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AEC RESEARCH AND DEVELOPMENT REPORT

Y-1693
Instruments

MASTER

AUTOMATED ULTRASONIC NONDESTRUCTIVE
TESTING SYSTEM

R. C. Maxson

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT** **Contract W-7405 eng 26**

**UNION
CARBIDE**

OAK RIDGE Y-12 PLANT
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Nuclear Division

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ABSTRACT

A small, general-purpose computer was used to automate an ultrasonic inspection machine designed to evaluate the internal integrity of flat plates and right circular cylinders. Application of the computer extended the capabilities of the basic system to include inspection of free-form surfaces of revolution. The automated system controls the positioning of the ultrasonic probe to maintain the probe perpendicular to and at a constant distance from the part surface. Using the front surface echo as the feedback control parameter, the desired tracking was achieved. Development of the automatic control system has greatly increased the versatility of the inspection device.

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SUMMARY

Ultrasonic inspection consists in transmitting ultrahigh-frequency sound through a medium and evaluating the reflections that occur at discontinuities in the density of the medium. An automated control system was developed for properly positioning the ultrasonic transducer with respect to the component under test. Using the front surface echo from the part as feedback, tracking of the surface was achieved. Several differently shaped parts have been successfully inspected. The main advantages of the system are: (1) its ability to inspect parts with any shape, (2) to operate unattended, and (3) to immediately locate flaws.

At some future date, the versatility of the system should be extended even further through the addition of an absolute positioning capability. In order to inspect welds in a shear mode, it is necessary to position the probe to a point in space determined by the part description. The computerized system may be easily adapted to include this technique.

INTRODUCTION

The use of ultrasonic waves to determine the internal integrity of metallic parts is very popular. Inspection by ultrasonic methods requires a source of ultrasonic sound, a medium through which to transmit the sound, and a receiver to convert the returning sound to a meaningful signal that can be interpreted. The inspection method requires that an ultrasonic source transmitter be held in a specific attitude with respect to the part's surface and at a fixed distance from the part. This orientation needs to be maintained throughout the test. A commercial ultrasonic system was purchased to perform this function, but the system was limited to testing flat plates and right circular cylinders. With the desire to ultrasonically inspect parts not having a regular geometric shape, it became necessary to modify the control mechanism so that the proper orientation of probe and part could be maintained throughout the test.

Initial system design centered around using a computer with the proper interfacing and programming to control the probe positioning of the existing system to inspect a free-form surface of revolution. The automated system controls only the relative positions of the probe to the part; it does not make any decisions based upon the returning echos other than to store the position of the probe when a flaw indication is issued by the flaw calibrator on the Immerscope. A significant feature of the machine control concept is that the program does not need to be altered when the part shape changes.

THE AUTOMATED TESTING SYSTEM

SYSTEM OPERATION

To ultrasonically inspect a part, the transducer probe must be maintained in the proper orientation to the part's surface. That is, a constant probe-to-part distance must be maintained, and the angle of incidence of the transmitted beam must be maintained within certain limits. The system that was in use and was to be automated controlled this probe-to-part relationship for flat plates and right circular cylinders only. Therefore, the automation criterion was to maintain the original functions of the machine, yet expand its scope to include an inspection of free-form surfaces of revolution.

In checking flat plates and right circular cylinders, it is not necessary to change the rate of drive of an axis; however, in checking a free-form surface of revolution this is necessary, thereby placing a more difficult requirement on the control system. In order to vary the drive rates of an axis while the test is in progress, the computer must either know beforehand the shape of the part and the required rate changes or have a feedback signal upon which decisions can be made and the rates changed. The feedback method was chosen so as to eliminate the need for a new part description every time a component with a differently shaped surface was to be inspected. The returning front surface echo from the part is the feedback signal. This technique limits the testing method to the use of longitudinal waves.

The various signals of interest and their time relationship are given in Figure 1. The early synchronization pulse is generated by the ultrasonic system as a timing pulse. The transmitted pulse occurs at a fixed time delay after the early synchronization pulse. After the transmitted pulse, echos return at a time dependent upon the probe-to-part distance, and the amplitude of the returning signals are dependent upon the angle of the probe with respect to the part. When the transmitted beam is normal to the part surface, the front surface echo will be at its maximum height; when the height of the front surface echo which is monitored by the computer decreases to a preset value, the probe is gimbaled in the proper direction to repeak this echo. The time between the front surface echo and the transmitted pulse is monitored by the computer to determine the proper standoff distance of the probe. One other signal is used but not shown in Figure 1 because it has no particular time relationship with any of the signals shown. This signal is the fast-flaw alarm and is used to indicate to the computer that the machine has seen a flaw and to take appropriate action. By monitoring these signals, the computer can fully control the operation of the machine.

When the automated system is started, the computer asks the operator to initialize two values that it needs in making its decision: (1) the distance (tangent to the part surface) between scans, and (2) the minimum front surface echo height before the probe is gimbaled to repeak the echo. After the turntable has rotated through 360 degrees, the computer will reposition the probe, with respect to the part's surface, the preset distance from its original position for the next scan. After this movement is

Figure 1. TIME RELATIONSHIP OF ULTRASONIC SYSTEM SIGNALS.

completed, the computer adjusts the probe-to-part relationship for the proper gimbal angle and standoff distance. The test is resumed, and the computer waits for the turntable to rotate another 360 degrees at which time the process is repeated. It should be noted that a flaw can be recorded at any point in the process. When the test is completed, the computer types out the x, y, and angle positions of the probe where flaws were recorded. Software is being written that will enable the operator to examine a flaw more closely by repositioning the probe over the flaw.

SYSTEM ANALYSIS

An interface is provided between the PDP8/I computer and the basic ultrasonic system. The function of the interface is to transform the digital commands of the computer into a form compatible with the basic system and to convert the return signals from the basic system to a form that can be interpreted by the computer. Since the computer is responsible for the complete control of the system, the interface must perform the task of issuing commands to control the motor drives and of monitoring the system to enable intelligent decisions to be made concerning its operation.

