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Y-1663
Mathematics and
Computers

APPLICATION OF A DIGITAL COMPUTER TO MECHANICAL TESTING

J. H. Smith

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**

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ABSTRACT

A digital computer is being used to record raw data and to provide automatic data calculations for mechanical tests. The computer which is connected through an analog-digital converter to a universal testing machine and to a torsion tester, stores the raw load-strain data, converts it to stress-strain data, and calculates any of the mechanical properties desired from the test. The computer can also provide a printout and a paper tape, both of which contain the stress-strain data points and the calculated data. In addition, the load-strain data that are normally obtained from the test machine are still available. An oscilloscope display is obtained as the data are being recorded.

Tests which are presently being performed using the computer are: tensile, compression, pin bearing, double shear, and torsion. Data, which are being recorded include: ultimate strength, offset yield strength, elastic and shear moduli, energy under the stress-strain curve, and a mathematical expression for the stress-strain curve. In addition to the mechanical load-strain curve provided by the test machine, the computer can provide a stress-strain curve and a listing of stress-strain data points.

CONTENTS

SUMMARY

A digital computer can be interfaced to any mechanical testing machine whose output is in the form of an electrical signal. The computer can be programmed to record raw data, convert them to stress-strain data, and calculate the mechanical properties desired from the test.

It should be possible in the near future to have the computer control such parameters of the test as: strain rate, load rate, and crosshead speed.

The advantages gained in time saved, and the ability to easily obtain data that would be very difficult to obtain by any other means, makes the computer an important new tool in the study of mechanical properties.

INTRODUCTION

In the latter part of 1966, while the Y-12 Plant Metallurgical Services Laboratory was performing a series of mechanical tests, a request was made to provide the data in a form such that it could be stored on magnetic tape.

After a brief investigation it was decided that, by using a small digital computer, the data could be furnished on magnetic tape. Also, the computer could perform the calculations and print out the results on a final report form, as well as provide many other desirable services. As a result, a PDP-8/S computer was purchased and was interfaced to a standard universal testing machine.

The system has been in operation for over a year, and over 1,000 tests of various types have been made. This report presents an evaluation of the system.

THE COMPUTER AND ITS APPLICATIONS

DESCRIPTION

The digital computer, shown in Figure 1, has been interfaced to a universal testing machine and to a torsion tester. Figure 2 shows the system in operation while an elevated-temperature tensile test is being conducted.

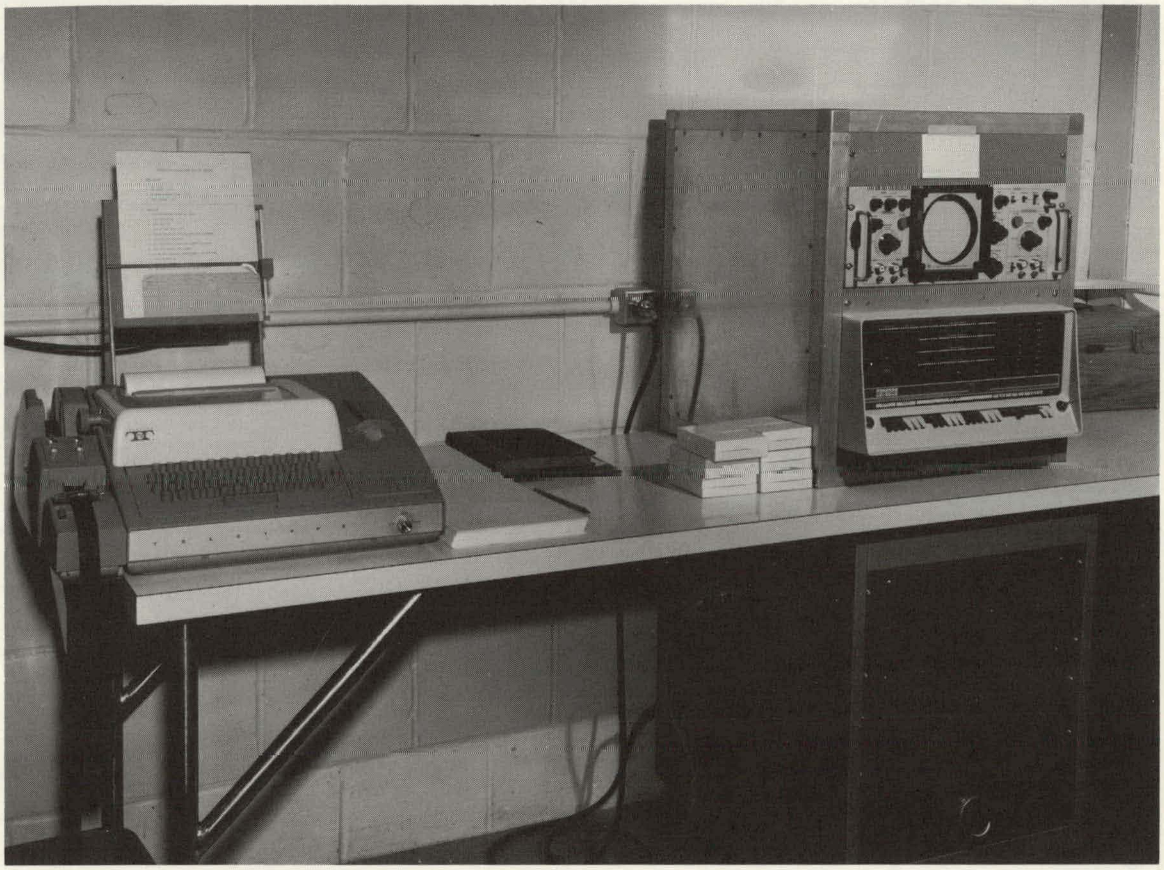

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Figure 1. COMPUTER AND TELETYPEWRITER.

The computer records and stores the raw data, converts them to stress-strain data, calculates the desired mechanical properties, and types the results out on a final report form which is located on the teletypewriter. In addition, a digital paper tape is produced which contains all of the information obtained from the test.

Tension, compression, torsion, pin-bearing, and double-shear tests can be performed using the computer. The various specimens can be seen in Figure 3.

122326

Figure 2. TENSILE TESTING USING THE COMPUTER SYSTEM.

Some of the principal specifications are: 115 V/60 cycle, solid state, basic time of 6 μ sec, up to 64 I/O devices, 12 bit word, operates on 2^s compliment arithmetic, standard memory of 4 k, can extend memory to 32 k, and can perform 27,778 additions/sec.

HARDWARE

Figure 4 presents a block diagram of the basic hardware that is used in the system.

Inputs to the computer can come from the teletypewriter keyboard, from tape, or from test signals which pass through an analog-to-digital converter.

Test signals can generate from any device that produces an electrical signal which is proportional to the property being measured. These devices will

