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**Automatic Visual Inspection
of Hybrid Microcircuits**

By R. E. Hines

Published May 1980

Final Report

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
Division**

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OF HYBRID MICROCIRCUITS**

By R. E. Hines

Published May 1980

Final Report
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**Kansas City
Division**

AUTOMATIC VISUAL INSPECTION OF HYBRID MICROCIRCUITS

BDX-613-2359, Final Report, Published May 1980

Prepared by R. E. Hines

An automatic visual inspection system using a minicomputer and a video digitizer was developed for inspecting hybrid microcircuits (HMC) and thin-film networks (TFN). The system performed well in detecting missing components on HMCs and reduced the testing time for each HMC by 75 percent.

DC-db

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SUMMARY

An automatic visual inspection system was developed for inspecting hybrid microcircuits (HMC) and thin-film networks (TFN). The system uses software image-analysis techniques and consists of a minicomputer, a video digitizer, a vidicon camera, a motorized X-Y positioning stage, and optics.

The system performs well in the application of automatically detecting missing beam lead devices and crossover wires on HMCs. The accuracy was acceptable and the time to verify the presence of up to 100 components per HMC was reduced by 75 percent (from 120 to 30 s for each HMC) over the manual method. The system is being used as a full-time work verification station by manufacturing personnel directly after the bonding operations.

The scanner system was programmed to inspect TFNs for visual defects such as circuit bridging, open circuits, and resistor voids. In this application, it is semi-automatic in the sense that it can automatically detect certain classes of visual defects but requires the presence of a human to detect the remaining defects and to judge the criticalness of all defects. Capability experiments were conducted to measure the effectiveness of an operator using this system versus the standard visual inspector. Those experiments indicate that the scanner/operator combination had an inspection accuracy that ranged from about 75 to 95 percent at four to five minutes per TFN. These results are comparable to those achieved by an average visual inspector. In the completely automatic mode, the scanner detects about 40 to 60 percent of the critical defects but falsely reports a large amount of non-critical artifacts. The subsequent time required by a human to recheck these false reports cause the totally automatic mode to be noncompetitive with a visual inspector. At present, the scanner/operator combination can be recommended only as an alternative method of TFN visual inspection or screening, but not as a demonstrable superior method.

Several other algorithms for TFN inspection were analytically examined. Some of these methods appear promising, but will require extensive development.

Polarized illuminators were constructed and provided to the inspectors for use on microscopes and CCTV systems after the polarizer's ability to improve optical contrast on TFN's had been determined on the automatic system.

Preliminary investigations were conducted with the scanner system into photomask inspection, radiograph analysis, and dimensional gaging.

DISCUSSION

SCOPE AND PURPOSE

Automatic HMC visual inspection has the objective of automating as much of the HMC and TFN visual inspection task as possible. This project was concerned with investigating and assessing the capability of various human, semi-automated, and automated visual inspection systems. The advantages of automatic visual inspection would be to relieve the inspectors of the eye fatigue associated with visual inspection, to decrease the subjectiveness of the human visual inspector, and to reduce the inspection time.

This report describes the application of an automated visual inspection system to two inspection tasks. The first was the inspection of TFNs for visual defects such as resistor voids and broken or bridged conductor paths. The second application was the inspection of HMCs for missing beam lead devices and cross-over wires.

PRIOR WORK

Previous investigations were conducted on the human visual inspector's capability¹ and on a computer interactive technique of performing visual inspection². Those investigations were performed to study the effectiveness of the human visual inspector when provided with aids to improve the visual image and with various levels of automation.

Some aspects of this work were based on information from previous work concerning rapid visual scanning. That work, in conjunction with the Missouri University Image Analysis Laboratory, had performed basic investigations into automatic visual inspection of HMCs and printed wiring boards. The selection of the digital scanning system hardware was based on information from that prior work.

ACTIVITY

Hybrid microcircuits produced at Bendix Kansas City consist of a ceramic substrate onto which thin-film layers of tantalum nitride and gold are deposited. A conductor and resistor network pattern is then produced in these layers by a photolith and etching process. At this level (Figure 1) they are called TFNs. The network pattern can be very dense with a minimum path width and spacing of 0.127 mm. The TFN then becomes known as an HMC as

Figure 1. Typical Thin-Film Network Pattern of an HMC

various components are thermocompression bonded, soldered, or epoxied in specific locations on the network pattern. This produces a circuit that performs a specified electrical function. The attached components consist of beam lead devices, chip capacitors, lead frame wires, and crossover wires.

Defects on the circuit must be detected visually. The method generally used for visually inspecting TFNs or HMCs consists of viewing a magnified portion of the circuit through a stereomicroscope and manually (or numerically controlled) positioning the part until all areas have been inspected. This technique is very tedious and difficult to sustain for long periods because of eye fatigue. Unless great care is exercised, areas of the circuit may be missed. There can also be some nonuniformity between inspections and inspectors because of the subjective judgement applied to the marginally critical defects. Higher production

nonuniformity between inspections and inspectors because of the subjective judgement applied to the marginally critical defects. Higher production levels in the future may cause this method to be inadequate and require the adoption of techniques to increase both inspection speed and uniformity.

The concept of applying automation to the visual inspection process becomes very appealing if a machine can be programmed to perform in a certain acceptable manner and continue that performance indefinitely. This work has the objective of developing an automated visual scanning system and evaluating its capability to perform various visual inspection tasks on TFNs and HMCs.

This report describes the approach used at Bendix and the degree of success obtained. There have been several other approaches reported in the literature but it is believed that the state-of-the-art has not yet provided a general purpose visual inspection system for production line use on HMCs. Ejiri³, et al, provide a very good discussion of the general problem of automated visual inspection and describe their experience with a system developed for printed circuit board inspection. Photo Digitizing Systems, Inc., has developed a system⁴ for the Honeywell Corporation that reportedly can perform automatic visual inspection on parts similar to TFNs. Several systems have been developed and some are commercially available that automatically inspect photomasks for artifacts; however, these systems are generally not applicable to the more general problem of production-type HMC inspection.

Defect Characteristics

The HMC is visually inspected at various stages of its manufacture. It is generally inspected once at the TFN level after all operations have been completed. As a HMC, it is inspected after several of the major assembly points. The HMC must meet various visual inspection criteria at each of these inspection points. Table 1 lists some of these visual characteristics and the criteria for rejection.

Figure 2 shows typical defects such as bridged conductor paths and voids in resistors.

Optical Reflectance Characteristics

The optical reflectance characteristics of the various materials composing the HMC control the amount of contrast that can be created for an automatic visual scanner. Ideally, the image of the pathwork and possible defects should have as much visual contrast as possible to maximize detection probability. Some HMCs or TFNs can be inspected using a backlight that creates a high contrast black and white image for a scanner system. This is quite useful for locating small open or bridged circuits and

Table 1. Typical Visual Characteristics and Rejection Requirements

Characteristic	Requirement for Rejection
TFN Level	
1. Resistor Voids	If greater than 0.0635 mm diameter or 20 percent of path width (whichever is greater).
2. Conductor Voids	If greater than 50 percent of path width.
3. Gold on Resistor	If any is observed.
4. Circuit Bridging	If extending more than 50 percent toward next path.
5. 0.127 mm path widths	If narrowed to less than 0.101 mm.
HMC Level	
1. Beam Lead Devices	If missing or misoriented; if having open, missing, broken, or peeled beams.
2. Ribbon Crossovers	If missing; if having open, fractured, or broken bonds.
3. Lead Frame Bonds	If broken, fractured, or open bond.

resistor voids. However, many HMCs have opaque backplane metallization that prohibits using a backlight. Therefore, reflected (topside) illumination must be used and since most scanners discern only shades of gray rather than color, the reflectance characteristics of the ceramic, gold, and tantalum must be considered. Once this information is known, it may be possible to select optical filters to increase the contrast.

Measurements were made to determine the relative reflectance versus wavelength of incident light for the three types of material. Figure 3 shows the reflectivity versus wavelength for the case in which a monochromator and a detector were aimed at $\pm 45^\circ$, respectively, to the surface. Since the detector probably does not intercept the same proportion of the beam for each material, this graph should be used only to indicate how the reflectance varies with wavelength for each individual material, but not to relate the materials on an absolute basis. A different

Figure 2. Critical Defects in Thin-Film Networks

Figure 3. Relative Reflectivity Versus Wavelength

measurement was made to determine the total reflectance from the surface of each material. This was done with an integrating sphere detector and a He-Ne (6328Å) laser source. The relative reflectances for tantalum, gold, and ceramic were 1, 1.65, and 2.13, respectively.

A final measurement was conducted to determine the reflectance versus angle of reflection, using the He-Ne laser source incident perpendicular to the surface and a solid-state detector (1 cm² area) positioned at various angles to the surface. Figure 4 is a polar graph of the reflectance from the three materials. The graph indicates that ceramic reflects more in all directions, that gold is intermediate, and that tantalum has the lowest reflection.

Another factor affecting the optical contrast is the slow transition of the gray level at edges between gold or tantalum and ceramic. As shown in Figure 5, it takes about 0.076mm for the full gray level transition to occur at these boundaries. In fact, if the total ceramic spacing is only 0.127mm, the full ceramic white level value may not be achieved. These effects limit the ability to automatically detect small visual defects. Figure 5 also shows improvement of the optical contrast obtained with polarized illumination. The polarized illumination proved to be better than color filters for contrast enhancement.

Figure 4. Reflectance Versus Angle

System Components

The system hardware (Figures 6 and 7) that was applied to both TFN and HMC inspection consists of the following equipment:

- An optical scanner with a vidicon camera and a television monitor (Spatial Data Corp.);
- A PDP 11/05 minicomputer with 24K words memory, an RK05 Disk, and a Decwriter (Digital Equipment Corp.);
- An X-Y positioning stage with a computer interface;

Figure 5. Gray Level Values Versus Material

Figure 6. Block Diagram of Visual Inspection System

- An optical microscope; and
- An illumination system.

The optical scanner serves as the analog to a digital conversion device between the video signal from the camera and the minicomputer. Upon request from the computer, it can sample the brightness and convert it to an 8-bit gray level (256 possible values) of any picture element (pixel) in the field of view. The image is covered by a two dimensional array of 512 horizontal by 480 vertical pixels. Under optimum conditions these points can be sampled at the television raster scan rate of 15,750 pixels per second. A 12-inch black and white television monitor is provided to display the unprocessed image that is being scanned. A small white cursor dot is superimposed on the image at the X-Y location being sampled. The television monitor is a peripheral device that is useful for the human operator to perform system set-up but is not required by the scanner system.

Figure 7. Automatic Visual Inspection System

The PDP 11/05 minicomputer is used to control the scanner, to process the image data, to control the X-Y stage, and to print out inspection results. The computer sends instructions to the scanner to set-up the X and Y location registers and to request the brightness of that X-Y pixel. When the scanner has that value available, it notifies the computer which can then receive it and place it in memory. After all necessary pixels in the image have been read into memory, the image processing portion of the program examines the data for potential visual defects.

A motorized X-Y stage that positions the TFN or HMC under the scanner is electronically interfaced to the computer. The controller interface (Appendix A) accepts an instruction from the computer software (Appendix B) that indicates the axis, the direction, and the number of steps. The controller causes the stepper motors to move the indicated number of steps and then flags the computer that the movement is complete. The computer is available for other functions during the stage movement since the controller operates independently of the computer. The mechanical stage has a 0.025mm step increment and a total range of 101 by 101mm which is sufficient to cover an entire herman (a composite TFN approximately 90 by 90mm).

The magnifying optics provide a magnification of about 3X on the vidicon tube face, a magnification zoom capability, and a 76mm working height between the TFN and the bottom of the microscope. The TFN or HMC is illuminated by a focused 150 watt tungsten-halogen lamp with a polarizer filter.

Operator interaction with the system is through a Decwriter keyboard. The Decwriter accepts operator commands and issues inspection results.

Automated TFN Visual Inspection

There are several methods that can conceivably be applied to automatically detect visual defects on TFNs. The most intuitive technique is image comparison or image subtraction which involves storing large amounts of data in the computer to characterize a correct TFN. Then the corresponding data is collected on each sample TFN and matched with the master data. This comparison is usually done on a point-by-point basis or some other involved technique. This method has the advantage that anything differing beyond a certain threshold would be detected. However, it has some major disadvantages compared with standard human visual inspection: large amounts of computer memory and mass storage are required; large processing time may be required; and the technique depends on precise alignment of the sample data with the master data. After the differing areas have been detected, they must

either be called to the inspector's attention for his classification or else further computer processing must be done in an attempt to automatically classify the detected artifacts. Analytical assessment of this technique and others will be described later in this report.

Small Feature Detection Algorithm

In order to avoid the disadvantages of the image comparison technique, a small feature detection algorithm was investigated that depends only on the prior knowledge of how the pathwork is designed on ideal TFNs. This includes the fact that all paths run either vertically or horizontally and the minimum feature size is 0.127mm. Therefore the data is processed to detect any features smaller than 0.127mm in the vertical or horizontal direction. It was assumed that most visual defects such as shorts, opens and voids would have some dimension that would be detected by this technique. This method has the advantages of requiring no precise alignment of the TFN, having relatively fast processing time, and requiring no special programming for each part number. However, there are two major disadvantages with this technique. First, certain critical defects are not automatically detected because their contrast is too low or their dimensions are greater than the 0.127mm size threshold. Second, many noncritical artifacts are flagged and consume the operator's time in judging them. These noncritical artifacts are much more common on TFNs than had been suspected. They consist of narrow borders of tantalum nitride along paths because of pattern misalignment, excess material left in various noncritical locations because of the etching process, and small noncritical scratches or burnish marks because of handling damage.

The small feature detection software consists of the following programs (See Appendix B for program listings).

- TFN: The Fortran main program that is used to call the various subroutines.
- SCN: As assembly language subroutine that scans the image data into the computer memory and applies the small feature detecting algorithm to each pixel.
- STOPX: An assembly language subroutine that checks for a keyboard space bar entry to stop the crosses from appearing on the monitor screen.
- STX: Similar to STOPX routine, except it uses the right bracket (]) symbol to stop the crosses.