As indicated in Figure 2, the motor control selector logic is the heart of the control system. It issues commands to the automatic and gimbal relays as well as to the x and y axis stepping motor drivers. A single input-output transfer (IOT) pulse energizes all of the control functions. This action is accomplished by decoding Accumulator Bits 0 - 11. All IOT pulses are generated in the computer by the correct operating code and outputted on the I/O line while Buffered Memory Buffer (BMB) Bits 3 - 8 are decoded to select the proper device to receive the IOT pulse.

Operating the auto relay disconnects the x and y axis stepping motors from the original drivers and connects them to a pair of externally mounted drivers. These components were installed to eliminate electromechanical relays from the motor control circuitry. Gimbal relays apply the correct polarity voltage to the direct current gimbal motor for clockwise and counterclockwise rotation of the ultrasonic transducer.

One other switch is controlled, but it is located in the interface and is associated with the system monitoring duties. The switch, as seen in the block diagram, operates with IOT pulses and acts like a single-pole, double-throw switch to select the proper

PDP 8/1

Figure 2. PRINCIPAL COMPONENTS OF THE AUTOMATED TESTING SYSTEM.

input to the analog-to-digital (A/D) converter. It should be noted that, due to the electronic circuitry involved in implementing the switch, the inputs can be shorted together through the switch.

Continuing with the monitoring duty of the interface, the inputs to the A/D are the angle transducer and the front surface echo integrator. The angle transducer outputs a direct current potential directly proportional to the angle between the transducer axis and the horizontal. The front surface echo integrator selects the front surface echo and integrates it over a time interval to supply a direct current potential that is related to the angle between the ultrasonic probe and a line normal to the part surface. These inputs are applied to the input of the A/D converter for conversion into a ten-bit digital word for interpretation by the computer. Distance between the transducer and the part surface is measured by the time lapse between transmitting a pulse and receiving its front surface echo. This timing is accomplished by starting a clock with the transmitted pulse and counting the clock cycles until the front surface echo is received. The time lapse is then related to distance since the velocity of sound is known for the transmission medium.

Horizontal and vertical position changes are noted by observing two optical pulse encoders. Each encoder outputs two quadrature pulses for every 0.24 degree of rotation with the phase relationship of the pulses dependent on the direction of rotation of the encoder. The relationship between the encoder counts and the linear axis movement determines the relative position of either axis which can be recorded by counting the pulses from the encoder.

Detailed engineering drawings are given in Appendix A, part flow charts occupy Appendix B, and the software listing is contained in Appendix C. Locating flaws is the primary objective of the system. By monitoring the flaw alarm from the ultrasonic system, the three-dimensional position of a flaw can be recorded.

The system monitoring is done in the program-interrupt mode. When a machine function needs servicing, it requests an interrupt that initiates a search of the various monitored functions to determine which one needs recognition. When the appropriate steps have been taken, the computer returns to the program in progress.

OPERATING PROCEDURE

Proper operation requires performance of the following steps:

1. Turn the computer, Immerscope, and bridge power on.
2. Allow a warmup period.
3. Place the probe at its starting position and adjust for maximum front surface echo.

4. Start the turntable.
5. Turn the bridge switch on.
6. Put the step continuous mode switch in the "step" position.
7. Set the computer's switch register to 4000.
8. See that the teletype is on line and the reader is off.
9. Press the load address switch.
10. Press the start switch.
11. Input the distance between latitude scans and the minimum front surface echo height.

The test will begin at this point and proceed unattended. When the test has been completed, perform the following operations:

1. Set the computer switch register to 4001.
2. Press the load address switch.
3. Press the start switch.

The computer will then type out the horizontal, vertical, and angle position of the probe where a flaw was recorded.

The inspection process is terminated by observing the following steps:

1. Press the computer stop switch.
2. Turn the teletype to the "off" position.
3. Turn the computer, Immerscope, and bridge power switches off.

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APPENDIX A

DETAILED ENGINEERING DRAWINGS

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Figure A-1. DEVICE SELECTOR.

Figure A-3. GATE AND INTEGRATOR.

Figure A-4. STEPPING MOTOR DRIVE.

Figure A-5. RELAY AND ANALOG VOLT SELECTOR.

Figure A-6. MISCELLANEOUS CIRCUITS.

Figure A-7. CLOCK GATING COUNTER AND MISCELLANEOUS COMPONENTS.

Figure A-8. RELAY INTERCONNECTION.

APPENDIX B
PROGRAM FLOW CHARTS

APPENDIX C
SOFTWARE LISTING

/PAGE ZERO
/COMMON CONSTANTS, STORAGE, SUBROUTINES

/SYMBOLS
RDCLK=6401
STRFLW=6402
CLRFLW=6404
BGN=6411
RLYON=6412
RLYOFF=6414
CNTDWN=6421
CNTUP=6422
CLRDWN=6424
CNTREV=6431
CNTFWD=6432
CLRUP=6434
CLRREV=6442
CLRFWD=6444
SKPREV=6451
RDADC=6452
STRADC=6454
WAIT=6441
COSINE=0004
SINE=0003
INPUT=0013

/

*0001
0001 5505 JMP I FLGCK

/

*0005

0005 7400 7400
0006 7200 7200
0007 5600 5600

/

*0010

0010 2177 2177 /FLAW STORAGE STARTING LOCATION MINUS 1
0011 2247 2247
0012 1777 1777 /INCREMENT TYPE OUT CODE LOCATION
0013 2054 2054 /PERCENT TYPE OUT CODE LOCATION
0014 2177 2177

