A SOIL-AGGREGATE
CRUSHING-ENERGY METER

by

DAVID WAYNE BOYD

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Major Professor

PREFACE

This thesis describes the design, construction, and testing of an instrument to measure the energy required to crush soil aggregates. Chapter I consists of an article submitted for publication describing the purpose of the work and containing brief descriptions of the solution and results. It is self-contained and is presented in the format required for submission to a journal, but later chapters assume that the reader is familiar with the material in Chapter I.

Later chapters, taken with the appropriate appendicies, constitute the documentation for the device. Appendix D is a separable operator's manual for the device and is thus presented last. However, familiarity with the material there may help to clarify some other parts of the thesis.

I would here like to acknowledge the contributions of several people who were instrumental in making this work possible. Dr. Garth Thompson has been a continual source of ideas, motivation and energy. Without him, this project may never have come about and certainly would have been more difficult.

I would like to thank Dr. Ed Skidmore for providing the problem to be solved, and his patience, and for his many helpful suggestions.

I would like to thank Mr. Bob Rousser whose expert machining skills and suggestions were vital and much appreciated.

And finally, a special thanks to Mr. Mike Schwartz at KSU Extension Agricultural Engineering for the use of the computer system there, for the considerable amount of time he spent assisting me with the system, and for his many suggestions.

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CHAPTER I

A SOIL-AGGREGATE CRUSHING-ENERGY METER

ABSTRACT

Soil aggregate stability is an important measurement in determining soil properties. One current method of evaluating soil aggregate stability involves measuring the energy required to crush a soil aggregate and the new surface area generated. The purpose of this work was to develop a new technique for measuring the *energy of crushing*. Criteria for the improved system: 1) Energy must be measured quickly and accurately. 2) A digital readout should be provided in convenient units. 3) The system must perform tests both independently and in parallel with the previous method. 4) The force on the sample at its initial fracture should be recorded. And 5) the system must be portable. The system developed consists mainly of two parts. A small crushing vise was constructed that can be hand driven or mounted in existing test equipment. A computer module measures the force on the sample and the displacement of the crushing mechanism using a load cell and a displacement transducer. The force X displacement product is numerically integrated to find the crushing energy. The entire system fits easily into a carrying case about the size of a small suitcase and is powered from a single 110 V electrical outlet. The design criteria were met and measurements taken by the new system showed excellent agreement with previous methods. Coefficients of determination between results found by the new device and those found by previous methods were greater than 0.999.

INTRODUCTION

Dry soil aggregate stability is an important measure in the evaluation of soil properties. It finds application in several areas including tillage and wind erosion research. However current methods of evaluating dry soil aggregate stability are tedious and time consuming.

One common method uses a sieving procedure (Chepil, 1953; Toogood 1978). A sample of aggregates is sieved from a given length of time and the remains are weighed. The remains are then sieved for a given length of time and the remains of that sieving are weighed. The dry soil aggregate stability is expressed as a function of the weights remaining after each sieving.

Aggregate stability has been considered to be a function of the energy required to alter a sample. Some (Marshall and Quirk, 1950; Grossman et al., 1959; Farrell, et al., 1967; Gill and McCreery, 1960) have used a drop-shatter technique. In this method, the aggregate stability is expressed in terms of the height from which the sample must be dropped onto a hard surface in order for the sample to fracture. The energy of impact, and thus the energy imparted to the sample, is proportional to the height from which the sample was dropped.

It has been further suggested that aggregate stability is more precisely defined in terms of the energy required to create new surface area in a sample. This has been the subject of recent research at the Wind Erosion Research Laboratory (Skidmore and Powers, 198_). In this method, a sample is crushed and both the energy imparted to the sample and the surface area after crushing must be measured. The crushing is done on an Instron model 1125 Universal Testing Instrument. The sample is placed on the compression table connected to a 0-200 kg load cell. The crosspiece of the machine then crushes the sample at a speed of 10 mm/min. The Instron machine is equipped with a chart recorder. The pen of the recorder is driven from the output of the load cell and thus deflects in proportion to the force on the sample. The chart is driven at a rate proportional to the crosspiece speed. The plot generated is then a force vs. displacement record of the test. The energy imparted to the sample is related to the area under this curve. The area is integrated by cutting out the portion of the chart under the curve and weighing it. The weight is compared to the weight of a known area of the same paper. Knowing the calibrations of the load cell and the displacement drive, the energy of crushing is easily figured.

The surface area is found by sieving the crushed sample into 13 size divisions. The average surface area for a particle in each size range is estimated and the total area is calculated as a weighted sum of the areas for all the divisions.

This procedure is obviously tedious and time consuming and the Instron machine is so large that it is essentially a permanent installation. The purpose of this work was to expedite the measurement of dry soil aggregate stability by using a different method of measuring the crushing energy. The criteria for the new measuring device were:

1) The device must measure the energy quickly and accurately.
2) A digital readout in the proper units should be provided.
3) The device should be able to perform tests both independently and in conjunction with the Instron machine, thus enhancing the output capabilities of that instrument.
4) The device should record the force on the sample at its initial fracture.
5) The device should be portable.

SYSTEM DESIGN

The system consists of two main parts, a crushing vise and a computer module. The system is pictured in Figure 1.

The crushing vise is built of ¼ inch aluminum plate with steel supporting rods. The travel of the crushing plate is 2.54 cm and is accomplished with 18-revolutions of the drive shaft.

The platform on which the sample rests is supported by an Interface SSM100 load cell. The load cell contains a strain gage bridge in a sealed aluminum package. It delivers a DC voltage proportional to the force on it. The load cell has a force capacity of 445 N (100 pounds).

The displacement of the crushing plate is measured by a Hewlett-Packard 7D-CDT1000 displacement transducer. This is a linear differential transformer that produces a DC voltage proportional to the displacement of its core.

Since the crushing energy is the integral of the product of the force on the sample and the displacement of the crushing plate, these two instruments provide the necessary information for the computer to calculate the crushing energy.

The vise was designed to mount in the Instron testing machine so that parallel tests can be run. This is desireable both for evaluating the system and for enhancing the information available from the Instron tests.

The computer module contains a single board computer, some interfacing circuitry, and the power supply for all of the devices. The computer is a SYM-1 made by Synertek Systems Corporation. It is built around a 6502 microprocessor. It has on board a 28-key keypad and a six-digit LED display that are accessible from user programs.

The interfacing circuitry consists of a Burr-Brown SDM856 hybrid data acquisition system and a Burr Brown 3606 digitally controlled programmable gain instrument amplifier. The data acquisition system is a single integrated circuit that contains an 8-channel differential input analog multiplexer, a sample/hold amplifier, and a 12-bit successive approximation analog to digital converter. The programmable gain amplifier provides 11 possible gains ranging from 1 to 1024. These are selected by lines from the computer. These devices allow handling of the relatively large (0-5V) displacement signal and the relatively small (0-15mV) force signal with the same system. They are also naturally suited to handling of floating point numbers since the gain of the amplifier is similar to an exponent.

When a test is in progress, the computer reads the force and displacement more than 20 times per second and calculates the energy integral using a trapezoidal algorithm. The computer software is written entirely in machine language and is stored in a 2716 EPROM on the computer board. The monitor program continually scans the keyboard waiting for commands to be entered. When a command is detected, control passes to the routine which processes that particular command. When the function has been performed, control passes back to the monitor and scanning begins again.

All calculations are performed to 16 bits of precision and a limited set of floating point arithmetic routines was written to do the calculation. Numbers are stored internally in a 3-byte floating point format. The software occupies approximately 1500 bytes of memory.

The displacement transducer was calibrated using a machinist's vernier caliper. The caliper was used to measure the overall length of the transducer. At the same time, the displacement reading in its unitless form was read into the computer and displayed. A scaling factor was calculated by comparing the unitless readings of several points with the known caliper readings. Multiplying the unitless reading by the scaling factor gives the displacement in the desired units. The scaling factor is stored in the computer's memory.

The load cell was calibrated in a similar manner. Weights are placed on the crushing platform of the vise in known increments and the force displayed on the computer module in its unitless form.

The scaling factor for energy values was calculated from the other two factors.

The entire system fits easily into a hard-shelled carrying case about the size of a small suitcase. Power to the system is supplied through a single 110 V standard outlet.

OPERATION

The entire system was designed for easy operation. Each command to the computer consists of a single keystroke. Usually the first command used is one which causes the current displacement of the crushing plate to be continually displayed. This is provided to facilitate adjusting the displacement transducer on the vise. This allows the displacement zero to be easily set.

When the vise and instruments are set up and a sample is in place on the crushing platform, the computer is signalled that a test is beginning. The computer takes about two seconds to initialize its variables and configure the input circuitry and then supplies an audible tone to signal the operator that crushing can begin. While the test is in progress, the force and displacement are read and the energy is integrated. The current force on the platform is displayed during the test. During the first part of the test, the computer monitors the crushing force to detect the initial fracture of the sample. This is defined as the force from which the force first drops 25 percent. This is seen more clearly on the typical crushing curve shown in Figure 2. When the break is detected, a flag is lighted in the computer display to inform the operator.

The endpoint of the test is determined from the break force. The default relation is that the test will be ended when the crushing force reaches 1.5 times the break force. This relation can be changed from the keyboard as described later.

During the part of the test after the break has been detected, the computer quits looking for the initial fracture and begins comparing the current force with the force at which the test is to be ended. The integration, of course, continues as before. When the stop force is reached, the computer sends out a series of audible tones to tell the operator to stop crushing immediately.

Several important values from the test are stored in the computer's memory and are available through other commands on the keyboard. The values available are the aspects of Figure 2 labelled F_0, D_0, F_f, D_f, Break Force, and Energy. The displacements are displayed in units of centimeters, the forces in Newtons, and the energy in Joules.

Another command allows changing the method of calculating the force at which to stop the test. As stated above, the default relation is that the test is stopped when the *current force* is larger than the break force by a factor of 1.5. Using this command, this factor can be changed to any multiple of .25 between 1.0 and 2.25 inclusive. Obviously, the higher this stopping factor the more energy is imparted to the sample. The stopping factor remains at the new value until the computer is shut off or reset. When either of these happens, the value reverts to 1.5.

One final command passes control from the soil testing software to the monitor program supplied with the computer. This allows all of the capabilities of the computer to be used including machine language and BASIC language programming. An RS-232 connector is provided on the computer module so that a terminal may be connected. These capabilities allow easy testing of the hardware.

RESULTS AND DISCUSSION

To verify the accuracy of the new system (dubbed SACEM for Soil-Aggregate Crushing-Energy Meter), the crushing vise was mounted in the Instron machine and 30 tests were run in parallel. Ten tests were run on each of three different soils. The first ten tests used a relatively soft soil of the Aquic Haploxerolls subgroup (Hot Lake). The second ten tests used a soil of the Typic Argiudolls subgroup (Reading). The final ten tests used a relatively hard soil from the Typic Calciorthids subgroup (Rillito). Soils of varying aggregate stability were used so that the system was tested over a wide segment of its operating range. All of the samples were crushed at 10 mm/min.

During early testing it was discovered that the force measuring system of the Instron machine was prone to drift. To minimize the effect of this, the Instron machine was calibrated frequently during the 30 tests.

The energy was calculated from the Instron chart in two different ways. First, the graph of force vs. displacement was cut out and weighed as described earlier. The weight was compared with the weight of a known area of the paper. From the calibration, it was known what energy the standard area represented. The crushing energy was the ratio of the two areas multiplied by the energy represented by the standard area.

The second method is more convenient when weighing a section of the chart paper. This alternate method involves counting the chart paper divisions enclosed by the crushing curve. The number of divisions was compared to the number of divisions in the standard area. The energy was calculated as the ratio of these two numbers multiplied by the energy represented by the standard area. These two methods should give the same results to within the accuracy of the cutting and counting.

The force at which the sample broke was read from the chart.

The break force and energy readings found by these methods were compared to the readings found by SACEM . The results of these comparisons are shown in figures 3-5. Figure 3 shows the break force read from the Instron chart plotted against the break force as determined by SACEM. Also plotted is a 45^{0} line indicating where ideal results would lie. Figures 4 and 5 show the energy found by both Instron methods plotted against the energy as determined by SACEM. The lines on these figures are also 45^{0} lines. Since a wide range of samples was used, the energy readings are plotted in two figures. Figure 4 shows the results for those samples with crushing energy less than 0.1 J and Figure 5 shows the results for those samples with crushing energy greater than 0.1 J.

Straight lines were fitted to the data using the method of least squares to get a measure of how closely the results match the ideal. The lines were constrained to pass through the origin. The slopes and correlation coefficients found are shown in Table 1. Ideally, each line should have a slope of exactly unity.

The SACEM results for the break force correlated with the Instron results to within 0.6 percent and the SACEM results for the crushing energy to within 0.2 percent with the Instron results found by counting the chart paper divisions. However, the energy measured by weighing the paper shows to be consistently about three percent higher than that found by the other two methods. Ideally, all of the methods should give the same results.

It was first suspected that the standard area being used for the weight comparisons was not representative of the chart paper overall. This could result of nonuniformity of the chart paper. If the standard area were taken from a section of the paper that was three percent lighter than average, this would account for the discrepancy. However another standard area taken from a different section of the chart paper was not much different in weight than the first and tests done near the sections where the standard areas were taken showed the same discrepancy.

It was then theorized that the difference resulted from incorrectly estimating fractions of divisions on the chart when counting was done. Since the crushing curves are very irregular, fractions of divisions must often be estimated. To test this theory, small rectangular sections of chart paper were taken near the place where one of the standard areas was taken. The number of divisions on a rectangular section can be counted accurately. These samples, though better, still did not show the expected agreement.

It was then noted that handling a chart paper sample could cause its weight to change. To evaluate the extent of this change another sample was cut from the chart paper. This sample was irregular but was composed of rectangular segments. This allowed the number of divisions in the sample to be accurately known but also caused the time required to cut out the sample to be relatively long -- similar to the time required to cut out a soil crushing curve. The longer the cutting time, the more the sample must be handled during cutting.

This sample showed nearly the same discrepancy as shown by the soil crushing curves. Evidently, the act of cutting out the crushing curves significantly affects the results because the moisture and oils from the operator's hands are transferred to the paper sample. The energy values measured from cutting out the chart paper are then apparently about three percent too high.

The time required to make an evaluation by the old methods is much longer than by SACEM. A highly irregular chart of typical size can take as long as 15 minutes to be cut out by a careful operator. The reading made by SACEM is available almost instantaneously.

One minor problem can occur occasionally with the definition of the sample break force. If the initial rise of the crushing curve is not smooth, a false break may be detected by SACEM. A slight shift in the sample position or a small fragment breaking off of the sample may cause the crushing force to drop 25 percent long before the sample actually fractures. This occurred once during the 30 tests used for comparison. To help minimize this problem, the computer is programmed to ignore any break detected when the crushing force is less than 2 Newtons.

It is obvious that the SACEM system gives results that are in excellent agreement with previous work and that the design criteria stated earlier are very well met.

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Table Headings and Figure Captions

Table 1. Slopes and Coefficients of Determination of Regression Variables of Comparison of Methods for Determining Break Force and Crushing Energy.

Figure 1. Photograph of Soil-Aggregate Crushing-Energy Meter (SACEM).

Figure 2. Typical Soil Crushing Curve

Figure 3. Comparison of Initial Break Force as Determined by Two Different Methods (Instron vs. SACEM).

Figure 4. Comparison of Crushing Energy as Determined by Two Different Methods. Samples with Energy Less than 0.1 Joules.

Figure 5. Comparison of Crushing Energy as Determined by Two Different Methods. Samples with Energy Greater Than 0.1 Joules.

TABLE 1

Regression Variables	Slope	r^2
Instron Break Force vs. SACEM Break Force	.9947	.9996
Instron Energy (Weighing) vs. SACEM Energy	1.0345	.9996
Instron Energy (Counting vs. SACEM Energy	1.0014	.9997

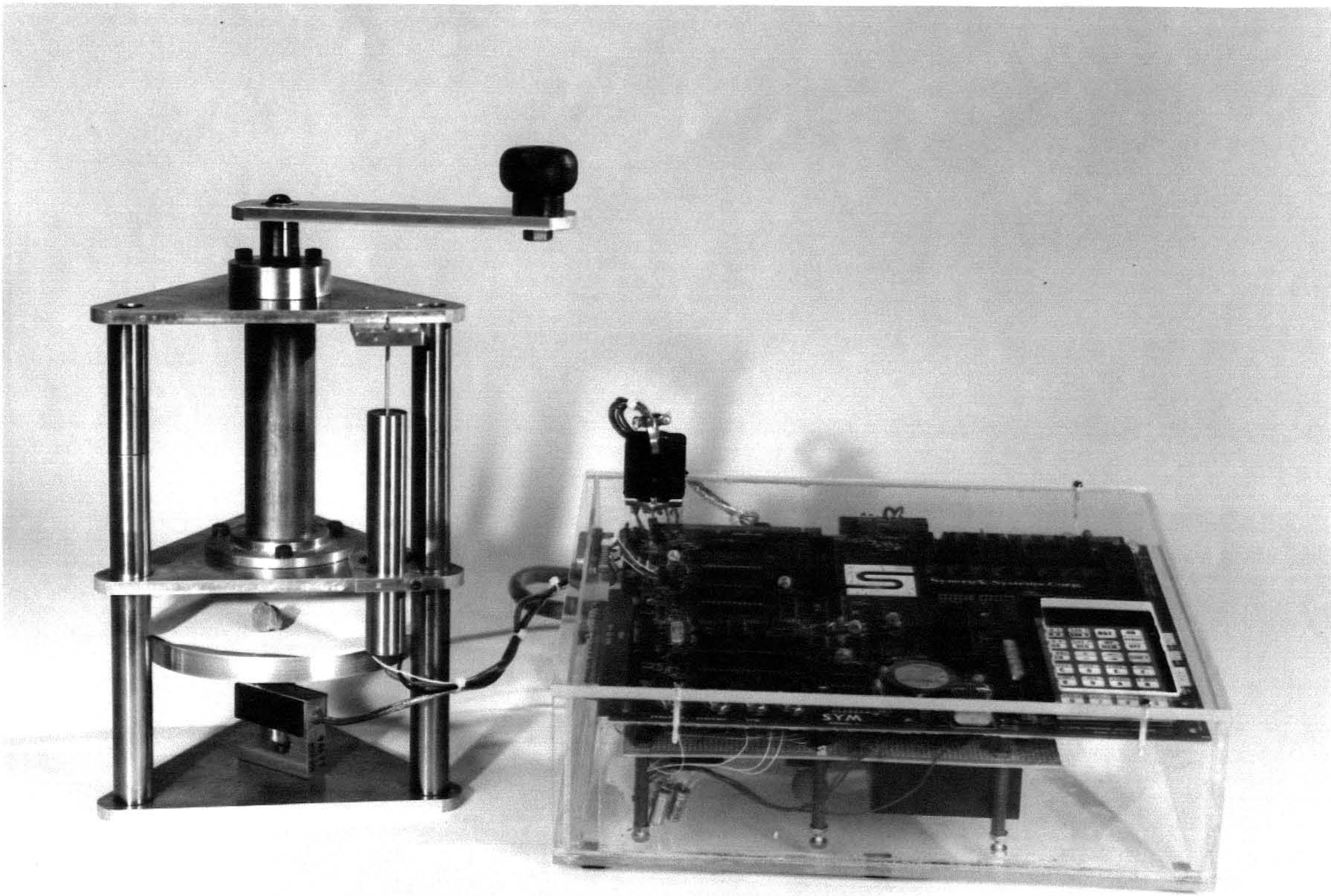


Figure 1

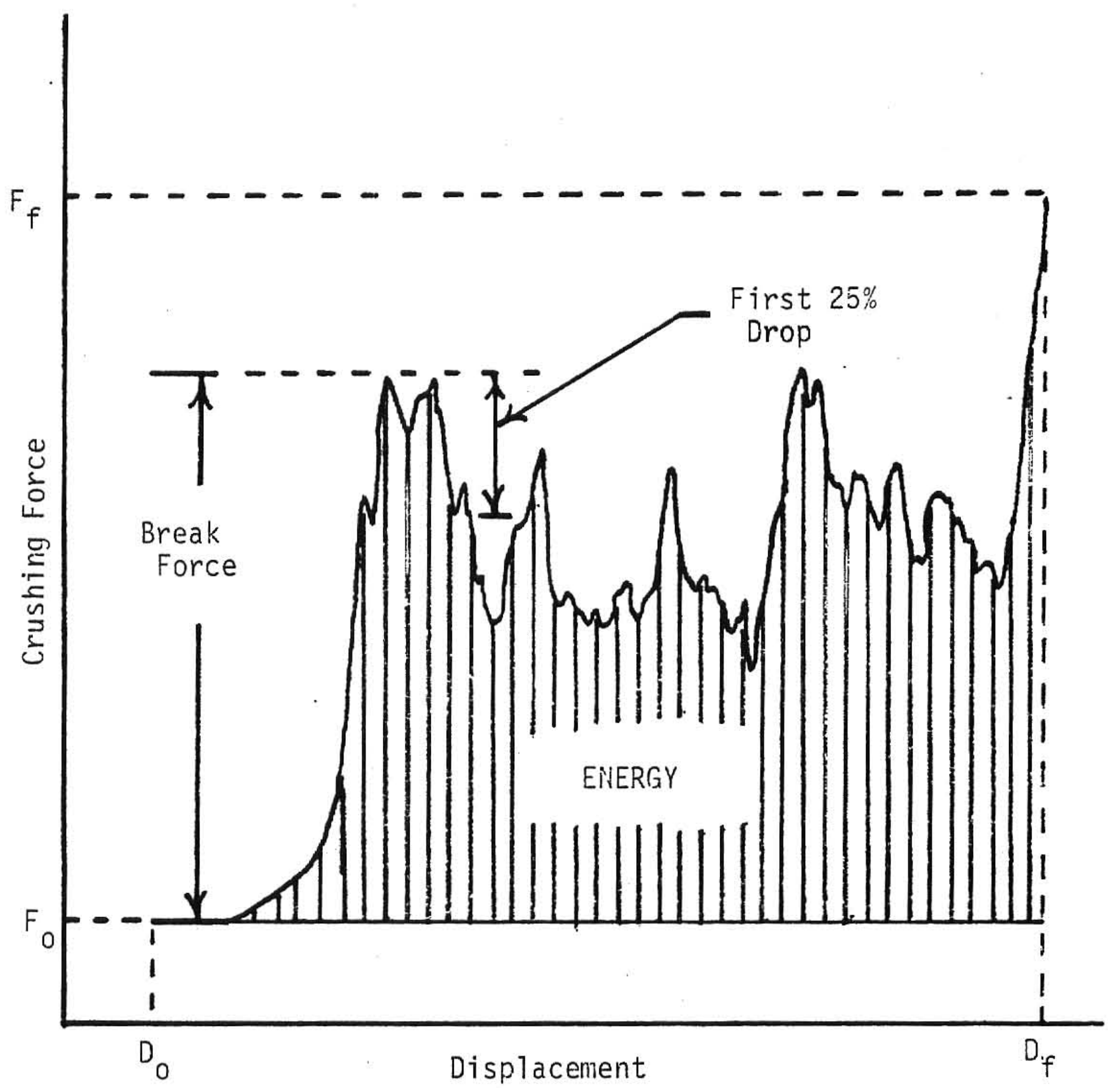
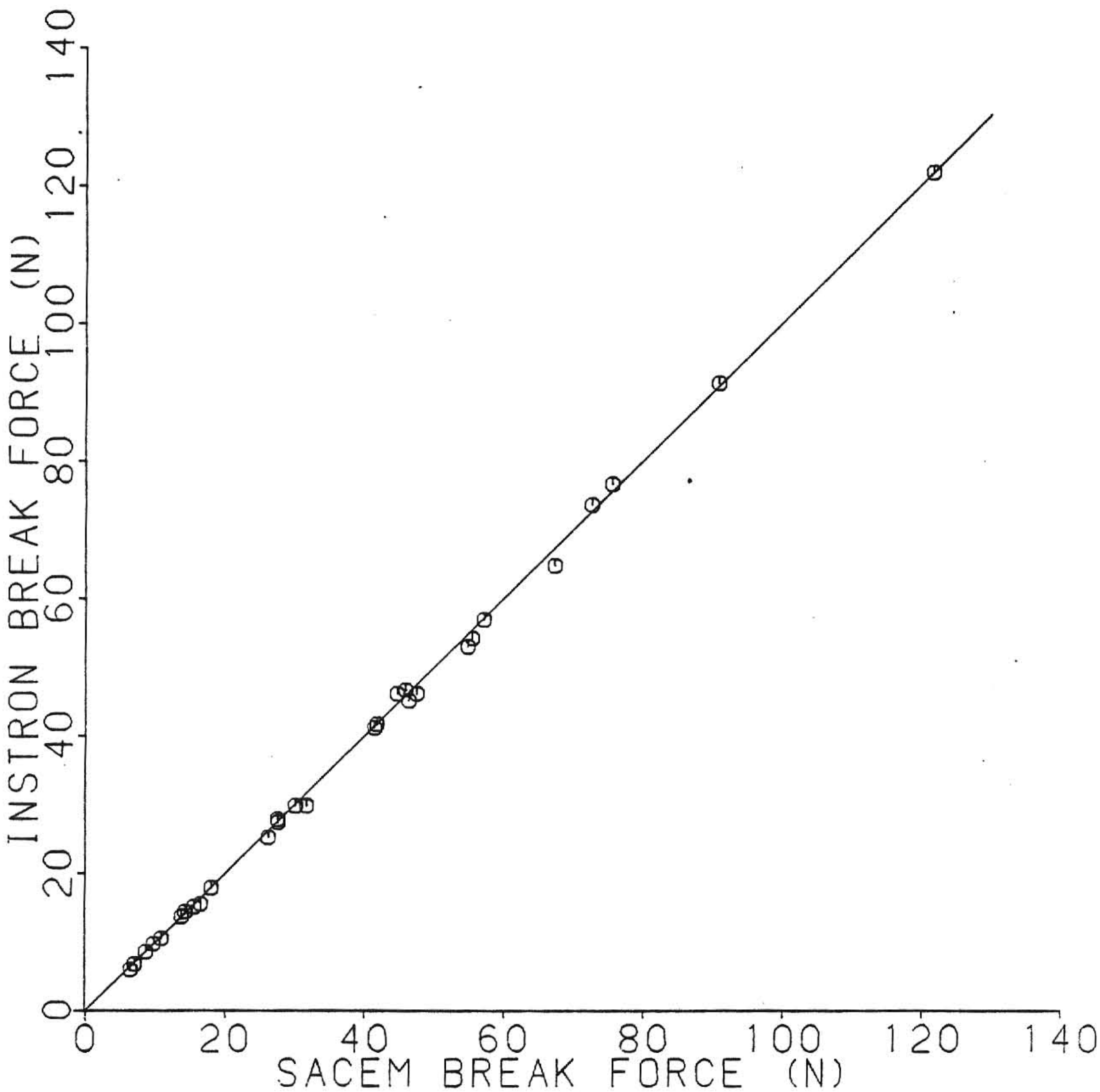

F f
First 25%
Drop
Crushing Force
Break
Force
ENERGY
F o
D o
Displacement
D f

Figure 2.



INSTRON BREAK FORCE (N)
0
20
40
60
80
100
120
140
SACEM BREAK FORCE (N)

Figure 3

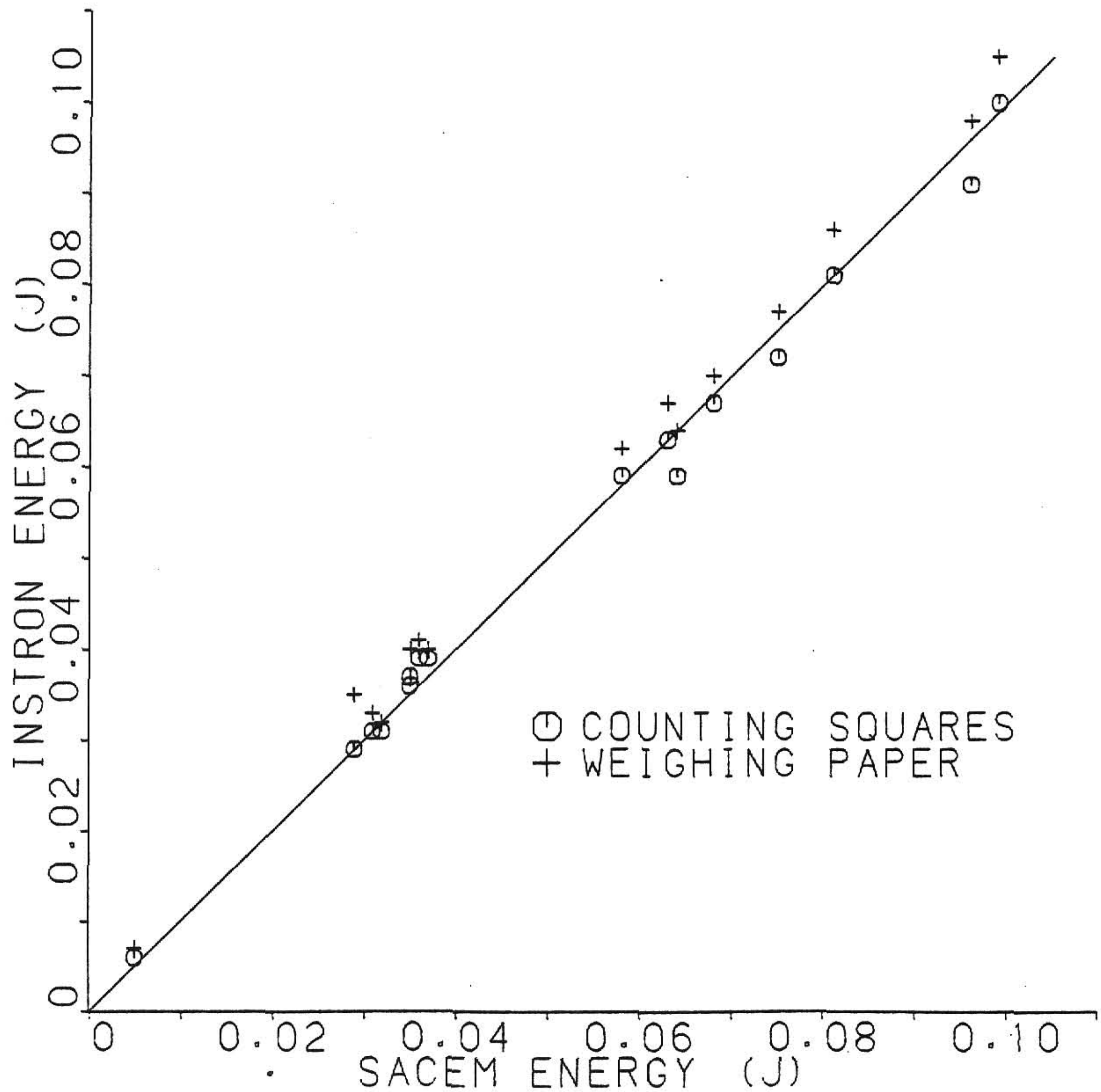

INSTRON ENERGY (J)
0
0.02
0.04
0.06
0.08
0.10
0
0.02
0.04
0.06
0.08
0.10
SACEM ENERGY (J)
COUNTING SQUARES
WEIGHING PAPER

Figure 4.

