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A personal computer based package for shake table testing

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Abstract: The developement and implementation of a shake table control and data acquisition package for the shake table facilities at McMaster University are described. The package utilizes a personal computer and an analog-I/O board, and is driven by home-written software.

1 INTRODUCTION

Shake table testing is a powerful tool for researchers and engineers in the field of earthquake engineering. In many instances, shake table testing is the only reliable method for evaluating the performance of a structural component or a piece of equipment during an earthquake. In the area of seismic qualification of equipment, where not only the structural integrity but also the ability of an equipment to function after an earthquake is interested, shake table testing is virtually the only reliable mean to study the problem.

To utilize a shake table effectively, one must be able to accurately control the table motion as well as collecting the response data for the test specimen. In the past, these jobs were usually done by using a variety of equipments, for example, FM tape player and recorder, minicomputer (PDP 11, Data General Eclipse) and other dedicated data acquisition equipments. The recent rapid development of personal computer (hereafter will be abbreviated as PC) technology give rise to a new possibility of using a relatively inexpensive PC to perform the tasks of data acquisition and control of shake table testing, which were traditionaly done by expensive equipments.

This paper reports the developement of a PC based package used for controlling and performing data acquisition for the shake table testing facilities at McMaster University. The chief objectives of this paper are to inform the possibility of such a relatively low cost and efficient alternative for shake table testing, and how this alternative can be implemented. Although the discussion refers specifically to the shake table system at McMaster University, the dicussion is also relevant to similar systems in other research institutes or laboratories.

2 SHAKE TABLE SYSTEM

The shake table facilities at McMaster University consist of two single axis tables; one for horizontal motion, one for vertical motion. Both tables utilize an MTS closed-loop control on a servo-hydraulic system with a 132 litres per minute capacity power supply. Other characteristics of the shake tables can be found in table 1. The shake tables can be operated in both acceleration control and displacement control modes. The operational block diagram for the shake table can be seen in figure 1. The entire system can be regarded as a black-box into which an input signal is fed, and from which the response signals of the table and the test specimen come out. The objective here is to use a PC to handle the input to and the output from the black-box.

Two types of signals are generally required for shake table testing, namely, sinusoidal signals and earthquake time history signals. Sinusoidal signals are usually generated by means of an oscillator which normally has two modes of operation: 1) up-and-down sweep between two frequency limits and 2) dwell at a specific frequency. For earthquake time history signals, a digital computer equipped with an D/A (digital to analog)

Table 1. Shake table specifications

	Horizontal Table	Vertical Table
Table dimensions	1.98 X 2.13m	0.91 X 1.52m
Table construction	Cellur aluminum on linear bearings	Cross-braced aluminum plate on air-bearing support
Maximum displacement (peak-to-peak)	25 cm	15 cm
MTS actuator force rating	106 KN	29 KN