/

*0020

0020 0000 ATOD, 0
0021 6454 STRADC
0022 6452 RDADC
0023 5022 JMP .-1
0024 5420 JMP I ATOD

/

/CONSTANTS AND STORAGE

/*0040 - 0061, 4557 - 7577 FLOATING POINT PACKAGE

*0062

0062 0000 X1, 0
0063 0000 X2, 0
0064 0000 Y1, 0
0065 0000 Y2, 0
0066 0000 FLWY, 0
0067 0000 FLWCNT, 0
0070 0000 MINPK, 0
0071 0000 ANGLE, 0
0072 7777 CLRRLY, 7777
0073 7000 C7000, 7000

```

0074 0030 C30, 30
0075 0020 PREUP, 0020
0076 0040 PREDOWN, 0040
0077 1000 ANG, 1000
0100 2000 PK, 2000
0101 0100 AUTO, 0100
0102 0002 BRGDRV, 0002
0103 0200 CONT, 0200
0104 0400 BRGREV, 0400
0105 1200 FLGCK, 1200
0106 0000 FLWX, 0
0107 0000 FLWANG, 0
0110 0000 HOLDX, 0
0111 0000 HOLDY, 0
0112 0000 TANX, 0
0113 0000 TANY, 0
0114 0000 HOLD, 0
0115 0000 SIDOFF, 0
0116 1777 TWELVE, 1777
0117 2054 THRTEN, 2054
0120 2777 FORTEN, 2777
0121 0001 FLAWS, 0001
0122 0000 DONEX, 0000
0123 0000 DONEY, 0000
0124 0000 MOVE, 0000
0125 0062 XCOUNT, 62
0126 0064 YCOUNT, 64
0127 0062 C62, 62
0130 0064 C64, 64

```

/

```

*140
0140 4542 JMS I OUTPUT
0141 7402 HLT
0142 1650 OUTPUT, 1650
*145
0145 0000 INIT, 0000
0146 3554 DCA I 154
0147 1014 TAD Z 14
0150 3010 DCA Z 10
0151 7001 IAC
0152 3121 DCA Z FLAWS
0153 5545 JMP I INIT
0154 1157 1157

```

```

*160
0160 0000 END, 0000
0161 1166 TAD MNO
0162 3410 DCA I 10
0163 1170 TAD POUT
0164 3014 DCA 14
0165 5560 JMP I END
0166 7714 MNO, -64
0167 0000 LST, 0
0170 2777 POUT, 2777
PAUSE

```

```

*200
0200 7300 CLA CLL
0201 1101 TAD Z AUTO
0202 6412 RLYON
0203 7200 CLA

```

/INITIALIZATION AND START UP

```

0204 4750      JMS I RANGLE
0205 3071      DCA Z ANGLE
0206 4272      JMS CLEAR
0207 4765      JMS I TPRPK
0210 7200      CLA
0211 1117      TAD Z THRTEEN
0212 3013      DCA Z 13
0213 4751      JMS I PERPK
0214 4145      JMS INIT
0215 4770      JMS I DELAY
0216 4747      JMS I RCLOCK
0217 3115      DCA Z STDOFF
0220 7200      CLA
0221 4766      JMS I TINC
0222 7200      CLA
0223 1116      TAD Z TWELVE
0224 3012      DCA Z 12
0225 4753      JMS I INCRE
0226 5265      JMP INTRON
      /BEGIN EXECUTIVE ROUTINE
0227 4761      BEGIN, JMS I CNIFLW      /WAIT FOR TURNABLE TO ROTATE
0230 4407      JMS I 7
0231 5343      FGET FINCRE
0232 6746      FPUT I FDIST
0233 0000      FEXT
0234 4754      JMS I COMPUT      /CALCULATE AMOUNTS TO MOVE
0235 5314      JMP ROTATE      /PROBE TANGENT TO PART
0236 4755      MVIAN, JMS I MOVIAN    /MOVE PROBE
0237 2121      ISZ FLAWS
0240 7000      NOP
0241 4756      JMS I CHEKPK      /IS PROBE NORMAL?
0242 7500      SMA              /YES
0243 4757      JMS I GIMBLE      /NO
0244 7200      CLA
0245 4770      JMS I DELAY
0246 7000      NOP
0247 4760      JMS I CHEKD      /CHECK STANDOFF
0250 7300      CLA CLL
0251 4754      JMS I COMPUT      /STANDOFF IS OUT OF TOLERANCE
0252 4771      JMS I CORECT      /CALCULATE AMOUNTS TO BRING BACK
0253 4524      JMS I MOVE        /MOVE PROBE NORMAL TO PART
0254 7200      CLA
0255 2363      ISZ C1
0256 7200      RETURN, QMR CEL6      /RETURN TO CHECK ANOTHER LATITUDE
0260 1364      TAD M2
0261 3363      DCA C1
0262 5227      JMP BEGIN
0263 7000      NOP
0264 7000      NOP
      /SUBROUTINES
0265 7200      INTRON, CLA      /TURN INTERRUPT ON
0266 6032      KCC
0267 6042      TCF
0270 6001      ION
0271 5227      JMP BEGIN
0272 0000      CLEAR, 0      /CLEAR NECESSARY REGISTERS
0273 7200      CLA
0274 3062      DCA Z X1
0275 3063      DCA Z X2
0276 3064      DCA Z Y1
0277 3065      DCA Z Y2

