Development of Instrumentation for Acoustic Emission Testing

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1. General description

In recent years, many authours have studied Acoustic Emissions (AEs) of rocks under high pressure from the view point of seismology.

The source mechanism and source parameters of AEs have been studied by Hirasawa and Yamamoto (1982), Ohnaka and Mogi (1981, 1982), Kusunose et al. (1980). The main results are as follows : (1) The source mechanism of AEs must be shear-type cracks. (2) The b-valve of AEs calculated by the distribution of maximum amplitudes decreases in the final stage of rock failure. (3) The predominant frequency of AE waves occurred just before rock failure became higher (Kusunose et al., 1980) or lower (Ohnaka and Mogi, 1981, 1982). These experiments had been done under constant rate of stress increase or under constant high stress.

Sano et al. (1982) studied the b-value using a servo controlled testing machine. They showed that under constant rate of axial strain increase the AE event count rate increased exponentially and the b-value decreased with stress. They also found that under constant rate of dilatant strain increase the AE event count rate and the b-value depend only upon the dilatant strain rate and the b-value is in inverse proportion to the dilatant strain rate. They suggested that the b-value must be one of the most useful precursor of rock failure.

Many results on AEs show that there may be analogy between AEs and earthquakes even though there is quite a difference in deformation. We will take the view that there is analogy between AEs and earthquakes and, in this spirit, we will discuss the source mechanism of AEs. In this paper, we describe the method and the instrument for our experiments.

2. Environment of instruments for experiment

In our experiment, it is necessary to take and store real-time data at constant time interval and at random instance whenever an AE bursts. It is also important to control stress or strain condition of a rock sample by using a computer. All requirements must be considered when constructing the new system which includes with softwares (AETHV2, XYPRE, DRCPBK, SELPBD) and a hardware (HRMTS-01) which connects a minicomputer PDP 11/10 to a servo testing machine MTS Model-450 and instruments for acoustic emission testing.

The PDP11/10 in our laboratory is operated under RT-11 Operating System which can run user's FORTRAN program with some device handlers. It is useful for us to use the RTS module provided in the PDP11/10 to take analog data and to send reference voltages to the MTS-450.

The transient recorder 610B, one of the acoustic emission testing instruments, converts analog AE waves to degital data with 6-bit resolution and maximum 10MHz word rate, and stores 256 data. The 610B can be controlled externally by command signals and outputs analog and degital data stored in it's memory.

Once an AE occurs, the 610B starts to record, and sends data throgh a channel which is used for recording stress and strain at a constant interval. The DR11-C, a general-purpose interface between the PDP11/10 and a user's device, could be used to transfer digital data in the 610B. But the maximum data rate through the DR11-C is too slow for this purpose.

The followings are basically designed for the new system.

(1) The RTS module with a completion routine will be used for taking and storing analog data and for controlling the MTS-450.

(2) High resolution reference voltages for the MTS-450 will be produced by a 16 bit D/A converter.

(3) AE event count must be collected, displayed and transfered to the PDP11/10 with a three-digit number.

(4) AE wave data stored in the 610B memory must be converted to analog data with suitable interval to fit the frequency response of an analog data-recorder.

(5) Some safety functions for the MTS-450 must be considered.

3. Hardware description on the HRMTS-0 l

The HRMTS-01 is in a small box. In the front pannel of it, there are three-digit number indicator for AE event count, one-digit number indicator for ISTAT, a pair of LEDs (green and red) for mode of operation of the HRMTS-01 and two BNC connectors for input signal from AE-amplifier (right) and signal output of the 16 bit D/A converter (left). Two interface cables # 1 and # 2 with Berg headers coming out from the DR11-C in the PDP11/10 join Berg pin connectors # 1 and # 2, respectively, in the rear pannel of this box. Signals to or from the 610B pass through a round connector. Analog AE wave data through the HRMTS-01 come out from the D-style 25 pin connector.

The power source of the HRMTS-01 is AC115V, 60Hz provided from power box of the PDP11/10 through a noise delimitater.

The HRMTS-01 is composed of 8 circuit blocks. The following discussion is provided to aid in understanding the invidual circuit.

