Fermi National Accelerator Laboratory

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An Eye for Accuracy -- Coordinate Measuring in an R & D Environment*

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An Eye For Accuracy--Coordinate Measuring in an R & D Environment

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with

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INTRODUCTION

The Fermi National Accelerator Laboratory (Fermilab) is a high energy physics research facility. Its purpose is to explore the basic composition of matter. Fermilab does not produce a product nor does it produce electrical power. Funded by the Department of Energy,[1] the main tool for its study is the Tevatron, the world's first superconducting particle accelerator. Fermilab fabricates and assembles the majority of magnets and other components for the accelerator rings of the atom smasher. The magnet is the key to accelerating subatomic particles (i.e. protons, anti-protons, etc.) which the particle accelerator uses to collide into other beams or fixed targets. The production of a magnet assembly requires stacking steel laminations of precisely the proper size and shape necessary to create the required magnetic field.

In this paper, I will discuss how coordinate measuring is accomplished at Fermilab, and how such things as tight budgets, and lack of product line can lead to some interesting and useful techniques.

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1) Fermilab is operated by Universities Research Association, Inc. for the Department of Energy.

R & D VERSUS INDUSTRY

One of the obvious differences between working in an R & D environment and an industrial one, is the lack of a product line and its associated sales. This difference impacts the quality discipline in two relatively major ways.

1. First of all, with a product line your items to be measured are well defined. One can easily select a coordinate measuring system or systems that meet all of your known needs with a high degree of confidence. In an R & D environment, one can only go by experience and anticipated needs. At Fermilab, we used this criteria to select our first coordinate measuring machine (CMM). This resulted in the purchase of a machine having approximately 30 inches of travel in the x axis.

2. In an industrial environment, the Quality Control group would normally get a budget based on actual and anticipated sales. Cost justifications can then be made for a coordinate measuring system on this basis. In an R & D environment, capital equipment costs of coordinate measuring systems must often go into the cost of a project. The problem is that often times a project is not large enough to support the purchase of a large piece of capital equipment, so one must improvise.

COORDINATE MEASURING MACHINE WITH A VIDEO SYSTEM

Approximately a year after we brought our CMM on line, Fermilab embarked on the Tevatron I project, which was to provide Fermilab with an anti-proton source for colliding proton and anti-proton beams. What this meant to our section, was the production of several hundred magnets (and other devices). Most of these were conventional magnets with magnetic fields which are primarily determined by the shape of the iron in the aperture. This entails producing and accurately stacking thousands of steel laminations of precisely the proper size and shape. We quickly found ourselves trying to figure out the best method to measure laminations produced from a compound blanking die, some of which were approximately 55" long. You may remember that our coordinate measuring machine had approximately 30" of range in the x axis. Normally this lack of machine capacity would not be a problem. One would just make multiple setups. However, it's a different story when measuring irregular surfaces dimensioned from a point in space.

Most of the laminations we needed to measure were 0.060 inch thick, and had conventionally sheared edges produced from a compound blanking die. This provided a very small measuring surface in which the touch probe could engage (Figure 1). Since CMMs have been optimized for use with touch probes, this was the obvious preferred method. However, when measuring such small thicknesses, and with the rough sheared edge produced from the blanking die, the touch probe gave inconsistent measurements.