```


0300	1127	TAD Z C62	
0301	3125	DCA Z XCOUNT	
0302	1130	TAD Z C64	
0303	3126	DCA Z YCOUNT	
0304	1120	TAD Z FORTEN	
0305	3014	DCA Z 14	
0306	6404	CLRFLW	
0307	6424	CLRDWN	
0310	6434	CLRUP	
0311	6442	CLRREV	
0312	6444	CLRFWD	
0313	5672	JMP I CLEAR	
0314	7200	ROTATE, CLA	/ROTATE COORDINATES FOR
0315	4407	JMS I 7	/TANGENTIAL MOVEMENT OF PROBE
0316	5773	FGET I FYDIST	
0317	3335	FMPY XYSCAL	
0320	0000	FEXT	
0321	4734	JMS I FIXED	
0322	1045	TAD Z 45	
0323	3112	DCA Z TANX	
0324	4407	JMS I 7	
0325	5772	FGET I FXDIST	
0326	3340	FMPY YXSCAL	
0327	0000	FEXT	
0330	4734	JMS I FIXED	
0331	1045	TAD Z 45	
0332	3113	DCA Z TANY	
0333	5236	JMP MVTAN	
0334	4757	FIXED,4757	
0335	7774	XYSCAL,7774	
0336	2203	2203	
0337	1342	1342	
0340	7774	YXSCAL,7774	
0341	2662	2662	
0342	1321	1321	
0343	0000	FINCRE,0	
0344	0000	0	
0345	0000	0	
0346	0560	FDIST,560	
0347	0475	RCLOCK,475	
0350	0457	RANGLE,457	
0351	1500	PERPK,1500	
0352	0475	RDCLOK,475	
0353	0600	INCRE,600	
0354	0400	COMPUT,400	
0355	0236	MOVTAN,236	
0356	0442	CHEKPK,442	
0357	1000	GIMBLE,1000	
0360	1455	CHEKD,1455	
0361	0522	CNTFLW,522	
0362	0000	MOV,0	
0363	7776	C1,-2	
0364	7776	M2,-2	
0365	1641	TPRPK,1641	
0366	1632	TINC,1632	
0367	5563	FLT,5563	
0370	0506	DELAY,506	
0371	0424	CORECT,424	
0372	0574	FXDIST,574	
0373	0571	FYDIST,571	

*400

/ SUBROUTINES

0400	0000	COMPUT,0000	/COMPUTES THE HORIZONTAL AND
0401	4257	JMS RANGLE	/VERTICAL DISTANCES TO BE MOVED
0402	3045	DCA Z 45	
0403	4757	JMS I FLT	
0404	4407	JMS I 7	
0405	6363	FPUT FANGLE	
0406	3342	FMPY M	
0407	2345	FSUB C	
0410	6366	FPUT THETA	
0411	0003	SINE	
0412	3360	FMPY FDIST	
0413	3350	FMPY YSCALE	
0414	6371	FPUT FYDIST	
0415	5366	FGET THETA	
0416	0004	COSINE	
0417	3360	FMPY FDIST	
0420	3353	FMPY XSCALE	
0421	6374	FPUT FXDIST	
0422	0000	FEXT	
0423	5600	JMP I COMPUT	
0424	0000	CORECT,0000	/CORRECT SCALE FOR PERPENDICULAR
0425	4407	JMS I 7	/MOVEMENT
0426	5374	FGET FXDIST	
0427	0000	FEXT	
0430	4756	JMS I FIXED	
0431	1045	TAD Z 45	
0432	3110	DCA HOLDX	
0433	4407	JMS I 7	
0434	5371	FGET FYDIST	
0435	0000	FEXT	
0436	4756	JMS I FIXED	
0437	1045	TAD Z 45	
0440	3111	DCA HOLDY	
0441	5624	JMP I CORECT	
0442	0000	CHEKPK,0000	/CHECKS NORMALITY OF PROBE
0443	7300	CLA CLL	/BY COMPARING THE INTEGRATED
0444	1100	TAD Z PK	/F.S. ECHO WITH THE ORIGINAL READ
0445	6412	RLYON	
0446	4020	JMS Z ATOD	
0447	7041	CIA	
0450	1070	TAD Z MINPK	
0451	3114	DCA Z HOLD	
0452	1100	TAD Z PK	
0453	6414	RLYOFF	
0454	7200	CLA	
0455	1114	TAD Z HOLD	
0456	5642	JMP I CHEKPK	
0457	0000	RANGLE,0000	/READS THE ANGLE ENCODER
0460	7300	CLA CLL	
0461	1100	TAD Z PK	
0462	6414	RLYOFF	
0463	7200	CLA	
0464	1077	TAD Z ANG	
0465	6412	RLYON	
0466	4020	JMS Z ATOD	
0467	3114	DCA Z HOLD	

0470	1077	TAD Z ANG	
0471	6414	RLYOFF	
0472	7200	CLA	
0473	1114	TAD Z HOLD	
0474	5657	JMP I RANGLE	
0475	0000	RDCLOK,0000	/READS THE TIME BETWEEN THE
0476	7300	CLA CLL	/MAIN BANG AND F.S. ECHO
0477	6401	RDCLK	
0500	5276	JMP .-2	
0501	7450	SNA	
0502	5276	JMP .-4	
0503	1073	TAD Z C7000	
0504	7040	CMA	
0505	5675	JMP I RDCLOK	
0506	0000	DELAY,0000	/GENERAL DELAY ROUTINE
0507	7300	CLA CLL	
0510	2317	ISZ DEL	
0511	5310	JMP .-1	
0512	2320	ISZ TIMES	
0513	5310	JMP .-3	
0514	1321	TAD MTIM	
0515	3320	DCA TIMES	
0516	5706	JMP I DELAY	
0517	0000	DEL,0000	
0520	7770	TIMES,-8	
0521	7770	MTIM,-8	
0522	0000	CNTFLW,0000	/WAITING SUBROUTINE TO WAIT ON
0523	7000	NOP	/THE TURNABLE SWITCH TO OPERATE
0524	6451	SKPREV	
0525	5323	JMP .-2	
0526	6451	SKPREV	
0527	7410	SKP	
0530	5326	JMP .-2	
0531	2337	ISZ SKPNO	
0532	5323	JMP .-7	
0533	7200	CLA	
0534	1340	TAD M2	
0535	3337	DCA SKPNO	
0536	5722	JMP I CNTFLW	
0537	7776	SKPNO,-2	
0540	7776	M2,-2	
0541	7000	NOP	
0542	7770	M,7770	
0543	3251	3251	
0544	7661	7661	
0545	7776	C,7776	
0546	3337	3337	
0547	2610	2610	
0550	0002	YSCALE,2	
0551	2565	2565	
0552	0160	0160	
0553	0002	XSCALE,2	
0554	2342	2342	
0555	5740	5740	
0556	4757	FIXED,4757	
0557	5563	FLT,5563	
0560	0000	FDIST,0	
0561	0000	0	
0562	0000	0	
0563	0000	FANGLE,0	
0564	0000	0	