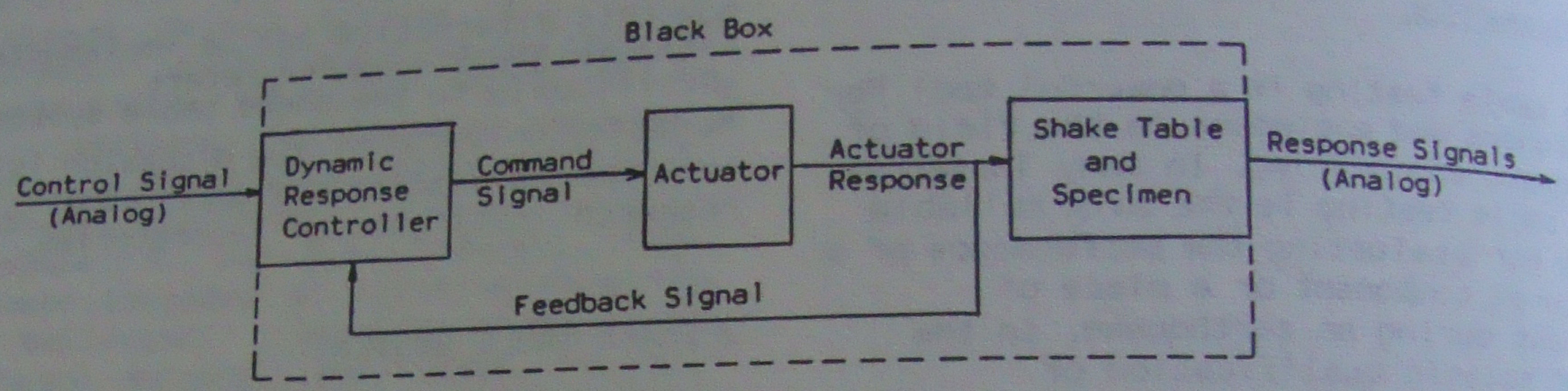

Fig. 1 Operational block diagram of shake table system

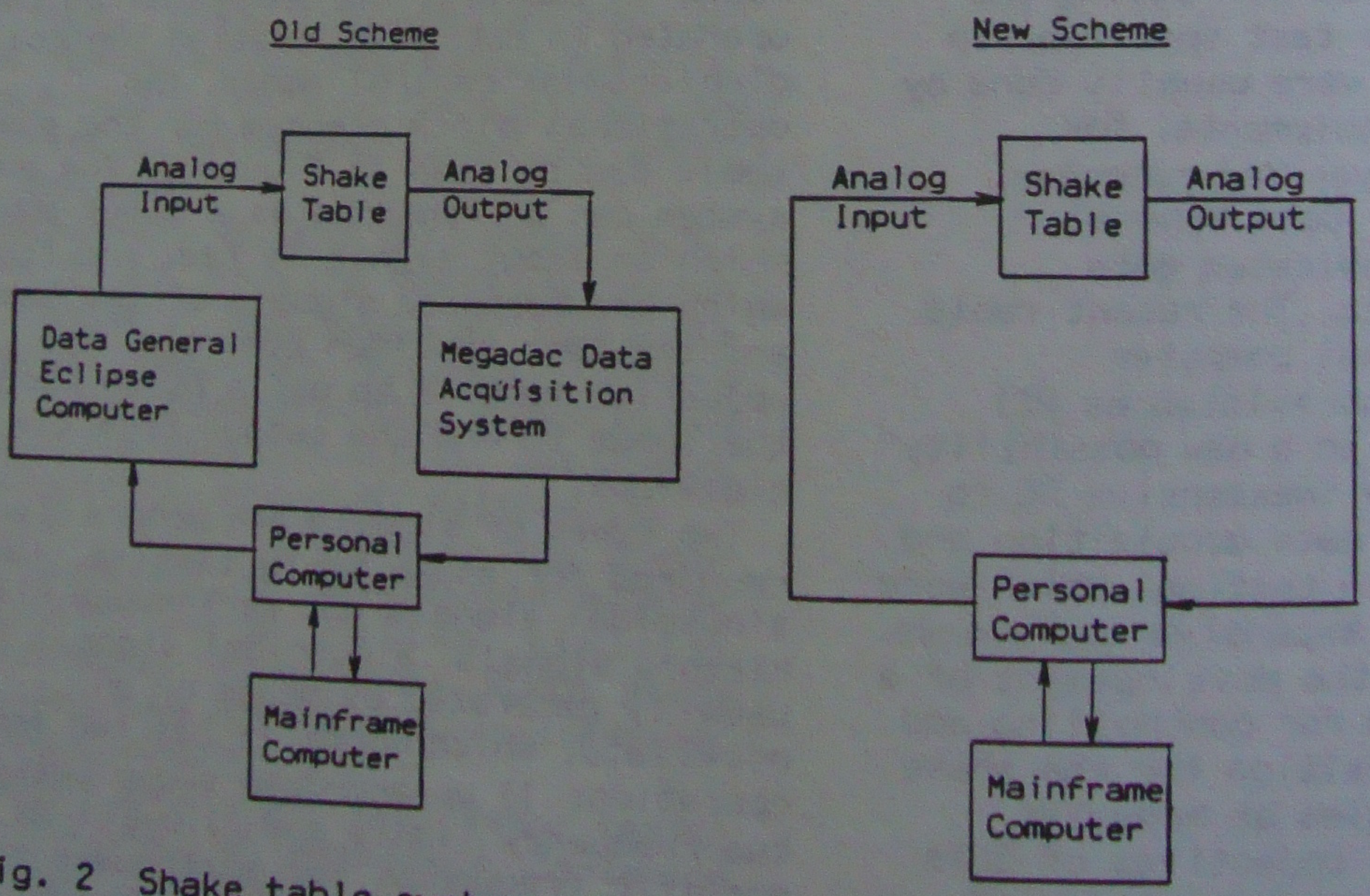

Fig. 2 Shake table system schematic

converter is used. The digital data of the required earthquake time history are stored in the computer memory or in its mass storage unit prior to a test run. During the test run the digital data are converted into analog signals at a prescribed rate by the D/A converter and subsequently fed into the controller of the shake table.

At the output end of the black-box shown in figure 1, response analog signals of the table and the test specimen can be plotted by strip chart recorder and recorded in digital form by a data acquisition unit. The data acquisition unit consists basically an A/D (analog to digital) conversion unit and a mass storage unit. The response signals, which are in analog form, are first converted into digital form and then saved in the mass storage unit.

