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BDX-613-1813 (Rev.)

**SEMIAUTOMATIC VISUAL-INSPECTION SYSTEM
FOR THIN-FILM NETWORKS**

By R. E. Hines

Published September 1978

Topical Report

Prepared for the United States Department of Energy
Under Contract Number EY-76-C-04-0613.

**Kansas City
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By R. E. Hines

Published September 1978

Topical Report
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BDX-613-1813 (Rev.), UNCLASSIFIED Topical Report, Published
September 1978

Prepared by R. E. Hines

A semiautomatic visual-inspection system using a closed-circuit color-television camera and CRT display, a computer-controlled positioning table, and an interactive CRT terminal has been developed for inspecting thin-film networks. Use of the system greatly decreases eye fatigue and reduces inspection time by approximately 30 percent.

WPC-pls

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SUMMARY

The method now used for visually inspecting thin-film networks (TFNs) consists of viewing a magnified portion of the TFN through a stereomicroscope and manually repositioning the part until all areas have been inspected. This technique is tedious and difficult to sustain for long periods because of eye fatigue. Also, unless great care is exercised, areas of the TFN may be missed. 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.

A semiautomatic visual-inspection system has been developed to aid in the inspection of TFNs. Features of the system include a closed-circuit color-television camera mounted on a microscope for obtaining a magnified image of the area to be inspected, a television display of the area to eliminate eye fatigue, a computer-controlled positioning table for moving the TFN in a regular pattern to assure complete coverage of the part, and an interactive CRT terminal to accept defect codes and issue the completed defect report.

Using Quality Division personnel to simulate visual inspectors, a laboratory evaluation was made of the prototype inspection system. Results indicate that TFNs can be adequately inspected from the television screen with an average inspection time of 3 to 4 minutes per part.

A short video tape recording showing the semiautomatic visual-inspection system in operation is available in the Advanced Inspection Engineering Department. Viewing may be arranged by contacting a member of the project team.

DISCUSSION

SCOPE AND PURPOSE

This report describes a semiautomatic system that has been developed and evaluated for use in visually inspecting the thin-film networks (TFNs) on hybrid microcircuits (HMCs). This system represents an intermediate accomplishment toward the eventual goal of a fully automatic system.

TFNs consist of densely packed conductor and resistor paths which have been etched on ceramic substrates. At the present time, inspections at Bendix Kansas City are performed by viewing areas 8.46 mm square through a stereo zoom microscope having a magnification from 10 to 15X. The TFN is manually repositioned under the microscope until all areas have been inspected. This technique has the following disadvantages.

- Continuous viewing through a microscope is tedious and creates eye fatigue.
- Some areas of the TFN may be overlooked.
- The inspector must write a defect report on any defective TFN.

A prototype inspection system was developed which consists of a closed-circuit color-television camera (CCTV) mounted on a microscope, a 305-mm viewing monitor, a computer-controlled positioning stage, a minicomputer, and an interactive CRT display (Figures 1 and 2). This combination of equipment, when applied to the inspection of TFNs, provides the following advantages.

- Because inspection is performed by viewing the TFNs on a color-television screen rather than through a microscope, eye fatigue is reduced.
- Computer-controlled X-Y positioning of the TFN directs the attention of the inspector to the area to be viewed and assures complete coverage of the part.
- Computer control of defect-code entries and defect reporting eliminates the need for the inspector to write defect reports.
- Computer-issued instructions are displayed on the CRT to guide the inspector at various stages of the inspection and provide a uniform procedure for either single or multiple inspectors.

Figure 1. Semiautomatic Visual-Inspection System for Thin-Film Networks

Figure 2. Block Diagram of Semiautomatic Visual-Inspection System

- The televised display of the area under inspection provides simultaneous viewing for several observers to make judgments on marginal defects, and it is an aid in the training of new inspectors.

This project was undertaken to demonstrate and evaluate the capability of techniques which are not being utilized at Bendix for the visual inspection of TFNs. Some of these techniques (tape-controlled X-Y tables and CCTV) are being used for some of the later stages of HMC inspection.

Although several different concepts were integrated into the total system here described, these concepts are modular and therefore could be utilized separately or in various combinations.

PRIOR WORK

Studies of the efficiency of unaided visual inspectors have been reported by other investigators.^{1,2} A previous report described an investigation at Bendix Kansas City of the unaided visual inspection of TFNs as a function of various types of illumination.³ All of these studies indicate a need for new inspection techniques to improve the accuracy and uniformity of inspection results obtained both from individual inspectors and from different inspectors working at the same task.