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0565 0000      0
0566 0000      THETA,0
0567 0000      0
0570 0000      0
0571 0000      FYDIST,0
0572 0000      0
0573 0000      0
0574 0000      FXDIST,0
0575 0000      0
0576 0000      0
          *600

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/SUBROUTINES

```

0600 0000  INCRE, 0000
0601 6046      TLS
0602 4407      JMS I 7
0603 0013      INPUT
0604 3372      FMPY CONVRT
0605 6771      FPUT I FINCRE
0606 0000      FEXT
0607 5600      JMP I INCRE
0610 0000  MOVTAN,0000      /MOVE THE PROBE TANGENT INITIALI
0611 7200      CLA
0612 1367      TAD FWD
0613 3337      DCA XDIR
0614 1367      TAD FWD
0615 3356      DCA YDIR
0616 1112      TAD Z TANX
0617 1525      TAD I XCOUNT
0620 3376      DCA NEWX
0621 1113      TAD Z TANY
0622 1526      TAD I YCOUNT
0623 3377      DCA NEWY
0624 7001      IAC
0625 3122      DCA DONEX
0626 7001      IAC
0627 3123      DCA DONEY
0630 1075      TAD Z PRBUP
0631 1102      TAD Z BRGDRV
0632 6412      RLYON      /START DRIVE MOTORS
0633 4312      JMS CHECK
0634 5610      JMP I MOVTAN
0635 0000  PRIN,0000      /MOVE PROBE IN NORMAL TO THE PART
0636 7200      CLA      /INITIALIZATION
0637 1367      TAD FWD
0640 3337      DCA XDIR
0641 1370      TAD REV
0642 3356      DCA YDIR
0643 1110      TAD Z HOLDX
0644 1525      TAD I XCOUNT
0645 3376      DCA NEWX
0646 1111      TAD Z HOLDY
0647 7041      CIA
0650 1526      TAD I YCOUNT
0651 3377      DCA NEWY
0652 7001      IAC
0653 3122      DCA DONEX
0654 7001      IAC
0655 3123      DCA DONEY
0656 1076      TAD Z PRBDWN

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0657	1102	TAD Z BRGDRV	
0660	6412	RLYON	/START DRIVE MOTORS
0661	4312	JMS CHECK	
0662	5635	JMP I PRIN	
0663	0000	PROUT,0000	/MOVE PROBE OUT NORMAL TO
0664	7200	CLA	/THE PART INITIALIZATION
0665	1370	TAD REV	
0666	3337	DCA XDIR	
0667	1367	TAD FWD	
0670	3356	DCA YDIR	
0671	1110	TAD Z HOLDX	
0672	7041	CIA	
0673	1525	TAD I XCOUNT	
0674	3376	DCA NEWX	
0675	1111	TAD Z HOLDY	
0676	1526	TAD I YCOUNT	
0677	3377	DCA NEWY	
0700	7001	IAC	
0701	3122	DCA DONEX	
0702	7001	IAC	
0703	3123	DCA DONEY	
0704	1075	TAD Z PRBUP	
0705	1104	TAD Z BRGREV	
0706	6412	RLYON	/START DRIVE MOTORS
0707	4312	JMS CHECK	
0710	5663	JMP I PROUT	
0711	7000	NOP	
0712	0000	CHECK,0000	/THE GENERAL CHECK WHILE
0713	7200	CLA	/MOVING EXECUTIVE ROUTINE
0714	1122	TAD DONEX	
0715	7440	SZA	
0716	4332	JMS CHECKX	
0717	7200	CLA	
0720	1123	TAD DONEY	
0721	7440	SZA	
0722	4351	JMS CHECKY	
0723	7000	NOP	
0724	7200	CLA	
0725	1122	TAD DONEX	
0726	1123	TAD DONEY	
0727	7440	SZA	
0730	5323	JMP .-5	
0731	5712	JMP I CHECK	
0732	0000	CHECKX,0000	/CHECK THE X MOVEMENT
0733	7200	CLA	
0734	1525	TAD I XCOUNT	
0735	7041	CIA	
0736	1376	TAD NEWX	
0737	7540	XDIR,SMA SZA	
0740	5732	JMP I CHECKX	
0741	7200	CLA	
0742	1102	TAD BRGDRV	
0743	1104	TAD BRGREV	
0744	6414	RLYOFF	/STOP HORIZONTAL DRIVE MOTOR
0745	7200	CLA	
0746	3122	DCA DONEX	
0747	5732	JMP I CHECKX	
0750	7000	NOP	
0751	0000	CHECKY,0000	/CHECK THE Y MOVEMENT
0752	7200	CLA	

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0753 1526      TAD I YCOUNT
0754 7041      CIA
0755 1377      TAD NEWY
0756 7550      YDIR, SPA SZA
0757 5751      JMP I CHECKY
0760 7200      CLA
0761 1075      TAD PRBUP
0762 1076      TAD PRBDWN
0763 6414      RLYOFF      /STOP VERTICAL DRIVE MOTOR
0764 7200      CLA
0765 3123      DCA DONEY
0766 5751      JMP I CHECKY
0767 7540      FWD, 7540
0770 7510      REV, 7510
0771 0343      FINCRE, 343
0772 0000      CONVRT, 0000
0773 2631      2631
0774 4631      4631
0775 7000      NOP
0776 0000      NEWX, 0000
0777 0000      NEWY, 0000

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*1000

/ SUBROUTINES