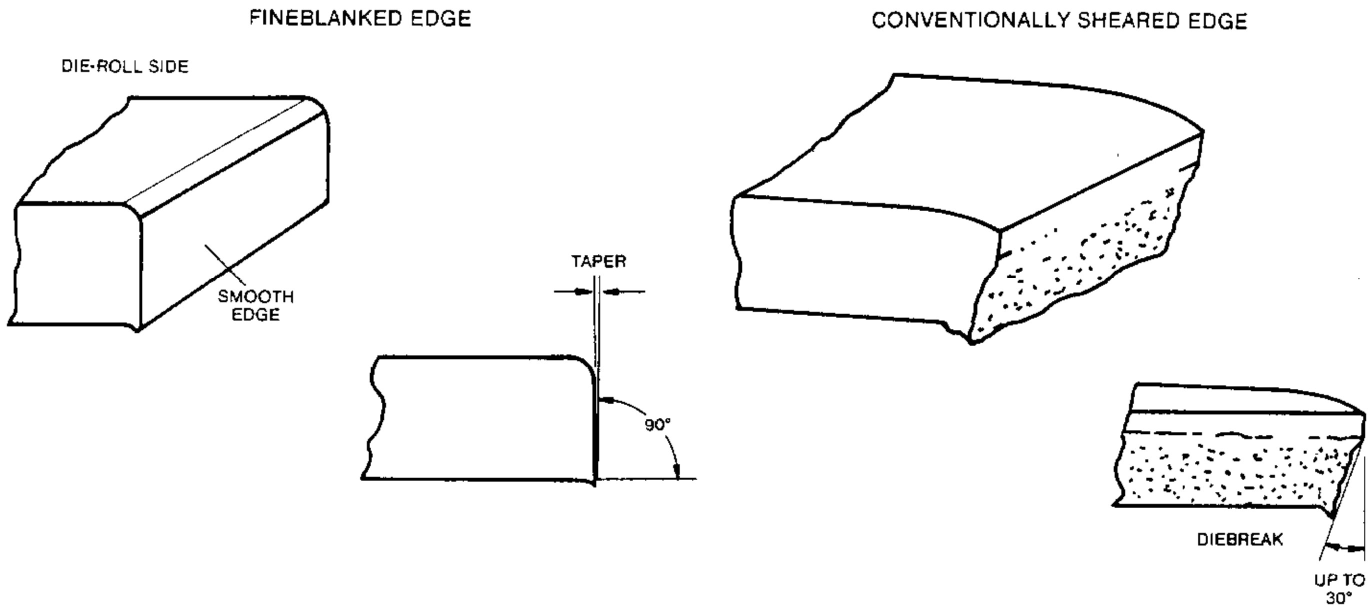

Figure 1. The taper and edge condition of the steel laminations contributed to measuring error when using the ruby tipped sensing probe.[2]

Replacing the round ruby touch probe with a hard rotatable knife edge probe did not eliminate the problem. The accuracy and repeatability required were at the design limitations of the machine using a touch probe (0.0002-0.0003 inch). With the combined effects of operator influence, the roughness and taper of the lamination's sheared edge, and the inherent error of the probe, our accuracy and repeatability just were not good enough. A vision inspection system seemed to be the answer. However, that required a large capital investment. An optical system that could be retrofitted to our existing CMM was a possible alternative. Some CMM manufacturers had optical video systems, but no one really had a high quality, high resolution video system that could be integrated with our CMM.

Optical measurement on a CMM requires a closed circuit T.V. camera with either a fixed or zoom lens. Both the camera and the light source are mounted to the z axis. The camera is coupled to a video display monitor. The monitor also displays a measurement reticle which is located between the camera and the lens.

Using the CMM's x and y axis find feed, the point of measurement (of the desired feature) is aligned with the reference marks (cross hairs or concentric circles) that are shown on the screen. This point is entered in the computer using the same processing as with a hard or touch probe. All other measurement practices are standard with the obvious exception that there is no correction for a probe. A definite advantage.

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2) Photo courtesy of Wagner Fineblanking

The first video system we purchased,provided high resolution and better repeatability than the hard knife edge probe. However, the camera mounted on the z axis, was large, bulky, and heavy enough (9 lbs) to effect the CMM's accuracy. This made it necessary to have the machine recalibrated when switching from the optical system to the use of probes. We needed the ability to measure a wide variety of surfaces, both optically and mechanically, without recalibrating.

Several different video systems were evaluated before Fermilab finally settled on the Sony CCD Video camera with a Unitron 1:6.5 zoom lens. Its light weight (2 3/4 lbs) and high resolution meet our needs very well. Both the camera and a Nikon Mark II fiber optic light source are mounted on the z axis (Figure 2). Depending upon the ambient light, parts to be measured, and accuracy required, supplemental light is not always necessary.

A reticle between the camera and focal length tube generate the reference lines on the video monitor. For measuring laminations, a series of vertical and horizontal lines with a series of concentric circles is used. Electronically generating the cross hairs seemed a possibility. However, the cross hairs were not narrow enough for the application. Accuracy and repeatability is about 0.0002 inch.