(1) Triggering system (Fig.1-A)

The system produces a pulse with about 0.5ms TTL-level (TRGo) when AE signals applied to the BNC input connector exceed a preset value of a threshold voltage (VTh). The VTh can be changed from 0 to 120mv by using a trimmer resistance on the circuit board. The maximum range of AE signals must be between −5v to +5v. The input resistance at the BNC connector is about 20kohm.

(2) Command generator (Fig.1-B)

This block produces commands for the 610B, that is, an external trigger (TRG) synchronized with TRGo to hold data in it's memory, word command signals (WDC) to pull out a next word data from the memory to the buffer and an external arm signal (ARM) to prepare the 610B enable for the next TRG. The train of WDC signals start at the negative going edge of TRG and continue for lsec. generating WDC-pluse with 4ms interval, so that 250 data come out from memory of the 610B. The 4ms time interval is provided by divide-by-four operation using 1kHz generator in the Display controller. The TRG, WDC and ARM commands are enable when ISTAT in the AETHV2 is 1 or 2.

(3) External analog converter for the 610B (Fig.1-C)

This part produces analog voltages synchronized to the buffer of the 610B. The A1 (MSB) and A2 of digital inputs of each D/A converter are grounded, because this part uses 8 bit D/A converters and the resolution of the 610B is 6 bit. The analog outputs are buffered by operational amplifiers with zero-trimming and smoothing circuits. A test for each D/A converter can be done by using each BCD rotary switch.

(4) AE Event counter (Fig.1-D)

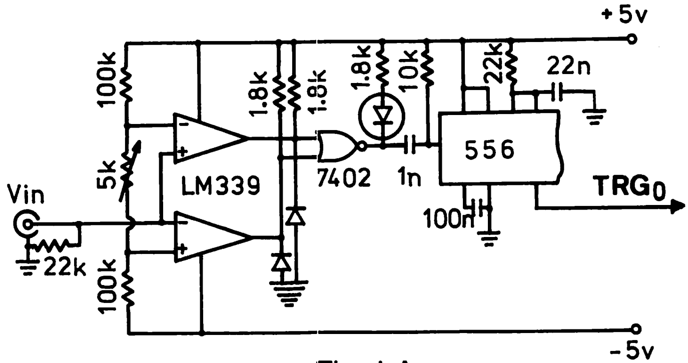
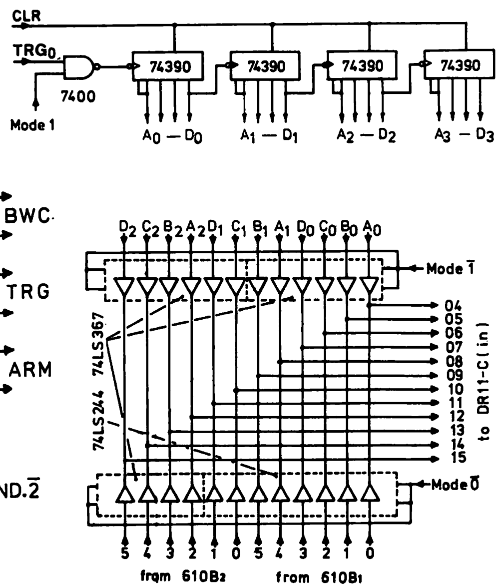


Fig. 1-A



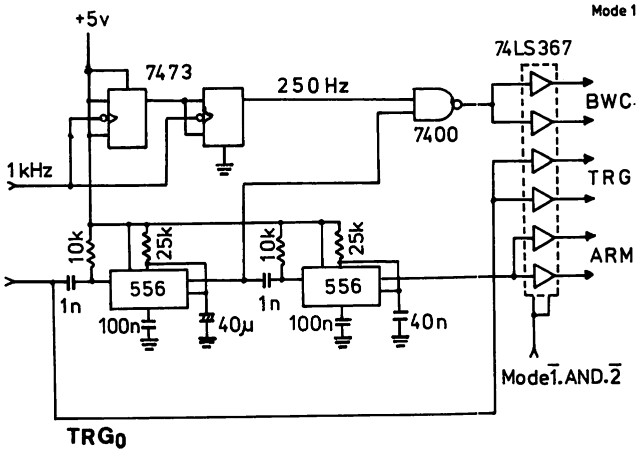


Fig. 1-B

Fig. 1-D

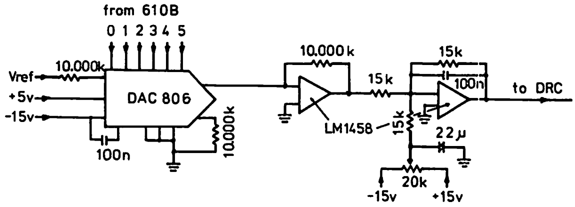


Fig. 1-C

Fig.1-A : Triggering system. *Resisters and capacitors are written in : ohm and farad, respectively.