MOVE: A Fortran subroutine that calculates the necessary direction and number of steps to position the X-Y stage to the next location.

MOTOR: An assembly language subroutine that is called by MOVE program and issues instructions to the motor controller interface.

XYTEST: An assembly language subroutine that interrogates the motor controller to determine if stage movement is complete.

CROSS: An assembly language subroutine that places a bright cross (X) on a television screen at a selected location.

INSP: An assembly language subroutine that accepts defect codes via the keyboard from an operator.

The scanner system operation begins with the inspector placing either a herman or an individual TFN under the scanner (Figure 8) and adjusting the X-Y table location until the TFN is correctly positioned. Exact registration is not required. The inspector must enter certain information (part number, serial number, etc.) through the keyboard and then the scanning procedure begins.

First the image brightness is sampled at 10,000 pixel locations on a 100 by 100 array. Since the area scanned in each subfield is 3.17 by 3.17mm, there is a spatial resolution of 0.0317mm per pixel. After all pixels have been read and stored in the computer memory, the program applies the small feature detection algorithm to each pixel. Basically this consists of searching for any location in the image where two adjacent edges are within approximately 0.114mm of each other. Each pixel value (P) is taken in sequence and considered as the central point and compared with its neighboring points in the following manner (Figure 9):

1. Compare P with neighbor one unit to left; if brightness difference exceeds threshold T, go to Step 4.
2. Compare P with neighbor one unit vertically above; if difference exceeds T, go to Step 7.
3. Otherwise, move to next pixel location and use as point P until all 10,000 pixels have been tested.
4. Compare P with neighbor one unit to right; if difference exceeds T, go to Step 10.
5. Otherwise, compare P with neighbor two units to right; if difference exceeds T, go to Step 10.
6. Otherwise, go to Step 2.

Figure 8. Composite-Sized TFN in Position Under the Camera

Figure 9. Flow Chart of Small Feature Detection Algorithm

7. Compare P with neighbor one unit below; if difference exceeds T, go to Step 10.
8. Compare P with neighbor two units below; if difference exceeds T, go to Step 10.
9. Otherwise, go to Step 3.
10. Compare sign of slope on one side of P with that on the other; if signs are same, go to Step 2 (Step 3 if horizontal and vertical directions have both been checked).
11. If signs are different, record pixel location in defect array for later flagging to operator.
12. When all pixels have been examined, flag all defective pixel locations on TV screen.
13. Operator views the flagged areas of image (also visually examines the rest of image for any defects not detected by scanner) and inputs defect codes via the keyboard for any critical defects.
14. The system writes out the subfield number, and the type of defect entered by the operator.

Comparative Evaluations of Scanner Versus Human

During the course of development and testing of the visual scanner system, three experiments were conducted to measure the relative inspection efficiencies of an inspector working with the aid of the scanning system versus inspecting by the standard method. (The standard method is for the inspector to visually inspect the TFN under a stereo-zoom microscope of 7 to 30X magnification and position the TFN by hand until all areas have been examined.)

Experiment One

Before the visual scanning system was fully implemented as an inspection system, some TFNs were borrowed from production to test the function of the scanner on actual product at the photolith stage. Table 2 summarizes the results based on 81 TFNs.

The author operated the scanner system during this unofficial inspection of TFNs. No official defect reports were written nor were the visual inspectors notified of the findings. The objective was to determine how the unofficial inspection at the photolith stage would compare with the standard final visual inspection. The comparison showed that the two inspections

Table 2. TFN Product Flow With and Without Scanner System

	With Scanner	Without Scanner
Photolith Scanner Inspection	81	
Scanner Reject	37	
Rework	22	
Laser Trim	66	81
Rework		8
Laser Trim*		8
Laser Trim	9	12
Line Scrap	5**	
Final Visual	57 61**	69
Visual Reject	1 1**	16
Rework	1 1**	6
Output	57 zero defects 61** zero defects	59 with 3 defects

*Second attempt Laser Trim.

**Appears that four of the nine trim line scrap were because of defects that the scanner would have detected.

basically agreed, except for three defects found by the visual scanning equipment and missed by the final visual inspector. Only one defect was observed by the visual inspector that had not been detected by the scanner system.

Another interesting feature in Table 2 is the overall production and quality sequence when the scanner inspection is performed at the photolith stage and when it is not. Without the scanner, 81 TFNs start into the process. All 81 are laser trimmed, resulting in eight that must be visually examined and reworked before the trim can be completed and 12 others that are line scrapped at the trimmer. The remaining 69 go to final visual inspection where 16 are rejected and six of those are reworked. This resulted in 59 TFNs being accepted by inspection with three of those still containing critical defects.

With the scanner inspection being inserted at the photolith stage the following results would be obtained. Again 81 TFNs start into the process, but 37 are rejected by the scanner and 22 of these are reworked. The laser trims 66 with only five line scrapped by the trimmer. Final visual inspection receives 61 and rejects one which is subsequently reworked. This results in 61 TFNs being accepted by inspection with zero known defects.

Although this experiment used the scanner to perform the photolith inspection, it is quite possible that a standard visual inspection at the photolith level would have produced similar overall results. In any event, with the inspection and rework at the photolith stage, two advantages are noticed:

1. The final product accepted contains fewer defects; and
2. The load on the trimmer is reduced since it spends more of its time trimming good product.

The main disadvantage is the added time and cost required to perform the photolith level inspection. However, this cost could be minimized if the inspection could be performed instead as a work verification operation and eliminate the corresponding paperwork that must be issued by the inspection department.

Experiment Two

Another comparison experiment was conducted during the period when the visual scanning system was an official inspection point in the inspection traveler. This experiment consisted of having the inspector operate the scanner system and report the results as usual. Following this, an unofficial inspection was performed by a visual inspector with a microscope and the results entered on a data form. The same operator ran the scanner system for the entire experiment, but four different inspectors were involved in the visual inspection part of the experiment.

Data was collected on 239 TFNs. An oversight in the design and control of this experiment was that an independent third party judgement was not performed on the involved TFNs and this complicated analysis of the data. The after-the-fact method of assessing the correctness of each inspection result was to observe the eventual disposition of the TFNs through production and final inspection. It took several months to determine this disposition.

Of the 239 TFNs inspected, it appears that 91 actually contained true defects. In the Quality Control Handbook, Juran⁵ defines two inspection parameters:

$$\text{Inspection Efficiency} = \frac{\text{True Defects Detected}}{\text{True Defects}} \times 100$$

$$\text{Waste} = \text{Percent of Good Pieces Rejected}$$

Following are the results of this comparative experiment based on these parameters:

	<u>Scanner System</u>	<u>Visual Inspector</u>
Inspection Efficiency	74 percent	90 percent
Waste	5 percent	49 percent

The 90 percent efficiency by the visual inspector agrees with normal assessments of inspector capability. The lower 74 percent of the scanner system is partially because there was not as much resolution or clarity of certain defects on the TV monitor for the operator to use in either detecting or classifying defects. For this experiment, the magnification of the scanner system had been decreased (36 views instead of 64) to make the total scan time more competitive with the visual inspector. This decreased magnification probably hindered the ability of the machine and the operator to resolve defects. Also, since the scanner can automatically detect only certain types of defects, it relies on the operator's diligence to detect other defects. Therefore the scanner operator's diligence may not have been the same as that of the visual inspectors.

The unusually large waste (49 percent) by the visual inspectors indicates a high degree of over-criticalness. Based on the backgrounds of the visual inspectors who were used for most of the experiment, this appears to be because of either less overall visual inspection experience or because of less experience with present criteria for rejection.

The inspection time required for each herman (containing 9 TFNs) was recorded for both the scanner and the visual inspector. Some of the hermans were inspected by a very experienced visual inspector and the rest by a visual inspector of average experience on TFNs. Also, the average experienced inspector inspected some TFNs for defects, then specified the location by referring to the drawing or visual aid as done during final visual inspection. The rest were examined for defects without specifying the exact location. It should be noted that the scanner printout automatically localizes the defect location in terms of the subfield number. The inspection time for each herman for these various situations, not including record keeping, is as follows.

Scanner	30.4 minutes
Very Experienced Inspector (Detect only)	12.8 minutes
Average Experienced Inspector (Detect only)	22.1 minutes
Average Experienced Inspector (Detect and specify location)	57.5 minutes

The initial analysis of the data based only on the total number of defects detected in the 239 TFNs showed that the visual inspectors reported 299 defects compared with only 94 by the scanner system. It was suspected that the visual inspectors were being over-critical based on the amounts and types of defects being reported.

Further analysis based on the total percentage of all TFNs rejected and on the disposition of each TFN in terms of either rejecting or accepting it showed the following results.

Scanner versus All Inspectors

Agreement on Disposition	63 percent
Rejected by Scanner	31 percent
Rejected by Visual	64 percent

Scanner versus Very Experienced Inspector

Agreement on Disposition	82 percent
Rejected by Scanner	22 percent
Rejected by Visual	27 percent

Scanner versus Average Experienced Inspector

Agreement on Disposition	59 percent
Rejected by Scanner	33 percent
Rejected by Visual	73 percent

It should be noted that the TFNs inspected by the very experienced inspector were not the same as for the average experienced inspector. However the experiment did provide an opportunity of comparing visual inspectors of various experience levels since five of the hermans (45 TFNs) were first inspected by an inexperienced visual inspector and then later reinspected by the experienced inspector. Following are these results in terms of number of agreements on reject-accept judgement.

Scanner versus Experienced Inspector	37 of 45
Scanner versus Inexperienced Inspector	21 of 45

Experienced versus Inexperienced Inspector	22 of 45
TFNs rejected by Scanner	10 of 45
TFNs rejected by Experienced Inspector	12 of 45
TFNs rejected by Inexperienced Inspector	21 of 45

These results indicate that there can be a large variation in results between an experienced and inexperienced inspector. The scanner tended to have better agreement with the experienced inspector.

Experiment Three

A third experiment was performed where an effort was made to thoroughly and independently examine the test TFNs ahead of time so the results of the inspectors could be better analyzed. Four inspectors were used in the experiment and eight sample TFNs were examined. There were actually six different TFNs since two were repeated to check the repeatability of each inspector. Seventeen confirmed defects, consisting of bridged circuits, open circuits, and resistor voids, were distributed among the eight TFNs. Two TFNs were free of defects and one TFN had five critical defects.

The experiment was designed to test for the following factors.

- Does the scanner improve the inspection efficiency of visual inspectors?
- Does the scanner decrease the inspection time?
- Does the scanner improve the uniformity of inspection for the same inspector?
- Does the scanner improve the uniformity of inspection among a group of inspectors with various levels of experience?

Table 3 shows the results of this experiment. The scanner system can detect some defects automatically, while others must be detected by the operator by simultaneously viewing the television screen. The scanner column indicates the defects that are detected automatically by the scanner and the defects that require the operator's assistance for detection. For the experiment, the automatic detection capability was disabled so that it could be determined how efficiently the inspectors could detect the entire group of defects by viewing the television screen. These results can then be modified to determine the effect of automatic flagging of defects by adding back in the defects that the system would automatically detect.

Table 3. Scanner Versus Human Inspection Results

Sample Number	Defect*		Scanner**		Inspector "A"		Inspector "B"		Inspector "C"		Inspector "D"	
	Number	Type	Auto. Detect	Operator Detect	Visual	Scanner	Visual	Scanner	Visual	Scanner	Visual	Scanner
1	1	RO	X		X	X	X	X	X	X	X	X
	2	RO	Xm		X	X	X	X	X	X	X	X
	3	RV	X		X	X	X	-	-	X	-	X
	4	SC	-	X	X	X	X	X	X	X	X	X
2	5	SC	Xm		-	X	-	X	X	-	X	-
	6	SC	-	X	X	X	X	X	X	X	X	X
3	NONE											
4	7	RV	X		X	X	X	X	X	X	X	X
	8	RV	X		X	X	X	X	X	X	X	X
5	NONE											
6**	9	RV	X		X	X	X	X	X	X	X	-
	10	RV	X		X	X	X	X	X	X	X	X
7	11	RV	-	X	X	X	X	X	X	X	-	-
	12	SC	-	X	X	X	X	X	X	X	X	X
	13	RV	-	X	X	X	X	X	X	X	X	-
	14	RV	X		X	X	-	X	X	X	X	X
	15	RV	X		X	X	X	X	X	X	-	X
8**	16	SC	Xm		X	X	X	X	X	X	X	X
	17	SC	-	X	-	X	X	X	X	X	X	X
True Defects Missed:					2	0	2	1	1	1	3	4
False Defects Reported:					9	6	0	0	5	4	5	1
Inspection Time for 8 TFN's (minutes):					30	50	23	30	30	35	50	40

*SC is Short Circuit; RO is Resistor Open; and RV is Resistor Void.

**Sample 6 is repeat of 4; sample 8 is repeat of 2.

*** (X) is Defect detected; (-) is Defect missed; and (Xm) is Marginally Detectable by Automatic Mode.

Four inspectors with various levels of experience were used in the experiment.

- Inspector A: Engineer with very little training or experience in TFN visual inspection.
- Inspector B: Engineer with moderate experience in TFN inspection gained through engineering projects.
- Inspector C: Hourly TFN visual inspector having several years visual inspection experience but less than one year on TFN inspection.
- Inspector D: Hourly TFN visual inspector having less than one year total visual inspection experience.

Inspection Efficiency: The group inspection accuracy based on 68 possible chances (17 defects times four inspectors) was 88 percent (eight defects missed) without scanner system, 91 percent (six defects missed) with scanner system but without automatic flagging of potential defects, and 97 percent (two defects missed) if scanner system had used automatic flagging since four of the missed defects would have been marginally detectable by the scanner.

On an individual basis, two inspectors (A and B) improved their accuracy, one (C) held even, and one (D) was worse using the scanner system. If automatic flagging had been used, all four would have improved their accuracy.

The other measure of inspection efficiency is how many non-critical artifacts are reported as critical. Without the scanner, 19 were reported; with the scanner, only 11 were reported.