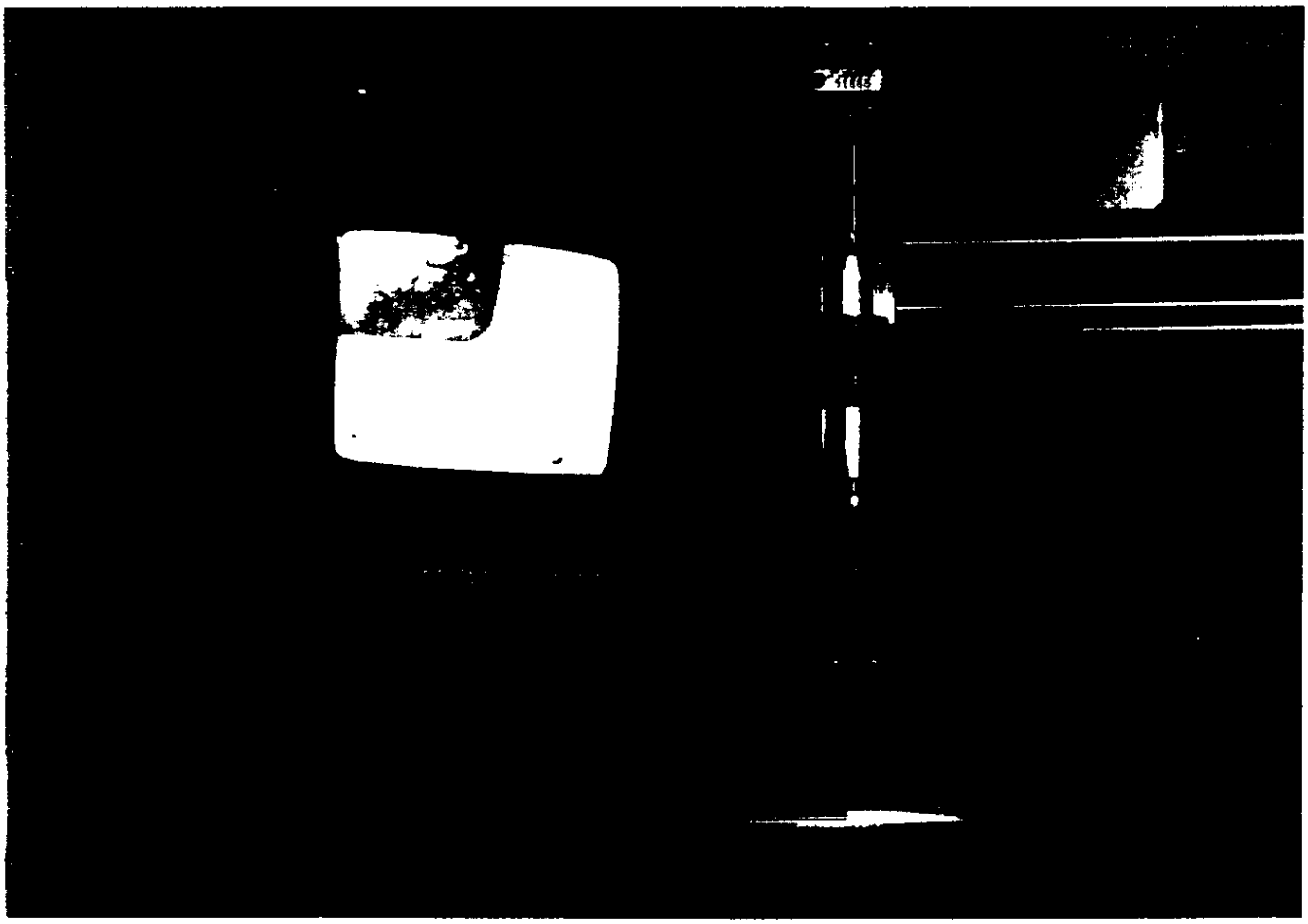

Figure 2. The Sony camera and light source are attached to the z axis of the CMM. The point of measurement is aligned with the reference marks shown on the screen.