Fig.1-B : Command generator for two transient recorders 610B-1 and 610B-2.

Fig.1-C : External analog converter for each 610B.

Fig.1-D : AE-Event counter, and its output bus lines to DR11-C and Doo's mode connection between 610B and DR11-C.

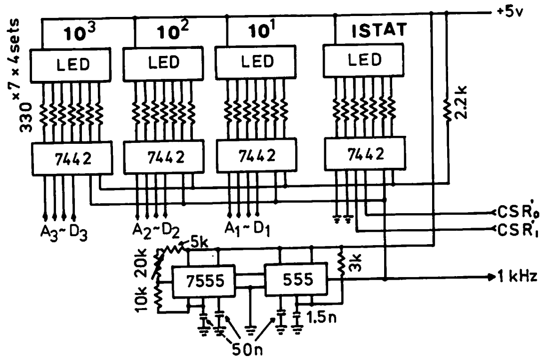


Fig. 1-E

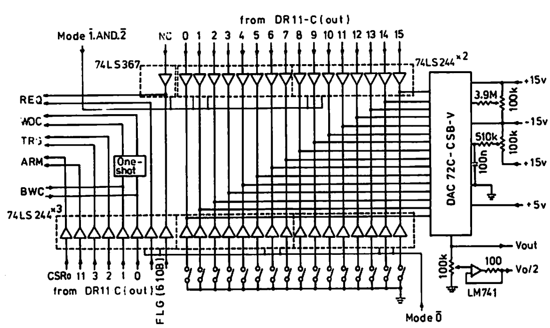


Fig. 1-F

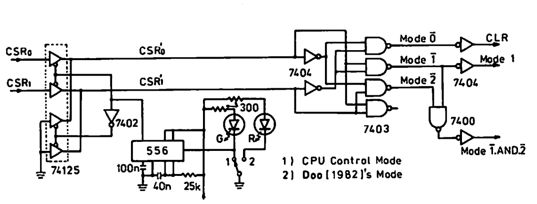


Fig. 1-G

Fig.1-E : Display controller with 1KHz oscillator.

Fig.1-F : Reference voltage generater to the MTS-450, and connection diagram of output bus lines from DR11-C and Doo's mode operation.

Fig.1-G : I/O bus lines controller.

This part consists of four BCD decade counters. A positive going edge of TRG must be an input. The outputs of each BCD counter A,B,C and D correspond to the value 1, 2, 4 and 8, respectively. The twelve outputs An, Bn, Cn and Dn as n=0−2 are connected into the bus lines of the DR11-C for input IN04-IN15 through tri-state bus buffers. It must be noted that the bus lines require binary data, so that a modefication BCD to binary should be done in a software. The reason that outputs are not connected to IN00-IN11 stands on the notice of Yi-Hsien Doo (1982) who says "BIT 3 OF THE INPUT BUFFER ON THE DR11-C BOARD STAYS HIGH ALWAYS". Inputs to the counter and outputs to bus lines of the DRC11-C are enable when ISTAT in the AETHV2 is 1.

(5) Display controller (Fig.1-E)

There are three type displays as mentioned before. Seven segments LEDs are drived by a ripple-blanking method with 1kHz frequency and one-third duty cycle to save power and heat. The 1kHz pulses are produced by an oscillator composed of a timer IC device, resisters and capacitors. The accuracy and stability of this oscillator is sufficient for our purpose. The green and red LED show the status whether the HRMTS-01 is under program control or not. The status can be defined by the red push-bottan operated only manually. User must pay attention to these LEDs when he starts the experiment using the HRMTS-01.