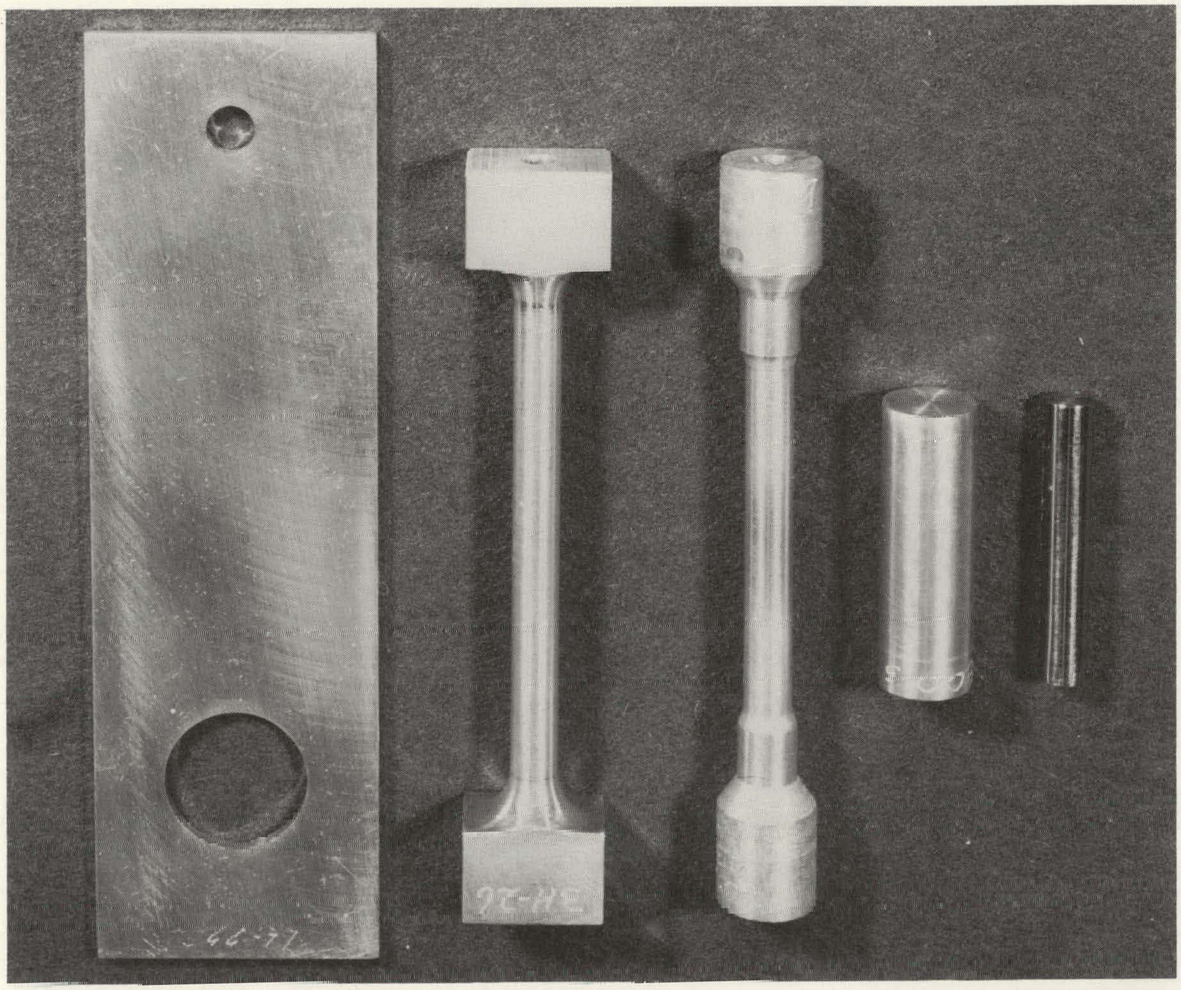

Figure 3. TYPICAL TEST SPECIMENS.

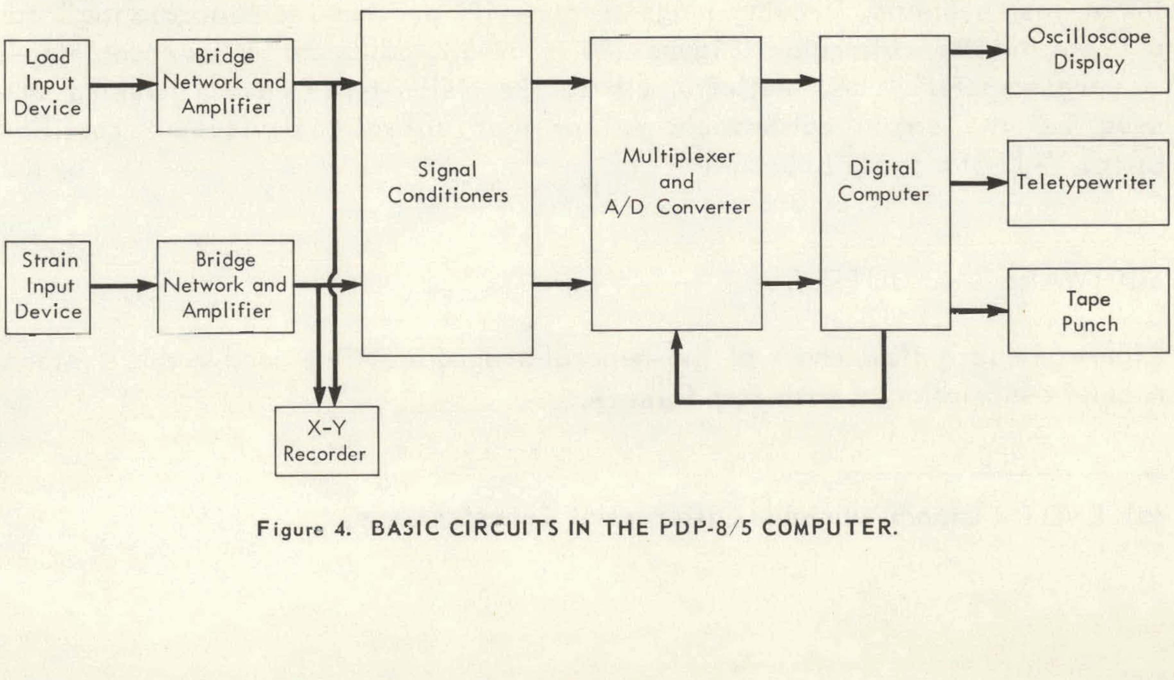

Figure 4. BASIC CIRCUITS IN THE PDP-8/5 COMPUTER.

generally be strain gages or LVDTs.[a] Views of some examples of input devices are presented in Figures 5 through 8.

The input signals are balanced and amplified using standard equipment that is available on the market. A strain amplifier is shown in Figure 9. The signals are then fed into a signal conditioner (see Figures 4 and 10).

The analog-digital (A/D) converter used in this system requires input signals that vary from 0 to -10 volts. The signal conditioners cause the input signals to vary from 0 to -10 volts and match the impedence of the system. These signal conditioners (Figure 10) were designed and built by the Y-12 Development Laboratory.

The multiplexer is a high-speed electronic switching unit that allows the computer to sample the signals from the A/D converter. The signals are thereby converted to binary form and stored in the computer's memory. The necessary calculations are performed by the computer and the output data are printed out on the teletypewriter, punched into a binary paper tape, and displayed on an oscilloscope.

A standard load-strain curve is obtained with the x-y recorder (Figure 4) which is independent of the computer operation.

Figure 11 shows the overall system connected to a standard torsion tester.

CALIBRATION

Calibration of this system is performed in the same manner as with conventional test systems. Proving rings (Figure 12) are used to calibrate the load; a linear motion calibrator (Figure 13) is used to calibrate the extensometers, compressometers, and deflectometers. Precision-type shunt resistors are used for the strain calibration. All of the calibration devices are certified by the Y-12 Standards Laboratory.

SOFTWARE AND OUTPUTS

Figure 14 is a flow chart of the general program outline used in this system. A brief description of each step follows.

(a) LVDT - Linear Variable Differential Transformers.