Prior to the implementation of a PC in the shake table facilities, a Data General Eclipse Minicomputer was used to provide the analog earthquake time history signals to drive the shake table. The output analog signals were converted into digital form and recorded on magnetic tapes by a Megadac data acquisition unit. The Megadac was linked to a PC so that the recorded data can be transferred to the PC for data processing. The PC was also linked to the university's mainframe computer where a strong motion record database and many useful data processing software packages reside. The PC also served as a linkage between the Data General Minicomputer and the mainframe computer. Through this linkage actual earthquake records from the database, or artificial earthquake time histories generated by the mainframe computer, can be transferred to the Data General minicomputer. The connections among the various pieces of equipment can be seen in figure 2a.

The disadvantage of the above system is that its operations consist of too many data transfers which are very tedious and often very time consuming. In many instances, such as seismic qualification test for equipment where the adequacy of the table motion has to be verified immediately before any further testing, the whole testing process becomes very inefficient because of the waiting time for data transfer. Another shortcoming of the above system is the painful task for a user to learn and remember all the necessary commands and procedures of so many pieces of equipments in order to operate the shake table.

3 IMPLEMENTATION OF PERSONAL COMPUTER

The new scheme of the shake table system can be seen in figure 2b where a PC is used for both controlling the shake table and performing data acquisition. An IBM PC is used in the system. The computer is equipped with 640 Kbytes of core memory, a 5 Mbytes hard disk, a serial port and a color graphic video interface. The IBM PC by itself cannot perform any analog input and output functions which are necessary for data acquisition and control. A special circuit board (hereafter referred as analog-I/O board, where I/O stands for input and output) is required to perform the tasks. (The readers should note that in this paper the terms, input and output or I/O, are used always with reference to the PC unless indicated explicitly.) A wide variety of such board is available for the IBM PC and compatibles. They usually can be installed in one of the expansion slots of the PC. Beside the hardware, software is required to drive the analog-I/O board. Softwares for such purpose are availabe from the board manufacturers as well as third party vendors.

In order to select the appropriate hardware and software for the new PC based system, one must specify the requirements on the performance of the shake table system. Based on past experiences with the old system, the followings are specified such that the new shake table system can perform at least as well as the old system:

1. at least 8 true differential data acquisition channels;
2. 200 samples/channel/second analog input sampling rate;
3. 100 samples/channel/second analog output sampling rate;
4. 12 bits data resolution for both analog input and output;
5. ± 10 volts of analog input voltage range;
6. ± 1.5 volts of analog output voltage range; and
7. programmable gains for analog input signals.

3.1 Hardware selection

A wide choice of analog-I/O boards is available from manufactures. The boards available in the market are usually mutifunction boards, i.e. beside the standard analog-I/O functions they also can perform other tasks, such as digital I/O and event counting. A brief survey on the standard features which most of the boards possess is given in the following paragraph. The readers who need more information should refer to the papers by Conner (1986) and Travis (1984) which provide very comprehensive surveys on a large number of analog-I/O boards.

The analog-I/O boards available in the market usually provide 4, 8 or 16 true differential input channels for analog input. Choices of data resolution include 8, 10, 12, 14, 16 bits (Data resolution is meant by the magnitude of the smallest analog signal which an A/D or D/A converter can resolve, for example, with a full scale range of ±1 volt, an D/A or A/D converter of 8 bits resolution can resolve an analog signal to $\pm 2^{-7}$ volt accuracy and $\pm 2^{-11}$ volt for a 12 bits resolution converter). The data resolution of a particular board is usually fixed, however, some manufacturers offer boards with programmable data resolution where the desired accuracy for data conversion can be selected using software. The overall maximum sampling rate for both analog input and analog output for different boards can range from 2.5 KHz to 130 KHz. One shold not be overly impressed by the high sampling rate specified for some of the boards because the maximum overall sampling rate is usually governed not by the hardware but by the software. The A/D and D/A voltage ranges of an analog-I/O board are usually limited to ±10 volts. Most of the boards have more than one range beside the standard ±10 volts, and they are selectable by software, or hardware by means of switches or jumpers. The user can select the optimum range to obtain the best data resolution for his instrumentation. Some of the boards can amplify the input analog signal for each individual channel before any A/D conversion by means of gain settings. The gain settings can be switch-selected or software-selected depending on the boards. One should note that when high gain (eg. 100 times) is being used, the maximum sampling rate of most of the boards can be reduced greatly. Majority of the boards have one or two channels of analog output with a data resolution of 12 bits.

Based on the requirements mentioned earlier, there is a wide choice of analog-I/O boards which are suitable for the intended application. The final choice is a Scientific Solutions's LabMaster TM-40 board with PGH programmable gain option. It is chosen manily because it has been used by other research groups in McMaster University, and it is desirable to have some experienced users close by when difficulties arise in implementing the board.