(6) Reference voltage generator to the MTS-450 (Fig.1-F)

This part consists of a 16 bit D/A converter (AD-DAC72-COB-V) and some devices and generates analog outputs ranging −10v through +10v. Digital inputs to the AD-DAC72-COB-V are connected to bus lines of the DR11-C OUT00-OUT15 or test 8 bit dip switches through tri-state bus buffers controlled by ISTAT in the AETHV2. When

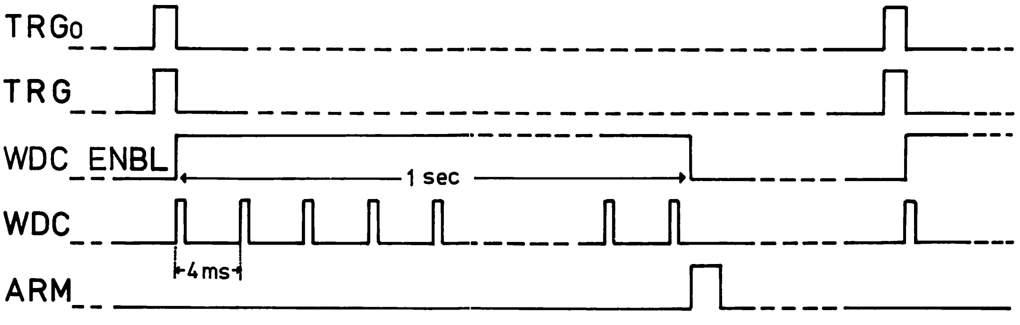


Fig. 2 Timing chart of TRGo, TRG, WDC and ARM which will be produced when AE-signals exceed a threshold level.

ISTAT is 0, 1 through 2 and 3, the outputs response to test switches, LEVELs in the AETHV2 and a full scale value, respectively. The AD-DAC72-COB-V uses the offset binary digital input code to be different from the digital output code of the DR11-C. User must design his program carefully.

(7) I/O bus lines lines controller (Fig.1-G)

This part consists of a decorder of control and status register's outputs (CSR0 and CSR1) from the DR11-C board. There are three modes of operation indicated by ISTAT in the AETHV2 for the HRMTS-01. ISTAT=0, 1 and 2 denote "RESET ALL", "ENABLE ALL FUNCTIONS" and "ENABLE ALL WITHOUT AE-EVENT COUNTER". ISTAT=3 is not related to any function now. ISTAT=0 through 3 are effective while the green LED is flushing. On the contrary, only ISTAT=0 is allowed in case of the red LED to be lit. Values of the ISTAT should be given in the AETHV2.

(8) Power supply

This part consists of five power sources, which are +5v (3A), +5v and −5v (0.5A each), +15v and −15v (0.3A each). The former 3 sources use 3-terminal voltage regulators and the last two are produced by the Burr-Brown's power unit.

Figures 1-A through 1-G show circuit diagrams in HRMTS-01. The timing chart of TRGo, TRG, WDC and ARM is indicated in Figure 2.

4. Software description

The programs for our experiment are written in FORTRAN and Macro assembler.

The AETHV2 with COMP, HRMTS0 and ON7015 is the program for taking data and controlling the MTS-450 in our experiment. This program allows 100Hz sampling for 10 channels including AE event count and to control axial stress of a sample in the MTS-450 under conditions of increasing or decreasing constantly, holding and decreasing rapidly. These conditions must be changed by using other increment of LEVEL in the AETHV2.

The XYPRE with AENUM0 and BEEP must be executed after AETHV2 running. This is the program to sort out experimental data on the file RK1 : EPRST. AED and send it to a specified file which will be used for analysis. The AE event count data will be modified by the AENUM0 as mentioned in Section 3.

The DRCPBK with COMP and BEEP is the program for taking the data of AE waves recorded on an analog magnetic tape recorder. The capacity of a smapling rate is depend on the transfer rate between