```

1000 0000      GIMBLE, 0000
1001 7300      CLA CLL
1002 1100      TAD Z PK
1003 6414      RLYOFF
1004 7200      CLA
1005 1077      TAD Z ANG
1006 6412      RLYON
1007 7000      NOP
1010 7000      NOP
1011 4020      JMS Z ATOD
1012 3071      DCA ANGLE
1013 1361      OPPDIR, TAD LSTDIR      /DO WE GIMBLE UP OR DOWN?
1014 7500      SMA
1015 5252      JMP GIMDEC      /DOWN
1017 7000      NOP
1020 7000      NOP
1021 7000      NOP
1022 7300      OK, CLA CLL
1023 3360      DCA TIMES
1024 1077      TAD Z ANG
1025 1100      TAD Z PK
1026 6414      RLYOFF
1027 7200      CLA
1030 4766      JMS I DELAY
1031 5600      JMP I GIMBLE
1032 7300      GIMINC, CLA CLL
1033 1364      TAD CCW
1034 6412      RLYON      /START GIMBLE
1035 7200      CLA
1036 1071      TAD Z ANGLE
1037 1355      TAD THREE
1040 7041      CIA
1041 3362      DCA NANG
1042 4020      JMS Z ATOD
1043 1362      TAD NANG

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1044	7510	SPA	/HAS GIMBLE BEEN COMPLETED?
1045	5242	JMP .-3	/NO.
1046	7200	CLA	/YES.
1047	1364	TAD CCW	
1050	6414	RLYOFF	/STOP GIMBLE
1051	7200	CLA	
1052	7000	NOP	
1053	7000	NOP	
1054	7000	NOP	
1055	4316	JMS SRI	/IS PROBE NORMAL?
1056	7200	CLA	/NO.
1057	1356	TAD CM1	
1060	3361	DCA LSTDIR	/CHANGE DIRECTION OF GIMBLE FLAG
1061	5213	JMP OPPDIR	/RETURN TO GIMBLE AGAIN
1062	7000	NOP	
1063	7000	NOP	
1064	7300	GIMDEC, CLA CLL	
1065	1363	TAD CW	
1066	6412	RLYON	/START GIMBLE
1067	7200	CLA	
1070	1355	TAD THREE	
1071	7041	CIA	
1072	1071	TAD Z ANGLE	
1073	7041	CIA	
1074	3362	DCA NANG	
1075	4020	JMS Z ATOD	
1076	1362	TAD NANG	
1077	7500	SMA	/HAS GIMBLE BEEN COMPLETED?
1100	5275	JMP .-3	/NO.
1101	7200	CLA	/YES
1102	1363	TAD CW	
1103	6414	RLYOFF	/STOP GIMBLE
1104	7200	CLA	
1105	7000	NOP	
1106	7000	NOP	
1107	7000	NOP	
1110	4316	JMS SRI	/IS PROBE NORMAL?
1111	1357	TAD CPI	/NO
1112	3361	DCA LSTDIR	/CHANGE DIRECTION OF GIMBLE FLAG
1113	5213	JMP OPPDIR	/RETURN TO GIMBLE AGAIN
1114	7000	NOP	
1115	7000	NOP	
1116	0000	SRI, 0000	
1117	7200	CLA	
1120	1077	TAD Z ANG	
1121	6414	RLYOFF	
1122	7200	CLA	
1123	4766	JMS I DELAY	
1124	4765	JMS I CHPK	/IS PROBE NORMAL?
1125	7500	SMA	
1126	7410	SKP	/NO
1127	5222	JMP OK	/YES
1130	7200	CLA	
1131	1360	TAD TIMES	/IS THIS SECOND GIMBLE?
1132	7450	SNA	
1133	7410	SKP	/NO
1134	5345	JMP STOP	/YES
1135	1357	TAD CPI	
1136	3360	DCA TIMES	/NEXT GIMBLE WILL BE SECOND ONE
1137	1077	TAD Z ANG	

1140	6412	RLYON	
1141	7200	CLA	
1142	7000	NOP	
1143	7000	NOP	
1144	5716	JMP I SRI	
1145	0000	STOP, 0000	/HALT TEST AND CLEAR
1146	7200	CLA	/ALL RELAYS
1147	1072	TAD Z CLRRLY	
1150	6414	RLYOFF	
1151	7200	CLA	
1152	4160	JMS END	
1153	7000	NOP	
1154	7402	HLT	
1155	0021	THREE, 21	
1156	7777	CM1, -1	
1157	0001	CP1, 1	
1160	0000	TIMES, 0	
1161	0000	LSTDIR, 0	
1162	0000	NANG, 0	
1163	0004	CW, 0004	
1164	0010	CCW, 0010	
1165	0442	CHKPK, 442	
1166	0506	DELAY, 506	

/PROG. INTRP. IDEN. AND ASSO. SUBROUTINES
/

1200	3324	*1200	
1201	7004	DCA ACC	
1202	3332	RAL	
1203	6422	DCA LINK	
1204	7410	CNTUP	/SKP IF UP COUNT
1205	5224	SKP	/NO, TEST NEXT DEVICE
1206	6421	JMP YABS	/YES, GO TO S. R. YABS
1207	7410	CNTDWN	/YDWN?
1210	5224	SKP	/NO
1211	6432	JMP YABS	/YES
1212	7410	CNTIFWD	/XFWD?
1213	5300	SKP	/NO
1214	6431	JMP XABS	/YES
1215	7410	CNTREV	/XREV?
1216	5300	SKP	/NO
1217	6402	JMP XABS	/YES
1220	7402	STRFLW	/FLAW?
1221	5254	HLT	/NONE OF THESE
1222	7000	JMP FLAW	/YES
1223	7000	NOP	
1224	7201	NOP	
1225	6422	YABS, CLA IAC	
1226	7041	CNTUP	/+ Y COUNT?????
1227	1526	CIA	/ NO. - Y COUNT..
1230	3526	TAD I YCOUNT	
1231	1526	DCA I YCOUNT	
1232	1325	TAD I YCOUNT	
1233	7440	TAD OVRFLO	
1234	5240	SZA	
1235	7001	JMP .+4	
1236	1126	IAC	
1237	3126	TAD Z YCOUNT	
1240	6434	DCA Z YCOUNT	
		CLRUP	