The LabMaster boards consist of a mother board and daughter board connected by a ribbon cable. The mother board can be installed in any of the expansion slot in the IBM PC. The daughter board sits outside the PC and is contained in a metal enclosure. The boards provide a standard of eight channels of true differential analog input (expandable to 128 channels) and two channels of analog output. The boards are capable of performing analog I/O at a maximum rate of 40 KHz with 12 bits data resolution. The analog input voltage range is limited to ± 10 volts. The PGH (programmable gain) option allows the input voltage to be amplified by 2, 4, or 8 times. The analog output voltage range is jumper-selectable, and the options are ± 2.5 volts, ± 5 volts and ± 10 volts. Five independent counters are available to be used in controlling the analog I/O timing.

The board is mapped with the PC through a set of 16 consecutive I/O ports in the PC. The PC controls the board by simply writting a pattern of bits onto the appropriate I/O ports. Digital data can be received from or sent to the board through these ports.

3.2 Software

Most of the analog-I/O boards, including the LabMaster, are supported by softwares from the board manufacturers and third party vendors. The software packages offered by the board manufacturers are usually in the form of subroutines callable by a host language, such as BASIC interpreter or compiler, FORTRAN and PASCAL compilers. Some examples of the library routines are analog input, analog output, clock counter and plotting. The user can create his own driving program by combining these routines together in a main program written in a host language.

The software packages offered by third party vendors are usually menu driven, and they do not require any programming by the user. Apart from the standard analog I/O features, these program packages usually provide many other useful features for both real time signal processing and post-processing. Some examples are real time display, FFT, curve fitting, integration and differentiation. Some of the software packages have foreground/background feature which allows "multitasking" operation, for example, performing analog input and output simultaneously.

These software packages provide a lot

of impressive features, and if they are used, a lot of time can be saved from writting one's own driving program. However, it was found that none of them is suitable for the intended application. The major drawback is that none of them can perform analog input and output "simultaneously" with the required sampling speed. The only choice left to the authors was to write their own software to drive the board.

4 DEVELOPEMENT OF SOFTWARE

The following subsections describe the developement of the software used to drive the analog-I/O board. The major features of the software will also be described.

4.1 Basic requirements

Two basic requirements were kept in mind in the developement of the software package. First, the software must be user friendly. This is essential because the shake table user should concentrate on his research rather than wasting his time and energy in struggling with a user unfriendly system. Second, the software package must be able to be used in performing the following tasks:

1. setting up data acquisition and shake table control parameters;
2. driving the analog-I/O board to perform data acquisition and to control the shake table;
3. displaying and plotting the acquired data on the computer screen; and
4. writting the acquired data on disk.

4.2 Computer programming language

As mentioned earlier, the board communicates with the PC through the I/O ports of the PC. Hence the programming language used in writting the software must be capable of accessing these I/O ports. This limits the choices of programming language to more or less BASIC, Turbo PASCAL and assembly language. Furthermore, the high speed requirement of analog I/O eliminates the choices of the high level languages (BASIC and PASCAL) leaving assembly language as the only choice. However, high speed is only required for analog I/O, and it is not necessary to use such difficult and inefficient (inefficent in terms of programming) programming language to write the rest of the program where speed is not critical. For this reason, the program routines which are used to perform analog I/O were written in assembly language as subroutines callable by the main program. The main program was written using BASIC interpreter.

4.3 Major features of the software package

Based on the requirements mentioned earlier, a software package was written. The operations of the software are menu driven, i.e. an operation is initiated by selecting a choice in a menu. The package is capable of driving the analog-I/O board to sample eight channels of analog signals at a maximum speed of 1000 samples/channel/second while simultaneously sending out analog signals to control the motion of the shake table.

The main menu of the package consists of the following ten options:

1. display current data acquisition and shake table control set-up;
2. set up for data acquisition;
3. set up for shake table control;
4. autobalancing;
5. initiate data acquisition and shaking;
6. display data on screen;
7. plot data on screen;
8. save data on disk;
9. binary file utilities; and
10. return to DOS.

The following paragraphs describe each of these options briefly.

If option 1 is selected, the current set up for data acquisition and shake table control will be displayed on the computer screen.

Option 2 is used to set up the control parameters for data acquisition. The user must provide the following information: total number of channels to be sampled; sampling speed; sampling duration; which channels are to be sampled and the corresponding gain settings. The entire set-up information can be saved on a disk file, and loaded back if the same set-up is needed again. The following choices can be found in option 2:

1. create or modify the current set-up;
2. load a set-up file from disk;
3. save a set-up file on disk; and
4. return to main menu.