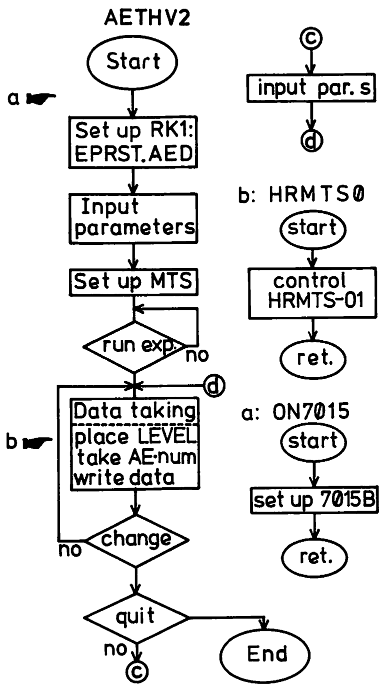


Fig. 3-A

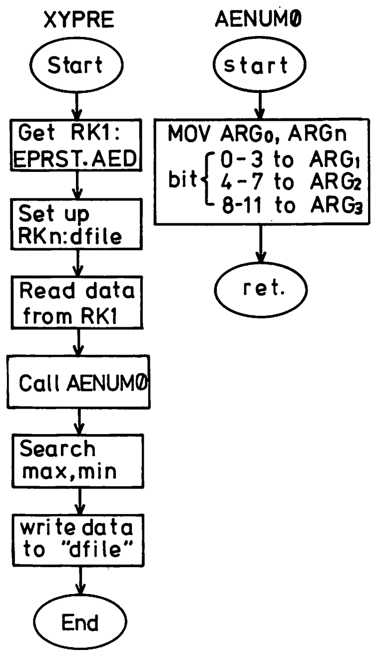


Fig. 3-B

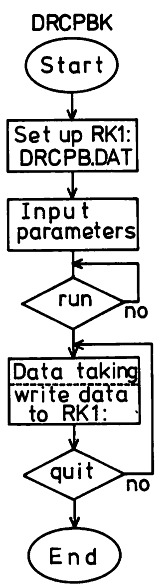


Fig. 3-C

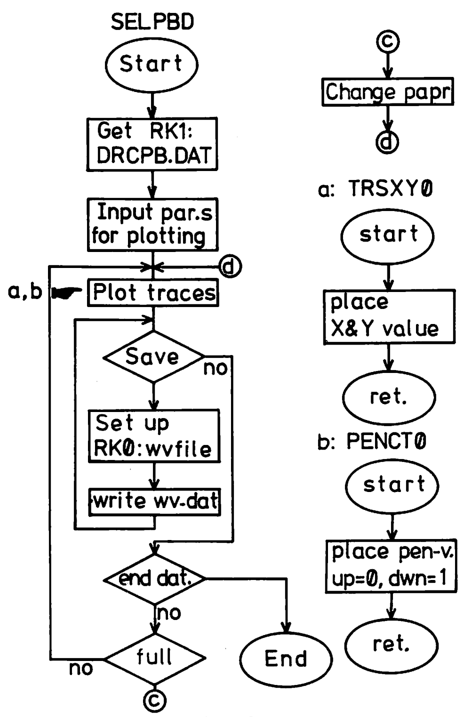


Fig. 3-D

Flow charts of programs for Acoustic Emission testing.

the interface AR-11 to the disk file RK1 : DRCPB. DAT. The maximum sampling rate examined is 250Hz for 4 channels. The RK1 : DRCPB. DAT must be very large volume, so that user should prepare and set almost an empty disk in the RK1 position.

The SELPBD with TRSXY0, PENCT0 and BEEP must be executed after DRCPBK ran. This is the program to sort out AE wave data on the RK1 : DRCPB. DAT and send it to a specified file for data analysis. User must set the hp-7015B recorder before this program will be run. Then AE waves can be seen on the hp-7015B and can be selected whenever user inputs parameters of a request, starting and ending time and a file name to keep data.

The flow charts of these programs are shown in Figure 3-A through 3-D. More detailed comments and operating procedures are written in each program listing.

5. Conclusion

Our experiments were performed under uniaxial compression by using Westerly Granite (WG) and Sierra Granodiorite (SG) samples. The sizes of samples were 22.2mm and 25.4mm in diameter and 42.1mm, 52.4mm and 56.0mm in length, respectively. Mean stress increasing rates were 2.8, 3.5, 5.0, 7.0 and 10.7 MPa/min. The stress, strains and AE event count of a sample were taken by the PDP11/10 at 1s interval. AE waves were recorded by a hp-3960 analog data-recorder with 15/16 inch/sec tape speed to allow 250Hz frequency response. Time markers to synchronize data aquisition time between PDP11/10 and hp-3960 data-recorder were provided by using an output register for an additional D/A converter. The timer generates different pulse hight signals for 1sec., 1min. and every 10mins. The schematic diagram of our experiment is shown in Figure 4. Figure 5 is an example of data taken by the PDP11/10. Data lines 0, 1 through 6 and 7 indicate stress, strains and AE event count of a sample, respectively. AE waves sorted out

