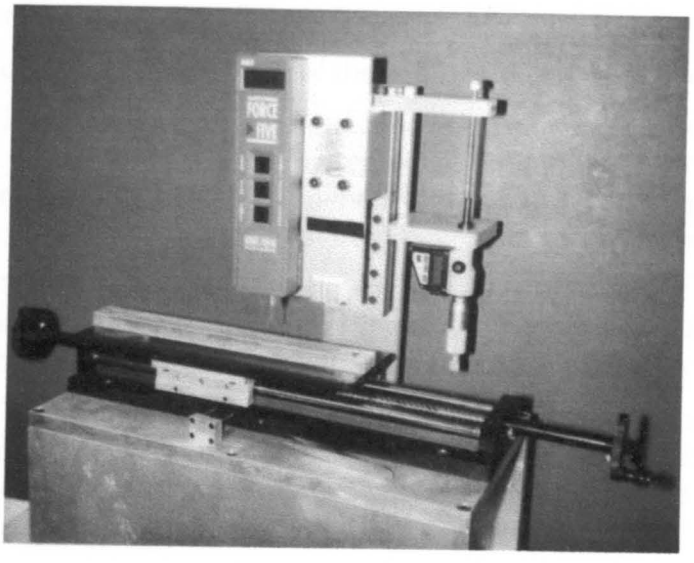


**Figure 9** – Push-test machine

## 4.2. Data Collection and Analysis

An initial set of scattered experiments with the new machine was very important to define certain limits or rules to be respected during the actual data collection.

For example:

a) It was established that, in most cases, the deflection applied to good units should not exceed 0.006 in. (=0.1524 mm) due to the danger of damaging the cathode attachment. When testing bad-weld units the deflection can be whatever we want...

b) The testing procedure should have the following steps:

   i) Reset the force-gage while not touching the unit

   ii) Go down slowly until the pin touches the unit (indication of light force in the gage's display)

   iii) Reset the micrometer

   iv) Go **as fast as possible** to the pre-defined deflection, without exceeding it (this requires a very good manual control of the micrometer)

   v) Read the force value **immediately after** stopping the micrometer

vi) Remove the load from the current unit, slide the lead-frame to the next position and start again in step i)

c) The explanation for steps iv) and v) of the testing procedure is very interesting.

In one of the initial tests, a certain deflection was applied to a unit and a certain value of force was read. Instead being removed, the pin was kept on the unit and something surprising (at first...) happened: the value of force appearing on the display did not remain constant; it started decreasing slowly until it stopped in another value.

The experiment was repeated several times and another unexpected 'rule' was determined: the slower the push-test, the less the total decrease in the end!

Conclusion: The materials involved in this process ('alloy 42', silver epoxy, Ta wire) are absorbing internally a small part of the tensions created by the total deformation (plastic behavior). This explains the slight decrease in the reaction to the external agent.

The tests were conducted in three types of units:

- Known **good welds** with **good epoxy** attachment
- Known **bad welds** with **good epoxy** attachment
- Known **good welds** with **weak epoxy** attachment

This last case is also an important issue among the causes of failure in the molded chip product and, therefore, it was decided that some experiments could also be done towards its detection by this method. To 'simulate' this kind of units, the lead-frames were forced to skip the curing stage at the assembly machine, and their dried epoxy was washed in an alcoholic solution.

A situation of "bad weld and weak epoxy attachment" is physically unlikely to 'survive' the standard chip testing as well as it is virtually impossible for these units to reach the molding operation without accidentally falling out or being removed due to visual inspection.

All the tests used a deflection of 0.006 in. (= 1524 mm).

It was referred in the last section that the forces read by the force-gage would be dependent on various factors. That is true, but the tests can still be very useful if we are able to maintain constant all the factors but the ones that we are evaluating.

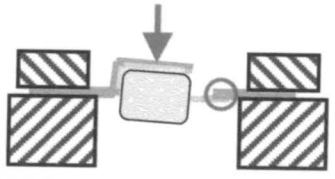
In our case:

| | |
|---|---|
| *the position where the pin is pushing* | constant |
| *the material of the lead-frame (its mechanical properties of flexion)* | " |
| *the cathode attachment condition (silver epoxy connection)* | **controlled** |
| *the position of the holding surfaces' edges* | constant |

*the deflection applied to the units by the pin*..... constant

*the weld condition*..... **controlled**

## GOOD WELDS (with good epoxy attachment)



- **Number of units measured**: 263
- **Mean**: 0.968783 lb.
- **Standard Deviation**: 0.165804 lb.
- Chart containing the empirical distribution function of our population and the correspondent Normal distribution:

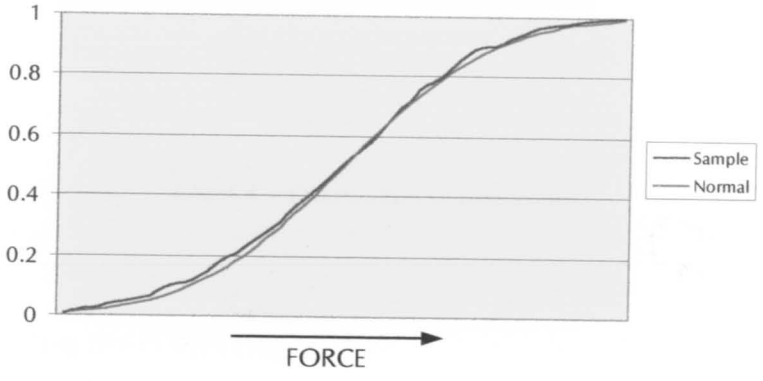


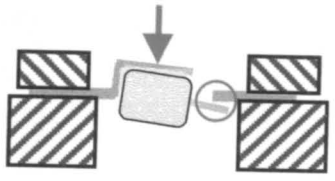

**Chart 3** – Distribution of Good Welds

Goodness-of-Fit Test (GOOD WELDS):

**KOLMOGOROV-SMIRNOV-LILLIEFORS (ONE SAMPLE)**
$H_0$ : Normal Population
$H_1$ : Other Population
Significance level = 0.05
$H_0$ true → E.T. $< 0.886 / \sqrt{n} = 0.886 / \sqrt{263} = 0.0546331$
E.T. = D = max | S(x) – F(x) | = 0.054761 > 0.0546331
$H_0$ Rejected : The population cannot be considered Normal.

(this test failed very narrowly)

## BAD WELDS (with good epoxy attachment)



- **Number of units measured**: 189
- **Mean**: 0.276614lb.
- **Standard Deviation**: 0.035448lb.
- Chart containing the empirical distribution function of our population and the correspondent Normal distribution:

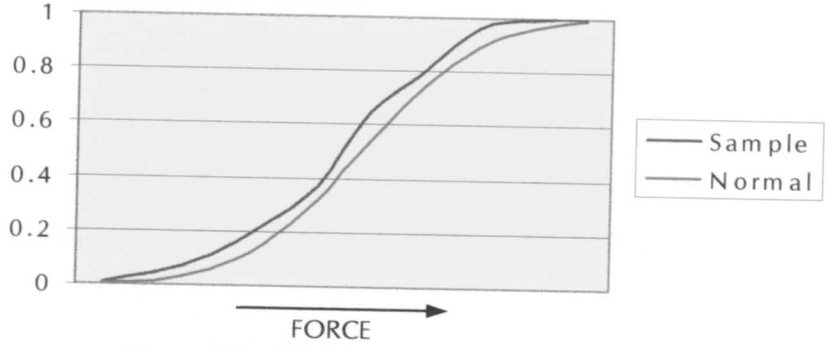
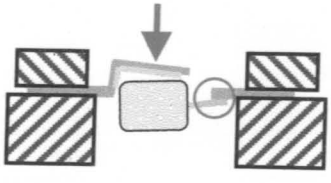



**Chart 4** – Distribution of Bad Welds

Goodness-of-Fit Test (BAD WELDS):

**KOLMOGOROV-SMIRNOV-LILLIEFORS (ONE SAMPLE)**
$H_0$ : Normal Population
$H_1$ : Other Population
Significance level = 0.05
$H_0$ true → E.T. $< 0.886 / \sqrt{n} = 0.886 / \sqrt{189} = 0.064447$
E.T. = D = max | S(x) – F(x) | = 0.167682 >> 0.064447
$H_0$ Rejected : The population is not Normal.

## GOOD WELDS AND WEAK EPOXY ATTACHMENT



- **Number of units measured**: 241
- **Mean**: 0.470207lb.
- **Standard Deviation**: 0.134575 lb.

- Chart containing the empirical distribution function of our population and the correspondent Normal distribution:

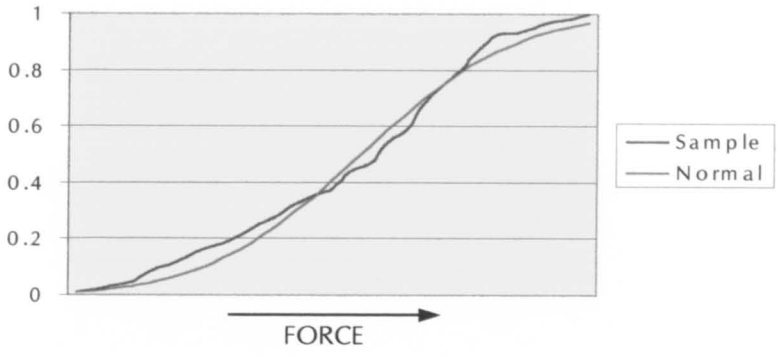



**Chart 5** – Distribution of Good Welds & Weak Epoxy

Goodness-of-Fit Test (GOOD WELDS & WEAK EPOXY):

> **KOLMOGOROV-SMIRNOV-LILLIEFORS (ONE SAMPLE)**
> $H_0$ : Normal Population
> $H_1$ : Other Population
> Significance level = 0.05 (95%)
> $H_0$ true → E.T. $< 0.886 / \sqrt{n} = 0.886 / \sqrt{241} = 0.057072$
> E.T. = D = max | S(x) – F(x) | = 0.118723 >> 0.057072
> $H_0$ Rejected : The population is not Normal.

[see **Annex 5** for raw data]

A possible reason for the total non-normality of the results in this last category may be the friction that is introduced by the remaining epoxy on the vertical section of the pellet-pocket. When the pellet is being forced down, it is actually centered on the weld) and its maximum radius (towards the "corner" of the pellet) overlaps the space available in the pocket, which is already reduced by the presence of epoxy.

How can we make this statistical knowledge useful?

Although the normality of our two main populations – Good and Bad Welds – has not been confirmed statistically, we will not be committing a great imprecision if we make such an approximation. Let us just assume, on the other hand, that 'Bad epoxy' units belong to a distribution (whatever it is) that ranges from below 0.2 lb. to almost 0.8 lb. (region marked in dashed blue on the chart).

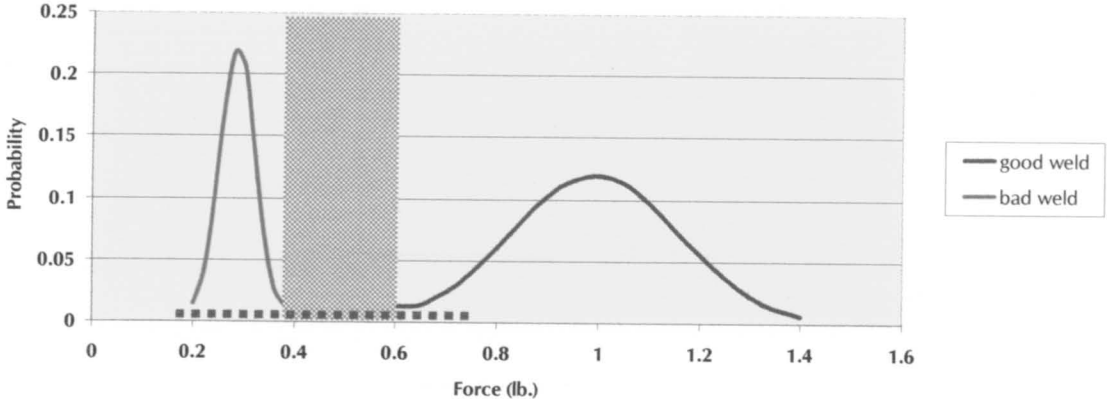



**Chart 6** – Bad Welds vs. Good Welds

By plotting the Normal Distributions from 'Good Welds' and 'Bad Welds', together in the same chart, we can easily conclude that the probability of two units, one from each of these two populations, reacting with the same amount of force is virtually null. It is possible, as a matter of fact, to define a very safe gap between 'good' and 'bad' units (marked vertically, in green, on the previous chart) that will, eventually, allow us to capture a good part of the 'bad epoxy' units together with the 'bad welds'! The remaining 'bad epoxy' units are in the 'good weld' region and thus cannot be discriminated.

A more conservative solution would establish a single border that puts apart almost all 'bad epoxy' unit. In this case we would be rejecting...

- 99.99% of 'bad weld' units
- the majority of 'bad epoxy' units
- the weaker 'good weld' units

... and accepting:

- hopefully no 'bad weld' units
- the stronger 'weak epoxy' units
- the great majority of 'good weld' units

Anyway, in our study we will only be concerned about 'bad welds', which is the main cause for 'opens'.

## 4.3. Possible Practical Applications

### 4.3.1. Pogo-Pins

This device consists on a pre-loaded spring that can be compressed to a certain limit and closes a switch after a certain internal travel. Graphically:

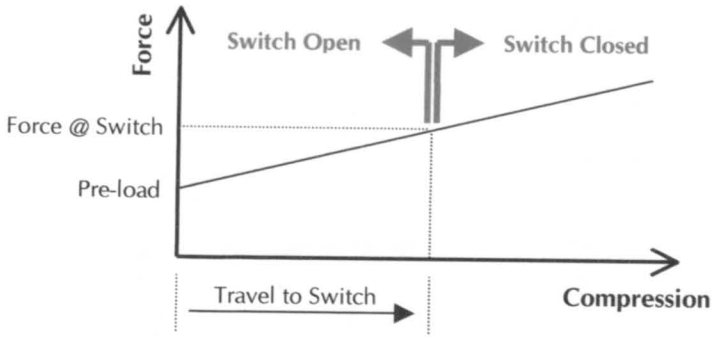



**Chart 7** – Switch probe concept

In the previous section, a statistical study was made based on a 0.006in. deflection. It revealed that when a 'good unit' is compressed of that amount, it reacts undoubtedly and substantially more than a unit with a poor weld attachment.

From this conclusion, and assuming linearity in the behavior of these units against the push-test, we would say, *"For any deflection applied, the reaction of 'good units' is always greater than the one of units with poor anode attachment"*. This is exactly the same as saying, *"For any outside force applied to a unit, the resulting deflection of 'good units' will always be lower than the one of units with poor anode attachment."*

This means that we have two possible approaches, regarding the identification of good and bad units:

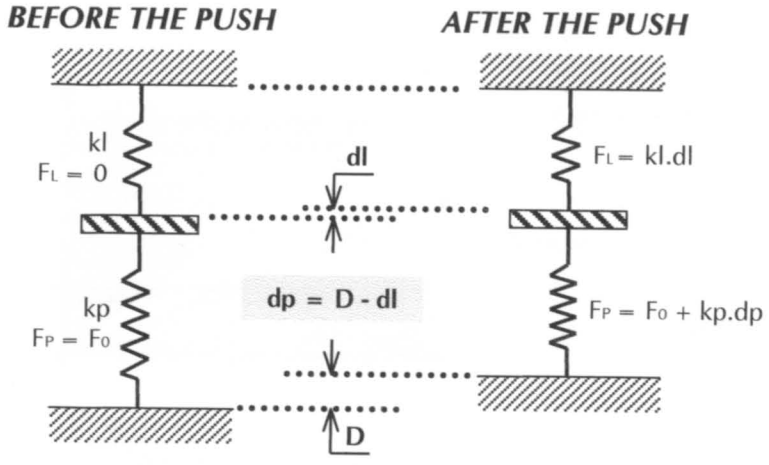
- Apply a critical deflection and decide based on the reaction force
- Apply a critical force and decide based on the resulting deflection

We know that a Pogo-Pin switches 'ON' at a certain moment characterized by a "travel to switch" and a "force at switch". If we press a Pogo-Pin against a rigid surface, the internal travel will be exactly the same as the external compression applied. On another hand, if we push our Pogo-Pin against an **elastic** surface, the external travel of our probe is going to be distributed by two distances:

- The internal travel of the Pogo-Pin
- A deflection on the elastic surface

It is legitimate to assume that "the greater the elastic constant of the surface, the greater the internal travel of the Pogo-Pin and the lower the deflection on that surface".

The units on the lead-frame behave like elastic surfaces. Let us assume, for now, that they react linearly to any push, as if they were simple springs. If we press them with a Pogo-Pin, traveling an outside distance D, the mechanical model is the following:




kl, kp – elastic constants of the lead-frame and Pogo-Pin

dl, dp – deflections on the lead-frame and in the Pogo-Pin (internally)

**Figure 10** – Mechanical model for Pogo-pins

For a certain Pogo-Pin model, with a Pre-Load $\mathbf{F_0}$ and an elastic constant **kp** we can determine the external travel **D** to which it:

- switches for the 'worst good unit' (wgu)
- does not switch for the 'best bad unit' (bbu)

For example, we can determine the external travels D(wgu) and D(bbu) to which the Pogo-Pin starts switching, and deduce a critical **D*** between the two. Of course, we want to maximize this gap between D(wgu) and D(bbu), so that we get a "clear shot" between 'good' and 'bad':

$$\text{Max } |D(wgu) - D(bbu)| = \text{Max } [\, D(bbu) - D(wgu) \,]$$

But, in this case, we know that D = tsw + dl, which means:

$$D(bbu) = tsw + dl(bbu) \qquad D(wgu) = tsw + dl(wgu)$$

(the internal travel to switch in the Pogo-Pin, tsw, is constant)

Therefore,

$$\begin{aligned} \text{Max [ D(bbu) – D(wgu) ]} &= \text{Max [ tsw + dl(bbu) – tsw – dl(wgu) ]} \\ &= \text{Max [ dl(bbu) – dl(wgu) ]} \end{aligned}$$

The difference [ dl(bbu) – dl(wgu) ] increases with the force involved in the pushing process. Considering a simple linear system, like the one presented before, this difference may be represented by:

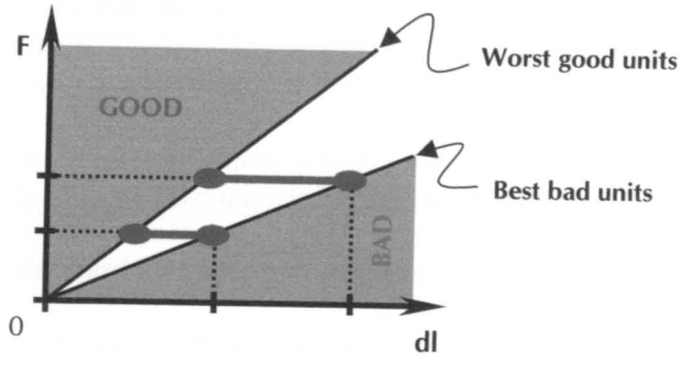



**Chart 8** – Worst good units *vs.* Best bad units

In reality, and after more data collection, the true behavior of the lead-frame in reaction to the push-test appears to be as follows (in grams and millimeters):

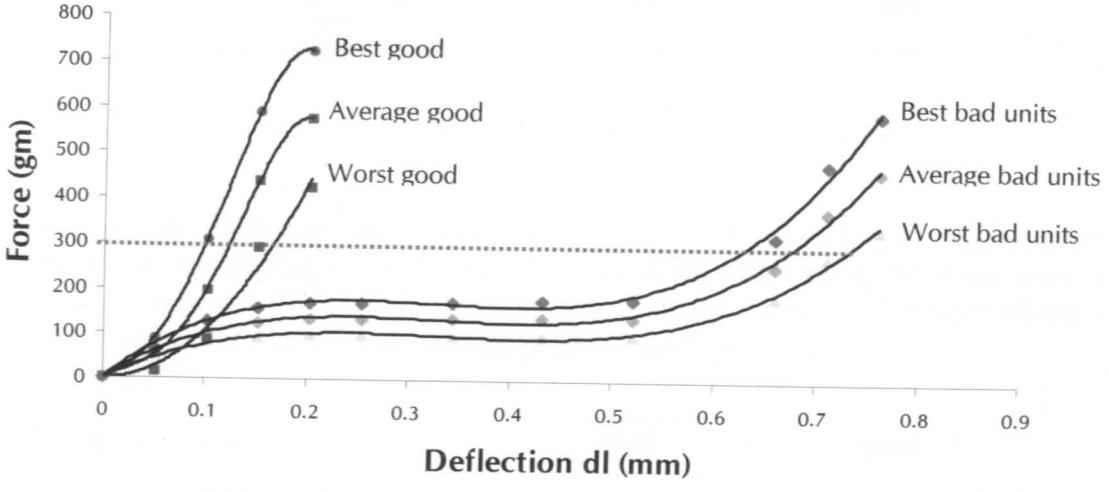



**Chart 9** – Real behavior of Good and Bad Welds

We do not want D* to cause a dl(wgu) greater than 0.006 in. (0.1524 mm) and so this restriction must be considered.

Assuming that:

$$D^*(wgu) = tsw + d^* + dl^*(wgu)$$

..., where d* is the spring compression beyond the switching point, we can predict that the force involved is

$$F^*(wgu) = Fsw + f^*$$

... where Fsw is the Force at Switch for the Pogo-Pin model considered and f* is the additional force beyond the switching point. F*(wgu) is causing the deflection dl*(wgu). From this last expression we learnt that the Fsw of the chosen Pogo-Pin must always be lower than F*(wgu). What F*(wgu) should we chose?

Here is where the restriction enters. Considering the approximation to the Normal distribution of "good welds" (all deflected to 0.006" = 0.1524 mm), we can calculate the force that rejects around 2.3% of the population on its left-hand side, by subtracting 2 standard deviations from the average: 288.98 gm.

The next table contains the main characteristics of two models of switch probes from the available IDINET catalogue [see **Annex 6** for specifications of switch probes in catalogue] : SW4 and SW5.

| | **SW4** | **SW5** |
|---|---|---|
| **Pre-load (gm)** | 70 | 148 |
| **Force @ switch (gm)** | **125** | **293** |
| **Travel to switch (mm)** | 2.72 | 0.76 |

**Table 3** – Main specifications of switch probes SW4 and SW5

As we can see, SW5 narrowly exceeds the F*(wgu) corresponding to the rejection of 2.6% of the population, on its left-hand side. On the other hand, SW4 operates in a very low range of forces, which generates a smaller gap of decision [dl(bbu) – dl(wgu)]. In fact, it was experimentally determined that:

| | **SW4** | **SW5** |
|---|---|---|
| **dl(bbu) – dl(wgu)** | ≈ 0.03 mm | ≈ 0.5 mm |

These values confirm what had been suggested by the graph representing the real behavior of 'good' and 'bad' units. The same experiments, in conjunction with previous statistical analysis, revealed the following approximated values of D(bbu) and D(wgu) for SW4 and SW5:

| (all measures in mm) | SW4 | SW5 |
|---|---|---|
| **Travel to switch** | **2.72** | **0.76** |
| dl(wgu) | 0.09 | **0.154** |
| **D(wgu)** | **2.81** | **0.91** |
| dl(bbu) | 0.12 | 0.65 |
| **D(bbu)** | **2.84** | **1.41** |

**Table 4** – Deflections for Wgu and Bbu

An adequate value of D* can now be studied, between D(wgu) and D(bbu).

The case of SW4 is not critical, because very small deflections are being applied to the worst good units: the average of D(wgu) and D(bbu) is perfectly suitable.

SW5 inspires a bigger concern, due to the high deflections to which the w.g.u. are subjected. We can only suggest that it should be above 0.91 mm, but not too much, so that dl(wgu) does not excessively surpass the "sacred" value of 0.1524 mm (0.006 in.).

| (measures in mm) | SW4 | SW5 |
|---|---|---|
| **D*** | **2.825** | **0.91+Δ** |

Very important questions must be raised after all these experimental calculations:

- "Are Pogo-Pins reliable, concerning forces and dimensions?"
- "Are lead-frames dimensionally accurate?"

These switch probes are not designed for this type of application. The most common use of these devices is in the cable harness testing industry, where they are used to verify the correct location of a terminal in a connector, while checking the retention force as well.

Force and dimension tolerances are not supplied in the current IDINET catalogue, but we requested that information at the Product Design Department of this company [see **Annex 7** for supplied information], and the figures are as follows:

| | SW4 | SW5 |
|---|---|---|
| **Pre-load (gm)** | 70 ± 20% | 148 (?) |
| **Force @ switch (gm)** | 125 ± 10% | 293 (?) |
| **Travel to switch (mm)** | 2.72 ± 0.203 | 0.76 ± 0.254 |

**Table 5** – Tolerances in Switch Probes

This means every Pogo-Pin of a certain model (SW4 or SW5) can be different from another Pogo-Pin of the same model in three dimensions. Graphically, this can be represented a nominal line surrounded by its possible tolerance domain (identical to the case of SW4):

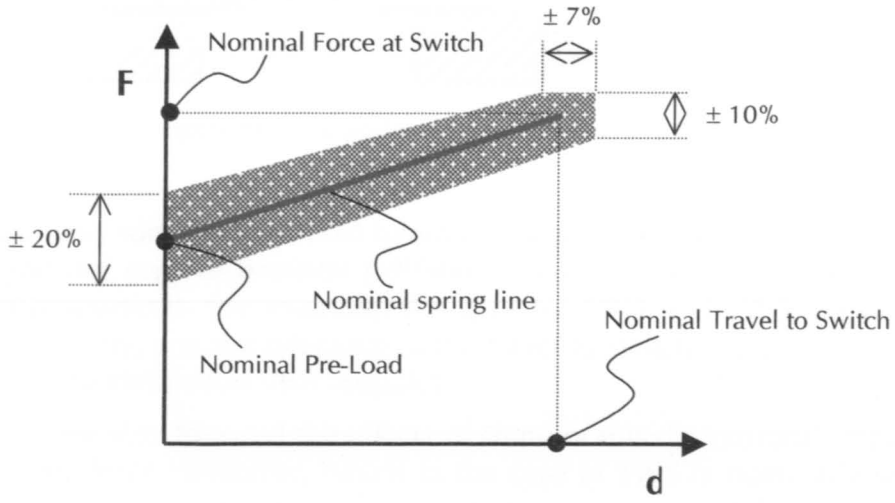



**Chart 10** – Tolerance domain

Another issue is the dimensional accuracy of the lead-frame.

In fact, this application essentially relies on the D* travel of a row of Pogo-Pins (as many as we can, along the lead-frame with all its 152 units) from a theoretical "zero-line", which is supposed to be common to every unit on the same side of the lead-frame.

The lead-frame itself is rather accurate in terms of thickness, but the bending process to which it is subjected allows certain variability concerning the pellet-pocket height.

| | | | |
|---|---|---|---|
| **Pellet-pocket height** | 0.023 in.<br>0.5842 mm | ± | 0.005 in.<br>0.127 mm |
| **Lead-frame thickness** | 0.0045 in.<br>0.1143 mm | | 0.0005 in.<br>0.0127 mm |

**Table 6** – Lead-frame dimensional tolerances

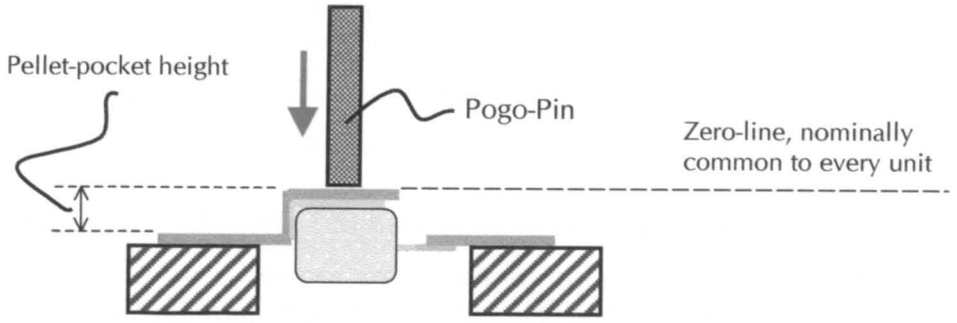



**Figure 11** – Dimensional accuracy required by push test

As we can see, some dimensional tolerances (both from the Pogo-Pins and the lead-frame) and our gaps of decision [ dl(bbu) – dl(wgu) ] are of identical or critically different proportions. For example, the gaps for SW4 and SW5 are 0.03 and 0.5 mm, respectively, and the tolerance of the travel to switch is 0.203 mm! [see **Annex 8** for tolerance simulation VBA module]

Even if we are able to avoid the effects of some of this dimensional imprecision we still have the force variability, which in the case of SW5 is nominally very critical, already.

## 4.3.2. Load-Cells

A load-cell is a measuring device whose output is proportional to the force applied to its embedded strain-gage.

A strain-gage is basically a resistor with piezo-electrical properties, i.e. whose electrical conductivity (or resistance) is dependent upon its mechanical stress condition. The strain-gage does not suffer any significant compression, though, and in consequence the load-cell must be pressed or pulled from the exterior through a very efficient contact, usually a screwed one.

Some of the best features of strain-gages are:

- accuracy (non-linearity varying between ±1% and ±2%, depending on the models)
- fatigue life (allowing 100 Kilocycles to 10 Megacycles)

Furthermore, these devices are supposed to be calibrated and re-calibrated, which can extend even more their life. In fact, although the output values can change with time, that change is likely to be proportional and can easily be monitored and corrected by software. Only when the change is due non-linearity is it advisable to replace the gage.

The next pictures show some load-cells' heads, in their most common configurations. Please notice the ability to screwed connections.

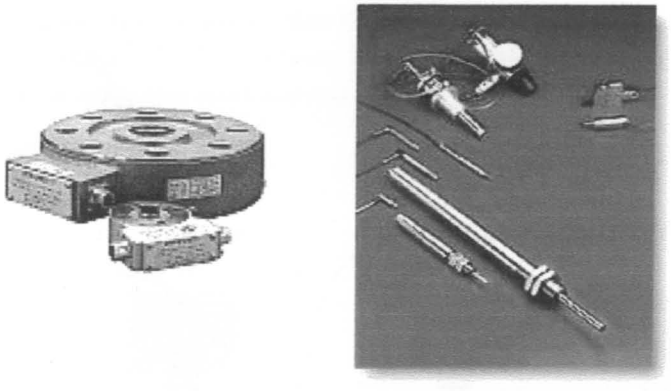


**Figure 12** – Different types of Load-Cells

How can we apply our knowledge through this kind of technology, regarding its application in a production environment?

A load-cell provides an electrical output (a voltage) that is directly related to the amount of force to which it is being subjected through the screwed connection. The

interface between the load-cell and the measured body does not really move in relation to the strain-gage; it is there only to mechanically transmit the load.

This means that we have to:

- apply a known deflection (for instance, 0.006 in.) to each unit using the sensitive contact of the load-cell
- measure the reactive force
- compare the observations with the statistical data and decide whether we have a good or bad unit

How can this procedure be automated and permit a continuous and reliable analysis of all the 76 units on each row of a lead-frame?

1) **First idea (optimistic...)**:

- The load-cell stays immovable, at a certain level
- The interface body, which is screwed to the load-cell, has a round and smooth contact surface on the top
- The position of the group "load-cell + interface body" causes a permanent deflection on the lead-frame
- The theoretical deflection is calculated in relation to an average zero-line of that side of the lead-frame
- The lead-frame slides under the round surface and each unit is measured independently, one at a time (alternatively, the load-cell and the interface can slide over the lead-frame)

Here is an illustration:

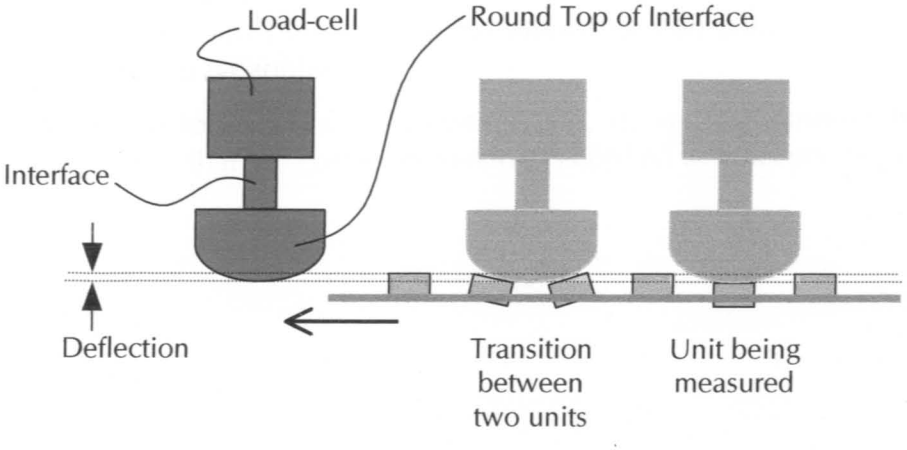



**Figure 13** – Sliding round surface load-cell

From the picture above, it is obvious that dimensional accuracy is again a very important issue. With this approach we can accurately monitor the forces involved in the process, but not the deflections. All we want is to make sure that we are pressing every unit to a point where:

- All the good units can show their strength without being damaged
- All the bad units can convincingly show their weakness

Even though the previously discussed tolerances did not suggest a very good "end" to this approach, some simple tests were performed, utilizing the force-gage that had originally been used during the data collection period. That device is, in truth, a load-cell together with a converter and a display, all in one. We simply had to apply a round head to the pushing pin.

One of the tests consisted in choosing (experimentally) a zero-line and sliding the lead-frame under the round head for several deflections: 0.006", 0.005", 0.004" and 0.003". Even at 0.003", some epoxies were broken...

The other experiment had the only purpose of testing the variability of the zero-line. For a certain lead-frame, a zero line was chosen, no additional deflection was applied and the lead-frame moved under the round head. The force output fluctuated between 0 and 0.18 lb.!!!

2) **Second idea (realistic...)**:

- Basically the same system as the one described above, with one difference: instead of being static, the load-cell and the attached interface body can move vertically, altogether as a single system
- For each unit, a distance measurement is performed prior to the force evaluation, so as to determine the individual start-point (zero-line) of the deflection to be applied
- When the load-cell is on a certain unit, its vertical position is already adjusted so that the correct deflection is applied to that specific unit

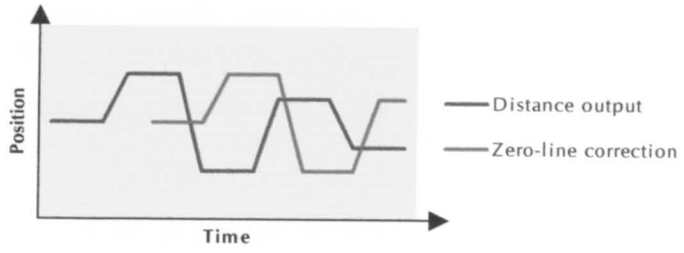



**Chart 11** – Load-cell vertical position adjusting system

Preferably, the distance measurement should be done in a non-touch basis (using laser or ultrasound sensors) and the vertical positioning of the load-cell should accurately be done by a rotary servo motor.

No further experiments were made regarding the "Load-Cells" approach.

The idea of having two separate systems, one measuring distance and the other evaluating forces, did not seem very advisable and a new option was considered: one single system, capable of measuring distance and force. That is what is described next.

### 4.3.3. Moving Coil Actuator (SMAC)

This device is a linear-motor-based electric actuator that provides variable control of position, speed and force [see **Annex 9** for more information].

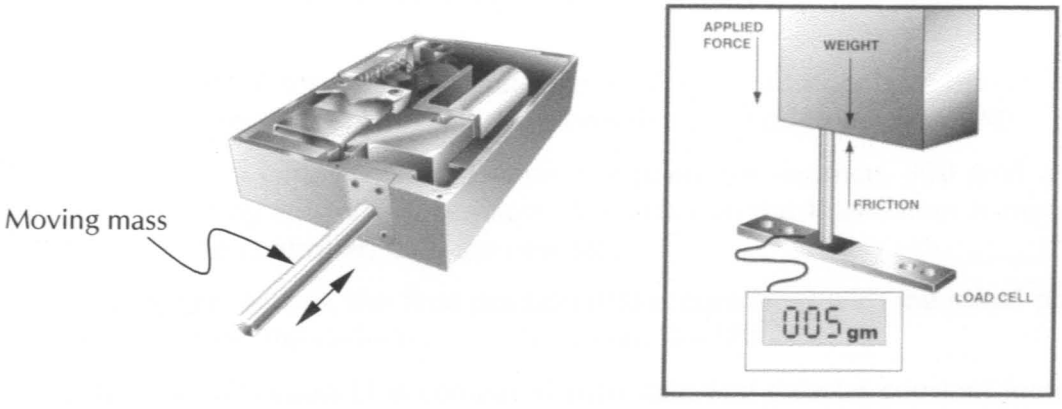



**Figure 14** – Moving Coil Actuator

- The forces involved are carefully controlled in terms of mass, acceleration and friction: Force = Mass x Acceleration + Weight - Friction
- The moving mass is approximately 200 gm and the accelerations can reach 70 times the acceleration of gravity! This can be important due to the production cycle time that has to be respected.
- The available forces can be as low as 50 millinewtons (≈5 gmf) or as high as 5 Newton (≈500 gmf). This is extremely useful in our case because, for each unit, the starting-point (zero-line) must be detected at virtually no-force.
- The life of these devices is very long: about 10,000 km of total travel per actuator!
- The dimensional resolution is more than enough for our application: 1μm to 5μm, depending on the linear optical encoder!

The moving coil technology has been used in many different industrial applications, like the ones listed below:

- *Electronic component assembly*
- *Inspection of automotive switches*
- *Measuring and sorting pneumatic valves*
- *Soft contact lens mold dimensional checking*
- *Medical material testing*
- *Handling and measuring hot cathodes for TV tubes*

In our case, the general procedure would be as follows:

a) The actuator is over the unit, at a certain distance

b) The moving mass is forced down, at very low acceleration (= very low force)

c) When it touches the unit, the position controller (the linear optical encoder) detects the halt and stores that position in memory (P0)

d) Then, a certain constant force is applied (for instance, 300 gmf) and the resulting advance in position (deflection on the lead-frame) is monitored by the controller, until the new stop

e) When it stops, the final position (P1) is compared with the initial position (P0) and the deflection is determined: $D = |P1 - P0|$

f) The deflection D is compared with statistical data (at constant force) and the final decision is made: good or bad!

g) Remove the load from current unit and move to the next one, starting again in step a).

It is much safer making decisions "at constant force" than at constant deflection.

If we analyze Graph n. [n] again, we conclude that after a force of 150 gm, the difference between the deflections of good and bad units suffers a tremendous increase, reaching a values around 0.5 mm for 300 gm. For a device with a resolution of 1μm to 5μm and such an accurate control over mass and acceleration (force), this is probably the best bet!

This gap of 0.5 mm and its meaning will be object of discussion in the next "possible practical application" section.

### 4.3.4. Plastic behavior of the lead-frame

Why do "bad units" react to the push with an initial increase, followed by a flat zone and a final rise in the force?

The reason is simple:

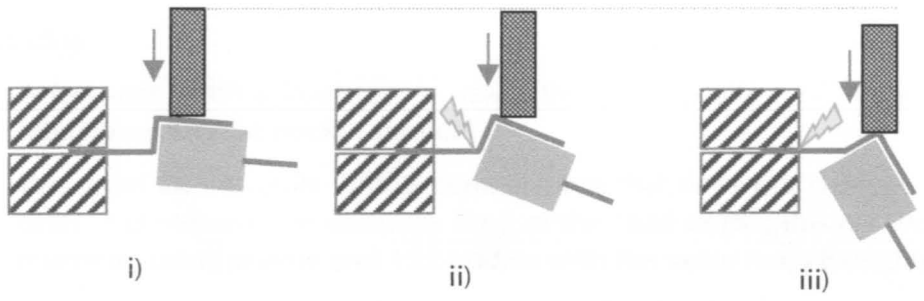



**Figure 15** – Continuous push-test

In stage i) the push test is trivial and equivalent to the one made with "good units"; the behavior is almost elastic, which means that if we release the unit it will recover nearly all the deformation.

In stage ii), the push is essentially bending the left-hand corner of the lead-frame, deforming it permanently, i.e. entering a plastic domain; there is no increase in the force because all the new tensions are being absorved in that corner (whose shape had actually been created by bending an originally flat paddle...); the lead-frame will never get back to the initial shape.

In the chart below a red arrow indicates the probable recuperation of a "bad weld" lead-frame after being pushed and released at the point marked with the red circle.

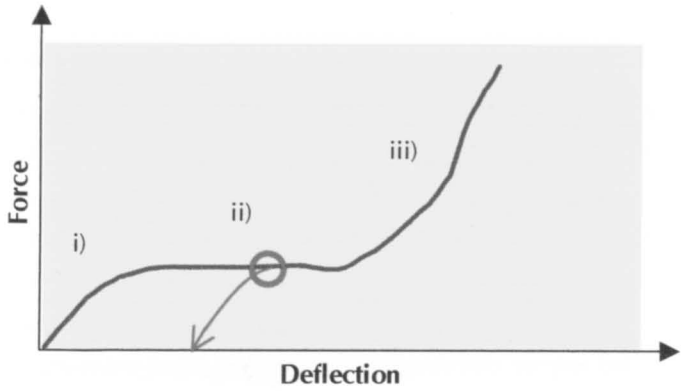



**Chart 12** – Plastic behavior

Finally, in stage iii) the corner is almost totally open and the lead-frame restarts reacting due to the momentum generated around the holding edges (see 'thunder storm' sign in the picture); the forces involved in this process increase rapidly and the deformation slows down.

How can we take advantage of this behavior?

1) **First idea**:

- A fast scan, with a laser sensor, reads the initial position of every unit in the lead-frame (on the pocket surface)
- We press all the units with a certain force that does not damage the "good units" but exceeds the elasticity limit of the "bad units"; this can be done, for example, using gravity and 152 bodies with the same mass (weight)
- When we remove the load the "good units" will return to their original state, while the "bad units" will remain deflected at a certain level beyond their initial position
- A new scan, with the laser sensor, reads the final position of every unit
- Comparing the initial and final profiles, "bad units" can easily be discriminated due their permanent deformation

2) **Second idea**:

- All the units in the lead-frame are pushed with the same force, just like in 1), but this time we use the maximum admissible force.
- We simply let the lead-frame proceed through production!
- Since the bad units are now deformed, the probability of detection in the chip testers (electrically) automatically increases

A simple experiment was conducted to test the Second idea.

**Experiment:**

*Two entire lead-frames containing **'only bad welds'** were in test.*

*All 152 units from one of the lead-frames (i) were pushed with the same force and suffered the consequent deflection. The other 152 units (from the other lead-frame, (ii)) remained intact.*

*Both lead-frames, (i) and (ii), were then sent through production and monitored until they reached the chip testers.*

*At that stage, all the units were removed from the production line and were tested for their electrical properties individually and manually at the laboratory.*

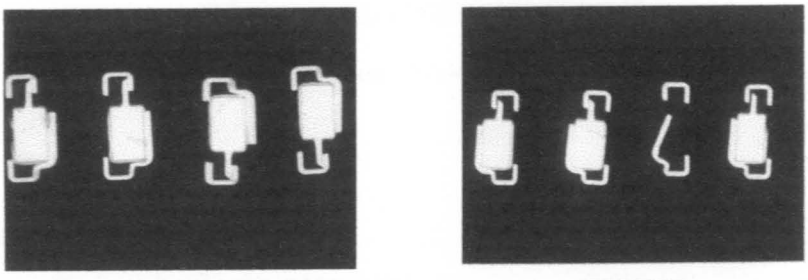
*The table below shows the proportion of units that appeared as **'good'**, out of each side (A and B) and out of the total number of units in each lead-frame, (i) and (ii).* [see **Annex 10** for image of the 152 units]

| | ***(i) NOT PUSHED*** | | | ***(ii) PUSHED*** | | |
|---|---|---|---|---|---|---|
| | ***Side A*** | ***Side B*** | ***Total*** | ***Side A*** | ***Side B*** | ***Total*** |
| ***n / N*** | *14 / 76* | *30 / 76* | *44 / 152* | *2 / 76* | *8 / 76* | *10 / 76* |
| ***%*** | *18.4211* | *39.4737* | ***28.9474*** | *2.6316* | *10.5263* | ***6.5789*** |

**Table 7** – Effect of pushing bad units beyond the elasticity limit

As we could see, the ratio "undetected units / all bad units" decreased more than 75% but is still high, considering the goal "zero-defect". Indeed, all the units were deformed after the assembly, but the molding operation forced them back to their original shape and that minority of about 7% even became apparently attached (electrically "closed").

The following pictures show an X-ray of some units in this experiment.



NOT PRESSED PRESSED

**Figure 16** – Effect of pushing bad units beyond the elasticity limit

# 5. WELD HEIGHT / THICKNESS

## 5.1. Basic Principles

The discrimination between good and bad units, concerning the anode wire attachment, can be made with the help of related measures, which are directly proportional to the quality (strength/efficiency) of the weld. One of those measures is the weld height or weld thickness.

As we described before, the welding process in the assembly machine is based on Joule Effect, counting on the electrical resistance of the Ta wire laying on the lead-frame.

If a certain weld **succeeded**, then:

- Enough heat was generated
  - **The Ta wire was compressed**
    - The solder flowed around the wire
      - **The lead-frame was smashed**
        - There was fusion between the two bodies

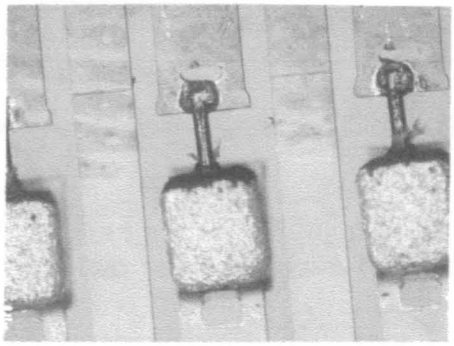


**Figure 17** – Good Welds on lead-frame

If a weld **did not succeed**, then:

- Insufficient heat was generated
  - **The wire was less compressed**
    - The solder could neither melt nor flow around the wire
      - **The lead-frame suffered less compression**
        - There was no fusion between the two bodies

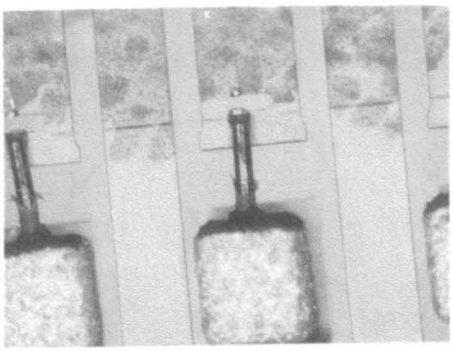


**Figure 18** – Bad Welds on lead-frame

The quality of the weld can, therefore, be assessed by the degree of compression of the Ta wire and lead-frame between the two electrodes. We call **'weld height'** to the distance between the lead-frame surface and the top of the supposedly welded wire, and **'weld thickness'** to the distance measured between the top of the supposedly welded wire and the opposite surface of the lead-frame. Graphically:

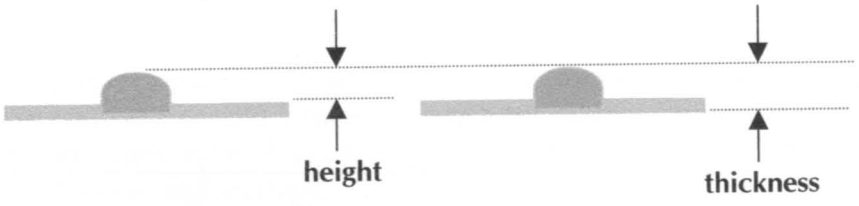



**Figure 19** – Difference between height and thickness of the weld

One of the most important variables in the welding process is the amount of current that actually flows through the two bodies that are being welded. In fact, the heat that leads to solder melting and flowing, wire compression and lead-frame smashing, is totally dependent on the intensity of current: $P = R.I^2$.