1241	6424	CLRDWN	
1242	7300	CLA CLL	
1243	1332	TAD LINK	
1244	7010	RAR	
1245	1324	TAD ACC	
1246	6001	ION	
1247	5400	JMP I 0	
1250	7000	NOP	
1251	7000	NOP	
1252	7000	NOP	
1253	7000	NOP	
1254	7200	FLAW,CLA	
1255	1121	TAD Z FLAWS	/HAS FLAW BEEN RECORDED ON THIS ■
1256	7450	SNA	/NO
1257	5271	JMP FORGET	/YES
1260	7200	CLA	
1261	3121	DCA Z FLAWS	
1262	7200	CLA	
1263	1525	TAD I XCOUNT	
1264	3410	DCA I Z 10	
1265	1526	TAD I YCOUNT	
1266	3410	DCA I Z 10	
1267	1071	TAD Z ANGLE	
1270	3410	DCA I Z 10	
1271	6404	FORGET,CLRFLW	
1272	7300	CLA CLL	
1273	1332	TAD LINK	
1274	7010	RAR	
1275	1324	TAD ACC	
1276	6001	ION	
1277	5400	JMP I 0	
1300	7201	XABS,CLA IAC	
1301	6432	CNTFWD	/+X COUNT ?
1302	7041	CIA	/NO,-X COUNT
1303	1525	TAD I XCOUNT	
1304	3525	DCA I XCOUNT	
1305	1525	TAD I XCOUNT	
1306	1325	TAD OVRFLO	
1307	7440	SZA	
1310	5314	JMP .+4	
1311	7001	IAC	
1312	1125	TAD Z XCOUNT	
1313	3125	DCA XCOUNT	
1314	7300	CLA CLL	
1315	1332	TAD LINK	
1316	7010	RAR	
1317	1324	TAD ACC	
1320	6444	CLRFWD	
1321	6442	CLRREV	
1322	6001	ION	
1323	5400	JMP I 0	
1324	0000	ACC,0	
1325	4001	OVRFLO,4001	
1326	7000	NOP	
1327	7000	NOP	
1330	7000	NOP	
1331	7000	NOP	
1332	0000	LINK,0	

*1400

/SUBROUTINES

1400	7300	HOWFAR,CLA CLL	/STANDOFF IS OUT OF TOLERANCE
1401	1333	TAD AMOUNT	/HOW FAR AND WHICH WAY???
1402	7041	CIA	
1403	7500	SMA	/TOO CLOSE??
1404	7410	SKP	/NO. TOO FAR!!!
1405	5216	JMP OUT	/YES.
1406	5223	JMP IN	
1407	7041	CIA	
1410	3045	DCA Z 45	
1411	4750	JMS I FLI	
1412	4407	JMS I 7	
1413	6746	FPUT I FDIST	
1414	0000	FEXT	
1415	5655	JMP I CHEKD	
1416	3114	OUT, DCA Z HOLD	
1417	1334	TAD MOVOUT	
1420	3124	DCA MOVE	
1421	1114	TAD Z HOLD	
1422	5207	JMP .-13	
1423	3114	IN, DCA Z HOLD	
1424	1335	TAD MOVIN	
1425	3124	DCA MOVE	
1426	1114	TAD Z HOLD	
1427	5210	JMP .-17	
1430	7000	NOP	
1431	7000	NOP	
1432	7000	NOP	
1433	0000	CHKDST,0000	/CHECK TO SEE IF PROBE IS
1434	7000	NOP	/+OR- .25 INCH FROM INITIAL STAND
1435	4753	JMS I RDCLOK	
1436	7041	CIA	
1437	1115	TAD Z SIDOFF	
1440	1337	TAD C25	
1441	7500	SMA	
1442	7410	SKP	
1443	4745	JMS I STOP	/PROBE MORE THAN .25 INCH TOO FAR
1444	1340	TAD M52	
1445	7510	SPA	
1446	7410	SKP	
1447	4745	JMS I STOP	/PROBE LESS THAN .25 INCH TOO CL
1450	7200	CLA	
1451	5633	JMP I CHKDST	/PROBE O.K.
1452	7000	NOP	
1453	7000	NOP	
1454	7000	NOP	
1455	0000	CHEKD, 0000	/CHECK TO SEE IF PROBE IS +OR-
1456	7300	CLA CLL	/ .1 INCH FROM INITIAL STANDOFF
1457	4753	JMS I RDCLOK	
1460	7041	CIA	
1461	1115	TAD Z SIDOFF	
1462	3333	DCA AMOUNT	
1463	1333	TAD AMOUNT	
1464	1351	TAD C7	
1465	7500	SMA	
1466	7410	SKP	
1467	5200	JMP HOWFAR	/PROBE MORE THAN .1 INCH TOO FAR