Option 3 is used to load a shake table displacement time history file from disk into the computer memory. A time history file is usually store as text file on disk in ASCII format. After it has been read into the computer memory, the time history values, which have the unit of displacement, must be scaled into the

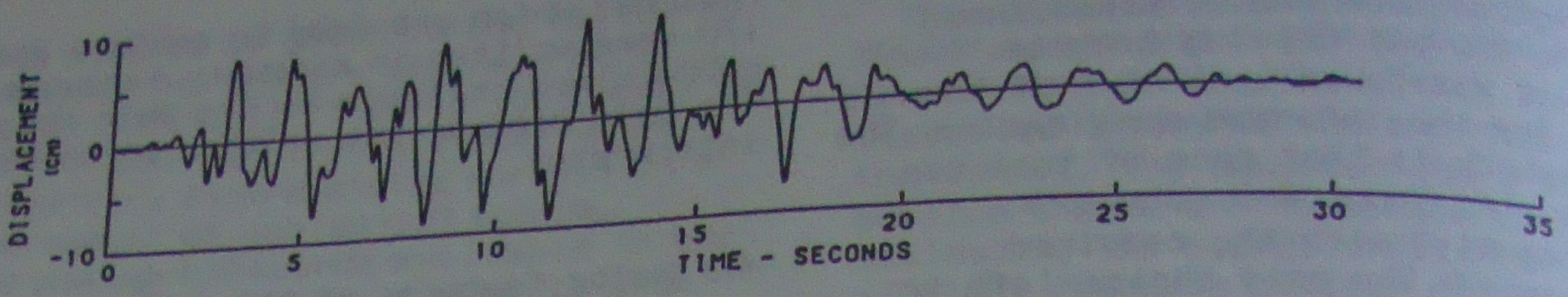

Fig. 3 Input Displacement time history for shake table

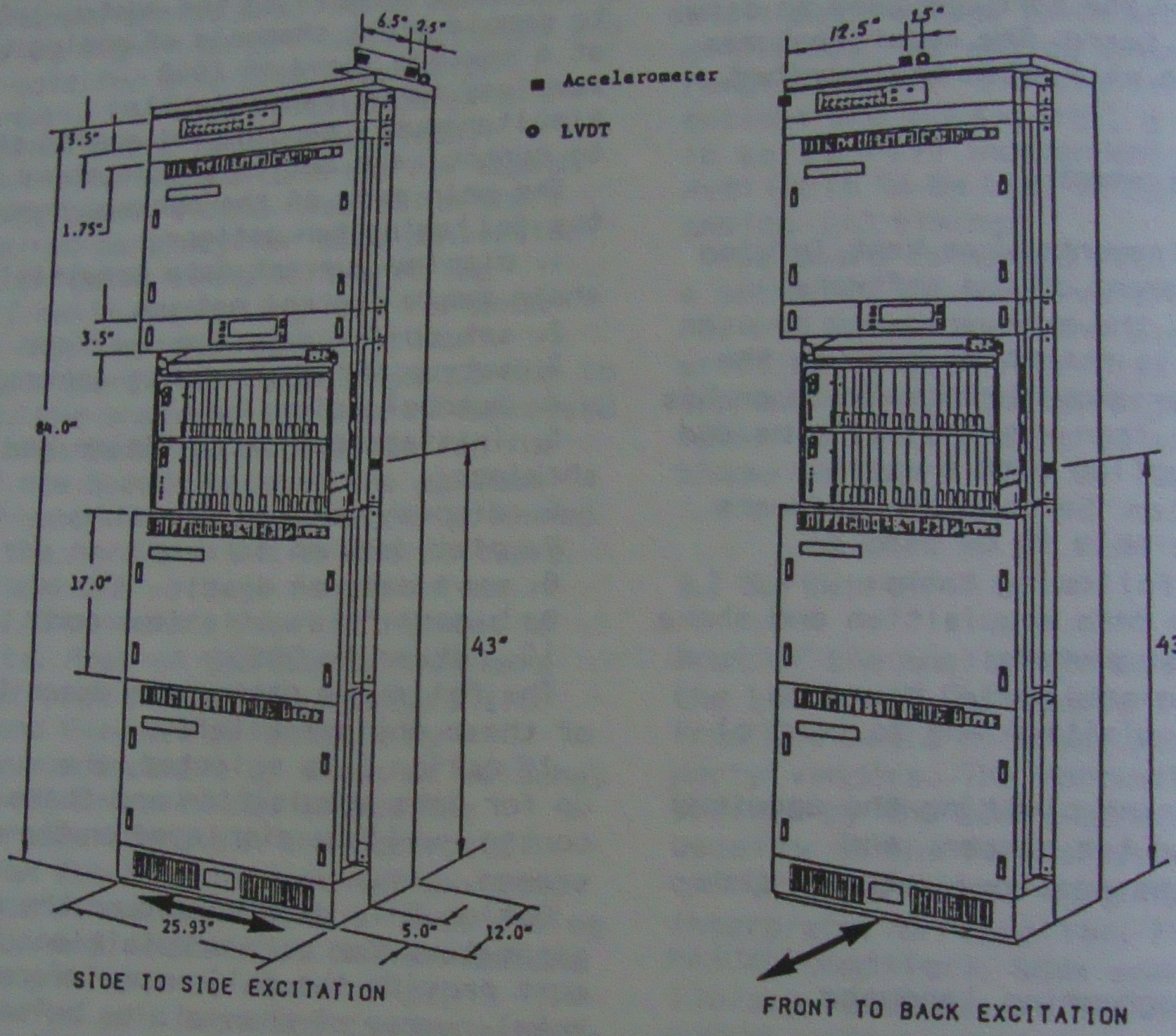

Fig. 4 Instrumentation

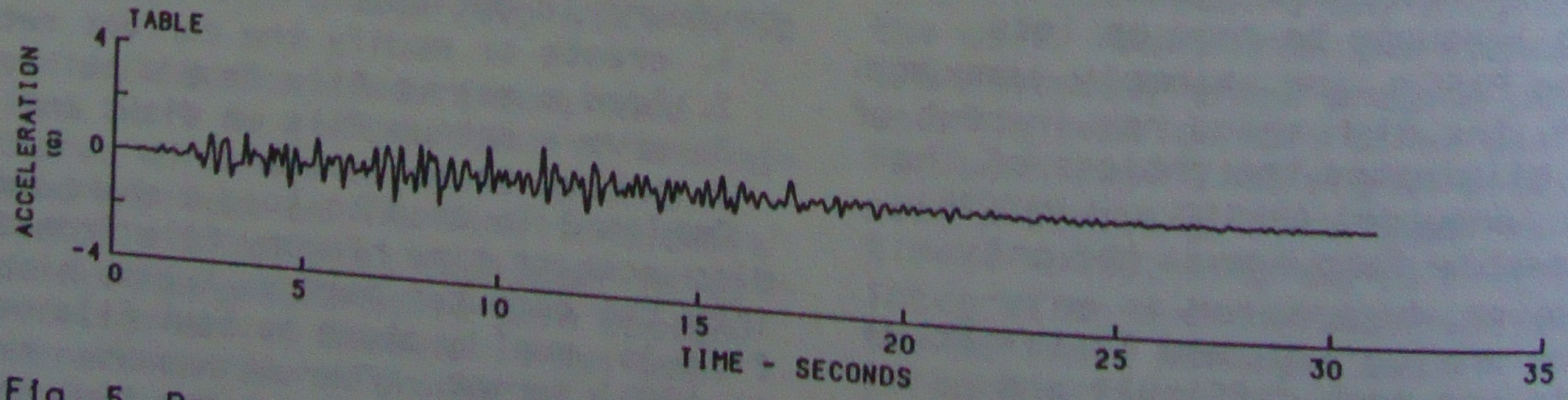

Fig. 5 Recorded table acceleration

appropriate voltage values. As other PC users probably have experienced, the reading in and scaling of a large set of numbers stored on a disk file in ASCII format is a very time consuming process (often takes two or three minutes). This is mainly due to the fact that the computer has to translate several thousands of ASCII coded numbers into binary numbers and scale them by performing several thousands of multiplications. Such time consuming task is very annoying if the same time history has to be used over and over again. One way to overcome this problem is that after the ASCII time history file has been read in, translated into binary numbers and scaled, the scaled binary version of the time history is saved back onto the disk as a binary file. Whenever the same time history is required again, it can be loaded into the computer memory in a matter of two or three seconds. Thus option 3 of the main menu allows the following choices:

1. input an ASCII time history from disk;
2. input a scaled binary time history from disk;
3. save the scaled time history in a binary file;
4. enter the discretization time interval for the time history; and
5. return to main menu.

The discretization time interval of the time history can be entered using the fourth choice.

Residual voltages often exist in transducers even when the table and the specimen are at rest and at the "zero" positions. Option 4 (autobalancing) allows the residual voltages to be removed digitally. To use this option, both the table and the test specimen must be at rest and at their "zero" positions. When this option is invoked, a series of reading are being taken for each of the analog input channels used. The average of the series is then calculated for each channel. During the actual data acquisition process, these average residual voltages are being substracted from the readings of the corresponding channels.

Option 5 has two choices. One is to perform data acquisition and shake table control simultaneously, and the other is to perform data acquisition only. The second choice is useful when the table is being controlled by other devices such as function generators. The data acquired are temporarily located in the computer's memory. The maximum total amount of data that can be collected at one time is 64 Kbytes. This limits the system to a maximum sampling duration of 40 seconds with eight channels sampling at 100 samples/channel/second. A longer sampling duration is possible if less channels or a slower sampling speed is used.