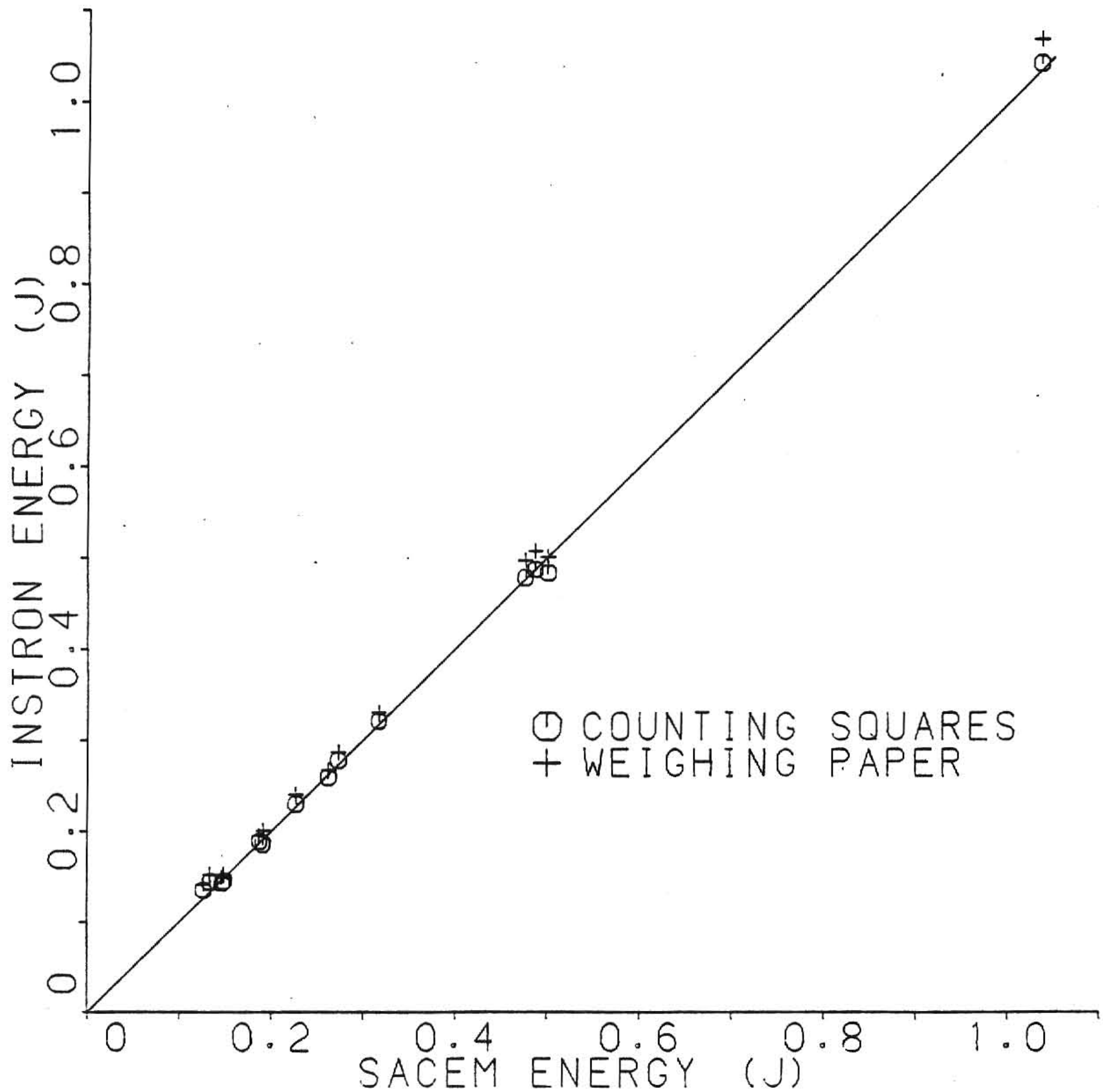

INSTRON ENERGY (J)
0
0.2
0.4
0.6
0.8
1.0
SACEM ENERGY (J)
0
0.2
0.4
0.6
0.8
1.0
COUNTING SQUARES
WEIGHING PAPER

Figure 5.

CHAPTER II

HARDWARE DESCRIPTION

The entire system was pictured in Figure 1.2 and consists of two main parts, the crushing vise and the computer module.

Crushing Vise:

The crushing vise was designed and manufactured specifically for the project. It is shown schematically in Figure 2.1. The crushing plate and end plates are made of ¼ inch aluminum plate. The platform is made of ½ inch plate to minimize bending. The support rods are of 3/4 inch diameter steel rod. The travel of the crushing plate is one inch (2.5 cm) and is accomplished with 18 revolutions of the drive crank. Detailed drawings of the vise and its components are shown in Appendix A.

The displacement of the crushing plate is measured by a Hewlett-Packard 7D-CDT1000 displacement transducer. This is a linear differential transformer. When supplied with a constant excitation voltage, this device puts out a voltage proportional to the displacement of its core.

The force on the sample is measured by an Interface SSM100 load cell which supports the platform. The load cell contains a strain gage bridge in a sealed aluminum package. When supplied with a constant excitation voltage, it delivers a voltage proportional to the force on it.

More detailed information about the load cell and displacement transducer can be found in data sheets supplied by the manufacturers of those devices.

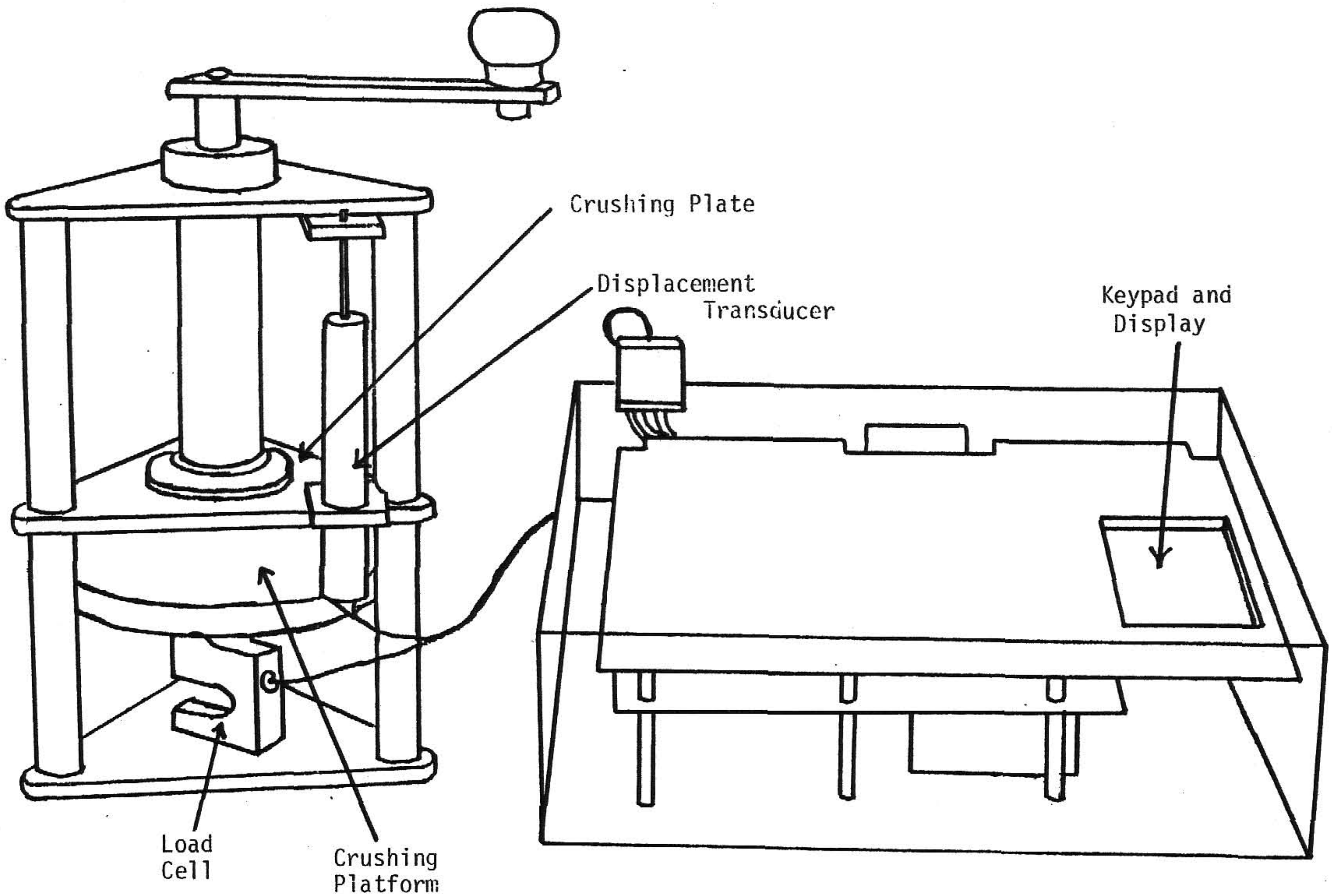


Figure 2.1
Parts of the Crushing Vise

Computer Module:

The computer module contains a single board microcomputer, some interfacing circuitry, and the power supply for all the devices.

The single board computer is a SYM-1 made by Synertek Systems Corporation. It is built around a 6502 microprocessor. It also includes a 28-key keypad, a six-digit LED display, 2½ available input/output ports, and 4K of Random Access Memory. It is provided with a monitor program stored in Read Only Memory. Several of the monitor input/output routines are used in the soil testing software. Though not used in the final implementation, a BASIC language interpreter and an RS-232C terminal connector were added to simplify hardware development and testing. The soil testing software is stored in Read Only Memory on the computer board. More detailed information about the computer can be found in the SYM-1 Reference Manual and the SYM-1 Programming Manual.

The interfacing circuitry consists of a Burr-Brown SDM856 hybrid data acquisition system and a Burr-Brown 3606 digitally controlled programmable gain instrument amplifier. The data acquisition system is a single integrated circuit that contains an 8-channel differential input analog multiplexer, a sample/hold amplifier, and a 12-bit successive approximation analog to digital converter. The programmable gain amplifier provides 11 possible gains ranging from 1 to 1024. These are selected by lines from the computer. These devices used in combination allow handling of the relatively large (0 to 5 V) displacement signal and the relatively small (0 to 15 mV) force signal with the same system. They are also naturally suited to handling floating point numbers since the gain of the amplifier is similar to an exponent.

The power supply is a Power General 326-A triple output switching model. It will supply 4 amperes at 5 volts and 0.2 amperes at both +15 and -15 volts.

More detailed information about the interfacing circuitry components can be found in data sheets supplied by the manufacturer of those devices.

A schematic diagram of the system circuitry is shown in Figure 2.2. When a reading is to be taken, a digital value is put out from the computer which selects both which device is to be read and the gain of the instrument amplifier. The displacement transducer and load cell are selected by different channels of the multiplexer. After a delay of about 300 microseconds to allow the system to settle, the sample/hold amplifier is commanded to hold its value and the A/D converter is commanded to convert the voltage to a digital representation. The digital value is examined to see if all 12 bits are required to represent the voltage. If not, the gain of the amplifier is doubled and the process is repeated until all 12 bits are required. In this manner, each reading can be made to have full precision whether the voltage read was relatively large or small. The amplifier gain required to obtain full precision is recorded by the computer along with the digital value in a floating point number format.

Circuit diagrams and explanations of each pin connection on all the devices can be found in Appendix A.

Accessories:

An adapter shaft was also constructed which allows the crushing vise to be mounted in the Instron testing machine so that parallel tests may be run. The shaft connects to the vise in place of the drive crank which is removed for parallel testing. The shaft also connects directly to the load cell fitting on the Instron machine. This shaft is detailed in Appendix A.

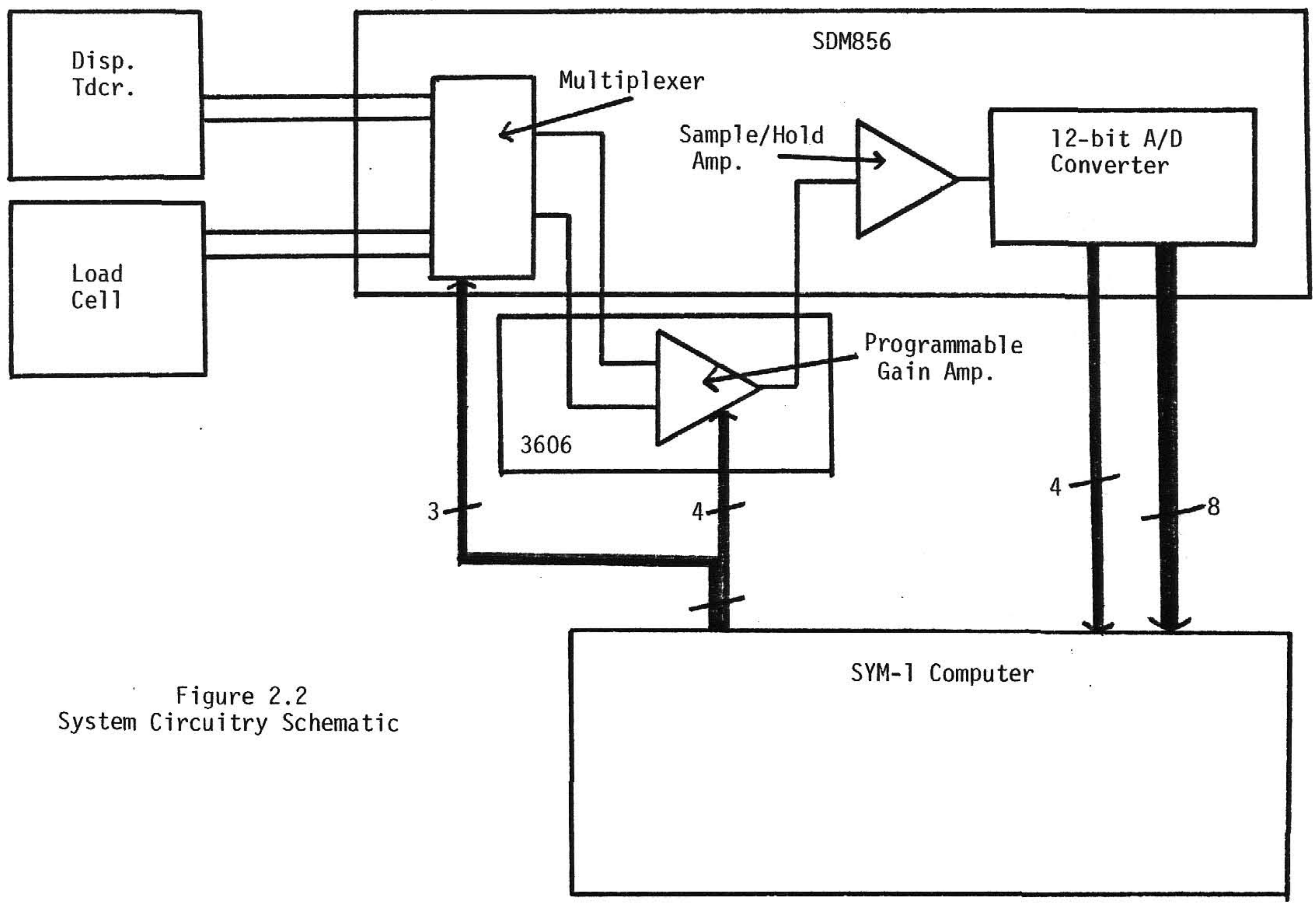


Figure 2.2
System Circuitry Schematic

CHAPTER III

SOFTWARE DESCRIPTION

Overview:

The software of the system consists of two main parts. The SYM monitor and supporting routines were supplied with the computer. The SACEM monitor and command routines were written specifically for this application. The SACEM monitor and command routines use several of the routines within the SYM monitor. The SYM monitor is described fully in the SYM-1 Reference Manual.

SACEM Monitor:

The SACEM monitor begins at memory location E700H. When it is first entered, the system is initialized and the message SOIL 1 is written to the display. The keyboard is then continually polled using a SYM monitor routine. When a keystroke is detected, a unique code identifying the key pressed is placed in the computer accumulator. This code is successively compared to the codes which represent valid commands. When a match is found, control is passed to the routine which processes that particular command. When the command has been executed, control passes back to the monitor and polling resumes. Flow charts for the monitor and the major subroutines used are found in Appendix B.

Several of the monitor functions involve displaying a scaled numeric value. The in-line routine PUTOUT calls the appropriate subroutines to do the scaling and display functions. The addresses of the number to be displayed and the scaling factor are passed to PUTOUT. It assumes a display of three decimal places. This can be altered by loading the computer accumulator with the desired number places and entering the routine at PUTOUT +2. This is done in the DISPE command.

Subroutine Descriptions:

The following are brief descriptions of all of the subroutines in the SACEM software. Each is headed by its name and the hexadecimal address of its first instruction. It is assumed that the reader is familiar with the architecture of the 6502 microprocessor. In the descriptions, A, X, and Y refer to the accumulator, and X index register, and the Y index register of the microprocessor. Flow charts of all but the simplest routines are found in Appendix B. A complete listing of all of the SACEM software is printed in Appendix C.

TEST E626

The TEST routine is executed during a crushing test. The required variables are initialized upon entry and the crushing energy is continually integrated until the test is ended. The display shows the current force on the crushing plate in kilograms. When the break force is detected, the upper element of the rightmost display digit is lighted as an indicator. The integration is stopped and the beeper is sounded when the current force passes the calculated stop force. If any key is pressed during the test, the test is immediately stopped. If the current force on the platform exceeds about 40 kilograms, the beeper is sounded repeatedly to warn the operator but execution of the TEST routine is continued.

BREAK E52D

The BREAK routine performs several functions and is called by the TEST routine each time through its sample loop. At the beginning of a test

BREAK keeps a running maximum of the crushing force. As soon as the current force drops more than 25 percent below a prior maximum, a flag is set to indicate that the break force has been found. The break force is stored for future reference. If a break force below 0.2 kilograms is detected it is ignored. This is to prevent noise on the force signal from causing false breaks to be registered. Once the break force has been found, BREAK calculates the force at which to stop the test by adding together fourths of the break force. Thereafter, instead of monitoring the force to detect a break, the routine checks to see if the stopping force has been exceeded. The location MAXFLG serves as a flag to indicate the status of the test as determined by BREAK. It is zero initially, is set to one when the break force is detected, and is set to two when the stopping force is exceeded.

INIT E5AF

The INIT routine initializes the variables in RAM. Most variables are initialized by a block move from a table that follows the INIT routine in ROM. Other variables are initialized by taking current readings of the force and displacement through the A/D converter. This routine is called on power up and at the beginning of each test.

DELTAE E414

The DELTAE routine calculates the change in crushing energy since the last time it was called. The mathematical expression evaluated by the routine is

EDEL=((Current force + Past force)/2)*(Current Disp. - Past disp.)

Once the calculation is made, the routine replaces the past values in memory with the current values since these will be the past values on the next call. The value returned is the absolute value of the energy change.

The sign of the result is indicated by the value in location 0. A negative result is indicated by a non-zero value there.

BASE E500

The BASE routine finds the average of eight successive readings of a specified multiplexer channel. The eight readings are added up and the exponent of the sum is decremented three times to get the average. This routine is used to get F_0 and D_0 at the beginning of each test.

READ E000

The READ routine reads a specified channel of the multiplexer and converts the results to the number storage format used by the arithmetic routines. A three-byte floating point format is used. The first byte is the exponent of the number in two's complement form. The next two bytes are the unsigned 16-bit mantissa.

The READ routine selects an amplifier gain of 1 and triggers an A/D conversion. If the result does not have full 12-bit precision the gain is doubled and another conversion is triggered. This continues until either the result has full precision or the highest amplifier gain has been used. Since some gains of the amplifier are selected by more than one combination of control bits, a look-up table is used to determine the proper value to avoid duplication.

CONV E200

The CONV routine converts a three-byte floating point number to a decimal number in the display buffer. The number is separated into integer and fraction parts by shifting it right until the exponent is zero. Each bit is then tested and the equivalent decimal value is added to a running sum if the bit is a one. When the sum is complete, the result is transferred to the display buffer in the SYM system RAM. If the number is too large to be converted, the display buffer is filled with E's. The largest number that can be converted is about 65,000 in decimal. Decimal equivalents of all the needed powers of two are kept in a table in ROM.

NORM E074

The NORM routine normalizes a floating point number. This is necessary to maintain precision in calculations and to facilitate comparing numbers. The number is shifted left until the most significant bit of the mantissa is a one. The exponent is correspondingly adjusted so that the value represented by the number is unchanged. Zero is represented by a zero mantissa with an exponent of -32. This value was selected so that any finite number generated by the calculations can be found to be greater than zero by comparing only the exponents.

ALIGN E08E

The ALIGN routine aligns two floating point numbers, by shifting the number with the lower exponent to the right and adjusting the exponent until the two numbers have the same exponent. This is necessary before addition or subtraction. This does not change the value represented by either number.

SWAP E0AE

The SWAP routine exchanges the contents of the X and Y registers using the stack. Nothing else is affected.

ADD E0B7

The ADD routine adds two floating point numbers. The numbers are aligned, their mantissas added, and the result is normalized.

SUB E0D5

The SUB routine subtracts one floating point number from another. Since negative numbers are not supported, the result is the absolute value of the difference. If the minuend was larger than the subtrahend, location zero contains a non-zero value on return. This is to indicate a negative result.

MPY E119

The MPY routine multiplies two floating point numbers. A shift and add algorithm is used. The multiplier is shifted right until it becomes zero. If a one is shifted out, the multiplicand is added to a running sum and shifted left. The result is normalized. The exponent of the result is found by adding the exponents of the numbers multiplied.

COMP E400

The COMP routine compares two floating point numbers and sets the flags in the computer's status register accordingly. The routine compares successive bytes of the two numbers until a difference is found. This method relies on the fact that all numbers generated in this application have negative exponents. This routine fails if the exponents of the numbers compared have differing signs.

MOVEM E457

The MOVEM routine moves a floating point number from one specified location to another.

RAM Locations:

All variables used are stored in zero-page RAM so that their addresses can be pointed to by the X and Y registers. The variables used are explained below.

Location	Name	Function
00-0C		Scratch space used by several subroutines. Location 0 is used to pass parameters by SUB, DELTAE, and CONV. Otherwise no meaningful data are here.
0D-1F		Not used
20-22	FO	F_0 in 3-byte floating point form
23-25	PASTF	Force from previous reading used by DELTAE
26-28	PASTD	Displacement from previous reading
29-2B	CURF	Current force reading used temporarily by DELTAE
2C-2E	CURD	Current displacement reading.
2F-31	EDEL	Change in crushing energy returned by DELTAE
32-34	FDIFF	Scratch locations used by BREAK
38	PLIM	Four times the current stopping factor. Initialized to 6 on power on and changed only by monitor command.
39	LIM	Counter value used to figure the stop force. Since this is destroyed during each test, a permanent copy of the value is kept in PLIM. LIM is copied from PLIM by the INIT routine.
3A	MAXFLG	Used by BREAK and TEST to monitor test status.
3B-3D	KG2	Approximately the force reading for a crushing load of 0.2 kg. Used by BREAK to suppress false breaks.
3E-40	FMAX	Used by BREAK for running force maximum. Becomes break force when the break is detected.
41-43	SCR1	Scratch locations
44-46	STOPF	Stop force calculated by BREAK
47-49	ESUM	Running energy integral
4A-4C	KG40	Approximately the force reading for a crushing force of 40 kg. Used to detect too high crushing force so operator can be warned.

4D-4F	FCONV	Unit conversion factor to convert A/D force readings to kg. Determined from load cell calibration. Initialized by INIT each time a test is begun.
50-52	DCONV	Unit conversion factor to convert A/D displacement readings to cm. Determined from displacement transducer calibration. Initialized by INIT each time a test is begun.
53-55	ECONV	Unit conversion factor to convert calculated energies to Joules. Determined from FCONV and DCONV.

CHAPTER IV

CALIBRATION AND TESTING

Displacement Transducer:

The displacement transducer was calibrated using a machinist's vernier caliper. The entire transducer was mounted solidly and the caliper used to measure the overall length. At the same time, the computer was used to read the displacement in its unitless form. The unitless form readings will be referred to in terms of "counts". Comparing the unitless readings with the known caliper measurements allowed calculation of a scaling factor. Multiplying the unitless reading by the scaling factor gives the displacement reading in the proper units.

The actual data points taken are given in Table 4.1. Figure 4.1 shows the calibration curve generated from these points. The data show excellent linearity over the specified range of the transducer. A straight line was fitted to the points using the method of least squares. The resulting relation is

$$\text{Unitless Reading} = -1885.5*(\text{Caliper Reading}) + 12283$$
$$r^2 = .9999$$

This gives a relation of 1885.5 counts per inch of displacement. The sign of the coefficient is irrelevant since the polarity of the transducer can be changed. The scaling factor used is calculated as

$$\text{DCONV} = (2.54 \text{ cm/in})/(1885.5 \text{ counts/in})$$

$$\text{DCONV} = .001347 \text{ cm/count}$$

Table 4.1

Displacement Transducer Calibration Data

Caliper Reading (inches)	Unitless Computer Reading (counts)
6.489	46.6
6.303	397.3
6.105	777.7
5.900	1161.
5.700	1543.
5.519	1862.
6.479	60.7
6.299	411.6
6.099	787.0
5.899	1165.
5.700	1543.
5.522	1859.
6.500	20.7
6.400	210.9
6.201	589.5
6.005	973.2
5.801	1350.
5.600	1724.
* 5.424	2012.
* 5.302	2128.
* 5.202	2167.

*These points were excluded from the analysis since they are outside the linear range of the transducer.

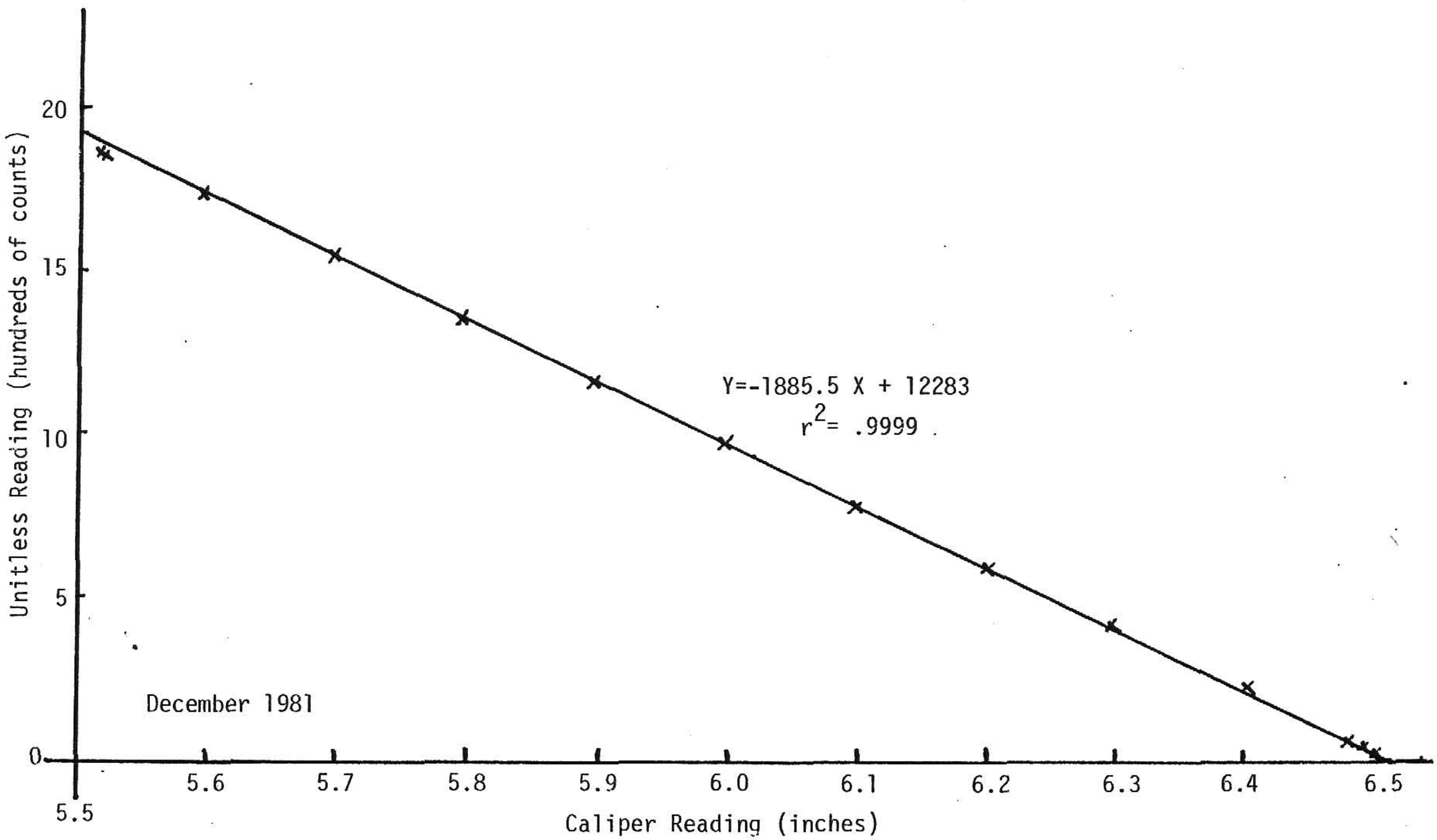


Figure 4.1

Displacement Transducer Calibration Curve

Load Cell:

The load cell was calibrated in a similar manner. Known weights were placed on the crushing platform of the vise and the unitless weight readings displayed on the computer. These readings were compared with the known weights to find a scaling factor in the proper units. A rough two point calibration had already been done while the system was still under development. The rough calibration produced a scaling factor of 2.4066 kg/count. The data points taken for the final calibration are shown in Table 4.2 Figure 4.2 shows the calibration curve generated from these points. The data again showed excellent linearity. A straight line was fitted to the points using the method of least squares. The resulting relation is

$$(\text{Unitless Reading})=1.0104*(\text{Actual Weight})+1.329$$

$$r^2= .999$$

The intercept term is due to the weight of the platform of the vise. Using this information and the previous calibration, the new scaling factor is calculated as

$$\text{FCONV}=2.4066/1.0104 = 2.3818 \text{ kg/count}$$

The scaling factor to convert unitless energy results to Joules was calculated as

$$\text{ECONV}=(2.3818 \text{ kg/count})*(.001347 \text{ cm/count})*(9.81 \text{ N/kg})/$$
$$(100 \text{ cm/m}) = .0003149 \text{ J/count}^2$$

The computer software uses these factors for display purposes only. All calculations are done in unitless form so that time is saved. Whenever a display is required, the number to be displayed is converted to the proper units in scratch memory.