Inspection Time: The group average for eight TFNs without the scanner was 32 minutes with a range from 23 to 50 minutes. With the scanner the time was 39 minutes with a range from 30 to 50 minutes. The 32 minute time without the scanner would be increased if the inspector is required to specify the defect location by referring to a visual aid or drawing.

Therefore the times appear to be comparable for both methods. Application of either method to actual inspection might result in a decrease of this measured time, since inspection can usually be terminated when the first nonrepairable defect is found.

Uniformity for Same Inspector: Two TFNs containing two defects each were resubmitted to each inspector without his knowledge. This provided an opportunity to see how repeatable their results

would be. Without the scanner the group repeated 13 times out of 16 chances (four repeats for each of four inspectors). With the scanner the group repeated 13 times. With automatic flagging, the group would have repeated on all 16 occasions since the defects missed were ones that were marginally detectable by the scanner. Note that all successful repeats consisted of the defect being detected each time; no instances consisted of missing the defect each time.

The results are somewhat inconclusive based on individual performance since the repeatability of two inspectors (A and B) increased with the scanner while the other two (C and D) decreased. With automatic flagging, it appears that all four would have improved.

Uniformity Among Inspectors: This was measured by determining the number of times out of 17 possible chances that all four inspectors correctly detected each defect. Without the scanner, all four agreed on 11 occasions. With the scanner, all four agreed on 12 occasions. If automatic flagging had been utilized, all four would have agreed on 15 occasions.

Summary Of Experiments. The results of the three experiments do not seem conclusive in favor of either the scanner or visual inspector. However it has enabled us to quantify some aspects of both techniques that were not well-defined previously, such as relative inspection results among different inspectors and the time required to perform the various functions associated with TFN visual inspection.

It should be noted that the scanner system is only semi-automatic since it requires an operator to stay with it to detect certain kinds of defects and to classify all defects. Therefore, when reference is made to the scanner's detection results, it should be understood to mean the scanner/operator combination. This factor also causes the overall efficiency of the scanner system to be greatly influenced by the operator's capability. Also, the full effect of the time consumed by the scanner's flagging of noncritical artifacts was not measured in experiment three since the automatic flagging feature was disabled.

Following are conclusions that may be drawn from the various experiments.

- A diligent scanner/operator combination has an inspection accuracy at least as high as a visual inspector on shorts, opens, and resistor voids. (Experiment One)
- It may be an economical advantage to perform a visual inspection at the photolith stage. (Experiment One)

- A visual inspector had a significantly higher inspection efficiency than the scanner, 90 percent versus 74 percent, but the inspector also had a higher waste factor, 49 percent versus 5 percent. (Experiment Two)
- The scanner is slower than a visual inspector for screening, 30 versus 13 to 22 minutes. However, the scanner may be faster if a visual inspector is required to specify defect locations, 30 versus 57 minutes. (Experiment Two)
- There can be large variations in inspection results among inspectors of various experience levels. (Experiment Two)
- The group inspection efficiency for circuit bridging, open circuits, and resistor voids is at least as high for the scanner/operator (91 to 97 percent) as for the visual inspector (88 percent). However, the results are not consistent on an individual basis. (Experiment Three)
- The group's average inspection time for each herman is slightly faster without the scanner, 32 versus 39 minutes, when the inspector approximates only the defect locations. (Experiment Three)
- The overall repeatability for the same inspector is at least as high for the scanner/operator as for the visual inspector. On an individual basis, the results are not consistent. (Experiment Three)
- Uniformity of results among inspectors was slightly higher for the scanner/operator combination. (Experiment Three)

Experience on Production Units. The TFNs are normally visually inspected only at the final visual inspection point. For a six-month period an extra inspection point was established for three part numbers. This inspection point was placed directly after the photolith etching operation and before the substrates are scribed, separated, and resistor laser trimmed. This point of inspection was chosen for several reasons:

- At this level, the TFNs are free of resistor laser trim kerfs and the corresponding electrical probe marks that cause erroneous output by the automatic visual scanning system.
- The TFNs have minimal handling damage at this level, which normally is only cosmetic damage but causes erroneous system output.

- An opportunity to study the overall effects on the total quality and production operation of rejecting or reworking defective TFNs was provided at the earliest and the least expensive level.

Table 4 summarizes the results obtained during the six-month period that used the automatic system inspection point and a two-month period following the removal of that inspection point. The defect rate detected by the automatic system was 29.1 percent and the final standard visual inspection detected a defect rate of 13.6 percent. The TFNs that were not sent through the automatic visual inspection point during this time period produced a 30.5 percent defect rate at final visual inspection. During the two-month period after the removal of the visual inspection system, the defect rate at final visual inspection was 28.8 percent.

Analysis of Alternative Algorithms for TFN Inspection

Since the TFN inspection system based on small feature detection could not be experimentally proven significantly superior to human inspection, it was decided to investigate alternative detection algorithms. This was done analytically rather than by completely programming the scanner to evaluate each method. A set of 20 typical TFN defects were selected and the scanner was used to read and print the gray level values for pixels that would encompass the defect and adjoining regions. Figure 10 shows a typical data array along with a photograph of the corresponding defect. This data can then be manually analyzed for the detection sensitivity of various algorithms.

Table 5 lists a description of the 20 sample defects and the extent to which they could be detected with each algorithm. One column shows the desired response since some defects were not critical. Following is a description and assessment of each algorithm.

1. Small Feature Detection Method. This is the same algorithm as evaluated experimentally. It was analytically examined, using a brightness threshold of 20 to compare its sensitivity to the other methods. It correctly inspected 9 of the 20 defects resulting in an inspection efficiency of 50 percent and waste of 75 percent. The advantages are no special programming for each microcircuit and no precise part alignment is required. The disadvantages are the lack of sensitivity to defects larger than 0.127mm or low in contrast and the large waste factor that requires a human to judge the potential defect.

Table 4. Production Unit Inspection Results

	Quantity Inspected	Quantity Defective	Total Defects	Percent Defective
Six-Month Period During Use of Automatic Visual Inspection Point				
Automatic System	690	201	348	29.1
Final Visual (For TFNs Inspected by Automatic System)	361	49	59	13.6
Final Visual (For TFNs Not Inspected by Automatic System)	118	36	48	30.5
Two-Month Period After Removal of Automatic Visual Inspection Point				
Final Visual	753	217	330	28.8

2. Integrated Gray Level Method. This algorithm compares the test TFN with a known correct TFN on the basis of the integrated gray level for corresponding small regions on each part. A 3 by 3 pixel grid representing a 0.10 by 0.10mm region was selected and the gray levels of the 9 pixels were summed and compared with the expected value based on the correct circuit. If corresponding sums differed by more than a selected threshold (typically 35), the area was flagged as a defect. This 3 by 3 grid comparison is moved in adjacent steps until the entire TFN is inspected.

This algorithm correctly inspected 8 of the 20 defects resulting in an efficiency of 44 percent and a waste of 75 percent. The advantages are a high sensitivity to large size defects and implementation with hard-wired logic to achieve higher speed. The disadvantages are the required precise registration with a master TFN or its stored image data and the lack of sensitivity to small critical defects.

3. Differing Pixels For Each Area Method. This algorithm is similar to the integrated gray level method except that each pixel within a 3 by 3 grid is compared with the corresponding pixel in the master TFN.

IXO, IYO, IStep (3I3) = 200200004

														CERAMIC	
125	125	125	121	121	124	119	116	161	170	173	171	169	168	167	166
123	121	125	127	123	122	121	114	163	169	168	164	156	150	146	146
123	121	125	121	130	122	122	115	158	166	168	150	108	105	102	112
124	124	124	122	128	123	117	109	156	164	163	145	113	125	126	125
123	124	127	127	126	125	123	110	150	158	155	141	115	123	123	124
120	126	126	126	123	125	125	108	139	146	145	133	111	128	123	124
121	122	123	128	123	124	124	107	102	101	103	110	114	126	126	126 GOLD
121	127	127	128	131	124	124	114	95	93	96	97	116	123	128	125
124	126	126	126	128	127	128	113	95	93	94	93	118	124	121	124
121	127	127	123	128	120	124	116	97	96	95	97	116	128	125	122
122	119	126	124	127	121	122	113	101	101	103	105	109	122	123	122
115	125	124	125	125	129	125	110	133	135	139	138	107	123	124	124
119	120	124	123	124	125	122	111	143	155	154	146	107	122	128	128
122	125	127	125	129	123	126	111	143	159	160	151	110	125	126	125
120	123	125	128	124	124	127	115	144	161	166	153	113	123	126	127
117	123	123	124	124	122	122	111	141	163	165	153	114	123	124	126
GOLD								CERAMIC

Figure 10. Gray Level Data-Array for a Typical Defect

Table 5. TFN Defect Detectability With Various Algorithms

Defect	Desired Response	1	2	3	4	5
1. Bridge (small)	Yes	X	No	No	No	No
2. Bridge (large)	Yes	No	Yes	Yes	Yes	Yes
3. Open Resistor	Yes	Yes	X	No	Yes	Yes
4. Resistor Void	Yes	Yes	Yes	Yes	Yes	Yes
5. Open Resistor (low contrast)	Yes	X	No	No	Yes	Yes
6. Bridge (large)	Yes	No	Yes	Yes	Yes	Yes
7. Bridge (low contrast; medium size)	Yes	No	No	No	X	Yes
8. Bridge (small; low contrast)	Yes	No	No	No	X	X
9. Bridge	Yes	No	X	No	X	Yes
10. Resistor Void (low contrast)	Yes	X	No	No	Yes	Yes
11. Resistor Void	Yes	X	No	No	No	No
12. Open Conductor	Yes	No	No	No	No	No
13. Bridge (long, narrow)	Yes	Yes	No	No	No	No
14. Bridge	Yes	X	No	No	Yes	Yes
15. Bridge (large)	Yes	No	Yes	Yes	Yes	Yes
16. Excess Tantalum	No	No	Yes	Yes	No	No
17. Excess Tantalum	No	Yes	Yes	Yes	No	No
18. Excess Tantalum	No	Yes	Yes	Yes	No	No
19. Excess Tantalum	No	Yes	No	No	No	No
20. Bridge	Yes	No	Yes	Yes	Yes	Yes

Totals:

Correct "Yes" Decisions:	16	8	7	5	12	12
Correct "No" Decisions:	4	1	1	1	4	4
Incorrect Decisions:	--	11	12	14	4	4

Marginal Detections (X) are considered correct decisions.

- 1: Small Feature Detection Method
- 2: Integrated Gray Level Method
- 3: Differing Pixels Per Area Method
- 4: Path Tracking Method
- 5: Selected Path Scanning Method

Two selectable thresholds are required for this method. A gray level threshold (typically 30) is used to decide if the brightness of the test pixel is significantly different than the master pixel. Then another threshold (typically 5) is used to determine how many of the 9 pixels in the 3 by 3 group must differ before the area is flagged as a defect.

This algorithm correctly inspected 6 of the 20 defects resulting in an efficiency of 31 percent and a waste of 75 percent.

The advantages and disadvantages are the same as those of the integrated gray level method. One additional advantage is the results are not influenced as severely by one very bright or dark pixel such as occasionally occurs on acceptable TFNs.

4. Path Tracking Method. This algorithm is based on the premise that the brightness of four adjacent pixels (covering about 0.127mm) taken perpendicularly to the length of a path should all be less than a certain gray level threshold. Similarly for a path spacing (ceramic), all four readings should be greater than a threshold.

This was simulated analytically by moving the four pixels lengthwise along a path (or path spacing) and requiring that at least three of the four pixels read less (greater) than a threshold (typically 120). The starting and ending points of each sampled path would be preprogrammed into the machine. This algorithm would be sensitive to interruption, voids, or narrowing of the sampled path.

This algorithm correctly inspected 16 of the 20 defects with an efficiency of 75 percent with no waste.

The advantages are the scans are made only in locations where critical defects are most probable and the speed would be fairly high. The disadvantages are the requirements for preprogramming the scanned coordinates and maintaining good registration of the part.

5. Selected Path Scanning Method. This method is similar to the path tracking method since the beginning and end coordinates of each scanned path (or path spacing) must be preprogrammed and stored in memory. The technique could be programmed for 0.127mm or 0.254mm pathwidths. The scan begins by sampling the gray level of about three pixels around the starting location and using the darkest (brightest) as the nominal gray level. Then sample one pixel at a time moving lengthwise along the path. If the gray level changes more than a preselected amount from the nominal value, this is considered to be either a potential defect or that the scanned path is running off the conductor path. In this case, a

sidewise step should be sampled to see if the gray level returns to the nominal range and if the scanned path can be continued to the end point. If a continuous path cannot be traced between the end points without encountering gray levels outside the nominal range, the region should be flagged as defective.

This algorithm correctly inspected 16 of the 20 defects resulting in an efficiency of 75 percent with no waste.

The advantages and disadvantages are similar to those of the path tracking method.

In summary, the various algorithms generally fall into two categories. Category one inspects a part based on a general knowledge of certain characteristics of a correct part and detects variations from that. This method can be fast and no registration is required, but the method is usually sensitive only to a small range of defects and can produce excessive waste unless human judgement is used also. Category two inspects a part by comparing it in some way on a region-by-region basis with a master. This method can be more accurate and can produce less waste but it requires a precise registration of the test part with the master part. The ultimate sensitivity to defects is limited by the precision with which the two patterns can be registered.

Automated HMC Visual Inspection

Some inspection tasks on HMCs can potentially be automated. The most feasible of these tasks is the inspection for missing components. Verification of the presence of beam lead devices and ribbon crossovers on HMCs (Figure 11) is a tedious visual comparison to a visual aid for each HMC. Some circuits contain almost 100 of these components. Manufacturing is allowed about 0.00035 standard hours per component for verification of beam lead devices and ribbon crossovers. Even with this 100 percent visual comparison performed by manufacturing personnel, missing components constitute a significant reject category at later product inspection points. For example, during 1977-78 for the I/O-1, I/O-2, MB, and DR HMCs, 2,110 were inspected for ribbon crossovers, 168 were defective, and 85.1 percent of these (6.8 percent of the total) were for missing ribbons. Similarly, of 2,152 HMCs inspected for beam lead devices, 112 were defective of which 46.4 percent (2.4 percent of total) had missing devices.