After a data acquisition process, it is desirable to check whether the data were sampled correctly. Option 5 and 6 can be used for this purpose. The actual data can be displayed on screen using option 6 or plotted on screen using option 7.

The acquired data can be saved permenantly on disk file using option 8. This option allows the data to be saved in ASCII format which can be readily accessed by other data processing softwares, or in binary fromat which can only be accessed by BASIC interpreter. As in the case of reading ASCII data, writting out data in ASCII format is also very time consuming, particularly, for a large number of channels of data recorded for a long duration. In most cases, not all the acquired data are needed to be processed immediately after a test, therefore, it is desirable to save the acquired data and the corresponding data acquisition set-up in a binary file, which only take a few seconds to be saved, and to continue with the rest of the experiment. When the data are needed later, they can be easily extracted and saved again in ASCII format using option 9. Saving data in binary format also has the advantage of saving a lot of disk space which would be at least three or four times larger if the same data are saved in ASCII format.

Option 9 contains the utilities which handle the binary files saved with option 8. This option consists of five utilities which are listed as follows:

1. load a binary data file from disk;
2. display data acquisition set-up;
3. display data on screen;
4. plot data on screen; and
5. save data on disk in ASCII format.

To access to a binary file, utility 1 must be first used to load the required binary data file into the computer memory. Utility 2 can be used to display the data acquisition set-up which was used to collect the data. The data can be viewed on screen using utility 3, and can be plotted on screen using utility 4. Any single channel or a combination of channels of data can be extracted and written on a disk file in ASCII format using utility 5.

Option 10 is used to terminate the program execution and to return to DOS.

5. SEISMIC QUALIFICATION TEST FOR A TELECOMMUNICATION EQUIPMENT

The newly developed shake table testing package was used in a series of shake table tests aimed to evaluate the performance of a telecommunication equipment subjected to strong seismic shaking. To qualify the equipment for the most severe seismic environment expected in North America, the 2% damped Earthquake Floor Response Spectrum for installation at an upper floor location in buildings located in zone 4 (Uniform Building Code zoning) given in Network Equipment Building System (NEBS) is adopted as the target spectrum for the input motion to the system.

To achieve the required level of excitation an acceleration time history which is compatible to the target spectrum was derived. The time history was passed through a high pass filter which cuts off the low frequency components (less than 0.5 Hz) to reduce the unnecessarily large displacement associated with the low frequency components. The filtered time history was then numerically integrated to yield the displacement time history which consituted to the input of the shake table system. The displacement time history is shown in figure 3. It has a duration of 30.7 sec, a maximum displacement of 9.39 cm and can produce a maximum acceleration of 1.05 g.

5.1 Test set-up and procedure

The equipment cabinet was mounted on a concrete slab which was secured on the shake table. A total of four accelerometers and two LVDT's were used in the experiment. Three accelerometers and one LVDT were mounted on the specimen as shown in figure 4 for both principal testing orientations. One accelerometer and one LVDT were attached to the table to measure the table motion. The test procedure includes, first, determining the natural frequencies and damping ratio of the equipment in both principal directions by sine-sweep tests, and second, monitoring the functioning of the equipment during the strong shakings in both principal directions and checking its integrity after the shaking. Only the second utilized the newly developed shake table testing package.

5.2 Using of the shake table testing package

This subsection illustrates how the shake table testing package was used in testing the equipment subjected to strong seismic shaking. The testing orientation of the equipment was side to side.

As soon as the driving software was loaded and run, the main menu appeared on the screen. Option 2 was first chosen to set up for the data acquisition process. After the required information had been entered, the set-up information was saved in a disk file for future uses. The third option was then invoked to load and scale the required displacement time history. Since the time history was in ASCII format, it was read in by the ASCII option. The scaled time history was saved back on the disk as binary file for future uses. With the table and the specimen at rest and at their "zero" positions, option 4 was invoked to eliminate the residual voltages existing in the transducers. At this point, all the required set-up for data acquistion and shake table control were completed. When option 5 was invoked, the whole test set-up information was displayed on the screen for the user to check whether it was correct. Upon the confirmation on the correctness of the set-up, the shaking and the data acquisition was initiated by pressing a key on the keyboard. After the completion of the shaking, the collected data were displayed and plotted on screen using option 6 and 7 to see whether they were sampled correctly. The entire six channels of data and the corresponding data acquisition set-up were saved in a binary file using option 8. The set of data corresponding to the table acceleration was extracted and saved in an ASCII file. The recorded table acceleration time history is shown in figure 5. A response spectrum was computed for the table acceleration and plotted along with the target spectrum as shown in figure 5. It can be seen that the computed spectrum is everywhere greater than the target spectrum in the region interested (greater than 2 Hz), hence the table motion was adequate. There was no malfunctioning or damage of the equipment detected during and after the shaking. The above procedure was also repeated for the front to back testing orientation, and again no malfunctioning or damage was detected.