1470	1352	TAD M16	
1471	7510	SPA	
1472	5747	JMP I RETURN	/PROBE O.K.
1473	5200	JMP HOWFAR	/PROBE MORE THAN .1 INCH TOO CLOSE
1474	7000	NOP	
1475	7000	NOP	
1476	7000	NOP	
1477	7000	NOP	
1500	0000	PERPK, 0000	/INITIALIZE THE PERCENT OF
1501	6046	TL5	/PEAK THRESHOLD
1502	4407	JMS I 7	
1503	0013	INPUT	
1504	6341	FPUT FPER	
1505	0000	FEXT	
1506	7200	CLA	
1507	1100	TAD Z PK	
1510	6412	RLYON	
1511	7200	CLA	
1512	4020	JMS Z ATOD	
1513	3114	DCA Z HOLD	
1514	1100	TAD Z PK	
1515	6414	RLYOFF	
1516	7200	CLA	
1517	1114	TAD Z HOLD	
1520	3045	DCA Z 45	
1521	4750	JMS I FLT	
1522	4407	JMS I 7	
1523	3341	FMPY FPER	
1524	3355	FMPY FRACT	
1525	0000	FEXT	
1526	4744	JMS I FIXED	
1527	7200	CLA	
1530	1045	TAD Z 45	
1531	3070	DCA Z MINPK	
1532	5700	JMP I PERPK	
1533	0000	AMOUNT,0	
1534	0665	MOVOUT,665	
1535	0636	MOVIN,636	
1536	0000	NCLOCK,0	
1537	0025	C25,25	
1540	7726	M52,-52	
1541	0000	FPER,0	
1542	0000	0	
1543	0000	0	
1544	4757	FIXED, 4757	
1545	1144	STOP,1144	
1546	0560	FDIST,560	
1547	0257	RETURN,257	
1550	5563	FLT,5563	
1551	0007	C7,7	
1552	7762	M16,-16	
1553	0475	RDCLOK,475	
1554	0506	DELAY,506	
1555	7772	FRACT,7772	
1556	2436	2436	
1557	5605	5605	

*1600

/TYPEOUT SUBROUTINES

```

1600 0000 TDIG, 0000
1601 7004 RAL
1602 3114 DCA HOLD
1603 4216 JMS ROTATE
1604 4216 JMS ROTATE
1605 4216 JMS ROTATE
1606 4216 JMS ROTATE
1607 6042 TCF
1610 5600 JMP I TDIG

```

/PRINT CHARACTER ROUTINE

```

1611 0000 TYP, 0000
1612 6046 TLS
1613 6041 TSF
1614 5213 JMP .-1
1615 5611 JMP I TYP

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/ROTATE AND CODING NUMBERS FOR OUTPUTING

```

1616 0000 ROTATE,0000
1617 7200 CLA
1620 1114 TAD HOLD
1621 7004 RAL
1622 7004 RAL
1623 7004 RAL
1624 3114 DCA HOLD
1625 1114 TAD HOLD
1626 0326 AND MASK
1627 1327 TAD CODE
1630 4211 JMS TYP
1631 5616 JMP I ROTATE

```

/TYPEOUT INITIALIZING QUESTION

```

1632 0000 INC, 0000
1633 7200 CLA
1634 1412 TAD I 12
1635 7510 SPA
1636 5632 JMP I INC
1637 4211 JMS TYP
1640 5233 JMP .-5

```

/TYPEOUT INITIALIZING QUESTION

```

1641 0000 PRPK, 0000
1642 7200 CLA
1643 1413 TAD I 13
1644 7510 SPA
1645 5641 JMP I PRPK
1646 4211 JMS TYP
1647 5242 JMP .-5
1650 7200 PNTOUT,CLA
1651 1414 TAD I 14
1652 7510 SPA
1653 5160 JMP END

```

1654	4200	JMS IDIG
1655	4260	JMS SKIP
1656	4277	JMS CARTN
1657	5250	JMP .-7

/SPACING BETWEEN COLUMNS

1660	0000	SKIP, 0000
1661	7200	CLA
1662	1317	TAD NO
1663	7500	SMA
1664	5660	JMP I SKIP
1665	7200	CLA
1666	1323	TAD SKIPS
1667	4211	JMS TYP
1670	2320	ISZ NOSKP
1671	5267	JMP .-2
1672	7200	CLA
1673	1321	TAD TAB
1674	3320	DCA NOSKP
1675	2317	ISZ NO
1676	5660	JMP I SKIP

/CARRIAGE RETURN AT END OF LINE

1677	7200	CARTN, CLA
1700	1317	TAD NO
1701	7440	SZA
1702	5677	JMP I CARTN
1703	7300	CLA CLL
1704	1325	TAD LNFD
1705	4211	JMS TYP
1706	7300	CLA CLL
1707	1324	TAD CRRTN
1710	4211	JMS TYP
1711	7200	CLA
1712	1322	TAD M2
1713	3317	DCA NO
1714	4716	JMS I DELAY
1715	5660	JMP I SKIP
1716	0506	DELAY,506
1717	7775	NO,-3
1720	7760	NOSKP,-20
1721	7760	TAB,-20
1722	7775	M2,-3
1723	0240	SKIPS,240
1724	0215	CRRTN,215
1725	0212	LNFD,212
1726	0007	MASK,0007
1727	0260	CODE,260

*4000

4000	5602	JMP I START
4001	5603	JMP I TPOUT
4002	0200	START,0200
4003	0140	TPOUT,140

*2000

2000	0323	323
2001	0324	324
2002	0305	305
2003	0320	320
2004	0240	240
2005	0311	311
2006	0316	316
2007	0303	303
2010	0322	322
2011	0305	305
2012	0315	315
2013	0305	305
2014	0316	316
2015	0324	324
2016	0212	212
2017	0215	215
2020	0311	311
2021	0275	275
2022	7700	7700
2023	0320	320
2024	0305	305
2025	0322	322
2026	0303	303
2027	0305	305
2030	0316	316
2031	0324	324
2032	0240	240
2033	0317	317
2034	0306	306
2035	0240	240
2036	0320	320
2037	0305	305
2040	0301	301
2041	0313	313
2042	0212	212
2043	0215	215
2044	0320	320
2045	0320	320
2046	0275	275
2047	7700	7700