Because of this significant level of missing components, the inspection department conducts 100 percent inspection for missing components instead of sampling. Inspection uses automatic indexing systems, but the inspector has to visually verify component presence by viewing through a microscope or on a television display. The accuracy of this inspection method has been quite acceptable, but it requires about six minutes for each HMC.

Figure 11. HMC With Attached Beam Lead Devices and Ribbon Crossovers

It appeared that the automatic visual inspection system previously used on TFNs could be reprogrammed to inspect HMCs for missing components. Preliminary scans were taken of areas on HMCs that contained beam lead devices and crossovers. These scans indicate that there should be enough optical contrast for the system to automatically determine if a component is missing. Gray levels were in the 160-220 range for ceramic, 120-160 for gold, 60-90 for tantalum nitride, 55-80 for beam lead devices, and 50-80 for ribbon crossovers. Therefore, the components should be easily discriminated from the gold and ceramic and confusion with the tantalum nitride could be avoided by using judicious scanning locations.

Missing Component Detection Algorithm

The missing component detection software consists of the following major programs (See Appendix C for program listing, except for those listed in Appendix B).

- HMC: The main Fortran program used to inspect the HMC and call various subroutines.
- CHECK: Fortran subroutine that reads from part definition file and calls various secondary subroutines.
- SCANX: Assembly language subroutine that samples the gray level of pixels in an X pattern at any specified location.
- JUDGE: Assembly language subroutine that checks the keyboard for any command code from the inspector.
- TRIREG: Fortran subroutine that automatically aligns the HMC to a reference point in the field-of-view.
- MOVE: See Appendix B.
- STOPX: See Appendix B.
- EYECTL: Assembly language subroutine that samples the gray level at a specified X, Y location.
- HWIDTH: Fortran subroutine that determines the number of pixels across a feature in a horizontal direction.
- VWIDTH: Fortran subroutine that determines the number of pixels across a feature in a vertical direction.
- MOTOR: See Appendix B.

The software for creating a part definition file on the disk consists of the following programs.

- HMCNEW: The main Fortran program used to create a new part definition file and to call various subroutines.
- JS0001: Assembly language subroutine that allows various keys on the teletype keyboard to control the positioning of a cursor on the monitor screen.
- SCANX: See previous description.
- TRIREG: See previous description.
- MOVE: See Appendix B.
- STOPX: See Appendix B.
- EYECTL: See previous description.

The software that allows later repositioning to any subfield on the HMC and the location of any X, Y coordinate within that subfield consists of the following programs.

- LOOK: The main Fortran program used to recheck various subfields and to locate X, Y coordinates.
- JS0001: See previous description.
- TRIREG: See previous description.
- MOVE: See Appendix B.
- STOPX: See Appendix B.
- EYECTL: See previous description.

The software that allows checkout of system contrast and magnification on a standard test pattern consists of the following programs.

- SETUP: The main Fortran program used to check brightness and magnification values.
- AVG: Fortran subroutine that calculates the average gray level in a localized region.
- SCANX: See previous description.

HWIDTH: See previous description.

VWIDTH: See previous description.

The scanner system operation begins by entering the HMC program and placing a HMC under the scanner. The inspector must enter certain information (part number, serial number, etc.) through the keyboard. The system then puts a small white pointer on the television screen and the inspector coarsely positions the HMC until the pointer lies within a registration triangle on the HMC. The TRIREG subroutine then automatically registers the HMC to within 0.025mm. Next, the CHECK subroutine reads the component identification and coordinate location information from the part definition file and calls the SCANX subroutine. SCANX samples the gray level in an X pixel pattern that encompasses the nominal location where a component should be bonded on the HMC. About 20 to 40 pixels are sampled, with each leg of the X being about 0.254 to 0.508mm in length. This gray level data is returned to the CHECK subroutine which determines how many pixels have a gray level less than a certain threshold. (This algorithm is used since the ribbon crossovers and beam lead devices produce a lower (or darker) gray level than the ceramic or gold that would be uncovered if the component were missing.) If the number of dark pixels exceeds a preselected value (typically, about half of those scanned), the component is automatically judged to be present. Otherwise, the system assumes the component is potentially missing and increases its search pattern to include possible misregistration of the HMC under the scanner or deviation in the attachment location of the component. If the component still cannot be found with the increased search pattern, the system classifies the component as missing. At this point, there are two options available depending upon which inspection mode has been selected. The automatic mode will cause the missing component's identification and location to be printed on the teletype and the remainder of the HMC is inspected. The interactive mode will cause the system to put a white pointer on the screen at the location of the missing component and then wait until the inspector either confirms or overrules the system. If the inspector agrees with the system, the component information is printed and scanning is resumed.

The HMCNEW program is used by the process engineer to create part definition files on the system disk. The program asks for the part number and the number of subfields in each direction that will be required to cover the HMC. A 25.4 by 25.4mm HMC is generally scanned with a 5 by 5 pattern of slightly overlapping fields. Next, the HMC is automatically registered with TRIREG. The engineer then uses the JS0001 subroutine to position a small white dot on the television screen to either the center or ends of the component to be recorded in the file. The SCANX subroutine

samples the gray level at the component location and prints the value for the engineer's evaluation. If the engineer approves, he enters the component identification which is recorded along with its X, Y location in the part definition file. This process continues until all components on the HMC have been recorded. An enlarged layout drawing of the HMC is useful during this process to assist in locating and identifying all the components since they are very small and look similar. The part definition file for a HMC containing about 100 components can be created in less than two hours.

Files for several hundred different part numbers could be contained on a single disk along with the inspection programs and operating system software.

LOOK and SETUP are other programs that may be used. LOOK allows an HMC to be repositioned to any subfield selected by the operator and the coordinates of any X-Y location within that subfield can be printed out. This capability is useful for reexamining a certain component location and for locating new components that might be added to an existing HMC design. SETUP allows the gray level gain, optical magnification, and illumination level of the system to be checked by scanning a test pattern of known size and gray level.

System Evaluation

A major technological problem is determining if an appropriate gray level threshold and dark pixel threshold can be selected that would allow the system to accurately detect missing components. Obviously, if these thresholds are too stringent, some missing components will not be detected; conversely, if they are too lenient, some acceptable product will be rejected. Selection of a searching pattern that provides the best probability of detecting a missing component is also important. During a field-test of the equipment, various threshold values and searching patterns were examined. The method that appears to perform best for threshold is to allow the scanner to calculate its own threshold on each HMC based on a quick initial scan of a specified area. The search pattern that gives the best detection probability is to scan a series of closely spaced crosses (X) between two end points that represent the expected location of the crossover or beam lead device. Missing beam lead devices are fairly easy to detect since they are generally large and dark. Missing ribbon crossover wires are more difficult to detect since they loop up from the substrate and the location of the darkest gray level can vary from wire to wire and from circuit to circuit.

The system has been programmed to inspect five different HMCs. The system's performance was evaluated by examining records for the first official inspection point that occurs after the work verification operation performed with the scanner system. A time period of four months before and two months after installing the scanner has been examined. During the four-month period, 1,070 HMCs were inspected and 47 crossovers and 20 beam lead devices were found to be missing. During the two-month period when the scanner was used, 257 HMCs were inspected and only one missing crossover and no missing beam lead devices were detected. This indicates that almost all of the potential defects due to missing components are being detected by having the production workers use the scanner system to verify their work directly after the bonding operation. This allows the HMC to be reworked quickly. It also means that the inspection department might then be able to inspect this product on a sampling plan basis, rather than 100 percent.

The scanner appears to be providing a time savings of about 75 percent. It previously took a human about 120 s to verify the presence of 100 components on a HMC. The scanner system is performing this operation automatically in less than 30 s.

Other Applications Investigated

The scanner system has been used for feasibility studies on several other applications, such as HMC photomask inspection, radiograph analysis, and high precision dimensional measurements. These studies generally involved writing some preliminary software for each application.

Photomask Inspection

Some preliminary investigations were made into inspecting the photomasks for artifacts and line widths. In some ways, the photomask presents a more suitable subject for the optical scanner system. The photomask can be backlit to present a high contrast image and most artifacts on the photomask that are large enough to be detected should be corrected.

The scanner has been applied in several different ways. The regular TFN inspection program has been used on photomasks to flag opaque or transparent artifacts that are smaller than 0.114mm and also to detect line widths that fall below 0.114mm. Later discussion with the process engineers indicated that a more important capability would be to flag and measure any line width that is out-of-tolerance. This has been approached by programming the system to do a 100 percent scan of a photomask to flag and measure any 0.132mm line width that is not in the range of 0.130 to 0.137mm. An accuracy of 1.27 μ m (50 μ in.) (one standard

deviation) has been demonstrated with respect to a master line width at calibrated locations in the field of view and $2.54\mu\text{m}$ ($100\mu\text{in.}$) at other locations. This accuracy was achieved in a well controlled experiment and has not yet been achieved on an actual photomask. However, it is felt that with further development of the illumination system, the calibration program, and the method of line edge detection, accuracies of $1.27\mu\text{m}$ ($50\mu\text{in.}$) can be achieved on the photomask line width measurements. This technique could do a 100 percent scan of a 25.4 by 25.4mm photomask area in 15 minutes and indicate the line widths that are not within tolerance.

Radiograph Analysis

A common nondestructive testing technique is to produce X-ray radiographs of a part and then have an experienced film reader interpret the radiograph for various characteristics. This often involves having the human detect and interpret very subtle changes in film density or gray level. In general, this is a time-consuming and tedious task and is subject to human variability.

The automatic scanner system has been evaluated on radiographs of two different products. One is a very thin aluminum foil whose thickness must be measured within one percent. The other was small glass microballoons whose inner and outer diameters and wall thickness must be non-destructively measured.

The foil radiograph presented problems because of spatial gradient of the X-ray beam intensity. However, since this is a repeatable effect, a software correction was made to the apparent film density to correct for both X-ray beam nonuniformities and for the scanner's illumination source nonuniformities. Radiographs of three calibrated foils that encompassed the expected thickness range were used to calibrate the scanner. Preliminary results indicated the scanner could resolve about 0.01 density units or about 0.12mm ($5\mu\text{in.}$).

The difficult aspect for human interpretation of the glass microballoon radiographs is the determination of the inside diameter and searching for thin wall areas. Once it is decided what gray level thresholds to select to represent these values, the scanner can automatically detect and measure these characteristics.

Dimensional Gaging

Automatic optical dimensional gaging is another possible application of the visual scanner system. The gaging is best applied to parts that are normally inspected on optical comparators. These are backlighted subjects which present a high contrast image to

the scanner. It then becomes a problem of accurately determining the location of edges of various features on the part. Datum reference features can be automatically recognized and locations and size of other features relative to these can be measured. A feasibility study was conducted with the automatic scanner to determine how well a 1mm diameter hole with a 1.75mm field-of-view could be measured.

The hole was measured with a one standard deviation repeatability of $1\mu\text{m}$ (40 $\mu\text{in.}$) on size, $1.3\mu\text{m}$ on horizontal location, and $0.66\mu\text{m}$ on vertical location.

Guidelines for Applying Automatic Visual Inspection

When contemplating the automation of some visual inspection task, certain characteristics of that task should first be considered. The ultimate system complexity and the time required to inspect the part can be greatly influenced by these characteristics. Following are some of the primary considerations:

1. Are the defects distinctive? Do the defects possess some unique characteristics such as size, shape, color, location, etc., that make them easily detectable? Also, can it be assumed that anytime a feature is detected with these characteristics that it will always be a critical defect or will further processing be required to classify the true defects?
2. What is the range or variety of defects to detect on each inspection pass? Is it just one type of defect or many different ones, such as all scratches and all missing components?

A human is relatively efficient at handling the first two considerations; however, these considerations are somewhat difficult for an automatic system.

3. How many gray-levels are required to adequately analyze the image? A product that has just one type of material on a substrate or a product that can be inspected with back-lighting generally constitutes a simpler image since only two gray levels (black and white) need to be used. However, three or more gray levels are required on some products such as HMCs.
4. Is real-time processing required or can a longer time be taken to inspect the part? Real-time processing would probably be desired on large samples of high production parts, but this time limitation also limits the amount of data that can be scanned into the computer and analyzed.

5. What is the spatial resolution required to adequately inspect the part? As a rough approximation, an accuracy of 1 percent of the field-of-view on vidicon scanners can usually be attained. Anything less than 1 percent would require more sophisticated processing or increasing the optical magnification resulting in longer processing time.

In addition to these considerations, a few others might be whether the image is in motion or stationary during each scan; whether the system should be able to make its own decisions and adapt itself depending on the quality of the part being inspected; and whether the system should be able to issue the inspection results in a printed report form.

All of these factors need to be assessed when deciding whether an inspection task is amenable to automation and what type of system is best suited to the task.

ACCOMPLISHMENTS

The effort described in this report has resulted in the following accomplishments.

- A prototype automatic TFN visual inspection system was developed and its performance was tested against visual inspectors on actual product.
- The inspection efficiencies and times of the TFN scanner system and various visual inspectors were quantified through several capability experiments.
- An automatic HMC visual inspection system was developed for accurately detecting missing components in 25 percent of the time previously required.
- The HMC scanner system is being used by the production department as a full-time work verification system and its performance is very promising.
- Preliminary investigation of automatic inspection of photo-masks on a 100 percent area coverage basis appears encouraging.
- The optical reflectance characteristics of ceramic, gold, and tantalum nitride were investigated and methods of enhancing the optical contrast were determined.

- Polarized illuminators were constructed and provided to the inspectors for use on microscopes and CCTV systems after the polarizers ability to improve optical contrast on TFNs was determined.

RECOMMENDATIONS

The present state of development of the automatic scanner system versus the capability of average visual inspectors results in the following recommendations.