Table 4.2

Load Cell Calibration Data

Known Weight (grams)	Unitless Reading
0	1.32
388	1.75
742	2.07
1264	2.59
1839	3.16
2423	3.81
2954	4.30
3343	4.66
3560	4.91
3780	5.15
4000	5.36
4217	5.56
4746	6.10
5341	6.81
5853	7.21
6237	7.74
6499	7.99
7406	8.87
8315	9.65
8767	10.1

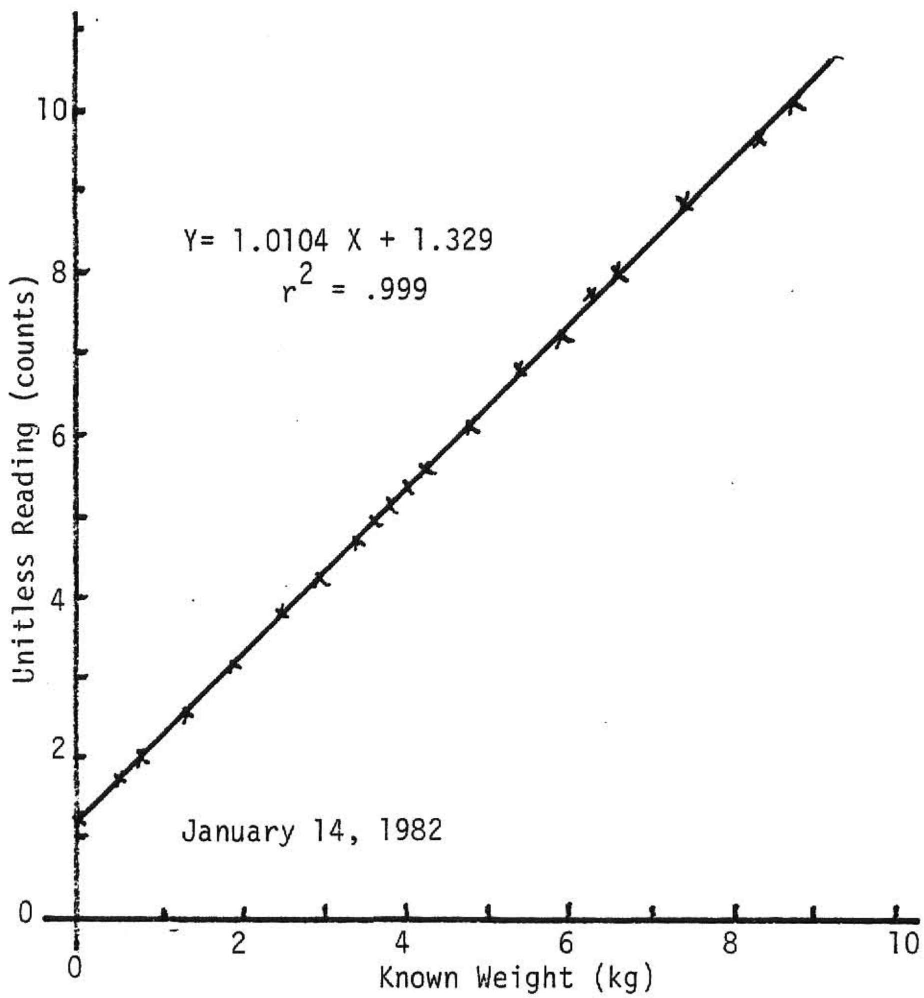


Figure 4.2

Load Cell Calibration Curve

System:

To test the system, the crushing vise was mounted in the Instron machine and crushing tests were run on 30 samples of varying aggregate stability. Ten tests were run on each of three different soils. The first ten tests used a relatively soft soil of the Aquic Haploxerolls subgroup (Hot Lake). The second ten tests used a soil of the Typic Argiudolls subgroup (Reading). The final ten tests used a relatively hard soil from the Typic Calciorthids subgroup (Rillito). Soils of varying aggregate stability were used so that the system was tested over a wide segment of its operating range. All of the samples were crushed at 10 mm/min.

During early testing, it was discovered that the force measuring system on the Instron machine was prone to drift. To minimize this effect, the Instron machine was calibrated frequently during the 30 tests.

The crushing energy was calculated from the Instron chart in two different ways. Each required that a standard sample be taken from the chart paper. A rectangular sample of 5000 chart divisions was taken. Different sensitivities were used for the different groups of ten tests so this standard area represented a different energy for each group. From the calibration of the Instron machine, the standard area represented 0.4905 Joules for the first ten tests, 0.981 Joules for the second ten, and 1.962 for the third ten.

In the first method of finding the crushing energy from the Instron chart, the area enclosed by the force vs. displacement curve is cut out and weighed. This weight is compared with the weight of the standard area. The crushing energy is given by

$$\text{Energy} = \frac{\text{(Weight of Area Under Curve)}}{\text{(Weight of Standard Area)}} * \text{(Energy Represented by Standard)}$$

The charts were weighed using a Mettler AK160 balance. The standard area was weighed each time a crushing plot was weighed to avoid effects of drift in the balance calibration.

In the second method, the number of chart paper divisions enclosed by the force vs. displacement curve are counted. This number is compared with the number of divisions on the standard area. The energy of crushing is given by

$$\text{Energy} = \frac{(\text{No. of Divisions Under Curve})}{(\text{No. of Divisions on Standard})} * (\text{Energy Represented by standard})$$

These methods should give identical results. Table 4.3 lists the data taken during the 30 tests. The SACEM values were read from the SACEM display.

Conclusions:

The SACEM results for the break force correlated with the Instron results to within 0.6%. The SACEM results for crushing energy correlated to within 0.2% with the Instron results found by the counting method and to within 3.5% with the Instron results found by the weighing results.

It was found that the procedure of cutting out and weighing the paper noticeably increased the Instron results found by that method.

These results are shown graphically in Chapter I.

The design criteria were well met. The system measures quickly and accurately and displays its results digitally. It can perform tests independently or in parallel with the Instron machine. It records the break force of the sample, and the entire system can be carried in a suitcase.

	INSTRON						SACEM	
					ENERGY			
RUN NO.	WEIGHT (gm)	STD. WEIGHT (gm)	NO. DIVISIONS	BREAK (kg)	WEIGHING (J)	COUNTING (J)	BREAK (kg)	ENERGY (J)
1	.1563	1.2347	597	1.41	.062	.059	1.41	.058
2	.0821	1.2343	314	.70	.033	.031	.73	.031
3	.1023	1.2360	393	1.55	.041	.039	1.60	.036
Recalibrated Instron								
4	.1005	1.2364	373	1.48	.040	.037	1.46	.035
5	.1679	1.2384	647	1.41	.067	.063	1.41	.063
6	.1777	1.2376	678	3.05	.070	.067	3.08	.068
7	.1023	1.2400	391	1.83	.040	.039	1.84	.037
Recalibrated Instron								
8	.0166	1.2398	59	1.00	.007	.006	1.00	.005
9	.1011	1.2464	371	.88	.040	.036	.89	.035
10	.2186	1.2455	827	2.84	.086	.081	2.81	.081
Recalibrated Instron								
11	.2475	1.2458	965	2.80	.195	.189	2.82	.187
12	.0812	1.2457	303	1.60	.064	.059	1.69	.064
Recalibrated Instron								
13	.1335	1.2465	509	1.08	.105	.100	1.11	.099
14	.4190	1.2442	1635	5.52	.330	.321	5.66	.317
15	.1919	1.2417	739	4.25	.152	.145	4.26	.148
16	.0406	1.2422	160	.61	.032	.031	.66	.032
17	.3375	1.2400	1321	5.80	.267	.259	5.83	.262
18	.0978	1.2401	366	2.58	.077	.072	2.68	.075
Recalibrated Instron								
19	.3627	1.2390	1417	4.76	.287	.278	4.68	.273
20	.1237	1.2443	464	3.05	.098	.091	3.24	.096
Recalibrated Instron								
21	.1520	1.2441	587	4.7	.240	.230	4.85	.227
22	.6783	1.2442	2660	12.4	1.070	1.044	12.4	1.036
23	.0962	1.2443	368	7.8	.152	.144	7.70	.133
24	.3180	1.2447	1230	6.6	.501	.483	6.86	.501
Recalibrated Instron								
25	.3217	1.2445	1241	7.5	.507	.487	7.40	.487
26	.3152	1.2446	1219	9.3	.497	.478	9.25	.476
27	.0900	1.2442	343	4.7	.142	.135	4.56	.126
28	.0219	1.2390	73	4.6	.035	.029	4.73	.029
29	.1268	1.2363	474	4.2	.201	.186	4.23	.191
30	.0939	1.2361	365	5.4	.149	.143	5.59	.146

Table 4.3

SACEM AND Instron Comparison Data

LITERATURE CITED

SYM-1 Reference Manual, Synertek Systems Corporation, 1981.

SY6500/MCS6500 Microcomputer Family Programming Manual, MOS Technology, Inc., 1975.

Synertek 6500 BASIC Reference Manual, Synertek Systems, 1981.

"3606 Digitally Controlled Programmable Gain Instrumentation Amplifier", PDS-388, Burr-Brown Research Corporation, 1978. Data sheet for amplifier integrated circuit.

"SDM856 Hybrid Data Acquisition System", PDS-402, Burr-Brown Research Corporation, 1978. Data sheet for data acquisition integrated circuit.

"Displacement Transducers, Series 7DCDT & 24DCDT", Hewlett-Packard, 1977. Data sheet for displacement transducer.

"Calibration Certificate, Installation Information", Interface, Inc., 1980. Data sheet for load cell.

APPENDIX A

DETAILED HARDWARE EXPLANATION

Crushing Vise:

Detailed views of the crushing vise are shown in Figure A.1. The adapter shaft is detailed in Figure A.2.

Computer Module:

It is assumed that the reader has access to the SYM-1 Reference Manual and the SYM BASIC Programming Manual.

Memory locations:

A memory map for the SYM-1 is shown in Figure A.3. Several changes were made to the SYM-1 to achieve this configuration. The BASIC interpreter resides in a single Read Only Memory in U21. The jumper changes necessary to decode this socket as an 8K ROM are detailed in the SYM BASIC Programming Manual.

The soil testing software resides in a 2716 Eraseable Programmable Read Only Memory in U22 and at address E000. The following jumper changes were made to achieve this:

1. Jumper L-12 removed
2. Jumper L-15 placed

The location E000 was chosen to allow the 8K BASIC at Location C000.

In order to have the system power on to the soil testing software, the reset vector was changed. The following were required to have the system

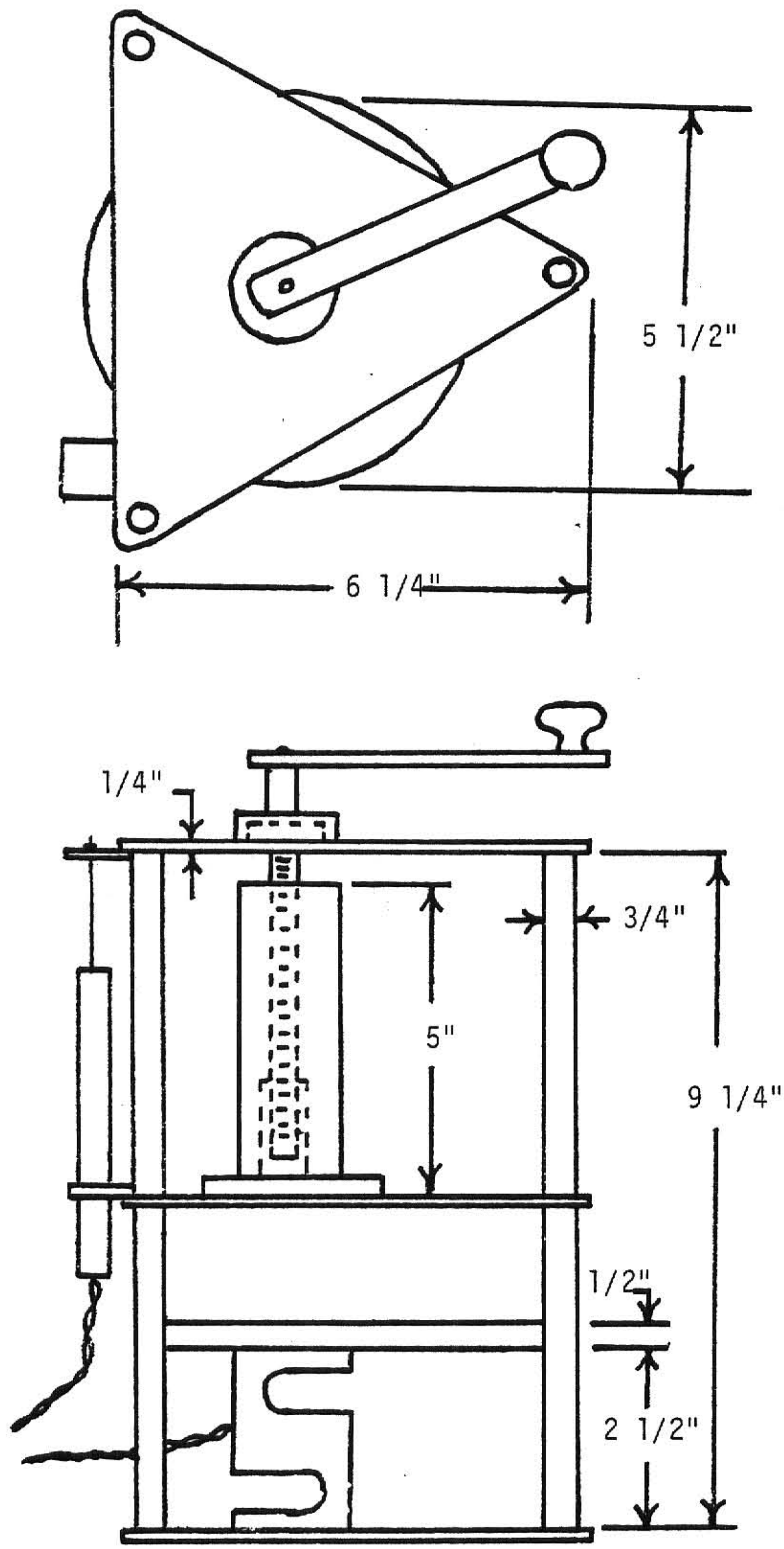


Figure A.1

Crushing Vise Detail

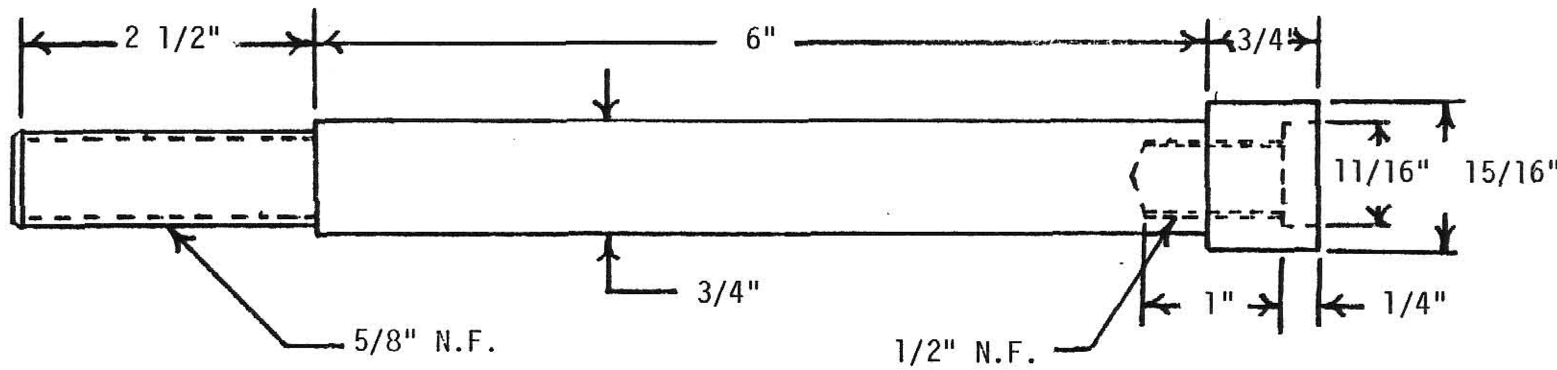


Figure A.2

Instron Adapter Shaft

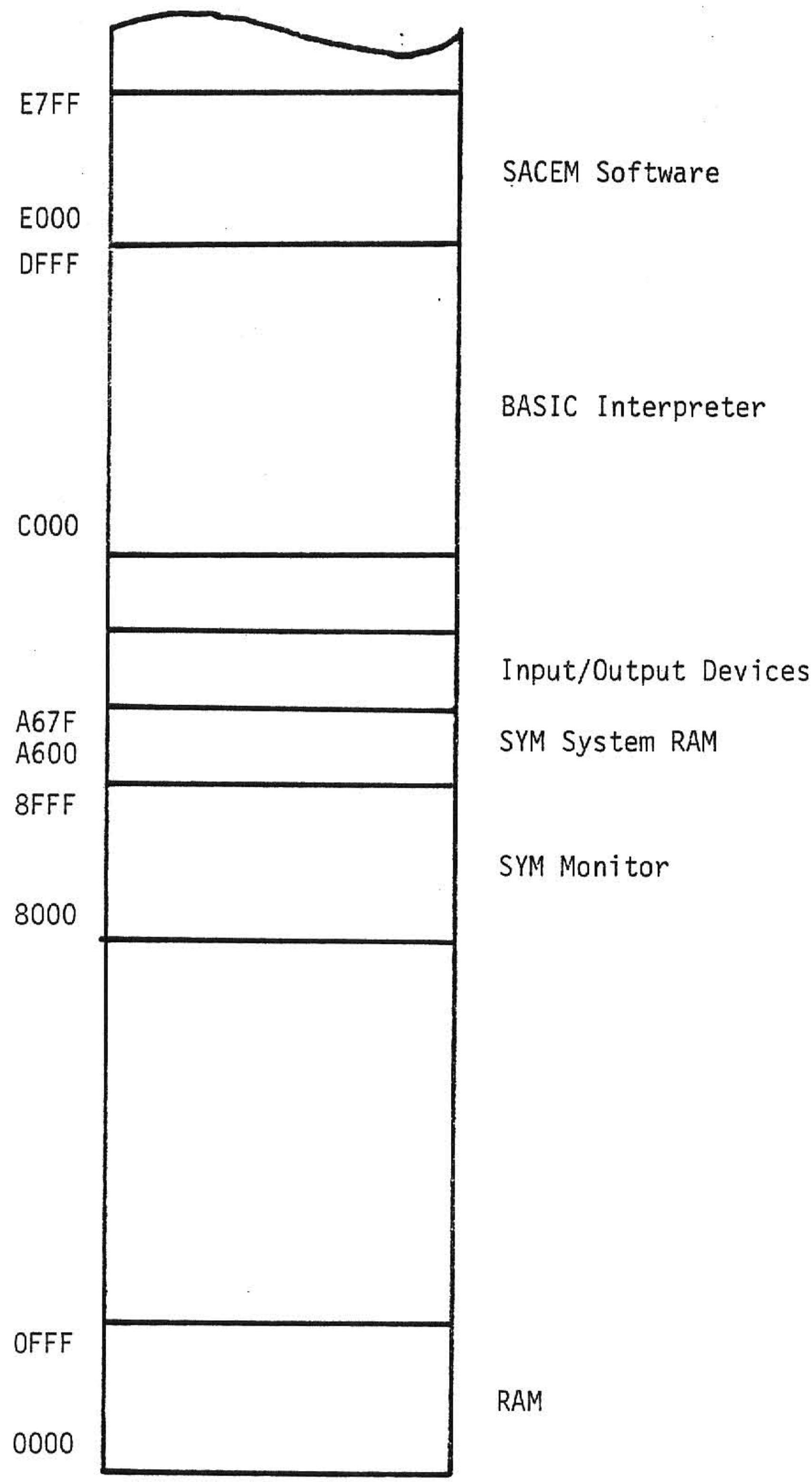


Figure A.3
SYM Memory Map

power on using the reset vector stored at the top of U22:

1. Jumper N-19 moved to N-20
2. Jumper R-20 moved to R-19

The data acquisition system and instrument amplifier appear at memory locations A800, A801, AC00, and A80C. The multiplexer channel and amplifier gain are latched into their respective devices by a transition on SYM control line 2CA2. The analog to digital conversion is triggered by dropping SYM control line 2CB2. A summary of the ports used and their addresses and functions is given in Figure A.4. The specific pin connections required to provide this configuration are given below.

Pin Connections:

The connections for the SDM856 are given first. The connections for involving the power supply are diagrammed in Figure A.5 and the connections involving data, address, and control signals are diagrammed in Figure A.6.

SDM856 Pin Connections

Pin No	Pin Function	Connection
1	Not used	No connection
2	Multiplexer high output.	Connects to pin 29 on 3606
3	Not used	No connection
4	Multiplexer input, high of channel 7	Connects to high output of displacement tdcr.
5	Multiplexer input, high of channel 6	Connects to high output of load cell
6-11	Multiplexer inputs, highs of channels 5-0 respectively	No connections
12	Multiplexer #2 enable	Connect to pin 13 for differential operation

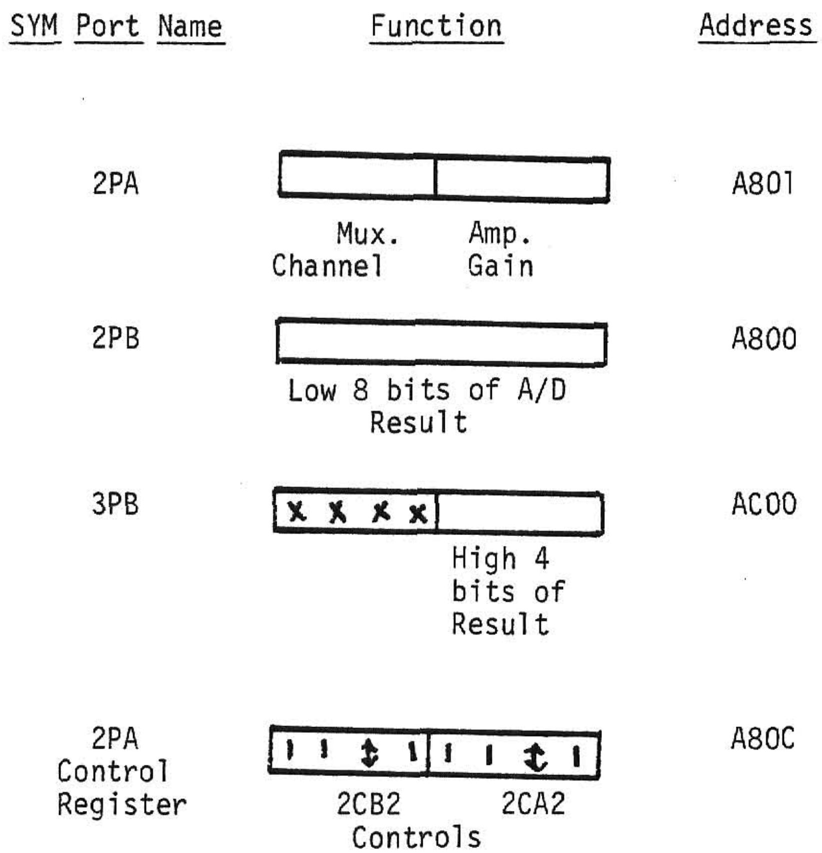


Figure A.4

Summary of SYM Port Configuration

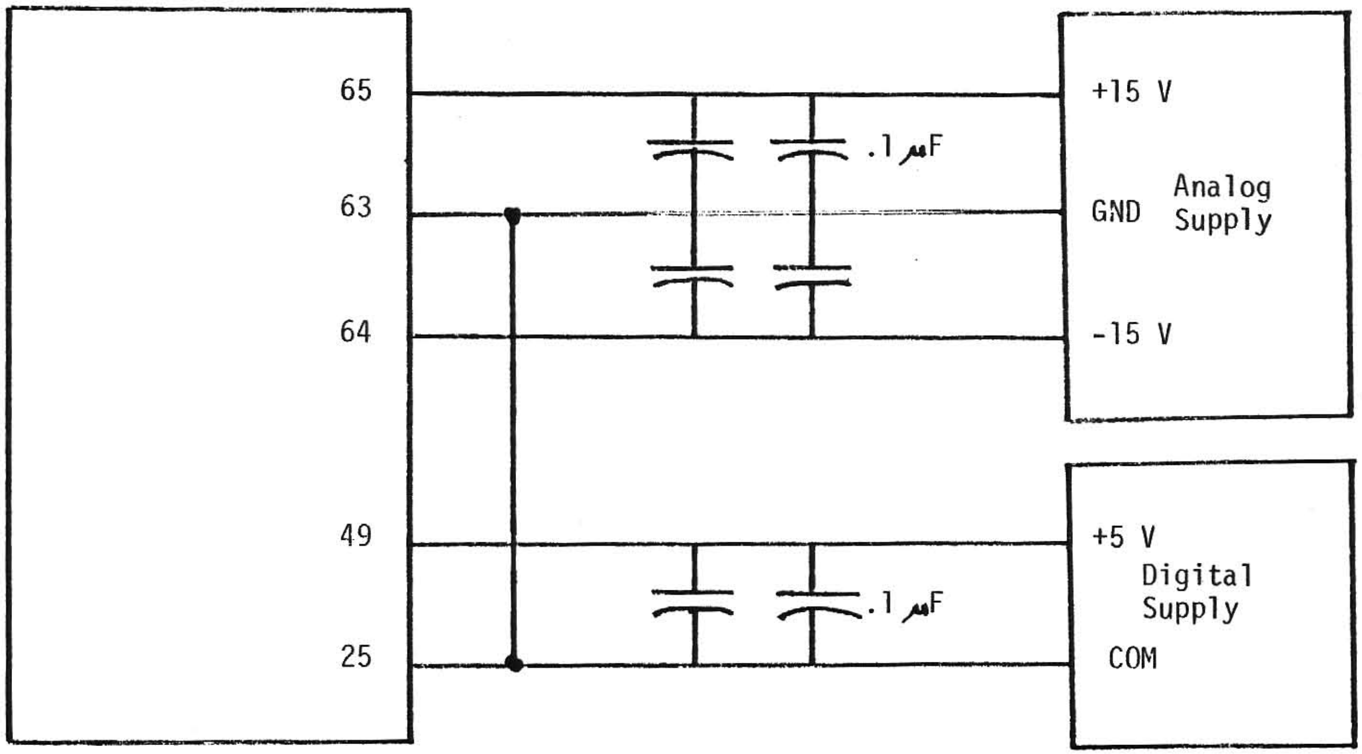


Figure A.5

SDM856 Power Supply Connections

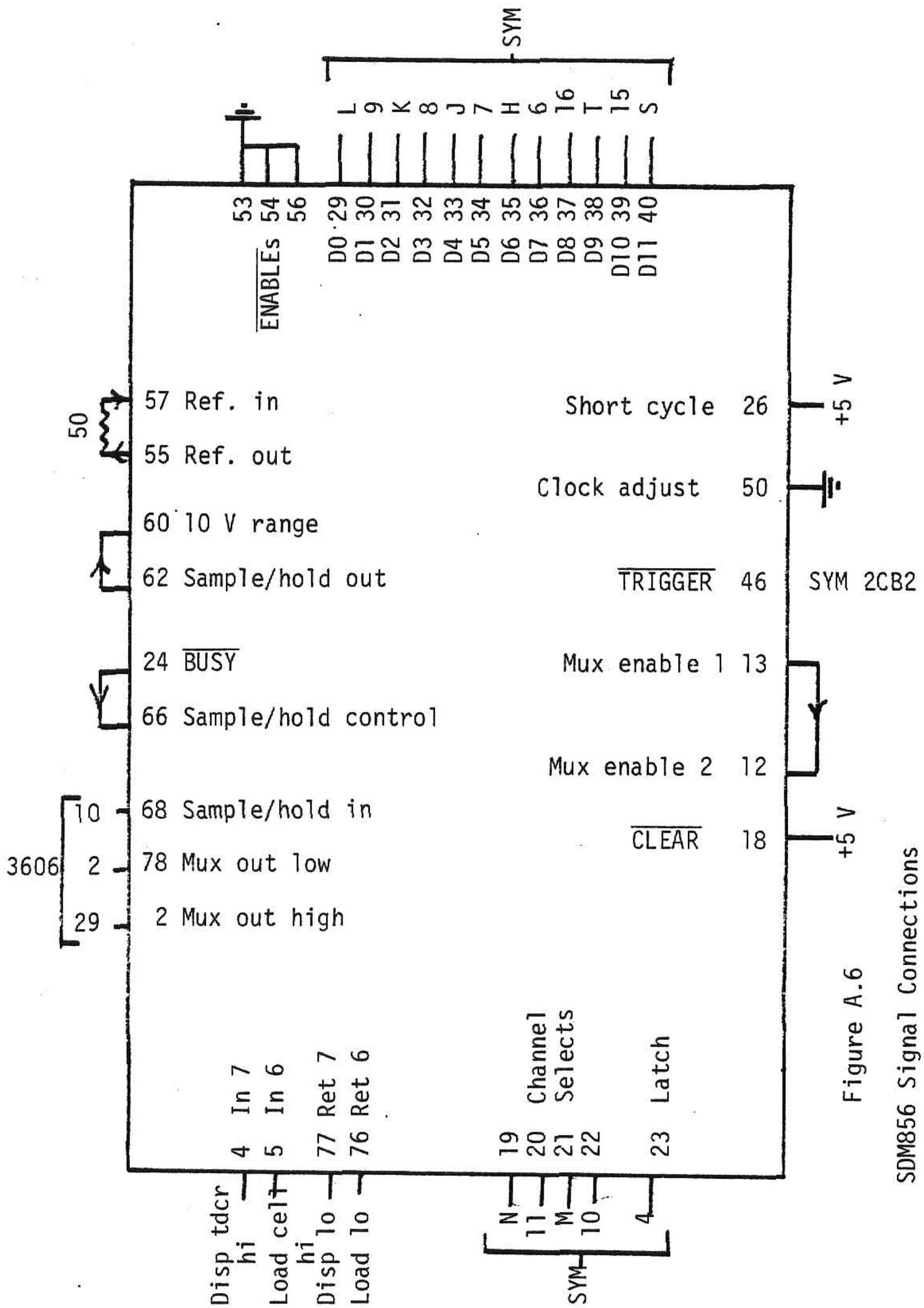


Figure A.6 SDM856 Signal Connections

13	Multiplexer #1 enable	Connect to pin 12
14	Single/differential	No connection
15	A2 out	No connection
16	A1 out	No connection
17	A0 out	No connection
18	$\overline{\text{CLEAR}}$ input	Connect to +5 V.
19-22	Multiplexer channel selects	These come from the upper 4 bits of port 2PA. Connect to SYM application connector respectively pins N,11,M,10.
23	Channel select latch line	Connect to SYM application connector pin 4
24	$\overline{\text{BUSY}}$ output	Connect to pin 66
25	Digital common	Connect to pin 63 and to power supply ground
26	Short cycle input	Connect to +5 V.
27	10 bit resolution	No connection
28	8 bit resolution	No connection
29-36	Low 8 bits of digital output	Connect to SYM application connector respectively pins L,9,K,8,J,7,H,6
37-40	Upper 4 bits of digital output	Connect to SYM application connector respectively pins 16,T,15,S
41	$\overline{\text{D11}}$ $\overline{\text{ENABLE}}$	No connection
42	BUSY $\overline{\text{ENABLE}}$	No connection
43	BUSY output	No connection
44	$\overline{\text{D11}}$ output	No connection
45	Delay out	No connection
46	$\overline{\text{TRIGGER}}$ input	Connect to SYM application connector pin 5

47	Delay adjust	No connection
48	$\overline{\text{STROBE}}$	No connection
49	5 volt input	Connect to +5 volt power supply and across capacitace to ground
50	Clock adjust	Connect to ground
51	Clock out	No connection
52	Serial out	No connection
53,54	Output $\overline{\text{ENABLE}}$s	Connect to ground
55	Reference out	Connect to pin 57 through 50 ohm resistor
56	Output $\overline{\text{ENABLE}}$	Connect to ground
57	Reference in	Connect to pin 55 through 50 ohm resistor
58	20 V range	No connection
59	Bipolar offset	No connection
60	A/D input resistor	Connect to pin 62
61	-6.4 V ref. out	No connection
62	Sample/hold out	Connect to pin 60
63	Analog common	Connect to pin 25 and to ground
64	-15 Volt input	Connect to -15 Volt power supply and across capacitance to ground
65	+15 Volt input	Connect to +15 Volt power supply and across capacitance to ground
66	Sample/hold control	Connect to pin 24
67	Sample/hold offset adjust	No connection
68	Sample/hold input	Connect to pin 10 of 3606
69	Not used	No connection

70-75	Multiplexer inputs, lows of channels 0 through 5	No connections
76	Multiplexer input, low of channel 6	Connects to low output of load cell
77	Multiplexer input, low of channel 7	Connects to low output of displacement tdcr.
78	Multiplexer low output	Connect to pin 2 of 3606
79	Not used	No connection
80	Not used	No connection

The pin connections for the 3606 instrument amplifier are given next. The connections involving the power supply are diagrammed in Figure A.7 and the connections involving data and control signals are diagrammed in Figure A.8.