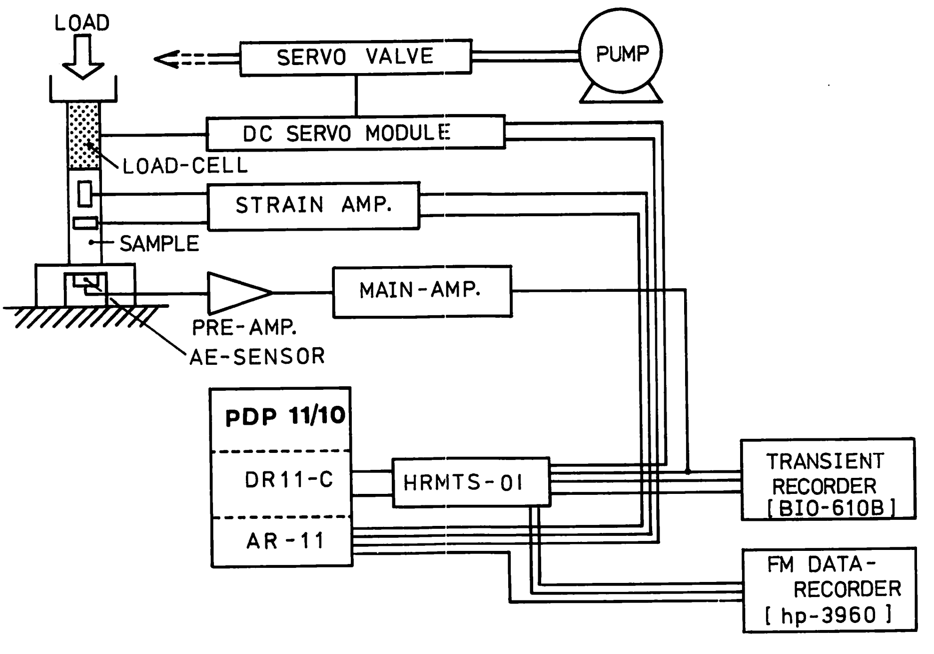


Fig. 4 Schematic diagram of Acoustic Emission testing.

by SELPBD are plotted in Figure 6. From our results, we see that the new system works very well.

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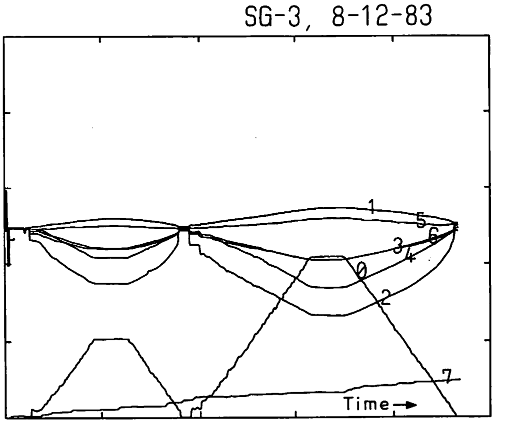

Fig. 5 Example of experiment data using Sierra Granodiorite. Stress, strains and AE-Event count are plotted.

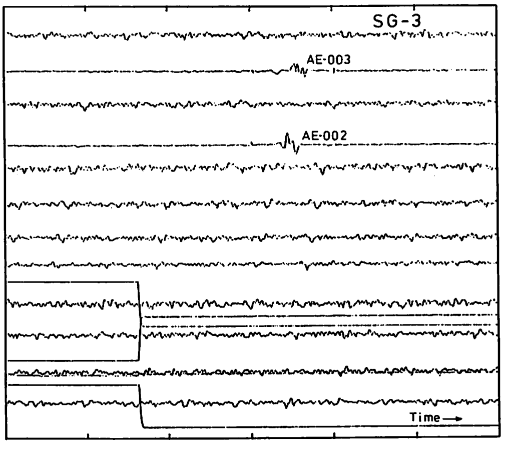

Fig. 6 Example of AE wave data.