- The automatic scanner system is highly recommended for use in detecting missing beam lead devices and crossover wires on HMCs.
- The scanner is not recommended for use as the exclusive final visual inspection device for TFNs because certain types of critical defects are difficult to detect with the scanner and electrical probe marks and laser trim cuts cause many noncritical artifacts that are erroneously flagged by the scanner.
- The scanner/operator combination could be recommended as an alternative method for thorough screening of TFNs at the photolith level. The overall performance on shorts, opens, and resistor voids is as good as a visual inspector if he is required to specify defect location. Otherwise, a visual inspector is faster.
- It is recommended that any further development effort on automatic visual inspection of TFNs be restricted to techniques that would be completely automatic in terms of defect detection and classification. In order to provide a significant improvement over an average visual inspector in a screening operation, the automatic system should scan a TFN in less than 60 seconds, detect at least 75 percent of the critical defects, and falsely report less than 10 percent of noncritical defects. This capability is presently beyond the known state-of-the-art in image processing; however, the capabilities of outside vendors should be assessed before continuing any in-house development.
- It is recommended that further effort be devoted to the development of an automatic scanning system for 100 percent inspection of photomask line widths.

FUTURE WORK

There are no definite plans at this time to continue an in-house effort toward automatic visual inspection of HMCs or TFNs. If the automatic HMC visual inspection system for missing component detection continues to perform satisfactorily, it should require no further software development. The only programming required is the routine creation or modification of part definition files.

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Appendix A

ELECTRONIC INTERFACE BETWEEN COMPUTER AND
X-Y STAGE

Figure A-1. Schematic of Computer-to-Stepper Motor Interface

Figure A-2. Interface to Allow Computer or Joystick Control

H803		H803		H803	
<u>A101</u>	<u>A104</u>	<u>A107</u>	<u>A109</u>	<u>A111</u>	<u>A114</u>
<u>A102</u>	<u>A105</u>	<u>A108</u>	<u>A110</u>	<u>A112</u>	<u>A113</u>
<u>A103</u>	<u>A106</u>	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

<u>MODULE</u>	<u>MANUFACTURER/MODEL</u>	<u>DESCRIPTION</u>
H803	DEC - H803	Connector Block (3 each)
A101	DEC - 901C	I/O Connector
A102	DEC - M236	Binary Up-Down Counter
A103	DEC - M236	Binary Up-Down Counter
A104	DEC - M403	Clock
A105	DEC - M236	Binary Up-Down Counter
A106	DEC - M236	Binary Up-Down Counter
A107	DEC - M113	10 - 2 Input NAND Gates
A108	DEC - M111	16 Inverters
A109	DEC - M246	5 D Flip-Flops
A110	DEC - M246	5 D Flip-Flops
A111	DEC - M133	10 2-Input NAND Gates
A112	DEC - M133	10 2-Input NAND Gates
A113	DEC - M113	10 2-Input NAND Gates
A114	DEC - W021B	Output Connector

Figure A-3. Layout of Card Locations

FROM	TO	FROM	TO
A101-T1	A102-T1	A108-K1	A109-N1
A114-C2	A102-C2	A108-J2	A110-A1
A101-D1	A102, A103, A105, A106-D1	A108-M1	A110-N1
A101-E1	A102, A103, A105, A106-E1	A104-J2	A108-K2
A101-F1	A102, A103, A105, A106-F1	A108-L2	A102, A103, A105, A106-A1
A101-H1	A102, A103, A105, A106-H1	A111-C1	A111-D1
A101-J1	A102, A103, A105, A106-J1	A111-F2	A111-H2
A101-K1	A102, A103, A105, A106-K1	A111-K1	A111-L1
A101-L1	A102, A103, A105, A106-L1	A111-N2	A111-P2
A101-M1	A102, A103, A105, A106-M1	A112-C1	A112-D1
A101-N1	A102, A103, A105, A106-N1	A112-F2	A112-H2
A101-P1	A102, A103, A105, A106-P1	A112-K1	A112-L1
A101-R1	A102, A103, A105, A106-R1	A112-N2	A112-P2
A101-S1	A102, A103, A105, A106-S1	A109-L2	A111-B1
A101-A1	A107-A1, B1, H1, L1	A110-L2	A112-B1
A101-B1	A107-E2, H2, J2, M1	A109-K2	A111-E2
A107-C1	A107-D1, D2	A110-K2	A112-E2
A107-K2	A107-E1, J1	A109-E2	A111-J1
A101-U2	A107-M2, R1, R2, U2	A110-E2	A112-J1
A107-F1	A108-A1	A109-D2	A111-M2
A107-K1	A108-C1	A110-D2	A112-M2
A107-F2	A108-D1	A109-E1	A101-K2
A107-N1	A108-F1		A111-A1, D2
A108-B1	A107-L2	A109-P2	A101-J2
A108-D2	A107-P1		A111-H1, L2
A108-E1	A107-P2	A110-E1	A101-F2
A108-H1	A107-T2		A112-A1, D2
A104-N2	A104-S2	A110-P2	A101-H2
A109-V1	A109-H1, J1, F2, M2		A112-H1, L2
	A102-V2, B1	A111-F1	A113-A1
	A103-V2, B1	A111-K2	A113-D1
A110-V1	A110-H1, J1, F2, M2	A111-N1	A113-D2
	A105-V2, B1	A111-S2	A113-H1
	A106-V2, B1	A112-F1	A113-H2
A109-M1	A109-B1, C1, P1, R1	A112-K2	A113-L1
A110-M1	A110-B1, C1, P1, R1	A112-N1	A113-L2
A101-V1	A109-K1, J2	A112-S2	A113-P1
	A110-K1, J2	A104-F2	A113-B1, E1, E2, J1, J2, M1, M2, R1
A107-N2	A102-C1	A113-C1	A114-D2
	A109-F1, L1	A113-F1	A114-E2
A107-S1	A103-C1	A113-F2	A114-H2
	A109-H2, N2	A113-K1	A114-K2
A107-S2	A105-C1	A113-K2	A114-M2
	A110-F1, L1		

Figure A-4. Wire Connection List

FROM	TO	FROM	TO
A107-V2	A106-C1	A113-N1	A114-P2
	A110-H2, N2	A113-N2	A114-S2
A102-T2	A108-E2	A113-S1	A114-T2
A103-T2	A108-J1		A102-A2
A105-T2	A108-H2	A109-V1	A111-E1, J2, M1, R2
A106-T2	A108-L1		A104-H2
A108-F2	A109-A1	A110-V1	A112-E1, J2, M1, R2

Figure A-4 Continued. Wire Connection List

BERG CONN
NUMBER ONE

DEC-901C

SIGNAL

BB	A1	Motor Selection
FF	B1	0,0=x;1,0=z;0,1=y;1,1=θ
C	D1	
K	E1	
NN	F1	
V	H1	
L	J1	Data Input
N	K1	For Number
R	L1	of Steps
T	M1	
W	N1	
X	P1	
Z	R1	
AA	S1	
J	T1	Ground
VV	U1	New Data Ready
HH	V1	Forward/Reverse

BERG CONN
NUMBER TWO

TT	K2	X Complete
LL	J2	Z Complete
H	F2	Y Complete
BB	H2	θ Complete

Figure A-5. Description of Connector Signals

Appendix B

COMPUTER PROGRAMS FOR TFN INSPECTION

C ---TFN.FTN---
C SCANS, PROCESSES AND HAS FULL INTERACTIVE MODE..

```

      DIMENSION IXPT(128), IYPT(128), Z(102,112)
      DIMENSION LX(64), LY(64)
      COMMON /MOV/LXNOW,LYNOW
      BYTE IPN(10), ISN(10), ILOT (6), ISNRG(10)
      BYTE ICODE
      INTEGER Z
      DATA LX/0,125,250,375,500,625,750,875,
1875,750,625,500,375,250,125,0,
10,125,250,375,500,625,750,875,875,750,625,500,375,250,125,
10,0,125,250,375,500,625,750,875,
1875,750,625,500,375,250,125,0,
10,125,250,375,500,625,750,875,
1875,750,625,500,375,250,125,0/
      DATA LY/8*0,8*125,8*250,8*375,8*500,8*625,8*750,8*875/

      WRITE (6,1500)
1500  FORMAT (1H$, 'DISPLAY CROSSES?(YES/NO)  ')
      READ (6,1502) ICROS
1502  FORMAT (A1)
      ITHO =20
10    WRITE (6,1000)
1000  FORMAT (' ***HERMAN***',5X,'INSPECTOR:',20X,'DATE:',/,
11H$, ' PN? ')
      READ (6,1002) IPN
1002  FORMAT (10A1)
      WRITE (6,1005)
1005  FORMAT (1H$, ' LOT NO.? ')
      READ (6,1006) ILOT
1006  FORMAT (6A1)
12    WRITE (6,1008) IPN, ILOT
1008  FORMAT (1H$, ' PN: ',10A1,5X,'LOT: ',6A1,5X,'SN? ')
      READ (6,1002) ISN

```

```

      ITH =ITHO
      IB =0

```

C SCAN THE IMAGE

```

      LXNOW =0
      LYNOW =0
      ICRIT =0
      IMACH =0
      IHTOT =0
      IMARG =0
      IFIELD =64
      DO 50 IP =1,IFIELD
      CALL MOVE (LX(IP), LY(IP))
      CALL STOPX (IDUMY)
      DO 60 IWAIT =1,5000
60    CONTINUE

```

```

CALL SCN(ITH,ISD,ISB,ILD,ILB,IHOR,IVER,IXPT,IYPT,Z)
IBAD =ISD+ISB+ILD+ILB
IF (ICROS.EQ.'N') GO TO 72
IF (IBAD.LE.1) GO TO 72
IF (IBAD.GT.2) GO TO 62
IV = IABS(IXPT(1)- IXPT(2))
IH = IABS(IYPT(1)- IYPT(2))
IF (IV.GT.20.OR.IH.GT.20) GO TO 72
62 IMACH =IMACH +1

```

C INDICATE DEFECTS

```

28 DO 30 N =1,IBAD
30 CALL CROSS(IXPT(N),IYPT(N),5)
CALL STX(ISTOP)
IF (ISTOP.EQ.0) GO TO 28
GO TO 70
72 CALL STOPX(IHALT)
IF (IHALT.NE.1) GO TO 50
IHTOT =IHTOT+1
70 CALL INSP(ICODE)
IF (ICODE.EQ.32) GO TO 50
IF (ICODE.EQ.49) GO TO 110
IF (ICODE.EQ.50) GO TO 120
IF (ICODE.EQ.51) WRITE (6,2004)
IF (ICODE.EQ.52) WRITE (6,2005)
IF (ICODE.EQ.53) WRITE (6,2006)
IF (ICODE.EQ.54) WRITE (6,2007)
IF (ICODE.EQ.55) WRITE (6,2008)
IF (ICODE.EQ.56) WRITE (6,2009)
IF (ICODE.EQ.57) WRITE (6,2010)
IF (ICODE.EQ.48) WRITE (6,2011)
IF (ICODE.EQ.45) GO TO 140
IF (ICODE.EQ.95) GO TO 150
IF (ICODE.EQ.66) GO TO 160
IF (ICODE.EQ.72) WRITE (6,2014)
IF (ICODE.EQ.74) WRITE (6,2015)
IF (ICODE.EQ.71) WRITE (6,2016)
IF (ICODE.EQ.65) GO TO 130
GO TO 70

```

```

110 ICRIT =ICRIT +1
WRITE (6,2000) IF
2000 FORMAT (' F:',I3,3X,'CRITICAL')
GO TO 70
120 IMARG =IMARG +1
WRITE (6,2002) IF
2002 FORMAT (' F:',I3,3X,'MARGINAL')
GO TO 70
130 WRITE (6,2003)
2003 FORMAT (' --ABORTED SCAN--')
GO TO 80

```

```

140      ITH =ITH +5
        WRITE (6,2012)
        GO TO 70
150      ITH =ITH +5
        WRITE (6,2013)
        GO TO 70
160      IP =IP -1
        CALL MOVE (LX(IP), LY(IP))
        IB =IB +1
        GO TO 70

2004     FORMAT (15X,'SHORT')
2005     FORMAT (15X,'VOID COND.')
2006     FORMAT (15X,'VOID RESISTOR')
2007     FORMAT (15X,'METAL F.M.')
2008     FORMAT (15X,'PINHOLES RESISTOR')
2009     FORMAT (15X,'SCRATCH')
2010     FORMAT (15X,'WIDTH RESISTOR')
2011     FORMAT (15X,'OTHER')
2012     FORMAT (15X,'MISALIGNMENT')
2013     FORMAT (15X,'LINE SPACING')
2014     FORMAT (15X,'TA CLOUD')
2015     FORMAT (15X,'OPEN')
2016     FORMAT (15X,'GOLD ON RESISTOR')

50       CONTINUE
80       CALL MOVE (0,0)
        IP =IP-1
        WRITE (6,1060) IP,IMACH,IHTOT,IB,IMARG,ICRIT
1060     FORMAT (/ ' FIELD SUMMARY:',/,5X,'TOTAL:',I3,5X,
1'FLAG:',I3,5X,'OPER:',I2,'/',I2,5X,'MARG:',I3,5X,
1'CRIT:',I3,/,35X,'*****',///)
85       CALL INSP (ICODE)
        IF (ICODE.EQ.84) GO TO 12
        IF (ICODE.EQ.69) GO TO 10
        GO TO 85
        CALL EXIT
        END

```

```

        .TITLE   SCN
        .GLOBL   SCN
;  SCAN, PROCESS, IN 4 SECTION AND SORTS AND RETURNS XY COORD
        .MCALL   .PARAM
        .PARAM

```

```

        CREG     =      164020
        XREG     =      164022
        YREG     =      164024
        ZREG     =      164026
        LKS      =      177546

```

```

SCN?:   MOV      @#44, -(SP)
        JSR      R5, @(SP)+
        MOV      12(SP), R5
        MOV      @2(R5), THRES
        CLR      BAD1
        CLR      BAD2
        CLR      CREG
        CLR      LKS
        CLR      ISD
        CLR      ISB
        CLR      ILD
        CLR      ILB
        CLR      IHQR
        CLR      IVER
        CLR      TOTAL
        MOV      20(R5), R1
        MOV      #200, R2          ; ZERO CORD ARRAYS
CLEAR:  CLR      (R1)+
        DEC      R2
        BNE      CLEAR
        MOV      22(R5), R1
        MOV      #200, R2
CLRY:  CLR      (R1)+
        DEC      R2
        BNE      CLRY