ACTIVITY

System Components

Whenever an inspection is performed by viewing a secondary display rather than viewing the object directly, degradation of the scene as little as possible by the image-forming equipment is very important. A combination of television camera, optical system, and illumination source was found that provided a suitable image for visual inspection (Figure 3). It was believed that a color display rather than a black-and-white display of the image would make thin-film-network defects more easily discernible.

A single-tube color camera designed specifically for use in combination with a microscope was purchased. Because of its small size and light weight (approximately 1.8 kg), it mounts easily on the top of a microscope with no additional support required. It has a horizontal resolution of 250 television lines and a vertical resolution of 300 television lines. While these values are less than those that can be achieved with black-and-white cameras, the overall resolution is comparable with the resolution obtained from color cameras costing several times more than \$4,000.

Another needed feature in a television camera is the simple operating and adjusting capability attained by incorporating automatic control circuits. Unlike many other color cameras that have a great amount of color distortion, the color is automatically corrected to remain stable despite variations in the intensity of the illumination. A built-in color-bar generator is useful in adjusting the television monitor for correct color presentation. Most of the associated electronics for the camera is contained in a separate 8.6-kg control unit.

Figure 3. Television Camera, Microscope, Illuminator, and Positioning Table

Because an area of approximately only 5.1 by 5.1 mm square is viewed, a magnification of 2X is required between the thin film network (TFN) and the camera. This magnification is lower than that of reflected-light microscopes, but it is greater than that of standard photographic lenses. High-quality optics having the correct magnification are required, as are a zoom lens for continuously varying the magnification and an adjustable iris for controlling the illumination.

The illumination source must have sufficient intensity to produce an image on the camera. The light from a 100-W halogen illuminator was heat-filtered and condensed to a spot having a diameter of 12.7 mm on the TFN. From a previous investigation, polarized light had been found advantageous for the visual inspection of TFNs.³ A polarizer therefore was inserted in the incident-light path and an analyzer was inserted in the reflected-light path. When the analyzer is rotated to its cross-polarized position, the visibility of resistor pinholes and voids is greatly increased, and the glare from the gold conductors is decreased.

A color-television monitor is used to display the area of the TFN under inspection (Figure 1). Typically, this area represents approximately one-sixteenth to one-twenty-fifth of the 25-mm square TFN. The color television monitor must produce bright, sharp, true-to-life pictures. From a viewing distance of approximately 1 m, the image of the TFN can be easily inspected on the television display for defects. If a potential defect observed on the screen is indistinct, an eyepiece included in the optical system permits a direct viewing of the area.

An X-Y positioning table is used to systematically move each area of the TFN requiring inspection under the television camera. This is accomplished in a regular pattern of 16 to 36 views (four X by four Y movements to six X by six Y movements), depending upon the magnification required to observe the defects. Small stepper motors, controlled by a minicomputer that has been programmed with the desired X-Y coordinates, determine the vertical and horizontal movements of the part. For this investigation, a table having a travel of 50.8 mm square and a speed of approximately 3.63 mm/s was used. A faster speed would decrease the positioning time.

The minicomputer performs several functions in the visual-inspection system. It issues the commands for the X-Y table to move to the next view, and it keeps track of each subview in the viewing sequence. The X-Y coordinates of each view are stored in its memory where they can be easily modified, if desired.

The minicomputer also accepts and interprets the defect codes that are entered by the inspector through the keyboard terminal. This information can be typed as an output report for each TFN, transferred to other long-term storage media, or passed to the Data Acquisition System.

The computer equipment used for this investigation consisted of the CPU with 24K words of memory, disk, cassette, CRT terminal, a line printer, and interfaces to the X-Y table. This system was utilized because the equipment was already available at Bendix Kansas City. Depending upon the desired system capability, less sophisticated computer equipment could be employed.

The inspector interacts with the visual-inspection system through the CRT terminal which consists of a viewing screen and a keyboard similar to that of a typewriter (Figure 4). A defect code is entered by striking the proper key, as indicated by the overlay, and then striking the carriage-return key. At appropriate times, the computer issues instructions and prompts the inspector, thus helping to assure the uniformity of all TFN inspections.

A low-speed printer can be incorporated in the system to provide a hard-copy printout of the inspection results. Because of equipment limitations during this investigation, printout was achieved by switching the CRT terminal signal to the line printer.