The assembly machine has a manual selector that allows us to define the level of current going through each unit in the lead-frame but not the current profile, which is an unchangeable characteristic of the machine. The current peak can vary between 110 and 340 amperes (not milliamperes...) and the current profile is similar to the following curve:

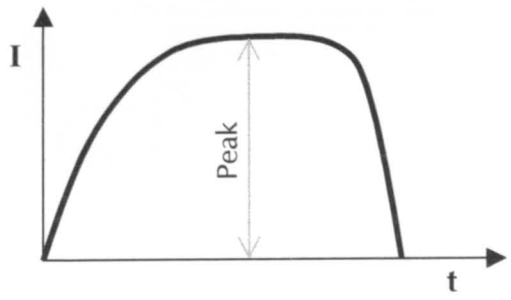



**Chart 13** – Approximate weld current profile

We have already made reference to the main causes for the occurrence of 'bad welds'. Among those, we referred the existence of shorts or shunts, which are intimately related to the current leakage:

- Direct contact between weld-head (electrode) and lead-frame
- Electric arc between weld-head and lead-frame

Having an easily assessable measure of the weld quality, such as the weld height or thickness (which are simple physical distances), and a controllable variable with which it is intimately related, such as the current intensity, we can go to the next step: data collection and analysis.

## 5.2. Data Collection and Analysis

In 'A case', which is the product size that is being object of this study, the lead-frame is 0.0045 in. (0.1143 mm) thick and the Ta wire has a diameter of 0.008 in. (0.2032 mm).

As we referred before, the welding current can be switched to 9 different values: 110, 150, 180, 200, 250, 270, 300, 320 and 340 amperes. Of course, there is also the option of switching off the welder, so that no current at all is supplied to the welding operation.

Measuring the weld height (referenced to the top lead-frame surface) is not an easy task and, in consequence, we decided to measure the weld thickness with the help of a micrometer like the one in the picture.

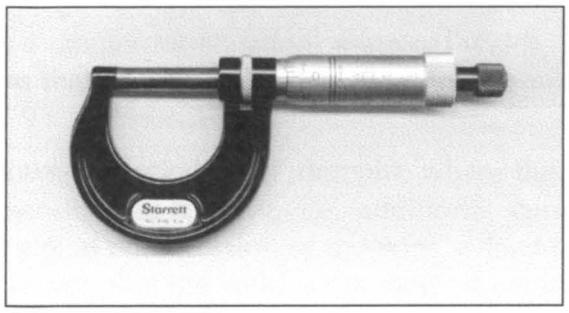



**Figure 19** – Micrometer

The measurements were made to 30 units of each type of weld schedule (9 positions + no-weld), in a total of 300 data points. The interest of performing a 'no-weld' is obvious: the compression can only be due to mechanical pressure of the upper electrode and, therefore, we are able to have a true idea of the contribution of the current to the compression of both the wire and the lead-frame.

The next chart contains all the data points:

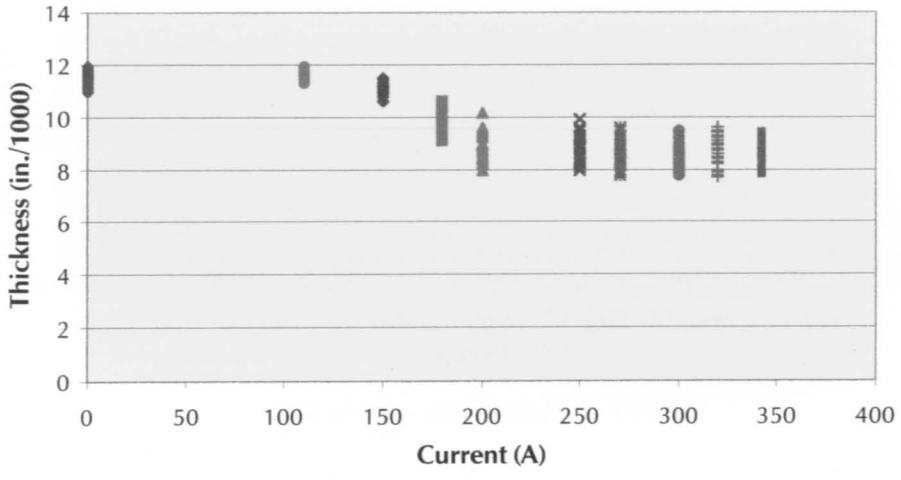



**Chart 14** – Weld Thickness vs. Current

As we can see and had already been predicted, there is an evident tendency for the decrease of the weld thickness with the increase in current.

The most interesting issue is, though, the existence of two distinct zones, clearly separated by a transition zone:

a) Thickness around 0.011 in. and higher, for currents below 150 A
b) Transition zone between 150 and 200 A
c) Thickness between 0.008 and 0.009 in, for currents above 200 A

In practice, zone a) corresponds to a situation of no-weld because, as explained above, not enough heat is generated for the fusion.

Zone b) represents a dangerous situation: marginal welds, in which there are some rare points of fusion that provide some bonding but are not very likely to assure its maintenance.

Finally, zone c) shows the 'good weld' domain, where the weld thickness does not seem to be very sensitive to current, i.e. additional current does not contribute significantly to the global compression of the wire + lead-frame. This last statement does not mean, however, that the weld is not better if we increase the current; other factors are positively affected by current, such as solder melting and flowing or the level of fusion between Ta wire and lead-frame. Currently, the assembly machine is operating with a welding current of 320 A.

If we consider 'weld height' (subtracting 0.0045 in. to the original data) and substitute all our data points by an average line with upper and lower limits (based on the rule "$\mu \pm 2.\sigma$") we obtain the following chart:

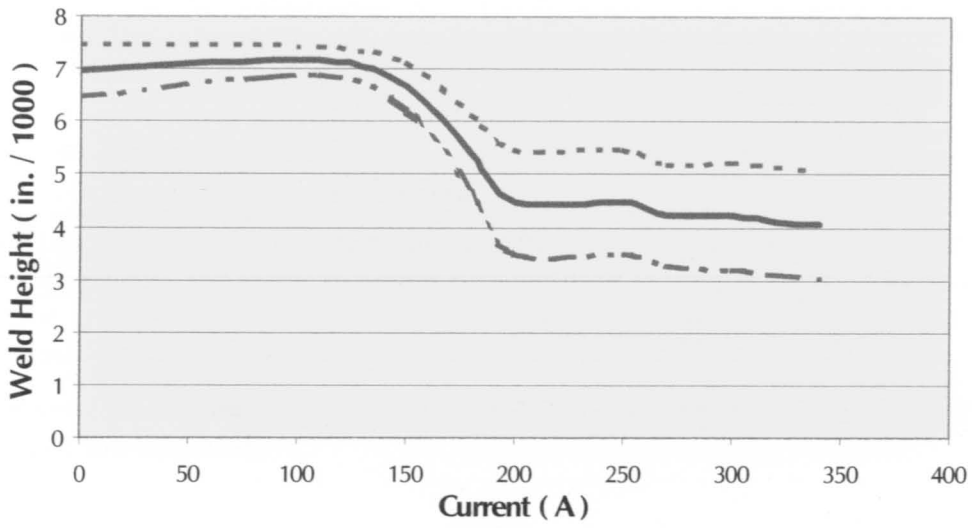



**Chart 15** – Weld Height vs. Current

For instance, from this chart we can say with some confidence that our 'good units' have their weld height below 0.0055 in. (or their thickness below 0.010 in.). On the other hand, we have the 'bad weld family' with heights clearly above 0.006 in. (or thickness greater than 0.0105 in.).

Having an objective criterion, based on which it is possible to establish borders between 'good' and 'bad', is all we need to proceed to practice.

## 5.3. Possible Practical Applications

### 5.3.1. Pogo-Pins

This device has already been object of a thorough study in the previous chapter, regarding its spring-based force and travel (distance) properties, and it was shown that the tolerances in which it operates are too large for a safe push-test.

Why should we consider it now?

In this approach our only concern is distance measurement and, despite the fact that we are dealing with very small ranges (roughly a 0.003 in. difference between good and bad welds' height/thickness), a Pogo-pin as a stand-alone system is actually a very accurate, repeatable and reliable device:

- The spring life can be very long, provided we do not work excessively beyond the switching point
- The travel to switch is perfectly constant for each device
- The histeresis of switch is very low (≈0.0005 in.), which provides a clean transition 0/1 (open/closed)

If we take two pogo-pins, they may be different between each other, concerning the travel to switch, the force at switch or even their length, but they can be assembled so that they switch in the exact same way for identical targets after a certain common external travel.

Basically, if we want the pogo-pin to switch for a thickness of 0.010 in. (or greater) we have the following:

| | **POGO 1** | **POGO 2** |
|---|---|---|
| **Travel to switch** | tsw1 | tsw2 |
| **Common external travel** | D | |
| **Distance between top and reference surface** | $D_0(1) = D - tsw1 + 0.010''$ | $D_0(2) = D - tsw2 + 0.010''$ |

**Table 8** – Two Pogo-Pins with common external travel

The picture below shows how a single Pogo-pin works in this application as well as the meanings of the variables referred in the previous table.

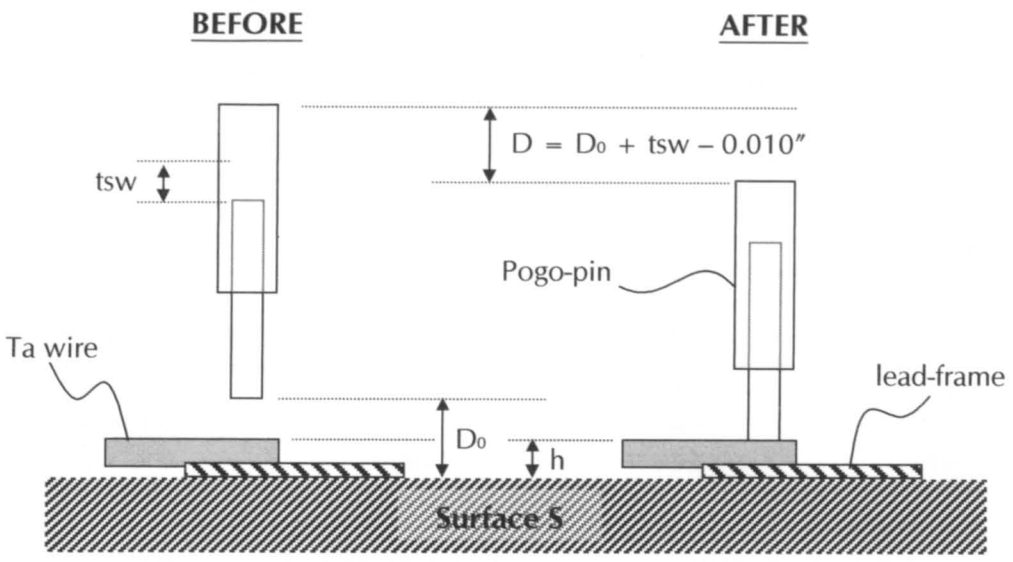



**Figure 20** – Distance assessment using Pogo-Pins

The usual cause of failure in these devices is related to the spring coating (electrical insulation between spring and its surroundings), and that occurs after a number of cycles that ranges from 100 K to 500 K [see emails from IDINET in **Annex 11**], depending on the type of usage. This knowledge allows us to estimate the cost of having this technology working in production line, testing 100% of the units:

- First of all, the production figures (at the time the study was made) [see **Annex 12**]

| | |
|---|---|
| **UNITS / HOUR** | 44 000 |
| **UNITS / LEAD FRAME** | 152 |
| LEAD FRAMES / HOUR | 290 |

- Depending on the life of the pogo-pin we can have different times in service:

| | **EXPECTED LIFE OF PROBE (CYCLES)** | | |
|---|---|---|---|
| | **100 K** | **300 K** | **500 K** |
| **EXPECTED TIME IN SERVICE** | **345 HOURS (24 DAYS)** | **1035 HOURS (71 DAYS)** | **1724 HOURS (119 DAYS)** |

- Considering 250 working days, at a rate of 14.5 hours/day:

| | EXPECTED LIFE OF PROBE (CYCLES) | | |
|---|---|---|---|
| | **100 K** | **300 K** | **500 K** |
| **EXPECTED REPLACEMENTS / YEAR** | **10.5** | **3.5** | **2.1** |
| **EXPECTED NUMBER OF DEVICES USED / YEAR** | **152 x 10.5 = 1596** | **152 x 3.5 = 532** | **152 x 2.1 = 319.2** |

- Finally, applying a cost of $8.00 / device:

| | EXPECTED LIFE OF PROBE (CYCLES) | | |
|---|---|---|---|
| | **100 K** | **300 K** | **500 K** |
| **TOTAL COST OF REPLAC.S / YEAR** | $12,768 | $4,256 | $2,554 |

These numbers roughly represent the cost of maintenance of our testing system, only for 'A case', which is the case size under study. The production numbers considered above correspond to a single assembly machine that operates in Sprague's Plant in Sanford, USA. If this testing system were to be fully implemented, we would have to consider more than 20 additional 'A case' assembly machines, located in Dimona, Israel. These figures can be compared with the assembly machine annual cost information in **Annex 13**, which leads us to the conclusion that the viability of this option is hardly justifiable.

## 5.3.2. Simple Contact Gages

As we have seen before, the weld thickness roughly varies between 0.008 and 0.012 in., and our decision border can be around 0.010 in. (0.254 mm).

If we clamp our system "wire + lead-frame" between two conducting (electrically) surfaces, A and B, that tend to be at a distance of 0.010 in. through the action of a spring based mechanism, we will have one, and only one of two situations:

1) There is electrical conductivity between A and B → weld thickness equal to or greater than 0.010 in. → bad unit
2) There is no electrical conductivity between A and B → weld thickness lower than 0.010 in. → good unit

If we attempt to send some current from A to B through the system "wire + lead-frame", that attempt will succeed in 1) and fail in 2).

The following picture can symbolize these two scenarios:

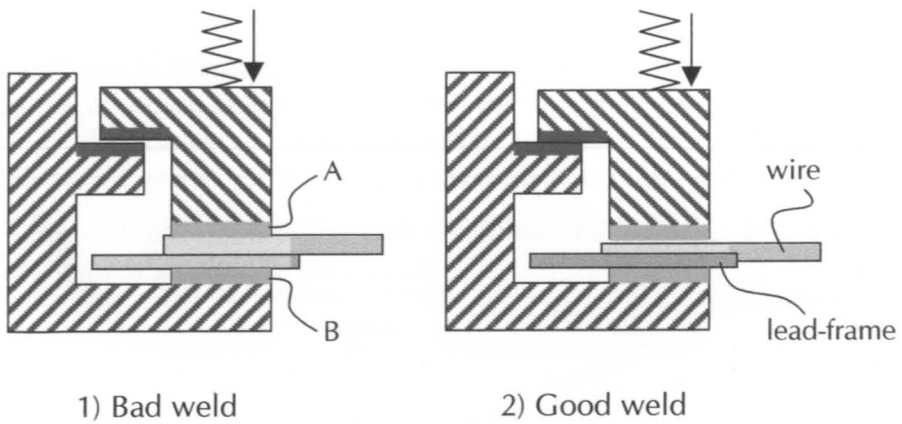



**Figure 21** – Simple contact gage concept

This method has the advantage of being executable for every unit in the lead-frame at the same time, using 152 independent spring loaded movable upper bodies (containing surfaces A) with reference to a common firm lower body (containing surfaces B). On the other hand, it requires a very high level of accuracy, especially to guarantee the maintenance of the decision distance through time.

## 5.3.3. Linear Variable Differential Transformer (LVDT)

This device is an electromechanical transducer that produces an electrical output proportional to the displacement of a separate movable core.

The primary coil is centered and the two secondary coils are symmetrically spaced on a cylindrical form. A free-moving, rod-shaped magnetic core inside the coil assembly provides a path for the magnetic flux linking the coils.

The frictionless movement and the induction principle by which the LVDT functions lead to virtually infinite resolution and mechanical life.

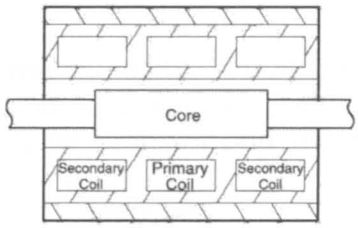



**Figure 22** – LVDT cross section

If we attach a small pin to the core of the LVDT and use it as the movable part of a micrometer (against a known reference surface), the thickness of a weld can easily be determined in proportion to the difference between two voltage outputs: *measurement on the reference surface* and *measurement on the weld*

If we operate in the central region of the coil assembly, the linearity is very good, as it can be seen in the next picture:

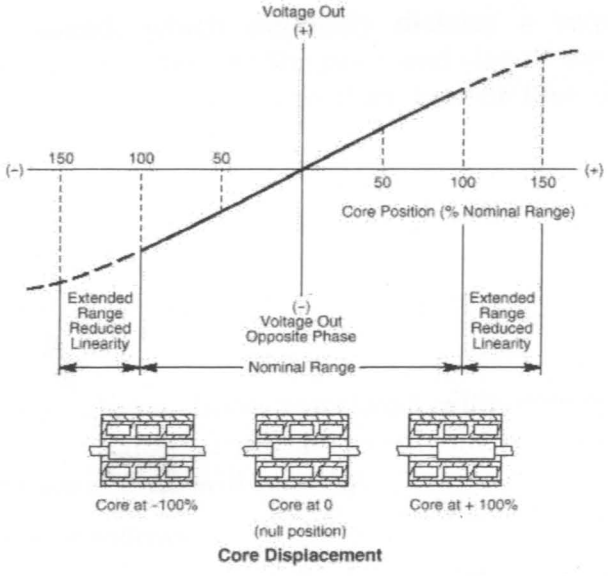



**Figure 23** – Linearity of LVDT's

The size and cost of these devices do not suggest an application where all the 152 units of a lead-frame are evaluated at the same time. Probably, the solution would be either sequential or multiple unit processing (using more than one LVDT).

### 5.3.4. Moving Coil Actuator (SMAC)

This accurate and versatile device has already been considered and described among the possible practical applications for measurement of "force vs. deflection".

The excellent measuring capabilities of this actuator should not be considered underutilized in an application like the weld height/thickness evaluation, where the purpose is only distance measurement. On the contrary, it is a privilege the combination of such accurate dimensional features (with a resolution of few microns) with the possibility to program and monitor the loads applied by the testing pin.

The methodology would be similar to the one stated for the LVDTs:

- Measure a known reference surface
- Measure on the top of the weld
- Calculate the difference between the two measurements to determine the weld thickness

A very important advantage of the moving coil actuator over the LVDT is that the vertical movement of the measuring pin is not dependent on an external device, which reduces the complexity and facilitates the maintainability of the system.

A disadvantage is speed, which definitely dictates a sequential measurement solution with more than one device. The price and size of the actuator, though, are not compatible with the usage of more than two or four devices per assembly machine.

### 5.3.5. Laser Sensor

Laser technology has always been associated with concepts such as "speed", "precision" and "remote action". These are exactly the features that make this option so attractive in our case and we will see why.

The basic principle is as follows:

1) A laser beam is sent towards the target, with a known direction
2) The reflected light is captured by one or more imaging optical sensors

3) The reflection angle (θ) and the distance to beam are determined internally
4) The distance to target is calculated by triangulation

The method is summarized in the following picture:

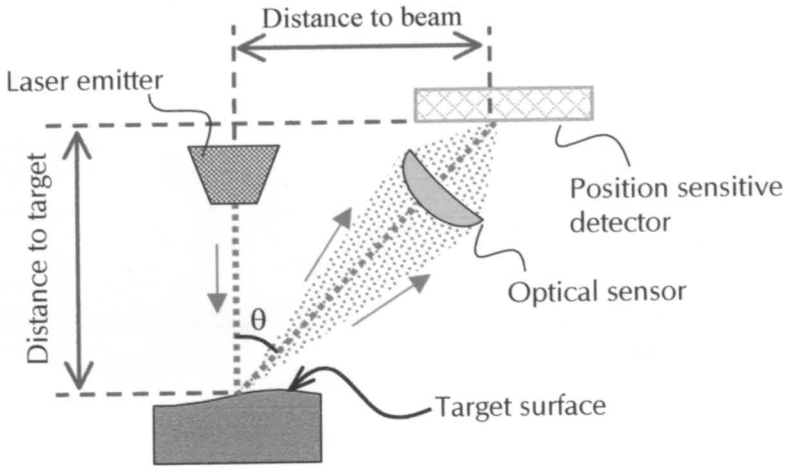



**Figure 24** – Laser sensor principle

Devices using this type of technology have several major characteristics that must be taken into account, so that the right model can be chosen for an application like ours. Among those characteristics we have:

| | |
|---|---|
| ***Spot size*****.....** | Dimensions of the light area hitting the target surface |
| ***Resolution*****.....** | The smallest distance variation detected by the device |
| ***Linearity*****.....** | The highest error along the conversion line (% of full scale) |
| ***Sampling Rate*****.....** | The output frequency |
| ***Measurement Range*****...** | Distance within which the measurements are made |
| ***Zero Distance*****.....** | Reference distance, centered in the measurement range |
| ***Output format*****.....** | The analog or digital signal proportional to distance, sent out by the device (voltage, current, etc.) |

From several devices available in the market, we decided to make some preliminary experiments with a Schaevitz TwinStar Laser sensor.

[see specifications in Annex 15]

It uses twin symmetrical imaging optics instead of only one, which provides a better contour tracking, when there are sharp increases in object height.

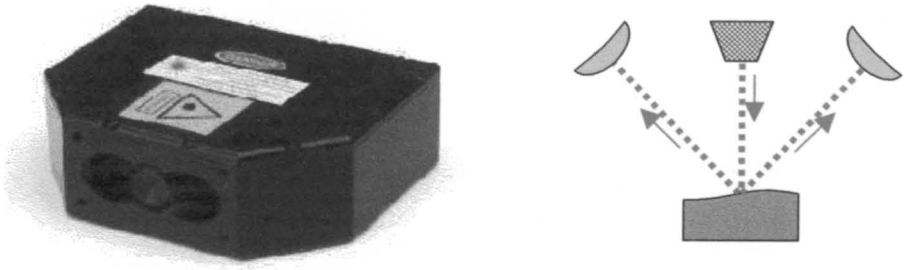


**Figure 25** – Twin Star picture and optical operating system

Other major features include:

| | |
|---|---|
| Minimum Spot Diameter | 0.0012″ (30 μm) |
| Resolution | 0.39 μ-inch (7 nm) |
| Linearity | ±0.15% of full scale |
| Sampling Rate | 100 kHz |
| Measurement Range | ±0.059″ (±1.5 mm) |
| Zero Distance | 0.591″ (15 mm) |
| Displacement Output | ±10 VDC |

Firstly, some calibration procedures were conducted, as recommended by the manufacturer. In fact, this technology is so sensitive and precise that it is always advisable to experimentally determine the right conversion factor for each single device.

In an initial attempt, three steel gage wires were measured against a flat magnet surface, not only to test linearity but also and especially to assess the ability to track surfaces similar to our round Ta wires. The results were rather satisfying.

**Experiment:**

- Flat, black, magnet, moving surface
- Steel wires with 20, 15 and 12 milli-inches of diameter on the moving surface
- Static laser sensor, at "zero distance" from moving flat surface
- Output voltage displayed in an Digital Oscilloscope (150 kHz)
- Results:

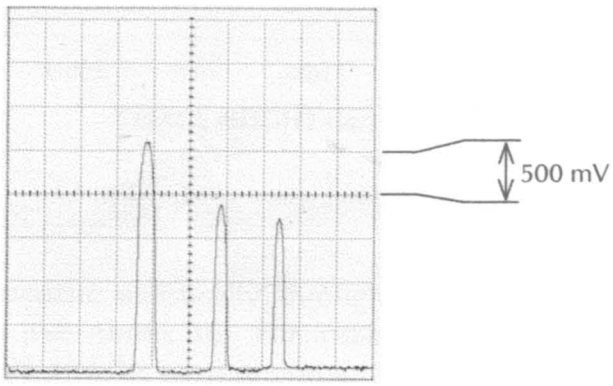



**Chart 16** – Three wires measured by the laser sensor

Afterwards, the calibration process itself took place with the help of a steel gage specifically designed and machined for that purpose. The gage included four flat surfaces providing exactly the same heights as the previous three steel wires, as we can see in the following scheme (measures in milli-inches):

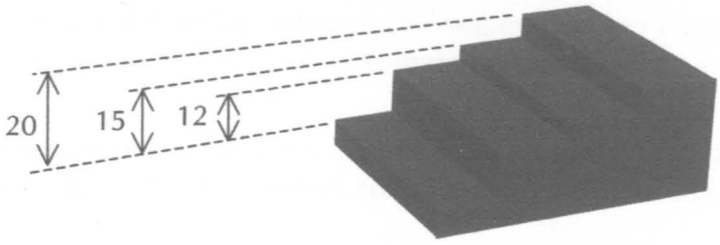



**Figure 26** – Step gage for laser calibration

The distance data was confirmed and refined with a micrometer.

The voltage data (output from laser) was tracked with a high-precision multimeter.

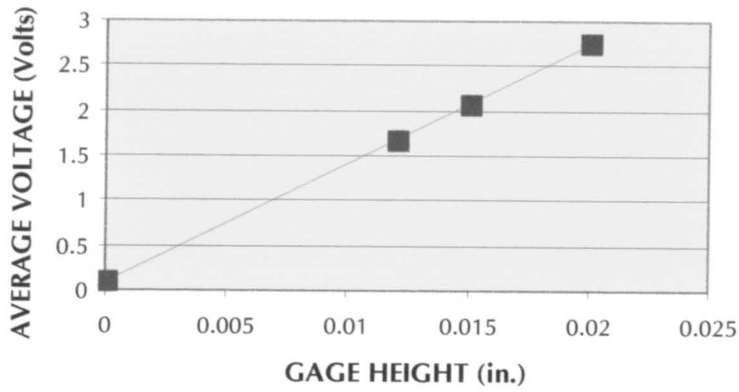



Chart 17 – Laser sensor linearity

Visually, the linearity is evident; statistically, through regression analysis, the results are also very convincing [see **Annex 16**]. For instance, the ANOVA resulted in a proof-value of 1.54079E-05 and the most important regression statistics (multiple R, R square, Adjusted R square) revealed values greater than 0.9999!!!

After the linear regression analysis, the relation between voltage (v) and distance (d) appears to be represented by the following function:

$$v(d) = v_0 + m.d$$

... where:

- $v_0$ depends on the original positioning of the sensor relatively to the target
- $m$ = 130.9962468 Volts / inch = 0.130996 Volts / (inchx$10^{-3}$)

We can now see the difference between the real conversion factor and the one that could simply be calculated from the nominal values in catalogue: 0.169492 Volts / (inchx$10^{-3}$).

Knowing the equivalence between distance and voltage and knowing that this relation is linear, at least in the central zone, we are now able to start measuring the welds.

The magnetic surface was used to hold the lead-frame (made of a stainless steel alloy) and the linear movement (on a plane perpendicular to the emitted laser beam) was provided by a DC motor.

Two positioning options were considered:

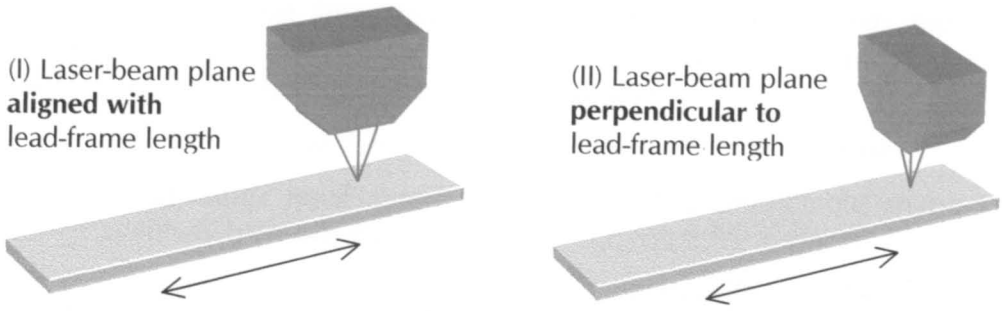



**Figure 27** – Relative positions of laser sensor and lead-frame

The second alternative (II) produced the best results, and the pictures below demonstrate typical profiles from good and bad welds, as captured by the digital oscilloscope.

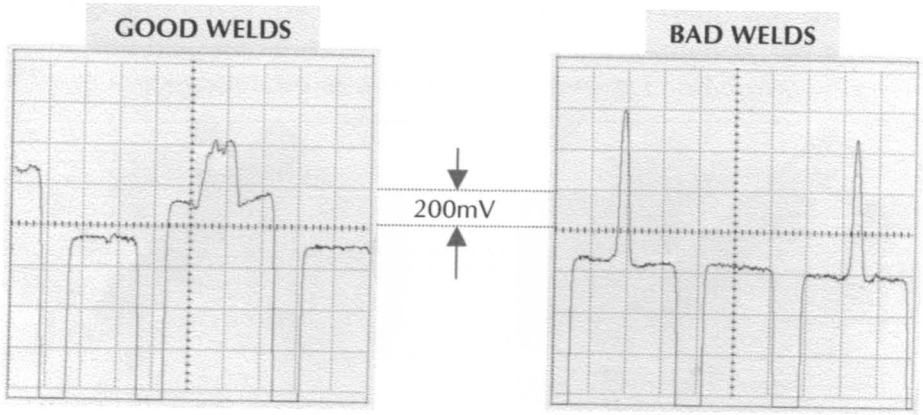



**Chart 18** – Laser outputs reading good and bad weld

As expected, the good welds showed up wider and less high in relation to the bad welds. For instance, for the good weld in the previous picture we would have:

$$\Delta v \approx 1.6 \times 0.2 = 0.32 \text{ Volts} \rightarrow \Delta d = 2.443 \times 10^{-3} \text{ inches}$$

For the bad weld on the left-hand side:

$$\Delta v \approx 3.8 \times 0.2 = 0.76 \text{ Volts} \rightarrow \Delta d = 5.802 \times 10^{-3} \text{ inches}$$

These distance values (in fact, "weld heights") do not match perfectly well the curve plotted during data collection and analysis, possibly due to the fact that we always

measured thickness instead of height (which was predicted subtracting a lead-frame thickness).

Nevertheless, the most important issue has been corroborated: the difference between good and bad welds' height really exists. Furthermore, some other interesting points can be concluded from these tests:

- bad welds are wider than good welds, due to compression
- good welds have a more irregular and unpredictable shape than bad welds (which are always clearly round, on a flat surface)
- in bad welds the lead-frame seems to remain flat, while in good welds it looks smashed towards the center
- in bad welds the lead-frame seems to remain non-deflected, while in good welds it is pulled up by the wire joint and is forced to be above the tie-bars' level

There were also some dubious readings coming from our laser device, like the ones shown below, but they still suggested a limpid distinction between the two quality types of welds. Moreover, by that time the mechanical setup was still very basic (the laser fixture, the lead-frame movement) and, in consequence, we tended to accept some of these inconsistencies as a result of the testing conditions.

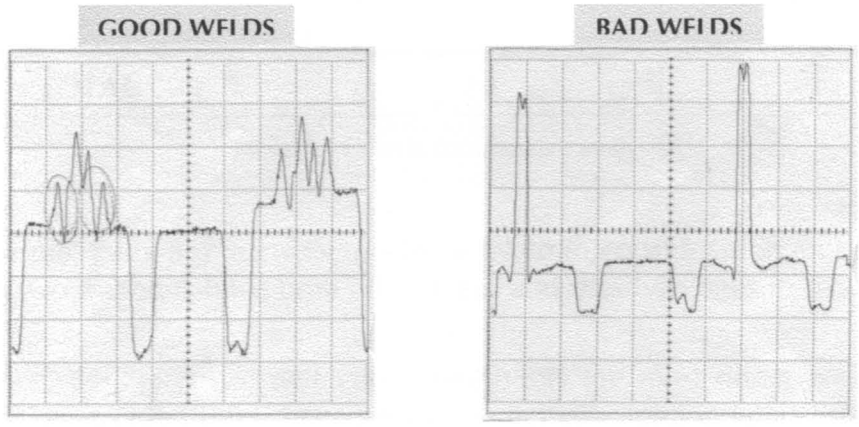



**Chart 19** – Unexplained laser outputs

# 6. CHOOSING A CRITERION AND A TECHNOLOGY

## 6.1. The Criterion

The previous chapters described two concepts that can be extremely useful in the distinction between good and bad welds: "force vs. deflection" and "weld height/thickness".

What is the most appropriate method?

The following table summarizes the evaluation of the two methods in discussion, leading to the final choice.

| | **Force vs. deflection** | **Weld height/thickness** |
|---|---|---|
| ***Relation with weld strength*** | + + + | + + |
| ***Destructibility of test procedures*** | + | + + + |
| ***Clarity of decision, borders definition*** | + + | + + |
| ***Independence from external factors*** | + | + + + |
| ***TOTAL*** | 7+ | 10+ |

**Table 9** – Criteria comparative analysis

As we can see, there are many factors to be taken in consideration and it is obvious that these two methods have both advantages and disadvantages in relation to each other.

For instance, the "force vs. deflection" represents the most direct way to test the strength of the welded joint, because we are actually forcing apart the two bodies involved: the Ta wire and the lead-frame paddle. This advantage leads, though, to a strong drawback: the destructibility of the push test.

On the other hand, when measuring the "weld height/thickness" we are not assessing any mechanical properties (such as force, tension or deflection) but only an external physical characteristic that can be measured without any harmful action against the weld bonding.

The final decision "good/bad" depends on ability to establish a border or, at least, a transition zone between the two types of welds. The collected data and its

subsequent statistical analysis revealed an evident distinction between the populations of good and bad welds, but did not allow the definition of a perfectly safe transition line. The "force vs. deflection" method is not able to eliminate some bad epoxy attachments and the "weld height/thickness" method may have some difficulties coping with marginal welds, that are sufficiently compressed but not enough fused.

As referred before, the "force vs. deflection" data is function of many variables, some of them totally independent from the welded joint itself (e.g. the epoxy adhesion), which may mislead the discrimination procedures. In return, the "weld height/thickness" data is completely straight and is only dependent on factors that directly influence the weld quality (e.g. current, electrodes).

In the end, we concluded that the best way to assess the weld quality in a reliable manner without sacrificing the units' integrity would be by putting in practice the "weld height/thickness" criterion.

## 6.2. The Technology

Having chosen the "weld height/thickness" criterion, we must now decide how to implement it, given the technological alternatives described before in the correspondent chapter "Possible Practical Applications".

Once more, we will use a table to classify the available means:

| | Pogo-Pins | Simple Contact Gage | LVDT | SMAC | Laser Sensor |
|---|---|---|---|---|---|
| ***Accuracy (setup)*** | + + | + + + | + + | + + | + |
| ***Accuracy (output)*** | + | + | + + + | + + + | + + + |
| ***Data utility*** | + | + | + + + | + + + | + + + |
| ***Speed*** | + + | + + + | + | + | + + + |
| ***Maintenance*** | + | + | + + | + + + | + + + |
| ***Risk of damage*** | + + | + | + | + | + + + |
| ***Cost ($)*** | + | + + | + | + + | + + |
| ***TOTAL*** | **10+** | **12+** | **13+** | **15+** | **18+** |

**Table 10** – Relative positions of laser sensor and lead-frame

Pogo-pins and the Simple Contact Gages are very rudimentary solutions, that do not require an excessively accurate setup but whose results can only be binary, i.e. we never measure, we only compare. These applications can be very efficient and fast because all the units (or half of them, in two cycles) are tested independently at the same time, generating instant results. Building and maintaining these mechanical systems is not an easy task, though.

The LVDT and the Moving Coil Actuator (SMAC) are identical in their output, both in accuracy and data usefulness. The main difference between these two technologies is that the LVDT is a passive device, contrarily to the SMAC that is perfectly independent and self-contained. The first one needs to be moved by an external actuator (electrical or pneumatic), while the latter generates its own linear movement towards the target (even controlling the acceleration or force, as we have seen before). The major disadvantage of these two devices is that they can only measure one unit at the time, which implies the utilization of one or more devices in a fast sequential measuring procedure, along the 152 units in the lead-frame. This situation increases the initial cost of these options, but their maintenance is fair.

All these are **"touching"** methods, based on electrical / electromagnetic / mechanical interactions and closely reproducing the manual measurement with a micrometer or caliper.

The laser sensor is positively the best option, for several reasons. Despite the requirement of a very accurate mechanical setup, with the object of assuring the appropriate laser-beam positioning, the type of output is the most complete and interesting we can get: a "cross-section" profile. All the data points can be treated through programming so that the weld height (and even width or shape) of each unit can be determined, leading to a certain decision. The major advantages of this method are speed (with a sampling rate of 100 kHz, one laser sensor is enough to respect the production cycle) and the fact that it is a **"non-touching"** measurement, avoiding any type of potentially damaging contact with the units. The cost per laser sensor is about $5,000 but we know that one device only is perfectly enough for the 152 units of each lead-frame. All other costs related to movement, electronics and/or software are equivalent to the SMAC or LVDT cases.

# 7. BUILDING A PROTOTYPE

## 7.1. General Concepts

After deciding the object of our measurements and the technology used to perform those measurements, we are now ready to simulate the introduction of this operation in production line.

Our prototype has, thus, the following purposes:

- testing the feasibility of the mechanical setup, concerning the accuracy requirements
- applying synchronized relative movements to the laser sensor and the lead-frame, for data collection
- experimenting 'instant' data collection from the voltage output
- developing and refining algorithms to treat collected data
- developing friendly output interface to display the results of lead-frame evaluation
- testing a large number of lead-frames of all types and under extreme conditions

The level of automation of this machine is not supposed to be very high. Basically, it should perform the following tasks:

| | Automatically | Manually |
|---|---|---|
| 1 | - | Receive and properly locate a new lead-frame |
| 2 | - | Give an order to start data collection operation |
| 3 | Apply relative movements to lead-frame and laser sensor, to allow the scanning of the 152 welds | - |
| 4 | Store and analyze collected data | - |
| 5 | Produce an output | - |
| 6 | - | Remove the lead-frame |

**Table 11** – Automatic and manual tasks in the prototype

We must not forget that if this detection system is to be introduced in production, then another system will be needed to receive the outputs and automatically remove the defective units. The removal system does not belong to the scope of this internship and, consequently, we will only make sure that a useful, reliable and prompt output is produced with the detection's hardware and software.

The prototype's main body, electrical and mechanical features were totally designed and built in the Annex Building, by a team of engineers, drafters, electricians and mechanists. All the hardware and software issues related to data collection, analysis and correspondent output were a responsibility of the internship reported in this document.

An isometric view of the project is shown below and, in the next sections, the main characteristics of the prototype will be described in more detail.

[see **Annex 17** for other views]

As we will see, this machine consists of a combination of different technologies, including "laser technology", which allow the automation of certain major tasks in a rather interesting, efficient and safe mode.

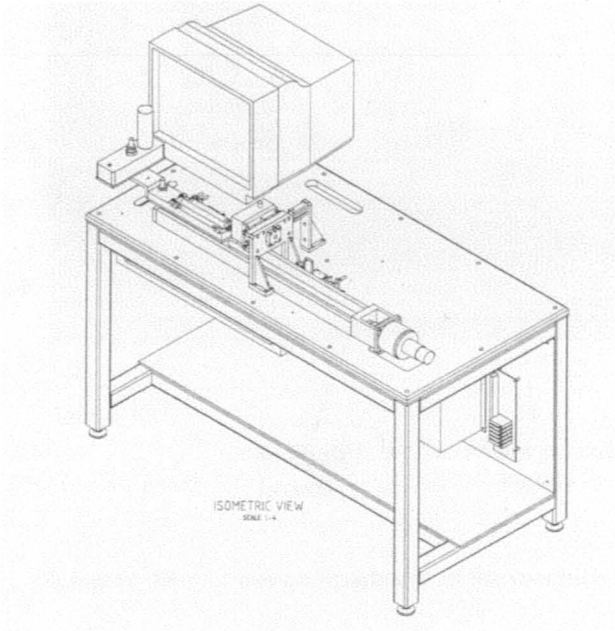



**Figure 28** – Isometric view of prototype machine

## 7.2. Mechanical and Electronic Features

The structure of the machine is made of thick sheets, bars and profiles of metal (mainly stainless steel and aluminum), which are all welded or screwed together in the most effective way possible. Rigidity is, indeed, a very important matter in a system that is supposed to perform highly accurate measurements and that, at the same time, will surely be subjected to various sources of vibration (motor, vacuum, air pressure, human action).

The lower compartment of the machine, underneath the table surface, contains:

- The main controller, a computer called MX-2000
- Power supplies and AC extensions for electrically fed devices such as the motor or the desktop PC, respectively
- Electric/electronic boards, relays, connectors, cables, etc.

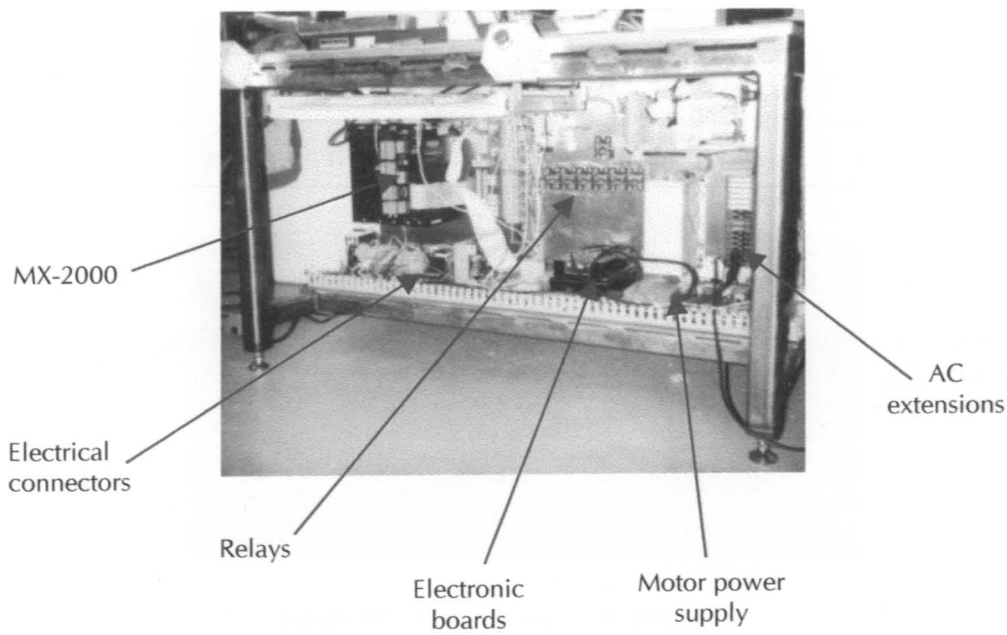



**Figure 29** – Lower compartment of the machine

The MX-2000, which is programmed in a DOS-based Basic language [see sample program in **Annex 18**], sends and receives every kind of digital signals that initiate, monitor, maintain or cancel the activity of electrical, electronic, electromagnetic, pneumatic, mechanical or optical systems.

On the table surface we have the "heart" of our machine:

- A DC motor
- A rotary slide ( connected to the DC motor) with a tray
- A vacuum system
- A laser sensor (the Schaevitz TwinStar)
- A short slide for the laser sensor
- A fiber-optics-based switch
- Several inductive sensors
- Two safety buttons
- A PC with an Data Acquisition A/D Card

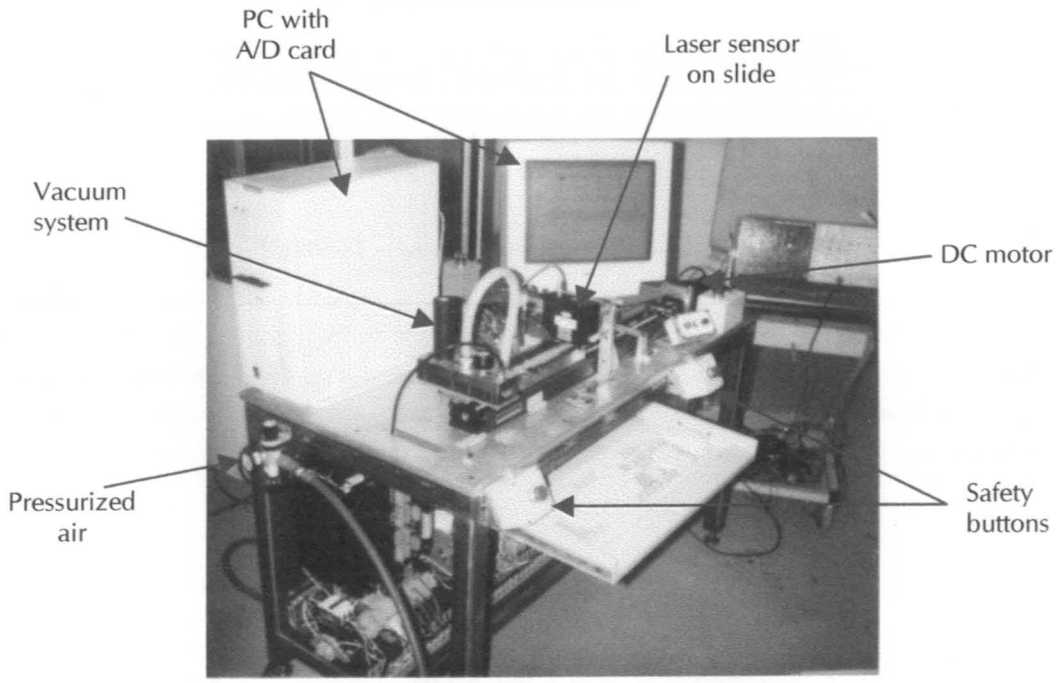



**Figure 30** – Corner view of the prototype

[see **Annex 19** for a bill of material]

The movement of the lead-frame and the two positions of the laser sensor allow the scanning of the 152 units (welds) in a very efficient way, considering that one lead-frame has two parallel rows of 76 units each. Basically, it works as follows:

- the laser sensor is located at one of two alternative positions, correspondent to one of the two sides of the lead-frame

- the lead-frame slides under the laser sensor and the beam scans all the welds in that side of the lead-frame
- after the first side is completely scanned, the laser sensor slides to the other position, which corresponds to the opposite side of the lead-frame
- then, the lead-frame slides back under the laser sensor, towards its original location, allowing the beam to scan its second side
- in the end, after the second side is completely scanned, the laser sensor returns to its original position

Graphically:

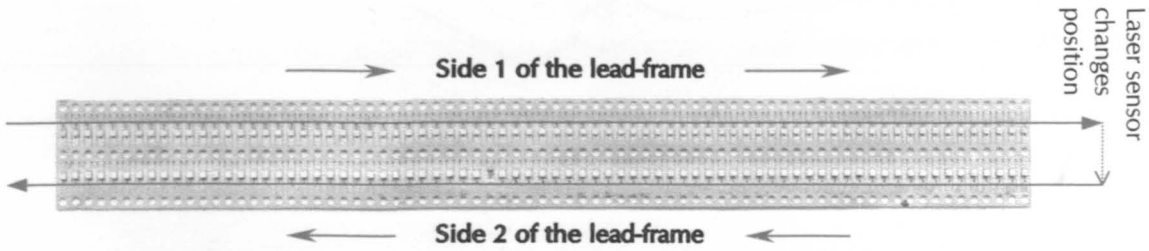



**Figure 31** – Laser beam path over the lead-frame

The DC motor is coupled with the rotary slide that holds the lead-frame on a tray. We could have applied a 'servo motor' or a 'stepper motor', which are certainly more reliable and controllable (positioning feedback), but are also more expensive.