```

```

        MOV      24(R5), R1
        MOV      R1, R2
        ADD      #5712., R2
        MOV      R1, R3
        ADD      #11424., R3
        MOV      R1, R4
        ADD      #17136., R4
        MOV      #28., XCOUNT
        MOV      XSTART, R0
MORE:  MOV      #102., YCOUNT
        MOV      YSTART, YREG
NEXTE: ADD      #100., R0

```

	MOV	R0, XREG
	MOV	#03, CREG
WAIT1:	BIT	#200, CREG
	BEQ	WAIT1
	MOV	ZREG, (R2)+
	SUB	#100., R0
	MOV	R0, XREG
	MOV	#03, CREG
WAIT2:	BIT	#200, CREG
	BEQ	WAIT2
	MOV	ZREG, (R1)+
	DEC	YCOUNT
	BNE	NEXTE
	ADD	#200., R0
	MOV	YSTPLI, YREG
	MOV	#102., YCOUNT
NEXT0:	ADD	#100., R0
	MOV	R0, XREG
	MOV	#03, CREG
WAIT3:	BIT	#200, CREG
	BEQ	WAIT3
	MOV	ZREG, (R4)+
	SUB	#100., R0
	MOV	R0, XREG
	MOV	#03, CREG
WAIT4:	BIT	#200, CREG
	BEQ	WAIT4
	MOV	ZREG, (R3)+
	DEC	YCOUNT
	BNE	NEXT0
	DEC	XCOUNT
	BEQ	DONE
	SUB	#196., R0
	BR	MORE
DONE:	MOV	24(R5), R0
	MOV	20(R5), XPT
	MOV	22(R5), YPT
	MOV	THRES, R2
	MOV	THRES, TH2
	ADD	#0., TH2
	MOV	THRES, TMAX
	ADD	TH2, TMAX
	MOV	#4, SEG
	ADD	#204., R0
	MOV	XSTART, XAXIS
P:	MOV	#2, R3
P0:	MOV	#2, R4
	MOV	YSTART, YAXIS
P1:	ADD	#2, R0

	MOV	(R0), R1
	SUB	-2(R0), R1
	BPL	POS1
	NEG	R1
POS1:	CMP	R1, R2
	BPL	VF1
HOR:	MOV	(R0), R1
	SUB	-204.(R0), R1
	BPL	POS2
	NEG	R1
POS2:	CMP	R1, R2
	BPL	HF1
	JMP	P2
VF1:	MOV	(R0), R1
	SUB	2(R0), R1
	BPL	POS3
	NEG	R1
POS3:	CMP	R1, TH2
	BPL	VFF1
VF2:	MOV	(R0), R1
	SUB	4(R0), R1
	BPL	POS33
	NEG	R1
POS33:	CMP	R1, TH2
	BPL	VFF2
	BR	HOR
VFF1:	CMP	(R0), -2(R0)
	BPL	V1
	CMP	(R0), 2(R0)
	BMI	V2
	BR	HOR
V1:	CMP	(R0), 2(R0)
	BPL	V2
	BR	HOR
V2:	INC	BAD1
	INC	IVER
	CMP	(R0), -2(R0)
	BPL	BRIT1
	INC	ISD
	BR	XY
BRIT1:	INC	ISB
	BR	XY
VFF2:	CMP	(R0), -2(R0)
	BPL	V11
	CMP	(R0), 4(R0)
	BMI	V22
	BR	HOR
V11:	CMP	(R0), 4(R0)
	BPL	V22
	BR	HOR
V22:	INC	BAD2

	INC	IVER
	CMP	(R0), -2(R0)
	BPL	BRIT2
	INC	ILD
	BR	XY
BRIT2:	INC	ILB
	BR	XY
HF1:	MOV	(R0), R1
	SUB	204.(R0), R1
	BPL	POS4
	NEG	R1
POS4:	CMP	R1, TH2
	BPL	HFF1
HF2:	MOV	(R0), R1
	SUB	408.(R0), R1
	BPL	POS44
	NEG	R1
POS44:	CMP	R1, TH2
	BPL	HFF2
	BR	P2
HFF1:	CMP	(R0), -204.(R0)
	BPL	H1
	CMP	(R0), 204.(R0)
	BMI	H2
	BR	P2
H1:	CMP	(R0), 204.(R0)
	BPL	H2
	BR	P2
H2:	INC	BAD1
	INC	IHOR
	CMP	(R0), -204.(R0)
	BPL	BRIT3
	INC	ISD
	BR	XY
BRIT3:	INC	ISB
	BR	XY
HFF2:	CMP	(R0), -204.(R0)
	BPL	H11
	CMP	(R0), 408.(R0)
	BMI	H22
	BR	P2
H11:	CMP	(R0), 408.(R0)
	BPL	H22
	BR	P2
H22:	INC	BAD2
	INC	IHOR
	CMP	(R0), -204.(R0)
	BPL	BRIT4
	INC	ILD

	BR	XY
BRIT4:	INC	ILB
XY:	MOV	XAXIS, @XPT
	MOV	YAXIS, @YPT
	ADD	#2, XPT
	ADD	#2, YPT
	MOV	BAD1, TOTAL ;SAVE ONLY 100 BAD PIXELS
	ADD	BAD2, TOTAL
	CMP	#98., TOTAL ;STOPS AT 99 COUNTS.
P2:	BMI	P3
	INC	R4
	ADD	#4, YAXIS
	CMP	R4, #100.
	BHI	P6
	JMP	P1
P6:	INC	R3
	ADD	#4, XAXIS
	CMP	R3, #26.
	BHI	P5
	ADD	#6, R0
	JMP	P0
P5:	DEC	SEG
	BEQ	P3
	ADD	#618., R0
	JMP	P
P3:	MOV	ISD, @4(R5)
	MOV	ISB, @6(R5)
	MOV	ILD, @10(R5)
	MOV	ILB, @12(R5)
	MOV	IHOR, @14(R5)
	MOV	IVER, @16(R5)
	MOV	@#46, -(SP)
	JSR	R5, @(SP)+
	RTS	R5
SEG:	.WORD	0
XSTART:	.WORD	56.
YSTART:	.WORD	40.
XCOUNT:	.WORD	0
YCOUNT:	.WORD	0
YSTPL1:	.WORD	41.
THRES:	.WORD	0
TH2:	.WORD	0
TMAX:	.WORD	0
BAD1:	.WORD	0
BAD2:	.WORD	0
ISD:	.WORD	0
ISB:	.WORD	0
ILD:	.WORD	0
ILB:	.WORD	0
IHOR:	.WORD	0

IVER:	.WORD	0
XPT:	.WORD	0
YPT:	.WORD	0
XAXIS:	.WORD	0
YAXIS:	.WORD	0
TOTAL:	.WORD	0
	.END	SCN

```

        .TITLE  INSP
        .GLOBL  INSP
; CALL INSP(ICODE)
; ACCEPTS SILENT KB CODES FROM INSPECTOR.
        .MCALL  .PARAM
        .PARAM

TKS      =      177560
TKB      =      TKS+2

INSP:    MOV     @#44, -(SP)
        JSR     R5, @(SP)+
        MOV     12(SP), R5
        BIC     #101, TKS          ;DISABLE TTY
WAIT:    TSTB    TKS
        BPL     WAIT
READ:    MOV     TKB, R1
        BIC     #000200, R1
        MOVB    R1, @2(R5)        ;CLR BIT 8 AND PASS BACK.
        BIS     #101, TKS          ;ENABLE TTY
        MOV     @#46, -(SP)
        JSR     R5, @(SP)+
        RTS     R5
        .END    INSP

```

```
.TITLE STX
.GLOBL STX
```

```
; CALL STX(ISTOP)
; CHECKS KB FOR A 'J' TO STOP CROSSES.
```

```

.MCALL .PARAM
.PARAM
TKS = 177560
TKB = TKS+2

STX:  MOV    @#44, -(SP)
      JSR    R5, @(SP)+
      MOV    12(SP), R5
      TSTB   TKS          ;LOOK FOR DONE
      BPL    GO           ;RETURN TO MAIN
READ: MOV    TKB, R1       ;BRING IN CHAR
      CMPB   #335, R1
      BEQ    STOP

GO:   MOV    #0, @2(R5)
      MOV    @#46, -(SP)
      JSR    R5, @(SP)+
      BIC    #101, TKS     ;KEEP TTY DISABLED
      RTS    R5
STOP: MOV    #1, @2(R5)
      MOV    @#46, -(SP)
      JSR    R5, @(SP)+
      BIS    #101, TKS     ;RE-ENABLE TTY
      RTS    R5
      .END    STX
```

```
.TITLE  STOPX
.GLOBL  STOPX
```

```
;CALL STOPX(ISTOP)
;CHECKS KB FOR A SPBAR TO STOP CROSSES ON MONITOR
```

```
.MCALL  .PARAM
.PARAM
```

```
SPBAR  = 240
TKS    = 177560
TKB    = TKS+2
```

```
STOPX: MOV    @#44, -(SP)
        JSR    R5, @(SP)+
        MOV    12(SP), R5
```

```
        TSTB   TKS          ;LOOK FOR DONE
        BPL    GO           ;RETURN TO MAIN
READ:   MOV    TKB, R1       ;BRING IN CHAR
```

```
        CMPB   #SPBAR, R1
        BEQ    STOP
```

```
GO:     MOV    #0, @2(R5)
        MOV    @#46, -(SP)
        JSR    R5, @(SP)+
```

```
        BIC    #101, TKS      ;KEEP TTY DISABLED
        RTS    R5
```

```
STOP:   MOV    #1, @2(R5)
```

```
        MOV    @#46, -(SP)
        JSR    R5, @(SP)+
        BIS    #101, TKS      ;RE-ENABLE TTY
```

```
        RTS    R5
        .END    STOPX
```

```

        .TITLE  CROSS
        .GLOBL  CROSS
; CALL CROSS(IX,IY,ISIZE)--DRAWS 'X' AT X,Y,....
        .MCALL  .PARAM
        .PARAM
CREG      =      164020
XREG      =      164022
YREG      =      164024
ZREG      =      164026
LKS       =      177546

CROSS:    MOV     @#44, -(SP)
          JSR     R5, @(SP)+
          MOV     12(SP), R5
          MOV     @2(R5), X
          MOV     @4(R5), Y
          MOV     @6(R5), LAST
          CLR     CREG
          CLR     LKS
          MOV     X, XSAV
          MOV     Y, YSAV
DIAG2:    MOV     LAST, R2
          MOV     Y, YREG
DIAG1:    MOV     X, XREG
NEXTZ:    MOV     #03, CREG
WAIT:     BIT     #200, CREG
          BEQ     WAIT
          MOV     ZREG, BUFF
          ADD     INCX, X
          DEC     R2
          BNE     DIAG1
          TST     INCX
          BMI     BACK
          NEG     INCX
          ADD     LAST, XSAV
          ADD     LAST, XSAV
          INC     YSAV
          MOV     XSAV, X
          MOV     YSAV, Y
          JMP     DIAG2
BACK:     NEG     INCX
          MOV     @#46, -(SP)
          JSR     R5, @(SP)+
          RTS     R5
XSAV:     .WORD   0
YSAV:     .WORD   0
X:        .WORD   0,0
Y:        .WORD   0,0
LAST:     .WORD   0,0
INCX:     .WORD   2.
INCY:     .WORD   2.
BUFF:     .WORD   0,0
          .END    CROSS

```

```

C          --MOVE.FTN--
C  MOVES TO INDICATED X,Y LOCATIONS...
SUBROUTINE MOVE (LX,LY)
COMMON /MOV/LXNOW,LYNOW
IERR =0
15  IDIFX =LX-LXNOW
    IDIR =0
    IF (IDIFX.GE.0) IDIR =1
30  IF (IABS(IDIFX).LT.4000) GO TO 32
    CALL MOTOR (IERR,IDIR, 0,4001)
    IF (IDIR.EQ.0) IDIFX =IDIFX + 4000
    IF (IDIR.EQ.1) IDIFX =IDIFX - 4000
    GO TO 30
32  ISTEPS =IABS(IDIFX) +1
    CALL MOTOR (IERR, IDIR, 0, ISTEPS)
    LXNOW =LX
    IDIFY =LY-LYNOW
    IDIR =0
    IF (IDIFY.GE.0) IDIR =1
40  IF (IABS(IDIFY).LT.4000) GO TO 42
    CALL MOTOR (IERR,IDIR,2, 4001)
    IF (IDIR.EQ.0) IDIFY =IDIFY + 4000
    IF (IDIR.EQ.1) IDIFY =IDIFY - 4000
    GO TO 40
42  ISTEPS =IABS(IDIFY) +1
    CALL MOTOR (IERR,IDIR, 2, ISTEPS)
    LYNOW =LY
    CALL XYTEST
    RETURN
END

```

```

        .TITLE  XYTEST
        .GLOBL  XYTEST
; DO NOT RETURN UNTIL ALL MOTORS ARE DONE---
;
        .MCALL  .PARAM
        .PARAM
MREG = 167772
MSR  = 167774
XYTEST: MOV     @#44, -(SP)
        JSR     R5, @(SP)+
        MOV     12(SP), R5
WAIT:   BIT     #000017, MSR
        BNE     WAIT
        MOV     @#46, -(SP)
        JSR     R5, @(SP)+
        RTS     R5
        .END    XYTEST