3606 Pin Connections

Pin no.	Pin Function	Connection
1	-15 V supply	Connect to power supply and across capacitance to ground
2	Low input	Connect to pin 78 of SDM856
3	Input stage output	Connect to pin 8
4	Offset trim	No connection
5	Summing junction	Connect to pin 10 across .0033 μF to provide output filtering
6	Offset trim	No connection
7	Filter pin	No connection
8	Output stage input	Connect to pin 3
9	Output reference	Connect to ground
10	Output	Connect to pin 5 through .0033 μF and directly to pins 11, 13, and 13. Connect to ground through 1 Megohm. Also connect to pin 68 on SDM856

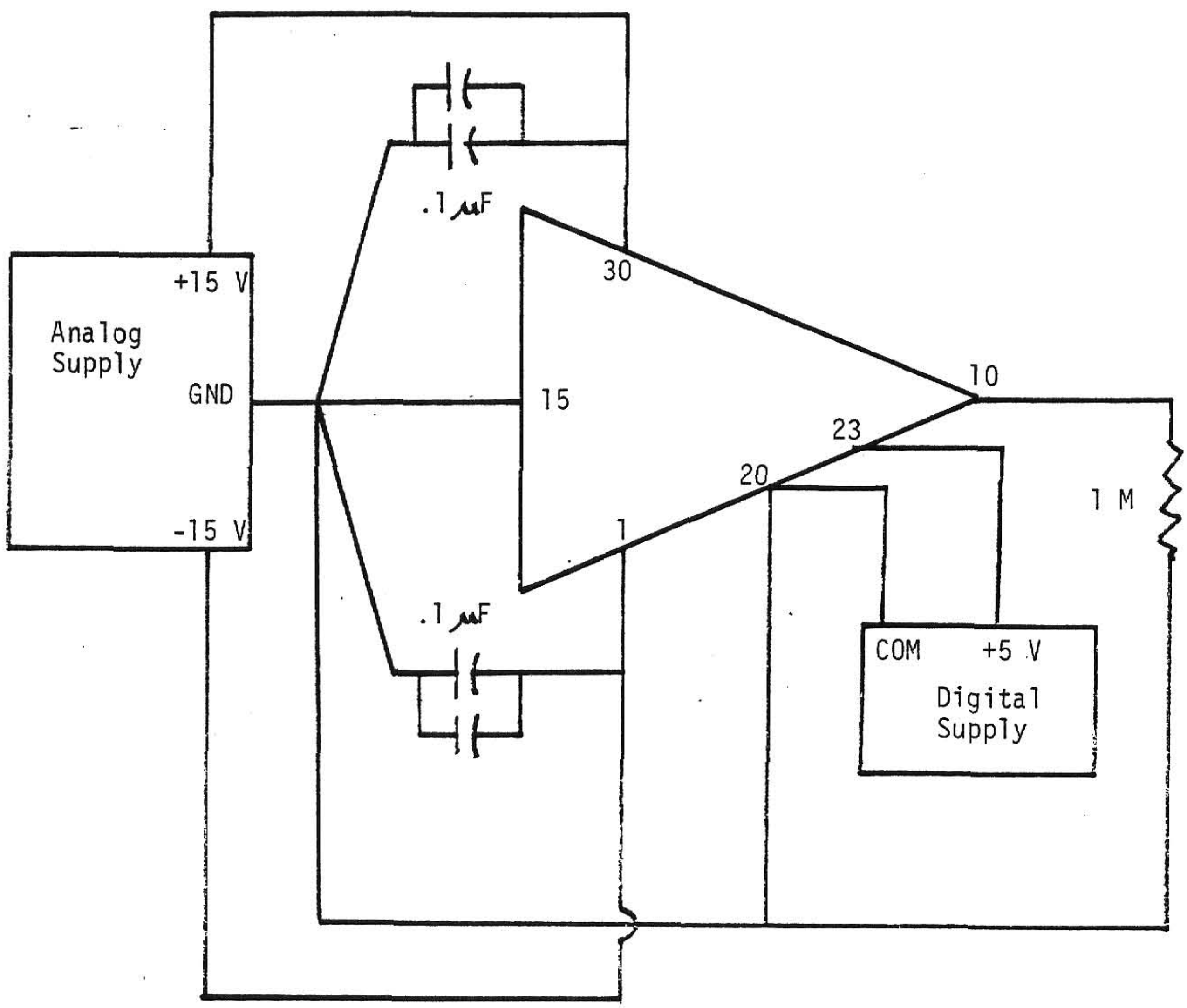


Figure A.7

3606 Power Supply Connections

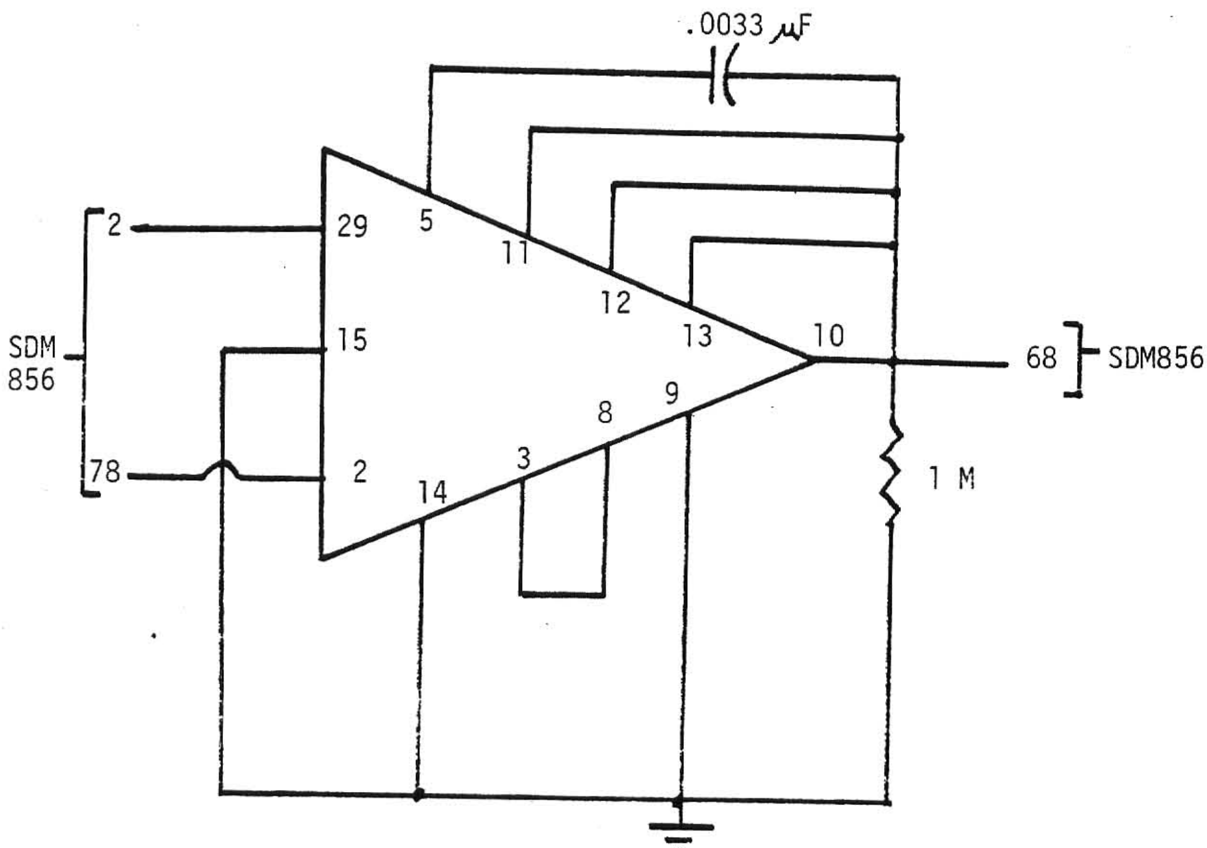


Figure A.8

3606 Signal Connections

11-13	Feedback	Connect each to pin 10
14	Output reference	Connect to ground
15	Analog common	Connect to ground
16	Not used	No connection
17,18	Digital inputs	Connect to SYM application connector respectively pins D,3
19	Latch	Connect to SYM application connector pin 4
20	Digital common	Connect to ground
21,22	Digital inputs	Connect to SYM application connector respectively pins C,12
23	+5 V supply	Connect to power supply
24,25	Not used	No connections
26,27	External gains	No connections
28	Input common mode	No connection
29	High input	Connect to pin 2 on SDM856
30	+15 V supply	Connect to power supply and across capacitance to ground
31,32	Optional input stage offset null	No connections

The pin connections on the SYM-1 are given next. The power supply connector is wired as on page 3-4 of the SYM Reference Manual. V_p is +15 volts and V_n is -15 volts from the power supply.

SYM Application Connector Connections

Pin No.	Pin Function	Connection
1	Ground	Connects directly or indirectly to all grounds on data acquisition chips
2	-15 V (V_n)	Connects to -15V pins on data acquisition chips

3	2PA1	Connects to pin 18 of 3606 as part of gain select
4	2CA2	Connects to pin 23 on SDM856 and to pin 19 on 3606
5	2CB2	Connects to pin 46 on SDM856
6-9	2PB7,5,3,1	Connects respectively to pins 36,34, 32,30 on SDM856
10-11	2PA7,5	Connect respectively to pins 22 and 20 on the SDM856
12	2PA3	Connect to pin 22 of 3606
13	RES	No connection
14	3CB1	No connection
15-16	3PB2,0	Connect respectively to pins 39 and 37 of SDM856
17-20	3PA6,3,4,5	No connections
21-22	3PB5,7	No connections
A	+5 V	Connects directly or indirectly to all pins on data acquisition chips requiring +5 volts
B	+15 V (V_p)	Connects to +15 V pins on data acquisition chips
C-D	2PA2,0	Connect respectively to pins 21 and 17 of 3606
E	2CA1	No connection
F	2CB1	No connection
H-L	2PB6,4,2,0	Connect respectively to pins 35,33,31 and 29 of SDM856
M-N	2PA7,5	Connect to pins 21 and 19 respectively of SDM856
P	3CA1	No connection
R	SCOPE	No connection
S-T	3PB3,1	Connect to pins 40 and 38 respectively of SDM856

U-X	3PA7,0,1,2	No connections
Y-Z	3PB4,6	No connections

All connections to the load cell and displacement transducer are made through a single connector brought out from the data acquisition chip and the power supply. Those connections are then run to another connector in the top panel of the computer module. This allows the module to be completely disassembled. The arrangement of the first connector as viewed from the computer is shown in Figure A.9. The connections are described below.

Connections for Power Supply and Transducers

Pin No.	Pin Function	Connection
1	+15 volts	Connects to power supply +15 volts
2	Not used	No connection
3	Multiplexer input, high of channel 6	Connects to pin 5 of SDM856
4	Multiplexer input, high of channel 7	Connects to pin 4 of SDM856
5	+5 volts	Connects to power supply
6	Not used	No connection
7	Not used	No connection
8	Not used	No connection
9	Ground	Connects to power supply ground
10	Not used	No connection
11	Multiplexer input, low of channel 6	Connects to pin 76 of SDM856
12	Multiplexer input, low of channel 7	Connects to pin 77 of SDM856

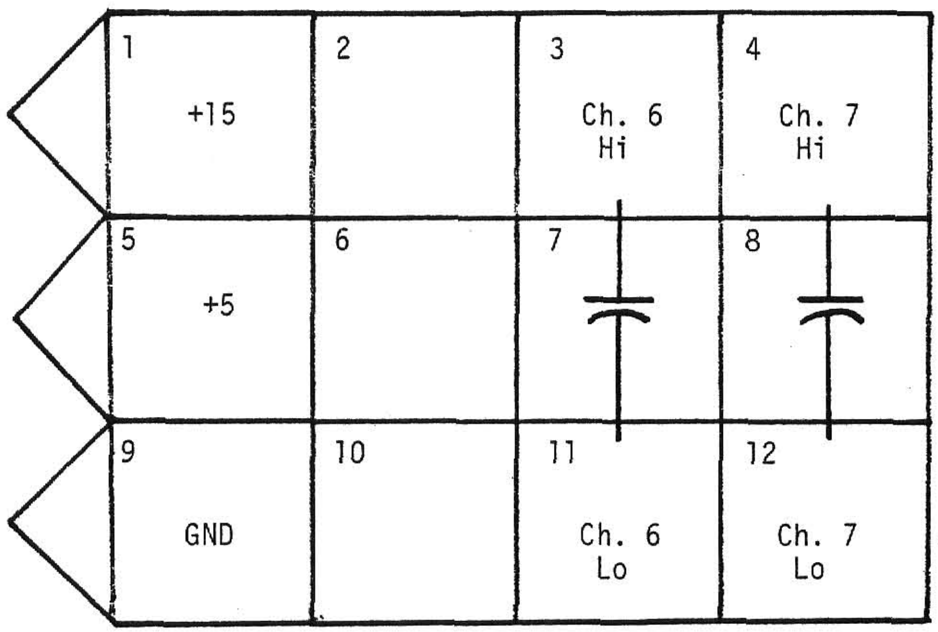


Figure A.9

Power Supply and Input Connector
(Viewed from Computer)

Also note that 10 microfarads of capacitance is connected between pins 3 and 11 and between pins 4 and 12. This is to provide some filtering of the input signals.

The arrangement of the front panel connector on the computer module is shown in Figure A.10. The connections on each pin are detailed below.

Front Panel Pin Connections

Pin No.	Function	Connection
1	+5 volts excitation for displacement transducer	Connects to pin 5 of power supply and input connector
2	High output of displacement transducer	Connects to pin 4 of power supply and input connector
3	+15 volts excitation for load cell	Connects to pin 1 of power supply and input connector
4	Load cell high output	Connects to pin 3 of power supply and input connector
5	Ground	Connects to pin 9 of power supply and input connector and to pins 6 and 7 of this connector
6	Low output of displacement transducer	Connects to pin 12 of power supply and input connector and to ground
7	Ground	Connects to pin 5
8	Low output of load cell	Connects to pin 11 of power supply and input connector

The eight lines from the load cell and displacement transducer are brought into a single connector which mates with the computer module front panel connector. These are diagrammed in Figure A.11. Each line is marked with the corresponding pin on the front panel connector that it mates to.

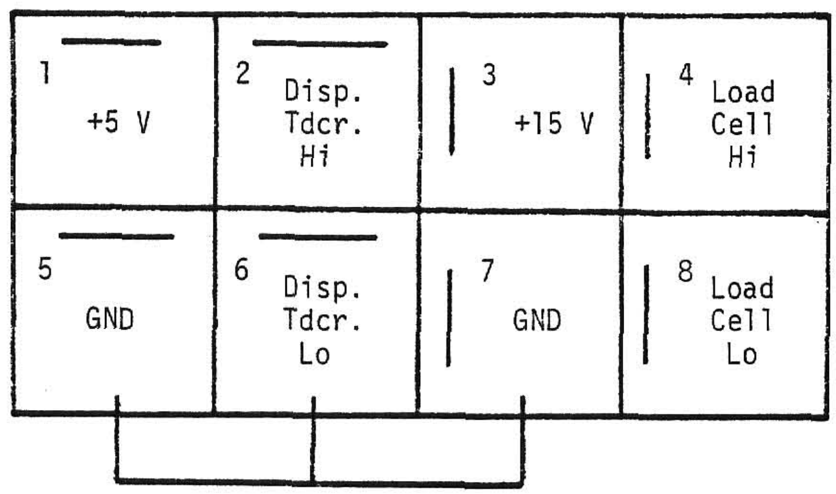


Figure A.10

Computer Module Front Panel Connector
(Viewed from Top of Computer Module)

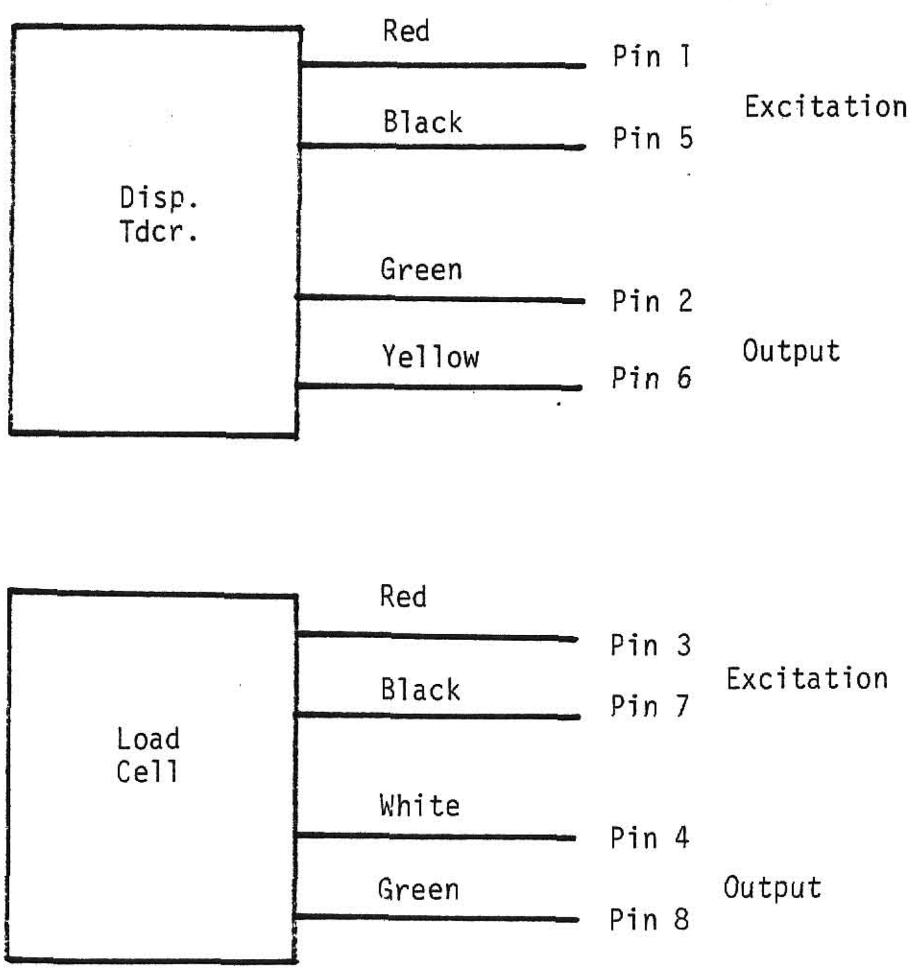


Figure A.11

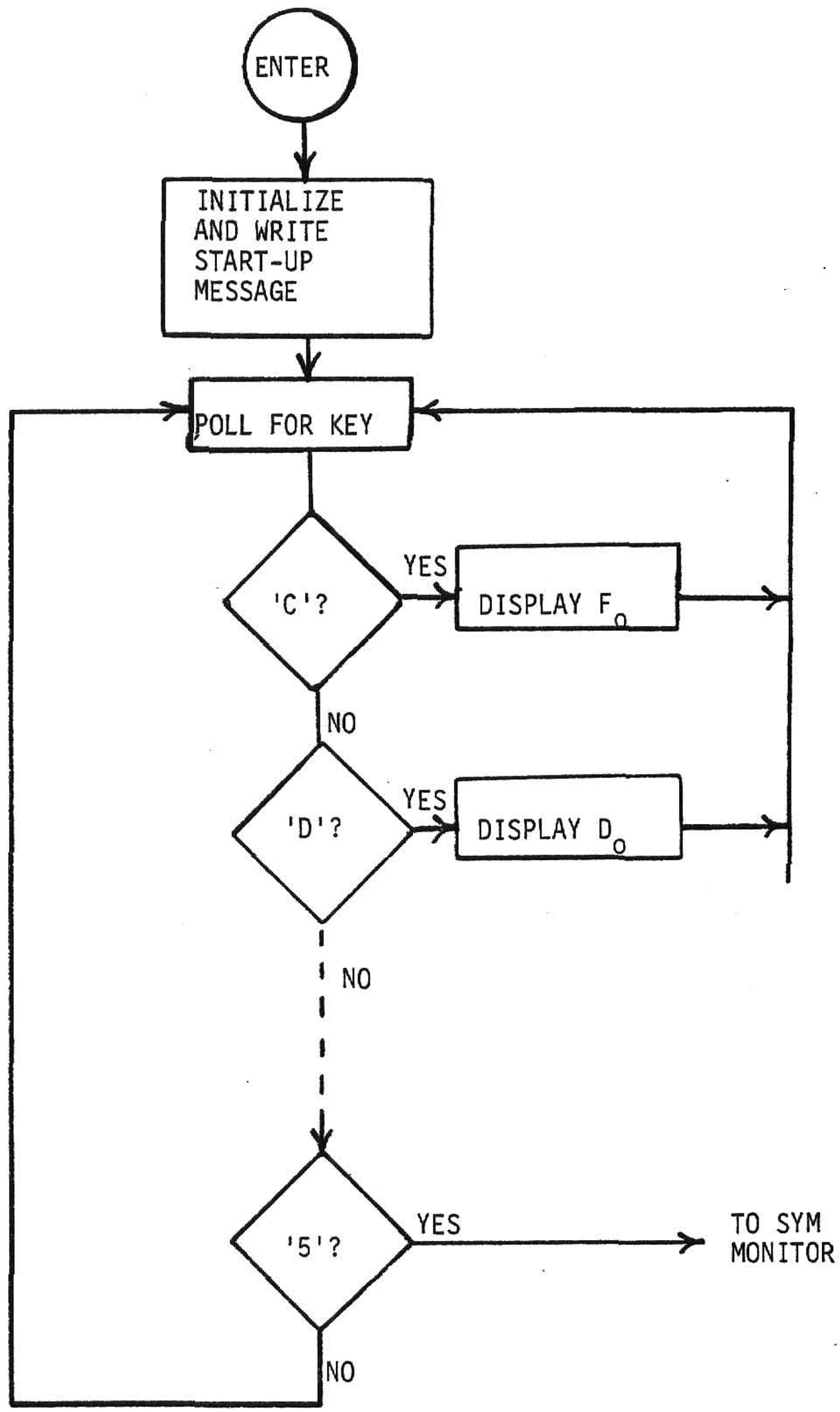
Transducer and Load Cell Connections

APPENDIX B

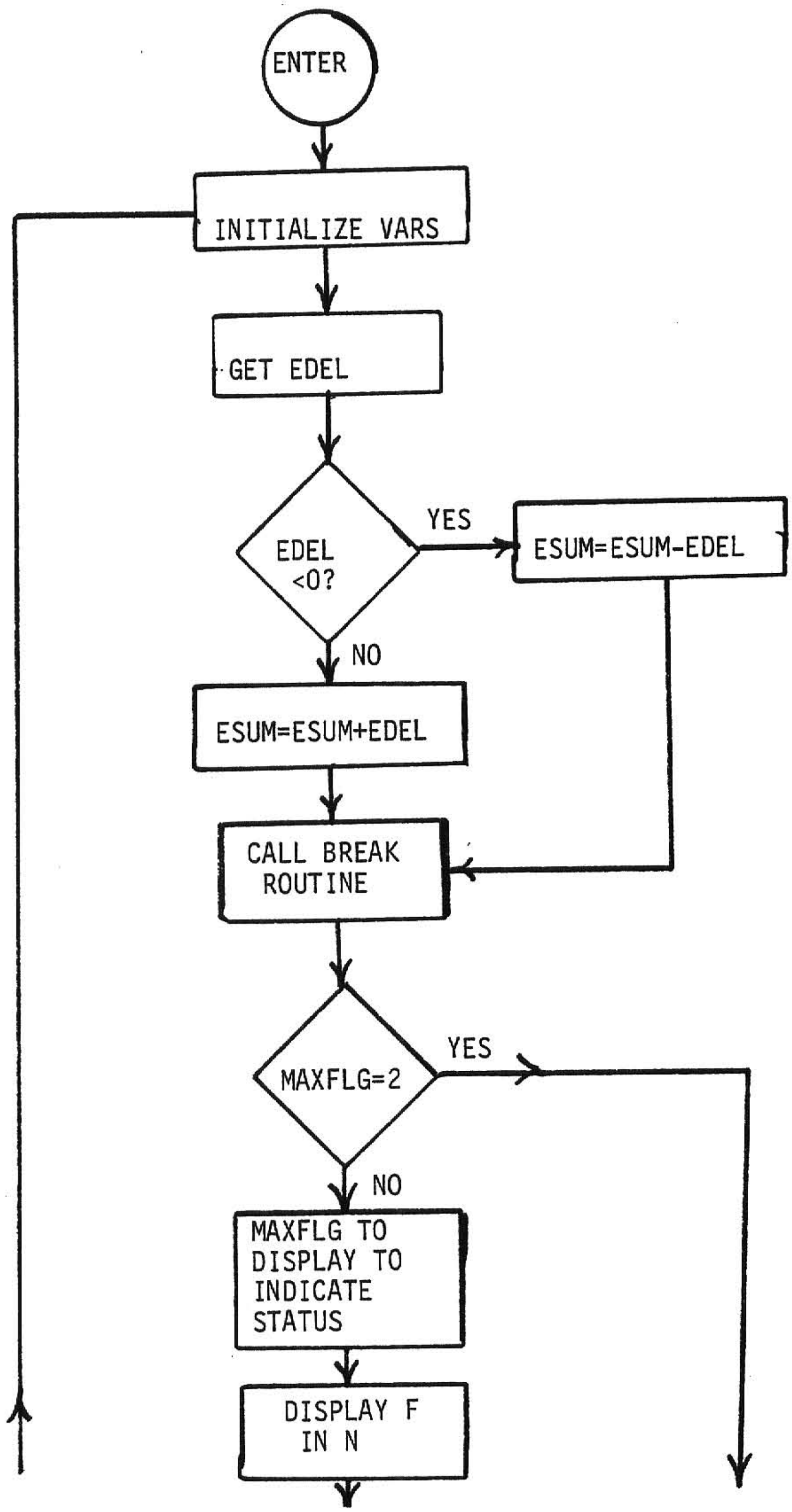
SOFTWARE FLOW DIAGRAMS

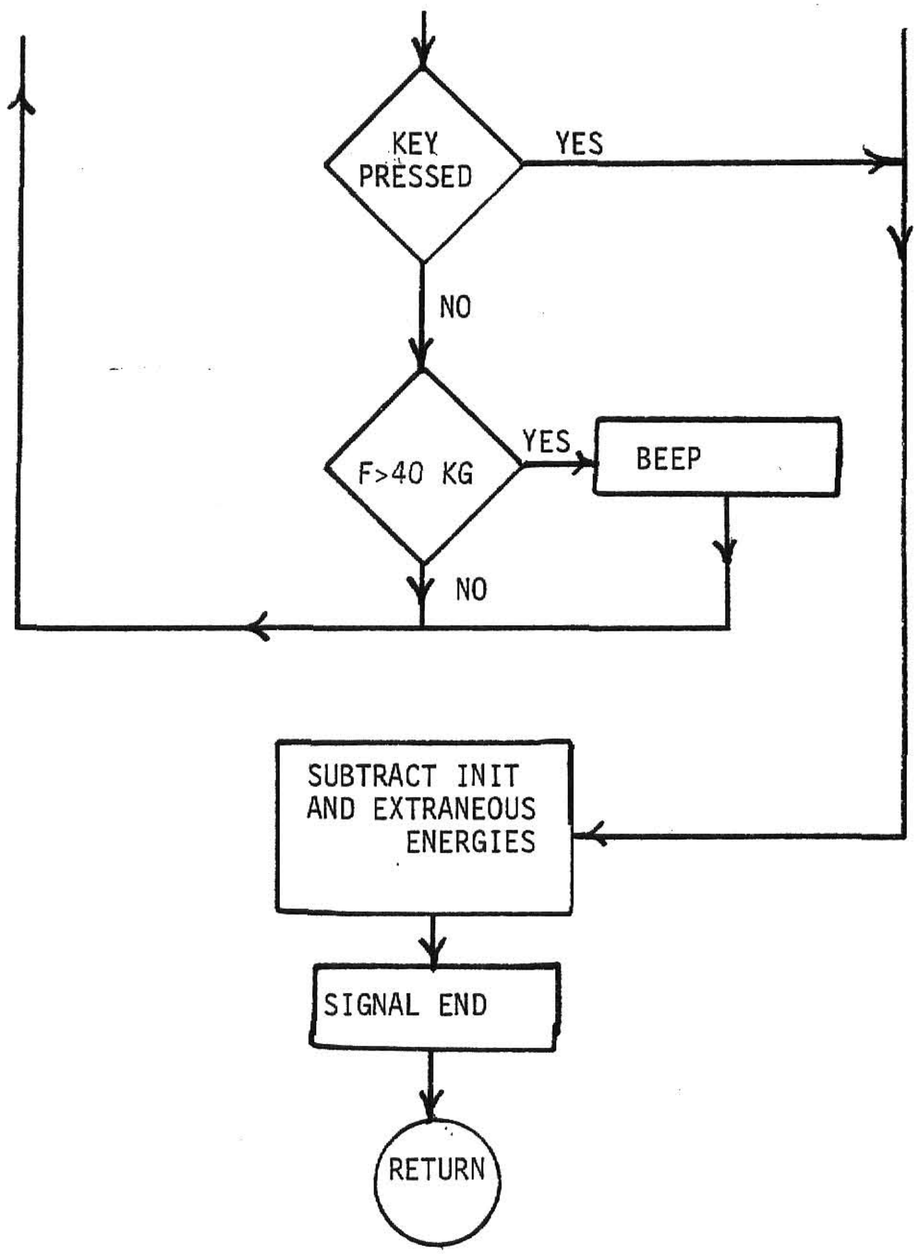
Following is a collection of flow diagrams for the major routines in the SACEM software. Complete assembly language listings of all the software can be found in Appendix C. Each diagram is headed by the name of the routine described. These names match those in the descriptions of chapter 3 and the assembly language labels at the beginning of each routine.