DISPLAYING THE RESULTS IN REAL TIME

After obtaining a satisfactory measuring process, another need for improvement became evident. The CMM's hard copy output is generally given by measurement or feature number which necessitates tying the output to a drawing that has the feature numbers marked on it. Trying to get a thorough understanding of what a part looks like is time consuming. It is sometimes difficult to determine if the part meets the specification. A good inspection facility can and should do more than identify a problem or problems on a given part or assembly. Ideally, one should analyze measurement data and make a recommendation of what should be done to correct the deviation.

Steve Merkler, Senior Technician, suggested that a plotter be used to draw a part the way it is supposed to be and then draw the measured part on the same drawing as it is being measured (Figure 3). A picture is truly worth a thousand words. Figure 4 shows the flow chart of the steps involved in graphically displaying the results in real time. The hard copy graphic output provides a visual representation of the actual part shape and size in reference to the specification (Figure 5). It also allows the inspection department to suggest how to correct an out of tolerance condition. Often times, features of the lamination are the proper size and shape, but are merely placed in the wrong location (Figure 6). This is really apparent with the graphics printout. Though the graphic output is normally in two axis, it has been done in three axis and plotted as an orthographic projection.

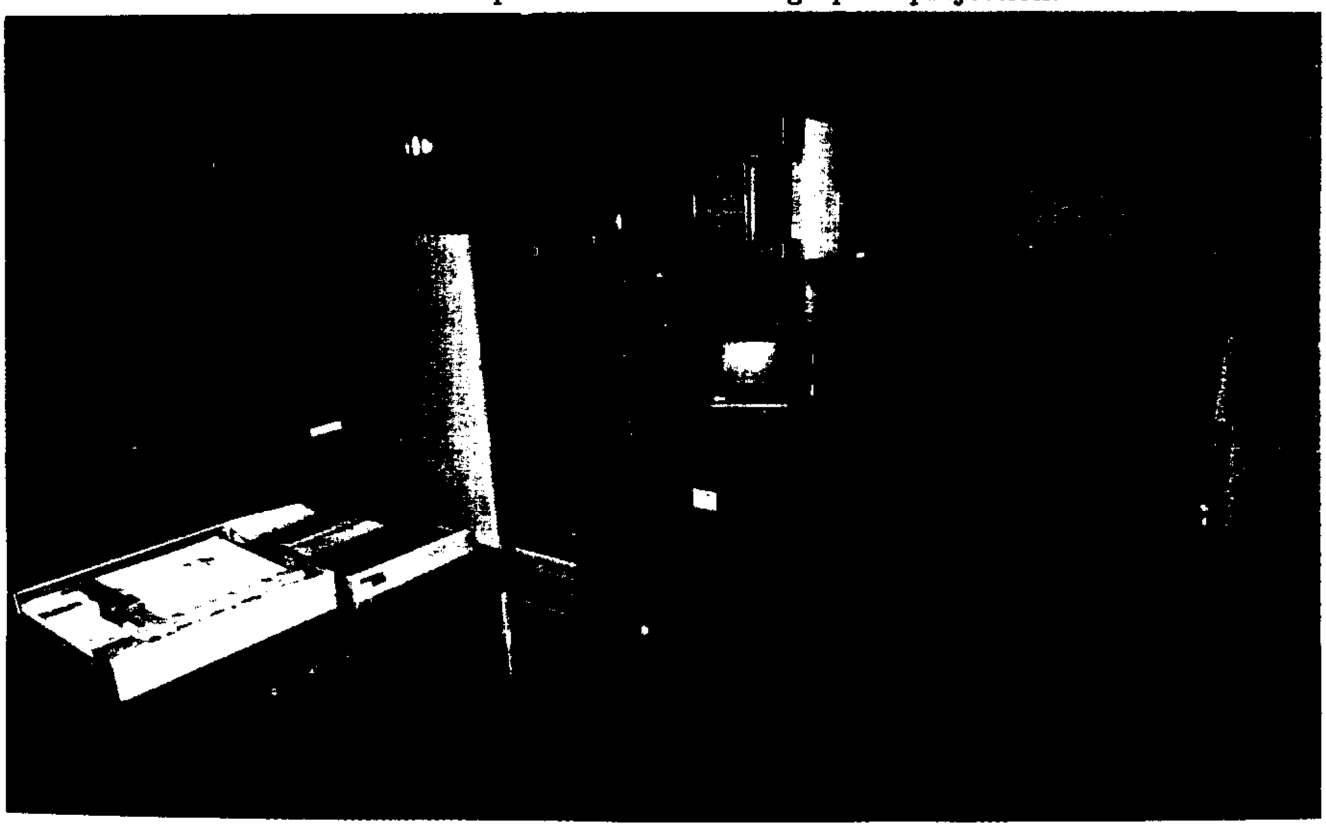

Figure 3. Shown here is the CMM with the vision system. The plotter draws the part in real time.