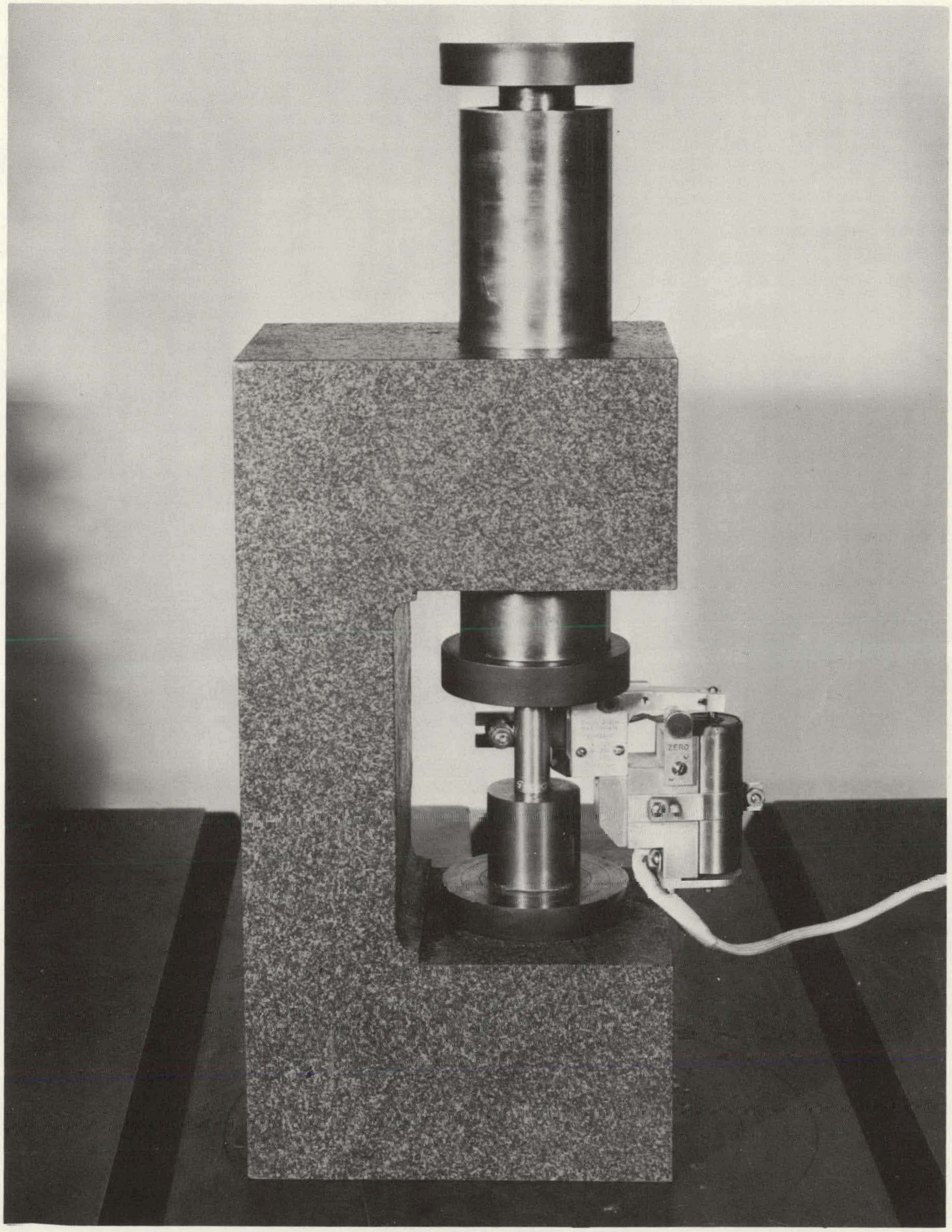

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Figure 5. COMPRESSOMETER ON A SPECIMEN.

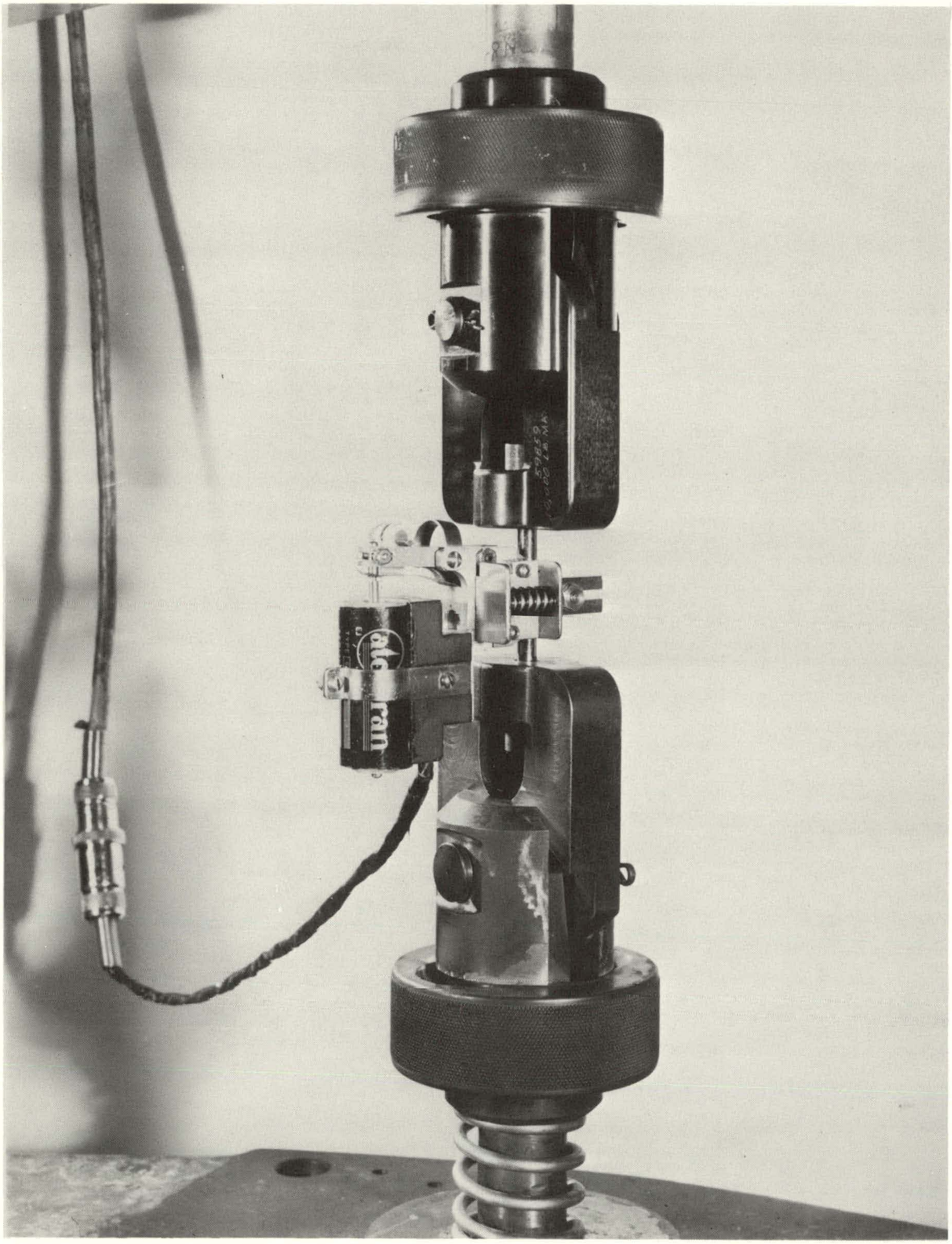

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Figure 6. EXTENSOMETER ON A SPECIMEN.