System Operation

Although the operation of the visual-inspection system is controlled by the inspector, the computer assumes such repetitious tasks as positioning the part, accepting defect codes, printing the output records, and prompting the operator with instructions. When the computer is awaiting a response from the inspector, the CRT displays two asterisks (**) and flashes the cursor. The response should consist of either a defect-code entry or a move to the next location. If a defect code is entered, the CRT displays the defect description and the number of the subview. If a non-permissible key should be inadvertently struck, the computer will ask the operator to make the correct entry.

The operating procedure that was utilized during the laboratory evaluation (illustrated in Figure 5) probably is similar to the procedure that would be used for an actual inspection operation. However, because the inspection system is especially flexible for changes in software, the procedure could be modified. The software flow diagram is shown in Appendix A, and typical computer programs are shown in Appendix B. The following inspection procedure was used during the evaluation.

Figure 4. Interactive CRT Terminal

Figure 5. Flow Diagram of Operating Procedure

1. Load the TFN to be inspected into the holding fixture on the X-Y table. (Precise registration is unnecessary.)
2. Visually inspect the view presented on the television monitor. Defects generally can be detected and classified by viewing the monitor; if greater resolution is required, the area can be observed directly through the eyepiece.
3. If a defect is present, enter the defect code by striking first the appropriate key on the keyboard, as indicated by the overlay, and then the carriage return.

The codes that were used for this evaluation are shown together with their corresponding keys in Table 1. Other defect categories can be added, if desired. The computer can convert the code into any designation compatible with defect nomenclature used at Bendix Kansas City.

4. When all defects present in the display have been recorded (or if none exist), move to the next subview by striking the carriage return as a response to the ** prompting of the computer.
5. When all subviews have been inspected, the system automatically will reposition the TFN to its starting location for removal from the X-Y table.
6. After first requiring that such identification information as the inspector, the date, the part number, and the serial number be entered, the computer prints each defect that was entered for the TFN together with the number of the subview (or *field*) in which the defect occurred. The CRT display shown in Figure 4 illustrates a typical output report for a defective TFN.

System Evaluation

The visual-inspection system was evaluated as a function of both the inspection time required and the accuracy achieved. For the evaluation, the X-Y table was programmed to move to 30 subviews that were located in a 5 by 6 arrangement. The subviews were sequentially adjacent to one another with a 10-percent overlap. The surface of each 25-mm-square TFN therefore was completely inspected.

Three people having different backgrounds in microelectronics were used to simulate inspectors. All were told the categories of defects for which to inspect, and they were instructed in the operation of the equipment. The following inspection results were obtained.

Table 1. Defect Classifications
and Codes Used for
Evaluation

Defect Code	Defect Classification
1	Excess Material
2	Short Circuit
3	Open Circuit
4	Resistor Void or Pinhole
5	Conductor Void
6	Conductor Scratch
7	Lead-Frame Damage
8	Bad Laser Trim
9	Contamination

Operator 1 was an engineer who possessed a general knowledge of the defect types, but he had had little experience in judging critical from noncritical defects. An average inspection time of 6 minutes, ranging from 3-1/2 to 9 minutes, was required for 6 different TFNs. The shorter times occurred on the latter samples, after this operator had gained some experience in judging the defects. While he detected all of the critical defects, he also tended to report many others that were noncritical.

Operator 2 was a foreman who had had some experience in micro-electronic inspection. The TFNs were inspected in an average time of 3 minutes each. This operator reported only the critical defects, and he spent very little time on each subview. He expressed the opinion that the inspection could be performed with a 4 by 4 pattern of larger views which would further decrease the total inspection time.

Operator 3 was an engineer who had had experience in microelectronic inspection. He reported all of the critical defects and took an average of 4 minutes for the inspection of each TFN.

All of the operators occasionally used the eyepiece to verify a decision on some of the defects. Several of the operators previously had participated in experiments in which the TFN was

positioned manually under the microscope. All commented that the semiautomatic visual-inspection technique was less tiresome, and that it provided greater confidence that the entire TFN had been inspected.

ACCOMPLISHMENTS

A technique utilizing a color-television camera and CRT display was investigated for increasing the accuracy, uniformity, and speed of the visual inspection of thin-film networks. Although current production quantities and the disadvantages of the inspection techniques now used do not economically justify incorporating the described concepts, the following advantages are stated for future consideration.