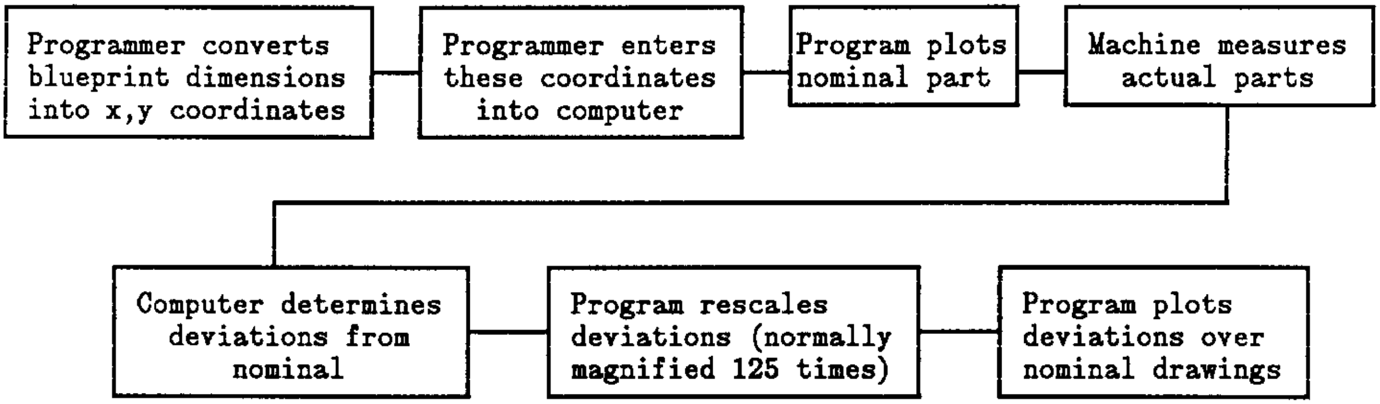

Figure 4. The steps involved in graphically displaying the measured results in real time.

We have the capability, thanks to Robert Riley, to store all of our measurements on disc for retrieval and plotting at a later date. We can also send the hard copy graphics output of our measurements to other National Laboratories, suppliers, etc. via a facsimile machine. It is self explanatory!

COORDINATE MEASURING WITH A CONTOUR PROJECTOR

The longer you have a coordinate measuring machine, chances are the busier it will become. You reach a point where you start looking for work that can be done elsewhere. When this occurred at Fermilab, one of the solutions was to purchase a contour projector. The idea was to take some of the smaller laminations currently being measured on the CMM, and measure them on the contour projector. Since the smaller laminations represented a significant amount of the work load, this would result in an immediate improvement.

We purchased a computer controlled machine with servo drive and an automatic edge finder. The beauty of this machine has proved to be its speed. Because the operator is taken out of the measurement process, we no longer have to make repeat measurements to demonstrate repeatability.

While this machine seems to meet our needs rather well, bear in mind that its selection was a trade off between cost and speed. There are faster machines, but they are also more expensive. Our machine was as fast as our budget allowed.

While we are able to graphically display the results of our measurements on the contour projector, we are as of yet unable to do it in real time. We recently obtained unprotected software from the manufacturer, and it is our goal to integrate this machine with our current graphic display method during the coming year. We are now plotting the part as a separate step in an off-line mode.