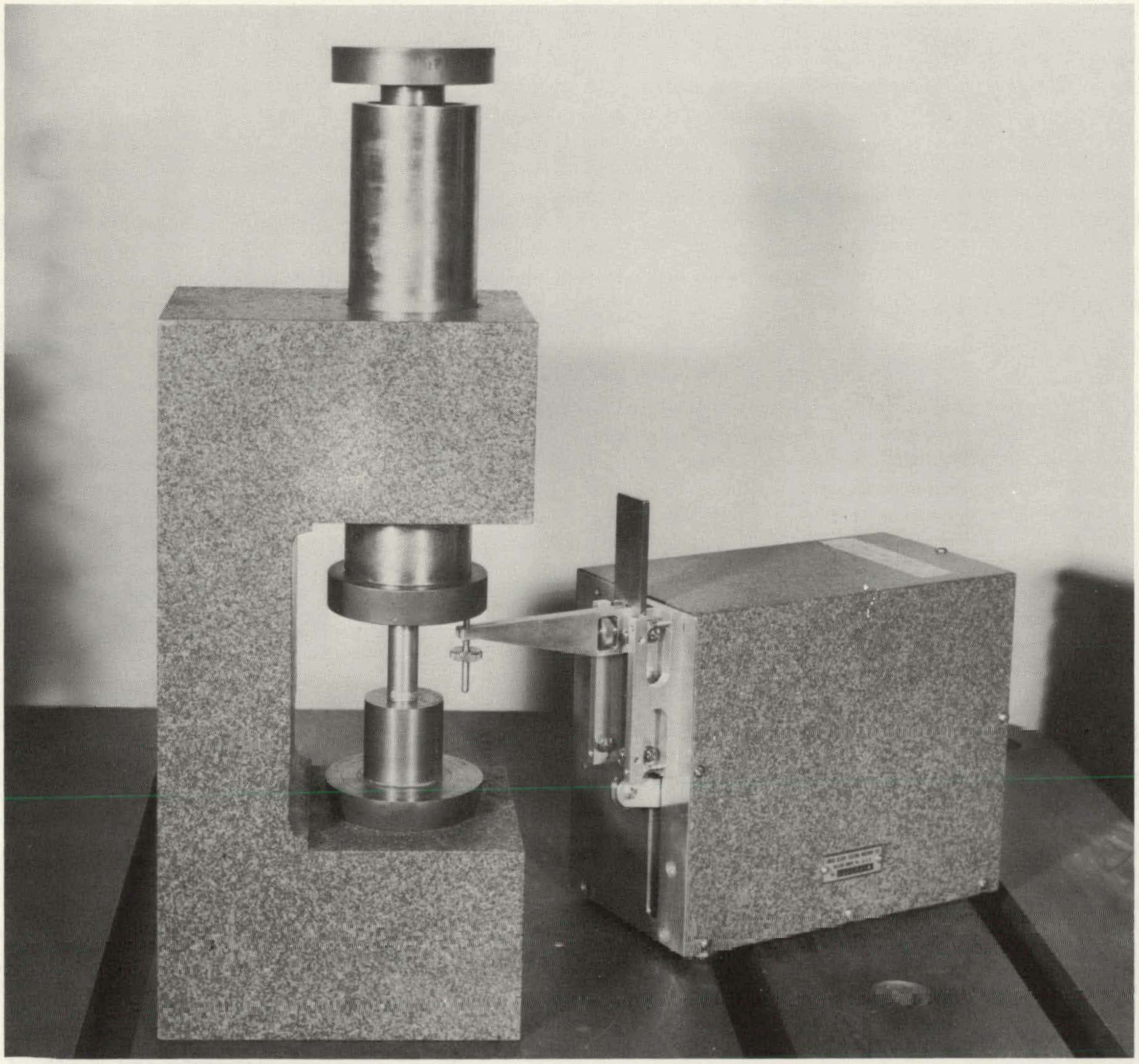

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Figure 7. A DEFLECTOMETER.

"Start" is where the starting address of the program is fed into the computer. "Initial data" are then typed in manually from the teletypewriter keyboard. Any information which is pertinent to the test can be inserted here, such as the specimen dimensions, or any information which may be desirable to have recorded with the test data.

The test is then begun and is controlled manually. As the test is being conducted, the computer will record and store the raw data. All data are displayed on an oscilloscope as the information is being recorded. This arrangement lets the operator know that the data are getting into the computer, and it allows

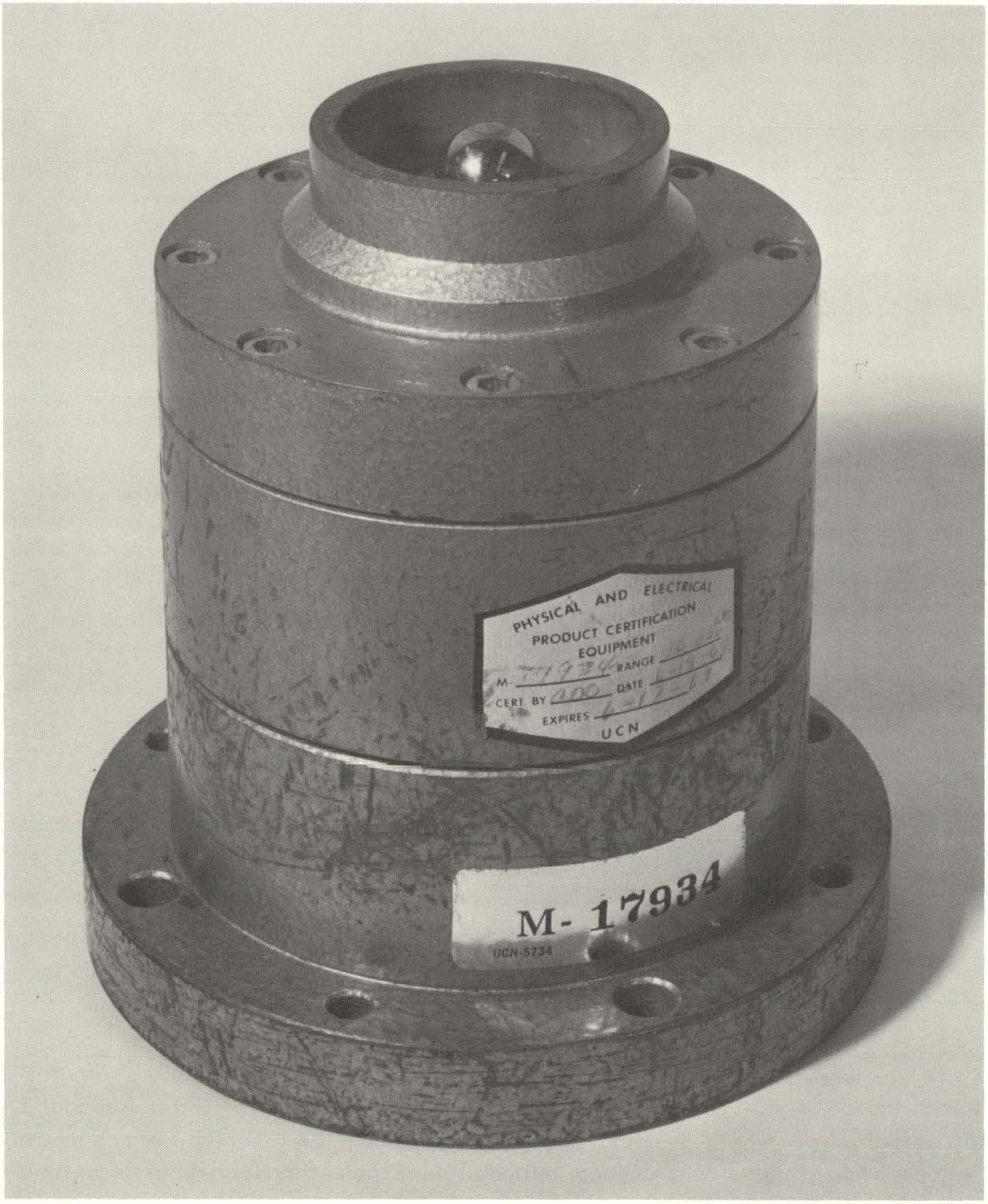

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Figure 8. A LOAD CELL.

him to see the shape of the stress-strain curve which provides a check on the overall setup.

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Figure 9. STRAIN AMPLIFIER.

At the end of the test, the operator presses the "stop" button on the testing machine. This action transmits a signal to the computer which lets it know that the test has been completed. The computer then disconnects from the A/D converter and begins the calculations.

Raw data are converted into stress-strain units and from binary to decimal form. Some decisions are made and the desired mechanical properties are then calculated. As the properties are calculated, they are printed out on a report form on the teletypewriter.

The format of the report form can be seen in Figure 15. The form is preprinted and can be single sheets, rolls, or fanfold paper. (Single sheets have been used for all testing at Y-12.)