- The visual inspection of TFNs for typical defects can be efficiently accomplished with a reduction in eye strain and fatigue through the use of a closed-circuit television display on a color-television monitor.
- Using the described system, the time required to inspect a TFN would be approximately three to four minutes, or 30 percent less than the time required by the method now used.
- The computer- or tape-controlled positioning stage improves the uniformity of the inspection and assures that the entire TFN is inspected by automatically dividing the area to be inspected into multiple subviews.
- The interactive CRT terminal and computer-controlled defect-code-entry capability provides a simple method for reporting defects. A hard-copy printout of the defect report can be produced to accompany the product, and the results can be transferred to other data-acquisition systems that are now in use at Bendix Kansas City.

A short video tape recording showing the semiautomatic visual-inspection system in operation is available in the Advanced Inspection Engineering Department. Viewing may be arranged by contacting a member of the project team.

FUTURE WORK

Unless a decision is made to develop a semiautomatic visual-inspection system for use in the inspection department, no further work will be done in this field. Future effort will be devoted to the application of visual scanners and computers to the totally automatic visual inspection of thin-film networks.

REFERENCES

¹D. H. Harris and F. B. Chaney, *Human Factors in Quality Assurance*. New York: John Wiley and Sons, 1969.

²J. W. Schoonard and others, "Studies of Visual Inspection." *Ergonomics*, Volume 16, Number 4, July, 1973, pp 365-379.

³R. E. Hines, *Factors Affecting Visual Inspection of Thin Film Networks* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1673, February 1978 (Available From NTIS).

Appendix A
SOFTWARE FLOW DIAGRAM

Figure A-1. Software Flow Diagram

Appendix B
COMPUTER PROGRAMS

```

C          ---TFN. FTFN---
C      INTERACTIVE PROGRAM FOR TFN INSPECTION

      DIMENSION LX(36), LY(36)
      COMMON/MOV/LXNOW,LYNOW/A/LOC,IFLAG,K,IDEF(30)
      DATA LX/0,2250,4500,6750,9000,9000,6750,4500,2250,0,
10,2250,4500,6750,9000,9000,6750,4500,2250,0,
10,2250,4500,6750,9000,9000,6750,4500,2250,0,6*0/
      DATA LY/5*0,5*1800,5*3600,5*5400,5*7200,5*9000,6*0/

20      IFLAG=0
      LOC =1
      LXNOW =0
      LYNOW =0
      K =0
      DO 30 L =1,30
30      IDEF(L) =0
510     CALL DEFECT
      LOC =LOC +1
      IF (LOC.GT.30) GO TO 550
      CALL MOVE (LX(LOC),LY(LOC))
      GO TO 510
550     CALL MOVE (0,0)
      IF (IFLAG.NE.0) GO TO 610
      WRITE (6,600)
600     FORMAT(' ---DONE - NO DEFECTS --- '////)
      GO TO 20
610     CALL REPT
      WRITE (6,620)
620     FORMAT ('*****/' LOAD NEXT PART '/')
      GO TO 20
      END

```

#KB:<DEFECT. FTM

```
      SUBROUTINE DEFECT
C          DEFECT CODE ENTRY ROUTINE...
      COMMON /A/LOC,IFLAG,K,IDEF(30)
100      WRITE (6,1000)
1000     FORMAT (1H$, '***')
      READ (6,1002) ICODE
1002     FORMAT (A1)
      IF (ICODE.EQ.' ') GO TO 99
      IF (ICODE.EQ.'1'.OR.ICODE.EQ.'2'.OR.ICODE.EQ.'3'.OR.
11CODE.EQ.'4'.OR.ICODE.EQ.'5'.OR.ICODE.EQ.'6'.OR.
11CODE.EQ.'7'.OR.ICODE.EQ.'8'.OR.ICODE.EQ.'9')
1 GO TO 200
      WRITE (6,1010)
1010     FORMAT (' ---WRONG CODE - RE-ENTER--- ')
      GO TO 100
200      K= K+1
      IDEF(K) = ICODE
      K =K+1
      IDEF (K)= LOC
      IFLAG =1
      IF (ICODE.EQ.'1') WRITE (6,2001) LOC
      IF (ICODE.EQ.'2') WRITE (6,2002) LOC
      IF (ICODE.EQ.'3') WRITE (6,2003) LOC
      IF (ICODE.EQ.'4') WRITE (6,2004) LOC
      IF (ICODE.EQ.'5') WRITE (6,2005) LOC
      IF (ICODE.EQ.'6') WRITE (6,2006) LOC
      IF (ICODE.EQ.'7') WRITE (6,2007) LOC
      IF (ICODE.EQ.'8') WRITE (6,2008) LOC
      IF (ICODE.EQ.'9') WRITE (6,2009) LOC
2001     FORMAT (10X,'EXCESS MATERIAL, FIELD ',I3)
2002     FORMAT (10X,'SHORTED PATH, FIELD ',I3)
2003     FORMAT (10X,'OPEN PATH, FIELD ',I3)
2004     FORMAT (10X,'RESISTOR VOID, FIELD ',I3)
2005     FORMAT (10X,'CONDUCTOR VOID, FIELD ',I3)
2006     FORMAT (10X,'CONDUCTOR SCRATCH, FIELD ',I3)
2007     FORMAT (10X,'LEAD FRAME DAMAGE, FIELD ',I3)
2008     FORMAT (10X,'BAD LASER TRIM, FIELD ',I3)
2009     FORMAT (10X,'CONTAMINATION, FIELD ',I3)
      GO TO 100
99      RETURN
      END
```