MONITOR

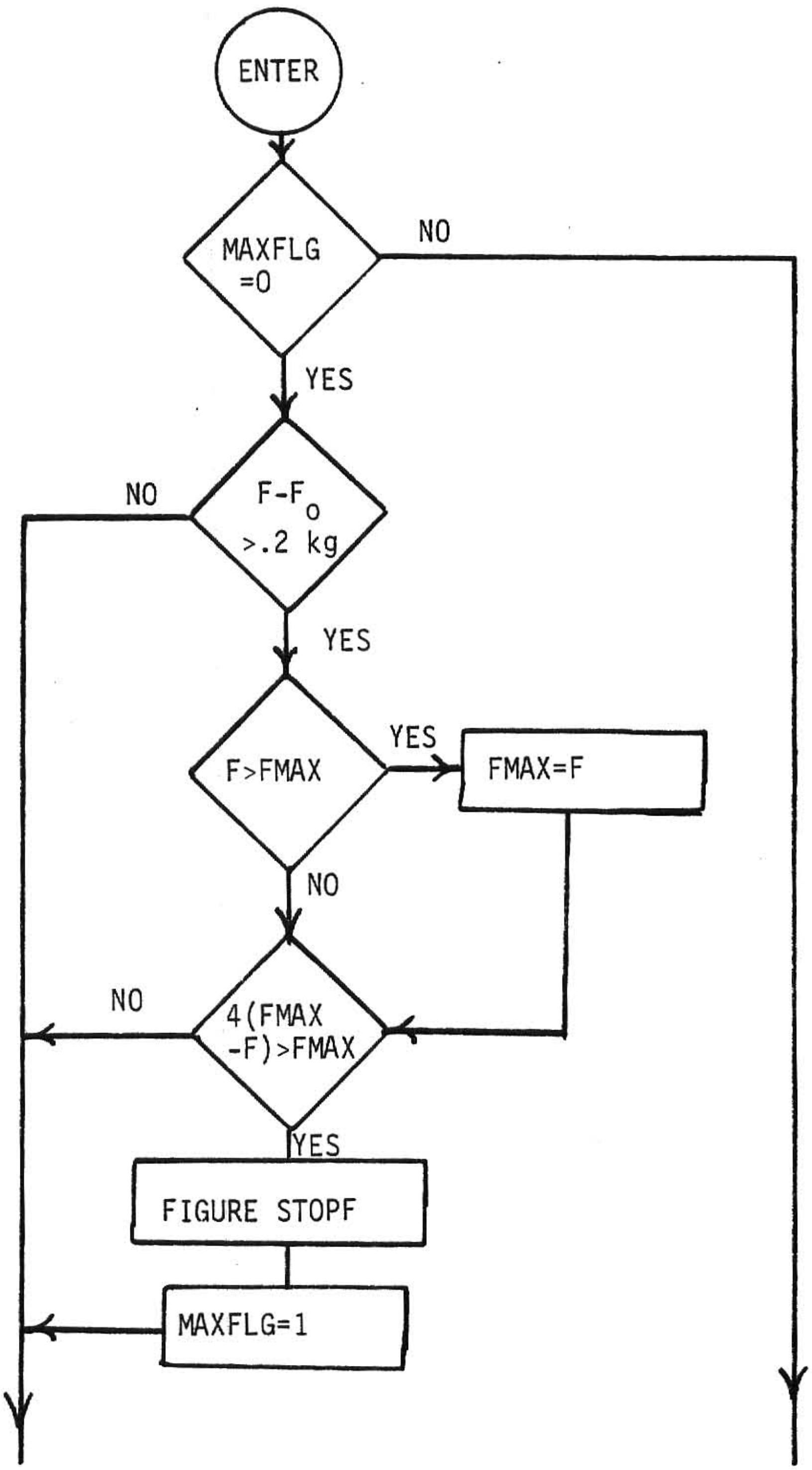

ENTER
INITIALIZE AND WRITE START-UP MESSAGE
POLL FOR KEY
'C'?
YES
DISPLAY F_O
NO
'D'?
YES
DISPLAY D_O
NO
'5'?
YES
TO SYM MONITOR
NO

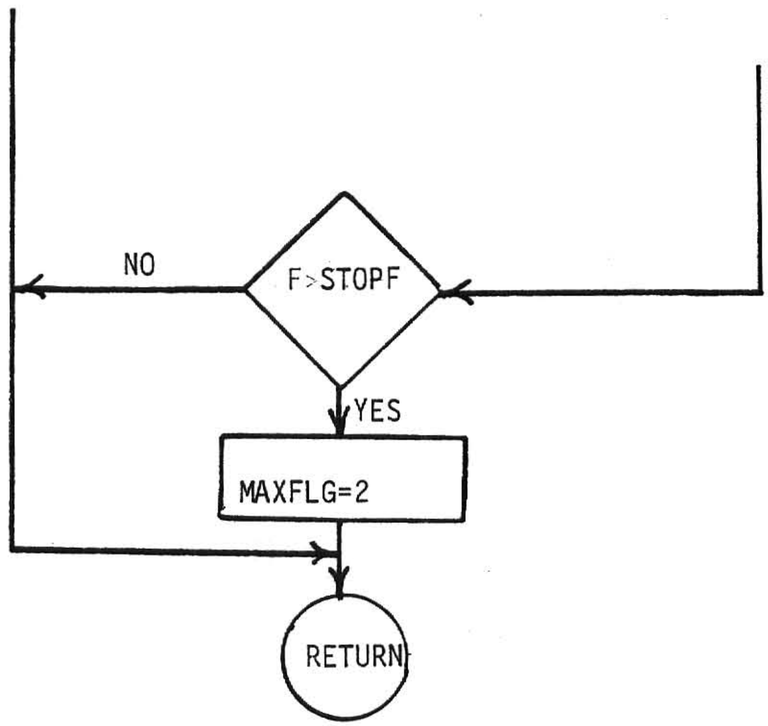
TEST


ENTER
INITIALIZE VARS
GET EDEL
EDEL <0?
YES
ESUM=ESUM-EDEL
NO
ESUM=ESUM+EDEL
CALL BREAK ROUTINE
MAXFLG=2
YES
NO
MAXFLG TO DISPLAY TO INDICATE STATUS
DISPLAY F IN N


KEY PRESSED
YES
NO
F>40 KG
YES
BEEP
NO
SUBTRACT INIT AND EXTRANEOUS ENERGIES
SIGNAL END
RETURN

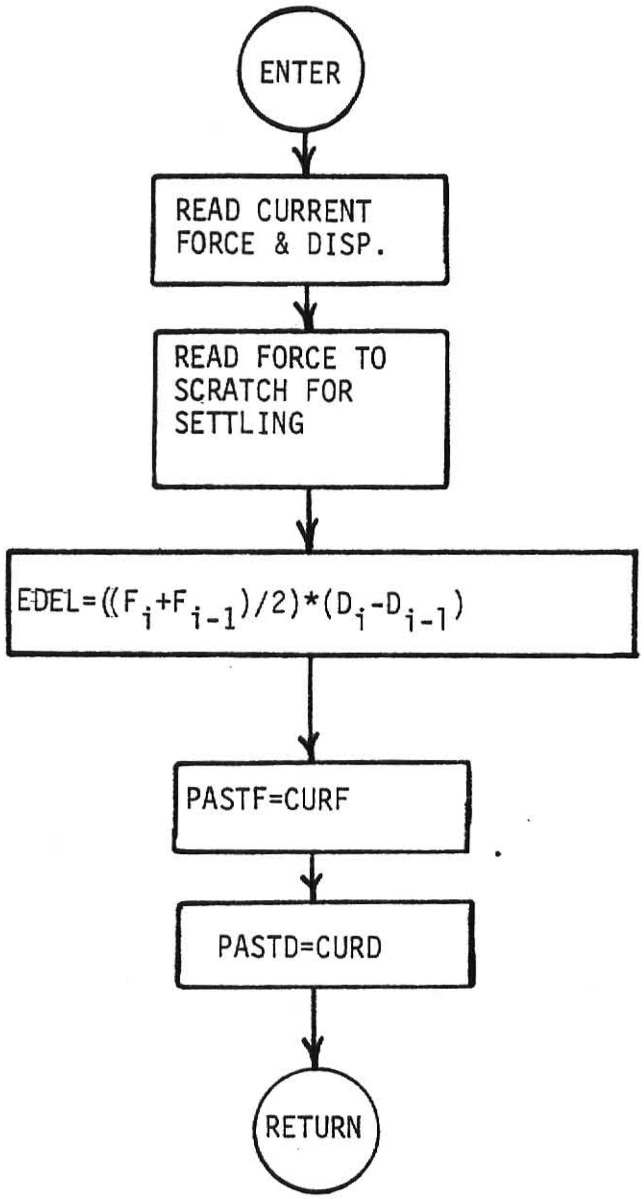
BREAK


ENTER
MAXFLG =0
NO
YES
F-F_o >.2 kg
NO
YES
F>FMAX
YES
FMAX=F
NO
4(FMAX -F)>FMAX
NO
YES
FIGURE STOPF
MAXFLG=1

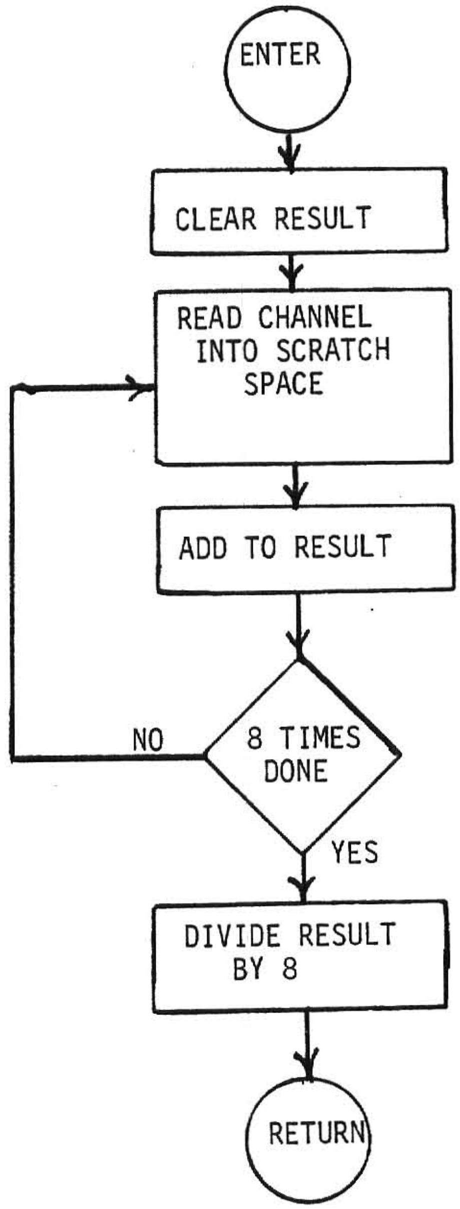


NO
F>STOPF
YES
MAXFLG=2
RETURN

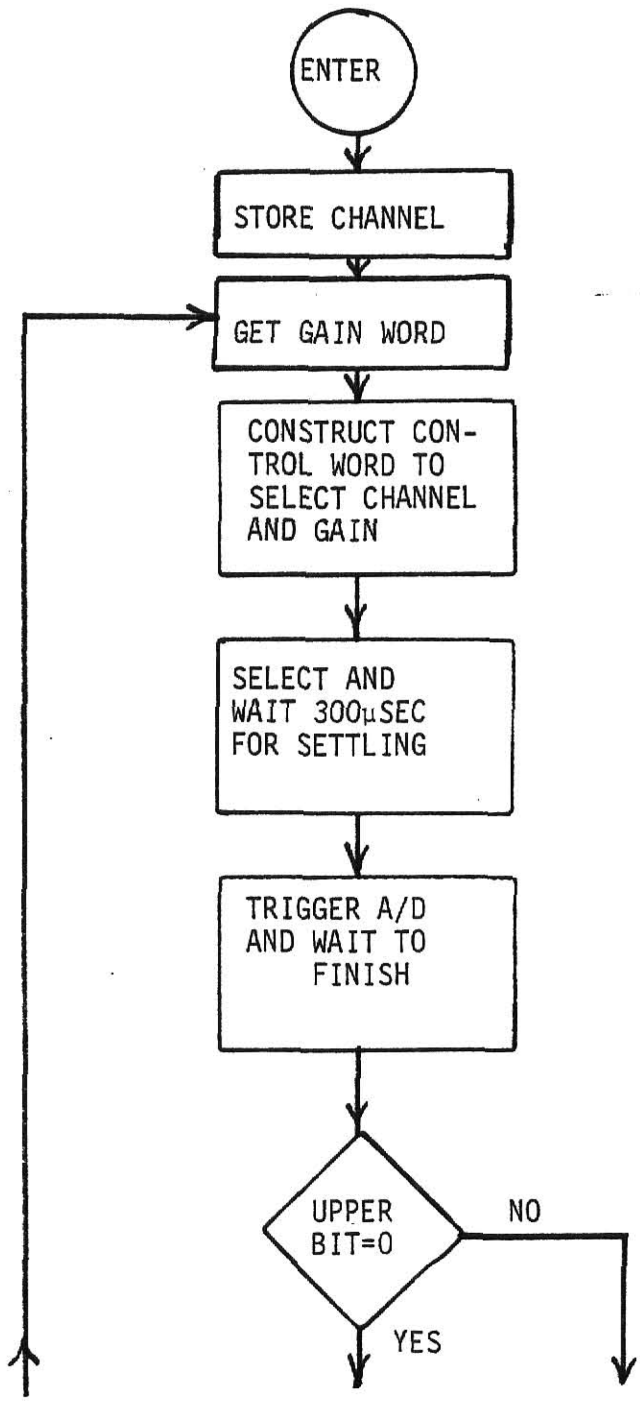
DELTAE

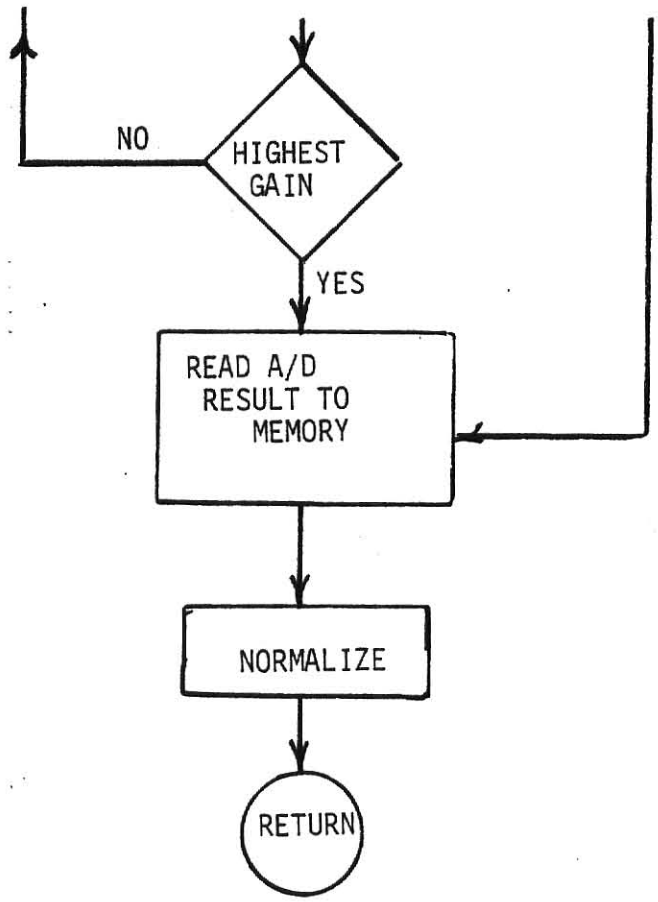

ENTER
READ CURRENT FORCE & DISP.
READ FORCE TO SCRATCH FOR SETTLING
EDEL=((F_i+F_{i-1})/2)*(D_i-D_{i-1})
PASTF=CURF
PASTD=CURD
RETURN

BASE

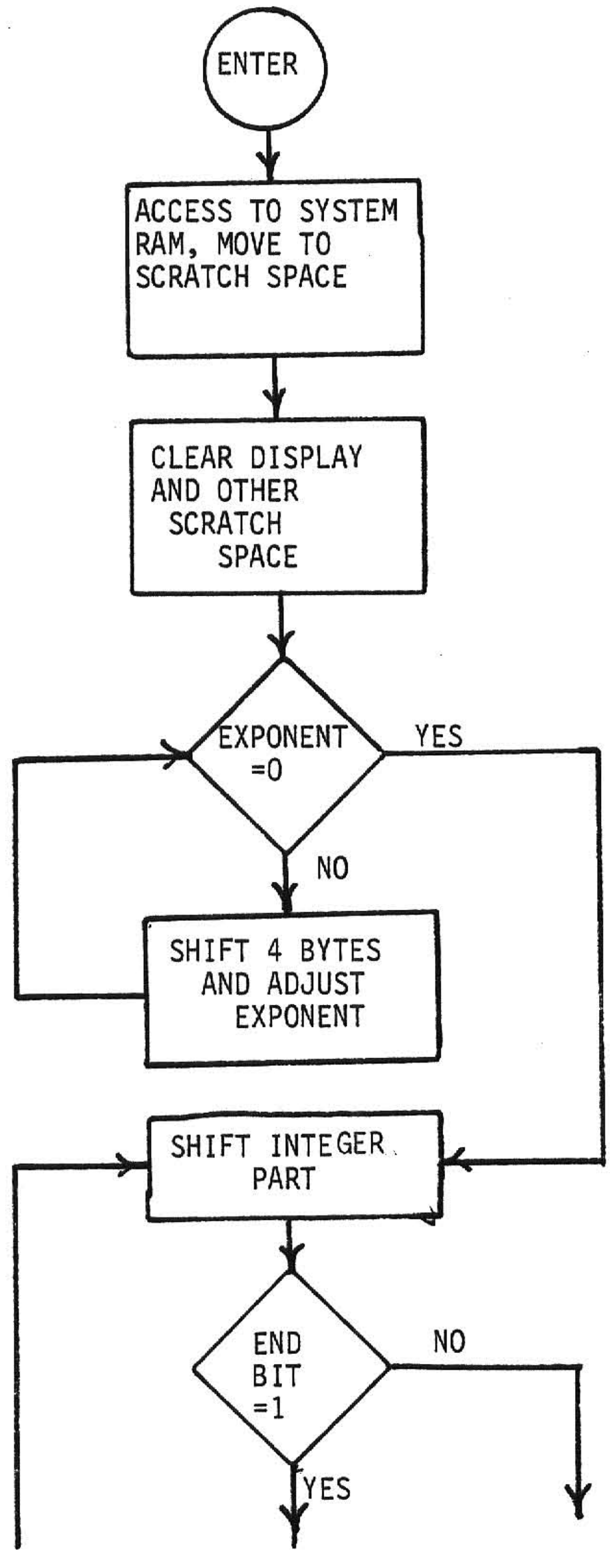

ENTER
CLEAR RESULT
READ CHANNEL INTO SCRATCH SPACE
ADD TO RESULT
8 TIMES DONE
NO
YES
DIVIDE RESULT BY 8
RETURN

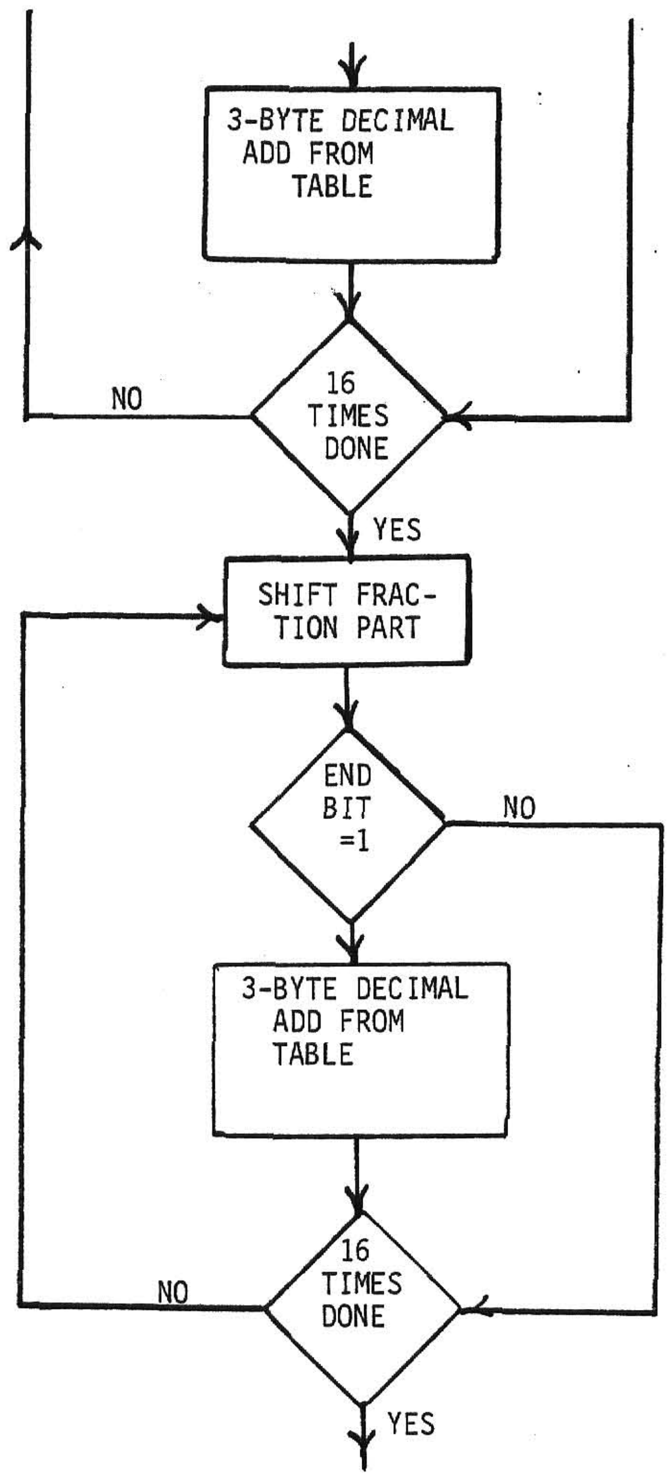
READ

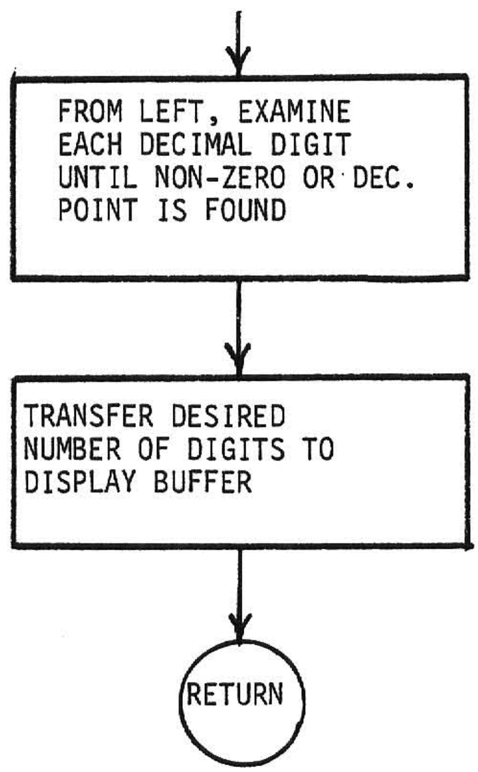

ENTER
STORE CHANNEL
GET GAIN WORD
CONSTRUCT CON-TROL WORD TO SELECT CHANNEL AND GAIN
SELECT AND WAIT 300μSEC FOR SETTLING
TRIGGER A/D AND WAIT TO FINISH
UPPER BIT=0
NO
YES


NO
HIGHEST GAIN
YES
READ A/D RESULT TO MEMORY
NORMALIZE
RETURN

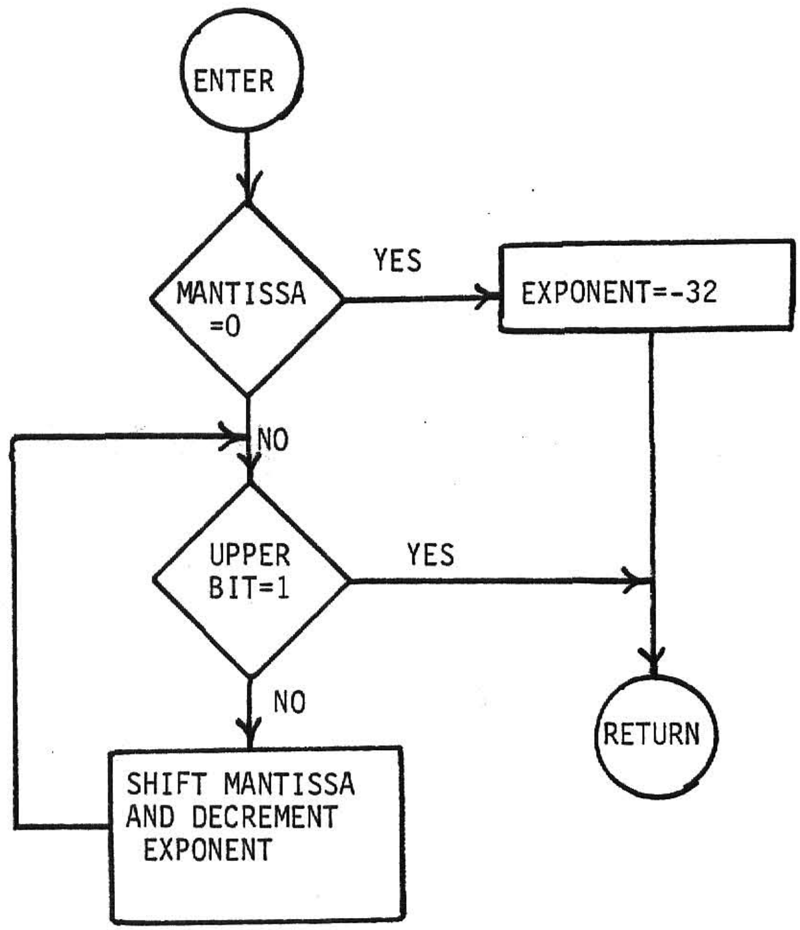
CONV:


ENTER
ACCESS TO SYSTEM RAM, MOVE TO SCRATCH SPACE
CLEAR DISPLAY AND OTHER SCRATCH SPACE
EXPONENT =0
YES
NO
SHIFT 4 BYTES AND ADJUST EXPONENT
SHIFT INTEGER PART
END BIT =1
NO
YES

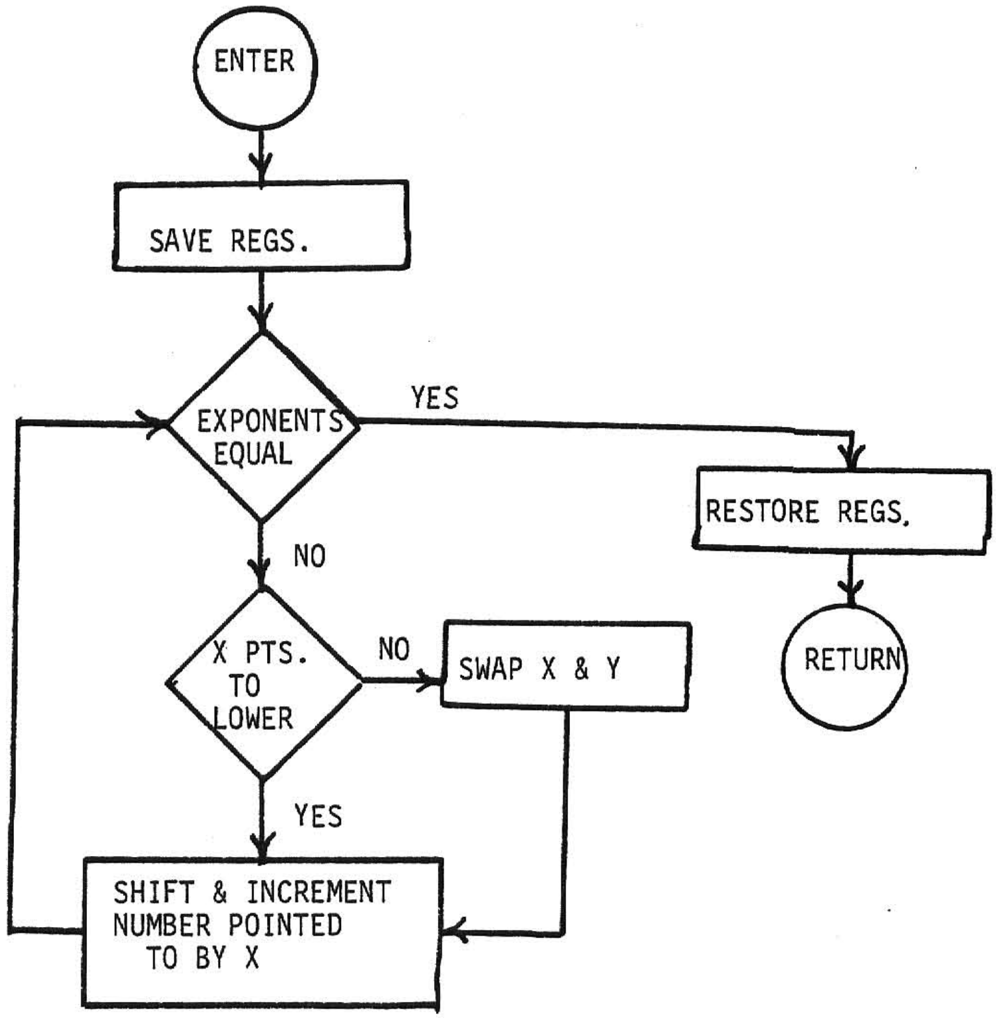

3-BYTE DECIMAL ADD FROM TABLE
NO
16 TIMES DONE
YES
SHIFT FRACTION PART
END BIT =1
NO
3-BYTE DECIMAL ADD FROM TABLE
NO
16 TIMES DONE
YES


FROM LEFT, EXAMINE
EACH DECIMAL DIGIT
UNTIL NON-ZERO OR DEC.
POINT IS FOUND
TRANSFER DESIRED
NUMBER OF DIGITS TO
DISPLAY BUFFER
RETURN