At the end of the printout, the computer will pause for comments. The operator can insert here any comment he wants to make about the test. The comments

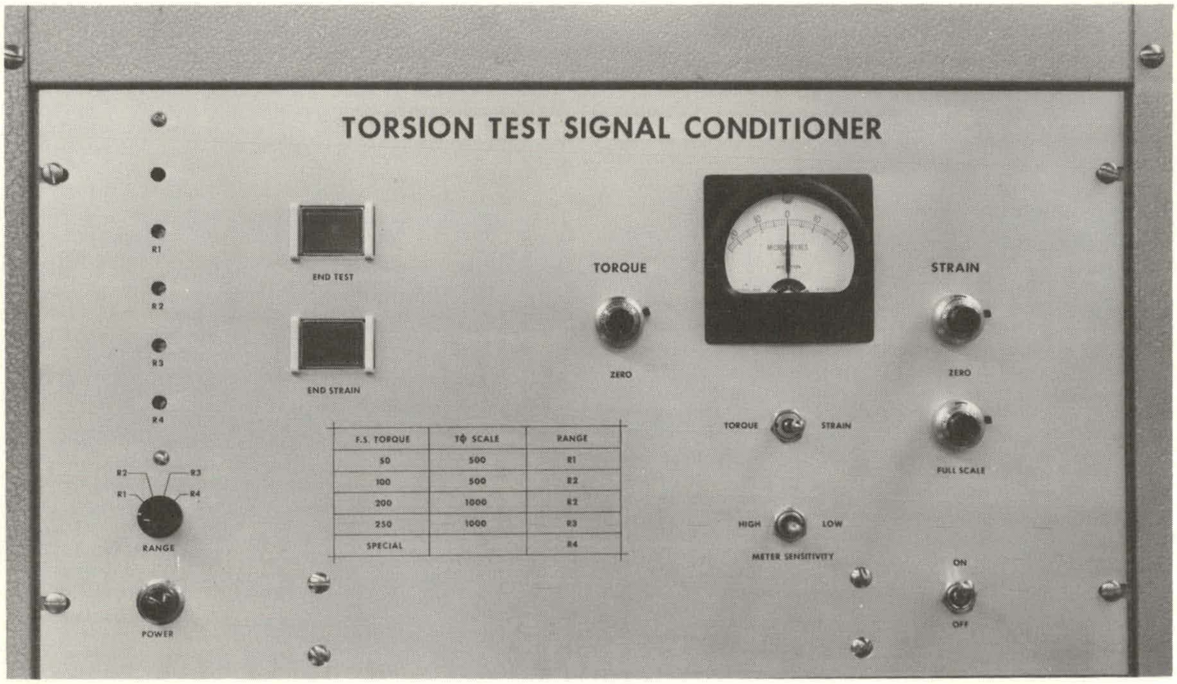

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Figure 10. SIGNAL CONDITIONER.

are entered manually from the teletype keyboard and have no effect on the program or the test. After the comments have been entered, a key is typed on the teletype keyboard which signals the computer to printout the stress-strain data points that were sampled during the test. At the end of the print-out, the computer will stop and the test is complete.

Figure 16 shows a flow chart for the subroutine used to determine the type test and the mechanical properties to calculate for three of the different tests. A number code was devised to distinguish the type test being conducted. The number code can be seen on the test form, Figure 15. For example, if a "4H" is typed in at this point, the computer will choose the subroutines to calculate properties for a high-magnification torsion test.

The "high" and "low" refer to strain magnification. A high-magnification test is made primarily to determine the elastic properties of the sample. The initial portion of the stress-strain curve is highly magnified and the extensometer is generally removed after sufficient data have been obtained to allow for a calculation of the offset yield strength. A low-magnification test is one on which the extensometer is left on the specimen to rupture, and the stress-strain curve is plotted for the entire test.

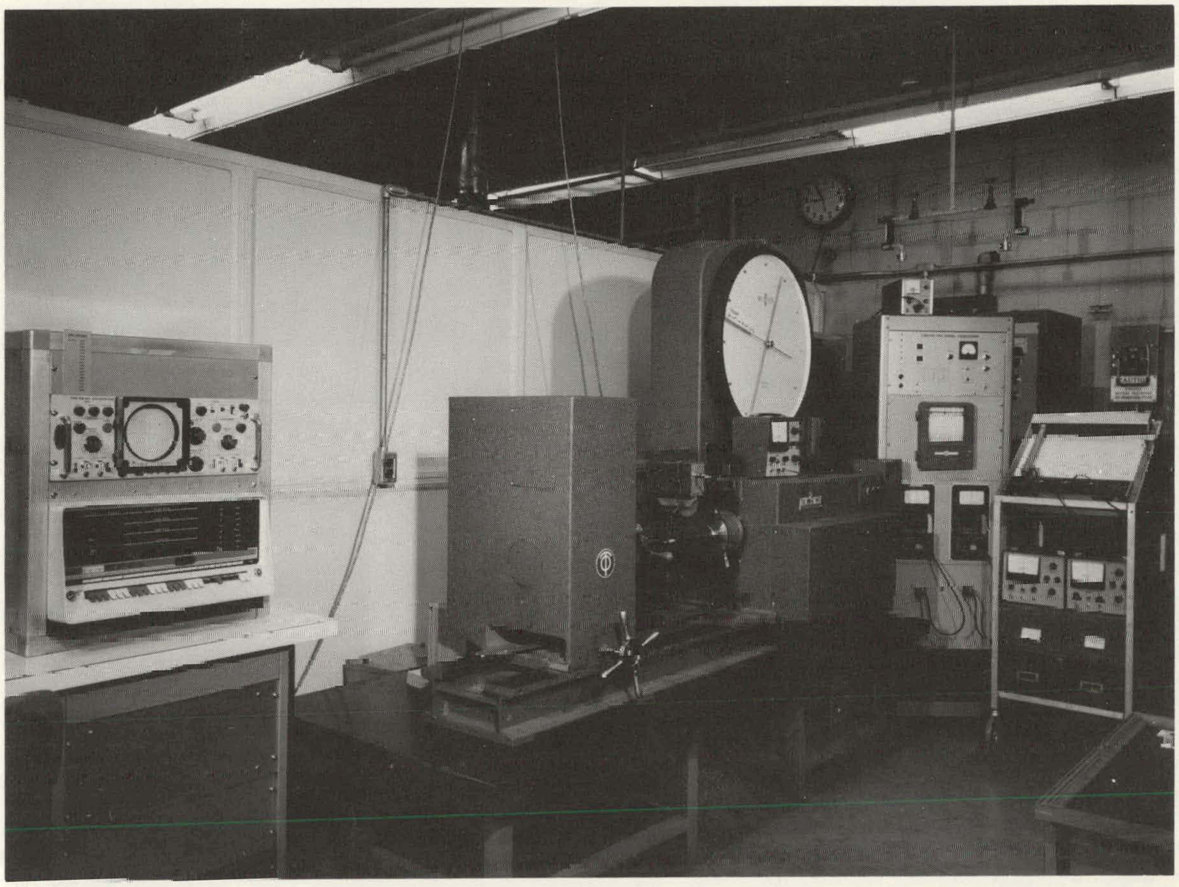

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Figure 11. TORSION TESTER WITH THE COMPUTER SYSTEM.

The mechanical properties on the report form, Figure 15, are defined in a general manner so that the same form can be used on all of the testing. For example, on a torsion test, the elastic modulus would represent the shear modulus.

The percent elongation and percent reduction in area are measured manually and are entered on the report form from the teletype keyboard.

The energy of the test, Figure 15, is the area under the stress-strain curve. On a high-magnification test, the area is calculated to the yield point; on a low-magnification test, the total area under the curve is calculated.

Figure 17 presents a data form that was obtained from an actual test. Figure 18 gives the associated stress-strain data point printout. The combined information makes up a single data report form.