#KB:<REPT.FTN

```
      SUBROUTINE REPT
C          OUTPUT REPORT ROUTINE FOR TFN DEFECTS....
C          R. E. HINES      JUNE,1976

      DIMENSION TODAY(3),INSP(10),IPN(4),ISN(4)
      COMMON /A/LOC,IFLAG,K,IDEF(30)
      K=K/2
      WRITE (6,100) K
100     FORMAT (////25X,'*** DEFECT REPORT ***',//,
1' DEFECTS = ',I4,//' -- ENTER REQUESTED DATA --'/)
      CALL DATE (TODAY)
      WRITE (6,500) TODAY
500     FORMAT (1H$, 'DATE: ',3A4,5X, 'INSPECTOR: ')
      READ (6,501) INSP
501     FORMAT (10A2)
      WRITE (6,502)
502     FORMAT (1H$, 'PART NO.: ')
      READ (6,503) IPN
503     FORMAT (4A2)

      WRITE (6,504)
504     FORMAT (1H$, 'SERIAL NO.: ')
      READ (6,505) ISN
505     FORMAT (4A2)
      K = 0
510     K= K+1
      ICODE =IDEF(K)
      K= K+1
      LOC =IDEF(K)
      IF (ICODE.EQ.0) GO TO 99
      IF (ICODE.EQ.'1') WRITE (6,1001) LOC
      IF (ICODE.EQ.'2') WRITE (6,1002) LOC
      IF (ICODE.EQ.'3') WRITE (6,1003) LOC
      IF (ICODE.EQ.'4') WRITE (6,1004) LOC
      IF (ICODE.EQ.'5') WRITE (6,1005) LOC
      IF (ICODE.EQ.'6') WRITE (6,1006) LOC
      IF (ICODE.EQ.'7') WRITE (6,1007) LOC
      IF (ICODE.EQ.'8') WRITE (6,1008) LOC
      IF (ICODE.EQ.'9') WRITE (6,1009) LOC
1001    FORMAT (' EXCESS MATERIAL, FIELD ',I3)
1002    FORMAT (' SHORTED PATH, FIELD ',I3)
1003    FORMAT (' OPEN PATH, FIELD ',I3)
1004    FORMAT (' RESISTOR VOID, FIELD ',I3)
1005    FORMAT (' CONDUCTOR VOID, FIELD ',I3)
1006    FORMAT (' CONDUCTOR SCRATCH, FIELD ',I3)
1007    FORMAT (' LEAD FRAME DAMAGE, FIELD ',I3)
1008    FORMAT (' BAD LASER TRIM, FIELD ',I3)
1009    FORMAT (' CONTAMINATION, FIELD ',I3)
      GO TO 510
99      RETURN
      END
```

#KB:<MOVE.FTN

```
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
```

KB:<MOTOR.MAC

```
.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    WAIT 1
        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
```

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L. Stratton, D/554, 2C44	20-22
R. P. Frohmberg, D/800, 2A39	23
T. A. Wiley, D/842, MD40	24
R. E. Kessler, D/865, 2C40	25

BDX-613-1813 (Rev.)

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Topical, September 1978

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SPECIAL PROJECTS: Automated Visual Inspection

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