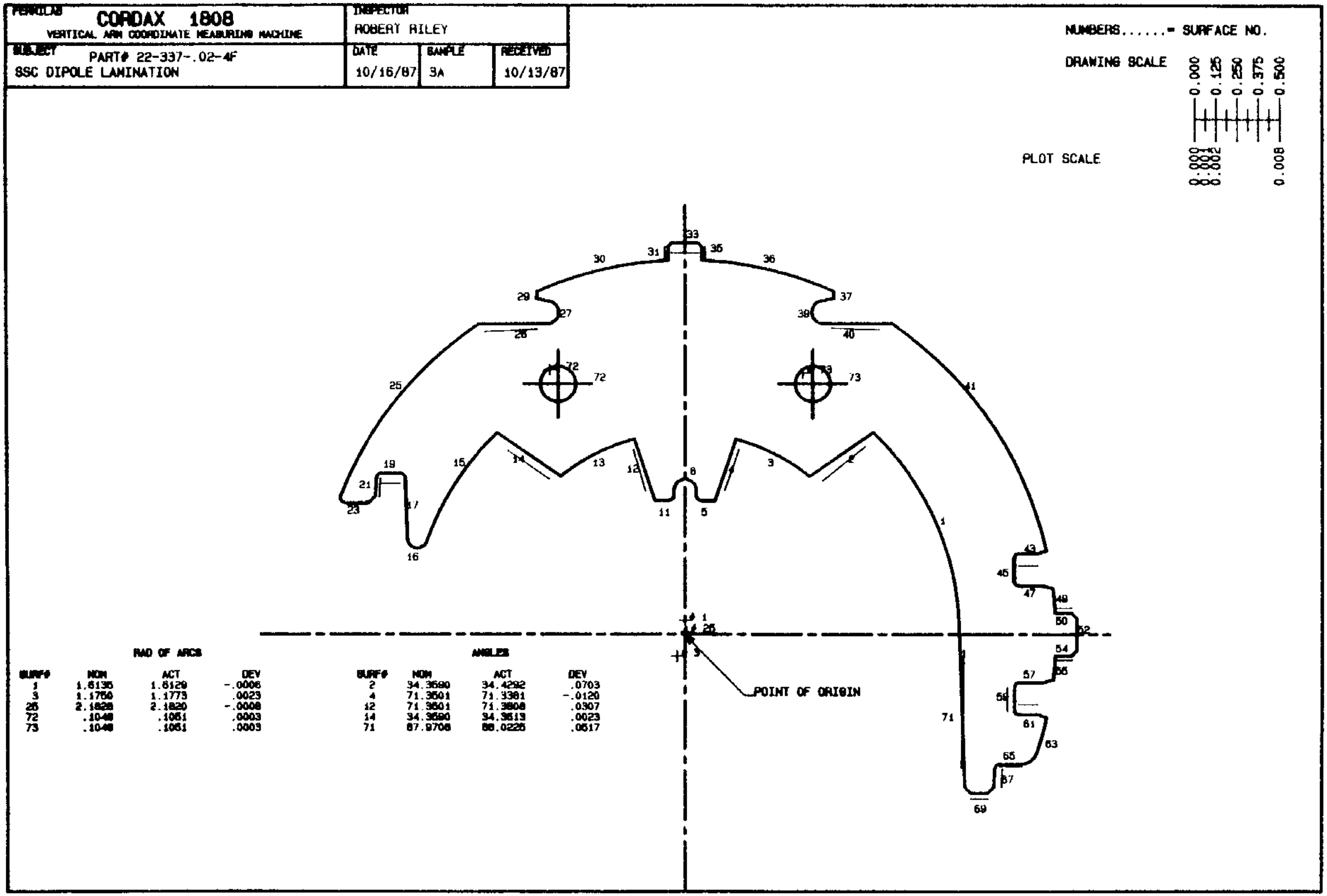

Figure 5. The heavy lined drawing represents the desired size and shape of the lamination. The thin line shows the actual part size and shape as measured. The crosses near the point of origin are where the centers of the various radii are. Hole center locations are also given. Notice the difference in the part drawing scale and the plotted scale.