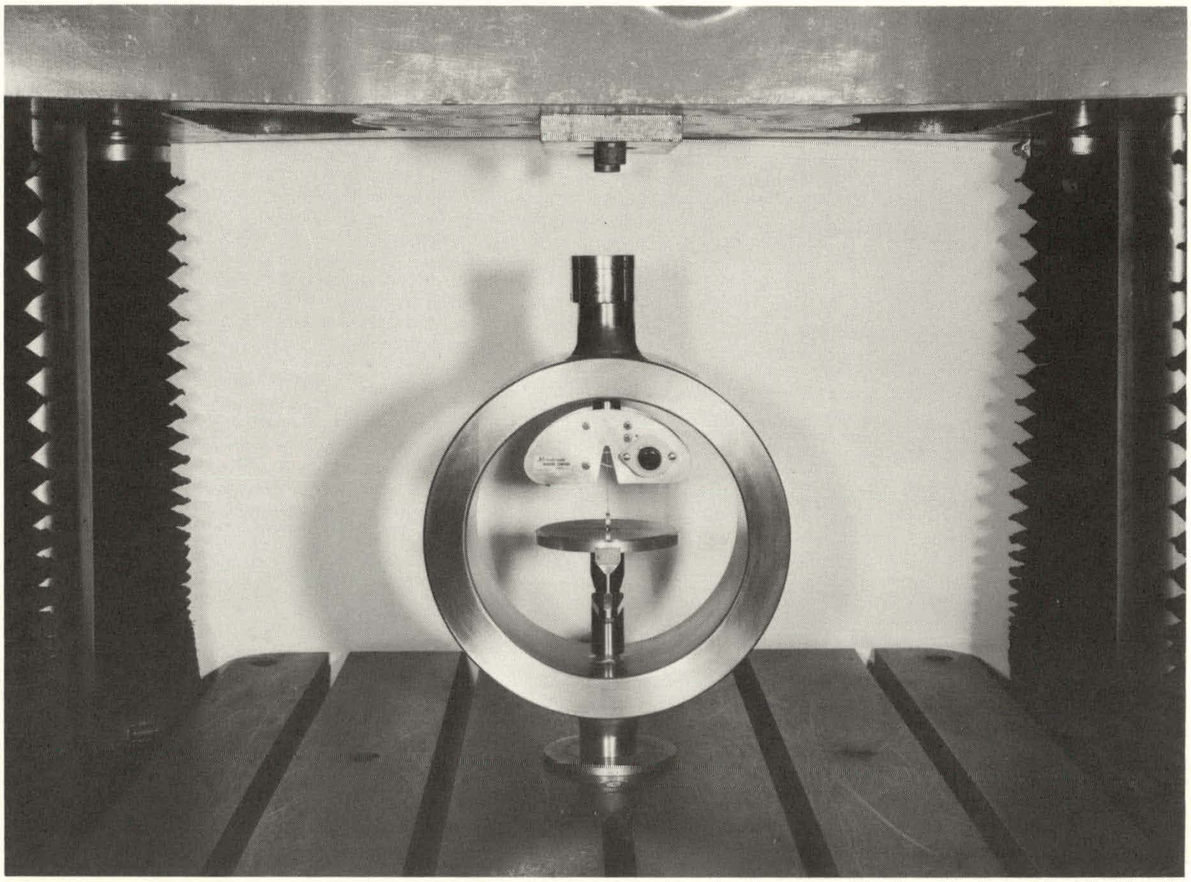

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Figure 12. A PROVING RING.

The computer samples 128 datum points each of stress and strain. The only restriction on the number of points sampled is in the available computer memory space.

To summarize, the test is set up manually and the initial data typed in from the teletype keyboard. The test is then conducted manually. The computer will record the data as the test is being conducted. At the end of the test the computer will calculate the desired mechanical properties. The results will be printed out on a report form, punched on a binary paper tape, and displayed on an oscilloscope. In addition, the standard load-strain curve can be obtained.

The computer can perform the calculations and print out the data in less than one minute. About four minutes are required to print out the stress-strain datum points. Most of the time is consumed by the teletype which can print only about ten characters per second. The total time could be reduced to

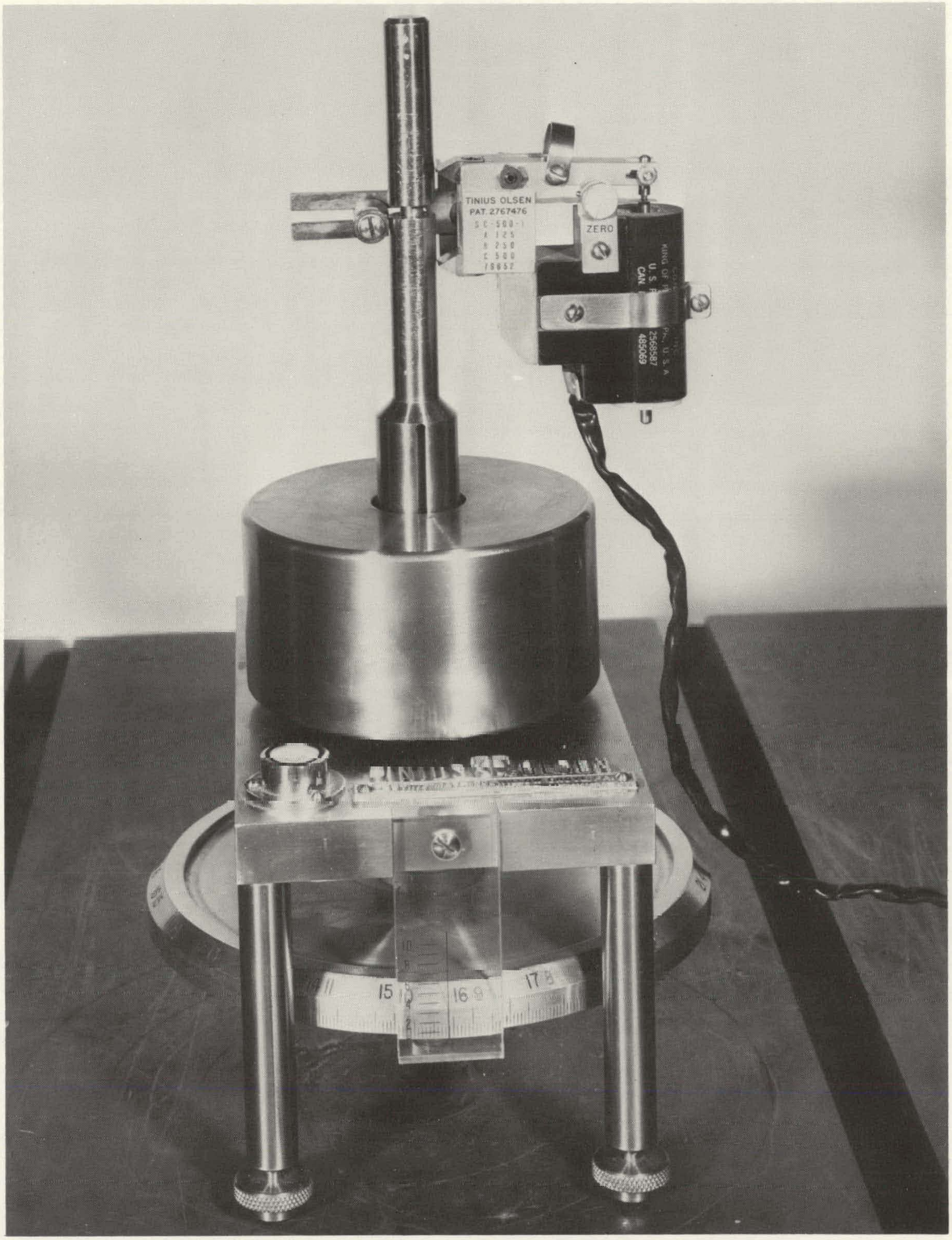

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Figure 13. LINEAR MOTION CALIBRATOR.

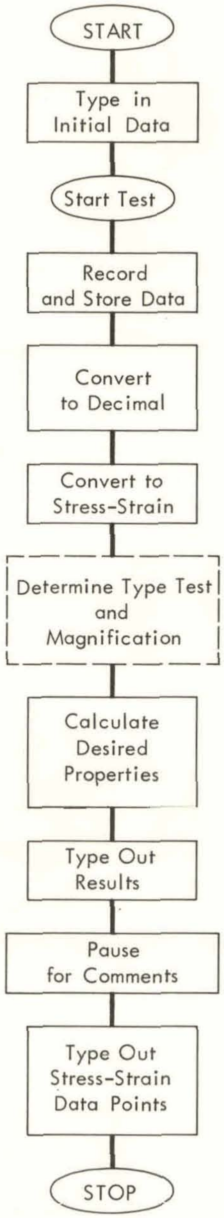

Figure 14. GENERAL PROGRAM OUTLINE.

about one minute if the datum points were only punched on tape, and a high-speed tape punch used.