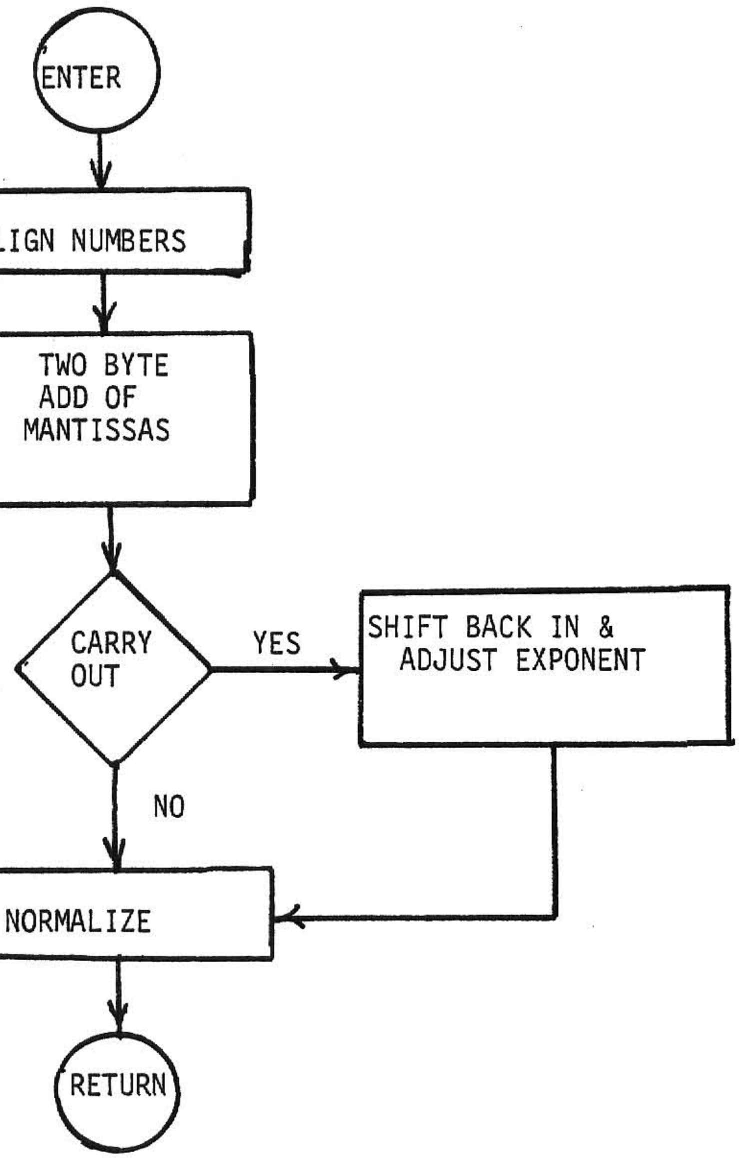
NORM


ENTER
MANTISSA =0
YES
EXPONENT=-32
NO
UPPER BIT=1
YES
NO
RETURN
SHIFT MANTISSA AND DECREMENT EXPONENT

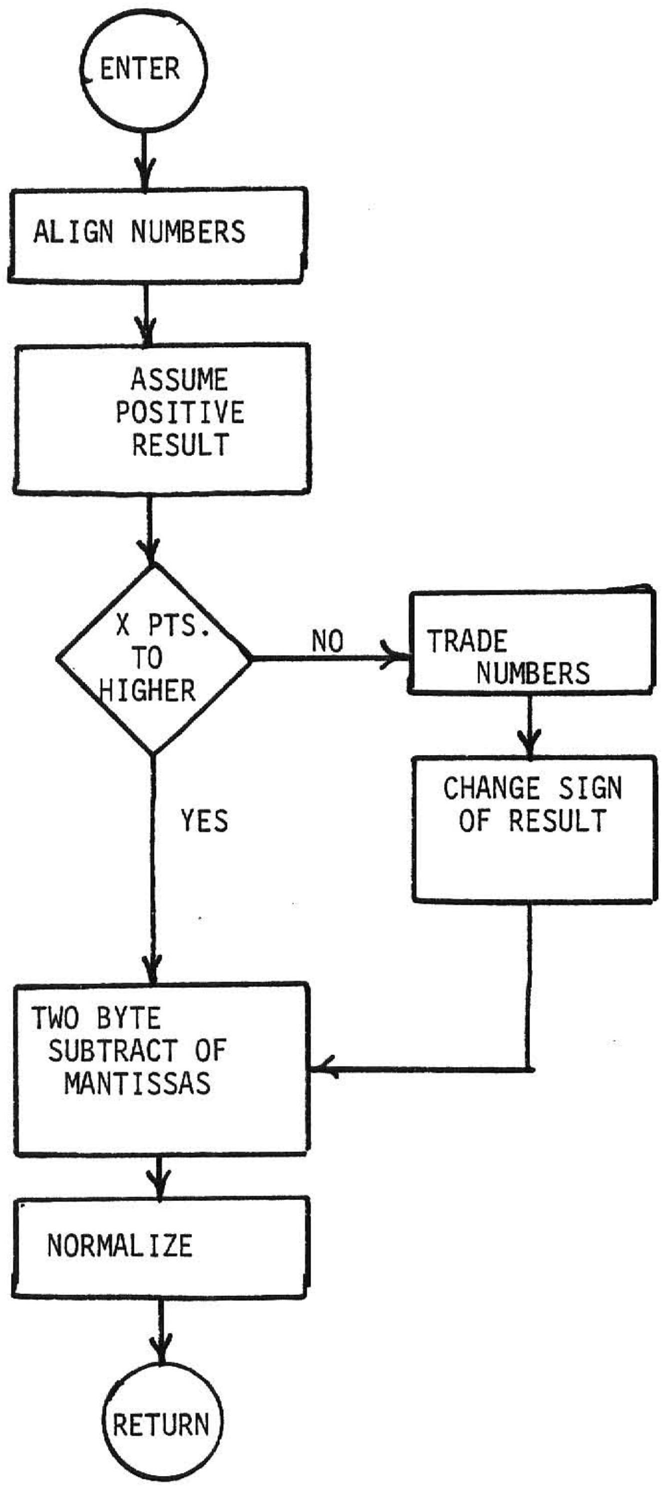
ALIGN


ENTER
SAVE REGS.
EXPONENTS EQUAL
YES
RESTORE REGS.
RETURN
NO
X PTS. TO LOWER
NO
SWAP X & Y
YES
SHIFT & INCREMENT NUMBER POINTED TO BY X

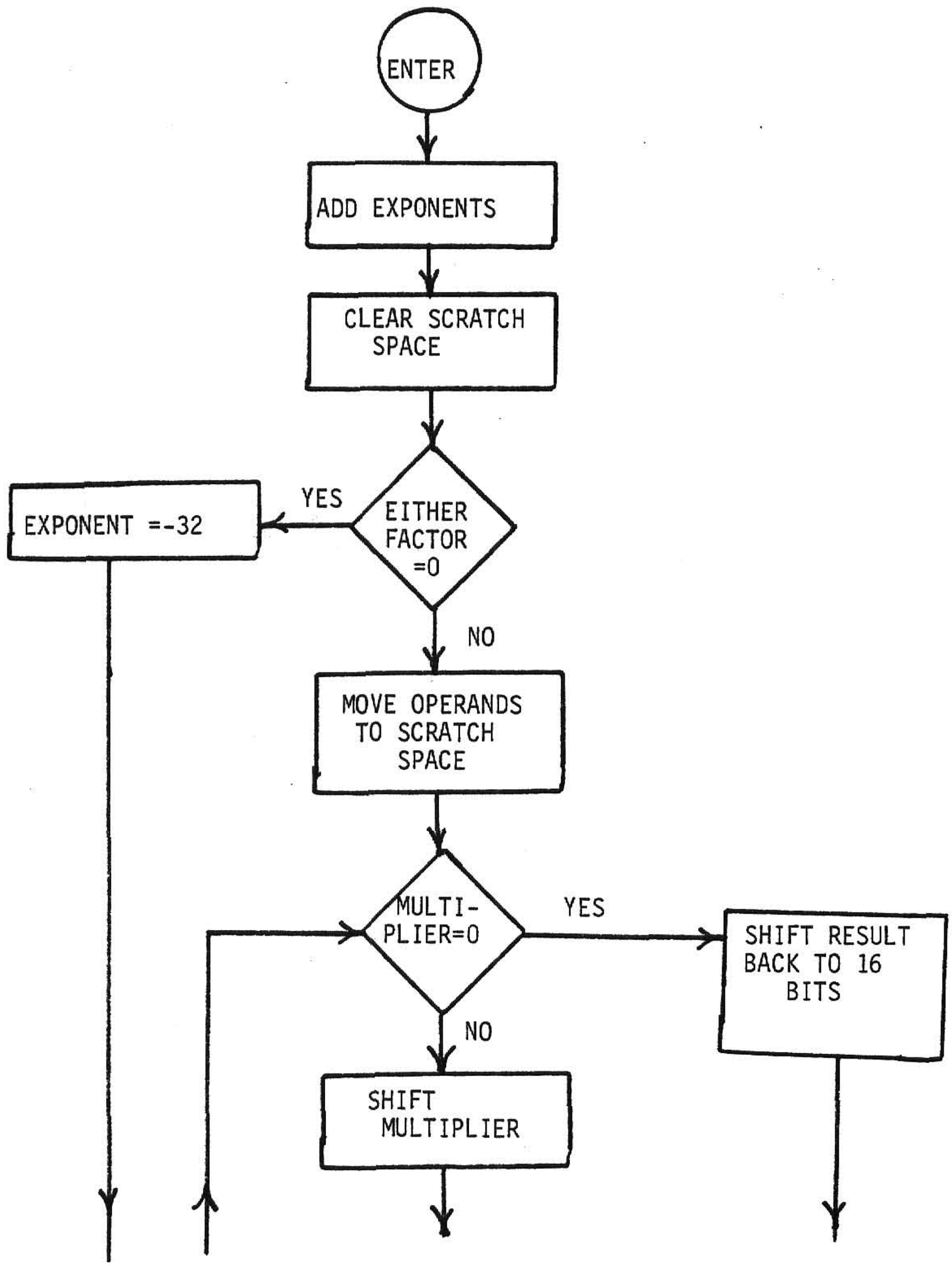
ADD

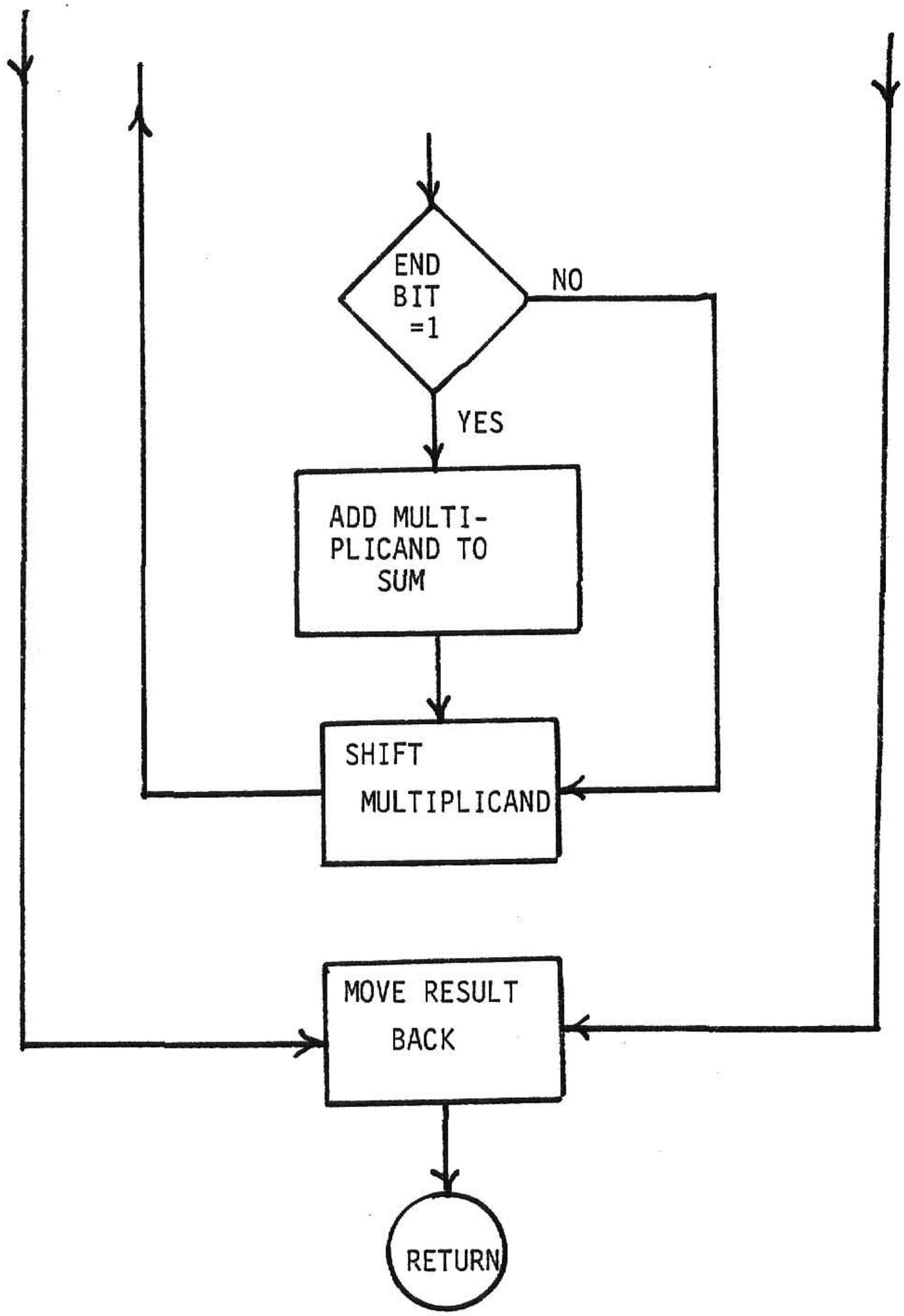

ENTER
ALIGN NUMBERS
TWO BYTE ADD OF MANTISSAS
CARRY OUT
YES
SHIFT BACK IN & ADJUST EXPONENT
NO
NORMALIZE
RETURN

SUB


ENTER
ALIGN NUMBERS
ASSUME POSITIVE RESULT
X PTS. TO HIGHER
NO
TRADE NUMBERS
CHANGE SIGN OF RESULT
YES
TWO BYTE SUBTRACT OF MANTISSAS
NORMALIZE
RETURN

MPY


ENTER
ADD EXPONENTS
CLEAR SCRATCH SPACE
EITHER FACTOR =0
YES
EXPONENT =-32
NO
MOVE OPERANDS TO SCRATCH SPACE
MULTI-PLIER=0
YES
SHIFT RESULT BACK TO 16 BITS
NO
SHIFT MULTIPLIER


END
BIT
=1
NO
YES
ADD MULTI-
PLICAND TO
SUM
SHIFT
MULTIPLICAND
MOVE RESULT
BACK
RETURN

APPENDIX C

PROGRAM LISTINGS

Below is a listing of the SACEM computer software in standard 6502 Assembly language.

```
                    .OS
                    .LS
       ;*******************************************************
       ;
       ;    SUBROUTINE TO READ THE A/D CONVERTER.  THE CHANNEL
       ; TO BE READ MUST BE IN REGISTER A ON ENTRY.  THE RESULT
       ; IS STORED AT THE LOCATION WITH ZERO-PAGE ADDRESS IN X.
       ; LOCATION 0,X CONTAINS THE EXPONENT AND 1,X TO 2,X
       ; CONTAIN THE NORMALIZED MANTISSA.  THE ROUTINE IS AUTO-
       ; RANGING.  VERSION 4. OCT 16, 1981
       ;
       ;-------------------------------------------------------
       ;
       UPPER       .DE $AC00            ;UPPER BITS OF DATA
       LOWER       .DE $A800            ;LOWER 8 BITS OF DATA
       CONTR       .DE $A80C            ;CONTROL REGISTER OF VIA
       DDR         .DE $A803            ;DATA DIRECTION REGISTER
       SELECT      .DE $A801            ;SELECT CHANNEL AND GAIN
       TEMP        .DE 00               ;TEMPORARY SCRATCH LOCATIO
       ;
                   .BA $E000
                   .MC $1000

E000- 0A        READ        ASL A                ;PUT CHANNEL IN UPPER 4
E001- 0A                    ASL A
E002- 0A                    ASL A
E003- 0A                    ASL A
E004- 85 00                 STA *TEMP
E006- 8A                    TXA                  ;STORE POINTER
E007- 48                    PHA
E008- A2 00                 LDX #0               ;GAIN COUNTER
                ;
E00A- A9 FF                 LDA #$FF
E00C- 8D 0C A8              STA CONTR            ;CONFIGURE VIA
E00F- 8D 03 A8              STA DDR
E012- A9 FD     AGAIN       LDA #$FD
E014- 8D 0C A8              STA CONTR            ;DROP LATCH LINE

E017- A5 00                 LDA *TEMP            ;SELECT CHANNEL AND GAIN
E019- 8D 01 A8              STA SELECT

E01C- A9 FF                 LDA #$FF
E01E- 8D 0C A8              STA CONTR            ;RAISE LATCH LINE

E021- A0 40                 LDY #$40
E023- 88        DELAY1      DEY                  ;ALLOW AMP. SETTLING TIME
E024- D0 FD                 BNE DELAY1

E026- A9 DF                 LDA #$DF
E028- 8D 0C A8              STA CONTR            ;TRIGGER A/D CONVERSION

E02B- A0 10                 LDY #$10
E02D- 88        DELAY2      DEY                  ;ALLOW CONVERT TIME
```

```
E02E- D0 FD                    BNE DELAY2

E030- A9 FF                    LDA #$FF
E032- 8D 0C A8                 STA CONTR

E035- AD 00 AC                 LDA UPPER         ;DONE IF D11 <> 0
E038- 29 08                    AND #$08
E03A- D0 11                    BNE GET

E03C- E0 0A                    CPX #$0A          ;DONE IF LOG(GAIN)=10
E03E- F0 0D                    BEQ GET

E040- E8                       INX               ;GET NEXT GAIN AND
E041- A5 00                    LDA *TEMP         ;TRY AGAIN
E043- 29 F0                    AND #$F0
E045- 1D 69 E0                 ORA TABLE,X
E048- 85 00                    STA *TEMP
E04A- 4C 12 E0                 JMP AGAIN

E04D- 8A          GET          TXA               ;CALCULATE 2'S COMP
E04E- 49 FF                    EOR #$FF          ;OF GAIN
E050- 18                       CLC
E051- 69 01                    ADC #01
E053- A8                       TAY               ;PUT IN Y

E054- 68                       PLA
E055- AA                       TAX               ;RESTORE POINTER

E056- 98                       TYA
E057- 95 00                    STA *0,X          ;STORE EXPONENT

E059- AD 00 AC                 LDA UPPER         ;GET UPPER 4
E05C- 29 0F                    AND #$0F
E05E- 95 01                    STA *1,X

E060- AD 00 A8                 LDA LOWER         ;GET LOW 8 BITS
E063- 95 02                    STA *2,X

E065- 20 74 E0                 JSR NORM          ;NORMALIZE NUMBER
E068- 60                       RTS
E069- 00 01 02    TABLE        .BY 0 1 2 5 6 8 9 $A $C $D $E
E06C- 05 06 08
E06F- 09 0A 0C
E072- 0D 0E

                  ;*******************************************************

                  ;     SUBROUTINE TO NORMALIZE A FLOATING POINT NUMBER.
                  ; THIS IS PERFORMED BY SHIFTING THE NUMBER LEFT UNTIL
                  ; D15=1 AND DECREMENTING THE EXPONENT.  A ZERO VALUE
                  ; IS GIVEN THE EXPONENT -32.  THE NUMBER TO BE
                  ; NORMALIZED IS FOUND AT THE ZERO PAGE ADDRESS IN X
                  ; AND THE RESULT IS LEFT THERE.
```

```

                   ;-----------------------------------------------------------

E074- B5 01        NORM       LDA *1,X              ;IF THE NUMBER IS ZERO,
E076- 15 02                   ORA *2,X              ;DON'T TRY TO SHIFT.
E078- F0 0F                   BEQ ZERO

E07A- B5 01        LOOPNO     LDA *1,X              ;CHECK FOR D15=1
E07C- 29 80                   AND #$80
E07E- D0 0D                   BNE DONENO

E080- 16 02                   ASL *2,X              ;DO SHIFTING AND TRY AGAIN
E082- 36 01                   ROL *1,X
E084- D6 00                   DEC *0,X
E086- 4C 7A E0                JMP LOOPNO

E089- A9 E0        ZERO       LDA #$E0              ;EXPONENT = -32
E08B- 95 00                   STA *0,X

E08D- 60           DONENO     RTS

                   ;**********************************************************

                   ;   SUBROUTINE TO ALIGN THE NUMBERS WITH ZERO-PAGE ADDRES-
                   ; SES IN X AND Y.  RESULTS ARE IN THE SAME LOCATIONS.
                   ; ALL REGISTERS ARE PRESERVED. THE ALIGNMENT IS PER-
                   ; FORMED BY SHIFTING THE NUMBER WITH THE LOWER
                   ; EXPONENT AND INCREMENTING ITS EXPONENT.

                   ;-----------------------------------------------------------

E08E- 48           ALIGN      PHA                   ;SAVE REGISTERS
E08F- 8A                      TXA
E090- 48                      PHA
E091- 98                      TYA
E092- 48                      PHA

E093- B9 00 00     TOP        LDA 0,Y
E096- D5 00                   CMP *0,X              ;COMPARE EXPONENTS
E098- F0 0E                   BEQ DONEAL

E09A- 10 03                   BPL SKIP              ;BE SURE X PTS TO LOWER
E09C- 20 AE E0                JSR SWAP              ;SWAP X&Y POINTERS

E09F- F6 00        SKIP       INC *0,X
E0A1- 56 01                   LSR *1,X              ;DO SHIFTING
E0A3- 76 02                   ROR *2,X
E0A5- 4C 93 E0                JMP TOP

E0A8- 68           DONEAL     PLA                   ;RESTORE REGISTERS
E0A9- A8                      TAY
E0AA- 68                      PLA
E0AB- AA                      TAX
```

```
E0AC- 68                       PLA
E0AD- 60                       RTS

                ;*********************************************************
                ;
                ;   SUBROUTINE TO SWAP X AND Y REGISTERS.

                ;---------------------------------------------------------

E0AE- 48        SWAP           PHA
E0AF- 8A                       TXA
E0B0- 48                       PHA
E0B1- 98                       TYA
E0B2- AA                       TAX
E0B3- 68                       PLA
E0B4- A8                       TAY
E0B5- 68                       PLA
E0B6- 60                       RTS

                ;*********************************************************

                ;   SUBROUTINE TO ADD THE FLOATING POINT NUMBERS WITH ZERO
                ; PAGE ADDRESSES IN X AND Y.  THE RESULT IS STORED AT
                ; THE ADDRESS IN X.

                ;---------------------------------------------------------

E0B7- 20 8E E0  ADD            JSR ALIGN            ;ALIGN NUMBERS

E0BA- B5 02                    LDA *2,X
E0BC- 18                       CLC                  ;ADD LOWS
E0BD- 79 02 00                 ADC 2,Y
E0C0- 95 02                    STA *2,X

E0C2- B5 01                    LDA *1,X
E0C4- 79 01 00                 ADC 1,Y              ;ADD HIGHS
E0C7- 95 01                    STA *1,X
E0C9- 90 06                    BCC DONEAD           ;IF NO CARRY, DONE

E0CB- 76 01                    ROR *1,X             ;SHIFT CARRY BACK IN
E0CD- 76 02                    ROR *2,X
E0CF- F6 00                    INC *0,X             ;ADJUST EXPONENT

E0D1- 20 74 E0  DONEAD         JSR NORM             ;NORMALIZE RESULT
E0D4- 60                       RTS

                ;*********************************************************

                ;   SUBROUTINE TO SUBTRACT THE NUMBERS WITH ZERO PAGE
                ; ADDRESSES IN X AND Y.  THE ABSOLUTE VALUE OF THE RESULT
                ; IS STORED AT THE ADDRESS POINTED TO BY X.  THE RESULT
                ; IS NORMALIZED.  THE SMALLER OF THE NUMBERS IS STORED
                ; AT THE ADDRESS POINTED TO BY Y.  A NEGATIVE RESULT IS
```

```
                ; INDICATED BY A NON-ZERO VALUE AT LOCATION ZERO.

                ;--------------------------------------------------------

                SIGN     .DE 0                   ;WHERE TO PUT SIGN

E0D5- 20 8E E0  SUB      JSR ALIGN               ;ALIGN NUMBERS

E0D8- A9 00              LDA #0
E0DA- 85 00              STA *SIGN               ;ASSUME POSITIVE RESULT

E0DC- B5 01              LDA *1,X
E0DE- D9 01 00           CMP 1,Y
E0E1- 90 09              BCC TRADE               ;EXCHANGE NUMBERS IF
E0E3- D0 21              BNE OK                  ;X PTS TO HIGHER
E0E5- B5 02              LDA *2,X
E0E7- D9 02 00           CMP 2,Y
E0EA- B0 1A              BCS OK

E0EC- B9 01 00  TRADE    LDA 1,Y
E0EF- 48                 PHA
E0F0- B5 01              LDA *1,X                ;SWAP HIGHS
E0F2- 99 01 00           STA 1,Y
E0F5- 68                 PLA
E0F6- 95 01              STA *1,X

E0F8- B9 02 00           LDA 2,Y
E0FB- 48                 PHA
E0FC- B5 02              LDA *2,X
E0FE- 99 02 00           STA 2,Y                 ;SWAP LOWS
E101- 68                 PLA
E102- E6 00              INC *SIGN
E104- 95 02              STA *2,X

E106- B5 02     OK       LDA *2,X
E108- 38                 SEC                     ;SUB LOWS
E109- F9 02 00           SBC 2,Y
E10C- 95 02              STA *2,X

E10E- B5 01              LDA *1,X                ;SUB HIGHS
E110- F9 01 00           SBC 1,Y
E113- 95 01              STA *1,X

E115- 20 74 E0           JSR NORM                ;NORMALIZE NUMBERS
E118- 60                 RTS

                ;*******************************************************

                ;   SUBROUTINE TO MULTIPLY THE NUMBERS WITH ZERO-PAGE
                ; ADDRESSES IN X AND Y.  THE PRODUCT IS STORED IN THE
                ; ADDRESS POINTED TO BY X.

                ;--------------------------------------------------------
```

```

E119- B5 00      MPY       LDA *0,X
E11B- 18                   CLC
E11C- 79 00 00             ADC 0,Y              ;ADD EXPONENTS
E11F- 95 00                STA *0,X

E121- 8A                   TXA
E122- 48                   PHA
E123- A2 06                LDX #06              ;CLEAR 6 SPACES
E125- A9 00                LDA #0               ;FOR SCRATCH
E127- 95 00      CLEAR     STA *0,X
E129- CA                   DEX
E12A- D0 FB                BNE CLEAR
E12C- 68                   PLA
E12D- AA                   TAX

E12E- B9 01 00             LDA 1,Y
E131- 19 02 00             ORA 2,Y              ;TEST FOR ZERO
E134- F0 51                BEQ ZEROMP           ;MULTIPLIER
E136- B5 01                LDA *1,X
E138- 15 02                ORA *2,X             ;TEST FOR ZERO
E13A- F0 4B                BEQ ZEROMP           ;MULTIPLICAND

E13C- B5 01                LDA *1,X
E13E- 85 07                STA *07
E140- B5 02                LDA *2,X             ;MOVE OPERANDS
E142- 85 08                STA *08              ;TO SCRATCH SPACE
E144- B9 01 00             LDA 1,Y
E147- 85 09                STA *09
E149- B9 02 00             LDA 2,Y
E14C- 85 0A                STA *$0A

E14E- A5 0A      LOOPMP    LDA *$0A             ;DONE IF
E150- 05 09                ORA *09              ;MULTIPLIER=0
E152- F0 20                BEQ OUT

E154- 46 09                LSR *09
E156- 66 0A                ROR *$0A             ;SHIFT MULTIPLIER
E158- 90 0F                BCC NOADD            ;CHECK END BIT

E15A- A0 04                LDY #04              ;FOUR-BYTE ADD ROUTINE
E15C- 18                   CLC
E15D- B9 00 00   ADD4      LDA 0,Y
E160- 79 04 00             ADC 4,Y
E163- 99 00 00             STA 0,Y
E166- 88                   DEY
E167- D0 F4                BNE ADD4

E169- 06 08      NOADD     ASL *08              ;SHIFT MULTIPLICAND
E16B- 26 07                ROL *07
E16D- 26 06                ROL *06
E16F- 26 05                ROL *05
E171- 4C 4E E1             JMP LOOPMP
```

```
E174- A5 01      OUT       LDA *01
E176- 05 02                ORA *02          ;SHIFT BACK UNTIL
E178- F0 11                BEQ DONE         ;UPPER 16=0

E17A- F6 00                INC *0,X         ;BUMP EXPONENT
E17C- 46 01                LSR *01
E17E- 66 02                ROR *02
E180- 66 03                ROR *03
E182- 66 04                ROR *04
E184- 4C 74 E1             JMP OUT

E187- A9 E0      ZEROMP    LDA #$E0         ;EXP=-32 IF ZERO
E189- 95 00                STA *0,X

E18B- A5 03      DONE      LDA *03          ;PUT RESULT BACK
E18D- 95 01                STA *1,X
E18F- A5 04                LDA *04
E191- 95 02                STA *2,X
E193- 60                   RTS
                           .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

ADD =E0B7            ADD4 =E15D           AGAIN =E012
ALIGN =E08E          CLEAR =E127          CONTR =A80C
DDR =A803            DELAY1 =E023         DELAY2 =E02D
DONE =E18B           DONEAD =E0D1         DONEAL =E0A8
DONENO =E08D         GET =E04D            LOOPMP =E14E
LOOPNO =E07A         LOWER =A800          MPY =E119
NOADD =E169          NORM =E074           OK =E106
OUT =E174            READ =E000           SELECT =A801
SIGN =0000           SKIP =E09F           SUB =E0D5
SWAP =E0AE           TABLE =E069          TEMP =0000
TOP =E093            TRADE =E0EC          UPPER =AC00
ZERO =E089           ZEROMP =E187
//0000,E194,1194
```

```
                      .OS
            ;*****************************************************
            
            ;     THIS IS A SUBROUTINE TO CONVERT THE FLOATING POINT
            ; BINARY NUMBER WITH ZERO-PAGE ADDRESS IN X TO A DECIMAL
            ; NUMBER IN THE DISPLAY BUFFER.  NUMBERS TOO LARGE ARE
            ; INDICATED BY E'S IN THE DISPLAY.  THE NUMBER OF
            ; DIGITS TO BE DISPLAYED SHOULD BE IN LOCATION 0.
            
            ;-----------------------------------------------------
            
                      .BA $E200
                      .MC $1000
                      .LS
            ACCESS    .DE $8B86
            DISBUF    .DE $A640
            
E200- 20 86 8B CONV   JSR ACCESS
E203- B5 00           LDA *0,X
E205- F0 05           BEQ OK
E207- 30 03           BMI OK
E209- 4C B3 E2        JMP TOOBIG
            
E20C- 85 02    OK     STA *02           ;MOVE NUMBER TO SCRATCH
E20E- B5 01           LDA *1,X
E210- 85 03           STA *03
E212- B5 02           LDA *2,X
E214- 29 F0           AND #$F0
E216- 85 04           STA *04           ;TRUNCATE TO 12 BITS
            
E218- A2 06           LDX #06           ;DISPLAY SPACE
E21A- A9 00           LDA #00
E21C- 95 06    CLEAR  STA *6,X
E21E- 9D 3F A6        STA DISBUF-1,X
E221- CA              DEX
E222- D0 F8           BNE CLEAR
E224- 85 05           STA *05
E226- 85 06           STA *06
            
E228- A5 02           LDA *02           ;TEST EXPONENT FOR 0
E22A- F0 0C           BEQ LINUP
            
E22C- 46 03    SLOOP  LSR *03           ; SHIFT RIGHT UNTIL
E22E- 66 04           ROR *04           ;EXPONENT=0
E230- 66 05           ROR *05
E232- 66 06           ROR *06
E234- E6 02           INC *02
E236- D0 F4           BNE SLOOP
            
E238- A9 0F    LINUP  LDA #$0F          ;DECIMAL PT IS AT END
E23A- 85 01           STA *01           ;OF $04 HERE
E23C- 06 04    ALOOP  ASL *04
E23E- 26 03           ROL *03           ;TEST EACH BIT TO
```

```
E240- 90 1E              BCC NOAD        ;ADD CORRESPONDING
E242- A5 01              LDA *01
E244- 0A                 ASL A           ;3*COUNTER IN X
E245- 65 01              ADC *01
E247- AA                 TAX
E248- F8                 SED             ;3-BYTE DECIMAL ADD
E249- 18                 CLC
E24A- A5 09              LDA *09
E24C- 7D C0 E2           ADC TAB+2,X
E24F- 85 09              STA *09
E251- A5 08              LDA *08
E253- 7D BF E2           ADC TAB+1,X
E256- 85 08              STA *08
E258- A5 07              LDA *07
E25A- 7D BE E2           ADC TAB,X
E25D- 85 07              STA *07
E25F- D8                 CLD
E260- C6 01      NOAD    DEC *01         ;INTEGR PART DONE HERE
E262- 10 D8              BPL ALOOP
E264- A9 0F              LDA #$0F        ;16 MORE TIMES
E266- 85 01              STA *01
E268- 06 06      ALOOP2  ASL *06
E26A- 26 05              ROL *05
E26C- 90 1E              BCC NOAD2       ;TEST EACH BIT
E26E- A5 01              LDA *01
E270- 0A                 ASL A
E271- 65 01              ADC *01         ;3*COUNTER IN X
E273- AA                 TAX
E274- F8                 SED             ;3-BYTE DECIMAL ADD
E275- 18                 CLC
E276- A5 0C              LDA *$0C
E278- 7D F0 E2           ADC TAB2+2,X
E27B- 85 0C              STA *$0C
E27D- A5 0B              LDA *$0B
E27F- 7D EF E2           ADC TAB2+1,X
E282- 85 0B              STA *$0B
E284- A5 0A              LDA *$0A
E286- 7D EE E2           ADC TAB2,X
E289- 85 0A              STA *$0A
E28B- D8                 CLD             ;FRACTION DONE HERE
E28C- C6 01      NOAD2   DEC *01
E28E- 10 D8              BPL ALOOP2
E290- A2 0D              LDX #$0D        ;12 POSSIBLE DIGITS
E292- 20 1E E3   LOOP    JSR NEXDIG      ;LOOK AT LEFT DIGITS
```

```
E295- CA              DEX                     ;UNTIL NON-ZERO OR DEC.
E296- E0 07           CPX #07                 ;PT IS FOUND.
E298- F0 04           BEQ GO

E29A- C9 3F           CMP #$3F
E29C- F0 F4           BEQ LOOP

E29E- A0 00     GO    LDY #0
E2A0- E0 07     LOOP2 CPX #07                 ;CHECK FOR PT.
E2A2- D0 02           BNE ARND
E2A4- 09 80           ORA #$80                ;PUT ON PT.

E2A6- 99 40 A6  ARND  STA DISBUF,Y
E2A9- 20 1E E3        JSR NEXDIG              ;GO UNTIL ALL
E2AC- CA              DEX
E2AD- C8              INY
E2AE- C4 00           CPY *00
E2B0- D0 EE           BNE LOOP2
E2B2- 60              RTS

E2B3- A2 06     TOOBIG LDX #06
E2B5- A9 79           LDA #$79                ;DISPLAY E'S
E2B7- 9D 3F A6  LOOPN STA DISBUF-1,X
E2BA- CA              DEX
E2BB- D0 FA           BNE LOOPN
E2BD- 60              RTS

E2BE- 00 00 01  TAB   .BY $00 $00 $01 ;TABLE OF DECIMAL EQUIV.
E2C1- 00 00 02        .BY $00 $00 $02 ;OF POWERS OF 2
E2C4- 00 00 04        .BY $00 $00 $04
E2C7- 00 00 08        .BY $00 $00 $08 ;2**3
E2CA- 00 00 16        .BY $00 $00 $16 ;2**4
E2CD- 00 00 32        .BY $00 $00 $32 ;2**5
E2D0- 00 00 64        .BY $00 $00 $64 ;ETC.
E2D3- 00 01 28        .BY $00 $01 $28
E2D6- 00 02 56        .BY $00 $02 $56
E2D9- 00 05 12        .BY $00 $05 $12
E2DC- 00 10 24        .BY $00 $10 $24
E2DF- 00 20 48        .BY $00 $20 $48
E2E2- 00 40 96        .BY $00 $40 $96
E2E5- 00 81 92        .BY $00 $81 $92
E2E8- 01 63 84        .BY $01 $63 $84
E2EB- 03 27 68        .BY $03 $27 $68 ;2**15
E2EE- 00 00 15  TAB2  .BY $00 $00 $15 ;TABLE OF NEGATIVE POWERS
E2F1- 00 00 31        .BY $00 $00 $31
E2F4- 00 00 61        .BY $00 $00 $61 ;2**-14
E2F7- 00 01 22        .BY $00 $01 $22 ;2**-13
E2FA- 00 02 44        .BY $00 $02 $44 ;ETC.
E2FD- 00 04 88        .BY $00 $04 $88
E300- 00 09 77        .BY $00 $09 $77
E303- 00 19 53        .BY $00 $19 $53
E306- 00 39 06        .BY $00 $39 $06
E309- 00 78 13        .BY $00 $78 $13
```

```
E30C- 01 56 25                 .BY $01 $56 $25
E30F- 03 12 50                 .BY $03 $12 $50
E312- 06 25 00                 .BY $06 $25 $00
E315- 12 50 00                 .BY $12 $50 $00
E318- 25 00 00                 .BY $25 $00 $00
E31B- 50 00 00                 .BY $50 $00 $00

               ;------------------------------------------------------

               ;   SUBROUTINE TO SHIFT LEFT FOUR BITS AND PUT THE
               ; SEGMENT CODES FOR THE NEXT DIGIT IN A.

E31E- 8A       NEXDIG     TXA                    ;SAVE REGISTERS
E31F- 48                  PHA
E320- 98                  TYA
E321- 48                  PHA
E322- A0 04               LDY #04                ;FOUR SHIFTS
E324- A2 06    OUTSH      LDX #06                ;SIX BYTES TO SHIFT
E326- 06 0C               ASL *$0C
E328- 36 05    SHFT       ROL *5,X
E32A- CA                  DEX
E32B- D0 FB               BNE SHFT
E32D- 88                  DEY
E32E- D0 F4               BNE OUTSH              ;SHIFTING DONE

E330- A5 06               LDA *06                ;LOAD A AND RESTORE X&Y
E332- 29 0F               AND #$0F
E334- A8                  TAY
E335- B9 41 E3            LDA DIGIT,Y
E338- 85 05               STA *05
E33A- 68                  PLA
E33B- A8                  TAY
E33C- 68                  PLA
E33D- AA                  TAX
E33E- A5 05               LDA *05
E340- 60                  RTS
E341- 3F 06 5B DIGIT      .BY $3F $06 $5B $4F $66 $6D $7D $07
E344- 4F 66 6D
E347- 7D 07
E349- 7F 67 77            .BY $7F $67 $77 $7C $39 $5E $79 $71
E34C- 7C 39 5E
E34F- 79 71
                          .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

ACCESS =8B86          ALOOP =E23C          ALOOP2 =E268
ARND =E2A6            CLEAR =E21C          CONV =E200
DIGIT =E341           DISBUF =A640         GO =E29E
LINUP =E238           LOOP =E292           LOOP2 =E2A0
LOOPN =E2B7           NEXDIG =E31E         NOAD =E260
NOAD2 =E28C           OK =E20C             OUTSH =E324
```

```
SHFT =E328            SLOOP =E22C           TAB =E2BE
TAB2 =E2EE            TOOBIG =E2B3
//0000,E351,1151
```

```
                     .LS
                     .OS
                     .BA $E400
                     .MC $1000
          ;*********************************************************
          ;   SUBROUTINE TO COMPARE TWO FLOATING POINT NUMBERS
          ; WITH ZERO-PAGE ADDRESSES IN X AND Y.  ON RETURN, THE
          ; FLAGS ARE SET AS IF TO SINGLE BYTES WERE COMPARED.
          ;---------------------------------------------------------
E400- B5 00     COMP     LDA *0,X            ;COMPARE EXPONENT
E402- D9 00 00           CMP 0,Y
E405- D0 0C              BNE RET
E407- B5 01              LDA *1,X            ;COMPARE FIRST BYTE
E409- D9 01 00           CMP 1,Y
E40C- D0 05              BNE RET
E40E- B5 02              LDA *2,X            ;COMPARE SECOND BYTE
E410- D9 02 00           CMP 2,Y
E413- 60        RET      RTS
          ;*********************************************************
          ;   SUBROUTINE TO FIND THE CANGE IN CRUSHING ENERGY SINCE
          ; LAST CALL.  THE ABSOLUTE VALUE OF THE CHANGE IS STORED
          ; AT $2F. AND THE SIGN IS INDICATED BY THE VALUE IN $0.
          ; A NON-ZERO VALUE IN $0 INDICATES A NEGATIVE RESULT.  THE
          ; ROUTINE ALSO ASSUMES THESE LOCATIONS:
          ;  $23  PAST FORCE              $26  PAST DISPLACEMENT
          ; LOCATIONS $29 THROUGH $31 ARE ALSO USED.
          ;---------------------------------------------------------
                READ     .DE $E000           ;ROUTINE TO READ A/D
                ADD      .DE $E0B7           ;ADDITION ROUTINE
                SUB      .DE $E0D5           ;SUBTRACTION ROUTINE
                MPY      .DE $E119           ;MULTIPLICATION ROUTINE
E414- A9 06     DELTAE   LDA #06             ;CURR F TO $29
E416- A2 29              LDX #$29
E418- 20 00 E0           JSR READ
E41B- A9 07              LDA #07             ;DURR D TO $2C
E41D- A2 2C              LDX #$2C
E41F- 20 00 E0           JSR READ
E422- A9 06              LDA #06             ;READ F AFTER D
E424- A2 00              LDX #0              ;TO LET SETTLE
E426- 20 00 E0           JSR READ
```

```

E429- A2 03              LDX #03           ;COPY CURR D TO $2F
E42B- B5 2B     LOOP     LDA *$2B,X
E42D- 95 2E              STA *$2E,X
E42F- CA                 DEX
E430- D0 F9              BNE LOOP

E432- A2 2F              LDX #$2F          ;ABS(DELTA D) IN $2F
E434- A0 26              LDY #$26
E436- 20 D5 E0           JSR SUB

E439- A2 23              LDX #$23          ;AVG F IN $23
E43B- A0 29              LDY #$29
E43D- 20 B7 E0           JSR ADD
E440- C6 23              DEC *$23

E442- A2 2F              LDX #$2F          ;ABS(DELTA E) IN $2F
E444- A0 23              LDY #$23
E446- 20 19 E1           JSR MPY

E449- A2 03              LDX #03           ;MOVE CURR F AND D TO PAST
E44B- B5 2B     MOVE     LDA *$2B,X
E44D- 95 25              STA *$25,X
E44F- B5 28              LDA *$28,X
E451- 95 22              STA *$22,X
E453- CA                 DEX
E454- D0 F5              BNE MOVE

E456- 60                 RTS
                ;*****************************************************

                ;   SUBROUTINE TO MOVE THE NUMBER WITH ZERO-PAGE
                ; ADDRESS IN X TO THE ZERO-PAGE ADDRESS IN Y.

                ;-----------------------------------------------------

E457- B5 00     MOVEM    LDA *0,X
E459- 99 00 00           STA 0,Y
E45C- B5 01              LDA *1,X
E45E- 99 01 00           STA 1,Y
E461- B5 02              LDA *2,X
E463- 99 02 00           STA 2,Y
E466- 60                 RTS

                ;*****************************************************

                ;   CONTROL PASSES TO HERE ON RESET.  THIS CODE WAS COPIED
                ; FROM THE SYM-1 REFERENCE MANUAL.  SYSTEM RAM IS INIT-
                ; IALIZED, THE SYM IS CONFIGURED, AND THE SOIL TESTING
                ; MONITOR IS INVOKED.

                ;-----------------------------------------------------