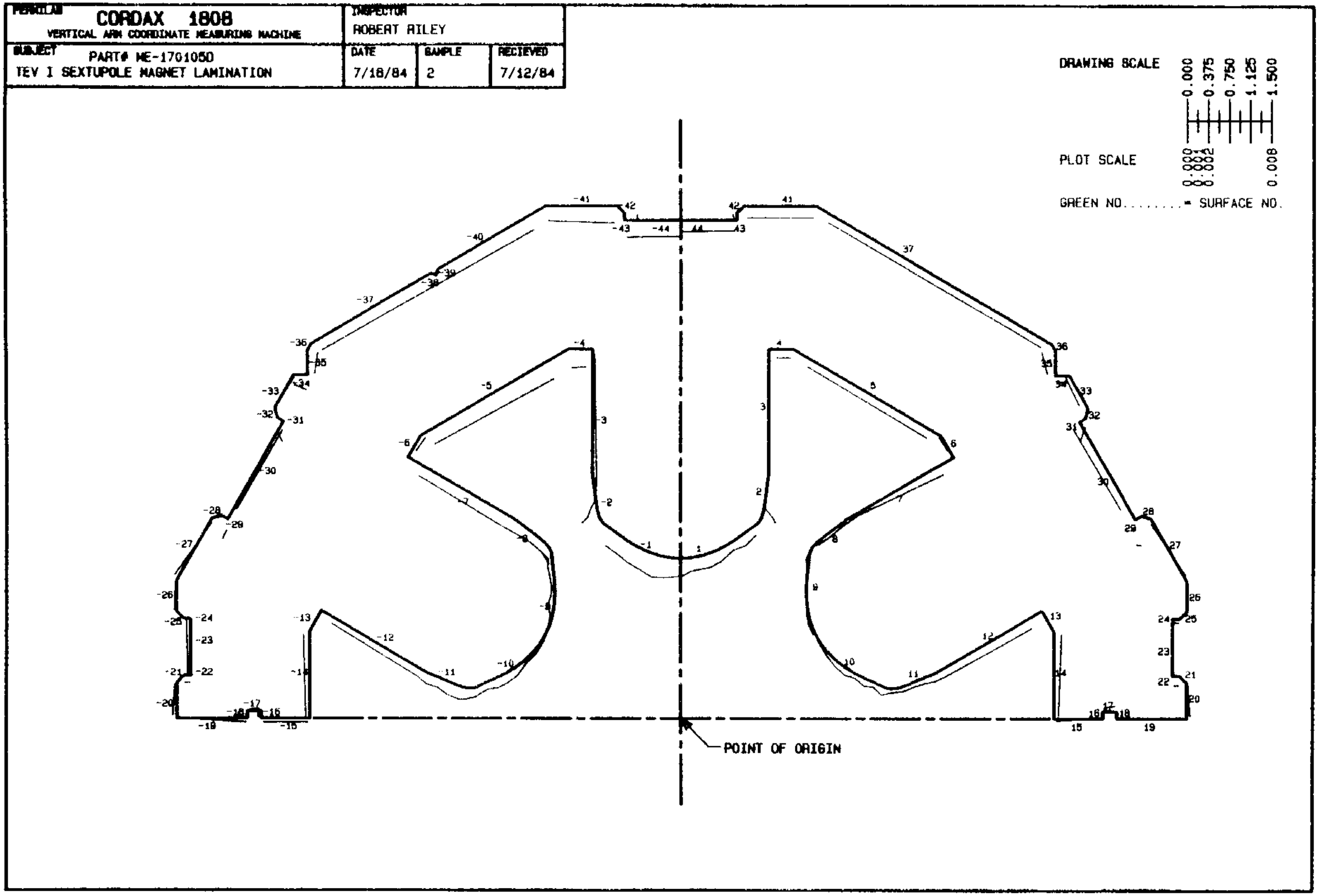

Figure 6. Part is drawn and plotted as discussed in Figure 5. Note how the three poles are very close to nominal values, but slightly out of registration.

OTHER COORDINATE MEASURING

During the past few months, we have continued to expand our capabilities in precision coordinate measuring. Towards this effort, we have added a large height gage capable of doing coordinate measuring in two axis. We have also added a new coordinate measuring machine which is part of the Machine Shop's quality control.

FUTURE PROJECTS

Future projects will undoubtedly be concentrated primarily on doing things easier. This means easier programming by interfacing with CAD. We will be looking very closely at how the Dimensional Measuring Interface Specification (DMIS)[3] does this. It also means we will want to be displaying or plotting our measurements on the contour projector in real time. And finally it would be a great achievement to see the aforementioned items completely integrated with each other.

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3) Developed by Computer Aided Manufacturing-International, Inc.