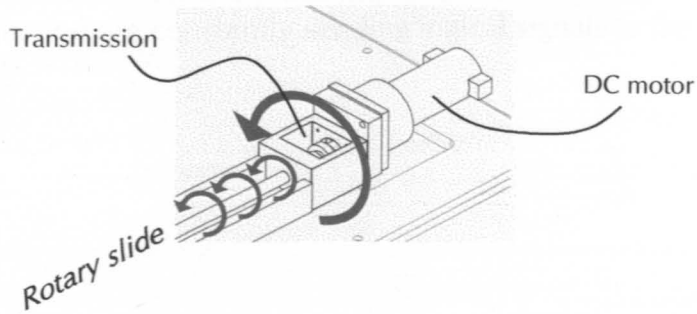



**Figure 32** – Lead-frame movement generation

The vacuum system moves together with the lead-frame tray and its function is to maintain the lead-frame as flat as possible, sucking through a small hole under every fourth welded paddle on each side of the lead-frame. This situation prevents out-of-range readings by the laser sensor due to any lead-frame unexpected curvature (resulting from human handling).

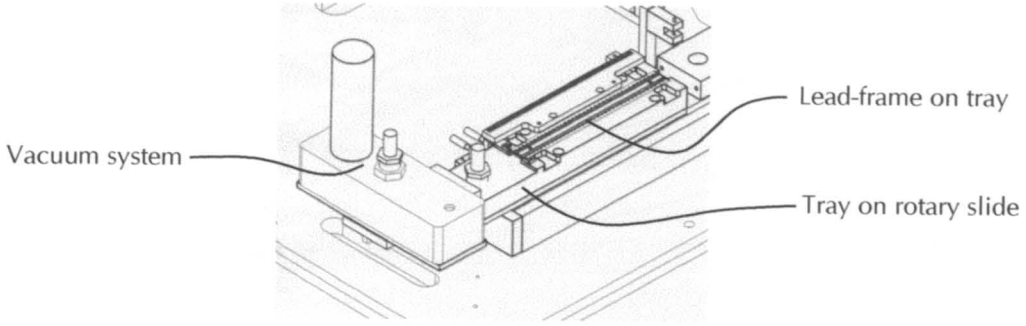



**Figure 33** – Lead-frame flattening

The laser sensor moves between two alternative positions, by the action of logic pneumatic actuators, standing permanently at a certain height ("zero distance") in relation to the lead-frame surface.

While the lead-frame moves under the laser beam, a light obstructer (a stripe of metal matching the length of a lead-frame plus a certain margin) cuts the transmission of light between the fiber optics (emitter and receptor). These transitions generate meaningful logical states that dictate both the beginning and the ending of data collection by the PC card.

Four inductive sensors detect the proximity of the rotary slide, when it reaches the extreme positions, and are constantly sending logical signals to the MX-2000.

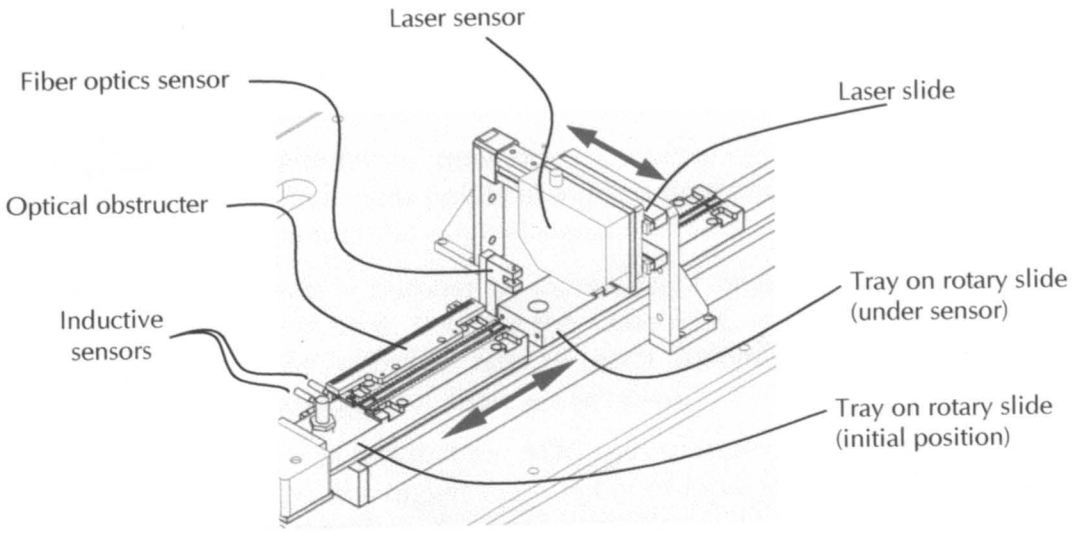



**Figure 34** – Laser slide system

Despite the fact that this machine is only a prototype, some safety issues were taken into consideration. For instance, the motor only starts moving if the operator presses two buttons (sufficiently distant so that both hands are needed) roughly at the same time. If, for any reason, at least one of the buttons is released, the motor stops immediately. Another example is a protection chamber designed to cover the laser area, to prevent any possibility of eye contact with the laser beam (type III-B).

We used a Dell PC (with a 233 MHz Intel Pentium II processor) and a Data Acquisition Card with an A/D converter to receive the analogue output from the laser sensor, turn it into a digital signal, treat it through programming and display results on a screen.

## 7.3. Hardware: NI-DAQ Card

Computers are prepared to electronically receive, treat and deliver digital data, and that is the reason why we need some kind of "translator" between the laser sensor and our PC. The role of "translator" is usually attributed to an "A/D Converter" (ADC), which it transforms **analogue** signals (like the voltage output from the TwinStar sensor) in **digital** signals that are easily interpreted by the computer.

However, not only do we want to convert the analogue voltage in a digital signal but we also need to store the converted data. Furthermore, we must be able to

receive digital data with which we can decide when to start and when to stop collecting new data.

Data Acquisition Cards are electronic boards specifically designed to perform all these tasks and their most common specifications are:

- **Sampling rate** - determines how often conversions can take place. A faster sampling rate acquires more points in a given time and therefore can often form a better representation of the original signal.
- **Number of channels** – number of independent analogue signals that can be acquired at the same time. Because the same ADC is sampling many channels instead of one, the effective rate of each individual channel is inversely proportional to the number of channels sampled.
- **Resolution** - number of bits that the ADC uses to represent the analog signal. The higher the resolution, the higher the number of input voltage divisions the range is broken into and, therefore, the smaller the detectable voltage change.
- **Range** - refers to the minimum and maximum voltage levels that the ADC can quantize.
- **Accuracy** - the smallest detectable change in voltage. It depends on the range, resolution, and gain available on a data acquisition board.
- **Non-linearity** - specified for the ADC, tells how the resulting plot deviates from the ideal signal.

The TwinStar laser sensor has some characteristics that must be taken into account for the selection of a convenient Data Acquisition Card, such as the sampling rate, voltage range and resolution.

In the table below we can compare those specifications for both the chosen board – a National Instruments Lab-PC-1200AI – and the laser sensor.

The fact that the ***available*** output voltage range of the laser (±10 VDC) exceeds the input voltage range of the card (±5 VDC) does not constitute a problem because, as we will see, the ***actual*** output voltage range of the laser usually fluctuates between –0.5 and 2 Volts.

The resolution of the card is lower than the one of the laser but, again, that does not justify any kind of concern because, in either case, we are dealing with values far below one tenth of a thousandth of an inch!

| | TwinStar | Lab-PC-1200AI |
|---|---|---|
| **Sampling Rate** | 100 kHz | 100kHz (max.) |
| **Voltage Range** | ±10 VDC | ± 5 VDC |
| **Correspondent Distance Range** | ± 0.059" ( ± 1.5 mm ) | ± 0.0295" ( ± 0.75 mm ) |
| **Resolution** | 0.39 μ-inch ( 9.906 nm ) | 14.4 μ-inch ( 0.366 μm ) **[ 12 bits = 4096 divisions ]** |

**Table 12** – Compatibility between TwinStar and Lab-PC-1200AI

[see **Annex 20** for Lab-PC-1200AI specifications]

The two lines coming from the TwinStar sensor that need to be connected to the NI-DAQ card, are *"Displacement Output"* and *"GND (ground)"*.

The first one is supposed to plug in one of the eight available analogue input channels [ACH0 to ACH7], for instance ACH0, while the second must be linked to the Analog Ground Pin, AGND.

As it was referred before, we also need to read digital information from the exterior, so that we know when to start and stop analogue data collection. Our card has three 8-bit digital ports, all bi-directional: PA<0..7>, PB<0..7> and PC<0..7>. Moreover, it has a single line that was particularly designed to trigger data acquisition operations: EXTTRIG. All these digital lines are TTL compatible and their reference is the Digital Ground (DGND), available in pins 13 and 50.

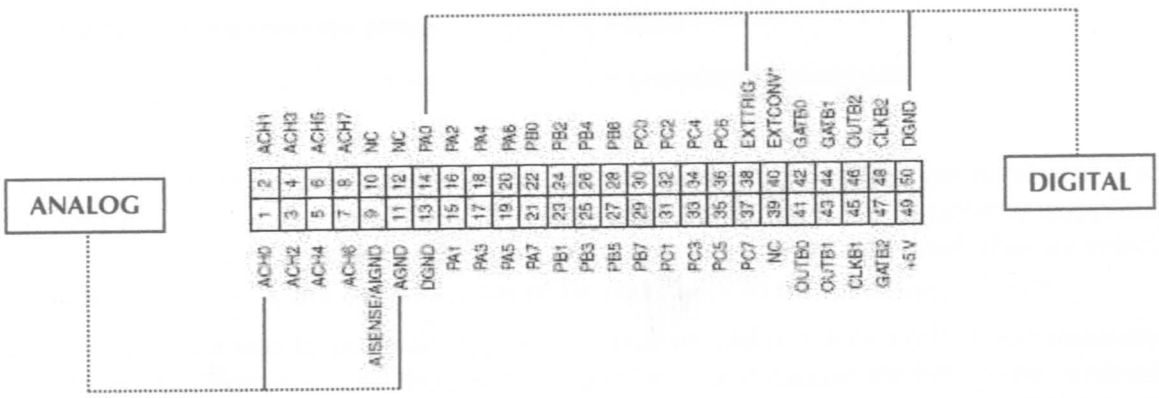



**Figure 32** – Pin Assignments of the Lab-PC-1200AI

# 7.4. Software: Visual Basic Application

## 7.4.1. Introduction

As we could see, the NI-DAQ Card can be an extremely useful piece of hardware, provided the right analog and digital connections are made. These physical means are controllable through Windows based software, by a group of functions that may be called in three different environments:

- Borland C++ for Windows
- Microsoft Visual C++
- Microsoft Visual Basic

We used "Microsoft Visual Basic 4.0 – 32 bits", which was the available tool in the company and, probably, the easiest and fastest option.

The NI-DAQ for Windows function libraries are DLLs, which means that NI-DAQ routines are not linked into the executable files of applications. Only the information *about* the NI-DAQ routines in the NI-DAQ import libraries (in our case, through the module "`nidaq32.bas`") is stored in the executable files.

The NI-DAQ functions are grouped according to the following classes, of which we used the ones in bold:

- **Initialization and general-configuration**
- Event message
- Software-calibration and device-specific
- **Analog input function group**
- Analog output function group
- **Digital I/O function group**
- Counter/Timer function group
- RTSI bus trigger
- SCXI
- Transducer conversion

In the beginning, some scattered experiments were made to test the hardware and software capabilities, essentially by studying the sample VB programs supplied among the NI-DAQ software documentation. In this stage, we were able to select and learn how to apply the functions to be used later in our own application.

The initial idea was to build an application that would not only collect and instantly analyze data, but also store the results in a relational database for future use, instead of simply displaying them on a screen. This refinement could not be fulfilled until the end of the internship because, as we will see, the central issue itself (data collection and analysis) gave us a long and complex debugging period.

## 7.4.2. The Interface

The first step, when building a VB application, is to create the forms that serve as a background to display *controls* and *information* (input and output).

***What do we need to control?***

All the movements and timings are controlled by the MX-2000. The digital data received by the PC from the fiber optics switch, through the NI-DAQ Card, constitutes the only logical contact with the mechanism.

The prototype was designed to function intensively in the analysis of single lead-frames, one by one, with the help of an operator. It is, thus, advisable that our software application is prepared to run cyclically, without any human intervention, from the beginning to the end of a certain series of lead-frames (for instance, a production lot).

Only two buttons were used: "RUN" initiates a new series, while "STOP" ends the current series.

***What information do we need to display?***

Despite having an experimental character, the prototype is supposed to work as an off-line testing station. Consequently, the operator running the machine only needs to know which are the defective units in each lead-frame in order to eliminate them, rather than having access to weld height data, which is only useful for engineering purposes and statistical process control.

A graphic reproduction of the lead-frame where the defective units are represented by red numbers on each side, after the laser scan, was the solution.

There was also space to include the identification codes of the lead-frames being analyzed (lot code, date code), some counters (n. of lead-frames, n. of units, n. of bad units, n. of good units, n. of no-units) and access to some useful current statistics (button "MORE..."). As we said before, during this internship it was not possible to implement the database to store all this data.

Actually, we have been describing the form that will be in the center of our attention from now on, which is the "OPERATE" form. This form is a MDIChild form under "LBQC" (meaning "Laser-Based Quality Control"), a multiple document interface (MDI) form.

The next picture shows the reset state of "OPERATE":

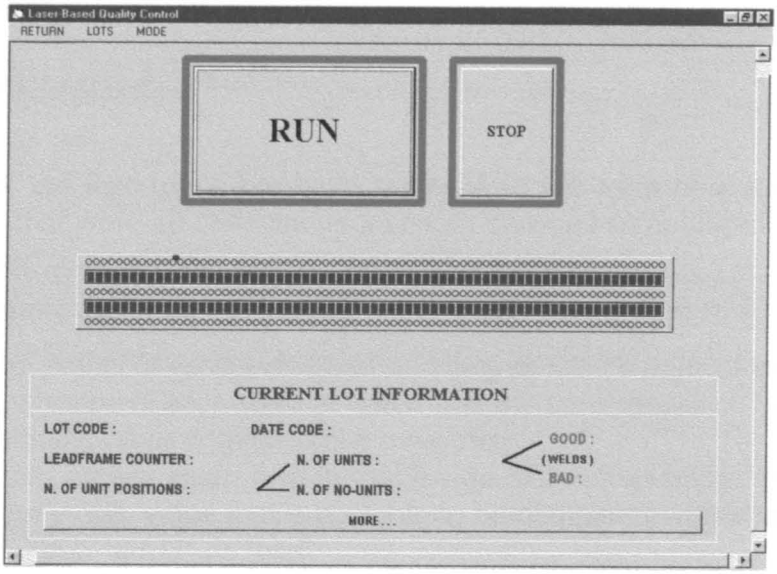



**Figure 33** – Operative Form

## 7.4.3. NI-DAQ Functions

This is the right occasion to introduce the syntax of the NI-DAQ functions.
Every NI-DAQ function is of the following form:

```
status = Function_Name (parameter 1, parameter 2, … parameter n)
```

where $n \geq 0$.

Each function returns a value in the **status** variable that indicates the success or failure of the function, as shown in the next table:

| Status | Result |
|---|---|
| Negative | Function did not execute because of an error |
| Zero | Function completed successfully |
| Positive | Function executed but with a potentially serious side effect |

The **parameters** of the function can both represent *inputs* or *outputs* and may be of different types (signed/unsigned integer, single/double-precision floating point, string) and dimensions (simple variables/constants or arrays).

## 7.4.4. Algorithm

### 7.4.4.1. Initial Considerations

For each side of the lead-frame we have a profile in the form of a succession of points (voltages) that were all collected at a certain constant sampling rate while the lead-frame moved longitudinally at a certain constant speed.

The **objectives** of the algorithm are to:

(a) identify the points of each individual unit among the 76 units of each side
(b) analyze the shape of each weld to determine the correspondent 'weld height' and, eventually, other differentiation measures
(c) produce two arrays, again one for each side of the lead-frame, that contain one, and *only one*, value that is passable to be compared with a reference for a binary output: "good" or "bad"

The reason why we admit 'other differentiation measures' is because we actually found other properties inherent to each type of weld quality that are also detectable through programming. We will talk about them later.

In the beginning, while the machine was not yet ready and we did not have access to real data, a simulation of the expected profiles had to be programmed. This stage was extremely useful because great attention was paid to all the uncertainties that might occur later with real data. Those precautions certainly contributed to the algorithm's efficiency. Examples of those uncertainties that must be taken care of are:

- random spikes with no meaning
- variability of the signal due to any electrical instability
- fluctuation of the tendency due to lead-frame bending
- misplacement of the wire on the lead-frame width (non-centered)
- lack of unit

The simulation program is in **Annex 21** and an example of a simulation is shown below:

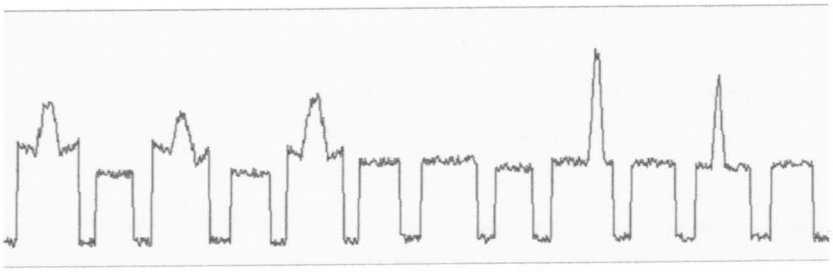


**Chart 20** – Laser output simulation

This is the type of profile that we can expect from the scanning of a certain side of a lead-frame: a total of 76 units, 75 tie-bars (between units) and 2 half-tie-bars (one in the beginning and another in the end) per side of the lead-frame.

The succession is always as follows:

**before – htb – h – up – h – tb – h – up – h – tb – ... – h – up – h – htb – after**

where:

**before**, **after** – base/ground level where lead-frame is laying down

**htb** – half-tie-bar

**h** – hole between tie-bars and units' position, at base/ground level

**up** – units' position that may correspond to a unit (good or bad weld) or a no-unit

In the picture above we can identify three units with good welds, followed by a no-unit and, finally, two units with bad welds. As a curiosity, please note the misplacement of the first bad weld, which is shifted to the right side of the paddle instead of being centered.

### 7.4.4.2. Some Methods

At this moment we started researching several methods of data filtering and analysis, as well as the most convenient way to calculate the weld height, or the 'delta' between the lead-frame surface and the top of the weld. We must not forget that our algorithm must not lose any time with irrelevant or redundant calculations since it is supposed to treat thousands of points and produce valuable results in a very short time after data collection.

For instance, the "moving average" technique was considered in several occasions, especially to eliminate noise and smooth the profile's most abrupt transitions.

A sequential analysis of the data points referring to a certain unit position brings about several problems:

- When should we consider the transitions "paddle – lead-frame"?
- What should be considered as the paddle level?
- What should be considered as the weld top?

In an effort to study these problems, two very interesting and original methods were considered: the "increasing average" and the "successive differences".

The "increasing average" is a representation of the averages of the first **k** points of a total of **n** points, for all $\mathbf{k} \leq \mathbf{n}$. The "first **k** points" may be counted from left to right (L-R) or from right to left (R-L).

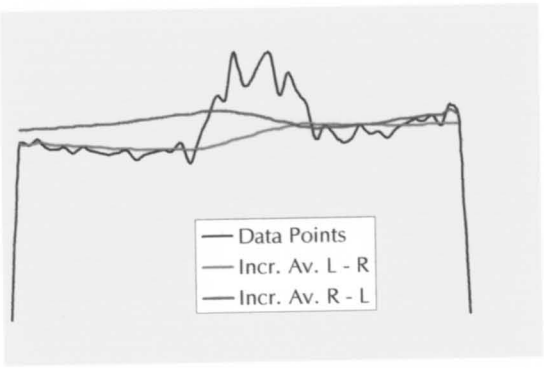



**Chart 21** – Increasing average method

As we can see, the "region" of the wire can easily be detected by evident inflections in the evolution of the "increasing average" functions, both L-R and R-L. This method is very 'heavy' and time-consuming (*simple* calculations, but *too many* calculations), though, and was never applied in practice.

The "successive differences" technique considers the absolute value of the variation between consecutive data points. In the beginning, this method was basically thought as a mean of detection of unwanted spikes but it soon revealed itself as an extremely useful way to identify the holes between units and tie-bars, or even to conclude about the weld quality itself!

In the next charts we can see the same profile we showed before (with an added negative spike) and the correspondent "successive differences" representation, including a "cumulative successive differences" series, which is also very clarifying.

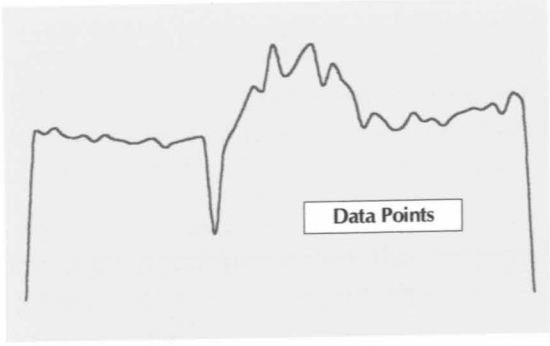



**Chart 22** – Simulated profile **with spike**

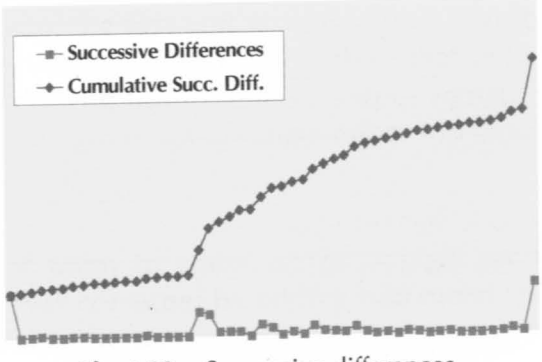



**Chart 23** – Successive differences

### 7.4.4.3. First Real Data

The first data obtained with the machine was stored in "*.dat files" and imported to Microsoft Excel worksheets. There, it could be visually analyzed, on charts, and algorithmically treated, making use of the Visual Basic for Applications (VBA) Editor.

The first lead-frames to be tested were manufactured with an alternate succession of good and bad welds, which was easily provided by the shifting mechanism of the assembly machine for 'A case'.

Here are the readings from some of the units in one of those lead-frames. The data was collected at a sampling rate of 10 kHz and a 'speed' of approximately 2 seconds per side of lead-frame.

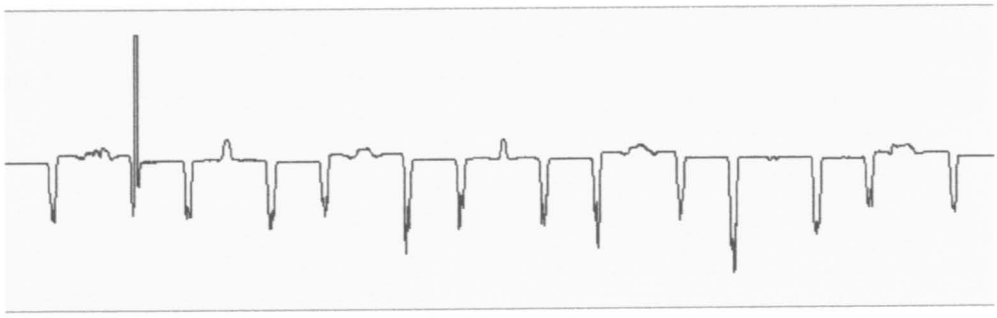


**Chart 21** – Increasing average method

From these seven units we can visually identify:

- 4 good welds (1st, 3rd, 5th and 7th)
- 2 bad welds (2nd and 4th)
- 1 no-unit (6th)

As we can see, there are also some irregularities, some of which we were already counting on. For instance, the long spike after the first unit is a jump to +5 Volts in our NI-DAQ Card (that cannot represent voltages above this value) that actually corresponds to approximately +12 Volts coming from the laser output signal. The +12 Volts output takes place whenever the target is out-of-range, either too close or too far.

When these readings were made, all the holes were indeed out-of-range and only physical speed prevented the majority of them to show up as a high positive voltage. Later in the project, this situation was corrected by adding two metal shims to the original slots and all the holes became 'in-range'.

In any case, the fact that the depth of those 'out-of-range' holes demonstrated such variability became a strong matter of concern in subsequent developments.

How can we analyze this data through programming?

### 7.4.4.4. Analyzing the First Real Data

If we recall the three objectives of the algorithm stated in section 7.4.4.1., the first step is to discriminate each individual unit among the 76 units of each side.

The method we used is based on the identification of holes as regions of high successive differences between data points. Let us illustrate this methodology with the section of 7 units considered above:

- Calculating the successive differences of all data points

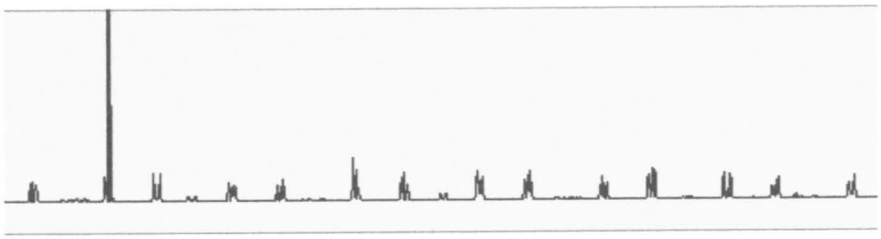


**Chart 22** – Series of successive differences

- Calculating a moving average of the successive differences

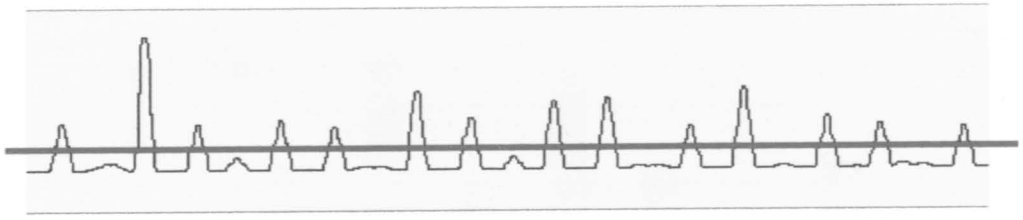


**Chart 23** – Moving Average of successive differences

- Comparing the peaks with a certain reference line (in red) and identifying the succession "**unit** – tie-bar – **unit** – tie-bar – **unit** – ..."
- Storing in a new array the relevant information about every single unit, conveniently substituting the data points referent to holes and tie-bars

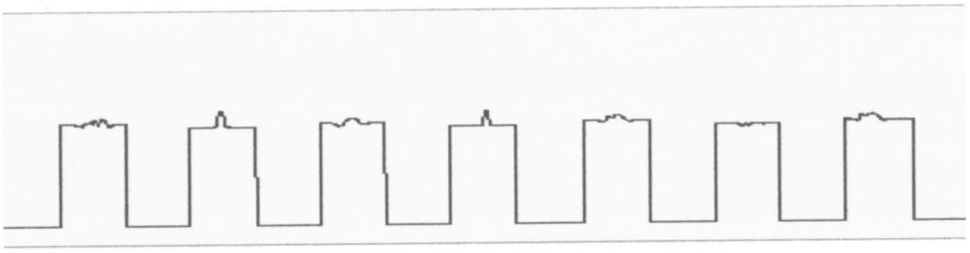


**Chart 24** – Only relevant information

After having the right data points, the second objective of our algorithm can be satisfied: analyzing each unit to determine the correspondent 'weld height'.

In the first version of the algorithm, the method was complex and a bit risky:

- interpolating a line between the two edges (first and last relevant data point) of each unit
- determining the vertical difference between all the data points and the interpolation line
- the 'weld height' is considered the greatest of those vertical differences

For the group of units that have been considered in previous illustrations, the results of this procedure are presented below:

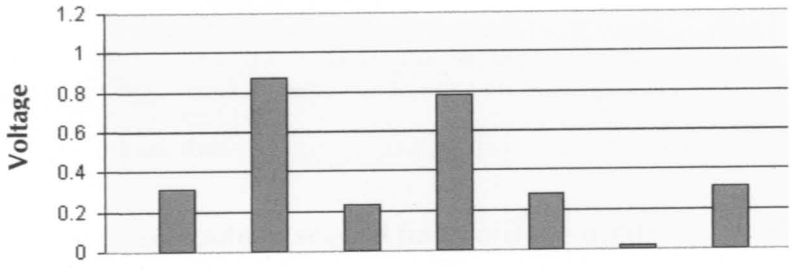



**Chart 25** – Calculated weld heights

Eventually, these voltages could now be converted to 'distance', but it is obvious that such conversion unavoidably takes more time and does not bring anything new for our final decision, that can perfectly be based in a *voltage* border value between "good" and "bad".

If we relied only on the seven units of our illustration to define a decision limit, we would probably choose a value between 0.4 and 0.6 Volts.

The analysis of several lead-frames revealed some interference between the voltage-heights of "good" and "bad" welds, which raised some doubts about:

- the method used to calculate the "heights"

- the reliability of the NI-DAQ Card acquisition
- the reliability of the laser outputs
- even the original premise about the "weld height" criterion!

Nonetheless, what we have seen until now is only the first approach towards the analysis of long and complex series of data points acquired by the NI-DAQ Card from the TwinStar laser sensor. This first version of the algorithm [see in **Annex 22]** is, in fact, the straightest attempt to the analysis of this kind of series; it is, indeed, what we would expect to be experimented in first place, before anything else.

As we have already suggested and as it is normal practice in the manufacturing of original equipment, many experiments / adjustments were made to the prototype and some of those tests / modifications involved software issues. Therefore, some alternatives to this version of the algorithm will be discussed in the 'DEBUGGING' chapter.

### 7.4.5. Sub-routines

By pressing command button "RUN", the device hardware and the NI-DAQ software are reinitialized (this is just a preventive action), and the data acquisition sub-routine ("collect") is called:

```
Private Sub Command2_Click()
    'operator ready to start!
    '(re)initialize board
    status = Init_DA_Brds(1, dnc%)
    'call data collection sub-routine
    collect
End Sub
```

In the data collection sub-routine, several functions are used:

`status = DAQ_StopTrigger_Config(1, 1, 10)`

... to make the data collection ending depend on the EXTTRIG logical state;

`status = DAQ_Rate(10000, 0, timebase%, sampleint%)`

... to calculate the "timebase" and "sampleint" parameters (as outputs) that are used later in the `DAQ_Start` function (as inputs);

`status = DIG_Prt_Config(1, 0, 0, 0)`

... to configure Port A (code 0) as an Digital Input Port;

`status = DIG_In_Line(1, 0, 0, state%)`

... to read the logical state (output) of Line 0 in Port A (code 0);

`status = DAQ_Start(1, 0, 1, binarray(0), 60000, timebase%, sampleint%)`

... to start data collection in Channel 0 and store the values in an array, as binary data;

```
status = DAQ_Check(1, stopped, retrieved)
```

... to verify if the external trigger (in EXTTRIG) is actuated;

```
status = DAQ_VScale(1, 0, 1, 1, 0, 60000, binarray(0), voltarray1(0))
```

... to convert the collected binary values to voltage values and store them in a new array.

[see **Annex 23** for further description of these functions]

The two sides of the lead-frame are collected independently, one after the other, and stored separately in two different arrays: `voltarray1()` and `voltarray2()`. In the end of this sub-routine, the data analysis algorithm – another sub-routine, called "algor" – is called.

The sub-routine "algor" has the mission of applying the algorithm, which we have already described in its very first version, to the voltage raw data that is stored in two arrays – `voltarray1()` and `voltarray2()`, one from each side of the lead-frame.

During this stage, two new arrays are created – for instance, `param1()` and `param2()`, which are the names used in the latest version of the algorithm. Each of these two arrays ends containing 76 values that shall be used in the final sub-routine ("output") as the input for the final binary decision.

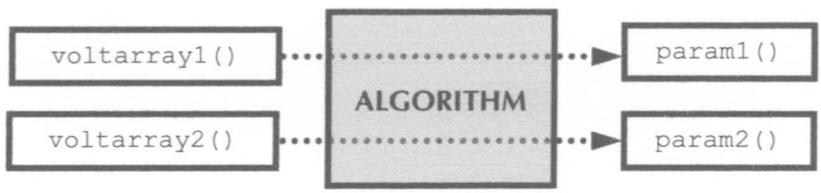



**Chart 34** – Array inputs and outputs of the algorithm

The "output" stage is the last one of the "trilogy": after acquiring and analyzing, it is essential to show the results.

In this sub-routine, the two arrays containing a single evaluation parameter for each unit (in a total of 152 values) are the main input. A certain decision limit, with which all the units can be compared and binary classified, is established according to the methodology used in the algorithm. For instance, for the first version of the algorithm the decision limit would be a voltage-height.

Two cycles are run, one for each side of the lead-frame, and the order numbers of the units supposedly with bad welds are displayed in bolded red, at their

approximate location on the correspondent side of the lead-frame. An example is shown below:

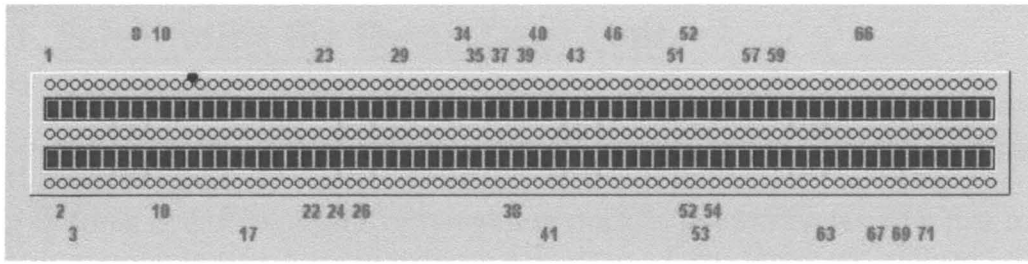



**Figure 35** – Output display example

After the results are available on the screen, the 'data acquisition' sub-routine ("collect") is called, but the form's appearance remains unaltered until the digital signals reinitiate the data collection process.

[see **Annex 24** for the sub-routine listings]

# 8. DEBUGGING

## 8.1. Substituting the Demo Laser Unit

As stated before, the first results manifested some inconsistency. For several times, the program could not even reach the output sub-routine, either being interrupted due to some over-flow errors, or remaining stuck in infinite cycles. The first reaction to this panorama was a more extensive analysis of the raw data collected through the NI-DAQ Card. The results were disappointing.

Some of the problems were detected for the first time, others were confirmed:

- inconstancy of the holes' depth between paddles and tie-bars
- some holes are lower in depth than what some bad welds are in height
- some holes do not even appear

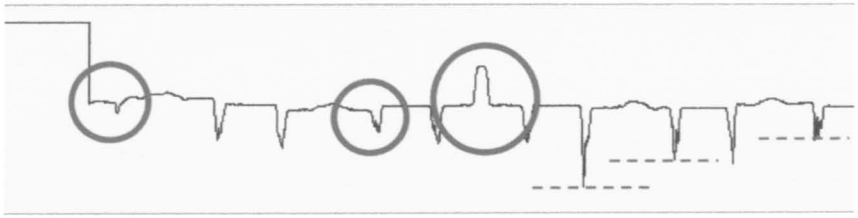


**Chart 26** – Scanning errors

- some bad welds appear surprisingly short when compared with others of the same lead-frame (that only contains bad welds)

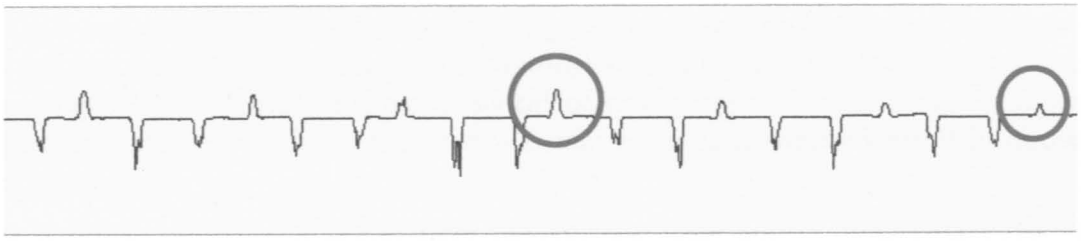


**Chart 27** – More erroneous readings

What reasons could be in the origin of these irregularities?

First of all, we verified the **alignment** of the lead-frame on the moving tray. Misplacement could be causing some instability.

We measured a lead-frame-shape sheet of metal with four holes (diameter of approximately 9 thousandths of an inch) accurately located in the path of the laser beam, two on each side and two on each end of the lead-frame.

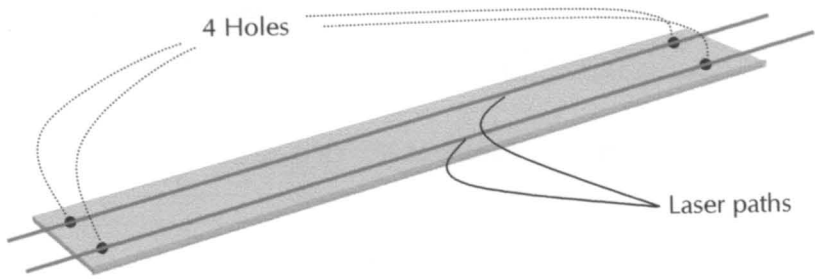



**Figure 36** – Alignment gage

The results were satisfactory and we can see an example of the profiles we obtained for each 'corner' of the alignment gage. The initial +5 Volts are, as we already explained, the region before the edge of the metal sheet that is completely out-of-range.




**Chart 28** – Alignment reading

The laser sensor that was installed on the prototype was the same that had been used for our preliminary studies, while choosing criteria and technologies. It had been ordered as a demo unit, for a period of one or two months and, once we decided to build the machine, the deal was that we would simply keep it in house and acquire it.

Being a demo unit, not a brand new device, the laser sensor might have some malfunctions that could be affecting the readings, thus, we decided to ask the manufacturer for a new sensor unit.

At the same time we made a small but structural change on the machine: the addition of two shims to the slots on the tray where the lead-frame lays down, so that the holes and the beginning/ending background surfaces are all in-range.

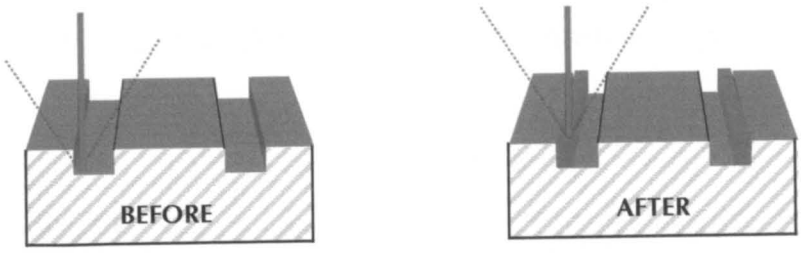



**Figure 37** – Slots become in-range

After the new laser sensor unit was installed, the results were clearly better than before. The depth was now nearly constant and, for instance, the shapes of good welds seemed much more consistent.

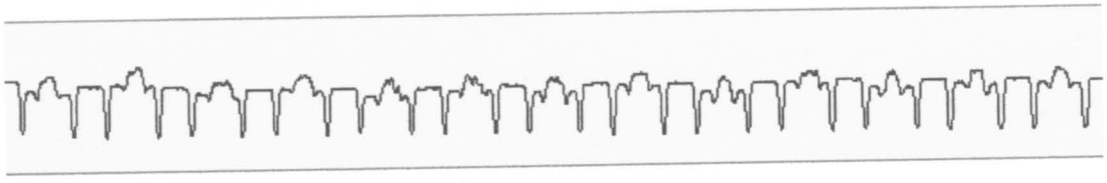


**Chart 29** – More consistency with new laser sensor

There was, however, another change: those 'same' good welds looked completely different in relation to the previous "model". Now, the paddle's surface did not seem so flat, the wire seemed wider and the surroundings of the wire presented some kind of depression or valley.

The first bad welds we could visualize in Excel charts looked very evident among a whole row of good welds, but when we tested once more a lead-frame with an alternate succession of good and bad welds, the results were somehow disappointing:

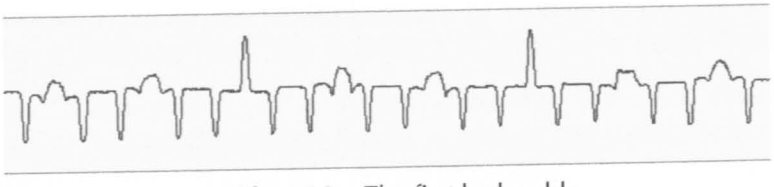


**Chart 30** – The first bad welds

The better stability of these new readings, especially concerning the good welds, increased our confidence in the new device, but the surprisingly narrow and short shape of wires from bad welds brought some discontentment again.

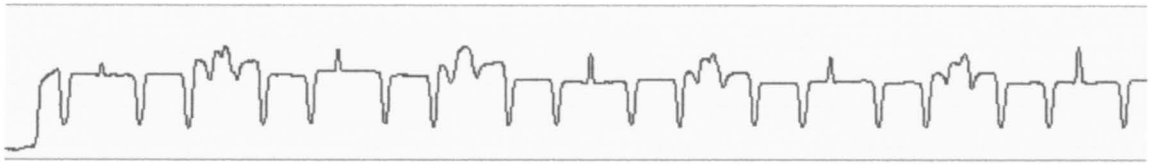


**Chart 31** – Good-Bad-Good-Bad... lead-frame

## 8.2. Programming Alternatives

Even before the demo TwinStar unit was substituted by the new one, it had been generally accepted that some changes in the algorithmic processes might be able to produce some satisfactory results. In reality, only a simplistic method had yet been tested.

The first innovation was the introduction of a multiplicity of criteria to help the final decision. If we look at the shape of both types of welds we conclude that 'height' is only one of several 'visual' characteristics that constitute a differentiation factor between good and bad welds, in voltage profiles.

The idea is simple:

- in the end, each unit still has only one classification value, that results from the conjugation of *n* criteria
- the criteria must be independent and of different nature
- the number of criteria must be large enough to spread the 'influences' and small enough to avoid redundancy
- the final classification mark of each weld should result from a mathematical function involving ***n*** parameters, one from each criterion
- in that mathematical function, the operation preceding the parameter of a certain criterion should either be multiplication or division, depending on if greater values of that criterion favor the existence of a bad or a good weld, respectively

The resulting classifications, in a system like the one just described, become extremely bipolar, especially if the chosen ***n*** criteria are independent enough not to act in opposite directions in case of a doubtful profile.

The second version of the algorithm considered three criteria:

- the difference between the total average and the greatest of a small moving average (weld height): **WH**

- the maximum average of *k* successive differences, along all the weld data points (the highest slope of the wire profile): **HS**
- the proportion of points above the total average line (weld width): **WW**

The worse the weld:

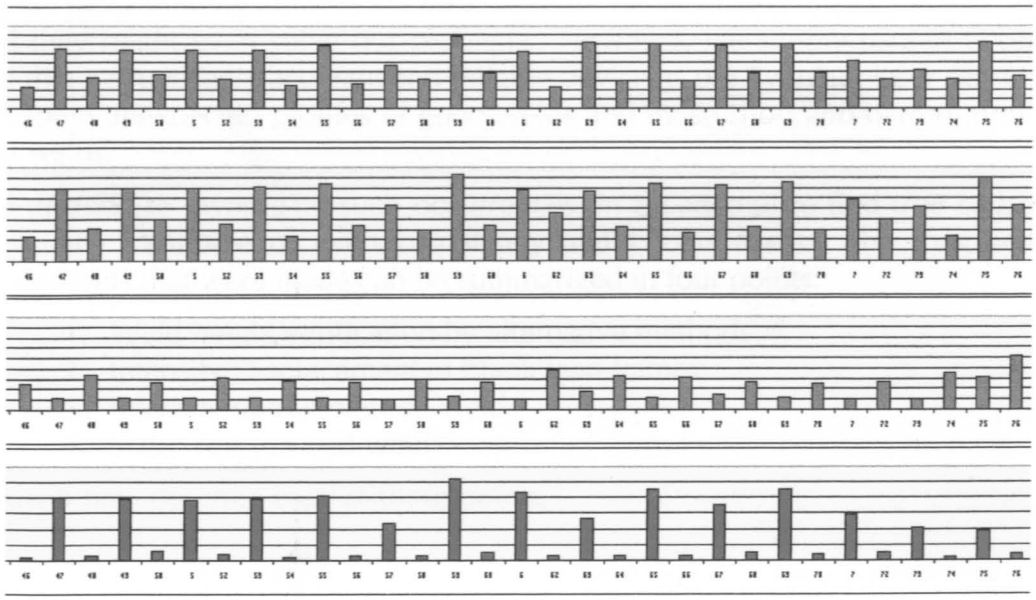
- the greater the weld height
- the greater the slope of the wire profile
- the narrower the weld/wire

For each unit ***u***, the correspondent classification mark can be calculated from these three factors, in the following manner:

$$CM(\boldsymbol{u}) = \frac{WH(\boldsymbol{u}) \times HS(\boldsymbol{u})}{WW(\boldsymbol{u})}$$

The next four charts show an example of this methodology, when applied to 31 units in a lead-frame with an alternate succession of good and bad welds:

- the three first charts represent the three factors WH, HS and WW
- the last chart contains the correspondent CM



**Charts 32 to 35** – Multiple Criteria Algorithm

Even though many structural doubts were raised after the new laser unit was mounted on the prototype, some more algorithmic experiments took place. A similar methodology was used, with only a few differences justified by the characteristics of the new profiles.

For instance, the method to identify the units among the whole data series of each side of the lead-frame became a simple matter of comparison with an absolute value, due to the new constancy of depth on holes.

The 'weld height' criterion remained unaltered, as well as the 'weld width', changing only the sequential treatment of the data points to perform the calculations. The criterion that evaluates the slope of the wire profile became simpler, searching only for the maximum successive difference along the weld profile region.

[see program in **Annex 25**]

## 8.3. Experimental Period

### 8.3.1. Introduction

All the programming artifices we described are rather interesting as a theory subject, and they might even solve our problems. However, we simply cannot accept the fact that a supposedly accurate and reliable device as the TwinStar laser sensor gives out some unexpected profiles of good welds and those short and narrow profiles of bad welds.

We decided to investigate such occurrences, in an attempt to find *true causes* and eventually minimize or even completely avoid their effects. The long series of experiments that were made can be summarized in four points:

1. Weld height verification by alternative methods
2. Intensity/Displacement of blank lead-frames
3. Intensity output of good welds
4. Static Test on bad welds

We will now describe each of these points.

## 8.3.2. Weld Height Verification

Every time we detected irregularities we immediately performed several alternative analysis, which included:

- Simple visual inspection, under the microscope
- Mechanical measurement of weld width
- Focus-based weld height measurement

Under the microscope, we could not detect any significant differences between the units that appeared well read and the ones that did not.

Successively, the mechanical measurements with several types of calipers or micrometers always confirmed the original premise of "a difference of about 3 to 4 thousandths of an inch between the widths of good and bad welds".

The most original test we conducted was the verification of the weld height under a microscope with a mini-step rotary control of focus.