ADDITIONAL DATA

Data on the paper tape are fed into a larger computer, such as an IBM-7090, where it is stored on magnetic tape. In addition, a stress-strain curve is

Y-12 PHYSICAL TESTING DEPARTMENT
MATERIALS PROPERTIES REPORT

IDENTIFICATION

PLATE THICKNESS (IN)

MATERIAL ROLLING DIRECTION

HRS @ ° F (CONDITIONING)

TEST TEMPERATURE (° F)

SPECIMEN DIMENSION (IN)

FULL-SCALE STRAIN (μIN/IN)

FULL-SCALE LOAD (LBS)

TYPE TEST	1. TENSION	H. HIGH
	2. COMPRESSION	L. LOW
	3. BEARING	
	4. TORSION	
	5. DOUBLE SHEAR	

ELASTIC MODULUS (PSI X 10^6)

OFFSET YIELD STRENGTH (PSI)

ULTIMATE STRENGTH (PSI)

ENERGY TO YIELD POINT (IN LBS/IN^3)

ENERGY TO END OF TEST (IN LBS/IN^3)

% ELONGATION

% REDUCTION IN AREA

UPPER YIELD STRENGTH (PSI)

COMMENTS:

Figure 15. MATERIALS PROPERTY REPORT.

plotted from the raw data (see Figure 19) and a stress-strain equation can be calculated which represents the stress-strain relationship for the test. The stress-strain equation is a Fourier series expansion.

There are two primary advantages to storing the data on magnetic tape: (1) there is a large space savings realized, and (2) the data can be stored in an organized manner. For example, approximately 5,000 tests can be stored on a single magnetic tape reel that is about 12.0 inches in diameter. Organizing the data means that data can be assembled, averaged, compared, or recalled in any manner by the computer. The manipulation that can be made with the data are unlimited in a large computer.

The magnetic tape also makes an excellent reference library for mechanical property data on various materials.

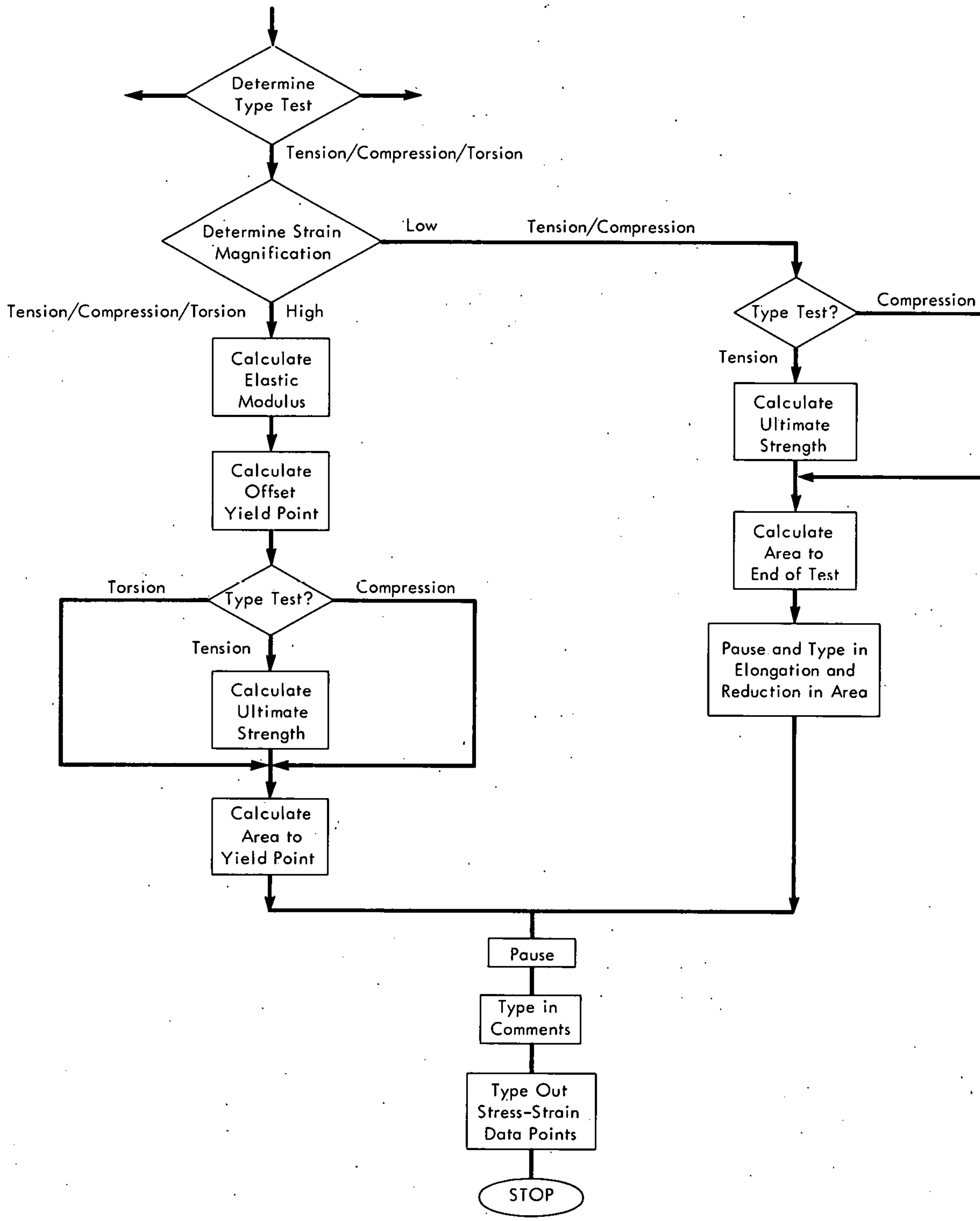

Figure 16. TENSION/COMPRESSION/TORSION SUBROUTINE.

Y-12 PHYSICAL TESTING DEPARTMENT
MATERIALS PROPERTIES REPORT

Ø4LT-Ø12Ø-2	IDENTIFICATION	
Ø.5Ø	PLATE THICKNESS (IN)	
5456-O-AL	MATERIAL L ROLLING DIRECTION	
Ø.5	HRS @ 2ØØ ° F (CONDITIONING)	
2ØØ	TEST TEMPERATURE (° F)	
Ø.252	SPECIMEN DIMENSION (IN)	
2ØØØØ	FULL SCALE STRAIN (µIN/IN)	
+ 6ØØØ	FULL SCALE LOAD (LBS)	
1 H	TYPE TEST 1. TENSION 2. COMPRESSION 3. BEARING 4. TORSION 5. DOUBLE SHEAR	H. HIGH L. LOW
+ 1Ø.22	ELASTIC MODULUS (PSI X 1Ø^{6})	
+ 22399	OFFSET YIELD STRENGTH (PSI)	
+ 49154	ULTIMATE STRENGTH (PSI)	
+ 65.41	ENERGY TO YIELD POINT (IN LBS/IN^{3})	
	ENERGY TO END OF TEST (IN LBS/IN^{3})	
35.Ø	% ELONGATION	
3Ø.6	% REDUCTION IN AREA	
	UPPER YIELD STRENGTH (PSI)	
COMMENTS:		

Figure 17. **ACTUAL DATA REPORT.**

ADVANTAGES AND DISADVANTAGES

The primary advantage of the computer system is the time savings realized, which is about 30 minutes per test. This total time considers that the same data can be obtained manually and the final report will be typed by hand.

Another advantage is the fact that data can be obtained that would be very difficult to obtain by any other method. Examples of this are the area under the curve (energy), the stress-strain curve, the stress-strain equation, and the stress-strain data point printout.

The disadvantages are primarily those that are associated with small computers. For example, there is a limited memory space available and some personnel training is required, but these limitations should cause no difficulty for the average technician who is familar with mechanical testing.