```

```
E467- A2 FF      107 RESET      LDX #$FF
E469- 9A         108            TXS                    ;INIT STACK
                 109
E46A- A9 CC      110 POR        LDA #$CC               ;DISABLE POR, TAPE OFF
E46C- 8D 0C A0   111            STA $A00C
E46F- A9 04      112            LDA #04
E471- 48         113            PHA
E472- 28         114            PLP
E473- 20 86 8B   115            JSR $8B86              ;RAM ACCESS
                 116
E476- A2 5F      117 DFTSR      LDX #$5F
E478- BD A0 8F   118            LDA $8FA0,X            ;INIT SYSTEM RAM
E47B- 9D 20 A6   119            STA $A620,X
E47E- CA         120            DEX
E47F- 10 F7      121            BPL DFTSR+2
                 122
E481- A9 07      123            LDA #7                 ;BEEP
E483- 20 47 8A   124            JSR $8A47              ;OUTCHR
E486- 20 A3 89   125            JSR $89A3              ;KSCONF
E489- 4C 00 E7   126            JMP $E700              ;TO MONITOR
                 127
                 128 ;*****************************************************
                 129            .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

ADD =E0B7              COMP =E400             DELTAE =E414
DFTSR =E476            LOOP =E42B             MOVE =E44B
MOVEM =E457            MPY =E119              POR =E46A
READ =E000             RESET =E467            RET =E413
SUB =E0D5
//0000,E48C,108C
```

```
                    ;*******************************************************
                    ;   SUBROUTINE TO TAKE EIGHT READINGS OF THE CHANNEL IN
                    ; A AND AVERAGE THEM INTO THE ADDRESS IN X.  LOCATIONS
                    ; 01 THROUGH 06 ARE ALSO USED.
                    ;-------------------------------------------------------
                                .OS
                                .LS
                                .BA $E500
                                .MC $1000
                    READ        .DE $E000
                    ADD         .DE $E0B7
E500- 85 05         BASE        STA *05
E502- A9 08                     LDA #8              ;DO EIGHT TIMES
E504- 85 04                     STA *04
E506- A9 E0                     LDA #$E0            ;ZERO RESULT
E508- 95 00                     STA *0,X
E50A- A9 00                     LDA #00
E50C- 95 01                     STA *1,X
E50E- 95 02                     STA *2,X
E510- 86 06                     STX *06
E512- A2 01         LOOP        LDX #01             ;READ INTO SCRATCH
E514- A5 05                     LDA *05
E516- 20 00 E0                  JSR READ
E519- A6 06                     LDX *06
E51B- A0 01                     LDY #01
E51D- 20 B7 E0                  JSR ADD
E520- C6 04                     DEC *04
E522- D0 EE                     BNE LOOP
E524- A6 06                     LDX *06
E526- D6 00                     DEC *0,X
E528- D6 00                     DEC *0,X
E52A- D6 00                     DEC *0,X
E52C- 60                        RTS
                    ;*******************************************************
                    ;   THIS IS A SUBROUTINE TO FIND THE INITIAL BREAK FORCE.
                    ; A RUNNING MAXIMUM IS KEPT UNTIL THE CURRENT FORCE DROPS
                    ; MORE THAN 25% BELOW THE MAXIMUM.  ALL FORCES ARE
                    ; RELATIVE TO AN INITIAL FORCE IN $20.  NOTHING IS
                    ; CONSIDERED UNTIL THE RELATIVE FORCE IS >.2 KG.
```

```
                ;   MATHEMATICALLY, THIS DEFINITION IS:
                ; BREAK=FMAX WHEN 4((FMAX-F0)-(F-F0))>(FMAX-F0)
                ; AND (F-F0)>.2 KG
                ;   IT IS ASSUMED THAT F0, MAXFLG, FMAX, AND KG2 ARE
                ; APPROPRIATELY INITIALIZED.
                ;   THE FORCE AT WHICH TO STOP THE TEST IS ALSO
                ; CALCULATED AS A NUMBER OF FOURTHS OF FMAX

                ;----------------------------------------------------

                F0          .DE $20
                CURF        .DE $29
                FDIFF       .DE $35
                KG2         .DE $3B
                MAXFLG      .DE $3A
                FMAX        .DE $3E
                SCR1        .DE $41
                MOVE        .DE $E457
                COMP        .DE $E400             ;COMPARE ROUTNE
                SUB         .DE $E0D5
                STOPF       .DE $44
                LIM         .DE $39
                NORM        .DE $E074

E52D- A5 3A     BREAK       LDA *MAXFLG           ;SKIP IF ALREADY FOUND
E52F- D0 72                 BNE CHECK

E531- A2 29                 LDX #CURF
E533- A0 35                 LDY #FDIFF
E535- 20 57 E4              JSR MOVE              ;MOVE OPERANDS TO SCRATCH

E538- A2 20                 LDX #F0
E53A- A0 41                 LDY #SCR1
E53C- 20 57 E4              JSR MOVE

E53F- A2 35                 LDX #FDIFF
E541- A0 41                 LDY #SCR1
E543- 20 D5 E0              JSR SUB               ;F-F0

E546- A2 35                 LDX #FDIFF
E548- A0 3B                 LDY #KG2
E54A- 20 00 E4              JSR COMP              ;IF F-F0<.2 KG
E54D- 90 5F                 BCC RET               ;THEN RETURN

E54F- A2 35                 LDX #FDIFF            ;IF F-F0>FMAX-F0
E551- A0 3E                 LDY #FMAX             ;THEN REPLACE FMAX
E553- 20 00 E4              JSR COMP
E556- 90 03                 BCC ARND

E558- 20 57 E4              JSR MOVE

E55B- A2 3E     ARND        LDX #FMAX
E55D- A0 41                 LDY #SCR1
```

```
E55F- 20 57 E4                JSR MOVE

E562- A2 35                   LDX #FDIFF          ;4*ABS(F-FMAX)
E564- A0 41                   LDY #SCR1
E566- 20 D5 E0                JSR SUB
E569- E6 35                   INC *FDIFF
E56B- E6 35                   INC *FDIFF

E56D- A2 35                   LDX #FDIFF          ;IF >FMAX THEN BREAK FOUND
E56F- A0 3E                   LDY #FMAX
E571- 20 00 E4                JSR COMP
E574- 90 38                   BCC RET

E576- E6 3A                   INC *MAXFLG
E578- C6 3E                   DEC *FMAX           ;FMAX/4
E57A- C6 3E                   DEC *FMAX

E57C- A2 3E                   LDX #FMAX
E57E- A0 44                   LDY #STOPF          ;MOVE TO STOPF
E580- 20 57 E4                JSR MOVE
E583- C6 39                   DEC *LIM

E585- A2 44          ADDS     LDX #STOPF          ;ADD LIM-1 TIMES
E587- A0 3E                   LDY #FMAX
E589- 20 B7 E0                JSR ADD
E58C- C6 39                   DEC *LIM
E58E- D0 F5                   BNE ADDS

E590- A2 3E                   LDX #FMAX           ;RESTORE FMAX
E592- 20 74 E0                JSR NORM
E595- E6 3E                   INC *FMAX
E597- E6 3E                   INC *FMAX

E599- A2 44                   LDX #STOPF          ;BACK TO NON-
E59B- A0 20                   LDY #F0             ;RELATIVE
E59D- 20 B7 E0                JSR ADD
E5A0- 18                      CLC
E5A1- 90 0B                   BCC RET

E5A3- A2 29          CHECK    LDX #CURF           ;CHECK FOR STOP FORCE
E5A5- A0 44                   LDY #STOPF
E5A7- 20 00 E4                JSR COMP
E5AA- 90 02                   BCC RET

E5AC- E6 3A                   INC *MAXFLG         ;INCREMENT AGAIN

E5AE- 60             RET      RTS

                     ;*******************************************************

                     ;   SUBROUTINE TO INITIALIZE THE VARIABLES IS SCRATCHPAD
                     ; RAM.  THE A/DCONVERTER IS READ ON BOTH CHANNELS TO ALLOW
                     ; SETTLING.  THE VARIABLES INITIALIZED ARE:
```

```
                      ;  KG2= ED D8 00          MAXFLG= 00
                      ;  FMAX= E0 00 00         F0= AVG. OF 8 READINGS
                      ;  D0= AVG OF 8           PASTF= READ FROM A/D
                      ;  PASTD= READ FROM A/D   LIM FROM PLIM
                      ;  ESUM= F1 80 00         SLIM= F5 80 00
                      ;  FCONV= F2 98 70        DCONV= E7 B0 A0
                      ;  ECONV= E5 A5 18        ONE= F1 80 00

                      ;   WHEN THE INITIALIZAION IS COMPLETE, THE BEEPER IS
                      ; SOUNDED FOUR TIMES

                      ;-------------------------------------------------------

                        BEEP     .DE $8972
                        SWAP     .DE $E0AE
                        PLIM     .DE $38

E5AF- A9 07             INIT     LDA #07            ;READ BOTH CHANNELS
E5B1- A2 20                      LDX #$20
E5B3- 20 00 E5                   JSR BASE
E5B6- A9 06                      LDA #06
E5B8- A2 20                      LDX #$20
E5BA- 20 00 E5                   JSR BASE

E5BD- A2 1F                      LDX #$1F           ;DO BLOCK MOVE
E5BF- BD 06 E6          LP2      LDA TABLE-1,X      ;FROM TABLE
E5C2- 95 39                      STA *$39,X         ;OF DEFAULT VALUES
E5C4- CA                         DEX
E5C5- D0 F8                      BNE LP2

E5C7- A0 60                      LDY #$60           ;DELAY ABOUT 2 SEC
E5C9- A2 00             OUTER    LDX #0             ;TO ALLOW SETTLING
E5CB- 20 AE E0          INNER    JSR SWAP
E5CE- 20 AE E0                   JSR SWAP
E5D1- CA                         DEX
E5D2- D0 F7                      BNE INNER
E5D4- 88                         DEY
E5D5- D0 F2                      BNE OUTER

E5D7- A9 06                      LDA #06
E5D9- A2 20                      LDX #$20
E5DB- 20 00 E5                   JSR BASE           ;READ F0

E5DE- A9 06                      LDA #06
E5E0- A2 23                      LDX #$23
E5E2- 20 00 E0                   JSR READ           ;GET PASTF

E5E5- A9 07                      LDA #07
E5E7- A2 32                      LDX #$32
E5E9- 20 00 E5                   JSR BASE           ; READ D0

E5EC- A9 07                      LDA #07
E5EE- A2 26                      LDX #$26
```

```
E5F0- 20 00 E0             JSR READ             ; READ PASTD

E5F3- A9 06                LDA #06              ;ALWAYS READ F
E5F5- A2 00                LDX #0               ;AFTER D
E5F7- 20 00 E0             JSR READ

E5FA- A5 38                LDA *PLIM
E5FC- 85 39                STA *LIM             ;INITIALIZE LIM

E5FE- A2 04                LDX #04
E600- 20 72 89    LPB      JSR BEEP             ;GIVE TONE SIGNAL
E603- CA                   DEX
E604- D0 FA                BNE LPB

E606- 60                   RTS

E607- 00          TABLE    .BY $00              ;MAXFLG
E608- ED 80 00             .BY $ED $80 $00 ;KG2
E60B- E0 00 00             .BY $E0 $00 $00 ;FMAX
E60E- 00 00 00             .BY $00 $00 $00
E611- E0 00 00             .BY $E0 $00 $00 ;STOPF
E614- F1 80 00             .BY $F1 $80 $00 ;SUM E
E617- F5 80 00             .BY $F5 $80 $00 ;STRESS LIMIT
E61A- F2 98 70             .BY $F2 $98 $70 ;FCONV=2.3818 KG/CT
E61D- E7 B0 A0             .BY $E7 $B0 $A0 ;DCONV=.0013475 CM/CT
E620- E5 A5 18             .BY $E5 $A5 $18 ;ECONV=.0003149 J/CT
E623- F1 80 00             .BY $F1 $80 $00 ;ONE=1

                  ;**********************************************************

                  ;   SUBROUTINE TO DO A COMPRESSION TEST.  THE ZERO-
                  ; PAGE VARIABLES ARE INITIALIZED AND THE CRUSHING ENERGY
                  ; IS INTEGRATED.  THE CURRENT FORCE IN KILOGRAMS IS DIS-
                  ; PLAYED.  WHEN THE BREAK FORCE IS FOUND, THE UPPER SEG-
                  ; MENT OF THE RIGHTMOST DISPLAY DIGIT IS LIT.  THE TEST
                  ; IS ENDED WHEN THE FORCE PASSES THE STOP FORCE.
                  ; PRESSING ANY KEY ON THE HEX KEYBOARD ABORTS THE TEST.
                  ; IF THE FORCE PASSES ABOUT 40 KG, THE BEEPER IS SOUNDED
                  ; EACH TIME THROUGH THE SAMPLE LOOP BUT THE TEST CONTINUES

                  ;----------------------------------------------------------

                  EDEL     .DE $2F
                  ESUM     .DE $47
                  DELTAE   .DE $E414
                  FCONV    .DE $4D
                  MPY      .DE $E119
                  SCAND    .DE $8906
                  INSTAT   .DE $8386
                  CONV     .DE $E200
                  PASTF    .DE $23
                  KG40     .DE $4A
                  ONE      .DE $56
```

```
                 CURD      .DE $2C
                 DO        .DE $32
E626- 20 AF E5   TEST      JSR INIT         ;INITIALIZE VARS
E629- 20 14 E4   AGN       JSR DELTAE       ;GET ENERGY CHANGE
E62C- A2 47                LDX #ESUM
E62E- A0 2F                LDY #EDEL
E630- A5 00                LDA *00
E632- D0 06                BNE NEG          ;GO ARND IF NEGATIVE
E634- 20 B7 E0             JSR ADD          ;SUM UP
E637- 18                   CLC
E638- 90 03                BCC OVER
E63A- 20 D5 E0   NEG       JSR SUB          ;SUBTRACT NEGATIVE
E63D- 20 2D E5   OVER      JSR BREAK
E640- A2 29                LDX #CURF        ;CONVERT TO KG
E642- A0 4D                LDY #FCONV
E644- 20 19 E1             JSR MPY
E647- A9 03                LDA #03          ;DISPLAY CURRENT F
E649- 85 00                STA *00
E64B- A2 29                LDX #CURF
E64D- 20 00 E2             JSR CONV
E650- A5 3A                LDA *MAXFLG
E652- C9 02                CMP #2           ;TEST DONE IF BREAK
E654- F0 22                BEQ END          ;RETURNS 2 IN MAXFLG
E656- 8D 45 A6             STA $A645        ;INDICATE BREAK FOUND
E659- A9 10                LDA #$10
E65B- 85 FF                STA *$FF         ;DISPLAY COUNTER
E65D- 20 06 89   DISP      JSR SCAND
E660- D0 13                BNE ABORT        ;GO IF KEY PRESSED
E662- C6 FF                DEC *$FF
E664- D0 F7                BNE DISP
E666- A2 23                LDX #PASTF
E668- A0 4A                LDY #KG40
E66A- 20 00 E4             JSR COMP         ;FORCE TOO BIG?
E66D- 90 03                BCC SKIP         ;GO IF OK
E66F- 20 72 89             JSR BEEP         ;WARN IF BIG
E672- 18         SKIP      CLC              ;DO AGAIN
E673- 90 B4                BCC AGN
E675- 20 86 83   ABORT     JSR INSTAT       ;DEBOUNCE KEY
E678- A2 47      END       LDX #ESUM        ;SUBTRACT INITIAL
E67A- A0 56                LDY #ONE         ;ENERGY
E67C- 20 D5 E0             JSR SUB
```

```
E67F- A2 2C                LDX #CURD          ;NEED TO SUBTRACT
E681- A0 32                LDY #D0            ;F0*(FINALD-D0)
E683- 20 D5 E0             JSR SUB            ;FINALD-D0

E686- A2 2C                LDX #CURD
E688- A0 20                LDY #F0
E68A- 20 19 E1             JSR MPY            ;MULTIPLY

E68D- A2 47                LDX #ESUM
E68F- A0 2C                LDY #CURD
E691- 20 D5 E0             JSR SUB            ;TAKE AWAY

E694- A2 03                LDX #03            ;SIGNAL END
E696- 20 00 E6             JSR LPB

E699- 60                   RTS

                    ;*****************************************************
                           .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

ABORT =E675          ADD =E0B7            ADDS =E585
AGN =E629            ARND =E55B           BASE =E500
BEEP =8972           BREAK =E52D          CHECK =E5A3
COMP =E400           CONV =E200           CURD =002C
CURF =0029           D0 =0032             DELTAE =E414
DISP =E65D           EDEL =002F           END =E678
ESUM =0047           F0 =0020             FCONV =004D
FDIFF =0035          FMAX =003E           INIT =E5AF
INNER =E5CB          INSTAT =8386         KG2 =003B
KG40 =004A           LIM =0039            LOOP =E512
LP2 =E5BF            LPB =E600            MAXFLG =003A
MOVE =E457           MPY =E119            NEG =E63A
NORM =E074           ONE =0056            OUTER =E5C9
OVER =E63D           PASTF =0023          PLIM =0038
READ =E000           RET =E5AE            SCAND =8906
SCR1 =0041           SKIP =E672           STOPF =0044
SUB =E0D5            SWAP =E0AE           TABLE =E607
TEST =E626
//0000,E69A,119A
```

```
                 ;*******************************************************
                 
                 ;   MONITOR PROGRAM TO DRIVE SOIL TESTING MACHINE.
                 ; AFTER INITIALIZATION, THE KEYBOARD IS SCANNED FOR
                 ; COMMANDS.  THE COMMAND TO BE EXECUTED IS DETERMINED
                 ; AND THE FUNCTION PREFORMED.  CONTROL IS THEN PASSED
                 ; BACK TO THE SCAN.  THE SYM MONITOR I/O ROUTINES ARE
                 ; USED.  THE FUNCTIONS AVAILABLE ARE:
                 ;   DISPLAY INITIAL FORCE
                 ;   DISPLAY INITIAL DISPLACEMENT
                 ;   DISPLAY FINAL FORCE
                 ;   DISPLAY FINAL DISPLACEMENT
                 ;   DISPLAY BREAKING FORCE
                 ;   DISPLAY ENERGY INTEGRAL
                 ;   CHANGE PLIM TO ADJUST STOP FORCE
                 ;   PERFORM COMPRESSION TEST
                 ;   SET THE DISPLACEMENT TRANSDUCER
                 ;   JUMP TO SYM MONITOR
                 
                 ;-------------------------------------------------------
                 
                            .OS
                            .LS
                            .BA $E700
                            .MC $1000
                 
                 INIT       .DE $E5AF
                 PLIM       .DE $38
                 DISBUF     .DE $A640
                 ACCESS     .DE $8B86
                 GETKEY     .DE $88AF
                 FCONV      .DE $4D
                 DCONV      .DE $50
                 PASTD      .DE $26
                 PASTF      .DE $23
                 FMAX       .DE $3E
                 ESUM       .DE $47
                 ECONV      .DE $53
                 DIGIT      .DE $E341
                 SCR1       .DE $41
                 MPY        .DE $E119
                 CONV       .DE $E200
                 SCAND      .DE $8906
                 F0         .DE $20
                 D0         .DE $32
                 TEST       .DE $E626
                 READ       .DE $E000
                 MOVE       .DE $E457
                 RESET      .DE $E467
                 
E700- 20 86 8B   SOIL       JSR ACCESS           ;ACCESS TO RAM
E703- A2 06                 LDX #06              ;WRITE START-UP
E705- BD 42 E7   LP3        LDA MESSGE-1,X       ;MESSAGE
```

```
E708- 9D 3F A6          STA DISBUF-1,X
E70B- CA                DEX
E70C- D0 F7             BNE LP3

E70E- A9 06             LDA #06
E710- 85 38             STA *PLIM           ;INITIALIZE PLIM
E712- 20 AF E5          JSR INIT            ;INITIALIZE  RAM

E715- 20 AF 88  MAIN    JSR GETKEY          ;SCAN AND POLL

E718- C9 43             CMP #'C'            ;DETERMINE COMMAND
E71A- F0 2D             BEQ DISPF0          ;INIT F

E71C- C9 44             CMP #'D'
E71E- F0 30             BEQ DISPD0          ;INIT D

E720- C9 45             CMP #'E'
E722- F0 33             BEQ DISPFF          ;FINAL F

E724- C9 46             CMP #'F'
E726- F0 36             BEQ DISPFD          ;FINAL D

E728- C9 38             CMP #'8'
E72A- F0 39             BEQ DISBRK          ;BREAK FORCE

E72C- C9 39             CMP #'9'
E72E- F0 3C             BEQ DISPE           ;ENERGY  INTEGRAL

E730- C9 41             CMP #'A'
E732- F0 41             BEQ CHANGE          ;CHANGE PLIM

E734- C9 42             CMP #'B'
E736- F0 61             BEQ SAMPLE          ;DO TEST

E738- C9 34             CMP #'4'
E73A- F0 63             BEQ SET             ;SET TRANSDUCER

E73C- C9 35             CMP #'5'
E73E- D0 D5             BNE MAIN
E740- 4C 4A 8B          JMP $8B4A           ;TO SYM MONITOR

E743- 6D 3F 06  MESSGE  .BY $6D $3F $06 $38 $00 $06
E746- 38 00 06

E749- A2 20     DISPF0  LDX #F0
E74B- A0 4D             LDY #FCONV          ;SET UP TO DISPLAY F0
E74D- 4C C9 E7          JMP PUTOUT          ;GO DISPLAY AND RETURN

E750- A2 32     DISPD0  LDX #D0             ;SETUP TO DISPLAY D0
E752- A0 50             LDY #DCONV          ;IN CM
E754- 4C C9 E7          JMP PUTOUT

E757- A2 23     DISPFF  LDX #PASTF          ;END FORCE FOUND HERE
```

```
E759- A0 4D              LDY #FCONV       ;IN KG
E75B- 4C C9 E7           JMP PUTOUT
E75E- A2 26     DISPFD   LDX #PASTD       ;END DISP
E760- A0 50              LDY #DCONV       ;IN CM
E762- 4C C9 E7           JMP PUTOUT
E765- A2 3E     DISBRK   LDX #FMAX        ;BREAK FORCE
E767- A0 4D              LDY #FCONV       ;IN KG
E769- 4C C9 E7           JMP PUTOUT
E76C- A2 47     DISPE    LDX #ESUM        ;ENERGY INTEGRAL
E76E- A0 53              LDY #ECONV       ;IN JOULES
E770- A9 04              LDA #04          ;TO 4 PLACES
E772- 4C CB E7           JMP PUTOUT+2
E775- A6 38     CHANGE   LDX *PLIM        ;DISPLAY OLD
E777- BD 41 E3           LDA DIGIT,X
E77A- 09 80              ORA #$80         ;PUT ON PT.
E77C- 8D 45 A6           STA $A645
E77F- 20 AF 88           JSR GETKEY       ;CHANGE TO WHAT
E782- 38                 SEC
E783- E9 30              SBC #$30         ;ASCII CONVERT
E785- C9 04              CMP #04          ;TEST FOR LEGAL RANGE
E787- 30 EC              BMI CHANGE       ;IGNORE ILLEGAL
E789- C9 0A              CMP #$0A         ;LEGAL= 4 TO 9
E78B- 10 E8              BPL CHANGE
E78D- 85 38              STA *PLIM        ;MAKE CHANGE
E78F- AA                 TAX
E790- BD 41 E3           LDA DIGIT,X      ;ECHO IN DISPLAY
E793- 8D 45 A6           STA $A645
E796- 4C 15 E7           JMP MAIN
E799- 20 26 E6  SAMPLE   JSR TEST         ;PERFORM TEST
E79C- 4C 15 E7           JMP MAIN
E79F- A9 07     SET      LDA #07          ;CONTINUOUS DISPLAY
E7A1- A2 41              LDX #SCR1
E7A3- 20 00 E0           JSR READ         ;OF DISP
E7A6- A2 41              LDX #SCR1        ;IN CM
E7A8- A0 50              LDY #DCONV
E7AA- 20 19 E1           JSR MPY
E7AD- A9 03              LDA #03          ;TO 3 PLACES
E7AF- 85 00              STA *00
E7B1- A2 41              LDX #SCR1
E7B3- 20 00 E2           JSR CONV
```

```
E7B6- A9 10                 LDA #$10          ;DISPLAY DRIVE
E7B8- 85 FF                 STA *$FF
E7BA- 20 06 89    DLOOP     JSR SCAND
E7BD- D0 07                 BNE ARND          ;KEY PRESSED?
E7BF- C6 FF                 DEC *$FF
E7C1- D0 F7                 BNE DLOOP
E7C3- 4C 9F E7              JMP SET

E7C6- 4C 15 E7    ARND      JMP MAIN          ;DONE

E7C9- A9 03       PUTOUT    LDA #03           ;DEFAULT 3 PLACES
E7CB- 48                    PHA
E7CC- 98                    TYA
E7CD- 48                    PHA
E7CE- A0 41                 LDY #SCR1         ;MOVE TO SCRATCH
E7D0- 20 57 E4              JSR MOVE

E7D3- 68                    PLA
E7D4- A8                    TAY
E7D5- A2 41                 LDX #SCR1
E7D7- 20 19 E1              JSR MPY           ;UNIT CONVERSION

E7DA- 68                    PLA
E7DB- 85 00                 STA *00           ;FILL DISPLAY
E7DD- 20 00 E2              JSR CONV
E7E0- 4C 15 E7              JMP MAIN

E7E3- FF FF FF              .BY $FF $FF $FF $FF $FF $FF $FF $FF $FF
E7E6- FF FF FF
E7E9- FF FF FF
E7EC- FF FF FF              .BY $FF $FF $FF $FF $FF $FF $FF $FF $FF
E7EF- FF FF FF
E7F2- FF FF FF
E7F5- FF FF FF              .BY $FF $FF $FF $FF $FF $FF $FF
E7F8- FF FF FF
E7FB- FF

E7FC- 67 E4                 .SE RESET         ;CHANGE RESET VECTOR

                  ;*****************************************************
                            .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

ACCESS =8B86          ARND =E7C6           CHANGE =E775
CONV =E200            D0 =0032             DCONV =0050
DIGIT =E341           DISBRK =E765         DISBUF =A640
DISPD0 =E750          DISPE =E76C          DISPF0 =E749
DISPFD =E75E          DISPFF =E757         DLOOP =E7BA
ECONV =0053           ESUM =0047           F0 =0020
FCONV =004D           FMAX =003E           GETKEY =88AF
INIT =E5AF            LP3 =E705            MAIN =E715
```