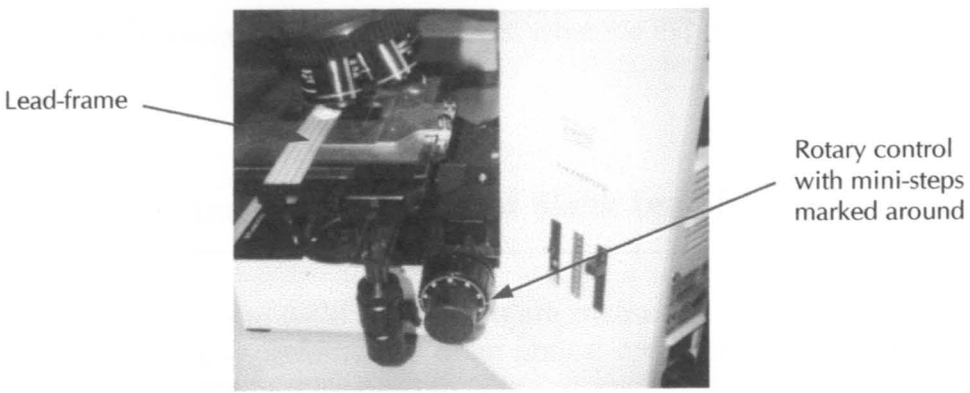
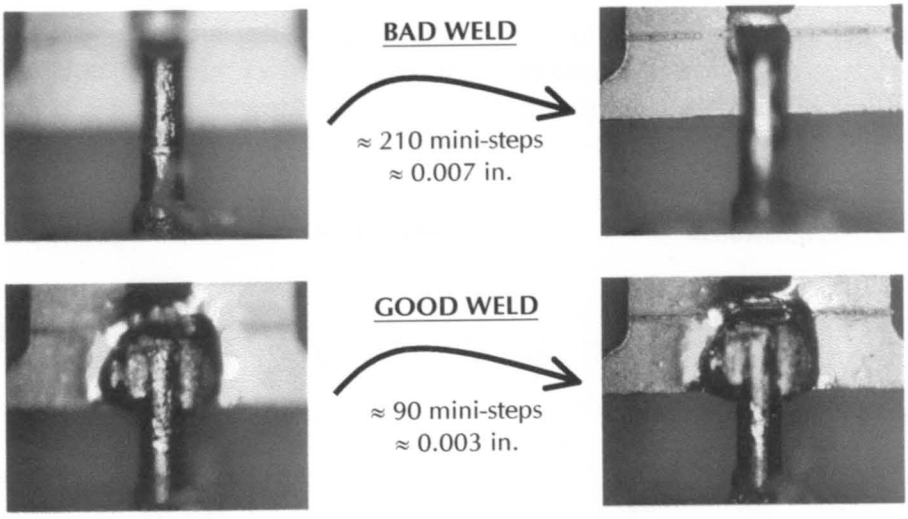



**Figure 38** – Microscope with mini-step focus mechanism

With this tool we could place ourselves either on the top of a certain wire or on the lead-frame surface, in terms of focusing, and determine the distance between the two positions controlling the number of mini-steps of the travel from one to the other. After an initial calibration, we determined that 0.001" corresponds to 30 mini-steps. An illustration of this interesting methodology is shown in below in both cases: bad and good weld.




**Figures 38 to 41** – Focus-based measurement method illustration

The results were always a reconfirmation of what we expected.

## 8.3.2. Intensity and Displacement of Blank Lead-frames

The Ta wires and all the weld regions we are measuring have an intrinsic property that may influence the performance of an optical measurement like the one we are doing: the brightness when exposed to light.

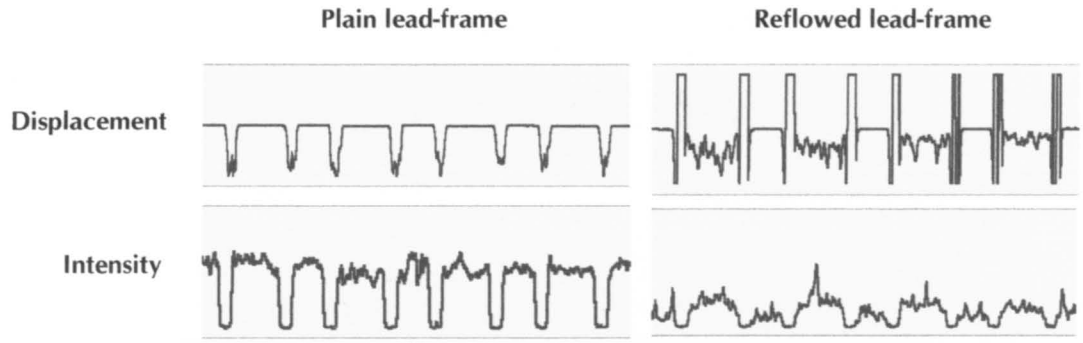
The laser sensor sends light waves with certain intensity and receives a feedback from the target. If the surface under evaluation is highly reflective, the chances of the beam to be absorbed by the surface are very low, but the strong feedback can either be very well captured by the optical sensors, or spread in all directions, depending on the surface's shape and quality (color and rugosity).

Some reflectivity tests were made using blank lead-frames (with no units at all) of two types:

- Plain lead-frames (normal brightness)
- Lead-frames with reflowed solder (increased brightness)

The tests consisted on collecting both the *displacement* and the *intensity* outputs of the laser sensor. The intensity output is a voltage that represents the amount or degree of strength of the light that is captured by the sensors.

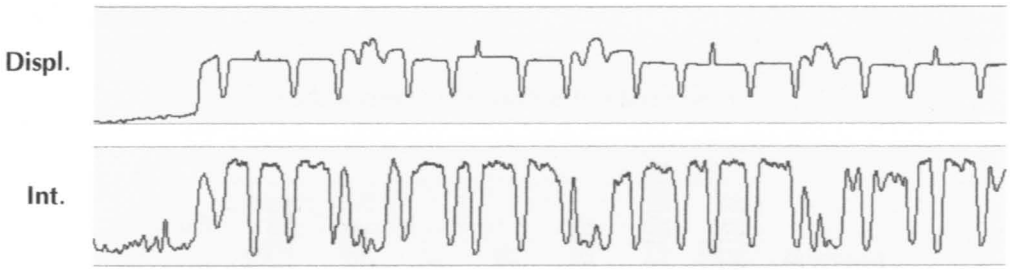
As we can see by the following charts, the results were not very positive because they revealed that our TwinStar sensor is extremely sensitive to surface reflectivity conditions. These tests were executed with the demo unit but the results were very similar for the new unit.




**Charts 36 to 39** – Reflectivity test on lead-frames

## 8.3.3. Intensity and Displacement of Good and Bad Welds

We also collected the *intensity* and *displacement* outputs for some lead-frames with good and bad welds. For instance, those depressions before and after the wire, in good welds, seemed very bright, as well as the top of some wires, in bad welds. The results were rather elucidative:

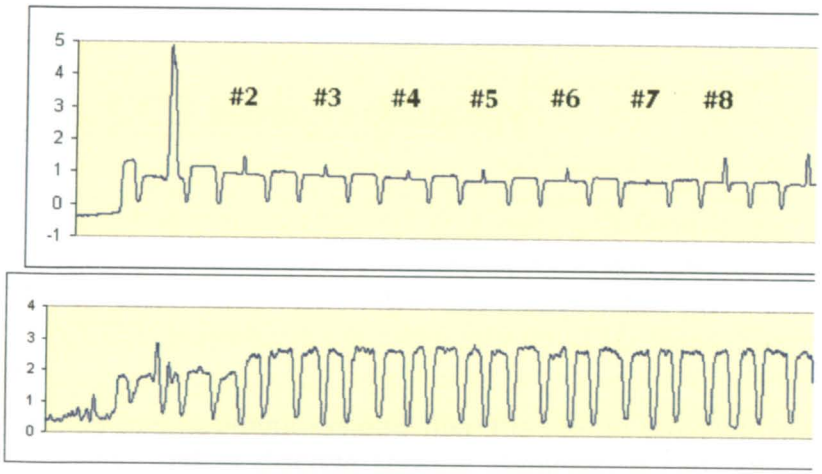



**Charts 40 and 41** – Intensity output for lead-frame with units

## 8.3.4. Static Tests on Ta wires of Bad Welds

During the debugging period, we not only performed reflectivity tests but also a series of color tests, painting lead-frames with different colors to observe the effects on intensity and displacement. The reaction of the laser sensor to the presence of a black (light absorbing) surface surrounding the laser spot on the target was the most convincing evidence that our results are affected by the surface condition.

Everything started with a group of bad welds that constantly presented very low height, as a displacement output from our sensor. That displacement output and the correspondent intensity are shown in the next charts.




**Charts 42 and 43** – Problematic group of 7 units

The alternative methods confirmed that they were all normal 'bad welds' with heights between 0.006" and 0.007".

The experiment we made after was decisive. A black paper with a small hole was put on the lead-frame, so that the measurement was made through the hole. This way we avoided any reflection in the surroundings of the weld. The voltage displacement output was read, first under these conditions and then after removing the black paper, but always with the lead-frame stopped and the laser beam hitting the top of the wire (static test). [see **Annex 26** for oscilloscope outputs] The results were astonishing:

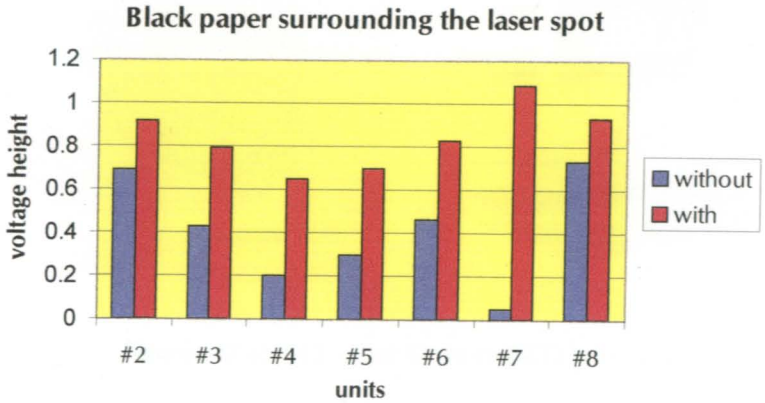



**Chart 44** – Static test results

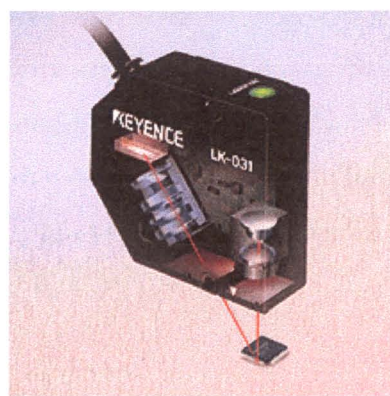
After this experiment we decided to research how laser technology can deal with highly reflective surfaces without giving out erroneous readings. The next chapter is the result of that research.

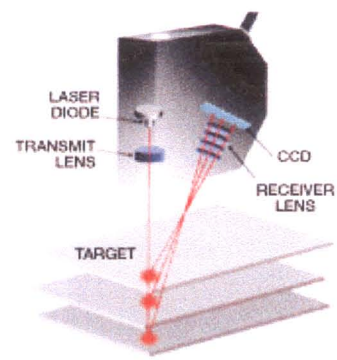
## 8.4. PSD vs. CCD Laser Technology

Only after long debates with Schaevitz engineers and technicians, concerning the feasibility of this application with the present TwinStar laser unit, did we finally discover that PSD (Position Sensing Detector) technology had recently been surpassed by CCD (Charge-Coupled Device) with LFTC (Laser Flash Time Control) technology.

The conventional measurement systems (like the one in our TwinStar) use the PSD, which is not comprised of discrete sensing elements. It can only utilize the light quantity distribution of the **entire beam spot**, which is focused on the PSD to determine the target's position. Depending on the diameter of the beam spot itself, measurement errors can be significant.

Keyence is a well-known Japanese manufacturer of a wide variety of sensors for factory automation. They have recently introduced in the market the LK CCD Laser Displacement Meter, which also uses a triangulation measurement principle. [see **Annex 27** for more details]




**Figures 42 and 43** – The Keyence CCD laser sensor

A semiconductor laser beam is reflected of the target surface and passes through a custom designed receiver lens system. The beam is then focused on the CCD sensing array, which detects the **peak** value of the light quantity distribution of the **beam spot for each pixel** (individual CCD sensing element) within the area of the beam spot and determines the precise target position. This technology can resolve positional changes of 1.0 micron, virtually in all kinds of material and under difficult conditions of color and texture. The next picture illustrates the advantage of CCD over PSD technology.

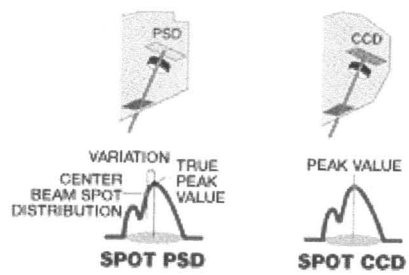



**Figure 44** – PSD vs. CCD

We ordered a demo unit and performed some tests. There was a specification of the LK model that we knew, from the beginning, would constitute a limitation: the maximum sampling rate available was around 2 kHz (sampling time of 1024 microseconds). We know that we must have at least the double of that because:

- Spot size (diameter) = 0.0012 in.
- Wire width = 0.008 in. → needs 0.008 / 0.0012 = 6.7 points
- Lead-frame length ≈ 8 in. → needs 8 / 0.0012 = 6700 points
- Scan of one side should take ≈ 2 seconds → Sampling Rate ≈ 3350 Hz

Despite the slower speed (in order to collect the required number of data points) and some electrical noise that had to be isolated, the very first results were promising:

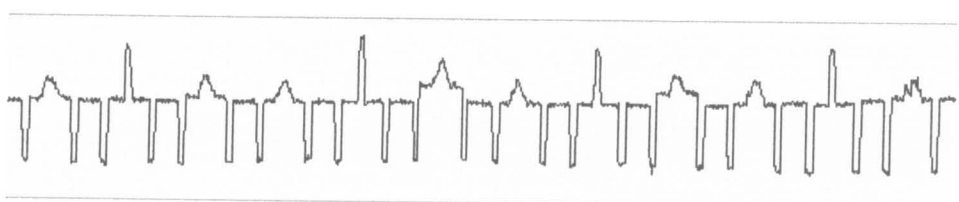


**Chart 45** – First results with the Keyence CCD

But very soon the same "ghosts" of the past reappeared... when we scanned a lead-frame full of bad welds:

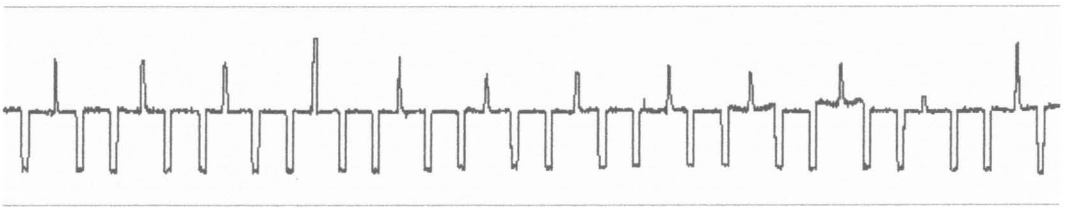


**Chart 46** – First bad weld erroneous readings

Once more, the very narrow and/or short wires of the bad welds showed up on the charts, destroying the new hope that CCD technology had just brought.

We also experimented another PSD laser sensor, from Keyence LC series, but the results were definitely not better than the ones we had had with our Shaevitz TwinStar sensor.

# 9. SMAC: A SHORT-TERM SOLUTION

In August, a definite and urgent compromise with a very important customer, concerning exactly the 'opens' issue, put an end to the long period of continuous experiments with the laser technology we have been describing. After so much time without producing the expected results, it is natural that the anxiety of customers has increased exponentially, transforming the *"convenience"* of solving this problem in the medium-run into a *"vital"* necessity for the company.

It was, therefore, decided that the prototype machine would become a production tool for quality monitoring, eventually statistical process control (SPC), making use of the SMAC Actuator for weld height evaluation. As we know, the moving coil technology is extremely accurate and mechanically the safest, in terms of the risk of damage for the measured parts. This short-term alternative is, after all:

- The best automated reproduction of a manual measurement of thickness with a micrometer, which always worked
- The most adequate substitute of the laser sensor device, considering the prototype's hardware, software and mechanical contexts

Even though being the safest and fastest mechanical solution to implement in short time, the moving coil actuator implied some structural changes in the movement control by the MX-2000:

- A servo-motor substituted the DC motor, so that we have a faster and regular movement, as well as a perfect linear position control (sending orders and receiving feedback)
- Periodic digital signals provide the coordination between the movement of the lead-frame (by the servo-motor) and the fast vertical measurements of the actuator

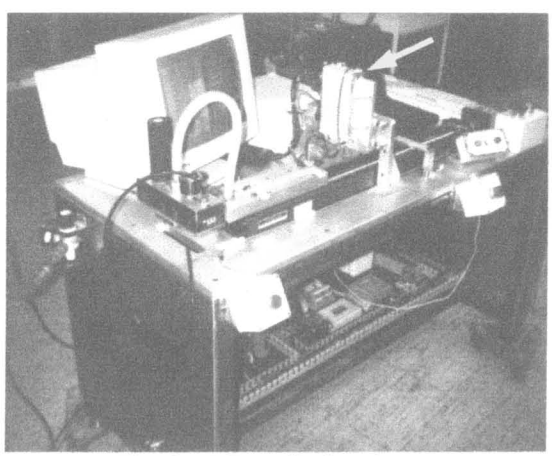


**Figure 45** – The SMAC applied to the prototype machine

# 10. CONCLUSIONS & RECOMMENDATIONS

The project described in this report has not yet finished. Even if the prototype had been working very successfully, with a laser sensor or with any other technology, the subject 'opens' would not be a closed item, at least for Sprague.

As we said in the beginning, the ultimate goal is always the correction of the problem on its origin. Even though we have not positively decided about the right way to detect the deficient welds in line, on a 100% basis, for subsequent automatic removal, we have certainly learnt a lot about the characteristics of the welds that can be considered to perform that detection, as well as we have now a better knowledge of the available technologies to execute that action.

The laser technology really seemed the best choice, for its accuracy (under 'normal' conditions...), for its speed and especially for the fact that it is a completely non-destructive method. The production amounts are, however, too big and the nature of this problem is too strict for a decision to be taken only based on a few preliminary experiments. This is why the prototype machine had to be built and all the experiments had to be conducted very carefully, to uncover any weaknesses and possibly reveal unknown strengths of the chosen technology.

The prototype has, thus, fulfilled its mission, showing us that even the greatest cutting edge technologies may have some drawbacks that undermine their performance in applications that seem perfectly attainable. Nevertheless, and in spite of the decision that transformed our prototype in a quality control station, using the SMAC Moving Coil Actuator, it would be radically unfair to conclude that laser technology is completely unsuitable to solve our situation, and we will explain why.

After such a long experimental period, in which we researched the most recondite details of the sensor and our own product, the objective conclusions must be:

- laser technology, either PSD or CCD, is not capable of performing reliable measurements directly on the lead-frame, due to reflectivity and, eventually, shape issues
- laser technology can easily and accurately measure on most surfaces presenting 'normal' levels of reflectivity, discreet colors and regular textures

After these two points, the logical question is "Why not using the laser on an easily readable surface whose position is proportional to the weld height or thickness?"

This solution may seem illogical because it means that we would have to *compress the weld between a spring loaded pass-through-pin and a known surface*, for us to measure on the opposite top of the pin, which would present an acceptable surface.

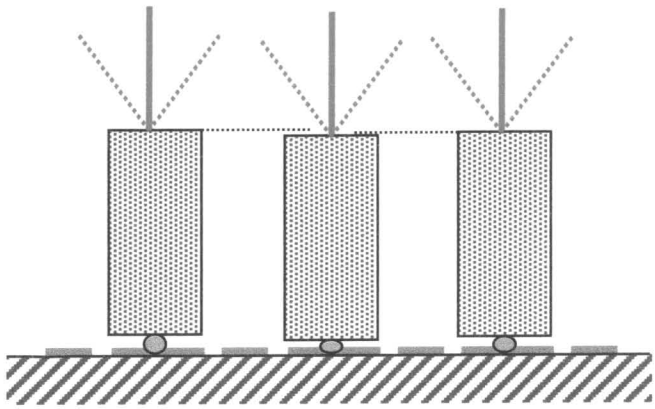


**Figure 46** – Laser measurements on known/easy surfaces

Yes, maybe one of the most important conclusions of this project is that it is very difficult, not to say impossible, to assess the weld quality without touching it. Now, the truth is that:

- we admit the utilization of mechanical methods (Moving Coil Actuators or LVDTs) for thickness measurement, knowing that those are *contact methods*
- we know that those accurate touching methods need to be sequential or multiple sequential, because each device only measures one unit at a time, and each of those measurements takes time

If we have already considered the possibility of making contact with the units, why not taking advantage of the speed capabilities of the laser sensor (high sampling rate), together with excellent accuracy and resolution features, by scanning simple surfaces that do not even need complex programming treatment?

This is a final suggestion that was not tested in practice but whose implementation might only constitute a challenge due to mechanical issues, specifically, the pass-through-pin system. A very good example of this mechanism is already operating in the assembly machine, exactly at the weld station, pushing down the weld heads (copper welding pins) against the Ta wire. We could even take advantage of the existing mechanical setup to measure either thickness (scanning after the welding operation) or penetration (scanning before and after welding operation).

Other conclusions can be taken from the internship reported in this document:

- Nowadays, customer satisfaction is probably the strongest driving force in the research, development and improvement of products and equipment
- Manufacturing original equipment has its costs but constitutes, after all, a major competitive advantage, especially as a refinement tool
- In engineering, 'problems' are a rule, not an exception

- At present, the available information and communication technologies cannot allow problems to be postponed nor solutions to be retained
- Frequent and systematic communication between people involved in the same problem is a very useful tool
- It is also very important to inform the productive and technical personnel about what is being researched for two reasons: motivation and possibility of some feedback
- All office work must be a cause and an effect of some practical experience

Finally, a quotation that can be seen everyday by all the people at Sprague, which has certainly a special meaning in the context of the 'opens' project:




**Figure 47** – Entry corridor at Sprague

# 11. BIBLIOGRAPHY & OTHER REFERENCES


- Vishay-Sprague Annual Report, 1997
- Physical Principles of the solid Tantalum Capacitor, Dr. Yuri Podzdeev
- IDINET Catalogue and Source Book, Fifth Edition, 1998
- Schaevitz Measurement Devices Reference Catalogue, 1997 Edition
- SMAC Moving Coil Technology Catalogue
- Keyence Laser Sensors Reference Catalogue, 1998 Edition
- National Instruments Data Acquisition Card Documentation
    - NI-DAQ User Manual
    - NI-DAQ Function Reference Manual
    - NI-DAQ Help
- Microsoft Visual Basic 4.0
    - Reference Manual
    - Function Reference
    - Advanced Programming Features

# 12. ANNEXES

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A.16. Laser Calibration Regression Analysis
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# A.1.
# Sample complaints from customers

BIBLIOTECA F.E. PORTO

VISHAY
SPRAGUE

CUSTOMER: DELCO
LOCATION: OAK CREEK WI
CUST. DOC. NO: WEL-1997-0459
CUST. CONTACT: R. TOMASHEK

DATE OPEN: 5-Nov-97
DATE CLOSED: 19-Nov-97
CAR#: 745-03C RA:
PROBLEM CODE: 34

MARKETING MGR: J. BOURNE
SALES REP: JOHN SHAW
MFG REP/SALES OFFICE: ISO
CUSTOMER P/N: 16072356
SPRAGUE P/N: 293D156X0016C
Detail 154

M.O. #:
P.O. #:
DATE CODE:J8
QTY SHIPPED: 11
DATE SHIPPED:
DATE RETURNED:11/05/97

CUSTOMER DESCRIPTION:
11 PARTS FAILED IN CIRCUIT TEST, D/C J8, REEL TID IS 0001156616

CONDITION CONFIRMED:
Of the eleven returned capacitors, one capacitor measured within specification requirements and the remaining capacitors measured as open circuits.

TEMPORARY CONTAINMENT ACTION:
1. The assembly operation is monitored using a stress test immediately after the welding is complete. Every twelfth lead frame is examined. All lots that exceed the upper control limit of the SPC at assembly are held for a multidisciplinary material review board (MRB).

The board has established an inspection criteria which included 100% inspection of the lots. Data was collected using an accelerated soldering simulation test on samples from lots that were processed per the established guidelines. The product performance was acceptable with zero failures found.

Effective August 1, 1997, all lots will be 100% inspected for defects prior to the disposition of the product. Data on the number and type of rejects will be presented to the MRB. This will enable the MRB to better evaluated the product.

2. The welding process specifications and equipment set up ~~is~~ are being reviewed. This review began 11/17/97 and will be completed by 11/21/97.

CUSTOMER: DELCO
LOCATION: KOKOMO IN
CUST. DOC. NO: SMIS-1997-1268
CUST. CONTACT: A. ANDREAS

DATE OPEN: 10-Nov-97
DATE CLOSED: 24-Nov-97
CAR#: 746-02C RA:
PROBLEM CODE: 34

MARKETING MGR: J. BOURNE
SALES REP: JOHN SHAW
MFG REP/SALES OFFICE: ISO
CUSTOMER P/N: 16066844
SPRAGUE P/N: 293D475X9035B
Detail 167

M.O. #:
P.O. #:
DATE CODE: J9
QTY SHIPPED: 6
DATE SHIPPED:
DATE RETURNED:11/10/97

CUSTOMER DESCRIPTION: LOW READING/OPEN @ IN-CKT TEST

CONDITION CONFIRMED:
Of the six returned capacitors: two measured within specification requirements and four were confirmed as open circuits.

TEMPORARY CONTAINMENT ACTION:
1. For this part number, product date coded "J9" was sampled for IR reflow. A limited amount of product was available. Samples representing seven manufacturing lots were tested with no failures found.
2. Effective 10/2/97, 24 pieces from each manufacturing lot of this part number are being sampled for IR reflow during manufacturing (accept on zero, reject on one).
3. The welding process specifications and equipment set up were reviewed. Weld current levels were adjusted to provide a stronger weld effective 11/21/97.

ROOT CAUSE: The capacitors failed due to marginal welds between the tantalum anode wire and the anode section of the lead frame. The appearance of the weld area suggests that there was adequate pressure during the welding operation. The cause of failure may be inadequate weld current.

CORRECTIVE ACTION:
The most recent update of the comprehensive plan to address anode and cathode attachment failures is attached.

CUSTOMER: DELCO
LOCATION: OAK CREEK, WI
CUST. DOC. NO: WCTe-SR-0138
CUST. CONTACT: R. TOMASHEK

DATE OPEN: 09-Jan-98
DATE CLOSED: 22-Jan-98
CAR#: 802-03C RA:
PROBLEM CODE: 34

MARKETING MGR: J. BOURNE
SALES REP: JOHN SHAW
MFG REP/SALES OFFICE: ISO
CUSTOMER P/N: 16191909
SPRAGUE P/N: 293D475X9010A

M.O. #:
P.O. #:
DATE CODE: Sept 1997
QTY SHIPPED:
DATE SHIPPED:
DATE RETURNED:

CUSTOMER DESCRIPTION: OPENS

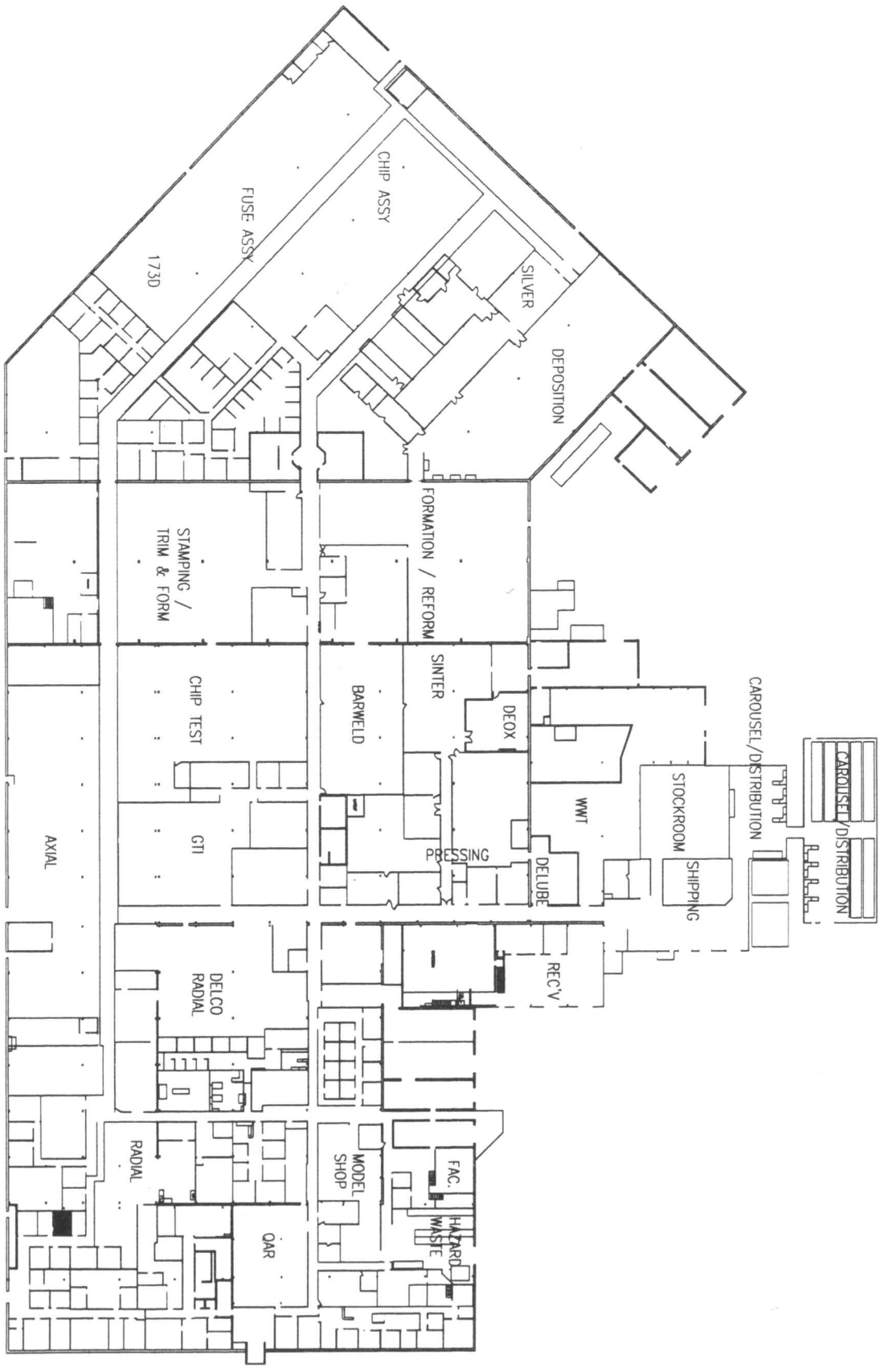
CONDITION CONFIRMED:
The capacitor was confirmed as an open circuit.

TEMPORARY CONTAINMENT ACTION:
1. There is no stock of the September 1997 date code for this Delco part number. The date code currently being shipped is December 1997.
2. A review of the alignment of the capacitor element with the lead frame and the variability of this process is in progress. Estimated completion date for this review is 2/3/98.

ROOT CAUSE: The capacitor failed because the MnO2/Silver broke away from the pellet. The angle and/or depth of the cathode paddle probably contributed to the cause the failure.

CORRECTIVE ACTION:
1. Mis-positioning of the lead frame with respect to the weld electrode can cause damage to the cathode attachment. The position of the lead frame with respect to the weld electrode is dependent on various assembly fixtures. Once recent improvement is a change in the material used for the fixture that holds the weld pin (pin tray). The drawing that is used to purchase the pin tray was updated to include the new material requirement as of June 1997. The fixture for the 'A' case size was replaced effective 9/30/97 (part date code October 1997). CAR# 802-03C

# A.2.
# Sanford plant map




| REV. | DATE | DESCRIPTION |
|---|---|---|
| | | |

| REV. | DATE | DESCRIPTION |
|---|---|---|
| | | |

| REV. | DATE | DESCRIPTION |
|---|---|---|
| | | |

VISHAY SPRAGUE
FACILITIES ENGINEERING
RT.109 P.O. BOX 231 SANFORD, MAINE 04073

SCALE NONE
DATE 2/17/98
APPROVED BY D. NASON
DRAWN BY MHL
TITLE PLANT LAYOUT
DWG. NO. 021798-SEC

# A.3.
# Competitive Analysis Report

VISHAY-SPRAGUE Inc.
SOLID TANTALUM CAPACITOR DIVISION
COMPETITIVE ANALYSIS REPORT - CONSTRUCTION

**STRIPPED CAPACITOR DIMENSIONS (inches)**

| | LENGTH | WIDTH | THICKNESS | *CV/CM$^3$ |
|---|---|---|---|---|
| **SPRAGUE** | .1625 | .1250 | .0660 | 40,700 |
| **HITACHI** | .1420 | .1255 | .0625 | 46,900 |

*Formula for calculating the approximate CV/CM$^3$:

$$\frac{\text{CAPACITANCE} * \text{ESTIMATED FORMATION VOLTAGE}}{\text{VOL (IN.}^3\text{)} * 6.14(\text{CM}^3/\text{IN.}^3) * \text{SINTER DENSITY(GRAMS/CM}^3\text{)}}$$

Typical sintered density is between 5 and 7 g/cm$^3$. (6 g/cm$^3$ was used for this calculation).

**THE VISIBLE CONSTRUCTION**

| | SPRAGUE | HITACHI |
|---|---|---|
| Tantalum Pellet | Yes | Yes |
| Anode Lead Wire | Tantalum | Tantalum |
| Barrier Material | Teflon (Green Band) | **?** (White Ring) |
| MnO2 Process | Sol | **?** |
| Body Silver | Follows the shape of the MnO2 dust particles | Follows the shape of the carbon layer |
| Anode Attachment | Electrode Weld | Laser Weld |
| Cathode Attachment | Adhesive | Adhesive |
| Attachment Composition | Ag | Ag |
| Lead Frame Core | Ni/Fe | Ni/Fe |
| --Percentages | 58.5/41.5 | 60.3/39.7 |
| Plating on Lead Frame | Sn/Pb | Sn/Pb |
| --Percentages | 54.9/45.1 | 98.9/1.1 |

**?** -- **Unknown**

ANALYSIS PERFORMED BY: [signature]
DATE: April 11, 1994

# A.4.
# Force Gage Specifications

## FORCE FIVE MODELS - COMPLETE GAGE

| | | | |
|---|---|---|---|
| FDV 5 | 5 lb x 0.005 lb | 2.5 kg x 0.002 kg | 25 N x 0.02 N |
| FDV 10 | 10 lb x 0.01 lb | 5 kg x 0.005 kg | 50 N x 0.05 N |
| FDV 30 | 30 lb x 0.02 lb | 15 kg x 0.01 kg | 150 N x 0.1 N |
| FDV 50 | 50 lb x 0.05 lb | 25 kg x 0.02 kg | 250 N x 0.2 N |
| FDV 100 | 100 lb x 0.1 lb | 50 kg x 0.05 kg | 500 N x 0.5 N |

## FORCE FIVE OPTIONAL FORCE CELL MODULES

| | | | |
|---|---|---|---|
| FCM 5 | 5 lb x 0.005 lb | 2.5 kg x 0.002 kg | 25 N x 0.02 N |
| FCM 10 | 10 lb x 0.01 lb | 5 kg x 0.005 kg | 50 N x 0.05 N |
| FCM 30 | 30 lb x 0.02 lb | 15 kg x 0.01 kg | 150 N x 0.1 N |
| FCM 50 | 50 lb x 0.05 lb | 25 kg x 0.02 kg | 250 N x 0.2 N |
| FCM 100 | 100 lb x 0.1 lb | 50 kg x 0.05 kg | 500 N x 0.5 N |

## FORCE FIVE OPTIONAL ACCESSORIES

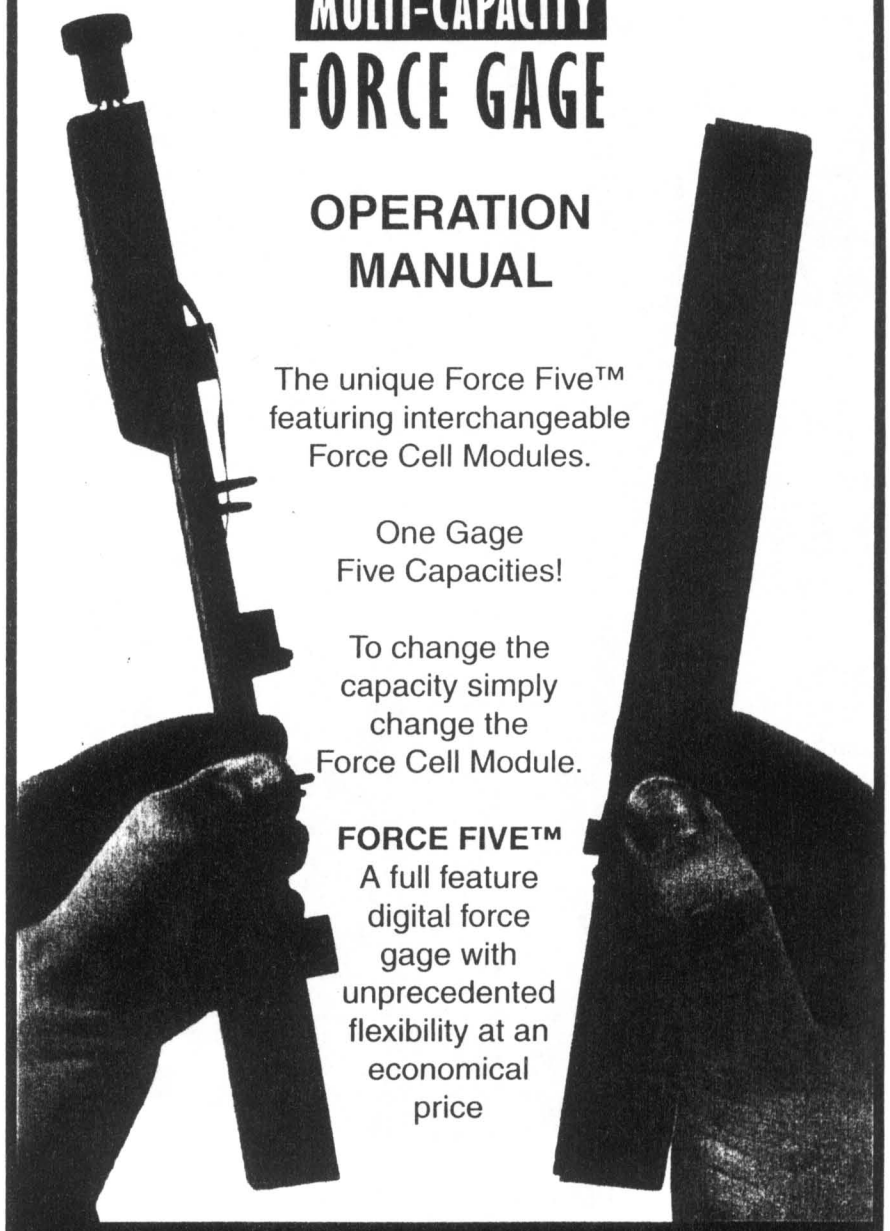
| | | | |
|---|---|---|---|
| FDM | Force Display Module | FD/ HDL | Aluminum Handles |
| FD/HL | Hinged Hook - Large | FDV/APL | Mounting Adapter |
| FD/CL | Hinged Cradle - Large | FDV/APR | Mounting Adapter |
| FD/HS | Hinged Hook - Small | FD/LB | Lithium Battery 9V |
| FD/CS | Hinged Cradle - Small | FD/NCB | Ni-Cad Battery 7.2V |
| FD/RT | Rubber Tip Implement | FD/ALB | Alkaline Battery 9V |
| FD/S-1 | Steel Hook - Large | FD/BE | Battery Eliminator |
| FD/A-1 | Aluminum Hook - Small | FDV/MC | Mating Output Connector |
| FD/A-2 | Flat Head | FDV/CAI | Cable - IBM |
| FD/A-3 | Cone Point | FDV/CAX | Cable - X-Y |
| FD/A-4 | Chisel Point | FDV/CAM | Cable - Mitutoyo |
| FD/A-5 | Wedge Tip | FDV/CAD | Cable - Datamyte |
| FD/A-6 | Extension Rod | FDV/CC | Carrying Case |

**WAGNER INSTRUMENTS**
**P.O. Box 1217, GREENWICH, CT 06836-1217, USA**
**TELEPHONE: (800) 345-4188 or (203) 869-9681**
**FAX: (800) 443-4149 or (203) 869-9871**

# FORCE FIVE™

## MULTI-CAPACITY FORCE GAGE

## OPERATION MANUAL



The unique Force Five™ featuring interchangeable Force Cell Modules.

One Gage
Five Capacities!

To change the capacity simply change the Force Cell Module.

**FORCE FIVE™**
A full feature digital force gage with unprecedented flexibility at an economical price

**PATENTED MODULAR DESIGN!**

# A. FORCE FIVE FEATURES

## CONSTRUCTION

- Patented modular design - one Force Display Module accommodates up to five Force Cell Module capacities.
- Compact Size: 7 3/4" x 2" x 1 3/8"
- 4 1/2" Force Cell Module for upward or downward pointing shaft.
- Optional adapter plates for easy mounting on all popular test stands.
- One year warranty.
- Made in the USA.

## OPERATION

- Change Force Cell Module to change capacity - 5, 10, 30, 50, & 100 lb.
- Menu Driven Selections.
- Fast Update: Up to 100 samples per second.
- All functions easily programmable on keyboard.
- Peak hold memory retains maximum tension and compression readings.
- Filtering of current and peak readings.
- Automatic shut-off after selected period of time: 1, 5, 10, 20 and 30 minutes.
- Non-volatile memory retains set-up after gage shutoff.

## DATA OUTPUT

- RS232, Mitutoyo and analog outputs.

## POWER REQUIREMENTS

- Unique power system provides up to 300 hours of continuous use with a single Lithium battery.
- Optional use of 9V alkaline battery, rechargeable Ni-Cad battery or battery eliminator.
- Display warns of low battery charge.

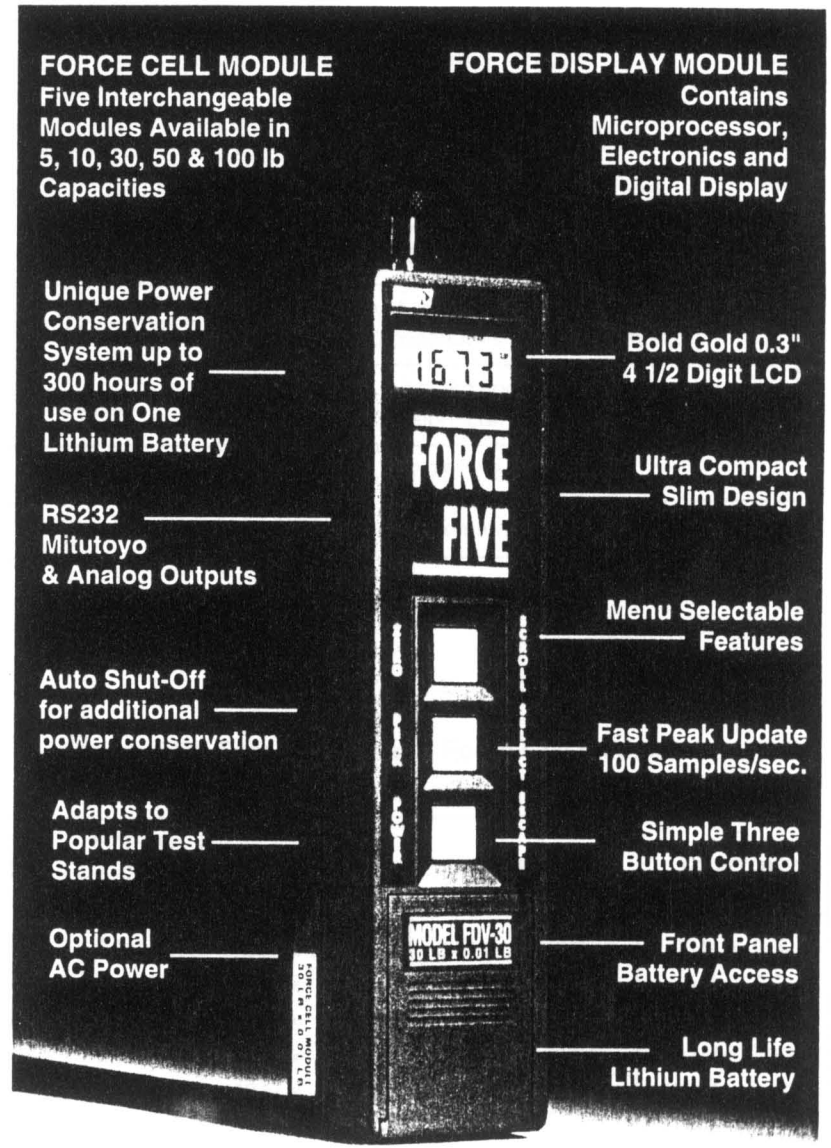
## ACCESSORIES

- The complete Force Five™ FDV System includes: Force Display Module, Force Cell Module, Lithium battery, battery eliminator, flat head, hook, carrying case, operating manual and NIST calibration certificate.
- Optional accessories include: Additional Force Cell Modules (5,10, 30, 50, and 100 LB), Ni-Cad or alkaline batteries, test stand adapter, various implements, accessories and data output cables.

## ACCURACY

- Accurate to ±0.3% ± 1 least significant digit; NIST calibration certificate is included with each gage.



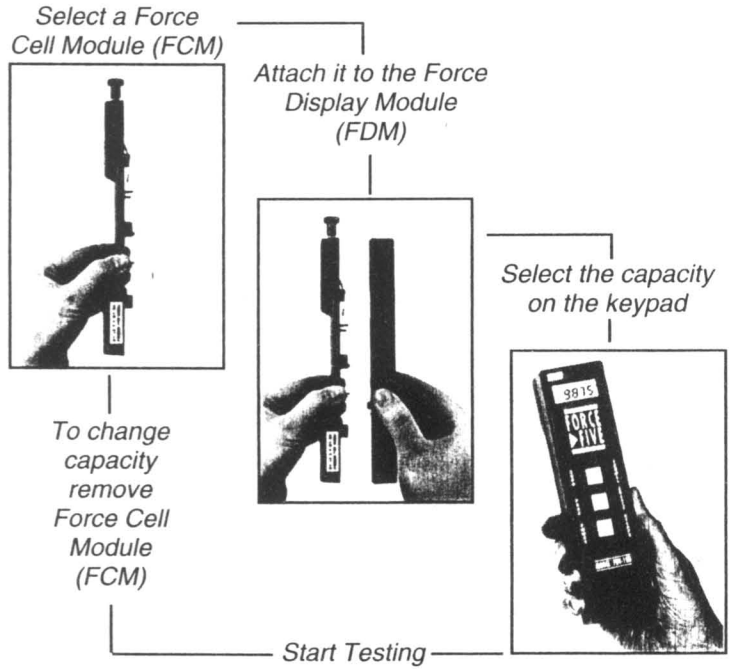


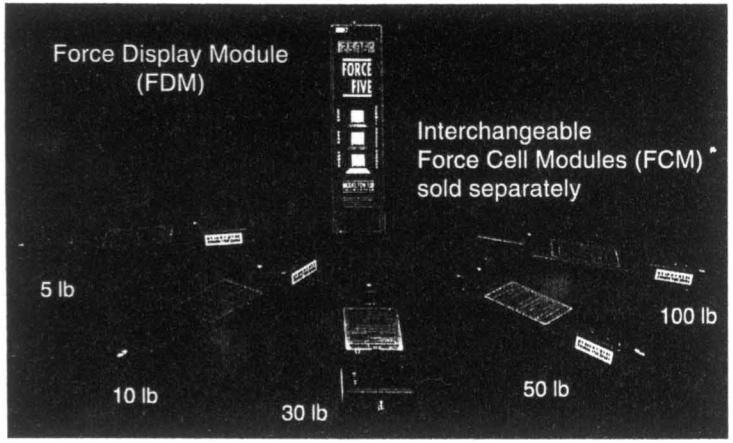

**Patented Design**

Patent #5,471,885

## B. HOW TO CHANGE CAPACITIES WITH FORCE FIVE ™

For detailed instructions on changing capacities see section G. Interchanging Force Cell Modules.