```



```

        .TITLE  MOTOR
        .GLOBL  MOTOR
;      CALL MOTOR(IERR, IDIR, MOTSL, ISTEPS)--ISSUES COMMANDS
;      TO STEPPER MOTORS...

        .MCALL  .PARAM
        .PARAM
        MREG = 167772
        MSR  = 167774

MOTOR:  MOV     @#44, -(SP)
        JSR     R5, @ (SP)+
        MOV     12(SP), R5
        MOV     @4(R5), DIR
        MOV     @6(R5), MOTSL
        MOV     @10(R5), STEP
        CLR     COMAND
        CMP     #1, DIR
        BEQ     D1
        BR      M1
D1:     BIS     #040000, COMAND
M1:     CMP     #0, MOTSL
        BEQ     M11
        CMP     #1, MOTSL
        BEQ     M2
        CMP     #2, MOTSL

        BEQ     M3
        CMP     #3, MOTSL
        BEQ     M4
        MOV     #1, @2(R5)
        BR      LEAVE
M11:    BIS     #000000, COMAND
        BIS     #000001, BUSY
        BR      NEXT
M2:     BIS     #010000, COMAND
        BIS     #000002, BUSY
        BR      NEXT
M3:     BIS     #020000, COMAND
        BIS     #000004, BUSY
        BR      NEXT
M4:     BIS     #030000, COMAND
        BIS     #000010, BUSY
NEXT:   NOP
WAIT1:  BIT     BUSY, @#MSR
        BNE     WAIT1
        MOV     COMAND, @#MREG
        ADD     STEP, COMAND
        MOV     COMAND, @#MREG
        CLR     BUSY
LEAVE:  MOV     @#46, -(SP)

```

	JSR	R5, @ (SP)+
	RTS	R5
DIR:	.WORD	0,0
MOTSL:	.WORD	0,0
STEP:	.WORD	0,0
BUSY:	.WORD	0,0
COMAND:	.WORD	0,0
	.END	MOTOR

Appendix C

COMPUTER PROGRAMS FOR HMC INSPECTION

C
C R.E. HINES --HMC.FTN-- OCT. 1978
C SCREENS HMC FOR MISSING CROSSOVERS AND BEAM LEAD DEVICES...

```

      DIMENSION LX(10),LY(10)
      BYTE MAST(10)
      COMMON /B/IPN(5)
      COMMON /MOV/LXNOW,LYNOW
      DATA LX/0,200,400,600,800,1000,1200,1400,1600,1800/
      DATA LY/0,200,400,600,800,1000,1200,1400,1600,1800/

      WRITE (6,1044)
1044  FORMAT(1H$, 'ENTER '1' FOR AUTOMATIC MODE: ')
      READ (6,1046) IMODE
1046  FORMAT (I1)
10    WRITE (6,1000)
1000  FORMAT (1H$, 'ZTHR & NO.?(2I3): ')
      READ (6,1002) ITHR,INO
1002  FORMAT (2I3)
      WRITE (6,1040)
1040  FORMAT (1H$, 'ENTER PART NO. & SUFFIX(XXXXXX.SSS) ')
      READ (6,1070) IPN
1070  FORMAT (5A2)
12    WRITE (6,1050) IPN
1050  FORMAT (20X, '*****', //, 1H$, 'PART NO: ', 5A2,
1'      SERIAL NO.? ')
      READ (6,1060) ISN
1060  FORMAT (A2)

```

C --AUTOMATIC REGISTER ON TRIANGLE--

```

14    CALL EYECTL(460,440,IZ)
      CALL EYECTL(462,440,IZ)
      CALL STOPX(ISTOP)
      IF(ISTOP.NE.1) GO TO 14
      CALL TRIREG(IEREG)
      IF(IEREG.NE.1) GO TO 16
      WRITE (6,1022)
1022  FORMAT (' ---RE-REGISTER---')
      GO TO 14
16    CONTINUE

```

C --GET MASTER FILE--

```

      ENCODE (10,2500,MAST) IPN(2),IPN(3), IPN(4), IPN(5)
2500  FORMAT ('PN',4A2)
      CALL ASSIGN (1,MAST,10,IERR)

      LXNOW =0
      LYNOW =0

1004  READ (1,1004) IPH,IPV
      FORMAT (2I6)
      DO 50 KV =1,IPV

```

```
DO 50 KH =1,IPH  
CALL MOVE (LX(KH), LY(KV))  
CALL XYTEST  
DO 60 IWAIT =1,5000  
60 CONTINUE  
CALL CHECK (KH,KV,ITHR,INO,IMODE)  
50 CONTINUE  
CALL MOVE (0,0)  
ENDFILE 1  
GO TO 12  
CALL EXIT  
END
```

```

C          --CHECK.FTN--
C          R.E. HINES                      OCT. 1978
C  CHECKS FOR PRESENCE OF XOVERS & BLDs ON HMC..CALLS SCANX...

```

```

      SUBROUTINE CHECK (KH,KV,ITHR,INO,IMODE)
      DIMENSION IDATA (40), ID(3)
      BYTE ICODE
      ILEN =5
      L2 =2*ILEN
      L4 =4*ILEN
20      READ (1,1000) ID, IX0,IY0
1000     FORMAT (3A2,2I6)
      IF (ID(1).EQ.'**') GO TO 60
      IFLAG =0
      IX =IX0-L2
      IY =IY0-L2
50      CALL SCANX (IX,IY,L2,IDATA)
      IDARK =0
      IDMAX =0
      DO 40 K =1,L4
40      IF(IDATA(K).LT.ITHR) IDARK =IDARK+1
      IF (IDARK.GT.IDMAX) IDMAX =IDARK
      IF(IDARK.GE.INO) GO TO 20
C      DOUBLE CHECK FOR MISSING ITEM..
      IFLAG =IFLAG +1
      IF (IFLAG.NE.1) GO TO 71
      IX =IX-L2
      GO TO 50
71      IF (IFLAG.NE.2) GO TO 72
      IX =IX+L2+L2
      GO TO 50
72      IF (IFLAG.NE.3) GO TO 73
      IX =IX-L2
      IY= IY-L2
      GO TO 50
73      IF (IFLAG.NE.4) GO TO 80
      IY = IY+L2+L2
      GO TO 50
80      CONTINUE

C      INTERACTIVE MODE ROUTINE...
      IVER = ' '
      IF(IMODE.EQ.1) GO TO 90
85      CALL SCANX (IX,IY,L2,IDATA)
      CALL JUDGE(ICODE)
      IF(ICODE.EQ.0) GO TO 85
      IF(ICODE.NE.80.AND.ICODE.NE.32) GO TO 85
      IF(ICODE.EQ.80) IVER = ' P'

C      ASSUME ITEM MISSING..
90      WRITE(6,1010) KH,KV,ID,IDMAX,IVER

```

```
1010  FORMAT(10X,'F:',I2,'-',I2,5X,3A2,I8,A2)  
      GO TO 20  
60     CONTINUE  
      RETURN  
      END
```

```

        .TITLE  SCANX
        .GLOBL  SCANX
; RETURNS IDATA( Z VALUES) OF CROSS, UPPER LEFT AT (IX,IY),
; DIAG LENGTH (L2),  --CALL SCANX (IX,IY,L2,IDATA)--

        .MCALL  .PARAM
        .PARAM
        CREG    =      164020
        XREG    =      CREG+2
        YREG    =      CREG+4
        ZREG    =      CREG+6
        LKS     =      177546

SCANX:   MOV     @#44, -(SP)
        JSR     R5, @ (SP)+
        MOV     12(SP), R5
        MOV     @2(R5), X
        MOV     @4(R5), Y
        MOV     @6(R5), LAST
        MOV     10(R5), R1
        CLR     CREG
        CLR     LKS
        MOV     X, XSAV
        MOV     Y, YSAV
DIAG2:   MOV     LAST, R2
        MOV     Y, YREG
DIAG1:   MOV     X, XREG
NEXT:    MOV     #03, CREG
WAIT:    BIT     #200, CREG
        BEQ     WAIT
        MOV     ZREG, (R1)
        ADD     #04, R1
        ADD     INCX, X
        DEC     R2
        BNE     DIAG1
        TST     INCX
        BMI     BACK
        NEG     INCX
        ADD     LAST, XSAV
        ADD     LAST, XSAV
        INC     YSAV
        MOV     XSAV, X
        MOV     YSAV, Y
        JMP     DIAG2
BACK:    NEG     INCX
        MOV     @#46, -(SP)
        JSR     R5, @ (SP)+
        RTS     R5
XSAV:    .WORD   0
YSAV:    .WORD   0
X:       .WORD   0,0

```


Y: .WORD 0,0
LAST: .WORD 0,0
INCX: .WORD 2.
.END SCANX

```
.TITLE JUDGE
.GLOBL JUDGE
```

```
;CALL JUDGE(ICODE)
;CHECKS KB FOR CODE & RETURNS IT. RETURNS ZERO IF NO INPUT..
```

```
.MCALL .PARAM
.PARAM
TKS = 177560
TKB = TKS+2

JUDGE: MOV @#44, -(SP)
JSR R5, @ (SP)+
MOV 12(SP), R5
TSTB TKS ;LOOK FOR DONE
BPL GO ;RETURN TO MAIN
JMP CODE

GO: MOV #0, @2(R5)
MOV @#46, -(SP)
JSR R5, @ (SP)+
BIC #101, TKS ;KEEP TTY DISABLED
RTS R5

CODE: MOV TKB, R1
BIC #000200, R1
MOVB R1, @2(R5)
MOV @#46, -(SP)
JSR R5, @ (SP)+
BIS #101, TKS ;RE-ENABLE TTY
RTS R5

.END JUDGE
```

C --TRIREG.FTN--
C AUTO. REGISTERS ON TRIANGLE...

```
-----  
SUBROUTINE TRIREG(IEREG)  
COMMON /MOV/LXNOW,LYNOW  
IEREG =0  
-----  
CALL HWIDTH(462,442,30,IWIDTH,IXL,IXR)  
IHC =(IXL+IXR)/2  
LXNOW =(IHC-460)/2  
-----  
CALL VWIDTH(IHC,442,30,IWIDTH,IYT,IYB)  
LYNOW =(IYB-460)/2  
-----  
IF(IABS(LXNOW).GE.10) GO TO 40  
IF(IABS(LYNOW).GE.10) GO TO 40  
CALL MOVE(0,0)  
GO TO 50  
-----  
40       IEREG =1  
50       RETURN  
-----  
END
```

	.TITLE	EYECTL	
	.GLOBL	EYECTL	
	.MCALL	.PARAM	
	.PARAM		
	CREG	=	164020
	XREG	=	CREG+2
	YREG	=	CREG+4
	ZREG	=	CREG+6
EYECTL:	MOV	@#44,-(SP)	;SAVE REGISTERS
	JSR	R5,@(SP)+	
	MOV	12(SP),R5	;RESTORE CALLERS R5
	MOV	@2(R5),XREG	;PICKUP CALLERS X
	MOV	@4(R5),YREG	;PICKUP CALLERS Y
	MOV	#1,CREG	;GO TO IT SCANNER
WAIT:	TSTB	CREG	;WAIT ON Z
	BPL	WAIT	
	MOV	ZREG,@6(R5)	;GIVE Z TO CALLER
	MOV	@#46,-(SP)	;RESTORE RESISTERS
	JSR	R5,@(SP)+	
	RTS	R5	
	.END	EYECTL	

```

SUBROUTINE HWIDTH (IXO,IYO,ITHR,IWIDTH,IXL,IXR)
M=-5
103  IX=IXO
      IY=IYO
      N=0
101  N=N+1
      CALL EYECTL (IX,IY,IZ)
      IF (N.EQ.1) IZO=IZ
      IDIF= IABS(IZ-IZO)
      IF (IDIF.GT.ITHR) GO TO 104
      IX=IX+M
      IF (N.LT.100) GO TO 101
      WRITE (6,150)
150  FORMAT (' NO EDGE IN IMAGE')
      STOP 00000
104  IZTEMP=0
      IX=IX-5
      DO 102 J=1,11
          CALL EYECTL (IX,IY,IZ)
          IF (J.EQ.1) GO TO 106
          IZDIF = IABS(IZ-IZL)
          IF (IZDIF.LE.IZTEMP) GO TO 102
          IZTEMP= IZDIF
          IXR= IX
106  IZL=IZ
102  IX=IX+1
      IF (M.LT.0) IXL=IXR
      IF (M.GT.0) GO TO 105
      M=5
      GO TO 103
105  IWIDTH= IXR-IXL
      RETURN
      END

```

```

SUBROUTINE VWIDTH (IXO,IYO,ITHR,IWIDTH,IYT,IYB)
M=-5
203  IX=IXO
      IY=IYO
      N=0
201  N=N+1
      CALL EYECTL (IX,IY,IZ)
      IF (N.EQ.1) IZO=IZ
      IDIF = IABS(IZ-IZO)
      IF (IDIF.GT.ITHR) GO TO 204
      IY= IY+M
      IF (N.LT.100) GO TO 201
      WRITE (6,251)
251  FORMAT (' NO EDGE IN IMAGE'//)
      STOP 000000
204  IZTEMP=0
      IY=IY-5
      DO 202 J=1,11
      CALL EYECTL (IX,IY,IZ)
      IF (J.EQ.1) GO TO 206
      IZDIF= IABS(IZ-IZL)
      IF (IZDIF.LE.IZTEMP) GO TO 202
      IZTEMP= IZDIF
      IYB= IY
206  IZL= IZ
202  IY=IY+1
      IF (M.LT.0) IYT=IYB
      IF (M.GT.0) GO TO 205
      M=5
      GO TO 203
205  IWIDTH= IYB-IYT
      RETURN
      END