MESSGE =E743	MOVE =E457	MPY =E119
PASTD =0026	PASTF =0023	PLIM =0038
PUTOUT =E7C9	READ =E000	RESET =E467
SAMPLE =E799	SCAND =8906	SCR1 =0041
SET =E79F	SOIL =E700	TEST =E626

//0000,E7FE,10FE

APPENDIX D

OPERATING INSTRUCTIONS

INTRODUCTION

This machine measures the energy required to crush soil samples as a first step in evaluating dry soil aggregate stability by an energy method. The system is sketched in Figure D.1.

Once the test is started, the computer periodically measures the force on the crushing platform and the displacement of the crushing plate. The force X displacement product is numerically integrated to find the total crushing energy. Measurements are taken many times per second so even small changes are detected. The force at which the sample first fractures is also recorded.

A typical crushing process plotted on force and displacement axes might look like Figure D.2.

The pertinent features on the graph are defined as follows:

F_o is the initial force on the platform due to the weights of the platform and sample.

D_o is the relative displacement of the crushing plate from its zero at the beginning of the test.

F_f is the force on the platform at the end of the test.

D_f is the relative displacement of the crushing plate from its zero at the end of the test.

The break force is defined as the force from which the force on the sample first drops 25 percent. This is shown on figure D.2.

The crushing energy is denoted by the shaded area.

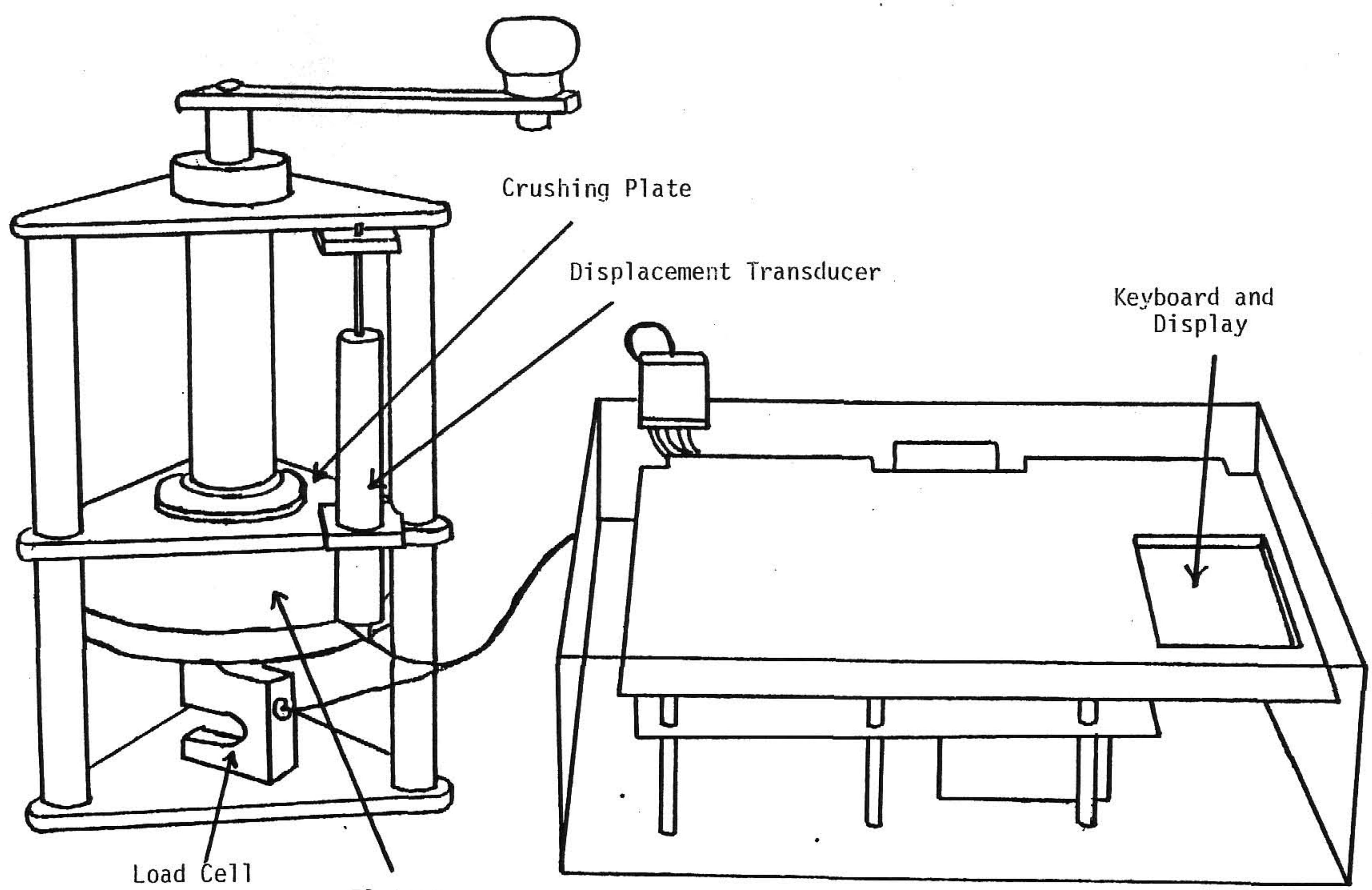


Figure D.1.

Sketch of SACEM System

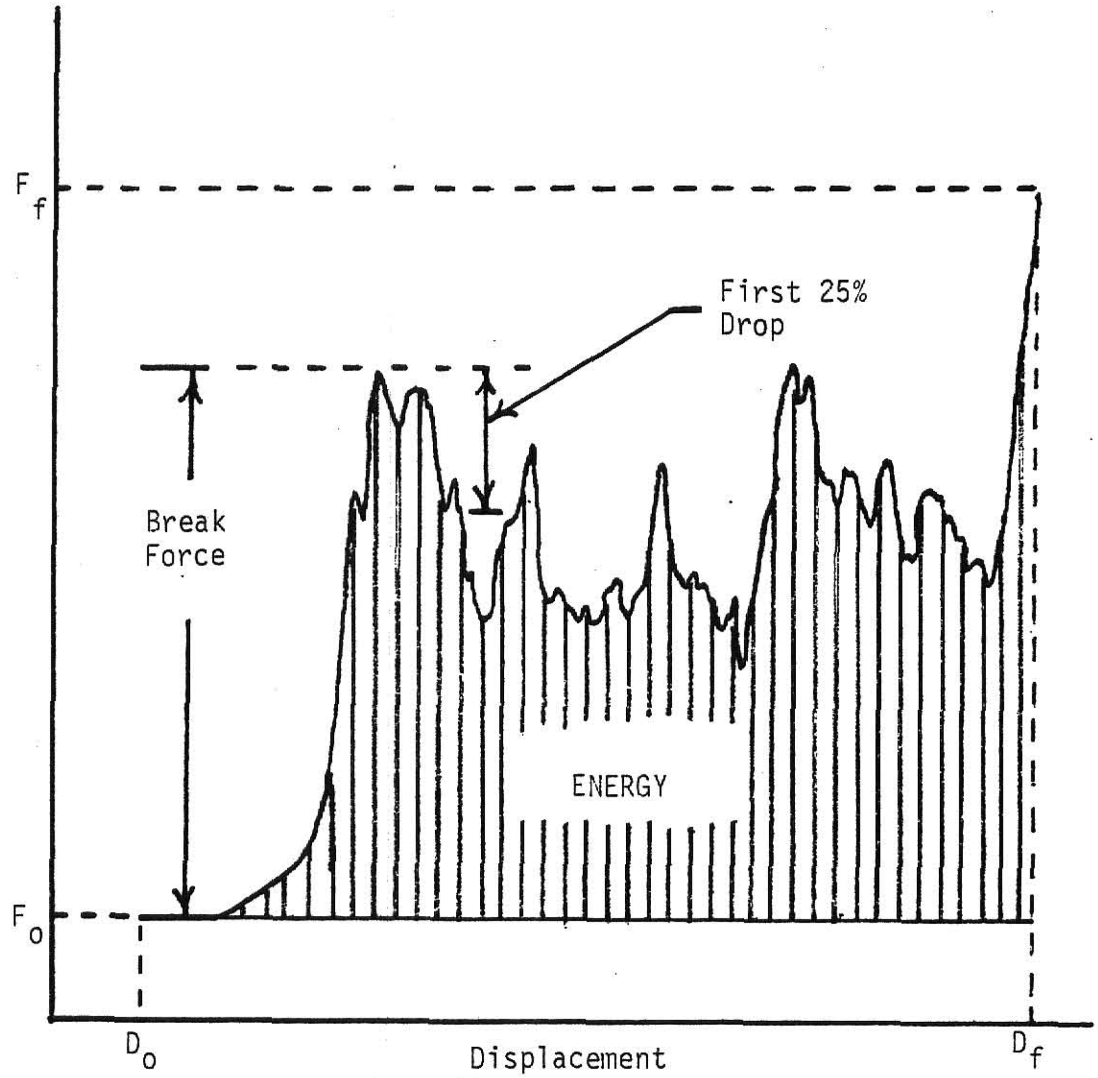


Figure D.2

Typical Soil Crushing Curve

OPERATION

The simplest method of testing is using the hand crank drive on the crushing vise. This is the configuration shown in Figure D.1. The instruments must be connected to the computer module through the connector provided and the computer module must be plugged into a standard 110 V outlet.

When power is supplied to the computer module, a short beep is sounded. After a delay of about two seconds (the computer uses this time for initialization), another tone is heard and the computer displays the message SOIL 1. The system is then ready for commands to be entered. Commands consist of single keystrokes. The computer responds immediately to each. The layout of the keyboard is shown in Figure D.3.

The first command used will probably be the [CURR DISP] command. This instructs the system to display the current displacement of the crushing plate in centimeters. This function is provided to allow the displacement transducer to be adjusted to its proper position on the vise. To do this, gently close the vise until the crushing plate and the platform touch. There should be nothing between the plates during this procedure. When the plates are touching, press the [CURR DISP] key. The value displayed should be between 2.40 and 2.50. If the value displayed is between 2.40 and 2.50 no adjustment is required. Pressing any other key will exit the command. If the display is not between 2.40 and 2.50 the displacement transducer must be adjusted as described below.

The displacement transducer can be adjusted in either of two different places. The connection to the top plate of the vise provides some adjustment. If that is not enough, the body of the transducer can be moved in its attachment to the crushing plate. The clamp must be loosened with an Allen wrench.

		RESET	
F_o	D_o	F_f	D_f
8 BREAK FORCE	9 ENERGY	CHANGE STOPF	RUN TEST
4 CURR DISP	5 SYM MON	6	7

Figure D.3

Keyboard Layout

Once the transducer is positioned, the system is ready to perform a test. The sample to be tested should be placed as nearly as possible in the center of the platform. It is important that the sample not be more than 2.4 cm high. If the sample is larger than this, erroneous readings may result.

When the sample is positioned and the vise is ready, press the [RUN TEST] key. The display will go dark for about two seconds while the system is initialized, and then a tone will be sounded. Once the tone has sounded, the test is underway. The test may be aborted at any time by pressing any key on the keyboard.

The number displayed during the test is the current force on the platform in kilograms. This includes the weights of the platform and sample. Turning the hand crank counterclockwise will cause the crushing to start. The crank should be turned fairly slowly. To obtain a crushing speed of 10 mm/min as has been used in other work, each revolution of the crank must take about eight seconds.

When the initial break of the sample occurs, the upper element of the rightmost display digit is lighted as an indicator. When the break is found, the stop force is calculated as 1.5 times the break force. This relation can be changed.

As crushing continues, the force is compared with the calculated stop force. When the stop force is reached, a tone is sounded and sampling of the force and displacement is halted. Crushing should be stopped immediately.

It is possible that in some cases no break force is detected and thus no stop force is calculated. If this happens, there will be no signal to indicate the end of the test. In this event, crushing should be stopped as soon as it becomes obvious that the test has gone awry. If crushing is not stopped, it is possible that the vise could be damaged due to too high a crushing force. The computer is programmed to warn the operator with a series of tones when the force gets dangerously high. If this happens, the test should immediately be stopped by pressing a key on the keypad and crushing should be stopped.

Once the test is ended, either by a keypress or because the stop force has been passed, several of the important values from the test can be recalled by commands from the keyboard. The quantities available are those defined on Figure D.2. For example, to find the force at which the sample broke, press the [BREAK FORCE] key. The value is displayed immediately in units of kilograms. When all the desired readings have been recorded, a new test may be started.

CHANGING THE STOP FORCE

A special command is provided to change the method of calculating the stop force. Whenever the computer is powered up or the [RESET] key is pressed, the factor for calculating the stop force from the break force is set to 1.5. This factor can be changed to any multiple of .25 between 1.0 and 2.25. To change it, press the [CHANGE STOPF] key. A number followed by a decimal point will appear in the rightmost digit of the display. This number indicates the current factor for calculating the stop force. The decimal point indicates that the computer is waiting for a new number to be keyed in.

The number is four times the stopping factor. For example, if a 7. appears, the current stopping factor is 1.75. To enter a new factor, press any key marked with a number between four and nine. Since the computer is expecting a number, any command associated with the key will not be executed. When a legal number has been entered, the new number appears in the display and the decimal point disappears to indicate that the change has been made. Any keys other than those marked with numbers four through nine are ignored.

ENTERING THE SYM MONITOR

The one remaining command allows the SYM computer monitor to be invoked. The system powers up to the soil testing monitor, but pressing the [SYM MON] key will cause the SYM monitor to be entered. This allows all the capabilities of the SYM to be used. This is useful for testing any suspect hardware or software associated with the soil tester. Short routines may be written in RAM to exercise the section in question.

Anyone interested in using this feature should refer to the SYM-1 Reference Manual and the SYM-1 Programming Manual. An RS-232C connector is provided on the computer module to allow use of a CRT terminal. The computer is also supplied with a BASIC language. This is described fully in the Synertek BASIC Reference Manual.

COMMAND SUMMARY

This is a listing of all the keyboard commands and brief descriptions of their functions.

RESET Resets the computer. This is equivalent to disconnecting the power and powering back up. All data are lost and the system is re-initialized.

CURR DISP Continually displays the current displacement of the crushing plate in centimeters. This is useful for positioning the crushing plate before a test and for adjusting the displacement transducer as described above. Pressing any other key exits the command.

RUN TEST Starts a crushing test. It is assumed that the vise is properly set up. The current platform force in kilograms is displayed continually during the test. If the force gets too high (about 40 kg) the beeper is sounded each time the force and displacement are sampled but the test continues. When the break force has been detected, the upper element of the rightmost display digit is also lighted. The stop force is calculated from the break force. When the stop force is passed, the beeper is sounded and control passes back to the monitor.

F_o Displays the force that was on the platform at the beginning of the last test run. If no test has been run, this is the force at the time the system was powered up. This reading includes the weights of the platform and sample.

D_o Displays the displacement of the crushing plate at the beginning of the last test run. If no test has been run, this is the displacement at the time the system was powered up. The units of the reading are centimeters.

F_f Displays the force on the platform including the weights of the platform and sample, at the end of the past test run. If no test has been run, this is equal to F_o. The units are kilograms.

D_f Displays the displacement of the crushing plate at the end of the last test run. If no test has been run, this is equal to D_o. The units are centimeters.

BREAK FORCE Displays the force in kilograms at which the sample first fractured during the last test run. The weights of the platform and sample are not included. If no test has been run this value is zero. If no break was detected during the last test, this is equal to F_f-F_o.

ENERGY Displays the energy integral generated during the last test run. The value is in Joules. The effects of the platform and sample weights have been taken out. If no test has been run, this value is zero.

CHANGE STOPF Allows changing the method of calculating the force at which to stop the test. The force is determined from the break force. When the force on the sample is large enough relative to the break force, the test is stopped. On power up the relation is set so that the stop force is 1.5 times the break force. This factor can be changed to any multiple of 0.25 between 1.0 and 2.25. When the command is entered, a number equal to four times the current factor appears in the right most digit of the display followed by a decimal point. The decimal point indicates that the computer is waiting for a new number to be entered. A key marked with a number between four and nine must then be pressed. The new number (four times the new stopping factor) then appears in the display and the decimal point disappears to indicate that the change has been made.

SYM MON Causes a cold start of the SYM monitor. All of the SYM capabilities are available for use. Complete instructions for the SYM computer can be found in the SYM-1 Reference Manual.

RUNNING PARALLEL TESTS WITH THE INSTRON

The crushing vise may be mounted in the Instron testing machine. This allows both machines to measure the same sample for calibration purposes and to enhance the output capabilities of the Instron. One extra fitting is required. The parallel system is sketched in Figure D.4. The crank drive must be removed from the vise and the adapter shaft threaded into its place.

The upper end of the adapter fits into the load cell fitting on the Instron. The crushing motion is generated by the crosspiece of the Instron so it is important that the operator be careful not to exceed the force limit of the vise. A headless bolt may also be threaded into the adapter shaft instead of mounting it on the load cell fitting. This allows the vise to be mounted in a drill press or other machine to generate the crushing motion.

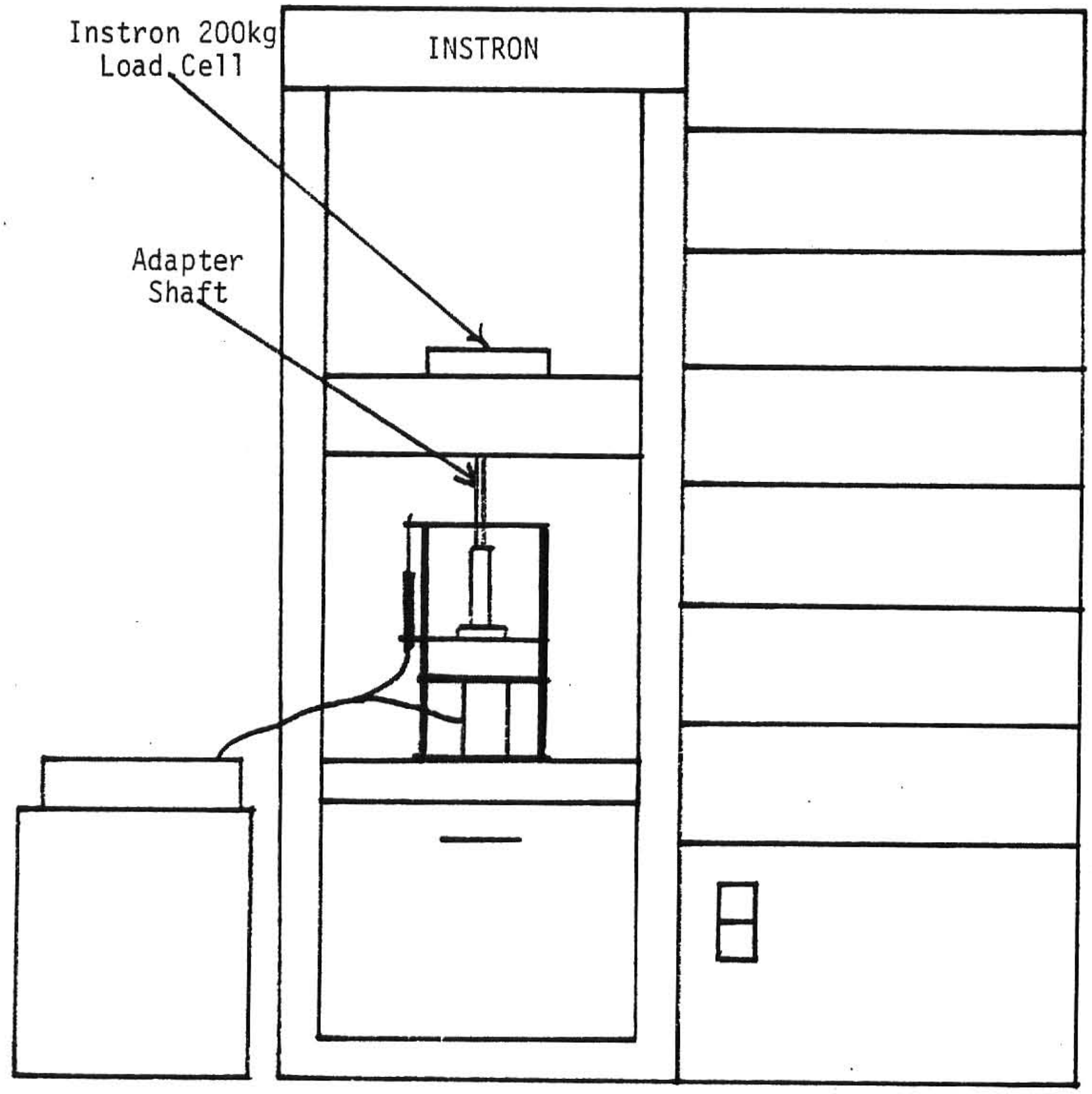


Figure D.4

Running Parallel Tests with the Instron

VITA

David W. Boyd

Candidate for the Degree of

MASTER OF SCIENCE

Thesis: A Soil-Aggregate Crushing-Energy Meter

Major Field: Mechanical Engineering

Biographical:

Personal Data: Born in Belleville, Kansas, February 13, 1959, the son of Mr. & Mrs. Joseph A. Boyd.

Educational: Graduated from Trego Community High School in May, 1977. Received a Bachelor of Science degree in Mechanical Engineering from Kansas State University in May, 1981. Completed the requirements for the Master of Science degree in Mechanical Engineering at Kansas State University in May, 1982.

A SOIL-AGGREGATE CRUSHING-ENERGY METER

by

DAVID WAYNE BOYD

B.S. Kansas State University, 1981

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering
KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Soil aggregate stability is an important measurement in determining soil properties. One current method of evaluating soil aggregate stability involves measuring the energy required to crush a soil aggregate and the new surface area generated. The purpose of this work was to develop a new technique for measuring the energy of crushing. Criteria for the improved system were that the system 1) measure the energy quickly and accurately, 2) provide a digital readout in the proper units, 3) perform tests both independently and in parallel with existing equipment, 4) record the force on the sample at its initial fracture, and 5) be portable. The system developed consists of two basic parts. A small crushing vise was constructed which can be hand driven or mounted in existing test equipment. A computer module measures the force on the sample and the displacement more than 20 times per second using a load cell and displacement transducer mounted on the vise. The force-displacement product is numerically integrated using a trapezoidal algorithm to find the crushing energy. The entire system fits easily into a carrying case about the size of a small suitcase. The design criteria were met and measurements taken by the new system showed excellent agreement with previous methods.