*Force Five (FDV) shown with all five optional Force Cell Modules (FCM)*



## C. SPECIFICATIONS

| ITEM | SPECIFICATIONS |
|---|---|
| Accuracy | ± 0.3% of full scale ±1 LSD |
| Sampling Rate | 100 Samples per second |
| Power Consumption | Approximately 4 mA; 9V Lithium battery provides up to 300 continuous hours of operation |
| Display | High contrast 4 1/2 digit gold LCD with indicators for units, peak, tension, compression and low battery |
| Dimensions | 7.75" x 2.0" x 1.35" |
| Weight | Approximately 10 ounces |

### Wagner FDV Force Gages and Force Cell Modules

| GAGE MODEL | FORCE CELL MODULE | ENGLISH | METRIC | NEWTONS |
|---|---|---|---|---|
| FDV 5 | FCM 5 | 5 lb x 0.005 lb | 2.5 kg x 0.002 kg | 25 N x 0.02 N |
| FDV 10 | FCM 10 | 10 lb x 0.01 lb | 5 kg x 0.005 kg | 50 N x 0.05 N |
| FDV 30 | FCM 30 | 30 lb x 0.02 lb | 15 kg x 0.01 kg | 150 N x 0.1 N |
| FDV 50 | FCM 50 | 50 lb x 0.05 lb | 25 kg x 0.02 kg | 250 N x 0.2 N |
| FDV 100 | FCM 100 | 100 lb x 0.1 lb | 50 kg x 0.05 kg | 500 N x 0.5 N |

# A.5.
# Raw Data from Distribution Functions

Good Welds

| Force | f | F | ND | D |
|---|---|---|---|---|
| 0.58 | 0.003802 | 0.003802 | 0.009518 | |
| 0.6 | 0.015209 | 0.019011 | 0.013067 | 0.009265 |
| 0.62 | 0.003802 | 0.022814 | 0.017707 | 0.005107 |
| 0.64 | 0.015209 | 0.038023 | 0.023686 | 0.014337 |
| 0.66 | 0.007605 | 0.045627 | 0.031277 | 0.01435 |
| 0.68 | 0.011407 | 0.057034 | 0.040779 | 0.016255 |
| 0.7 | 0.007605 | 0.064639 | 0.052499 | 0.01214 |
| 0.72 | 0.026616 | 0.091255 | 0.066747 | 0.024508 |
| 0.74 | 0.015209 | 0.106464 | 0.083817 | 0.022646 |
| 0.76 | 0.015209 | 0.121673 | 0.103976 | 0.017697 |
| 0.78 | 0.026616 | 0.148289 | 0.127436 | 0.020853 |
| 0.8 | 0.038023 | 0.186312 | 0.154346 | 0.031966 |
| 0.82 | 0.022814 | 0.209125 | 0.184767 | 0.024358 |
| 0.84 | 0.034221 | 0.243346 | 0.218662 | 0.024684 |
| 0.86 | 0.034221 | 0.277567 | 0.255881 | 0.021686 |
| 0.88 | 0.038023 | 0.315589 | 0.296162 | 0.019428 |
| 0.9 | 0.045627 | 0.361217 | 0.339127 | 0.023537 |
| 0.92 | 0.041825 | 0.403042 | 0.384294 | 0.023077 |
| 0.94 | 0.038023 | 0.441065 | 0.431091 | 0.028049 |
| 0.96 | 0.045627 | 0.486692 | 0.478876 | 0.037812 |
| 0.98 | 0.041825 | 0.528517 | 0.526968 | 0.040276 |
| 1 | 0.038023 | 0.56654 | 0.57467 | 0.046152 |
| 1.02 | 0.053232 | 0.619772 | 0.621301 | 0.054761 |
| 1.04 | 0.053232 | 0.673004 | 0.666229 | 0.046457 |
| 1.06 | 0.041825 | 0.714829 | 0.708891 | 0.035888 |
| 1.08 | 0.04943 | 0.764259 | 0.748818 | 0.033989 |
| 1.1 | 0.030418 | 0.794677 | 0.785644 | 0.021386 |
| 1.12 | 0.038023 | 0.8327 | 0.819122 | 0.024445 |
| 1.14 | 0.041825 | 0.874525 | 0.849115 | 0.025409 |
| 1.16 | 0.022814 | 0.897338 | 0.8756 | 0.021738 |
| 1.18 | 0.007605 | 0.904943 | 0.89865 | 0.006293 |
| 1.2 | 0.022814 | 0.927757 | 0.91842 | 0.013477 |
| 1.22 | 0.015209 | 0.942966 | 0.935132 | 0.007834 |
| 1.24 | 0.019011 | 0.961977 | 0.949056 | 0.012921 |
| 1.26 | 0.011407 | 0.973384 | 0.960489 | 0.012895 |
| 1.29 | 0.003802 | 0.977186 | 0.973648 | 0.003539 |
| 1.3 | 0.007605 | 0.984791 | 0.977122 | 0.007668 |
| 1.32 | 0.007605 | 0.992395 | 0.982924 | 0.009472 |
| 1.34 | 0.003802 | 0.996198 | 0.987419 | 0.008779 |
| 1.4 | 0.003802 | 1 | 0.995349 | 0.004651 |
| | 1 | | | |
| | | | ET | 0.054761 |

Bad Welds

| Force | f | F | ND | D |
|---|---|---|---|---|
| 0.18 | 0.005291 | 0.005291 | 0.00321 | |
| 0.2 | 0.042328 | 0.047619 | 0.015336 | 0.032283 |
| 0.22 | 0.063492 | 0.111111 | 0.055122 | 0.055989 |
| 0.24 | 0.116402 | 0.227513 | 0.150828 | 0.076685 |
| 0.26 | 0.142857 | 0.37037 | 0.319649 | 0.092136 |
| 0.28 | 0.275132 | 0.645503 | 0.538052 | 0.167682 |
| 0.3 | 0.15873 | 0.804233 | 0.745288 | 0.099785 |
| 0.32 | 0.15873 | 0.962963 | 0.889513 | 0.08528 |
| 0.34 | 0.031746 | 0.994709 | 0.963124 | 0.031585 |
| 0.36 | 0.005291 | 1 | 0.990673 | 0.009327 |
| | | | ET | 0.167682 |

Goodness-of-fit Test

A statistical test in which the validity of one hypothesis is tested without specification of an alternative hypothesis is called a goodness-of-fit test. The general procedure consists in defining a test statistic, which is some function of the data measuring the distance between the hypothesis and the data (in fact, the badness-of-fit), and then calculating the probability of obtaining data which have a still larger value of this test statistic than the value observed, assuming the hypothesis is true. This probability is called the size of the test or confidence level. Small probabilities (say, less than one percent) indicate a poor fit. Especially high probabilities (close to one) correspond to a fit which is too good to happen very often, and may indicate a mistake in the way the test was applied, such as treating data as independent when they are correlated.

The most common tests for goodness-of-fit are the chi-square test, Kolmogorov test, the Cramer-Smirnov-Von Mises test, runs.

Good Weld & Bad Epoxy

| Force | f | F | ND | D |
|---|---|---|---|---|
| 0.16 | 0.008299 | 0.008299 | 0.010581 | |
| 0.18 | 0.008299 | 0.016598 | 0.015523 | 0.007224 |
| 0.2 | 0.016598 | 0.033195 | 0.022329 | 0.010866 |
| 0.22 | 0.012448 | 0.045643 | 0.031496 | 0.014147 |
| 0.24 | 0.037344 | 0.082988 | 0.043575 | 0.039413 |
| 0.26 | 0.020747 | 0.103734 | 0.059143 | 0.044592 |
| 0.28 | 0.029046 | 0.13278 | 0.07877 | 0.05401 |
| 0.3 | 0.033195 | 0.165975 | 0.102975 | 0.063 |
| 0.32 | 0.016598 | 0.182573 | 0.132176 | 0.050397 |
| 0.34 | 0.033195 | 0.215768 | 0.166635 | 0.049132 |
| 0.36 | 0.037344 | 0.253112 | 0.206413 | 0.046699 |
| 0.38 | 0.033195 | 0.286307 | 0.251329 | 0.034979 |
| 0.4 | 0.037344 | 0.323651 | 0.30094 | 0.022711 |
| 0.42 | 0.033195 | 0.356846 | 0.354544 | 0.030892 |
| 0.44 | 0.024896 | 0.381743 | 0.411197 | 0.054351 |
| 0.46 | 0.058091 | 0.439834 | 0.469769 | 0.088026 |
| 0.48 | 0.029046 | 0.46888 | 0.529004 | 0.08917 |
| 0.5 | 0.074689 | 0.543568 | 0.587603 | 0.118723 |
| 0.52 | 0.045643 | 0.589212 | 0.644308 | 0.10074 |
| 0.54 | 0.091286 | 0.680498 | 0.697985 | 0.108774 |
| 0.56 | 0.06639 | 0.746888 | 0.747688 | 0.06719 |
| 0.58 | 0.049793 | 0.796681 | 0.792706 | 0.045818 |
| 0.6 | 0.078838 | 0.875519 | 0.832593 | 0.042925 |
| 0.62 | 0.049793 | 0.925311 | 0.867163 | 0.058148 |
| 0.64 | 0.004149 | 0.929461 | 0.896471 | 0.03299 |
| 0.66 | 0.020747 | 0.950207 | 0.920776 | 0.029431 |
| 0.68 | 0.020747 | 0.970954 | 0.940493 | 0.030461 |
| 0.7 | 0.012448 | 0.983403 | 0.95614 | 0.027263 |
| 0.72 | 0.016598 | 1 | 0.968285 | 0.031715 |
| | | | ET | 0.118723 |



## TABELA 9 - VALORES CRÍTICOS DA DISTRIBUIÇÃO DA ESTATÍSTICA D (LILLIEFORS, POPULAÇÕES NORMAIS)

Valores críticos da distribuição da estatística $D = \max|S(x) - F_0(x)|$ para populações normais e parâmetros estimados a partir de amostras de dimensão n.

| Dimensão da Amostra | Nível de Significância (α) | | | | |
|---|---|---|---|---|---|
| n | 0.20 | 0.15 | 0.10 | 0.05 | 0.01 |
| 4 | 0.300 | 0.319 | 0.352 | 0.381 | 0.417 |
| 5 | 0.285 | 0.299 | 0.315 | 0.337 | 0.405 |
| 6 | 0.265 | 0.277 | 0.294 | 0.319 | 0.364 |
| 7 | 0.217 | 0.253 | 0.276 | 0.300 | 0.348 |
| 8 | 0.233 | 0.244 | 0.261 | 0.285 | 0.331 |
| 9 | 0.223 | 0.233 | 0.249 | 0.271 | 0.311 |
| 10 | 0.215 | 0.224 | 0.239 | 0.258 | 0.294 |
| 11 | 0.206 | 0.217 | 0.230 | 0.249 | 0.284 |
| 12 | 0.199 | 0.212 | 0.223 | 0.242 | 0.275 |
| 13 | 0.190 | 0.202 | 0.214 | 0.234 | 0.268 |
| 14 | 0.183 | 0.194 | 0.207 | 0.227 | 0.261 |
| 15 | 0.177 | 0.187 | 0.201 | 0.220 | 0.257 |
| 16 | 0.173 | 0.182 | 0.195 | 0.213 | 0.250 |
| 17 | 0.169 | 0.177 | 0.189 | 0.206 | 0.245 |
| 18 | 0.166 | 0.173 | 0.184 | 0.200 | 0.239 |
| 19 | 0.163 | 0.169 | 0.179 | 0.195 | 0.235 |
| 20 | 0.160 | 0.166 | 0.174 | 0.190 | 0.231 |
| 25 | 0.149 | 0.153 | 0.165 | 0.180 | 0.203 |
| 30 | 0.131 | 0.136 | 0.144 | 0.161 | 0.187 |
| >30 | $\frac{0.730}{\sqrt{n}}$ | $\frac{0.768}{\sqrt{n}}$ | $\frac{0.805}{\sqrt{n}}$ | $\frac{0.886}{\sqrt{n}}$ | $\frac{1.031}{\sqrt{n}}$ |

Fonte: H. W. Lilliefors [1967], "On the Kolmogorov-Smirnov Test for Normality with Mean and Variance Unknown", *American Statistical Association Journal*, June 1967.

# A.6. Specifications of Switch Probes in Catalogue

# SWITCH PROBES

A Switch Probe is a spring contact probe and receptacle combination that is normally open, and after a designated travel the switch probe closes. The most common use for switch probes is in the cable harness testing industry. The switch probe is used to verify the correct location of a terminal in a connector while checking the retention force as well.

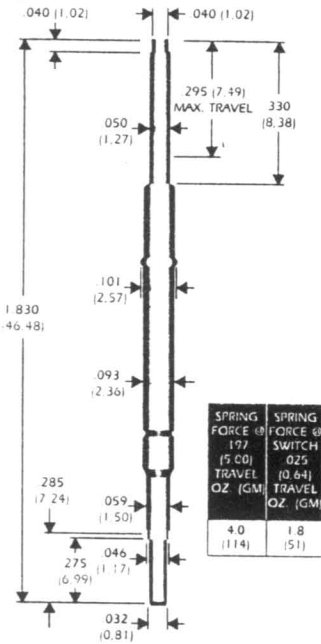
Switch probes also verify the presence of nonconductive components such as caps for connectors or devices on a circuit board.

There are two separate current paths in a switch probe. From the plunger tip to the tail is normally open and closes only after the probe deflects to the designated travel. The second path, from the plunger tip to the outside of the receptacle is always closed.

IDI manufactures three sizes of switch probes:

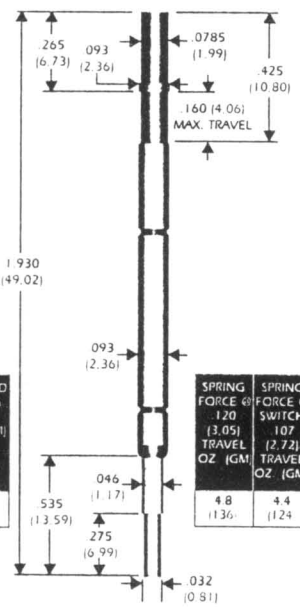
Size 3—.125" (3,18) centers,
Size 4—.156" (3,96) centers,
Size 5—.187" (4,75) centers.

## SIZE SW3



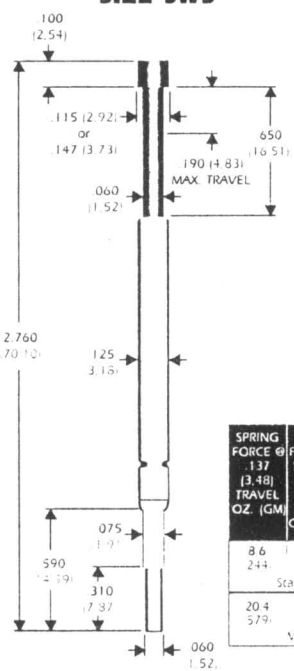

| SPRING FORCE @ .197 (5.00) TRAVEL OZ. (GM) | SPRING FORCE @ SWITCH .025 (0.64) TRAVEL OZ. (GM) | PRELOAD SPRING FORCE OZ. (GM) |
|---|---|---|
| 4.0 (114) | 1.8 (51) | 1.4 (40) |

## SIZE SW4




| SPRING FORCE @ .120 (3.05) TRAVEL OZ. (GM) | SPRING FORCE @ SWITCH .107 (2.72) TRAVEL OZ. (GM) | PRELOAD SPRING FORCE OZ. (GM) |
|---|---|---|
| 4.8 (136) | 4.4 (124) | 2.5 (71) |

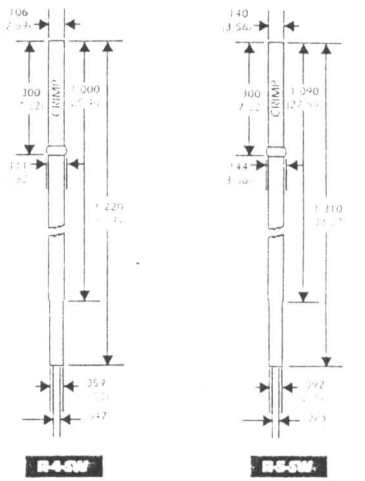
## SIZE SW5




| SPRING FORCE @ .137 (3.48) TRAVEL OZ. (GM) | SPRING FORCE @ SWITCH .030 (0.76) TRAVEL OZ. (GM) | PRELOAD SPRING FORCE OZ. (GM) |
|---|---|---|
| 8.6 (244) | 4.0 (113) | 1.3 (37) |
| Stainless Steel | | |
| 20.4 (579) | 10.3 (293) | 5.2 (148) |
| Music Wire | | |

## RECEPTACLE SIZES 4 & 5

**Connections**—
Style CR: Crimp
**Material**—Nickel/silver, gold plated




**Drill Size:** #35
**Mounting Hole Size:** .108/.110 (2.74/2.79)

**Drill Size:** 3.6mm
**Mounting Hole Size:** .141/.143 (3.58/3.63)

Specifications subject to change without notice.
Dimensions in inches (millimeter).

## PROBE TECHNICAL SUMMARY

Recommended Minimum Centers—.125 (3,17)
Current Rating—3 amps continuous
Travel to Switch Point— .025 (0,64)
Spring Force at Switch Point—1.8 oz.
Recommended Working Travel—.197 (5.00)

## MATERIALS

Contact Barrel—Nickel/silver, gold plated
Springs—Music wire
Plunger—Beryllium copper, gold plated
Insulator—Delrin
Contact—Beryllium copper, gold plated

## PROBE TECHNICAL SUMMARY

Recommended Minimum Centers—.156 (3,96)
Current Rating—3 amps continuous
Travel to Switch Point— .107 (2,72)
Spring Force at Switch Point—4.4 (1,24)
Recommended Working Travel—.120 (3,05)

## MATERIALS

Contact Barrel—Nickel/silver, gold plated
Springs—Stainless steel, gold plated
Plunger—Beryllium copper, nickel plated
Insulator—Delrin
Contact—Beryllium copper, gold plated

## PROBE TECHNICAL SUMMARY

Recommended Minimum Centers—.187 (4,75)
Current Rating—3 amps continuous
Travel to Switch Point— .030 (0,76)
Spring Force at Switch Point—4.0 or 10.3 oz.
Recommended Working Travel—.137 (3,48)

## MATERIALS

Contact Barrel—Nickel/silver, hard silver plated
Springs—Stainless steel or music wire
Plunger—Beryllium copper, nickel plated
Insulator—Delrin
Contact—Beryllium copper, hard silver plated

## RECEPTACLE SIZE 3

The Size 3 Switch Probe shown does not require a receptacle. The barrel of the switch probe is a receptacle.

**Drill Size:** #41
**Mounting Hole Size:** .094/.096 (2,39/2,44)

## HOW TO ORDER:

FAX 913-342-7043 TEL 913-342-5544

| SW | 3 | CS | 1.8 | G |
|---|---|---|---|---|
| SPRING CONTACT PROBE | SIZE | STYLE | SPRING FORCE @ SWITCH | PLUNGER PLATING |

## HOW TO ORDER:

FAX 913-342-7043 TEL 913-342-5544

| SW | 5 | F | 4.0 | EN | 115 |
|---|---|---|---|---|---|
| SPRING CONTACT PROBE | SIZE | STYLE | SPRING FORCE @ SWITCH | PLUNGER PLATING | HEAD DIAMETER |



INTERCONNECT DEVICES, INC.
E-mail: info@idinet.com Web Site: http://www.idinet.com

INTERCONNECT DEVICES, INC.
E-mail: info@idinet.com Web Site: http://www.idinet.com

# A.7.
# Tolerances for Switch Probes

IDI

# Facsimile Transmission

**TO:**
**FROM:** Thad Sketers
**RE:** Product Specifications
**FAX:** (207)490-7248

**ATTENTION:** Joao Silva
**DATE:** 3-30-98
**PAGES:** 4 including cover

Interconnect Devices, Inc. • 5101 Richland Ave. • Kansas City, KS 66106
(913) 342-5544 • fax (913) 342-7043 • e-mail thad@mail.idinet.com

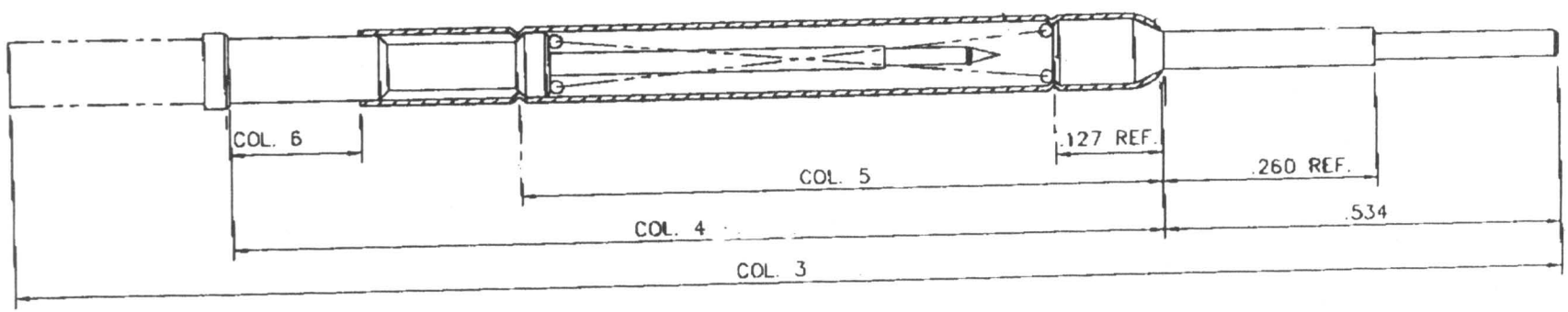
SW-4

ORIGINAL

| PART NO. | PRL | COL. 1 | COL. 2 | TRAVEL TO SWITCH POINT ± .008 | FORCE AT SWITCH POINT ±10% oz. | PRELOAD FORCE ±20% oz | COL. 3 | COL. 4 | COL. 5 | COL. 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 100238-01 | F | 300055-99 | 100261-01 | .107 | 68.8 | 17.3 | 1.929 | 1.130 | .777 | .160 |
| 100238-02 | F | 300055-100 | 100261-01 | .107 | 35.4 | 11.1 | 1.929 | 1.130 | .777 | .160 |
| 100238-03 | N | 300055-04 | 100261-01 | .107 | 4.4 | 2.5 | 1.929 | 1.130 | .777 | .160 |
| 100238-04 | F | RFQ-100238 | 100261-02 | .080 | 43.7 | 15.5 | 1.929 | 1.130 | .777 | .160 |
| 100238-05 | N | 300055-189 | 100261-03 | .090 | 5.8 | 3.5 | 1.929 | 1.130 | .777 | .160 |
| 100238-06 | N | 300055-04 | 100261-02 | .080 | 3.9 | 2.5 | 1.929 | 1.130 | .777 | .160 |
| 100238-07 | N | 300055-04 | 100261-04 | .039 | 3.9 | 3.2 | 1.929 | 1.091 | .736 | .121 |
| 100238-08 | F | 300055-196 | 100261-05 | .107 | 1.5 | 4.6 | 1.929 | 1.130 | .777 | .160 |
| 100238-09 | G | 300055-196 | 100261-01 | .107 | 1.5 | 4.6 | 1.929 | 1.130 | .777 | .160 |
| 100238-10 | L | 300055-207 | 100261-01 | .107 | 15.5 | 7.6 | 1.929 | 1.130 | .777 | .160 |
| 100238-11 | N | 300055-04 | 100261-05 | .107 | 4.4 | 2.5 | 1.929 | 1.130 | .777 | .160 |
| 100238-12 | P | 300055-100 | 100261-02 | .080 | 29.3 | 11.1 | 1.929 | 1.130 | .777 | .160 |

DRAWING NO 100238

REV P




| REVISIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CHG LTR | DATE | CHANGE NO | APPR BY | CHG LTR | DATE | CHANGE NO | APPR BY | CHG LTR | DATE | CHANGE NO | APPR BY |
| | | | | M | 10/8/96 | 5503 | BP | F | 11/4/94 | 4437 | RW |
| | | | | L | 8/6/96 | 5350 | BT | E | 3/11/93 | 3524 | MD |
| | | | | K | 12/12/95 | 5102 | BT | D | 9/3/92 | 3329 | BT |
| | | | | J | 10/11/95 | 4994 | BT | C | 9/14/90 | 2842 | BT |
| P | 10/01/97 | 5980 | BT | H | 9/4/95 | 4888 | BT | B | 7/31/90 | 2803 | BT |
| N | 10/28/97 | 5532 | LD | G | 7/20/95 | 4866 | BT | A | 05/17/90 | 2741 | BT |

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FINISH

MATERIAL

PART TO BE FREE OF BURRS AND SHARP EDGES

DO NOT SCALE THIS DRAWING

| TITLE | SIGNATURE | DATE |
|---|---|---|
| DR | BT | 05/17/90 |
| CHK | | |
| APP | | |
| APP | | |

INTERCONNECT DEVICES, INC.
5101 RICHLAND AVENUE
KANSAS CITY, KANSAS 66106

TITLE
SW4 SWITCH PROBE ASSEMBLY

| SIZE | DRAWING NO. | REV |
|---|---|---|
| B | 100238 | P |

SCALE: N.T.S. SHEET 1 OF 1

003 SYNERGETIX 03/30/98 MON 18:09 FAX 913 342 6823

# A.8.
# Simulation program for tolerances

```
Option Explicit
Sub simulation()

    Dim tolarray(1 To 20, 1 To 4) As Single
    Dim i, j, m As Byte
    Dim f, s As Boolean
    Dim bbukl, wgukl, maxdl As Single
    Dim trswnom, bxhenom, lfthnom As Single
    Dim plval, fswval, factpl, factfsw As Variant
    Dim pl, fsw As Single
    Dim trswtol, poletol, bxhetol, lfthtol As Single
    Dim kp1, kp2 As Single
    Dim dbbu, dwgu As Single
    Dim d, dl, dp, dlx, dpx, plx As Single



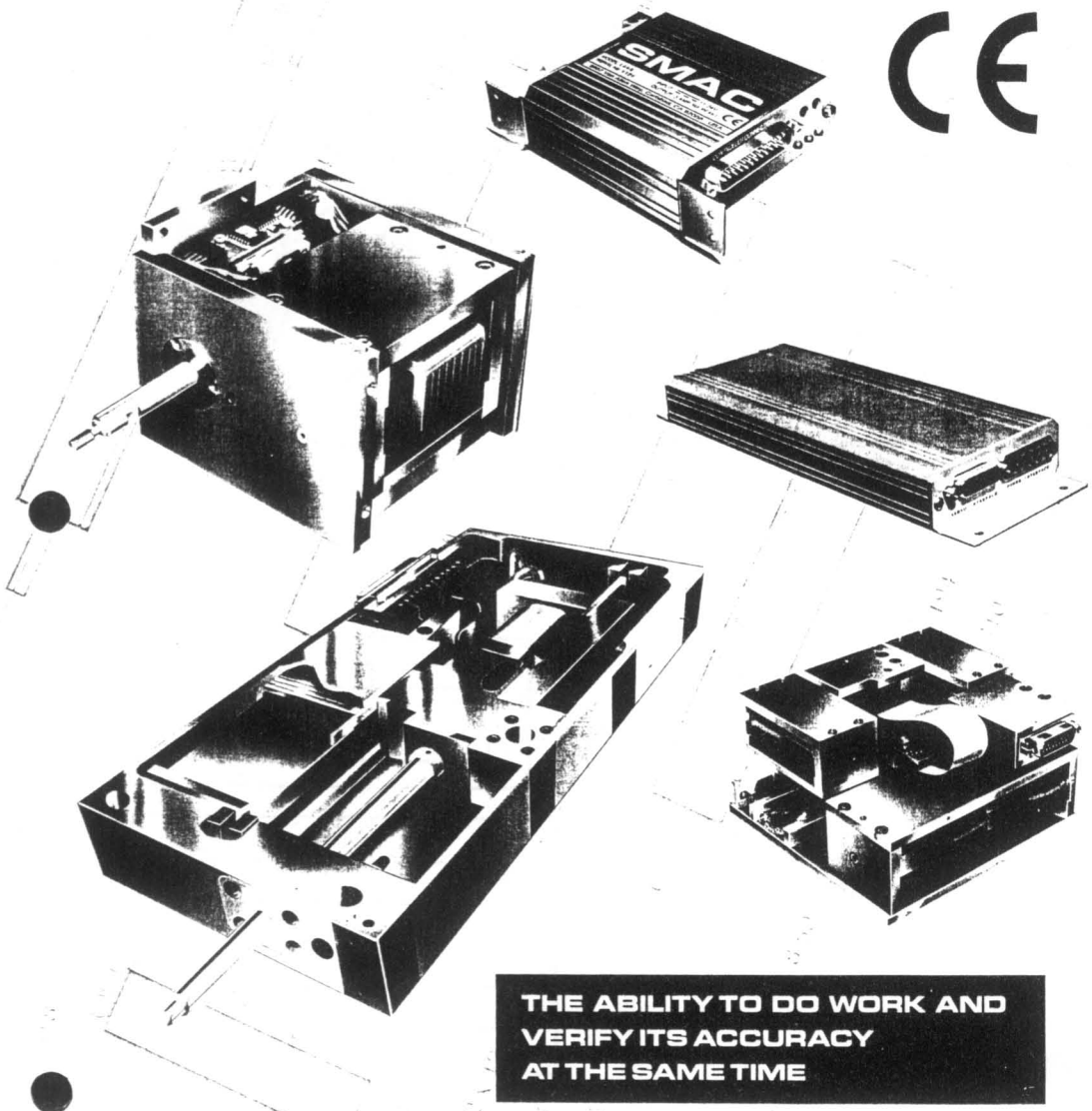
    For i = 37 To 52
        For j = 1 To 4
            tolarray(i - 35, j) = Worksheets("sheet1").Cells(i, j)
        Next j
    Next i
    MsgBox "start"
    m = 1
    bbukl = Worksheets("sheet1").Range("f31")
    wgukl = Worksheets("sheet1").Range("f32")
    maxdl = Worksheets("sheet1").Range("i23")
    trswnom = Worksheets("sheet1").Cells(36, 1)
    bxhenom = Worksheets("sheet1").Cells(36, 3)
    lfthnom = Worksheets("sheet1").Cells(36, 4)
    For plval = 10 To 100 Step 1
        For fswval = (plval + 1) To 400 Step 1
            f = 0
            For factpl = 0.9 To 1.1 Step 0.2
                'pre-load
                pl = plval * factpl
                For factfsw = 0.9 To 1.1 Step 0.1
                    'force @ switch
                    fsw = fswval * factfsw
                    For i = 2 To 17
                        trswtol = tolarray(i, 1)
                        poletol = tolarray(i, 2)
                        bxhetol = tolarray(i, 3)
                        lfthtol = tolarray(i, 4)
                        kp1 = (fsw - pl) / (trswnom + trswtol)
                        kp2 = 2 * kp1
                        'determining Dbbu
                        dbbu = 0
                        s = 0
                        Do While s = 0
                            dl = (kp1 * dbbu + pl) / (kp1 + bbukl)
                            dp = (bbukl * dbbu - pl) / (kp1 + bbukl)
                            If dp > (trswnom + trswtol) Then
                                s = 1 'switch!
                            Else
                                dbbu = dbbu + 0.1
                            End If
                        Loop
                        'determining Dwgu
                        dwgu = 0
                        s = 0
                        Do While s = 0 And f = 0
                            dl = (kp1 * dwgu + pl) / (kp1 + wgukl)
                            dp = (wgukl * dwgu - pl) / (kp1 + wgukl)
                            If dp > (trswnom + trswtol) Then
                                s = 1 'switch!
                            Else
                                dwgu = dwgu + 0.1
                            End If
                            dlx = (kp1 * (dwgu + 0.75 * (dbbu - dwgu)) + pl) / (kp1 + wgukl)
                            dpx = (wgukl * (dwgu + 0.75 * (dbbu - dwgu)) - pl) / (kp1 + wgukl)
                            If dpx > (trswnom + trswtol) Then
                                plx = fsw
                                dlx = fsw / wgukl
                                dpx = trswnom + trswtol
                                d = dwgu + 0.75 * (dbbu - dwgu) - dlx - dpx
                                dlx = dlx + (kp2 * d + plx) / (kp2 + wgukl)
                                dpx = dpx + (wgukl * d - plx) / (kp2 + wgukl)
                            End If
                            If dl > maxdl Or dlx > maxdl Or (dbbu - dwgu) < 1 Then
                                f = 1
                            End If
                        Loop
                        If f = 1 Then
                            Exit For
                        End If
                    Next i
                    If f = 1 Then
                        Exit For
                    End If
                Next factfsw
                If f = 1 Then
                    Exit For
                End If
            Next factpl
            If f = 0 Then
                Worksheets("results").Cells(m, 1) = plval
                Worksheets("results").Cells(m, 2) = fswval
                Worksheets("results").Cells(m, 3) = dwgu
                Worksheets("results").Cells(m, 4) = dbbu
                m = m + 1
            End If
        Next fswval
    Next plval
    MsgBox "end"


End Sub
```

# A.9.
# SMAC Moving Coil Actuator

# SMAC

## MOVING COIL ACTUATORS FOR AUTOMATION

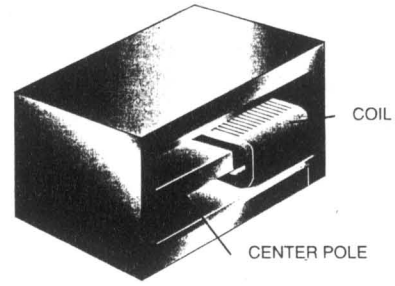



**THE ABILITY TO DO WORK AND VERIFY ITS ACCURACY AT THE SAME TIME**

**SMAC** • 5807 Van Allen Way • Carlsbad, California 92008 • Fax: (760) 929-7588 • Tel: (760) 929-7575

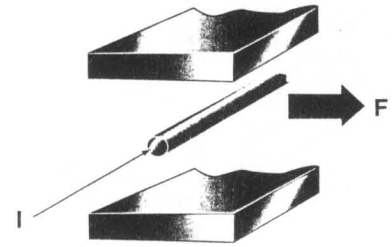
### FORCE

The magnet circuit (below) produces a uniform magnetic field in the air gap. The coil wound around the center pole conducts current perpendicular to the flux lines and generates a force parallel to the direction of travel.

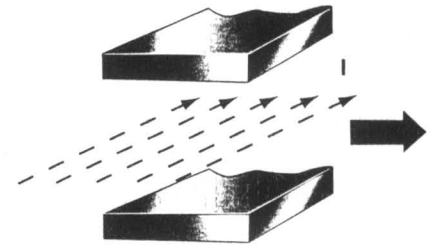


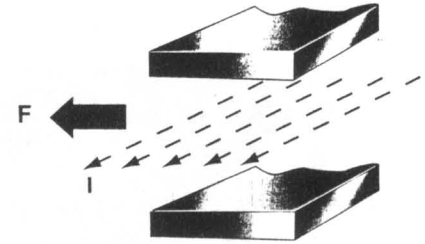

The force generated is proportional to **N I B** where:

**N** is the number of turns in the winding,
**I** is the current flowing through the winding and
**B** is the magnetic flux.




Force increases if the current, number of turns or flux strength is increased.



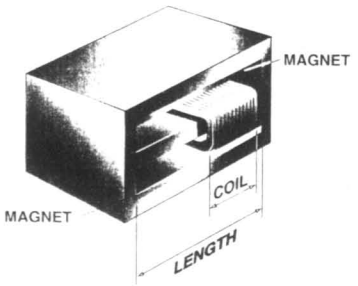




By changing the direction of the current (i.e. reversing the polarity), the force can be reversed.

**SMAC** • 5807 Van Allen Way • Carlsbad, California 92008 • Fax: (760) 929-7588 • Tel: (760) 929-757

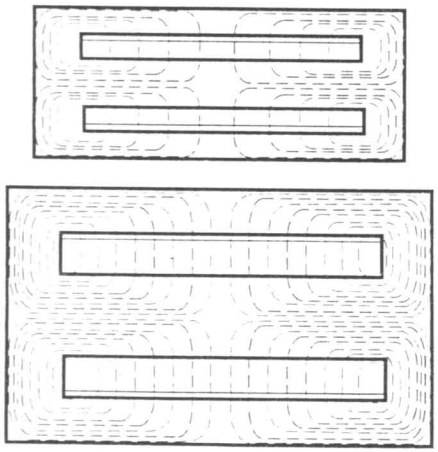
## STROKE

The Stroke is determined by the length of the magnet circuit less the width of the coil.



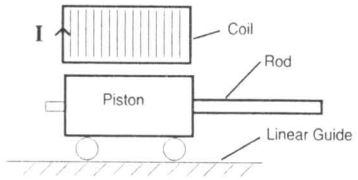

**STROKE** = Length – Coil width

It should be noted that when the length is increased, the thickness of the assembly has to be increased to carry the extra flux lines generated by the extra magnets.

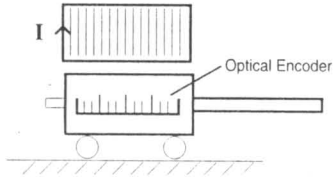


## POSITION CONTROL

The moving coil can do useful work when it is mounted to a linear guide so it can slide back and forth. It would operate like an air cylinder using electrical current (instead of air) as the driving force.




Addition of a linear optical encoder has made the SMAC moving coil actuator into a practical device for factory automation. The coil position (end-effector position) can now be program controlled to implement sophisticated motion profiles required by customers.






# LINEAR AND ROTARY/LINEAR MOVING COIL ACTUATORS

**Two Axis Moving Coil Actuator Designed for Pick, Orient and Place**

- Semiconductor insertion
- Circuit board assembly
- Precision assembly with verification

Independent 2-axis control

Precision packaged, ready to mount

Low moving mass for high speed response

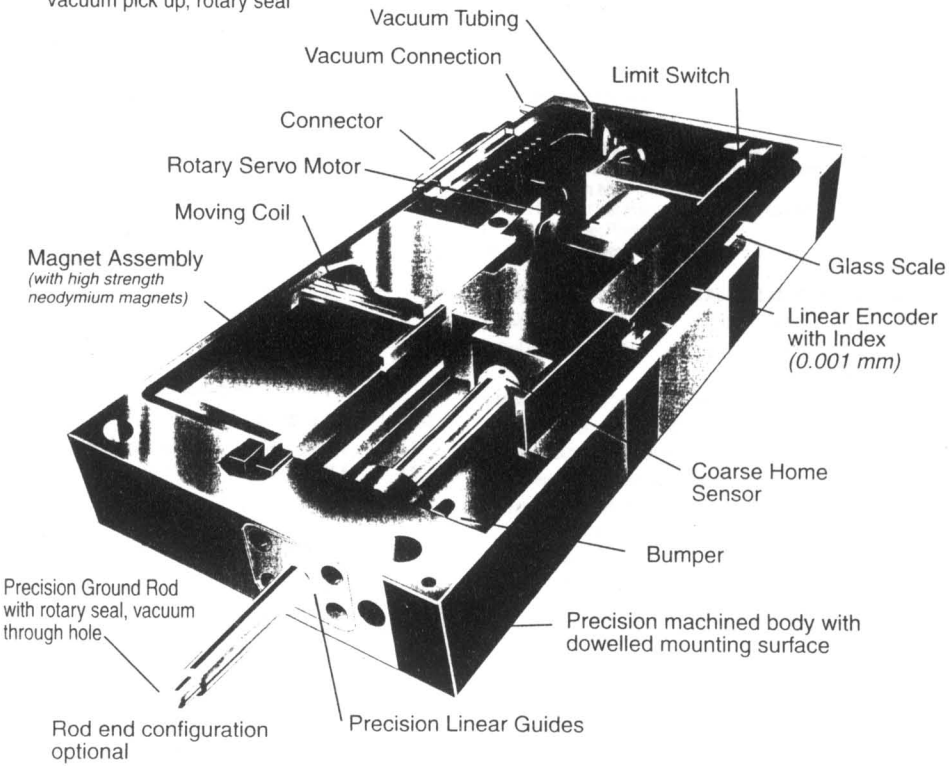
Vacuum pick up, rotary seal

**Linear:**

- Up to 100mm stroke, 0.5,1 or 5 micron resolution
- Programmable position, force, speed
- Vacuum pick-up

**Rotary:**

- Multi-turn servo motor, 0.007° to 0.07° resolution
- Low and zero backlash options



## SINGLE BUILT-IN PACKAGE

- 2 Independent servo axes (Z + Theta)
- Actuator rod (with minimum run-out)
- Precision linear guides
- Linear optical encoder with index
- Rotary (optical or magnetic) encoder with index
- Limit and rotary home switches
- Vacuum connection
- Over temperature protection
- Ready to mount and program

### Standard Features

- Very low moving mass, 200 gms
- Stroke, up to 150 mm
- Programmable force, 0.5 to 300 newtons
- Direct linear servo motion, no rotary to linear conversion
- Very slow to very high speeds (0.005 mm/sec to 1000 mm/sec)
- Rod runout less than 0.025 mm over stroke
- Precision mounting surfaces with dowel locations
- 0.0005mm to 0.005mm encoder resolution with index line (contact + non-contact types)
- Single ended or differential encoder signals

## APPLICATIONS

*Semiconductors*
*Circuit board assembly*
*Disk drives*
*Medical - catheters, hypodermic needles*
*Automotive*
*Process control*
*Punching*
*Volume assembly*
*Cam replacement - high speed*
*Packaging - dispensing, labeling*
*In process inspections*
*Pull testing*
*Precision screw installation*
*High volume - lighters, razors, batteries, switches, sensors, trimpots, cellular phones, bearings etc.*
*Inspection - critical dimension, measure and sort, force testing, stroke*
Machining - honing, press in, and threaded part assembly

## NEW DEVELOPMENTS

- Strokes to 300mm
- Forces to 500 newtons
- Multi-independently programmable fingers on electric gripper
- Mini XY, high speed / high resolution
- New low cost 2- axis controller
- New ultra low cost single axis controller



# SPECIFICATIONS

### Linear/Rotary Actuators

**Mechanical Specifications:**

| *Linear:* | *LAR-30* | *LAR-37* | *LAR-50* |
|---|---|---|---|
| 1. Stroke (mm): | 25 | 50 | 50 |
| 2. Total Weight: (gms): | 690 | 1100 | 4150 |
| 3. Moving Mass (gms): | 210 | 250 | 275 |
| 4. Maximum Force (newtons): | 10 | 10 | 25 |
| 5. Maximum Acceleration (g): | 3 | 3 | 8 |

6. Encoder Resolution: 0.005 mm, optional 0.001 mm
7. Position Accuracy (no load): +/– 2 encoder counts
8. Rod Diameter: 8 mm O.D., 3 mm I.D.
9. Body: Anodized Aluminum
10. Rod Runout Over Full Stroke: 0.05 mm or less
11. Thermistor Set Point: 70° C
12. Operating Ambient: 0 to 50° C

***Rotary:***

| | |
|---|---|
| 1. Torque (newton-meter): | 0.1 |
| 2. Resolution (deg): | 0.074 |
| 3. Speed (rpm): | 150 |
| 4. Gear Ratio: | 76:1 |
| 5. Backlash (deg): | 0 |
| 6. Encoder (lines/rev) | 16X4 |
| 7. Rotary Index: | yes |
| 8. Coarse Home: | yes |

*Other gearing & motors available for finer resolution and faster revolutions*

### Electrical Specifications:

| *Linear:* | *LAR-30* | *LAR-37* | *LAR-50* |
|---|---|---|---|
| 1. Coil Resistance (ohms): | 5.6 | 5.6 | 5.5 |
| 2. Coil Inductance (mH): | 6.8 | 7.4 | 8.0 |

3. Voltage: 24 VDC
4. Maximum current: 2.5 amps continuous
5. Encoder power supply: 5 VDC
6. Encoder Output: single ended or differential
7. Over-temperature protection (optically isolated, open collector)
8. Front and rear End-of-stroke Limits (optically isolated,open collector)
9. 40% maximum duty cycle
10. LED indicators:
    GREEN: Power on
    RED: Over temperature detected

*(Electrical specifications continued)*

***Rotary:***

1. Voltage: 24 VDC
2. Maximum current: 0.1 amps continuous
3. Encoder power supply: 5 VDC
4. Encoder pulse/rev: 16
5. Encoder Two Channel Quadrature Output
6. Encoder Output: Single ended or complementary
7. Rotary Index: standard
8. Coarse Home: Standard (optically isolated, open collector)

### Linear Actuators

| **Mechanical Specifications:** | *LAL-30* | *LAL-37* | *LAL-50* | *LAL-90* |
|---|---|---|---|---|
| 1. Stroke (mm): | 25 | 50 | 100 | 50 |
| 2. Total Weight: (gms): | 630 | 1050 | 4080 | 2100 |
| 3. Moving Mass (gms ): | 150 | 170 | 225 | 250 |
| 4. Maximum Force (newtons): | 10 | 10 | 25 | 100 |
| 5. Maximum Acceleration (g): | 5 | 5 | 10 | 15 |
| 6. Rod Diameter (mm): O.D. | 8 | 8 | 8 | 10 |
| I.D. | 3 | 3 | 3 | 3 |

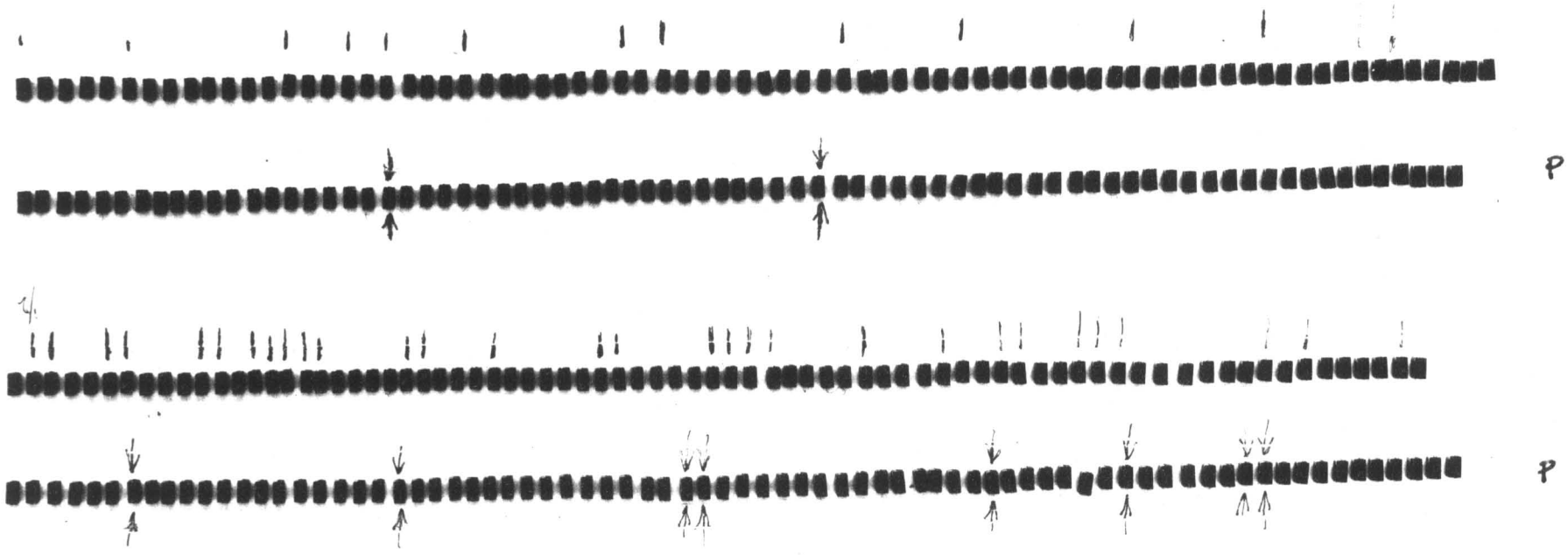
7. Encoder Resolution: 0.005 mm, optional 0.001 mm
8. Position Accuracy (no load): +/- 2 encoder counts
9. Body: Anodized Aluminum
10. Rod Runout Over Full Stroke: 0.05 mm or less
11. Thermistor Set Point: 70°C
12. Operating Ambient: 0 to 50°C

### Electrical Specifications:

| | *LAL-30* | *LAL-37* | *LAL-50* | *LAL-90* |
|---|---|---|---|---|
| 1. Coil Resistance: (ohms) | 5.6 | 5.6 | 5.5 | 12 |
| 2. Coil Inductance: (mh) | 6.8 | 7.4 | 8.0 | 7.5 |
| 3. Voltage: (VDC) | 24 | 24 | 24 | 48 |

4. Maximum current: 2.5 amps continuous
5. Encoder power supply: 5 VDC
6. Encoder Output: single ended or differential
7. Over-temperature protection (optically isolated, open collector)
8. Front and rear End-of-stroke Limits (optically isolated,open collector)
9. 40% maximum duty cycle
10. LED indicators:
    GREEN: Power on
    RED: Over temperature detected

# A.10.
# RX test for pushed/non-pushed bad welds


P
P

# A.11.
# IDINET email exchange about pogo-pins

From: **Jon Diller <jon@mail.idinet.com>**
Send reply to: **"jon@mail.idinet.com" <jon@mail.idinet.com>**
To: **"'Joao Dias de Silva'" <joao_d@vsprague.com>**
Subject: **RE: URGENT!!! - switch probes**
Date sent: **Wed, 20 May 1998 08:52:40 -0500**
Organization: **Interconnect Devices, Inc.**

Mr. da Silva,

I hope that our conversation today adequately prepared you for your meeting. If I can be of any further assistance, please let me know.