+ .ØØ	+ .ØØ	+ 3Ø826.93	+ 112218.9
+ 2545Ø.15	+ 1564.Ø2	+ 3Ø7Ø7.46	+ 113978.4
+ 33Ø97.14	+ 3323.55	+ 3Ø587.97	+ 115738.Ø
+ 33336.1Ø	+ 5Ø83.Ø8	+ 3Ø349.Ø1	+ 117497.5
+ 33336.1Ø	+ 6647.11	+ 3Ø229.52	+ 119257.Ø
+ 33336.1Ø	+ 84Ø6.64	+ 3Ø11Ø.Ø4	+ 121Ø16.6
+ 33455.59	+ 1Ø166.17	+ 29871.Ø7	+ 122776.1
+ 33575.Ø8	+ 11925.7Ø	+ 29751.58	+ 124535.6
+ 33575.Ø8	+ 13685.24	+ 29512.61	+ 126295.2
+ 33694.56	+ 15444.77	+ 29393.13	+ 128Ø54.7
+ 33814.Ø4	+ 172Ø4.3Ø	+ 29273.64	+ 129814.2
+ 33814.Ø4	+ 18963.83	+ 29Ø34.68	+ 131573.7
+ 33814.Ø4	+ 2Ø723.36	+ 28915.2Ø	+ 133333.3
+ 33933.53	+ 22482.89	+ 28676.22	+ 135Ø92.8
+ 33933.53	+ 24242.42	+ 28437.25	+ 136852.4
+ 33933.53	+ 26ØØ1.95	+ 28198.28	+ 138611.9
+ 33933.53	+ 27761.48	+ 28Ø78.8Ø	+ 14Ø371.4
+ 33933.53	+ 29521.Ø1	+ 27839.83	+ 142131.Ø
+ 33933.53	+ 3128Ø.54	+ 276ØØ.87	+ 14389Ø.5
+ 33933.53	+ 33Ø4Ø.Ø8	+ 27361.9Ø	+ 14565Ø.Ø
+ 33933.53	+ 34799.61	+ 27242.41	+ 1474Ø9.5
+ 33933.53	+ 36559.14	+ 27ØØ3.44	+ 149169.1
+ 33933.53	+ 38318.66	+ 26644.98	+ 15Ø928.6
+ 33933.53	+ 4ØØ78.2Ø	+ 26525.5Ø	+ 152688.1
+ 33933.53	+ 41837.72	+ 26286.53	+ 154447.7
+ 33933.53	+ 43597.26	+ 26Ø47.56	+ 1562Ø7.2
+ 33933.53	+ 45356.79	+ 258Ø8.6Ø	+ 157966.7
+ 33933.53	+ 47116.32	+ 2545Ø.15	+ 159726.2
+ 33933.53	+ 48875.85	+ 25211.17	+ 161485.7
+ 33933.53	+ 5Ø635.38	+ 24852.72	+ 16344Ø.8
+ 33933.53	+ 52394.91	+ 24613.76	+ 1652ØØ.4
+ 33814.Ø4	+ 54154.44	+ 24255.3Ø	+ 167155.3
+ 33814.Ø4	+ 55913.98	+ 24Ø16.33	+ 168914.9
+ 33694.56	+ 57673.51	+ 23657.88	+ 17Ø674.5
+ 33694.56	+ 59433.Ø4	+ 23299.43	+ 172434.Ø
+ 33575.Ø8	+ 61192.56	+ 22821.49	+ 174193.5
+ 33575.Ø8	+ 62952.Ø8	+ 2Ø431.81	+ 176344.Ø
+ 33575.Ø8	+ 64711.63	+ 16727.79	+ 1781Ø3.5
+ 33455.59	+ 66471.17	+ 1386Ø.17	+ 18Ø84Ø.6
+ 33336.1Ø	+ 6823Ø.68		
+ 33336.1Ø	+ 6999Ø.22		
+ 33216.62	+ 71749.75		
+ 33216.62	+ 735Ø9.28		
+ 33Ø97.14	+ 75268.82		
+ 33Ø97.14	+ 77Ø28.34		
+ 32977.65	+ 78787.87		
+ 32977.65	+ 8Ø547.41		
+ 32858.16	+ 823Ø6.92		
+ 32738.68	+ 84Ø66.47		
+ 32619.2Ø	+ 85826.ØØ		
+ 32619.2Ø	+ 87585.54		
+ 32499.71	+ 89345.Ø6		
+ 3238Ø.23	+ 911Ø4.59		
+ 3226Ø.75	+ 92864.12		
+ 32141.27	+ 94623.62		
+ 32Ø21.79	+ 96383.17		
+ 319Ø2.3Ø	+ 98142.7Ø		
+ 31782.81	+ 999Ø2.23		
+ 31663.33	+ 1Ø1661.7		
+ 31543.85	+ 1Ø3421.2		
+ 31424.36	+ 1Ø518Ø.8		
+ 313Ø4.87	+ 1Ø694Ø.3		
+ 31185.39	+ 1Ø8699.8		
+ 3Ø946.42	+ 11Ø459.4		

Figure 18. ACTUAL STRESS-STRAIN POINT TABULATION.

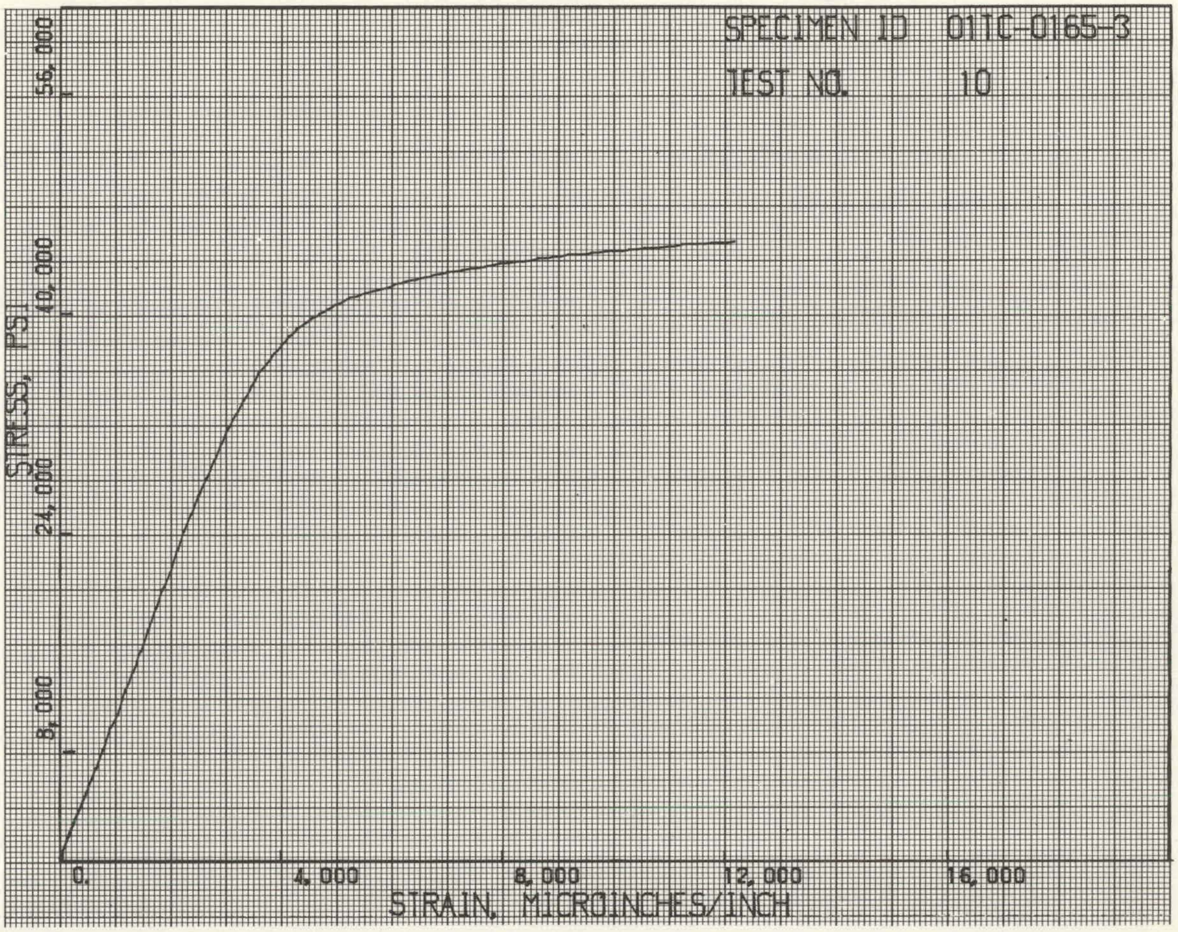

Figure 19. TYPICAL STRESS-STRAIN CURVE.

The advantages of this system are best realized when a large number of similar tests are made on a single material.

ACKNOWLEDGEMENTS

The author would like to give specific recognition to J. L. Arrowood and A. E. Stephens for their contributions in interfacing and programming this system.