6 SUMMARY

An efficient and relatively low cost data

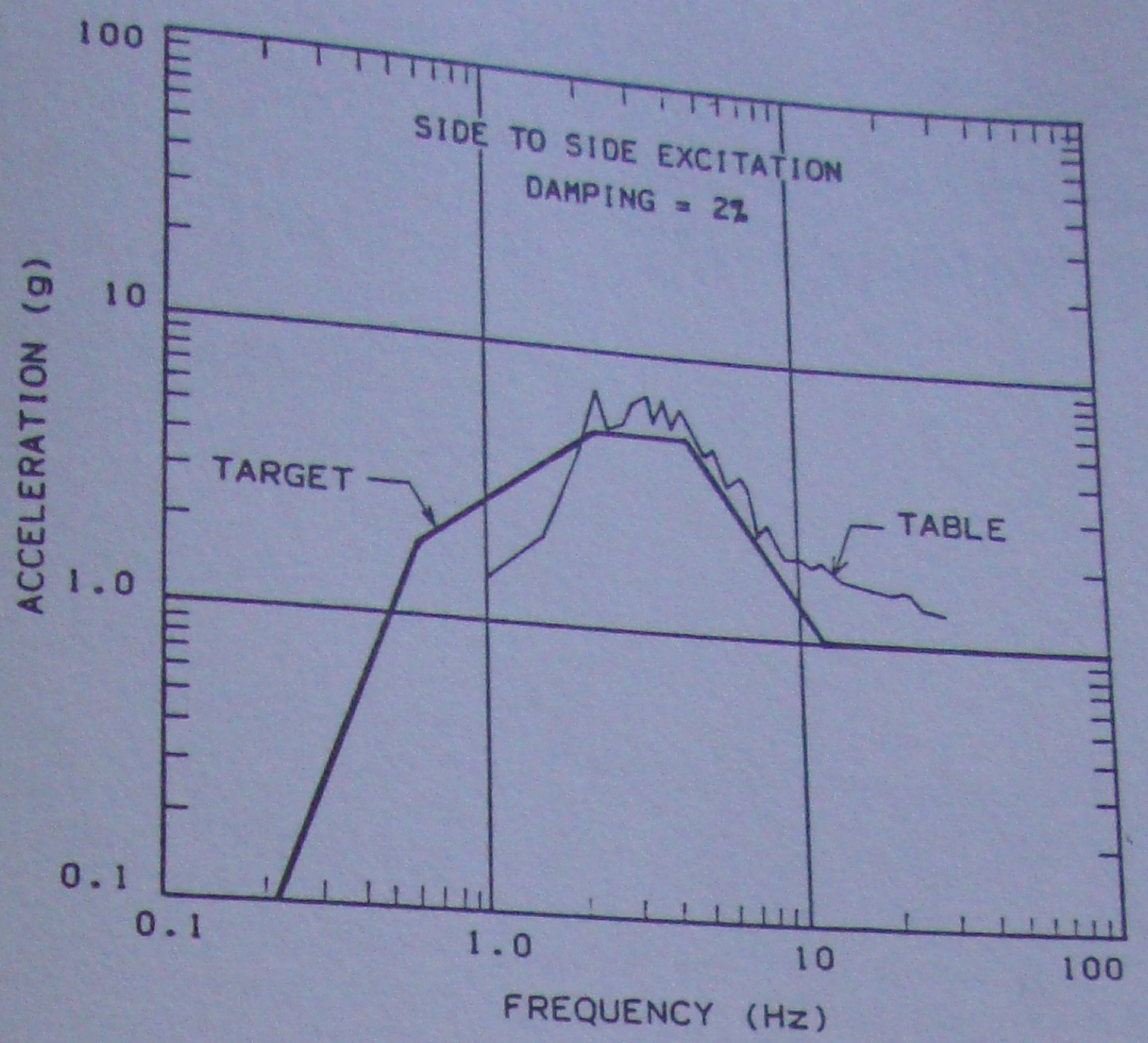

Fig. 6 Response spectra

acquisition and control package was developed for the shake table facilities at McMaster University using a personal computer and an analog-I/O board. The software used to drive the system was home-written in BASIC and assembly language. The system is capable of sampling eight channels of data at a maximum sampling rate of 1000 samples/channel/second while simultaneously controlling the shake table. The performance of the package was found very satisfactory and is very adequate for small scale shake table testing such as seismic qualification test for equipment. Although the package was developed for the shake table facilities at McMaster University, it can also be adapted to other single axis shake table system as well.

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