Respectfully,
Jon Diller
Project Manager
Interconnect Devices, Inc.
jon@mail.idinet.com

[50 K ; 500 K]

On Wednesday, May 20, 1998 9:19 AM, Joao Dias de Silva [SMTP:joao_d@vsprague.com] wrote:
> This message is for THAD SKETERS, from 'Product Designing'.
> .....
>
> This is Joao da Silva, from VISHAY-SPRAGUE, in Sanford, Maine.
> (I tried first to send this mail to you directly but it didn't work.)
>
> I called you about 1 month ago, asking you to send me technical
> information (drawings with dimensional and force tolerances) about
> switch probes SW3, SW4 and SW5. I received it promptly and it was very
> useful. Thanks for that.
>
> Meanwhile, we left these devices behind because we were studying other
> approaches, using totally different technologies.
>
> Now, we have another approach in which we might come again to the use
> of switch probes.
>
> My doubts are now related to the life of these devices, concerning the
> switch mechanism: for how long can we be sure that a certain probe
> will switch always at the same travel distance (whatever it is), with
> an accuracy of about +/- 0.0005 in.?



From: **"Christy" <christyc@mail.idinet.com>**
Organization: **Interconnect Devices Inc.**
To: **"Joao Dias de Silva" <joao_d@vsprague.com>**
Date sent: **Tue, 20 May 1998 09:35:44 CST**
Subject: **Re: URGENT!!! - switch probes**
Priority: **normal**

Joao,

Thad is out of the office this week, and your message has been forwarded to me.

As for the life span of the switch probes, with the SW-3 and SW-4 you can expect 100K cycles on the lower spring forces and about 10K- 15K on the higher spring forces. When you do start to see failures, it will be do spring failure, or the coating on the spring wearing off, not from failure of the switch mechanism. The switch will activative at the same travel distance each time the probe is cycled.

I hope this answers your questions.

Please let me know if you need anything else.

Thanks,
Christy Cameron
Product Manager
IDI
913/342-5544
Fax 913/342-7043
From: "Joao Dias de Silva" <joao_d@vsprague.com>
Organization: Vishay Sprague Inc.
To: products@idinet.com
Date: Wed, 20 May 1998 09:18:39 -0500
Subject: URGENT!!! - switch probes
Priority: normal

This message is for THAD SKETERS, from 'Product Designing'.
.....

This is Joao da Silva, from VISHAY-SPRAGUE, in Sanford, Maine.
(I tried first to send this mail to you directly but it didn't work.)

# A.12.
# Production information in assembly line

CHIP ASSEMBLY CURRENT DATE: 19-May-98
START 7,927 MILLION
FINISH 6,500 MILLION
WITHOUT TA PELLETS

**LASER**

| CASE SIZE | REQ.'D 000'S | 10 WK. PCS./HR | MACH. UPTIME | HR./ SHIFT | MACH.'S | 1 SHIFT OVER/ UNDER | 1 SHIFT CAP. | 2 SHIFT OVER/ UNDER | 2 SHIFT CAP.** | 3 SHIFT OVER/ UNDER | 3 SHIFT CAP.** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ALL | 7,927 | 21,000 | 0.9 | 7.25 | 6 | (3,816) | 4,111 | 295 | 8,222 | | |

**ASSEMBLY**

| CASE SIZE | REQ.'D 000'S | 10 WK. PCS./HR | MACH. UPTIME | HR./ SHIFT | MACH.'S | 1 SHIFT OVER/ UNDER | 1 SHIFT CAP. | 2 SHIFT OVER/ UNDER | 2 SHIFT CAP.** | 3 SHIFT OVER/ UNDER | 3 SHIFT CAP.** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1,683 | 44,000 | 0.92 | 7.25 | 1 | (509) | 1,174 | 371 | 2,054 | | |
| B | 2,378 | 30,500 | 0.91 | 7.25 | 1 | (1,372) | 1,006 | (366) | 2,012 | 137 | 2,515 |
| C | 1,683 | 29,500 | 0.93 | 7.25 | 1 | (887) | 796 | (291) | 1,392 | | |
| D | 1,768 | 22,500 | 0.82 | 7.25 | 2 | (698) | 1,070 | 104 | 1,873 | | |
| E | 415 | 19,500 | 0.83 | 7.25 | 1 | 55 | 469 | 407 | 821 | | |
| | | | | | | | | | | | |
| TOTAL | 7,927 | | | | 6 | (3,412) | 4,515 | 226 | 8,153 | 729 | 8,656 |

** B LINE 100% STAFFED
** 1ST SHIFT REMAINING LINES 80% STAFFED
** 2ND SHIFT REMAINING LINES 60% STAFFED

**MOLD**

| CASE SIZE | REQ.'D 000'S | 10 WK. PCS./HR | MACH. UPTIME | HR./ SHIFT | MACH.'S | 1 SHIFT OVER/ UNDER | 1 SHIFT CAP. | 2 SHIFT OVER/ UNDER | 2 SHIFT CAP.** | 3 SHIFT OVER/ UNDER | 3 SHIFT CAP.** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1,683 | 46,000 | 0.96 | 7.25 | 1 | (402) | 1,281 | 558 | 2,241 | | |
| B | 2,378 | 33,000 | 0.98 | 7.25 | 1 | (1,206) | 1,172 | (33) | 2,345 | 553 | 2,931 |
| C | 1,683 | 28,000 | 0.98 | 7.25 | 1 | (887) | 796 | (290) | 1,393 | | |
| D | 1,768 | 17,000 | 0.96 | 7.25 | 2 | (822) | 947 | (112) | 1,656 | | |
| E | 415 | 17,000 | 1 | 7.25 | 1 | 78 | 493 | 448 | 863 | | |
| | | | | | | | | | | | |
| TOTAL | 7,927 | | | | 6 | (3,239) | 4,688 | 571 | 8,498 | 1,157 | 9,084 |

** B LINE 100% STAFFED
** 1ST SHIFT REMAINING LINES 80% STAFFED
** 2ND SHIFT REMAINING LINES 60% STAFFED

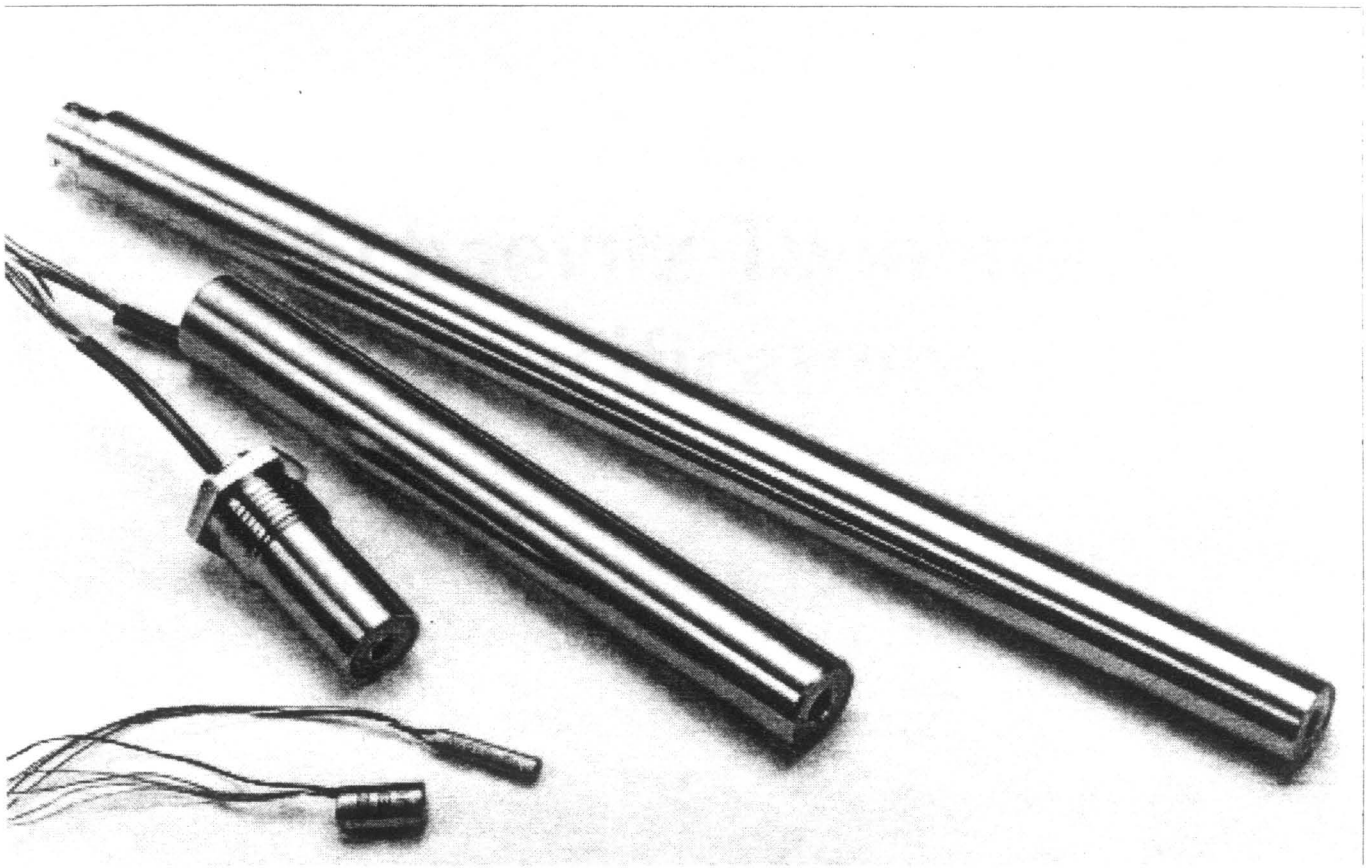
# A.13.
# Annual Cost Information

| MONTH-TO-DATE ACTUAL THIS YR | MONTH-TO-DATE ACTUAL LAST YR | MONTH-TO-DATE BUDGET THIS YR | MONTH-TO-DATE ACT/BUD VARIANCE | ACCT | DESCRIPTION | YEAR-TO-DATE ACTUAL THIS YR | YEAR-TO-DATE ACTUAL LAST YR | YEAR-TO-DATE BUDGET THIS YR | YEAR-TO-DATE ACT/BUD VARIANCE |
|---|---|---|---|---|---|---|---|---|---|
| 22,904 | 14,940 | 9,972 | 12,932 | 510500 | DM, SILVER | 269,125 | 345,512 | 114,254 | 154,871 |
| 146,155 | 102,184 | 68,692 | 77,463 | 510600 | DM, LEADFRAMES | 1,626,026 | 2,274,947 | 787,029 | 838,997 |
| 1,977 | 1,191 | 1,172 | 805 | 510900 | DM, CHEMICALS | 23,334 | 39,610 | 13,430 | 9,904 |
| 1,608 | | 22 | 1,586 | 511200 | DM, MARKEM INK | 17,888 | 622 | 257 | 17,631 |
| | | 15 | -15 | 511300 | DM, LABELS | 208 | 407 | 168 | 40 |
| 48,004 | 19,395 | 20,353 | 27,651 | 511400 | DM, FLU BED & MLDING PWD | 467,318 | 669,159 | 233,191 | 234,127 |
| 11,414 | 3,923 | 6,530 | 4,884 | 511500 | DM, PKG MATERIALS | 143,650 | 211,649 | 74,815 | 68,835 |
| | | 6 | -6 | 511700 | DM, PREF/STRING SOLDER | 1,104 | 171 | 70 | 1,034 |
| 35,756 | 20,038 | 24,854 | 10,902 | 511800 | DM, TAPE | 490,913 | 813,497 | 284,765 | 206,148 |
| | | | | 511900 | DM, RESIN | 736 | | | 736 |
| | | 2,964 | -2,964 | 519100 | DM, MISCELLANEOUS | | 82,096 | 33,963 | -33,963 |
| 267,819 | 161,672 | 134,580 | 133,239 | 500000 | TOTAL DIRECT MATERIAL | 3,040,303 | 4,437,670 | 1,541,942 | 1,498,361 |
| 177,001 | 121,736 | 111,102 | 65,899 | 611131 | DL, EMPLOYED-MOLDED CHIP | 1,962,555 | 3,171,795 | 1,272,939 | 689,616 |
| 30 | | | 30 | 621131 | DL, PURCHASED-MOLDED CHI | 86,881 | 22,154 | | 86,881 |
| 17,645 | 18,394 | 1,355 | 16,290 | 631000 | DL, PREMIUMS-OVERTIME | 183,182 | 159,667 | 15,521 | 167,661 |
| 9,395 | 455 | | 9,395 | 632000 | DL, PREMIUMS-SHIFT | 91,468 | 249,626 | | 91,468 |
| 4,632 | | 6,397 | -1,765 | 639100 | DL, FRNG-VACATION | 165,588 | | 73,292 | 92,296 |
| 7,816 | | 6,081 | 1,735 | 639200 | DL, FRNG-HOLIDAY | 90,933 | | 69,667 | 21,266 |
| 19,050 | | 11,859 | 7,191 | 639500 | DL, FRNG-EMPLYR PYRL TAX | 199,712 | | 135,868 | 63,844 |
| -4,418 | | 1,580 | -5,998 | 639600 | DL, FRNG-WORKERS COMP | 25,565 | | 18,096 | 7,469 |
| 7,457 | | 8,557 | -1,100 | 639700 | DL, FRNG-GROUP INSUR | 140,292 | | 98,045 | 42,247 |
| 3,323 | | 1,457 | 1,866 | 639800 | DL, FRNG-PENSION | 38,215 | | 16,689 | 21,526 |
| 4,314 | | 1,882 | 2,432 | 639900 | DL, FRNG-401K MATCH/ADMI | 39,591 | | 21,564 | 18,027 |
| 246,245 | 140,584 | 150,270 | 95,975 | 600000 | TOTAL DIRECT LABOR | 3,023,981 | 3,603,241 | 1,721,681 | 1,302,300 |
| 7,540 | 8,616 | | 7,540 | 701100 | COMP, INDIRECT LABOR-EMP | 97,029 | 224,954 | | 97,029 |
| 300 | | | 300 | 701200 | COMP, INDIRECT LABOR-PUR | 428 | | | 428 |
| | | | | 702100 | COMP, PREM/OVERTIME-EMPL | 835 | 1,944 | | 835 |
| | | | | 702300 | COMP, PREM/SHIFT-EMPLOYE | | 3,251 | | |
| 9,611 | 9,595 | 9,140 | 471 | 703100 | COMP, SALARY-BASE | 135,090 | 303,361 | 109,680 | 25,410 |
| 2,055 | -2,301 | 220 | 1,835 | 709100 | COMP, FRNG-VACATION | 6,985 | 208,724 | 2,640 | 4,345 |
| 294 | -5,459 | 160 | 134 | 709200 | COMP, FRNG-HOLIDAY | 3,987 | 146,118 | 1,920 | 2,067 |
| | 2,365 | 50 | -50 | 709300 | COMP, FRNG-BONUS DAYS | | 49,106 | 600 | -600 |
| 1,431 | | 964 | 467 | 709500 | COMP, FRNG-EMPLYR PYRL T | 19,687 | | 11,568 | 8,119 |
| -378 | | 128 | -506 | 709600 | COMP, FRNG-WORKERS COMP | 2,829 | | 1,536 | 1,293 |
| 638 | | 695 | -57 | 709700 | COMP, FRNG-GROUP INSUR | 14,799 | | 8,340 | 6,459 |
| 281 | | 118 | 163 | 709800 | COMP, FRNG-PENSION | 3,988 | | 1,416 | 2,572 |
| 369 | | 153 | 216 | 709900 | COMP, FRNG-401K MATCH/AD | 4,117 | | 1,836 | 2,281 |
| 22,142 | 12,816 | 11,628 | 10,514 | 700000 | TOTAL COMPENSATION | 289,774 | 937,458 | 139,536 | 150,238 |
| 346 | 215 | 1,133 | -787 | 711100 | SUPP, OFFICE | 4,140 | 10,289 | 13,596 | -9,456 |
| 18,494 | 11,337 | 5,260 | 13,234 | 711200 | SUPP, OPERATING | 158,692 | 190,467 | 60,263 | 98,429 |
| | 1,057 | 1,009 | -1,009 | 711900 | SUPP, SMALL TOOLING | 1,525 | 29,747 | 11,564 | -10,039 |
| 26,673 | 18,934 | 20,233 | 6,440 | 721900 | EQMT, ASSEMBLY | 311,665 | 623,818 | 231,813 | 79,852 |
| 5,230 | 9,670 | 23,975 | -18,745 | 722000 | EQMT, MOLDING | 237,231 | 684,915 | 274,691 | -37,460 |
| 13,572 | 43,951 | 15,946 | -2,374 | 722100 | EQMT, DEF/STMP/INS/THER | 259,226 | 551,454 | 182,698 | 76,528 |
| 780 | 4,501 | 4,249 | -3,469 | 722200 | EQMT, TESTING | 58,541 | 152,510 | 48,678 | 9,863 |
| | 225 | 1,349 | -1,349 | 722300 | EQMT, FINISHING | 6,813 | 39,261 | 15,450 | -8,637 |

# A.14.
# LVDT Functional Advantages

# Schaevitz™ LVDT Technology

## LVDT Functional Advantages and Operation Principles



An LVDT is an electromechanical transducer that produces an electrical output proportional to the displacement of a separate movable core.

The LVDT has many commendable features that make it useful for a wide variety of applications.

### Frictionless Measurement

Ordinarily, there is no physical contact between the movable core and coil structure, which means that the LVDT is a frictionless device. This permits its use in critical measurements that can tolerate the addition of the low-mass core, but cannot tolerate friction loading. Two examples of such applications are dynamic deflection or vibration tests of delicate materials and tensile or creep tests on fibers or other highly elastic materials.

### Infinite Mechanical Life

The absence of friction and contact between the coil and core of an LVDT means that there is nothing to wear out. This gives an LVDT essentially infinite mechanical life. This is a paramount requirement in applications such as the fatigue-life testing of materials and structures. The infinite mechanical life is also important in high-reliability mechanisms and systems found in aircraft, missiles, space vehicles and critical industrial equipment.

### Infinite Resolution

The frictionless operation of the LVDT combined with the induction principle by which the LVDT functions gives the LVDT two outstanding characteristics. The first is truly infinite resolution. This means that the LVDT can respond to even the most minute motion of the core and produce an output. The readability of the external electronics represents the only limitation on resolution.

### Null Repeatability

The inherent symmetry of the LVDT construction produces the other feature—null repeatability. The null position of an LVDT is extremely stable and repeatable. Thus the LVDT can be used as an excellent null position indicator in high-gain closed-loop control systems. It is also useful in ratio systems where the resultant output is proportional to two independent variables at null.

### Cross-Axis Rejection

An LVDT is predominantly sensitive to the effects of axial core motion and relatively insensitive to radial core motion. This means the LVDT can be used in applications where the core does not move in an exact straight line; as, for example, when an LVDT is coupled to the end of a bourdon tube to measure pressure.

Some of these features are unique to the LVDT and are not available in any other transducer (element). These features arise from the basic fact that the LVDT is an electrical transformer with a separable non-contacting core.

# A.15.
# Schaevitz TwinStar Specifications

# TwinStar Laser Sensor

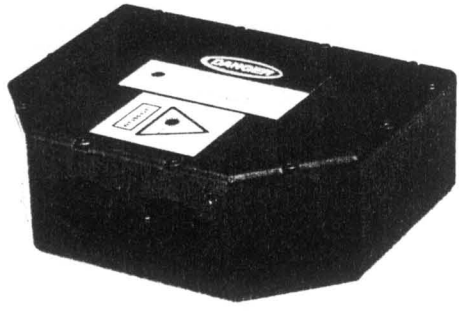
## ±1.5 to 6.0 mm Measurement Range

**Schaevitz Laser Technology**
Resolution to 0.007 µm
100 kHz Sampling Rate
DC Input/DC Output

The Schaevitz™ TwinStar sensor is a laser beam sensor with a visible light spot that offers excellent accuracy and linearity, and superior response time compared to other measurement scanning methods.

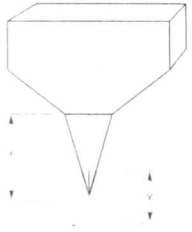
The patented TwinStar sensor uses optical triangulation to sense surface variations as fine as 0.007 µm when the signal is averaged to 100 Hz. The TwinStar's 100 kHz sampling rate allows for exceptional process throughput while providing excellent resolution.

The TwinStar emits a visible beam from a solid state laser diode. The beam strikes the object's surface which reflects a spot through twin imaging optics onto two position sensitive detectors (PSDs). These twin optics provide better contour tracking when there are sharp increases in object height. If the reflective spot to one PSD is obscured by a change in the object's surface the other PSD will see it. The dual triangulation sensor allows you to measure under difficult surface and lighting conditions.



### Features

- ❑ *CE compliant**
- ❑ *Resolution as fine as 0.007 µm*
- ❑ *100 kHz sampling rate*
- ❑ *Proprietary optical triangulation technology*
- ❑ *Improved immunity to changing light/surface conditions*
- ❑ *DC in/DC out*
- ❑ *LED indicator for in-range/out-of-range*
- ❑ *Auxiliary output to indicate out-of-range condition*



### General Specifications

| | |
|---|---|
| **Linearity** | ±0.15% of full scale |
| **Sampling Frequency** | 100 kHz |
| **Spot Diameter (min)** | 0.0012" (30µm) |
| **Light Source** | 780 nm, 30 mW FDA Class IIIB Laser Diode |
| **Input Voltage** | ±15 VDC; ±5% |
| **Input Current** | ±300 mA |
| **Outputs:** | |
| **Displacement** | ±10 VDC |
| **Intensity** | 0 to 3 VDC |
| **Range** | In Range: -0.7 VDC<br>Out of Range: -4.7 VDC |
| **Operating Temperature Range** | 32 to 122 F (0 to 50 C) |
| **Tempco/°C** | 0.1% of Full Scale |
| **Dimensions** | See page 95 |

### How to Order

Specify the appropriate model number.

| Specifications by Model | 15/3 | 15/6 | 15/12 |
|---|---|---|---|
| **Measurement Range (y)** | ±0.059" (±1.5 mm) | ±0.118" (±3.0 mm) | ±0.236" (±6.0 mm) |
| **Zero Distance (x)** | 0.591" (15 mm) | 0.591" (15 mm) | 0.591" (15 mm) |
| **Resolution (100 kHz)** | 0.39 µ-inch (7 nm) w/100 Hz avg | 0.78 µ-inch (14 nm) w/100 Hz avg | 1.57 µ-inch (28 nm) w/100 Hz avg |

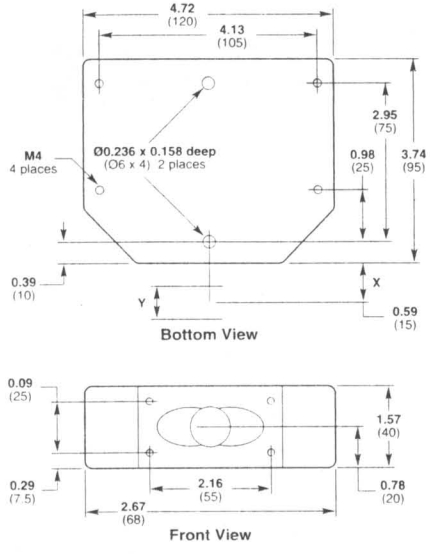
CE

*The TwinStar, when correctly installed, is CE certified to comply with the EMC Directive 89/336/EEC Generic Standards for Residential, Commercial, Light Industrial and Industrial Environments.*

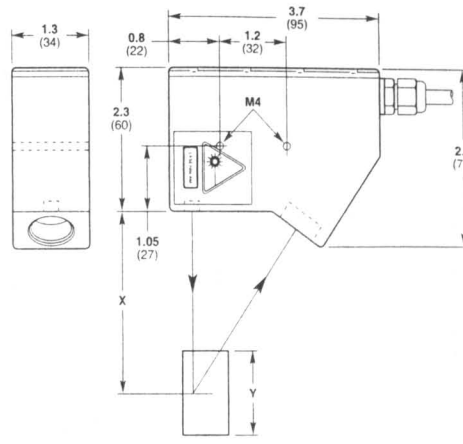


# Laser Sensor Dimensions

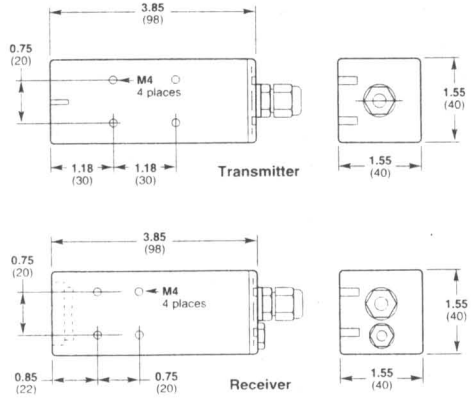
**TwinStar Dimensions in (mm)**




**DistanceStar Dimensions in (mm)**




**BeamStar Dimensions in (mm)**






Lucas VARITY

## WARRANTIES/REPAIRS

### Warranties

Schaevitz™ instruments are warranted during a period of one year from date of shipment of original purchaser to be free from defects in material and workmanship. The liability of Seller under this warranty is limited to replacing or repairing any instrument or component thereof which is returned by Buyer, at his expense, during such period and which has not been subjected to misuse, neglect, improper installation, repair, alteration or accident. Seller shall have the right to final determination as to the existence and cause of a defect. In no event shall seller be liable for collateral or consequential damages. This warranty is in lieu of any other warranty, expressed, implied, or statutory; and no agreement extending or modifying it will be binding upon Seller unless in writing and signed by a duly authorized officer.

### Receiving Inspection

Every Schaevitz™ instrument is carefully inspected and is in working order at the time of shipment. Each instrument should be checked as soon as received. If the unit is damaged in any way, or fails to operate, a claim should immediately be filed with the transportation company.

### Repairs

All units being returned to the factory for any reason require an RMA (Return Material Authorization) number before they will be accepted. This number may be obtained by calling the Repair Department at 1-800/745-8008 in the U.S. and (1753) 537622 in Europe, with the following information:

- Model Number
- Quantity
- Serial Number
- Symptoms of the problem with the unit if being returned for service.
- Original P.O. Number or Schaevitz™ Sales Number if under warranty.

If a Schaevitz™ instrument requires service, first contact the nearest Schaevitz™ representative. He/she may be able to solve the problem without returning the unit to the factory. If it is determined that factory service is required, call the Repair Department for an RMA number before returning the unit.

Lucas Control Systems Products reserves the right to alter products and specifications without notice. The statements, information and data published in this literature are, to the best of our knowledge, accurate, reliable, and true. Because Lucas Control Systems Products has no control over the use to which others may put these products, we do not guarantee that the same results as those described herein will be obtained. Each user should test under his own conditions to determine the product's suitability for his own particular applications.

## FEATURES

- Resolution to 0.007µm*
- 100kHz Sampling Rate
- Auxiliary Output to Indicate Out of Range Condition
- Proprietary Optical Triangulation Technology
- Improved Immunity to Changing Light/Surface Conditions
- DC In / DC Out
- LED Indicator for In/Out of Range

| SPECIFICATIONS/MODEL | 15/3 | 15/6 | 15/12 |
|---|---|---|---|
| Measurement Range (y): | ± .059" (+/-1.5 mm) | ± .118" (+/-3.0 mm) | ± .236" (+/-6.0mm) |
| Zero Distance (x): | .591" (15 mm) | .591" (15 mm) | .591" (15 mm) |
| Minimum Spot Diameter: | .0012" (30 µm) | .0012" (30 µm) | .0012" (30 µm) |
| Light Source | 780 nm, 30mW FDA Class IIIB Laser Diode | | |
| Input: Voltage | ± 15V dc. ±5% | ± 15V dc. ±5% | ± 15V dc. ±5% |
| Current | ± 300 mA | ± 300 mA | ± 300 mA |
| Outputs: Displacement | ± 10 V dc. | ± 10 V dc. | ± 10 V dc. |
| Intensity | 0 to 5 V dc. | 0 to 5 V dc. | 0 to 5 V dc. |
| Range | -0.7 V dc. = In Range<br>+4.7 V dc.= Out of Range | -0.7 V dc. = In Range<br>+4.7 V dc.= Out of Range | -0.7 V dc. = In Range<br>+4.7 V dc.= Out of Range |
| Linearity | ± .015% of Full Scale | ± .015% of Full Scale | ± .015% of Full Scale |
| Sampling Frequency: | 100 kHz | 100 kHz | 100 kHz |
| Resolution: | 0.39 µinch (7 nm) (w/100Hz avg.) | 0.78 µinch (14 nm) (w/100Hz avg.) | 1.57 µinch (28 nm) (w/100Hz avg.) |
| Operating Temperature Range | 32 to 122 deg. F (0 to 50 deg. C.) | 32 to 122 deg. F (0 to 50 deg. C.) | 32 to 122 deg. F (0 to 50 deg. C.) |
| Tempco Per Deg. C | .01% of Full Scale | | |

**North American Operations**
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Schaevitz™ Sensors
1000 Lucas Way
Hampton, Virginia 23666
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Schaevitz™ Sensors
543 Ipswich Road
Slough, Berks SL1 4EG
United Kingdom
(01753) 537622
FAX: (01753) 823563

Lucas VARITY



## INSTALLATION & WIRING CONNECTION

### General

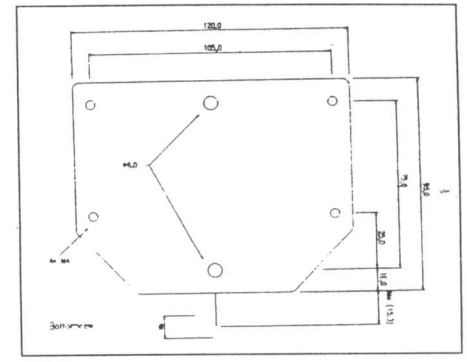
**Before installing the Schaevitz™ TwinStar, please check the following:**
ALWAYS WEAR LASER SAFETY GLASSES!

- The laser power supply must be switched off. **WARNING:** Avoid direct eye contact with the beam.
- Ensure that you mount the laser securely. Measurement repeatability will be affected if the unit is not properly anchored.
- Vibration and other external mechanical noise can affect the measurement stability.
- The near infrared light may be aligned by holding a white or gray card in front of the laser, and blocking out the ambient light.
- Protect the lens from dirt and dust. Clean with an optical quality lens cloth as required.
- An intermittent clean, dry, air jet may be employed to clean lens as necessary.
- Protect sensor lens from direct exposure to welding arc and debris.
- The laser operating temperature is between 32 to 122 deg. F, (0 to 50 deg. C).
- Direct sunlight, and some factory lighting may affect laser output.

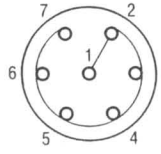
### Installation

***Note: These devices are sold as components only. As such they are NOT compliant with FDA sec. 21, sub chapter J. To meet these safe operation requirements, they must be installed with the proper safety devices, i.e. warning lights, key switches, delay timers and shrouds, appropriate for a class 3b laser device. Please consult the relevant governing body regulations for this device in your locality.***

- Place the laser sensor in the appropriate position.
- Switch on the system. Allow 10 minutes for the system to warm up.
- Calibrate to your system using a gage block or micrometer and target.




### Connections



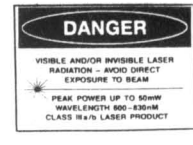

Plug view from solder side

| | |
|---|---|
| Brown | +15Vdc |
| Black/Green | GND |
| White | -15Vdc |
| Yellow | Output, Displacement |
| Gray | Output, Intensity |
| Pink | Range Enable |

Plug type: FGG 1B 307 CLA D72 (LEMO)

### Warming-up time

Please allow a warm-up time of ~10 minutes.




**North America Tel:** 800/745-8008
**Europe:** (01753) 537622

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# A.16.
# Laser Calibration Regression Analysis

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999984592 |
| R Square | 0.999969185 |
| Adjusted R Square | 0.999953777 |
| Standard Error | 0.007655114 |
| Observations | 4 |

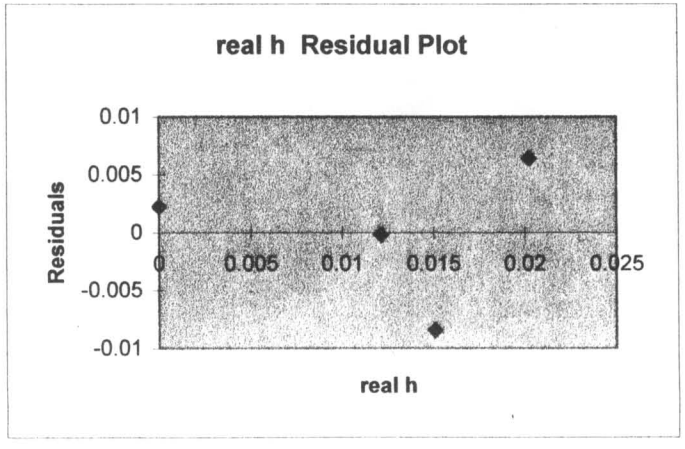
ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 3.803217397 | 3.803217397 | 64900.47 | 1.54079E-05 |
| Residual | 2 | 0.000117202 | 5.86008E-05 | | |
| Total | 3 | 3.803334599 | | | |

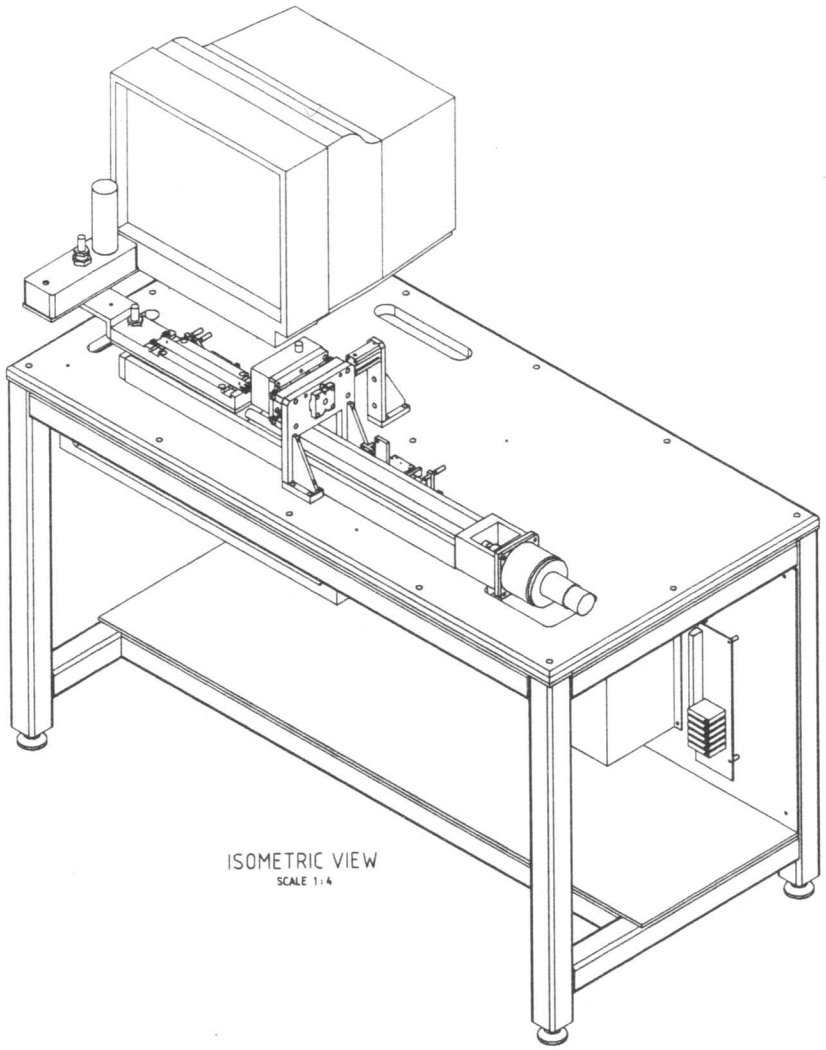
| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.104630962 | 0.007206625 | 14.51871859 | 0.0047105 | 0.073623335 | 0.135638589 | 0.073623335 | 0.135638589 |
| real h | 130.9962468 | 0.514203384 | 254.7557071 | 1.541E-05 | 128.7838067 | 133.208687 | 128.7838067 | 133.208687 |

RESIDUAL OUTPUT

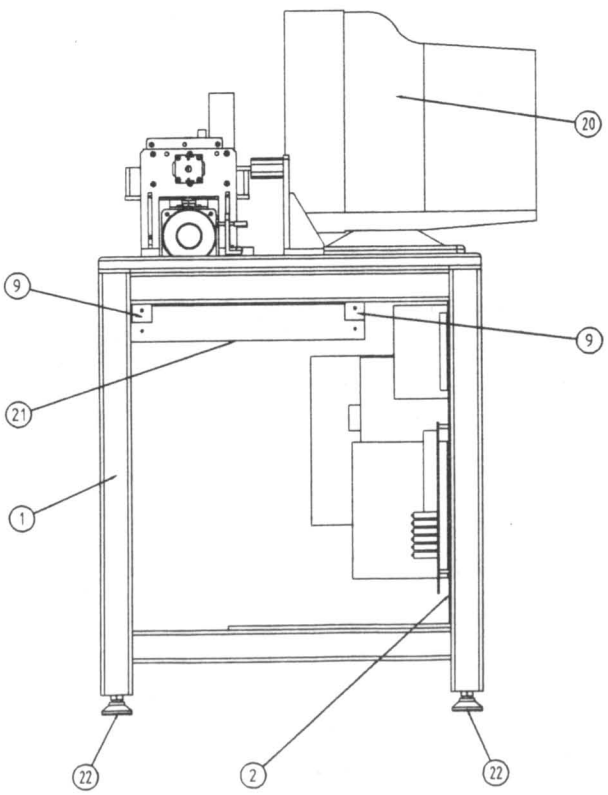
| *Observation* | *Predicted v* | *Residuals* | *Standard Residuals* |
|---|---|---|---|
| 1 | 0.104630962 | 0.002219038 | 0.355024852 |
| 2 | 1.696235361 | -0.000180815 | -0.028928699 |
| 3 | 2.082674289 | -0.008440955 | -1.350471997 |
| 4 | 2.75730496 | 0.006402732 | 1.024375844 |



# A.17.
# Other Views of the prototype machine



ISOMETRIC VIEW
SCALE 1:4




| REV | DESCRIPTION | BY | DATE |
|---|---|---|---|
| - | ORIGINAL APPROVAL | | |
| - | ORIGINAL DRAFTING | MD | 6/03/98 |