```

```

C          --HMCNEW.FTN--
C          --USED TO CREATE NEW PART DEFINITION FILE--

```

```

      DIMENSION IDATA(40), LX(10), LY(10), IPN(5), IDENT(3)
      BYTE MAST (10)
      COMMON /MOV/LXNOW,LYNOW
      DATA LX/0,200,400,600,800,1000,1200,1400,1600,1800/
      DATA LY/0,200,400,600,800,1000,1200,1400,1600,1800/

10      WRITE (6,1000)
1000     FORMAT (1H$, 'ZTHR & NO.?(2I3) ')
      READ (6,1002) ITHR,IND
1002     FORMAT (2I3)
      WRITE (6,1104)
1104     FORMAT (1H$, 'ENTER PART NO. & SUFFIX(XXXXXX.SSS) ')
      READ (6,1106) IPN
1106     FORMAT (5A2)
      WRITE (6,1100)
1100     FORMAT (1H$, 'NO. OF HOR.& VERT. FIELDS?(HHVV) ')
      READ (6,1102) IPH,IPV
1102     FORMAT(2I2)
C          --AUTOMATIC REGISTER ON TRIANGLE--
14      CALL EYECTL (460,440,IZ)
      CALL EYECTL (461,440,IZ)
      CALL STOPX(ISTOP)
      IF (ISTOP.NE.1) GO TO 14
      CALL TRIREG(IEREG)
      IF (IEREG.NE.1) GO TO 16
      WRITE(6,1022)
1022     FORMAT ('___RE-REGISTER___')
      GO TO 14
16      CONTINUE
C          --ESTABLISH PART DEFINITION FILE--
2500     ENCODE (10,2500,MAST) IPN(2),IPN(3),IPN(4),IPN(5)
      FORMAT ('PN',4A2)
      CALL ASSIGN(2,MAST,10,IER2)
      WRITE (2,1108) IPH,IPV
1108     FORMAT (2I6)

      WRITE (6,1010)
1010     FORMAT('  FIELD  XLOC  YLOC  DARK  AVG  MAX  MIN  IDENT?')
      ILEN =5
      L2 =2*ILEN
      L4 =4*ILEN
      LXNOW =0
      LYNOW =0
C          MOVE THRU EACH FIELD AND PROGRAM ITEM LOCATIONS..
      DO 50 KV =1,IPV
      DO 50 KH =1,IPH
      WRITE(6,1024) KH,KV
1024     FORMAT('  _HOR.=',I2,'  VERT.=',I2,'__')

```

```

30      CALL MOVE (LX(KH), LY(KV))
      CALL JS0001(IERR, IX0,IY0,IZ)
      IX =IX0-L2
      IY =IY0-L2
      CALL SCANX(IX,IY,L2,IDATA)
      IDARK =0
      DO 40 K=1,L4
40      IF(IDATA(K).LT.ITHR) IDARK =IDARK+1
      ISUM =0
      MIN =250
      MAX =0
      DO 45 KK=1,L4
      IF(IDATA(KK).LT.MIN) MIN =IDATA(KK)
      IF (IDATA(KK).GT.MAX) MAX =IDATA(KK)
45      ISUM =ISUM +IDATA(KK)
      IAVG =ISUM/L4

      WRITE (6,1020) IP,IX0,IY0,IDARK,IAVG,MAX,MIN
1020    FORMAT(1H$, 7I6, 3X)
      READ (6,1030) IDENT
1030    FORMAT (3A2)
      IF (IDENT(1).EQ.'NN') GO TO 30
60      WRITE (2,1050) IDENT, IX0,IY0
1050    FORMAT (3A2,2I6)
      IF (IDENT(1).NE.'**') GO TO 30
50      CONTINUE
      CALL MOVE (0,0)
      ENDFILE 1
      CALL EXIT
      END

```



```
.TITLE JS0001
.GLOBL JS0001
```

```
WRITTEN BY D.L.BULLARD D/744 LAST MODIFIED 11-NOV-74
```

```
THIS SUBROUTINE USES THE TTY KEYBOARD AS
A JOYSTICK FOR POSITIONING THE SCANNER
MONITOR CURSOR.
```

```
CALL JS0001 (IERR,IX,IY,IZ)
```

```
IERR = ERROR INDICATOR
IX = X POSITION OF THE CURSOR
IY = Y POSITION OF THE CURSOR
IZ = THE INTENSITY OF THE PIXEL
```

```
DN = 312
UP = 313
RT = 314
LF = 310
HO = 311
MEASUR = 315
SPBAR = 240
HOME = 255.
XMIN = 0
XMAX = 511.
YMIN = 0
YMAX = 511.
```

```
PSW = 177776
CREG = 164020
XREG = CREG+2
YREG = CREG+4
ZREG = CREG+6
TKS = 177560
TKB = TKS+2
LKS = 177546
```

```
JS0001: MOV @#44,-(SP) ;SAVE ALL REGISTERS
JSR R5,@(SP)+
MOV 12(SP),R5 ;RESTORE CALLERS R5
MOV #HOME,R3 ;LOAD HOME POSITION (X CORD.)
MOV #HOME,R4 ;LOAD HOME POSITION (Y CORD.)
MOV 60,V.60 ;SAVE PRESENT VECTORS
MOV 62,V.62
MOV #TTYINT,60 ;SETUP INTERRUPT SERVICE
MOV #240,62
```

	CLR	LKS	;KILL TIME
	MOV	PSW,PS.SAV	;SAVE THE PRESENT STATUS
	CLR	PSW	;DROP PROCESSOR PRIORITY
SPB.1:	MOV	#101,TKS	;ENABLE TTY INTERRUPT
	CLR	TKS	;DISABLE TTY
	JSR	R5,S.1	;KEEP OUTPUTTING PRESENT X AND Y
	MOV	#101,TKS	;ENABLE TTY
	JMP	SPB.1	
TTYINT:	CMP	(SP)+,(SP)+	;DON'T RTI--SO CLEAR STACK
	MOV	TKB,R1	;SAVE TTY CHAR FOR LATTER
	CLR	PSW	;DROP PROCESSOR PRIORITY
	MOV	#101,TKS	;ENABLE TTY
	CMPB	#SPBAR,R1	;LOOK FOR A SPACE TYPED
	BEQ	SPB.1	;HOLD PRESENT POSITION
DN.1:	CMPB	#DN,R1	;LOOK FOR A "J" TYPED (DOWN)
	BNE	UP.1	;NOT A "J" LOOK FARTHER
DN.2:	INC	R4	;MOVE CURSOR DOWN ONE POINT
	CLR	TKS	;DISABLE TTY
	JSR	R5,S.1	;GO OUTPUT THE NEW POSITION
	MOV	#101,TKS	;ENABLE TTY
	CMP	#YMAX,R4	;HAVE WE GONE TOO FAR?
	BEQ	BAD.1	;RESET CURSOR TO HOME POSITION
	JMP	DN.2	;KEEP GOING UNTIL INTERRUPTED
UP.1:	CMPB	#UP,R1	;LOOK FOR A "K" (UP)
	BNE	RT.1	
UP.2:	DEC	R4	;MOVE CURSOR UP ONE POINT
	CLR	TKS	;DISABLE TTY
	JSR	R5,S.1	;GO OUTPUT THE NEW POSITION
	MOV	#101,TKS	;ENABLE TTY
	CMP	#YMIN,R4	;HAVE WE GONE TOO FAR?
	BNE	UP.2	;KEEP GOING UNTIL INTERRUPTED
BAD.1:	MOV	#HOME,R3	;LOAD HOME POSITION
	MOV	#HOME,R4	
	JMP	SPB.1	
RT.1:	CMPB	#RT,R1	;LOOK FOR A "L" (RIGHT)
	BNE	LF.1	;NOT A "L" LOOK FARTHER
RT.2:	INC	R3	;MOVE CURSOR RIGHT ONE POINT
	CLR	TKS	;DISABLE TTY
	JSR	R5,S.1	;GO OUTPUT THE NEW POSITION
	MOV	#101,TKS	;ENABLE TTY
	CMP	#XMAX,R3	;HAVE WE GONE TOO FAR?
	BEQ	BAD.1	;RESET CURSOR TO HOME POSITION
	JMP	RT.2	;KEEP GOING UNTIL INTERRUPTED

```

;
;
LF.1:  CMPB    #LF,R1          ;LOOK FOR A 'H' (LEFT)
      BNE     MEA.1           ;CALLER WANTS TO MEASURE
LF.2:  DEC     R3              ;MOVE CURSOR ONE POINT LEFT
      CLR     TKS             ;DISABLE TTY
      JSR     R5,S.1          ;GO OUTPUT NEW POSITION
      MOV     #101,TKS        ;ENABLE TTY
      CMP     #XMIN,R3        ;HAVE WE GONE TOO FAR?
      BEQ     BAD.1           ;RESET CURSOR TO HOME POSITION
      JMP     LF.2
;
;
MEA.1:  CMPB    #MEASUR,R1      ;LOOK FOR A 'M' (MEASURE)
      BEQ     EXIT            ;NOT A 'M' LOOK FARTHER
;
;
HQ.1:  CMPB    #H0,R1          ;LOOK FOR AN 'I' (HOME)
      BEQ     BAD.1           ;TAKE IT HOME
      MOV     #1,@2(R5)        ;SEND FORTRAN A BAD CHAR ERROR
EXIT:  MOV     R3,@4(R5)        ;SEND FORTRAN A X VALUE
      MOV     R4,@6(R5)        ;SEND FORTRAN A Y VALUE
      MOV     Z.SAV,@10(R5)    ;SEND FORTRAN A Z VALUE
      MOV     PS.SAV,PSW       ;RESTORE PROCESSOR STATUS
      MOV     V.60,60          ;RESTORE TTY VECTORS
      MOV     V.62,62
      MOV     @#46,-(SP)       ;RESTORE REGISTERS
      JSR     R5,@(SP)+
      RTS     R5
;
;
S.1:  MOV     R3,XREG          ;LOAD MONITOR X-REG.
      MOV     R4,YREG          ;LOAD MONITOR Y-REG.
      MOV     #1,CREG          ;GO TO IT
WAIT:  TSTB    CREG            ;WAIT FOR COMPLETION
      BPL     WAIT
      MOVB    ZREG,Z.SAV
      RTS     R5
;
;
R3.TMP: .WORD    0
R4.TMP: .WORD    0
V.60:   .WORD    0
V.62:   .WORD    0
Z.SAV:  .WORD    0
PS.SAV: .WORD    0
;
;
      .END      JS0001

```

```

C          --LOOK.FTN--
C  USED TO RE-CHECK FIELDS OR LOCATE COORDINATES..

      DIMENSION LX(10), LY(10)
      COMMON /MOV/LXNOW,LYNOW
      DATA LX/0,200,400,600,800,1000,1200,1400,1600,1800/
      DATA LY/0,200,400,600,800,1000,1200,1400,1600,1800/

      WRITE (6,1030)
1030  FORMAT (1H$, 'ENTER *1* FOR COORDINATE DATA: ')
      READ (6,1032) IMOD
1032  FORMAT (I1)
C          --AUTOMATIC REGISTER ON TRIANGLE--
14    CALL EYECTL (460,440,IZ)
      CALL EYECTL (461,440,IZ)
      CALL STOPX (ISTOP)
      IF (ISTOP.NE.1) GO TO 14
      CALL TRIREG (IEREG)
      IF (IEREG.NE.1) GO TO 16
      WRITE (6,1022)
1022  FORMAT ('___RE-REGISTER___')
      GO TO 14
16    CONTINUE

      LXNOW =0
      LYNOW =0
20    WRITE (6,1010)
1010  FORMAT (1H$, 'FIELD NO?(HHVV) ')
      READ (6,1020) IPH,IPV
1020  FORMAT (2I2)
      IF (IPH.EQ.0) GO TO 50
      CALL MOVE (LX(IPH), LY(IPV))
      IF (IMOD.NE.1) GO TO 20
      CALL JS0001(IERR,IXD,IYD,IZ)
      WRITE (6,1040) IXD,IYD
1040  FORMAT (6X,'X= ',I3,4X,'Y= ',I3,4X,'IDENT.=_____' )
      GO TO 20
50    CALL MOVE (0,0)
      CALL EXIT
      END

```

C
C

--AVG.FTN--
CALCULATES Z AVG. AT X,Y AND PRINTS..

```
SUBROUTINE AVG(IX,IY)
DIMENSION IDATA(40)

CALL SCANX (IX,IY,10,IDATA)
ISUM =0
DO 45 KK=1,20
45  ISUM =ISUM + IDATA(KK)
    IAVG =ISUM/20
WRITE (6,1000) IX,IY,IAVG
1000 FORMAT (' X=',I4,' Y=', I4,' LEVEL=',I4)
RETURN
END
```

C
C

--SETUP.FTN--

CHECKS BRIGHTNESS & MAGNIFICATION VALUES..

```
WRITE (6,1000)
1000  FORMAT (20X,'*** SYSTEM CHECKOUT ***'//)
      WRITE (6,1010)
1010  FORMAT (20X,'CERAMIC UNIFORMITY'//,1H$,
      1'PLACE CERAMIC SAMPLE & ENTER <CR>:')
      READ (6,1020) IDUM
1020  FORMAT (A1)

      CALL AVG(250,250)
      CALL AVG(100,100)
      CALL AVG(400,100)
      CALL AVG(100,400)
      CALL AVG(400,400)
      WRITE (6,1030)
1030  FORMAT(///,20X,'GOLD UNIFORMITY'//,1H$,
      1'PLACE GOLD SAMPLE & ENTER <CR>:')
      READ (6,1020) IDUM
      CALL AVG(250,250)
      CALL AVG(100,100)
      CALL AVG(400,100)
      CALL AVG(100,400)
      CALL AVG(400,400)

      WRITE (6,1040)
1040  FORMAT (///,20X,'TANTALUM UNIFORMITY'//,1H$,
      1'PLACE TANTALUM SAMPLE & ENTER <CR>:')
      READ (6,1020) IDUM
      CALL AVG(250,250)
      CALL AVG(100,100)
      CALL AVG(400,100)
      CALL AVG(100,400)
      CALL AVG(400,400)

      WRITE (6,1050)
1050  FORMAT (///,20X,'MAGNIFICATION'//,1H$,
      1'CENTER TARGET AREA ON SCREEN & ENTER <CR>:')
      READ (6,1020) IDUM
      CALL HWIDTH(250,240,40,IWID1,IXL,IXR)
      CALL HWIDTH(250,260,40,IWID2,IXL,IXR)
      IHWID =(IWID1+IWID2)/2

      CALL VWIDTH(240,250,40,IWID1,IYT,IYB)
      CALL VWIDTH(260,250,40,IWID2,IYT,IYB)
      IVWID =(IWID1+IWID2)/2
      WRITE (6,1060) IHWID,IVWID
1060  FORMAT ('  HORIZ SCALE= ',I4,5X,'VERT SCALE= ',I4)

      WRITE (6,1070)
```

```
1070  FORMAT (//,20X,'--- TEST COMPLETE ---'//  
1'    NOTIFY ENGINEER IF ANY VALUES NOT WITHIN TOLERANCE')  
CALL EXIT  
END
```

BDX-613-2359

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SPECIAL PROJECTS: Automatic Inspection

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