VIRAY SPRAGUE COMPONENT ENGINEERING RT. 90 PO BOX 239 LANSING, MAINE 04853

ITEM 1 | B.M. SEE MDL

USED ON: LASER MEASUREMENT PROTOTYPE

TITLE: MAIN ASSEMBLY

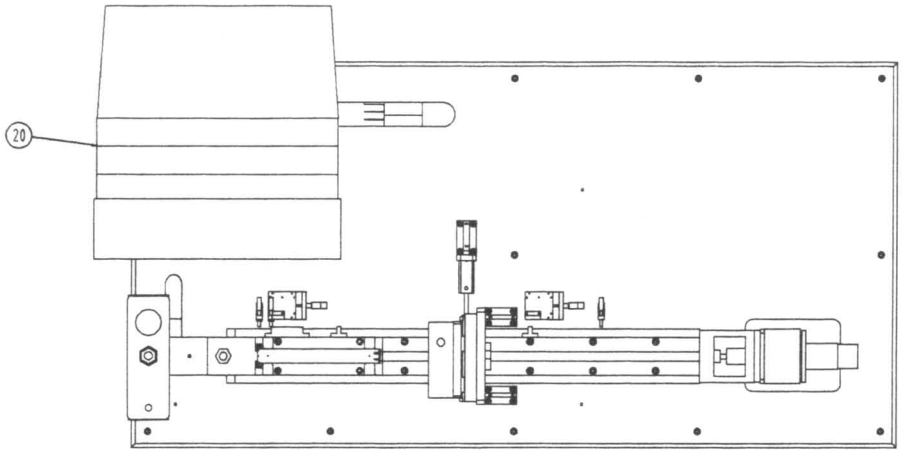
MATERIAL: SEE BM E-170494

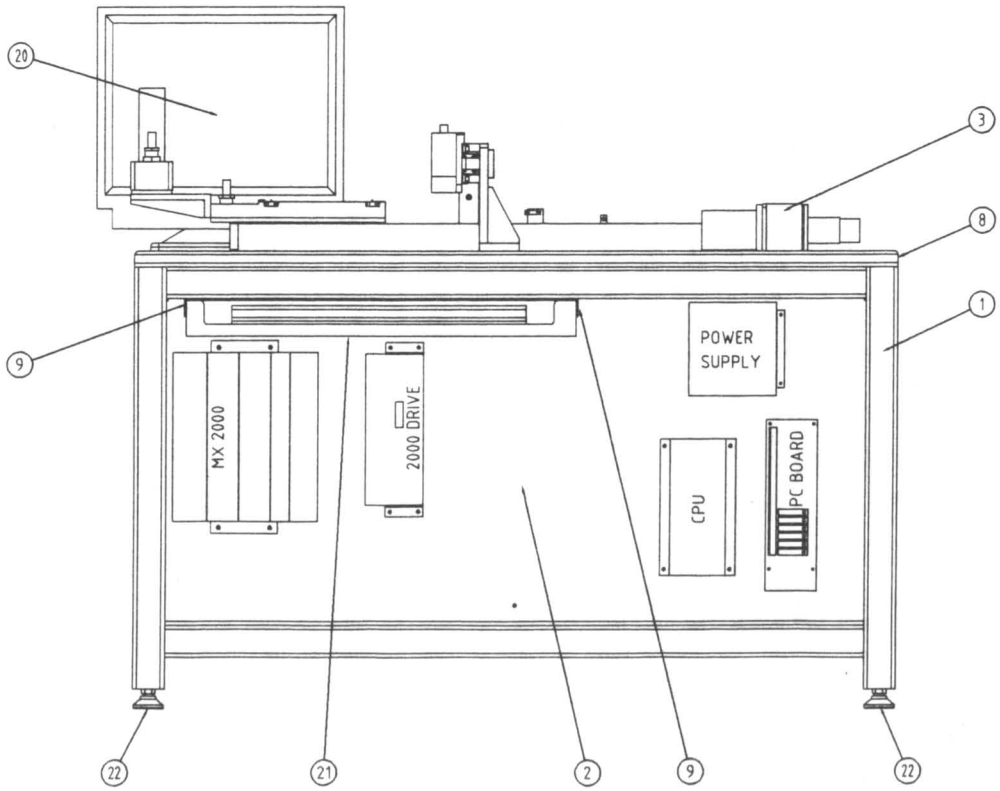
FINISH: NONE

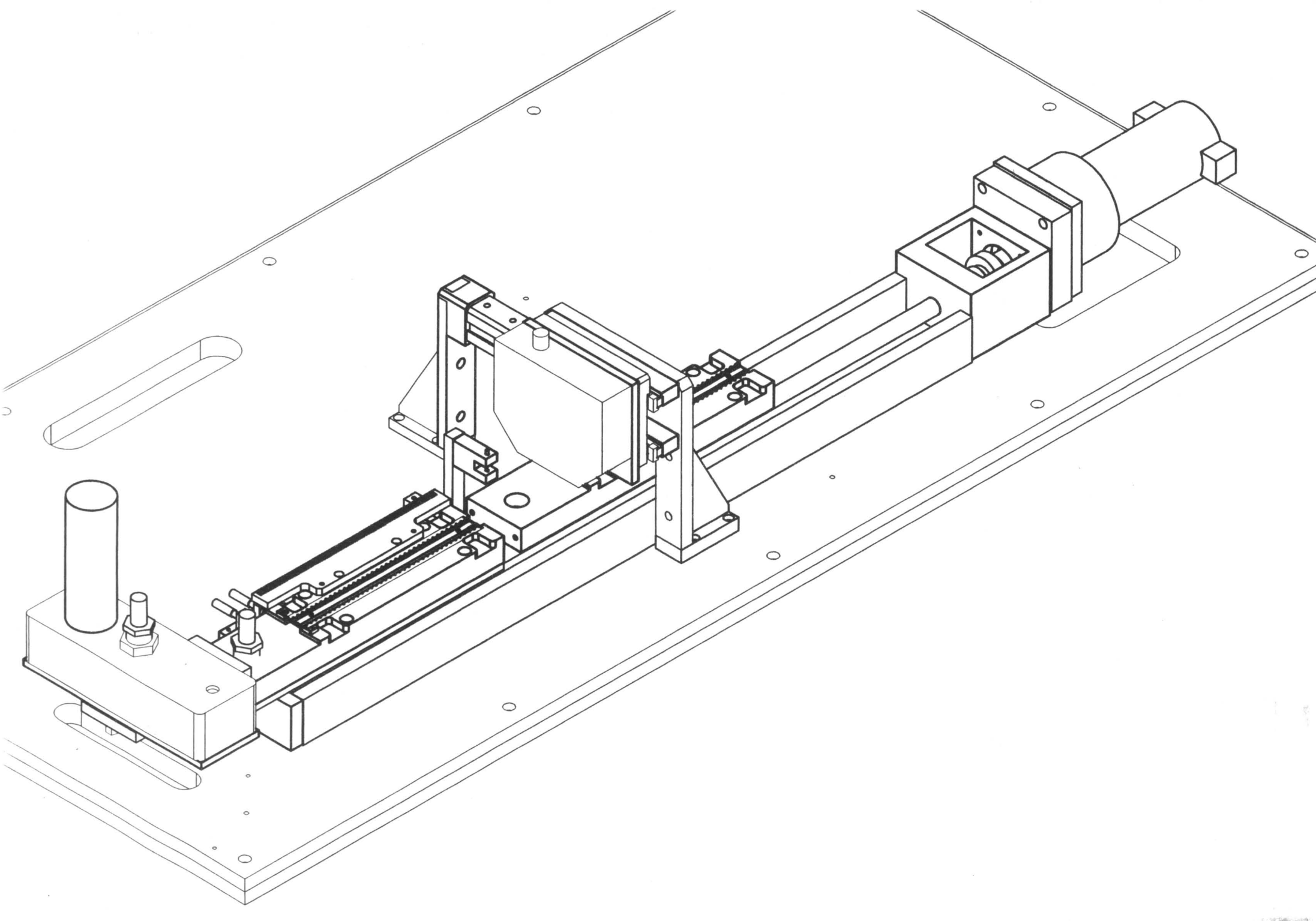
SCALE: 1:2

SHT. 1 OF 1 | MDL 9806 | DRAWING NUMBER E-170494 | REV. -

PAGE


20


20
3
8
1
9
POWER
SUPPLY
MX 2000
2000 DRIVE
CPU
PC BOARD
22
21
2
9
22



# A.18.
# MX-2000 Sample Program

```
'*************************************************************************
'*                    TITLE :  Laser weld tester                         *
'*                                                                       *
'*                       Filename :  x170624.prj                         *
'*                       ----------------------                          *
'*                                                                       *
'*                   orig. design date : 09 / 11 /98                     *
'*                   orig. designer : Robert Rudy                        *
'*                                                                       *
'*-----------------------------------------------------------------------*
'*                                                                       *
'*                   O R D E R   O F   C O N T E N T S                   *
'*                                                                       *
'*          Initialization.....................................          *
'*          Sub-routines list ( alphabetically listed.....               *
'*          Mainprocess.....................................             *
'*                                                                       *
'*************************************************************************
'*                                                                       *
'*          HARDWARE REQUIREMENTS : MX2000 MULTI-AXIS CONTROLLER         *
'*          SOFTWARE REQUIREMENTS : MX2000 SOFTWARE Ver.3.4 WINDOWS 95)  *
'*                                                                       *
'*          FILE TYPES : *.PRJ  ( Project files )                        *
'*                     : *.TSK  ( Task files    )                        *
'*                                                                       *
'*                                                                       *
'*************************************************************************
'* * * * * * * * * * I N I T I A L I Z A T I O N * * * * * * * * * * * *
'*********      V A R I A B L E   D E C L E R A T I O N     ************
CNT=0
DIST1=3.2                                   'INITIAL MOVE FROM HOME
DIST2=.1015                                  'LF PITCH
LFPTCH=76

'*****************  WELD MEASURE SYSTEM I/O DEFINITION  ***************
#DEFINE STPSWON       EXIN(100)=1           'Stop input on
#DEFINE STPSWOFF      EXIN(100)=0           'Stop input off
#DEFINE STRTSWON      EXIN(101)=1           'Start input on
#DEFINE STRTSWOFF     EXIN(101)=0           'Stop input off
#DEFINE RSTSWON       EXIN(102)=1           'Reset system
#DEFINE RSTSWOFF      EXIN(102)=0           'No reset
#DEFINE NOLATRNON     EXIN(103)=1           'NOLATRON ANTI TIE DOWN ACTIVE
#DEFINE NOLATRNOFF    EXIN(103)=0           'NOLATRON ANTI TIE DOWN INACTIVE
#DEFINE SMACFRNTON    EXIN(105)=1           'Laser scanhead in front pos
#DEFINE SMACFRNTOFF   EXIN(105)=0           'Laser scanhead not in front pos
#DEFINE SMACBCKON     EXIN(106)=1           'Laser scanhead in back pos
#DEFINE SMACBCKOFF    EXIN(106)=0           'Laser scanhead not in back pos
#DEFINE FIREBARON     EXIN(107)=1           'FIRING BAR SENSOR BLOCKED
#DEFINE FIREBAROFF    EXIN(107)=0           'FIRING BAR SENSOR UNBLOCKED
#DEFINE MONRDYON      EXIN(111)=1           'MONITOR SYSTEM READY
#DEFINE MONRDYOFF     EXIN(111)=0           'MONITOR SYSTEM NOT READY
#DEFINE SETON         EXIN(121)=1           'S M A C  IS SET IF ON
#DEFINE SETOFF        EXIN(121)=0           'S M A C IS NOT SET IF OFF
#DEFINE BSYON         EXIN(122)=1           'S M A C IS BUSY IF ON
#DEFINE BSYOFF        EXIN(122)=0           'S M A C IS NOT BUSY IF OFF
#DEFINE DATON         EXIN(123)=1           'S M A C DATA 1 = BAD
#DEFINE DATOFF        EXIN(123)=0           'S M A C DATA 0 = GOOD

#DEFINE DAV_ON        EXOUT(108)=1          'MONITOR DATA VALID CLOCK ACTIVE
#DEFINE DAV_OFF       EXOUT(108)=0          'MONITOR DATA VALID CLOCK INACTIVE
#DEFINE WLDOK_ON      EXOUT(109)=1          'MONITOR WELD OK 1 = GOOD PART
#DEFINE WLDOK_OFF     EXOUT(109)=0          'MONITOR WELD OK 0 = BAD PART
#DEFINE WLDBAD_ON     EXOUT(110)=1          'MONITOR WELD BAD 1 = BAD PART
#DEFINE WLDBAD_OFF    EXOUT(110)=0          'MONITOR WELD BAD 0 = GOOD PART
#DEFINE STOPLTON      EXOUT(112)=1          'STOP LIGHT ON
#DEFINE STOPLTOFF     EXOUT(112)=0          'STOP LIGHT OFF
#DEFINE SMCFRNBCKON   EXOUT(113)=1          'SOLENOID TO MOVE SMAC FRONT
```



```
#DEFINE SMCFRNBCKOFF  EXOUT(113)=0          'SOLENOID TO MOVE SMAC BACK
#DEFINE STRTLTON      EXOUT(114)=1          'START LIGHT ON
#DEFINE STRTLTOFF     EXOUT(114)=0          'START LIGHT OFF
#DEFINE RESETLTON     EXOUT(115)=1          'RESET LIGHT ON
#DEFINE RESETLTOFF    EXOUT(115)=0          'RESET LIGHT OFF
#DEFINE VACON         EXOUT(116)=1          'LEADFRAME VACUME ON
#DEFINE VACOFF        EXOUT(116)=0          'LEADFRAME VACUME OFF
#DEFINE RDYON         EXOUT(117)=1          'MX2000 TO SMAC READY BIT ON
#DEFINE RDYOFF        EXOUT(117)=0          'MX2000 TO SMAC READY BIT OFF
#DEFINE TRGON         EXOUT(118)=1          'TRIG BIT TO SMAC ON
#DEFINE TRGOFF        EXOUT(118)=0          'TRIG BIT TO SMAC OFF
#DEFINE MSV0ON        EXOUT(119)=1          'MODE SELECT BIT 0 ON
#DEFINE MSV0OFF       EXOUT(119)=0          'MODE SELECT BIT 0 OFF
#DEFINE MSV1ON        EXOUT(120)=1          'MODE SELECT BIT 1 ON
#DEFINE MSV1OFF       EXOUT(120)=0          'MODE SELECT BIT 1 OFF

PRINT#1,"INITIALIZATION COMPLETE"
WAIT=.5
GOSUB INI
DO
PRINT#1,"WAIT FOR SMAC SET BIT"
LOOP UNTIL SETON
GOTO MAIN

'*************************************************************************
'* * * * * * * * * * S U B - R O U T I N E S * * * * * * * * * * * * * *
'*************************************************************************
'  PROCESS : BEGIN MEASUREMENT MODE
'
BEGINMSR:
 MSV0OFF
 MSV1OFF
 TRGOFF
 IF EVENT1(1)=1 THEN                                    '
    GOSUB CHKSAFTIES                                    '
    MOVE(1)=DIST1                                       'MOVE LF TO 1 POS
   IF EVENT1(1)=0 AND CNT=0 THEN                        '
      GOSUB LDFRMHME                                    '
   END IF                                               '
 END IF                                                 '
BEGINMSR1:                                              '
 FOR X=1 TO LFPITCH STEP 1                              '
     GOSUB CHKSAFTIES                                   '
     MSV0OFF                                            '
     MSV1OFF                                            '
     TRGON                                              'TRIGGER SMAC MEASURE MODE
     DO                                                 '
     GOSUB HNDSHK                                       '
     LOOP UNTIL BSYON AND SETOFF                        'SMAC BUSY ACTIVE IN MEASURE MODE
     TRGOFF                                             '
     DO                                                 '
     GOSUB HNDSHK                                       'SMAC MEASURE DONE
     LOOP UNTIL BSYOFF AND SETON                        '
     MSV0OFF                                            '
     MSV1ON                                             '
     WAIT=.01                                           '
     TRGON                                              'TRIGGER SEND DATA MODE
     DO                                                 '
     GOSUB HNDSHK                                       '
     LOOP UNTIL BSYON AND SETOFF                        'SMAC SENDING DATA
     TRGOFF                                             '
     MSV1OFF                                            '
     WLDOK_OFF                                          '
     WLDBAD_OFF                                         '
     DAV_OFF                                            '
     IF BSYON AND DATON THEN                            'SMAC DATA POSTED, BAD WELD
        IF MONRDY AND FIREBARON THEN                    'SEND RESULTS TO MONITOR SUB SYSTEM
```

```
;*  TITLE: DELCO WELD MEASUREMENT PROGRAM (SMAC)
;*************************************************************
;*                    Filename : AXXXXXX.TXT
;*                  orig. design date : 08/27/98
;*              orig. designer    : Robert B. Rudy
;*             O R D E R     O F     C O N T E N T S
;*  Initialization or power up macro ( MD0 ) .............
;*  Macro's are listed sequentially ......................
;*
;* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
;                 I N I T I A L I Z A T I O N
;* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

;*************************************************************
;     Process : TURN MOTOR OFF RESET MACROS IN M.C. RAM
;             : INITIALIZATION OR POWER UP MACRO 0
MF
RM
MD0,CL0,CL1,CL2,CL3,CF0,CF1,CF2
MD1,MC220,MJ5

MD2,PH0,SG100,SI200,SD1800,IL5000,FR1,SV2700000,SA2480000,RC

;* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
;                  M A I N   P R O G R A M
;* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

;*************************************************************
;     Process: MAIN LOOP WAIT FOR TRG AND COMPLETE HNDSHK
;
MD5,IN0,CF0,NO                          ;IN0,ON SETOFF
MD6,IN1,NO,MJ15,WA25                    ;ANY TRIGGER LINES SET
MD7,IF0,CN0,NO                          ;INO OFF SETON
MD8,IN1,NO,MJ15,WA25,MJ5

MD10,EP

;*************************************************************
;     Process: TEST MODE SELECT LINES ACTIVE ?
;
MD15,IN2,NO,MJ16,IN3,NO,MJ30,MJ20
MD16,IN3,NO,MC220,MJ5


;*************************************************************
;     Process : MEASUREMENT ROUTINE MEASURES MAGNITUDE OF ERROR
;               IF ERROR GREATER THAN 2000 DAT BIT ACTIVE
;
MD20,CN1,AL0,AR20,PM,SV2700000,SA2480000,MA1000,GO,WS10
MD21,MC22,CF1,MC50,MJ5
MD22,PM,SV440000,SA248000,MA5000,GO,WS150,MC24       ;DOWN
MD23,PM,SV550000,SA225000,MA1000,GO,WS50,RC          ;UP
MD24,RW538,AR24,IG2000,NO,CN2,CF2,TR24,RC            ;ERR?

;*************************************************************
;     Process : POST DATA
;
MD30,MC50,CN1,AL0,AR24,TR24
MD31,IF3,NO,MJ32,TR24

,MJ31
MD32,CF1,CF2,MJ5
```





```
;*************************************************************
;     Process : IS TRIGGER INACTIVE ?
;
MD50,IF1,NO,RC,MG"TRIGG ACTIVE",MJ50                ;TRGR DONE

;*************************************************************
;     Process : ROUTINE HOMING MACRO AND PID INI.
;
MD220,CN1,AL0,AR3,AR4,AR10,AR11
MD221,PH0,SG100,SI750,SD1800,IL5000,FR1,SV2700000,SA2480000
MD222,VM,DI1,MN,GO,WA500
MD223,RW538,IB-1000,ST,MJ224,RP
MD224,PM,DH,MA100,GO,WS250,DH,GH,WS10,CF1,WA250,CN0,RC
```

# A.19.
# Prototype bill of material

# BILL OF MATERIAL

NOTES:

| ITEM | CKT. DES. | QTY | DRAWING TITLE / DESCRIPTION | PART NUMBER | MANUFACTURER |
|---|---|---|---|---|---|
| 1 | | 1 | LEADFRAME BLOCK | D-170495 | |
| 2 | | 2 | LOCATING PIN | A-170411 | |
| 3 | | 1 | SENSOR PLATE | C-170500 | |
| 4 | | 1 | COUPLING BRACKET | B-170502 | |
| 5 | | 1 | SLIDE TOP RAIL | C-170503 | |
| 6 | | 1 | SLIDE BOTTOM RAIL | C-170504 | |
| 7 | | 1 | SLIDE VERTICAL PLATE | D-170505 | |
| 8 | | 1 | TOPPLATE,LASER MEAS. PROTOTYPE | E-170511 | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | 2 | SLIDE HORIZONTAL PLATE | B-170515 | |
| 13 | | 4 | SLIDE GUSSET | B-170516 | |
| 14 | | 1 | SENSOR STOP BLOCK | B-170519 | |
| 15 | | 1 | STOP PLATE | B-170520 | |
| 16 | | 1 | CYLINDER VERTICAL PLATE | B-170522 | |
| 17 | | 1 | CYLINDER HORIZONTAL PLATE | B-170523 | |
| 18 | | 1 | CYLINDER GUSSET | B-170524 | |
| 19 | | 1 | COVER | C-170526 | |
| 20 | | | | | |
| 21 | | | | | |
| 22 | | 1 | SENSOR FLAG I | B-170536 | |
| 23 | | 2 | LIMIT SENSOR BRACKET | B-170537 | |
| 24 | | 1 | HOME SENSOR BRACKET | B-170538 | |
| 25 | | 1 | SENSOR FLAG II | B-170539 | |
| 26 | | 1 | COUPLING | CO78A-4 | |
| 27 | | 1 | FITING | 201A-8D | |
| 28 | | 1 | BUSHING 3/4 X 1/2 | 110A-ED | |
| 29 | | 1 | MOTOR | | |
| 30 | | 1 | REVERSE SENSOR BRACKET | B-170540 | |
| 31 | | 1 | VACUUM PUMP ANGLE | B-170542 | |
| 32 | | 1 | VACUUM PUMP PLATE | B-170543 | |

VISHAY SPRAGUE
EQUIPMENT ENGINEERING
RT 109 PO BOX 231
SANFORD, MAINE 04073

| ITEM | B.M. |
|---|---|
| 3 | E-170494 |

USED ON: ? LASER MEASUREMENT PROTOTYPE

TITLE: SLIDE ASSEMBLY

| REV | DESCRIPTION | BY | DATE |
|---|---|---|---|
| - | ORIG. APPROVAL | | |
| - | ORIG. DRAFTING | DHB | 06/08/98 |

| SHEET | MDL | DRAWING NUMBER | REV. |
|---|---|---|---|
| 1 OF 2 | 9806 | B.M. E-170547 | - |



| ITEM | CKT. DES. | QTY | DRAWING TITLE / DESCRIPTION | PART NUMBER | MANUFACTURER |
|---|---|---|---|---|---|
| 33 | | 1 | VACUUM PUMP GUSSET | B-170545 | |
| 34 | | 1 | LEADFRAME STOP-BACK | B-170548 | |
| 35 | | 1 | LEADFRAME STOP-FRONT | B-170549 | |
| 36 | | | | | |
| 37 | | | | | |
| 38 | | | | | |
| 39 | | | | | |
| 40 | | 1 | VACUUM PUMP | MLD50 | PIAB |
| 41 | | 1 | TWINSTAR LASER SENSOR | 15/3 | SCHAERVITZ |
| 42 | | 1 | AIR CYLINDER | CRS2U12X7/8-BB-I | PHD |
| 43 | | 1 | SLIDE | KR4620D+740L | THK |
| 44 | | 2 | BALL SLIDE W/"POSI-LOCK" | 201-X | DELTRON |
| 45 | | | | | |
| 46 | | 1 | TESTING FLAG I | C-170553 | |
| 47 | | 1 | FIBEROPTIC HOLDER | B-170554 | |
| 48 | | 1 | FIBEROPTIC BRACKET | B-170555 | |
| 49 | | 2 | STOP BRACKET | B-170568 | |
| 50 | | 1 | STOP PLATE | B-170569 | |
| 51 | | 1 | DC MOTOR ADOPTER | B-170572 | |
| 52 | | 1 | CYLINDER VERTICAL PLATE II | B-170573 | |
| 53 | | 1 | SENSOR FLAG III | B-170583 | |
| 54 | | 1 | TESTING FLAG | C-170587 | |
| 55 | | | | | |
| 56 | | 1 | DC MOTOR | 24A4BEPM-Z2/0157 | BODINE |
| 57 | | | | | |
| 58 | | 1 | SUBPLATE (KEYENS SENSOR) | C-170786 | |
| 59 | | | | | |
| 60 | | | | | |
| 61 | | | | | |
| 62 | | | | | |
| 63 | | | | | |
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| 75 | | | | | |

| TITLE: | SHEET | MDL | DRAWING NUMBER | REV. |
|---|---|---|---|---|
| SLIDE ASSEMBLY | 2 OF 2 | 9806 | B.M. E-170547 | - |

# A.20.
# Lab-PC-1200AI
# Specifications

# Specifications

Appendix A

This appendix lists the specifications for the 1200 Series boards. These specifications are typical at 25° C unless otherwise stated.

## Analog Input

### Input Characteristics

Number of channels ..... Eight single-ended, eight pseudodifferential or four differential, software selectable

Type of ADC ..... Successive approximation

Resolution ..... 12 bits, 1 in 4,096

Max sampling rate ..... 100 kS/s single channel

Input signal ranges .....

| Board Gain (Software-Selectable) | Board Range (Software-Selectable) | |
|---|---|---|
| | ±5 V | 0 to 10 V |
| 1 | ±5 V | 0 to 10 V |
| 2 | ±2.5 V | 0 to 5 V |
| 5 | ±1 V | 0 to 2 V |
| 10 | ±500 mV | 0 to 1 V |
| 20 | ±250 mV | 0 to 500 mV |
| 50 | ±100 mV | 0 to 200 mV |
| 100 | ±50 mV | 0 to 100 mV |

Input coupling ..... DC

Max working voltage
(signal + common mode) ..... In differential or NRSE mode, the negative input /AISENSE should remain within ±5 V (bipolar input range) or -5 to +2 V (unipolar input range) of AGND. The positive input should remain within -5 V to +10 V of AGND.

Overvoltage protection ..... ±35 V powered on, ±25 V powered off

Inputs protected ..... ACH<0..7>

FIFO buffer size ..... 512 S

Data transfers ..... DMA, interrupts, programmed I/O

Dither ..... Available

### Transfer Characteristics

Relative accuracy ..... ±0.5 LSB typ dithered, ±1.5 LSB max undithered

DNL ..... ±1 LSB max

No missing codes ..... 12 bits, guaranteed

Offset error

Pregain error after calibration ..... 10 µV max

Pregain error before calibration... ±20 mV max

Postgain error after calibration.... 1 mV max

Postgain error before calibration . ±200 mV max

Gain error (relative to calibration reference)

After calibration ..... 0.02% of reading max

Before calibration ..... ±2% of reading max

Gain ≠ 1 with gain error adjusted to 0 at gain = 1 ..... ±0.8% of reading max

### Amplifier Characteristics

Input impedance

Normal powered on ..... 100 GΩ in parallel with 50 pF

Powered off ..... 4.7 kΩ min

Overload ..... 4.7 kΩ min

Input bias current ..... ±100 pA

Input offset current ..... ±100 pA

CMRR ..... 70 dB, DC to 60 Hz

## Stability

Offset temperature coefficient ..... ±50 µV/°C

Gain temperature coefficient ..... ±30 ppm/°C

## Explanation of Analog Output Specifications

- Lab-PC-1200

  *Relative accuracy* in a D/A system is the same as nonlinearity because no uncertainty is added due to code width. Unlike an ADC, every digital code in a D/A system represents a specific analog value rather than a range of values. The relative accuracy of the system is therefore limited to the worst-case deviation from the ideal correspondence (a straight line), except noise. If a D/A system has been calibrated perfectly, the relative accuracy specification reflects its worst-case absolute error.

  DNL in a D/A system is a measure of deviation of code width from 1 LSB. In this case, code width is the difference between the analog values produced by consecutive digital codes. A specification of ±1 LSB differential nonlinearity ensures that the code width is always greater than 0 LSBs (guaranteeing monotonicity) and is always less than 2 LSBs.

## Digital I/O

Number of channels ..... 24 I/O (three 8-bit ports; uses the 82C55A PPI

Compatibility ..... TTL

Digital logic levels .....

| Level | Min | Max |
|---|---|---|
| Input low voltage | -0.3 V | 0.8 V |
| Input high voltage | 2.2 V | 5.3 V |
| Output low voltage | — | — |
| ($I_{OUT}$ = 2.5 mA) | — | 0.4 V |
| Output high voltage | — | — |
| ($I_{OUT}$ = -40 µA) | 4.2 V | — |
| ($I_{OUT}$ = -2.5 mA) | 3.7 V | — |

Power-on state ..... All ports mode 0 input





Protection ..... -0.5 V to 5.5 V powered on, ±0.5 V powered off

Data transfers ..... Interrupts, programmed I/O

## Timing I/O

Number of channels ..... 3 counter/timers

Protection ..... -0.5 V to 5.5 V powered on, ±0.5 V powered off

Resolution

Counter/timers ..... 16 bits

Compatibility ..... TTL

Base clock available ..... 2 MHz

Base clock accuracy ..... ±50 ppm max

Max source frequency ..... 8 MHz

Min source pulse duration ..... 125 ns

Min gate pulse duration ..... 100 µs

Digital logic levels .....

| Level | Min | Max |
|---|---|---|
| Input low voltage | -0.3 V | 0.8 V |
| Input high voltage | 2.2 V | 5.3 V |
| Output low voltage | — | — |
| ($I_{OUT}$ = 2.1 mA) | — | 0.45 V |
| Output high voltage | — | — |
| ($I_{OUT}$ = 0.92 mA) | 3.7 V | — |

Protection ..... -0.5 to 5.5 V powered on, ±0.5 V powered off

Data transfer ..... Interrupts, programmed I/O

## Digital Trigger

Compatibility ..... TTL

Response ..... Rising edge

Pulse width ..... 50 ns min

# A.21.
# Lead-frame profile generation module

| | | - | + | range | |
|---|---|---|---|---|---|
| number of values/unit | 112 | | | | |
| values of unit | 50 | 2 | 2 | 10 | |
| values of hole | 14 | 1 | 1 | 6 | |
| values of tie bar | 34 | 2 | 2 | 8 | |
| values of bad weld | 12 | | | | |
| values of good weld | 24 | | | | |
| | | | | 0.3 | 2.290142 |
| number of units | 76 | | | | |
| total number of values | 8512 | | | | |
| sensitivity | 130.99625 | V/in. | | | |
| | 0.1309962 | V/(th.in.) | | 10E-3 inch | 0.0254 mm |
| base height | -0.0045 | 0.0001 | 0.0001 | 0.0002 | |
| base variation | 0 | 0.0003 | 0.0003 | 0.0006 | |
| tie-bar height | 0 | 0.0005 | 0.0005 | 0.001 | |
| tie-bar variation | 0 | 0.0003 | 0.0003 | 0.0006 | |
| **bad weld base surface** | | | | | |
| av. Height | 0 | 0.0005 | 0.0005 | 0.001 | |
| surface variation | 0 | 0.0003 | 0.0003 | 0.0006 | |
| **bad weld wire** | | | | | |
| delta | 0.006 | 0.0015 | 0.0015 | 0.003 | |
| values up | 4 | 1 | 1 | 2 | |
| values down | 4 | 1 | 1 | 2 | |
| values top | 3 | 1 | 1 | 2 | |
| top variation | 0 | 0.0005 | 0.0005 | 0.001 | |
| variation up | 0 | 0.0005 | 0.0005 | 0.001 | |
| variation down | 0 | 0.0005 | 0.0005 | 0.001 | |
| **good weld surface** | | | | | |
| av. Height | 0.001 | 0.0005 | 0.0005 | 0.001 | |
| 1st peak | 0.0004 | 0.0001 | 0.0001 | 0.0002 | |
| 1st bottom | -0.0002 | 0.0001 | 0.0001 | 0.0002 | |
| 2nd bottom | -0.0002 | 0.0001 | 0.0001 | 0.0002 | |
| 2nd peak | 0.0004 | 0.0001 | 0.0001 | 0.0002 | |
| **good weld wire** | | | | | |
| delta | 0.003 | 0.001 | 0.001 | 0.002 | |
| values up | 8 | 1 | 1 | 4 | |
| values down | 8 | 1 | 1 | 4 | |
| values top | 8 | 1 | 1 | 4 | |
| top variation | 0 | 0.001 | 0.001 | 0.002 | |
| variation up | 0 | 0.0005 | 0.0005 | 0.001 | |
| variation down | 0 | 0.0005 | 0.0005 | 0.001 | |
| **position of wire** | | | | | |
| 80% | 20% | | | | |
| 10% | 60% | | | | |
| 5% | 15% | | | | |
| 5% | 5% | | | | |

Module1 - 1

```
Sub sample_generation()

    Randomize

    i = 0
    v = 1


    holeheight = Worksheets("data").Range("e15")
    holeheight = holeheight - Worksheets("data").Range("f15") + Rnd() * Worksheets("data").Range
("h15")

    For k = 1 To 100

        vari = -Worksheets("data").Range("f16") + Rnd() * Worksheets("data").Range("h16")
        y = (holeheight + vari)
        Worksheets("sheet2").Cells(v, 1) = y
        v = v + 1

    Next k

    While i < 76

        newunit = Rnd()
        If newunit < 0.05 Then
            u = 0
        Else
            If newunit < 0.3 Then
                u = 1
            Else
                u = 2
            End If
        End If

        'u = InputBox("0 - no ... 1 - bad ... 2 - good")




        'TIE-BAR

        'number of values for tie-bar
        ntie = Worksheets("data").Range("e5") - Worksheets("data").Range("f5") + Int(Rnd() * Wor
ksheets("data").Range("h5") + 0.5)

        'tie-bar average height
        tieheight = Worksheets("data").Range("e17") - Worksheets("data").Range("f17") + Rnd() *
Worksheets("data").Range("h17")
        y = tieheight

        For k = 1 To ntie

            vari = -Worksheets("data").Range("f18") + Rnd() * Worksheets("data").Range("h18")
            y = (tieheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            v = v + 1

        Next k


        '1ST HOLE

        nhole = Worksheets("data").Range("e4") - Worksheets("data").Range("f4") + Int(Rnd() * Wo
rksheets("data").Range("h4") + 0.5)

        'hole average height
        holeheight = Worksheets("data").Range("e15")
        holeheight = holeheight - Worksheets("data").Range("f15") + Rnd() * Worksheets("data").R
ange("h15")

        For k = 1 To nhole
```

Module1 - 2

```
            vari = -Worksheets("data").Range("f16") + Rnd() * Worksheets("data").Range("h16")
            y = (holeheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            v = v + 1

        Next k


        'UNIT

        'No unit
        'u = 0
        If u = 0 Then
            'number of values for no-unit
            nnu = Worksheets("data").Range("e3") - Worksheets("data").Range("f3") + Int(Rnd()
Worksheets("data").Range("h3") + 0.5)

            'no-unit average height
            nuheight = Worksheets("data").Range("e17")
            nuheight = nuheight - Worksheets("data").Range("f17") + Rnd() * Worksheets("data"
ange("h17")

            For k = 1 To nnu

                vari = -Worksheets("data").Range("f18") + Rnd() * Worksheets("data").Range("h
)
                y = (nuheight + vari)
                Worksheets("sheet2").Cells(v, 1) = y
                v = v + 1

            Next k

        End If



        'Bad unit
        'u = 1
        If u = 1 Then
            'number of values for bad unit
            nbu = Worksheets("data").Range("e3") - Worksheets("data").Range("f3") + Int(Rnd()
Worksheets("data").Range("h3") + 0.5)

            'bad-unit average height
            buheight = Worksheets("data").Range("e20") - Worksheets("data").Range("f20") + Rnd
* Worksheets("data").Range("h20")

            'wire values
            vu = Worksheets("data").Range("e24") - Worksheets("data").Range("f24") + Int(Rnd()
Worksheets("data").Range("h24") + 0.5)
            vd = Worksheets("data").Range("e25") - Worksheets("data").Range("f25") + Int(Rnd()
Worksheets("data").Range("h25") + 0.5)
            vt = Worksheets("data").Range("e26") - Worksheets("data").Range("f26") + Int(Rnd()
Worksheets("data").Range("h26") + 0.5)
            nwire = vu + vd + vt
            nrange = nbu - nwire


            'wire position
            p = Rnd()
            If p >= 0.1 And p < 0.9 Then
                begin = Int((0.4 + 0.2 * (p - 0.1) / 0.8) * nrange)
            Else
                If p >= 0.05 And p < 0.1 Then
                    begin = Int((0.1 + 0.3 * (p - 0.05) / 0.05) * nrange)
                Else
                    If p >= 0.9 And p < 0.95 Then
                        begin = Int((0.6 + 0.3 * (p - 0.9) / 0.05) * nrange)
                    Else
                        If p >= 0.025 And p < 0.05 Then
                            begin = Int((0.025 + 0.075 * (p - 0.025) / 0.025) * nrange)
                        Else
```

Module1 - 3

```
                        If p >= 0.95 And p < 0.975 Then
                            begin = Int((0.9 + 0.075 * (p - 0.95) / 0.025) * nrange)
                        Else
                            If p >= 0 And p < 0.025 Then
                                begin = Int((0 + 0.025 * (p - 0) / 0.025) * nrange)
                            Else
                                begin = Int((0.975 + 0.025 * (p - 0.975) / 0.025) * nrange)
                            End If
                        End If
                    End If
                End If
            End If

            'delta
            delta = Worksheets("data").Range("e23") - Worksheets("data").Range("f23") + Rnd() *
Worksheets("data").Range("h23")



            For k = 1 To begin - 1

                vari = -Worksheets("data").Range("f21") + Rnd() * Worksheets("data").Range("h21"
)
                y = (buheight + vari)
                Worksheets("sheet2").Cells(v, 1) = y
                v = v + 1

            Next k

            du = delta / (vu + 1)
            buheight = buheight + du

            For k = 1 To vu

                vari = -Worksheets("data").Range("f28") + Rnd() * Worksheets("data").Range("h28"
)
                y = (buheight + vari)
                Worksheets("sheet2").Cells(v, 1) = y
                buheight = buheight + du
                v = v + 1

            Next k

            For k = 1 To vt

                vari = -Worksheets("data").Range("f27") + Rnd() * Worksheets("data").Range("h27"
)
                y = (buheight + vari)
                Worksheets("sheet2").Cells(v, 1) = y
                v = v + 1

            Next k

            dd = delta / (vd + 1)
            buheight = buheight - dd

            For k = 1 To vd

                vari = -Worksheets("data").Range("f29") + Rnd() * Worksheets("data").Range("h29"
)
                y = (buheight + vari)
                Worksheets("sheet2").Cells(v, 1) = y
                buheight = buheight - dd
                v = v + 1

            Next k

            For k = 1 To nbu - begin - nwire

                vari = -Worksheets("data").Range("f21") + Rnd() * Worksheets("data").Range("h21"
)
                y = (buheight + vari)
```

Module1 - 4

```
                Worksheets("sheet2").Cells(v, 1) = y
                v = v + 1

            Next k

        End If


        'Good unit
        'u = 2
        If u = 2 Then
            'number of values for good unit
            ngu = Worksheets("data").Range("e3") - Worksheets("data").Range("f3") + Int(Rnd()
Worksheets("data").Range("h3") + 0.5)

            'good-unit average height
            guheight = Worksheets("data").Range("e31") - Worksheets("data").Range("f31") + Rn
 * Worksheets("data").Range("h31")

            'good-unit 1st peak deviation (rel. to av. height)
            gupeak1 = Worksheets("data").Range("e32") - Worksheets("data").Range("f32") + Rnd
* Worksheets("data").Range("h32")

            'good-unit 1st bottom deviation (rel. to av. height)
            gubottom1 = Worksheets("data").Range("e33") - Worksheets("data").Range("f33") + R
) * Worksheets("data").Range("h33")

            'good-unit 2nd peak deviation (rel. to av. height)
            gupeak2 = Worksheets("data").Range("e35") - Worksheets("data").Range("f35") + Rnd
* Worksheets("data").Range("h35")

            'good-unit 2nd bottom deviation (rel. to av. height)
            gubottom2 = Worksheets("data").Range("e34") - Worksheets("data").Range("f34") + R
) * Worksheets("data").Range("h34")

            'wire values
            vu = Worksheets("data").Range("e38") - Worksheets("data").Range("f38") + Int(Rnd(
 Worksheets("data").Range("h38") + 0.5)
            vd = Worksheets("data").Range("e39") - Worksheets("data").Range("f39") + Int(Rnd(
 Worksheets("data").Range("h39") + 0.5)
            vt = Worksheets("data").Range("e40") - Worksheets("data").Range("f40") + Int(Rnd(
 Worksheets("data").Range("h40") + 0.5)
            nwire = vu + vd + vt
            nrange = ngu - nwire


            'wire position
            p = Rnd()
            If p >= 0.1 And p < 0.9 Then
                begin = Int((0.4 + 0.2 * (p - 0.1) / 0.8) * nrange)
            Else
                If p >= 0.05 And p < 0.1 Then
                    begin = Int((0.1 + 0.3 * (p - 0.05) / 0.05) * nrange)
                Else
                    If p >= 0.9 And p < 0.95 Then
                        begin = Int((0.6 + 0.3 * (p - 0.9) / 0.05) * nrange)
                    Else
                        If p >= 0.025 And p < 0.05 Then
                            begin = Int((0.025 + 0.075 * (p - 0.025) / 0.025) * nrange)
                        Else
                            If p >= 0.95 And p < 0.975 Then
                                begin = Int((0.9 + 0.075 * (p - 0.95) / 0.025) * nrange)
                            Else
                                If p >= 0 And p < 0.025 Then
                                    begin = Int((0 + 0.025 * (p - 0) / 0.025) * nrange)
                                Else
                                    begin = Int((0.975 + 0.025 * (p - 0.975) / 0.025) * nrange
                                End If
                            End If
                        End If
                    End If
                End If
            End If
```

Module1 - 6

```
            y = (guheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            guheight = guheight + dbp
            v = v + 1

        Next k


    End If




    '2ND HOLE

    nhole = Worksheets("data").Range("e4") - Worksheets("data").Range("f4") + Int(Rnd() * Wo
rksheets("data").Range("h4") + 0.5)

    'hole average height
    holeheight = Worksheets("data").Range("e15")
    holeheight = holeheight - Worksheets("data").Range("f15") + Rnd() * Worksheets("data").R
ange("h15")

    For k = 1 To nhole

        vari = -Worksheets("data").Range("f16") + Rnd() * Worksheets("data").Range("h16")
        y = (holeheight + vari)
        Worksheets("sheet2").Cells(v, 1) = y
        v = v + 1

    Next k

    i = i + 1

Wend

holeheight = Worksheets("data").Range("e15")
holeheight = holeheight - Worksheets("data").Range("f15") + Rnd() * Worksheets("data").Range
("h15")

For k = 1 To 100

    vari = -Worksheets("data").Range("f16") + Rnd() * Worksheets("data").Range("h16")
    y = (holeheight + vari)
    Worksheets("sheet2").Cells(v, 1) = y
    v = v + 1

Next k



End Sub
```

Module1 - 5

```
        'delta
        delta = Worksheets("data").Range("e37") - Worksheets("data").Range("f37") + Rnd()
Worksheets("data").Range("h37")

        dpb = (gupeak1 - gubottom1) / (begin + 1)
        guheight = guheight + gupeak1

        For k = 1 To begin - 1

            vari = -Worksheets("data").Range("f21") + Rnd() * Worksheets("data").Range("h
)
            y = (guheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            guheight = guheight - dpb
            v = v + 1

        Next k

        'good-unit average height
        guheight = Worksheets("data").Range("e31") - Worksheets("data").Range("f31") + Rn
 * Worksheets("data").Range("h31")

        du = delta / (vu + 1)
        guheight = guheight + du

        For k = 1 To vu

            vari = -Worksheets("data").Range("f28") + Rnd() * Worksheets("data").Range("h
)
            y = (guheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            guheight = guheight + du
            v = v + 1

        Next k

        For k = 1 To vt

            vari = -Worksheets("data").Range("f27") + Rnd() * Worksheets("data").Range("h
)
            y = (guheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            v = v + 1

        Next k

        dd = delta / (vd + 1)
        guheight = guheight - dd

        For k = 1 To vd

            vari = -Worksheets("data").Range("f29") + Rnd() * Worksheets("data").Range("h
)
            y = (guheight + vari)
            Worksheets("sheet2").Cells(v, 1) = y
            guheight = guheight - dd
            v = v + 1

        Next k

        'good-unit average height
        guheight = Worksheets("data").Range("e31") - Worksheets("data").Range("f31") + Rn
 * Worksheets("data").Range("h31")

        dbp = (gupeak2 - gubottom2) / (ngu - begin - nwire)
        guheight = guheight + gubottom2

        For k = 1 To ngu - begin - nwire

            vari = -Worksheets("data").Range("f21") + Rnd() * Worksheets("data").Range("h
)
```

# A.22.
# First version of the Algorithm

Module1 - 1

```
Sub algor()

    Dim p(1 To 25000) As Single
    Dim v(1 To 25000) As Single
    Dim d(1 To 25000) As Single
    Dim h(1 To 80) As Single


    For i = 1 To 20950
        v(i) = Worksheets("sheet1").Cells(i, 1)
    Next i

    MsgBox "ready"

    For i = 1 To 20956
        d(i) = Abs(v(i + 1) - v(i))
    Next i


    f1 = 0
    f2 = 0
    f3 = 0


    For i = 13 To 20956 - 12

        s = 0
        For j = i - 12 To i + 12
            s = s + d(j)
        Next j
        sdma = s / 25

        If f1 = 0 Then
            If sdma < 0.12 Then
                p(i - 12) = v(i)
            Else
                f1 = 1
                p(i - 12) = -5
            End If
        Else
            p(i - 12) = -5
            If f2 = 0 Then
                If sdma < 0.12 Then
                    f2 = 1
                End If
            Else
                If f3 = 0 Then
                    If sdma >= 0.12 Then
                        f3 = 1
                    End If
                Else
                    If sdma < 0.12 Then
                        f1 = 0
                        f2 = 0
                        f3 = 0
                    End If
                End If
            End If
        End If

    Next i

    MsgBox "finished"

    For i = 1 To 20950 - 25
        Worksheets("sheet2").Cells(i, 1) = p(i)
    Next i

    MsgBox "start heights"
    'heights

    u = 0
```

Module1 - 2

```
    i = 1

    While p(i) > -5
        i = i + 1
    Wend

    While u < 76

        While p(i) = -5
            i = i + 1
        Wend

        u = u + 1

        edge1 = p(i)
        pos1 = i

        i = i + 1

        While p(i) <> -5
            i = i + 1
        Wend

        edge2 = p(i - 1)
        pos2 = i - 1

        n = pos2 - pos1 + 1

        wh = -9999

        For j = pos1 To pos2
            y = edge1 + (edge2 - edge1) * (j - pos1 + 1) / (pos2 - pos1 + 1)
            dif = p(j) - y
            If dif > wh Then
                wh = dif
            End If
        Next j

        h(u) = wh


    Wend

    MsgBox "heights"


    For u = 1 To 80
        Worksheets("sheet2").Cells(u, 2) = h(u)
    Next u



End Sub
```

# A.23.
# NI-DAQ Functions

# DAQ_Check

## Format

**status = DAQ_Check (deviceNumber, daqStopped, retrieved)**

## Purpose

Checks whether the current DAQ operation is complete and returns the status and the number of samples acquired to that point.

## Parameters

### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |

### Output

| Name | Type | Description |
|---|---|---|
| **daqStopped** | i16 | indication of whether the data acquisition has completed |
| **retrieved** | u32 | progress of an acquisition |

## Parameter Discussion

**daqStopped** returns an indication of whether the data acquisition has completed.

0: The DAQ operation is not yet complete.

1: The DAQ operation has stopped. Either the buffer is full, or an error has occurred.

**retrieved** indicates the progress of an acquisition. The meaning of **retrieved** depends on whether pretrigger mode has been enabled (see `DAQ_StopTrigger_Config`). If pretrigger mode is disabled, **retrieved** returns the number of samples collected by the acquisition at the time of the call to `DAQ_Check`. The value of **retrieved** increases until it equals the **count** indicated in the call that initiated the acquisition, at which time the acquisition terminates. However, if pretrigger mode is enabled, **retrieved** returns the offset of the position in your buffer where the next data point is placed when it is acquired. When the value of **retrieved** reaches **count**-1 and rolls over to 0, the acquisition begins to overwrite old data with new data. When NI-DAQ applies a signal to the stop trigger input, the acquisition collects an additional number of samples indicated by **ptsAfterStoptrig** in the call to `DAQ_StopTrigger_Config` and then terminates. When `DAQ_Check` returns a status of 1, **retrieved** contains the offset of the oldest data point in the array (assuming that the acquisition has written to the entire buffer at least once). In pretrigger mode, `DAQ_Check`





# DAQ_Rate

## Format

**status = DAQ_Rate (rate, units, timebase, sampleInterval)**

## Purpose

Converts a DAQ rate into the timebase and sample-interval values needed to produce the rate you want.

## Parameters

### Input

| Name | Type | Description |
|---|---|---|
| **rate** | f64 | desired DAQ rate |
| **units** | i16 | pts/s or s/pt (see `CTR_Rate`) |

### Output

| Name | Type | Description |
|---|---|---|
| **timebase** | i16 | onboard source signal used |
| **sampleInterval** | u16 | number of timebase units that elapse between consecutive A/D conversions |

## Parameter Discussion

**rate** is the DAQ rate you want. The units in which **rate** is expressed are either points per second (pts/s) or seconds per point (s/pt), depending on the value of the **units** parameter.

Range: Roughly 0.00153 pts/s through 5,000,000 pts/s or 655 s/pt through 0.000001 s/pt.

**units** indicates the units used to express **rate**.

0: pts/s.

1: s/pt.

**timebase** is a code representing the resolution of the onboard clock signal that the device uses to produce the acquisition rate you want. You can input the value returned by **timebase** po directly to n[illegible] 20 MHz clock used as the timebase (50 ns) (E Series only) has the fo[illegible]

−1: 200 ns (AT-MIO-16F-5, AT-MIO-64F-5, AT-MIO-16X and E Series devices only).

# DAQ_Start

## Format

**status = DAQ_Start (deviceNumber, chan, gain, buffer, count, timebase, sampInterval)**

## Purpose

Initiates an asynchronous, single-channel DAQ operation and stores its input in an array.

### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |
| **chan** | i16 | analog input channel number |
| **gain** | i16 | gain setting |
| **count** | u32 | number of samples to be acquired |
| **timebase** | i16 | timebase value |
| **sampInterval** | u16 | sample interval |

### Output

| Name | Type | Description |
|---|---|---|
| **buffer** | [i16] | used to hold acquired readings |

## Parameter Discussion

**chan** is the analog input channel number. If you are using SCXI, you must use the appropriate analog input channel on the DAQ device that corresponds to the SCXI channel you want. Select the SCXI channel using `SCXI_Single_Chan_Setup` before calling this function. Refer to the *NI-DAQ User Manual for PC Compatibles* for more information on SCXI channel assignments.

Range: See Table B-1 in Appendix B, *Analog Input Channel, Gain Settings, and Voltage Calculation*.

**gain** is the gain setting to be used for that channel. This gain setting applies only to the DAQ device; if you are using SCXI, you must establish any gain you want at the SCXI module either by setting jumpers on the module or by calling `SCXI_Set_Gain`. Refer to Appendix B, *Analog Input Channel, Gain Settings, and Voltage Calculation*, for valid gain settings. If you use invalid gain settings, NI-DAQ returns an error. NI-DAQ ignores **gain** for the 516 and LPM devices and DAQCard-500/700.





# DAQ_StopTrigger_Config

## Format

**status = DAQ_StopTrigger_Config (deviceNumber, stopTrig, ptsAfterStoptrig)**

## Purpose

Enables the pretrigger mode of data acquisition and indicates the number of data points to acquire after NI-DAQ applies the stop trigger pulse at the STOPTRIG* input of the MIO-16/16D; the EXTTRIG* input of an AT-MIO-16F-5, AT-MIO-64F-5, or AT-MIO-16X or the EXTTRIG input of Lab and 1200 Series devices; or the PFI1 pin. Refer to the PFI1 pin of an E Series device. If you are using an E Series device, see the `Select_Signal` description for information about the external timing signals.

## Parameters

### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |
| **stopTrig** | i16 | enable or disable the pretriggered mode |
| **ptsAfterStoptrig** | u32 | number of points to acquire after the trigger |

## Parameter Discussion

**stopTrig** indicates whether to enable or disable the pretriggered mode of data acquisition.

0: Disable pretrigger (the default).
1: Enable pretrigger.

**ptsAfterStoptrig** is the number of data points to acquire after the trigger. This parameter is valid only if **stopTrig** equals 1. For a multiple channel scanned acquisition, **ptsAfterStoptrig** must be an integer multiple of the number of channels scanned.

Range: 3 through *count*, where *count* is the value of the **count** parameter in the Start call used to start the acquisition. For Lab and 1200 Series devices, the maximum is always 65,535. For an E Series device or DSA device, the range is 2 through **count**.

## Using This Function

Calling `DAQ_StopTrigger_Config` with the **stopTrig** parameter set to 1 causes any subsequent Start call to initiate a cyclical mode data acquisition. In this mode, NI-DAQ writes data continually into your buffer, overwriting data at the beginning of the buffer when NI-DAQ has filled the entire buffer. You can use `DAQ_Check` or `Lab_ISCAN_Check` in this situation to determine where NI-DAQ is currently depositing data in the buffer. When you

## DAQ_VScale

### Format

**status = DAQ_VScale (deviceNumber, chan, gain, gainAdjust, offset, count, binArray, voltArray)**

### Purpose

Converts the values of an array of acquired binary data and the gain setting for that data to actual input voltages measured.

### Parameters

#### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |
| **chan** | i16 | channel on which binary reading was taken |
| **gain** | i16 | gain setting |
| **gainAdjust** | f64 | multiplying factor to adjust gain |
| **offset** | f64 | binary offset present in reading |
| **count** | u32 | length of **binArray** and **voltArray** |
| **binArray** | [i16] | acquired binary data |

#### Output

| Name | Type | Description |
|---|---|---|
| **voltArray** | [f64] | double-precision values returned |

### Parameter Discussion

**chan** is the onboard channel or AMUX channel on which the binary data was acquired. For devices other than AT-MIO-16X, AT-MIO-64F-5, and E Series devices and DSA devices, this parameter is ignored because the scaling calculation is the same for all of the channels. However, you are encouraged to pass the correct channel number.

**gain** is the gain setting at which NI-DAQ acquired the data in **binArray**. If you used SCXI to take the reading, this gain parameter should be the product of the gain on the SCXI module channel and the gain used by the DAQ device.





## DIG_In_Line

### Format

**status = DIG_In_Line (deviceNumber, port, line, state)**

### Purpose

Returns the digital logic state of the specified digital line in the specified port.

### Parameters

#### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |
| **port** | i16 | digital I/O port number |
| **line** | i16 | digital line to be read |

#### Output

| Name | Type | Description |
|---|---|---|
| **state** | i16 | returns the digital logic state |

### Parameter Discussion

**port** is the digital I/O port number.

Range: 0 or 1 for the AT-AO-6/10, DAQCard-500/700, PC-TIO-10, PC-OPDIO-16, AO-2DC, Am9513-based, 516 and LPM devices.
0 for the E Series devices, except the AT-MIO-16DE-10.
0 through 2 for the DIO-24 and Lab and 1200 Series devices.
0 and 2 through 4 for the AT-MIO-16DE-10.
0 through 3 for the VXI-AO-48XDC.
0 through 4 for the DIO-32F, DIO 6533 (DIO-32HS), and AT-MIO-16D.
0 through 11 for the DIO-96.
0 through 15 for the VXI-DIO-128.
0 for the PCI-4451 and PCI-4452.
0 through 3 for the PCI-4551 and PCI-4552.

**line** is the digital line to be read.

Range:0 through *k*-1, where *k* is the number of digital I/O lines making up the port.

# DIG_Prt_Config

## Format

**status = DIG_Prt_Config (deviceNumber, port, mode, dir)**

## Purpose

Configures the specified port for direction (input or output). `DIG_Prt_Config` also sets the handshake mode for the DIO-24, AT-MIO-16D, AT-MIO-16DE-10, DIO-96, and Lab and 1200 Series devices.

## Parameters

### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |
| **port** | i16 | digital I/O port number |
| **mode** | i16 | handshake mode |
| **dir** | i16 | direction, input, or output |

## Parameter Discussion

**port** is the digital I/O port number.

Range: 0 or 1 for the AT-AO-6/10, DAQCard-500/700, PC-TIO-10, PC-OPDIO-16, 516 devices, AO-2DC, Am9513-based MIO devices, and LPM devices.
0 for the E Series devices, except the AT-MIO-16DE-10.
0 through 2 for the DIO-24 and Lab and 1200 Series devices.
0 through 3 for the DIO-32F and DIO 6533 (DIO-32HS).
0 and 2 through 4 for the AT-MIO-16DE-10.
0 through 3 for the VXI-AO-48XDC.
0 through 4 for the AT-MIO-16D.
0 through 11 for the DIO-96.
0 through 15 for the VXI-DIO-128.
0 for the PCI-4451 and PCI-4452.
0 through 3 for the PCI-4551 and PCI-4552.

**mode** indicates the handshake mode that the port uses.

0: Port is configured for no-handshaking (nonlatched) mode. You must use **mode** = 0 for all other ports and boards. You can use the DIO-32F and DIO 6533 (DIO-32HS) for handshaking, but only through the group calls (see `DIG_Grp_Config`).





# Init_DA_Brds

## Format

**status = Init_DA_Brds (deviceNumber, deviceNumberCode)**

## Purpose

Initializes the hardware and software states of a National Instruments DAQ device to its default state, and then returns a numeric device code that corresponds to the type of device initialized. Any operation that the device is performing is halted. This function is called automatically and does not have to be explicitly called by your application. This function is useful for reinitializing the device hardware, for reinitializing the NI-DAQ software, and for determining which device has been assigned to a particular slot number. `Init_DA_Brds` will clear all configured messages for the device just as if you called `Config_DAQ_Event_Message` with a mode of 0.

## Parameters

### Input

| Name | Type | Description |
|---|---|---|
| **deviceNumber** | i16 | assigned by configuration utility |

### Output

| Name | Type | Description |
|---|---|---|
| **deviceNumberCode** | i16 | type of device |

## Parameter Discussion

**deviceNumberCode** indicates the type of device initialized.

−1: Not a National Instruments DAQ device.
0: AT-MIO-16L-9.
1: AT-MIO-16L-15.
2: AT-MIO-16L-25.
4: AT-MIO-16H-9.
5: AT-MIO-16H-15.
6: AT-MIO-16H-25.
7: PC-DIO-24.
8: AT-DIO-32F.
11: AT-MIO-16F-5.
12: PC-DIO-96.
13: PC-LPM-16.

# A.24.
# Sub-routines of the Application

Form1 - 1

```
Dim stopped As Integer
Dim retrieved As Long
Dim retrieved1, retrieved2 As Long
Dim binarray(60000) As Integer
Dim voltarray1(60000) As Double
Dim voltarray2(60000) As Double
Dim param1(1 To 80) As Single
Dim param2(1 To 80) As Single



Sub algor()

    'SIDE 1

    u = 0
    i = 1

    While u < 76 And i < retrieved1

        'skip-tie-bar

        While voltarray1(i) < 0.3
            i = i + 1
        Wend

        While voltarray1(i) > 0.3
            i = i + 1
        Wend

        'approach unit region

        While voltarray1(i) < 0.3
            i = i + 1
        Wend

        ustart = i
        u = u + 1

        'search unit

        s = 0
        maxv = -999

        While voltarray1(i) > 0.3
            s = s + voltarray1(i)
            If voltarray1(i) > maxv Then
                maxv = voltarray1(i)
            End If
            i = i + 1
        Wend

        uend = i - 1

        av = s / (uend - ustart + 1)
        h = maxv - av                          'HEIGHT


        j = ustart
        While Abs(voltarray1(j + 1) - voltarray1(j)) > 0.02
            j = j + 1
        Wend
        slstart = j

        j = uend - 1
        While Abs(voltarray1(j + 1) - voltarray1(j)) > 0.02
            j = j - 1
        Wend
        slend = j + 1
```

Form1 - 2

```
        slmax = -999
        For j = slstart To slend
            dif = Abs(voltarray1(j + 1) - voltarray1(j))
            If dif > slmax Then
                slmax = dif
            End If
        Next j                                 'MAX SLOPE

        c = 0
        For j = ustart To uend
            If voltarray1(j) > av Then
                c = c + 1
            End If
        Next j

        p = c / (uend - ustart + 1)            '% POINTS ABOVE LINE

        param1(u) = h * slmax / p

    Wend

    '_____________________________________


    'SIDE 2


    u = 0
    i = 1

    While u < 76

        'skip-tie-bar

        While voltarray2(i) < 0.3
            i = i + 1
        Wend

        While voltarray2(i) > 0.3
            i = i + 1
        Wend

        'approach unit region

        While voltarray2(i) < 0.3
            i = i + 1
        Wend

        ustart = i
        u = u + 1

        'search unit

        s = 0
        maxv = -999

        While voltarray2(i) > 0.3
            s = s + voltarray2(i)
            If voltarray2(i) > maxv Then
                maxv = voltarray2(i)
            End If
            i = i + 1
        Wend

        uend = i - 1

        av = s / (uend - ustart + 1)
        h = maxv - av                          'HEIGHT


        j = ustart
        While Abs(voltarray2(j + 1) - voltarray2(j)) > 0.02
            j = j + 1
```

```
        Wend
        slstart = j

        j = uend - 1
        While Abs(voltarray2(j + 1) - voltarray2(j)) > 0.02
            j = j - 1
        Wend
        slend = j + 1

        slmax = -999
        For j = slstart To slend
            dif = Abs(voltarray2(j + 1) - voltarray2(j))
            If dif > slmax Then
                slmax = dif
            End If
        Next j                                  'MAX SLOPE

        c = 0
        For j = ustart To uend
            If voltarray2(j) > av Then
                c = c + 1
            End If
        Next j

        p = c / (uend - ustart + 1)             '% POINTS ABOVE LINE


        param2(u) = h * slmax / p

    Wend

    '-------------------------------

    output

End Sub


Sub collect()

    'ready to start side 1
    status = DAQ_StopTrigger_Config(1, 1, 10)
    status = DAQ_Rate(10000, 0, timebase%, sampleint%)
    'waiting for signal in port 0
    status = DIG_Prt_Config(1, 0, 0, 0)
    status = DIG_In_Line(1, 0, 0, state%)
    While state% = 0
        status = DIG_In_Line(1, 0, 0, state%)
        DoEvents
    Wend
    ProgressBar1.Value = 0

    Cls


    'collect side 1
    status = DAQ_Start(1, 0, 1, binarray(0), 60000, timebase%, sampleint%)
    stopped = 0
    While stopped = 0 And status = 0
        status = DAQ_Check(1, stopped, retrieved)
        ProgressBar1.Value = Int(100 * retrieved / 60000)
        DoEvents
    Wend
    ProgressBar1.Value = 100
    retrieved1 = retrieved
    Debug.Print retrieved
    status = DAQ_VScale(1, 0, 1, 1, 0, 60000, binarray(0), voltarray1(0))


    'clear DAQ-system

    status = DAQ_Clear(1)
```



```
    'ready to start side 2
    ProgressBar2.Value = 100
    status = DAQ_StopTrigger_Config(1, 1, 10)
    status = DAQ_Rate(10000, 0, timebase%, sampleint%)
    'waiting for new signal in port 0
    status = DIG_Prt_Config(1, 0, 0, 0)
    status = DIG_In_Line(1, 0, 0, state%)
    While state% = 0
        status = DIG_In_Line(1, 0, 0, state%)
    Wend
    'collect side 2
    status = DAQ_Start(1, 0, 1, binarray(0), 60000, timebase%, sampleint%)
    stopped = 0
    While stopped = 0 And status = 0
        status = DAQ_Check(1, stopped, retrieved)
        ProgressBar2.Value = Int(100 - 100 * retrieved / 60000)
        DoEvents
    Wend
    ProgressBar2.Value = 100
    retrieved2 = retrieved
    Debug.Print retrieved
    status = DAQ_VScale(1, 0, 1, 1, 0, 60000, binarray(0), voltarray2(0))


    'clear DAQ-system

    status = DAQ_Clear(1)

    'call procedure to analyse collected data

    Open "side1.dat" For Output As #1
    For i = 1 To retrieved1
        Print #1, voltarray1(i)
    Next i
    Close #1

    Open "side2.dat" For Output As #1
    For i = 1 To retrieved2
        Print #1, voltarray2(i)
    Next i
    Close #1




    'algor



End Sub

Private Sub exit_Click(Index As Integer)

    End

End Sub

Sub output()

    ForeColor = vbRed
    FontBold = True

    x = 1370
```

```
    For i = 1 To 76

        If param1(77 - i) > 0.2 Then

            If i < 10 Then
                CurrentX = x + 40
            Else
                CurrentX = x
            End If

            If (i + 2) Mod 2 = 0 Then
                CurrentY = 3100
            Else
                CurrentY = 3320
            End If
            Print i

        End If


        If param2(i) > 0.2 Then

            If i < 10 Then
                CurrentX = x + 40
            Else
                CurrentX = x
            End If
            If (i + 2) Mod 2 = 0 Then
                CurrentY = 4830
            Else
                CurrentY = 5050
            End If
            Print i

        End If

        x = x + 120

    Next i

    Refresh
    collect


End Sub

Private Sub Command2_Click()

    'operator ready to start!

    'settings in port 1 - op. presses 'start' button

    'status = DIG_Prt_Config(1, 1, 0, 0)
    'status = DIG_In_Port(1, 1, state%)
    'While state% = 0
    'status= DIG_In_Port(1, 1, state%)
    'Wend

    status = Init_DA_Brds(1, dnc%)
    status = DAQ_Rate(10000, 0, timebase%, sampleint%)
    status = DAQ_Start(1, 0, 1, binarray(0), 10, timebase%, sampleint%)
    status = DAQ_Clear(1)
    collect


End Sub


Private Sub Command3_Click()

    status = DAQ_Clear(1)
```



```
End Sub



Private Sub Command4_Click()

    Form1.Enabled = False
    MDIForm1.Enabled = False
    Form2.Show

End Sub


Private Sub Form_Activate()

    ProgressBar1.Value = ProgressBar2.Max
    ProgressBar2.Value = ProgressBar2.Max
    yu = 4200 - 480
    ym = 4680 - 480
    yl = 5160 - 480

    For x = 1500 To 10500 Step 120
        Circle (x, yu), 50
        Circle (x, ym), 50
        Circle (x, yl), 50
    Next x

    'x = 1370

    'For i = 1 To 76
    '    If i < 10 Then
    '        CurrentX = x + 40
    '    Else
    '        CurrentX = x
    '    End If
    '
    '    If (i + 2) Mod 2 = 0 Then
    '        CurrentY = 3580
    '    Else
    '        CurrentY = 3800
    '    End If
    '    Print i
    '    If i < 10 Then
    '        CurrentX = x + 40
    '    Else
    '        CurrentX = x
    '    End If
    '    If (i + 2) Mod 2 = 0 Then
    '        CurrentY = 5310
    '    Else
    '        CurrentY = 5530
    '    End If
    '    Print i
    '
    '    x = x + 120
    '    MsgBox i
    'Next i


End Sub

Private Sub Form_Click()

    ProgressBar1.Value = ProgressBar1.Min
    ProgressBar2.Value = ProgressBar2.Min
    For i = 1 To 100
        For j = 1 To 50000
        Next j
        ProgressBar1.Value = i
    Next i
    For i = 1 To 100
```

# A.25. Alternative programming methods

```
Sub algor()

    Dim p(1 To 25000) As Single
    Dim v(1 To 25000) As Single
    Dim d(1 To 25000) As Single
    Dim h(1 To 80) As Single
    Dim mav(1 To 80) As Single
    Dim paa(1 To 80) As Single
    Dim lfha(1 To 25000) As Single


    For i = 1 To 20950
        v(i) = Worksheets("sheet1").Cells(i, 1)
    Next i

    'MsgBox "ready"
    For i = 1 To 20956
        d(i) = Abs(v(i + 1) - v(i))
    Next i


    f1 = 0
    f2 = 0
    f3 = 0

    c = 0

    For i = 13 To 20956 - 12

        s = 0
        For j = i - 12 To i + 12
            s = s + d(j)
        Next j
        sdma = s / 25

        If f1 = 0 Then
            c = c + 1
            If sdma < 0.1 Then
                p(c) = v(i)
            Else
                f1 = 1
                p(c) = -5
            End If
        Else
            If f2 = 0 Then
                If sdma < 0.1 Then
                    f2 = 1
                End If
            Else
                If f3 = 0 Then
                    If sdma >= 0.1 Then
                        f3 = 1
                    End If
                Else
                    c = c + 1
                    p(c) = -5
                    If sdma < 0.1 Then
                        f1 = 0
                        f2 = 0
                        f3 = 0
                    End If
                End If
            End If
        End If

    Next i

    'MsgBox "finished"

    'For i = 1 To 20950 - 25
    '    Worksheets("sheet2").Cells(i, 1) = p(i)
    'Next i
```

Module1 - 2

```
'MsgBox "start heights"
'heights

u = 0
i = 1

While p(i) > -5
    lfha(i) = 5
    i = i + 1
Wend

While u < 76

    While p(i) = -5
        lfha(i) = -5
        i = i + 1
    Wend

    u = u + 1

    edge1 = p(i)
    pos1 = i

    i = i + 1

    While p(i) <> -5
        i = i + 1
    Wend

    edge2 = p(i - 1)
    pos2 = i - 1

    m1 = -9999
    m2 = -9999

    s0 = 0

    For j = pos1 To pos1 + 9
        s0 = s0 + p(j)
    Next j


    For j = pos1 + 10 To pos2 - 11

        s0 = s0 + p(j)
        s1 = 0
        s2 = 0

        For k = j - 10 To j + 10
            s1 = s1 + Abs(p(k + 1) - p(k))
        Next k

        ad = s1 / 21
        If ad > m1 Then
            m1 = ad
        End If

        mav(u) = m1                 'maximum average of differences

        For k = j - 2 To j + 2
            s2 = s2 + p(k)
        Next k

        ah = s2 / 5                 'voltage moving average of 5
        If ah > m2 Then
            m2 = ah                 'm2 is maximum voltage m. a.
        End If

    Next j

    For j = pos2 - 9 To pos2
        s0 = s0 + p(j)
```

Module1 - 3

```
    Next j

    lfh = s0 / (pos2 - pos1 + 1)    'lead-frame height


    n = 0
    For j = pos1 To pos2
        lfha(j) = lfh
        If p(j) > lfh Then
            n = n + 1
        End If
    Next j

    paa(u) = n / (pos2 - pos1 + 1)  'percentage above average

    h(u) = m2 - lfh                 'weld height




    'For j = pos1 To pos2
    '    y = edge1 + (edge2 - edge1) * (j - pos1 + 1) / (pos2 - pos1 + 1)
    '    dif = p(j) - y
    '    If dif > wh Then
    '        wh = dif
    '    End If
    'Next j
    '
    'h(u) = wh


Wend


For u = 1 To 20950
    Worksheets("sheet2").Cells(u, 2) = lfha(u)
Next u

For u = 1 To 80
    Worksheets("sheet2").Cells(u, 3) = h(u)       'height
Next u

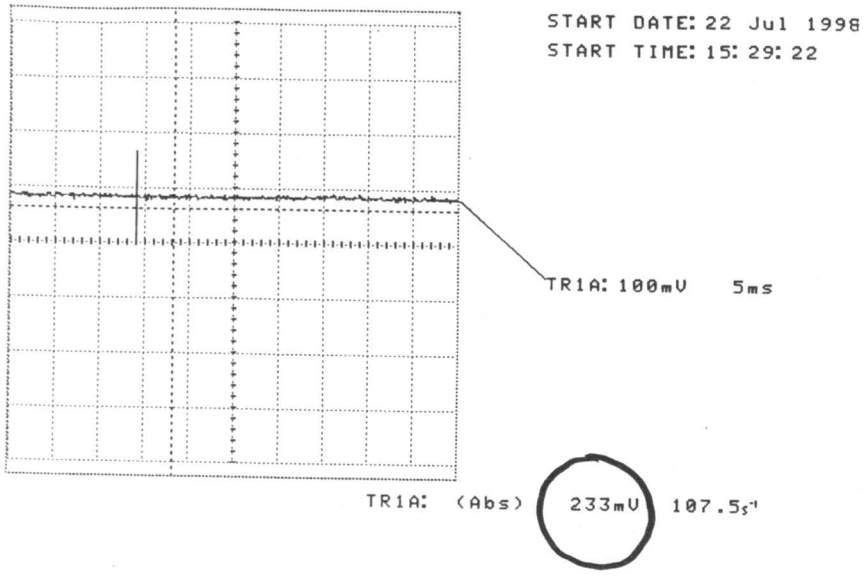
For u = 1 To 80
    Worksheets("sheet2").Cells(u, 4) = mav(u)     'slopes
Next u

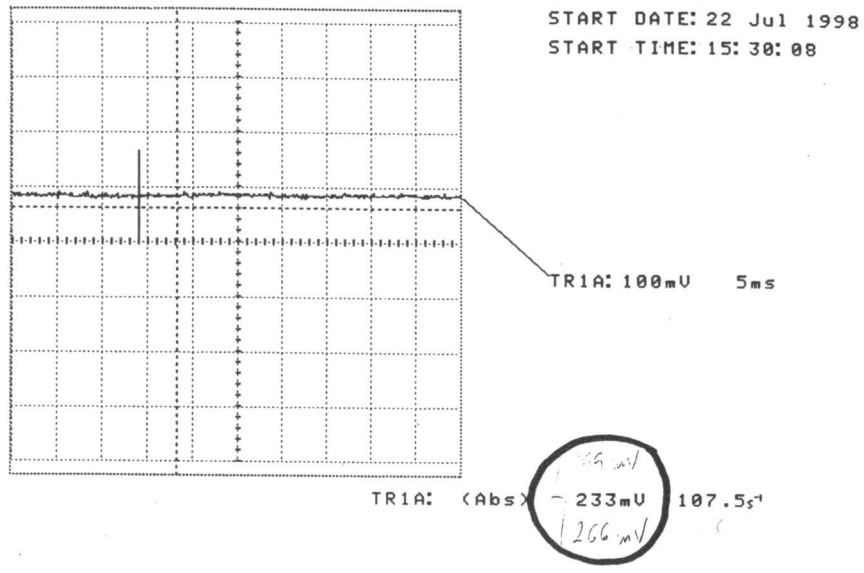
For u = 1 To 80
    Worksheets("sheet2").Cells(u, 5) = paa(u)     'points above line
Next u



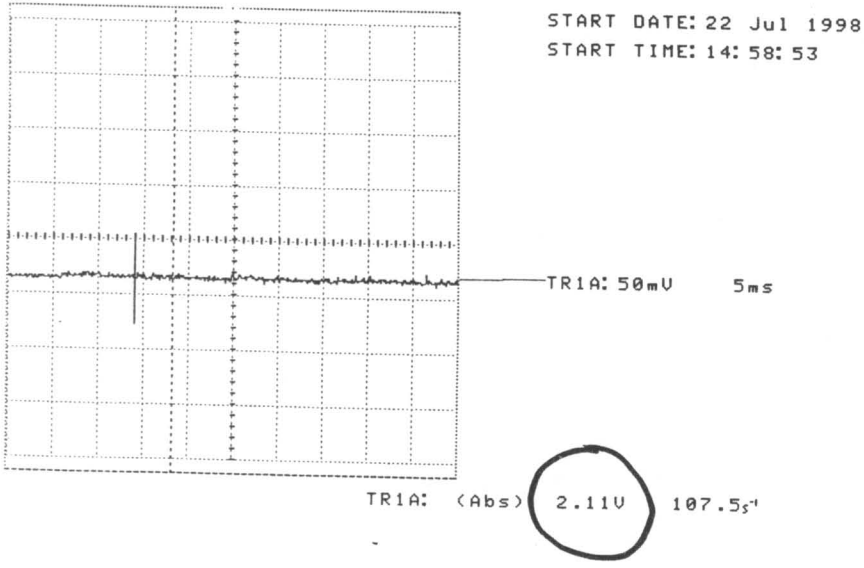
End Sub
```

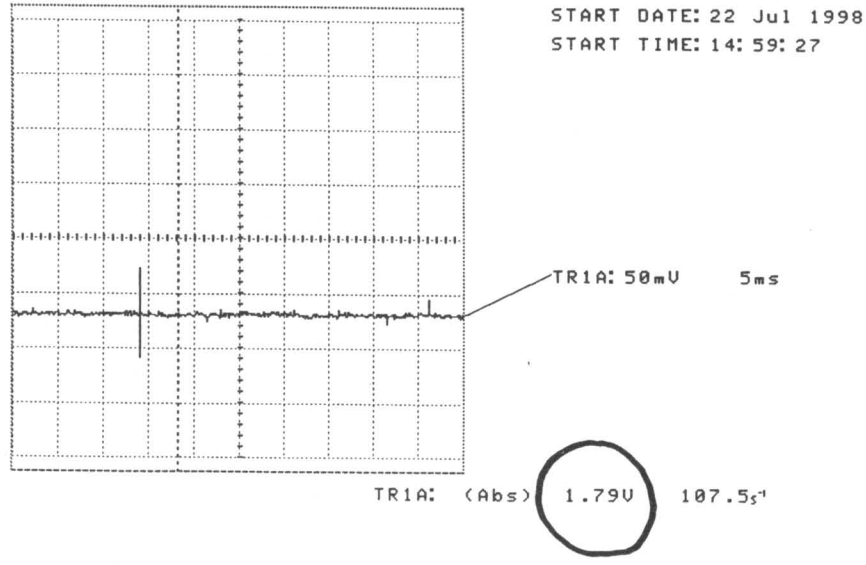
# A.26.
# Static Test-Oscilloscope outputs

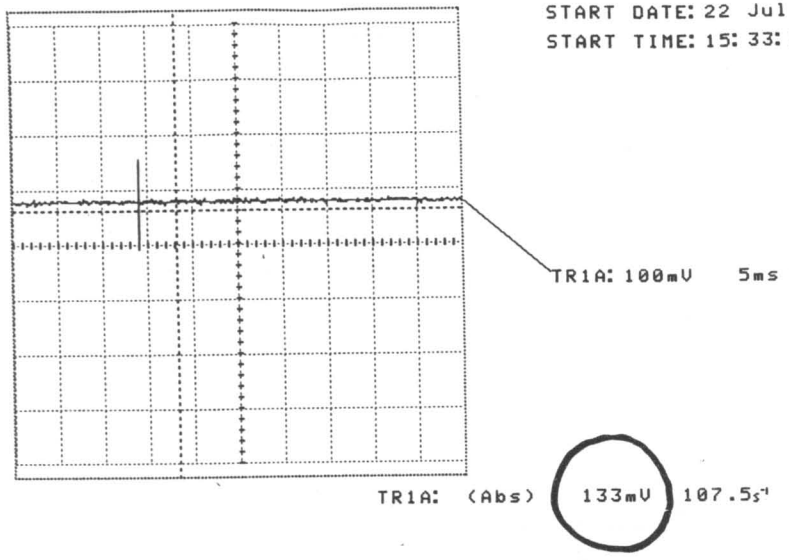

START DATE: 22 Jul 1998
START TIME: 15: 29: 22
TR1A: 100mV 5ms
TR1A: (Abs) 233mV 107.5s⁻¹

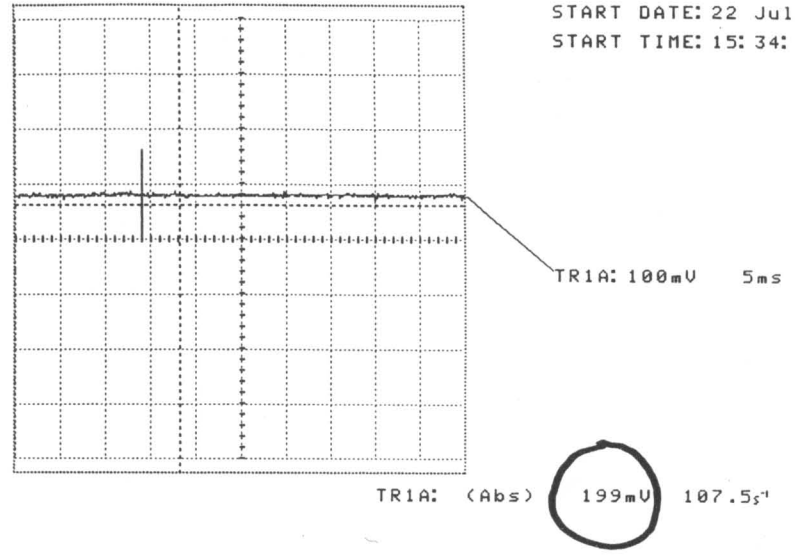

START DATE: 22 Jul 1998
START TIME: 15: 30: 08
TR1A: 100mV 5ms
TR1A: (Abs) 233mV 107.5s⁻¹

#2

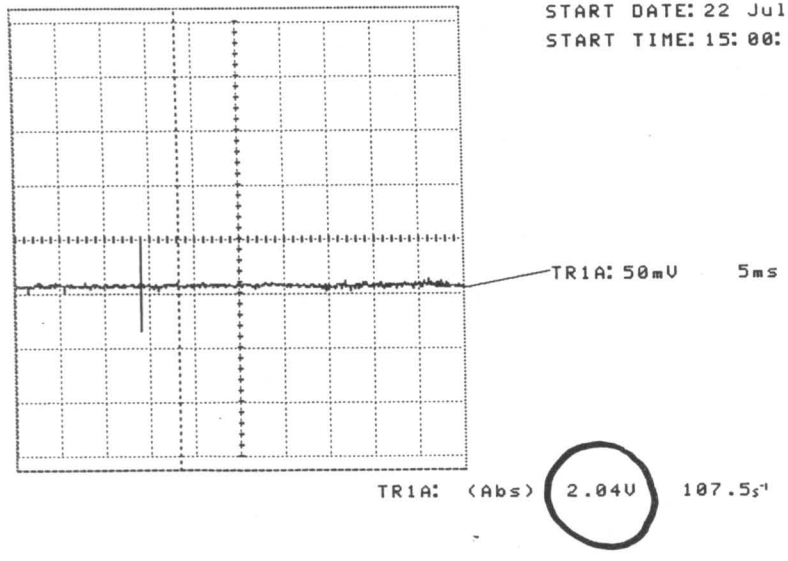

START DATE: 22 Jul 1998
START TIME: 14: 58: 53
TR1A: 50mV 5ms
TR1A: (Abs) 2.11V 107.5s⁻¹

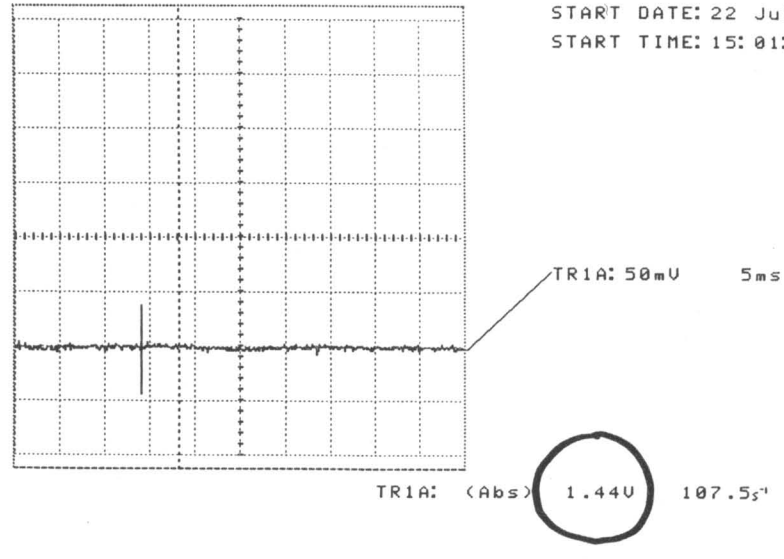

START DATE: 22 Jul 1998
START TIME: 14: 59: 27
TR1A: 50mV 5ms
TR1A: (Abs) 1.79V 107.5s⁻¹

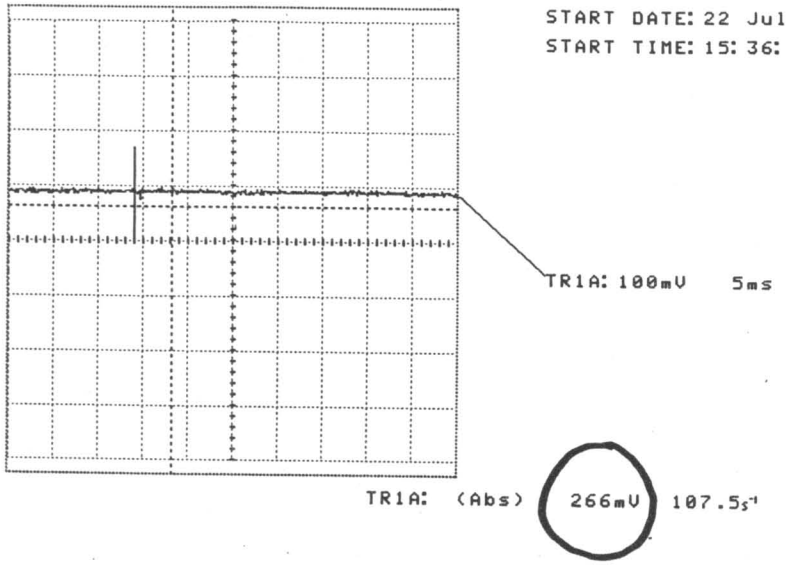

START DATE: 22 Jul 1998
START TIME: 15: 33: 55
TR1A: 100mV 5ms
TR1A: (Abs) 133mV 107.5s⁻¹

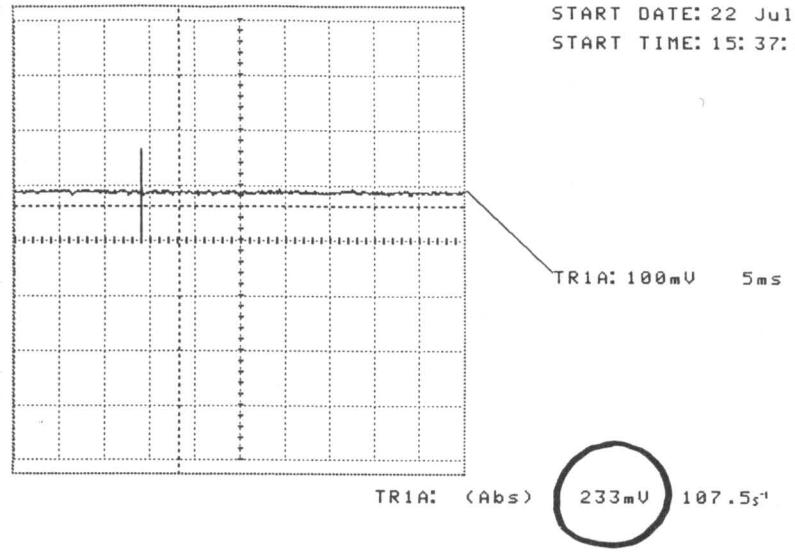

START DATE: 22 Jul 1998
START TIME: 15: 34: 49
TR1A: 100mV 5ms
TR1A: (Abs) 199mV 107.5s⁻¹

#7

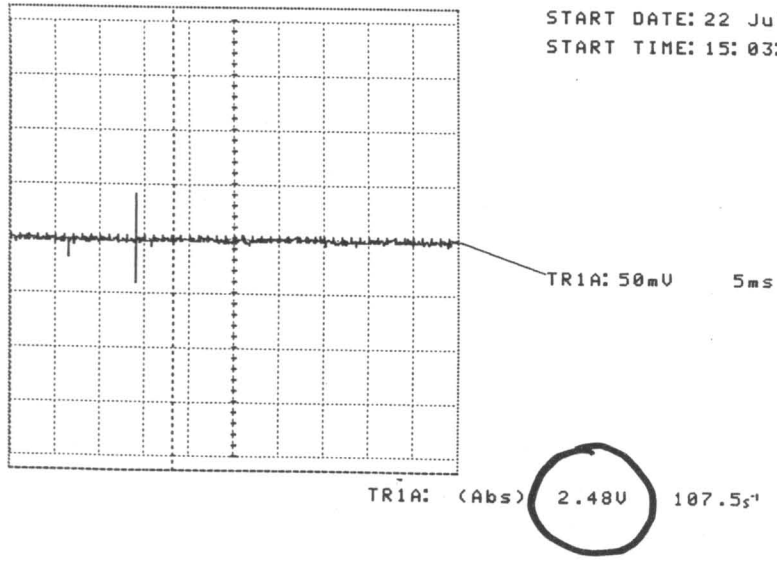

START DATE: 22 Jul 1998
START TIME: 15: 00: 42
TR1A: 50mV 5ms
TR1A: (Abs) 2.04V 107.5s⁻¹

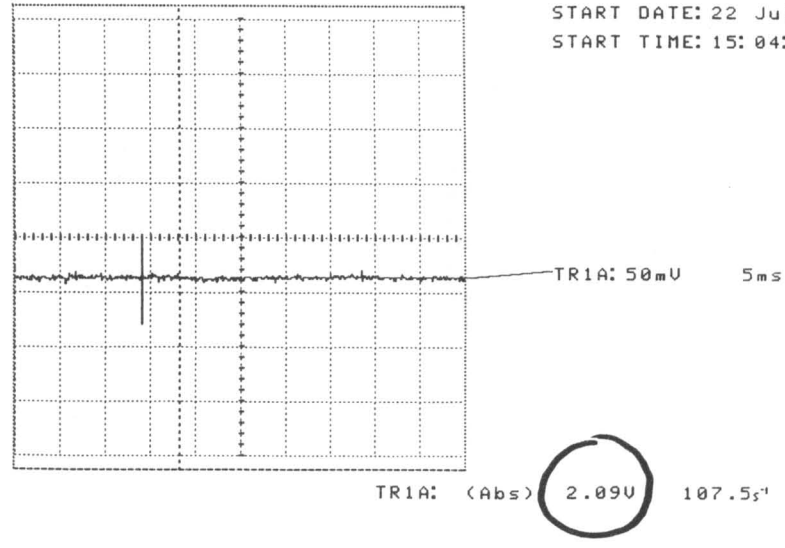

START DATE: 22 Jul 1998
START TIME: 15: 01: 18
TR1A: 50mV 5ms
TR1A: (Abs) 1.44V 107.5s⁻¹


START DATE: 22 Jul 1998
START TIME: 15: 36: 40
TR1A: 100mV 5ms
TR1A: (Abs) 266mV 107.5s⁻¹


START DATE: 22 Jul 1998
START TIME: 15: 37: 36
TR1A: 100mV 5ms
TR1A: (Abs) 233mV 107.5s⁻¹

#8


START DATE: 22 Jul 199
START TIME: 15: 03: 39
TR1A: 50mV 5ms
TR1A: (Abs) 2.48V 107.5s⁻¹


START DATE: 22 Jul 1998
START TIME: 15: 04: 13
TR1A: 50mV 5ms
TR1A: (Abs) 2.09V 107.5s⁻¹

# A.27.
# Keyence CCD Technology

KEYENCE
Sensors for Factory Automation

# New, Laser Measurement System Features Custom CCD with LFTC* Technology

## LK Topics of Interest


- Features and Benefits
- LK Operating Principle
- CCD vs PSD Performance
- Measuring Different Surface Types
- Metal Profiling Applications
- Additional Applications
- LK Controller
- Specifications


SEND INFO




The new LK is available in two models: the LK-031 High Precision and the LK-081 Long Range.

## LK Series Features and Benefits:

- **Custom designed CCD** sensing array provides improved performance over conventional PSDs (Position Sensing Detectors)
- **1-µm resolution** with a linearity of ±1% F.S.
- **Semiconductor laser** with 30-µm diameter beam spot.
- **L.F.T.C.** (Laser Flash Time Control circuitry) provides automatic control of laser emission time.
- **Response speed selection** system compensates for sporadic transients in measurement data.
- **Sophisticated alarm circuitry** senses false alarm conditions.
- **Auto gain function** assures measurement stability.
- **IP-67 (NEMA4) enclosure rating** for harsh environments.
- **Auto zero key** provides fast, simplified calibration.
- **Far/Near** warning system.
- **LED warning indicator** alerts user to poor beam alignment and target out-of-range conditions.



**KEYENCE Custom CCD**

## LK Product Overview

The new LK Series CCD Laser Measurement System is a high-accuracy, semiconductor laser based triangulation measurement system with 1.0 micron resolution. Measurements of surface profile, thickness and size, are unaffected by color, surface texture or stray light for practically every application. The LK uses a high resolution CCD sensing array (conventional measuring systems use PSDs which can give rise to measurement errors) provides measurement precision which is unaffected by stray light or beam reflections from nearby objects. Measurement accuracy is further increased by Laser Flash Time Control (LFTC) circuitry which automatically controls laser emission time based on target surface conditions. Shiny, mirrored surfaces and rough black objects are meassured with the same 1.0-micron resolution. With its higher response speed and wider range of laser beam control, LFTC provides increased accuracy and measurement stability compared with conventional PSD based measuring systems.

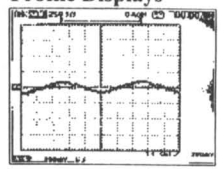


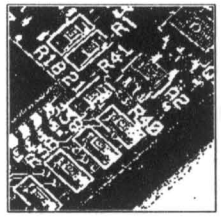




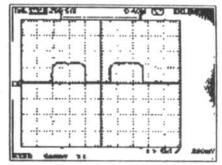
**Shiny, Glossy Surfaces**
The use of a CCD, prevents beam "spread" on shiny surfaces which can lead to measurement errors. LK accuracy is unaffected by scattered light reflections from the target surface itself.

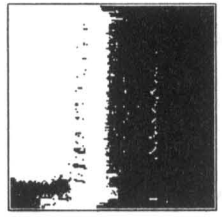
**Actual Surface Profile Displays**



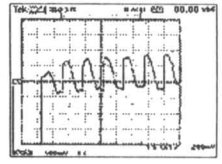


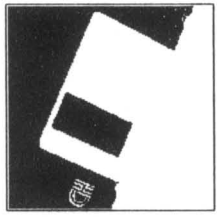
**Multicolored Surfaces**
The LK's Laser Flash Time Control technology automatically adjusts the emitted light quantity up to 150 times to compensate for color differences. Measurement errors are eliminated.



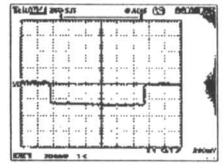


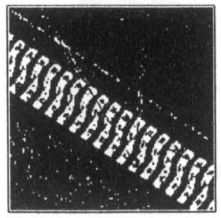
**Angled Surfaces**
Profiling of angled surfaces has been virtually impossible with conventional measuring systems. The combination of CCD and LFTC technologies in the new LK provides accurate measurements on any type of surface.



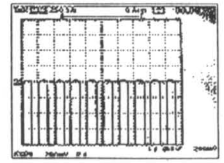


**Dark, Rough Surfaces**
The LK's small 30 micron diameter beam spot and CCD light processing capability enables the system to handle wide transitions in target color while not being affected by small hairline cracks or surface defects such as the metal-to-plastic transitions on this floppy diskette.





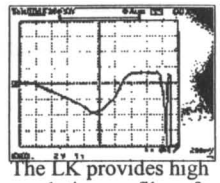
**Tiny Objects**
The new LK easily measures extremely small objects with precision. Accuracy is not affected by stray light or reflections from nearby objects such as encountered during the measurement of pin warpage on IC chips.



**Metal Profiling Applications That Could Not Be Performed Before Are Now Possible!**



**Smooth, unpolished surfaces**
The LK provides accurate profiling data that cannot be performed with contact type measurement systems. This means that data can be obtained from hot or installed machinery parts or wet surfaces that are not easily accessed.



The LK provides high resolution profiles of any type of metal surface.



**Polished Metal Surfaces**
The LK's CCD technology prevents beam spread on highly polished and mirrored metal surfaces. Troublesome reflections from adjacent surfaces and stray light do not reduce resolution.



**Measurement of Rough, Black Surfaces**
The LK easily handles extreme measurement conditions. LFTC automatically adjusts laser beam strength up to 150 times to compensate for the low reflectivity of dark, rough surfaces.



**Height Measurement on Rough Metal Surfaces**
The LK provides high resolution on any metal surface. A NEMA4 enclosure rating makes it suitable for use in harsh production type environments.



**Profiling of Angled Surfaces**
LFTC compensates for angular changes on target surfaces to maintain constant measurement accuracy.

## Additional Applications...only a partial listing is possible

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**Automotive...measurement of:**

- Engine valve stroke.
- Thickness of paint and other coatings (even when wet).
- Fan belt runout.
- Engine block width, piston stroke, etc.
- Radiator fin height uniformity.

**Electronic components and applicances...measurement of:**

- IC and microprocessor pin alignment.
- Solder paste height on PCBs.
- IC orientation on PCBs.
- Electric motor part dimensions.
- LED chip thickness through plastic window.

**Food and pharmaceutical packaging...measurement of:**

- Corrugated cardboard height.
- Shapes of cookies and other baked goods.
- Dough thickness.
- Swelling of bottle caps and aluminum can tops.

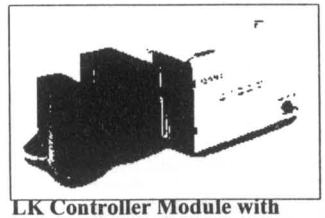
**Metal and machinery...measurement of:**

- Thickness of metal sheet materials.
- Presence/absence of snap-rings, o-rings and other assembly components.
- Ferrite thickness.
- Warpage of hot cast parts.

**Molding...measurement of:**

- Width and groove depth of molded gear parts.
- Thickness of extruded sheet materials.
- Tire tread shape and groove depth.
- Golf ball dimple depth.
- Windshield wiper thickness and shape.

## LK Controller and Specifications



**LK Controller Module with Model LK-031 and LK-081 sensor heads.**

The LK Controller is supplied in two versions. Model LK-2001 is required for operation with Model LK-031 Sensor Head. Model LK-2101 is required for operation with Model LK-081 Sensor Head.
**Output:** ±5 V @ 100 ohms
**Alarm:** NPN open-collector, 100mA
**Features:** Auto-Zero, response speed selection, FAR/NEAR output, Analog Output HOLD (holds analog output immediately before alarm is output)

## Specifications

| | |
|---|---|
| **Sensor Heads:** | LK-031 High Precision with Model LK-2001 Controller<br>LK-081 Long Range with Model LK-2101 Controller |
| **Reference Distance:** | LK-031: 30 mm ± 5 mm<br>LK-081: 80 mm ± 15 mm |
| **Spot Diameter:** | LK-031: 30-microns<br>LK-081: 70 microns |
| **Sampling Time:** | LK-031: 512 microseconds<br>LK-081: 1024 microseconds |
| **Power Consumption:** | 400 mA max. |
| **Housing Material:** | Sensor head: Aluminum die-cast<br>Controller: Polycarbonate |
| **Weight:** | LK-031: 260 gm<br>LK-081: 385 gm<br>Controller: 512 gm |

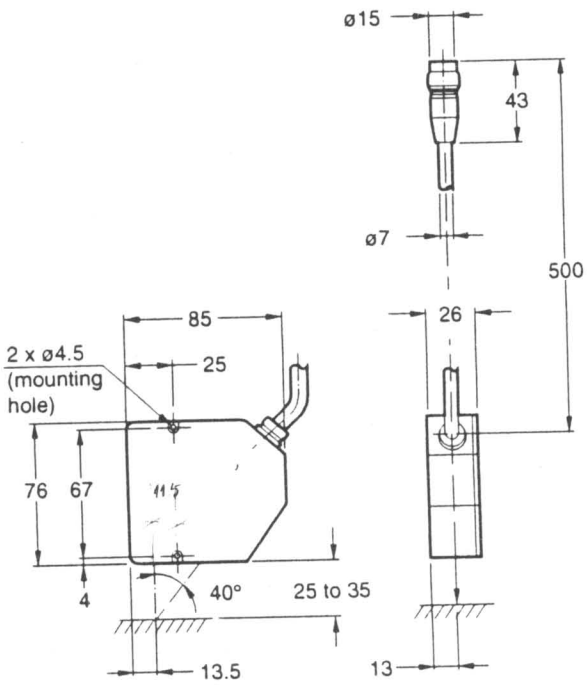
HOME | PREV. MENU | email | SEND INFO



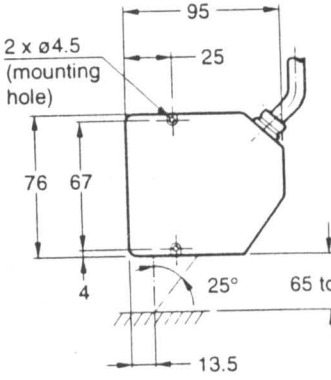
# DIMENSIONS

## Sensor head

### LK-031




### LK-081




Specifications are subject to change without notice.

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