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A MINICOMPUTER BASED VIBRATION TEST AND ANALYSIS SYSTEM

Russell B. Spencer and Paul Ibáñez
ANCO Engineers, Inc.
1701 Colorado Avenue
Santa Monica, California 90404

INTRODUCTION

The seismic qualification of equipment for the power generation industry is becoming of increased concern due to tighter requirements placed by the Environmental Protection Agency (EPA) for nuclear power plants. The engineering time required for vibration test planning, set-up, execution, data reduction and analysis, and report preparation is considerable and is increasing with the added requirements placed by the EPA, NRC and other cognizant agencies. The advent of the minicomputer has allowed even small companies to take advantage of the computers speed and precision to reduce much of the engineering intensive aspects of seismic qualification testing.

This paper presents an advanced Computerized Vibration Test and Analysis System (CVTAS) based on a commercially available minicomputer. Standard hardware has been employed in the computer system. However, the software has a number of unique features that have been developed by the authors and their co-workers over a five-year period. The following paragraphs describe the basic computer hardware system and the major elements and features of the software for the minicomputer based vibration test and analysis system.

PURPOSE OF SYSTEM

The primary objectives of the CVTAS is to assist engineers in the planning, data generation, data reduction and analysis, and report generation for seismic qualification tests of equipment. The CVTAS is designed to be used in either the laboratory for shake table testing or in the field for testing large pieces of equipment or structures using portable vibrators.

By entering basic equipment geometry and structural configuration information, along with test instrumentation data (proposed vibrator locations, potential accelerometer locations, type of test, etc.), the test engineers can obtain a preliminary test plan to guide the efficient testing of a structure or equipment item. The CVTAS gathers the test data and processes the data plan as the test is proceeding to take maximum advantage of new measurements as they are obtained. It is much easier to re-run a test when all the equipment is in place than to re-test a week or two later when normally data would be in a form to make decisions on test modifications.

The CVTAS allows test engineers to: (1) gather more meaningful data points (locations and frequency); (2) concentrate on the overall test of an object or desired results; and (3) be relieved of spending tedious hours reducing data by hand. The cost savings in engineering time and the improved quality of the test results are the primary benefits gained by employing the CVTAS for vibration testing.

HARDWARE DESCRIPTION

Although any 32k-word memory minicomputer with a disk operating system and FORTRAN language compiler could be used, the CVTAS is based on a Data General NOVA/3 minicomputer with a 5 Mbyte dual disk system. Figure 1 schematically presents the major hardware components of the system. The physical configuration of the hardware in three portable "half-racks" is shown in Figure 2.(1) The main components of the hardware are the:

- 12-slot NOVA/3 chassis;
- 32k-word (64 byte) memory and CPU;
- Dual disk 5 Mbyte drives and adapter;
- 1/2-inch magnetic tape drive (9 track);
- CRT interactive terminal;
- DecWriter II printing terminal;
- Houston Instruments DP-1 incremental digital plotter; and,
- Real Time Peripheral (RTP) 64 channels of A/D and 4 channels of D/A.

These hardware items, or equivalent components, are all commercially available. Care was taken to assure that the components were compatible for voltage, impedance, and timing and sequence of digital signals.(2)

SOFTWARE DESCRIPTION

The current software system is an outgrowth of an earlier vibration analysis software system developed by the authors.(3) The overall configuration of the present software for the CVTAS is shown in

Figure 3. The symbols, which are used in the more detailed diagrams for the software sub-packages, are defined in Table I. There are five major groups of programs, as shown in Figure 3, and these are indicated in Figures 4 through 7. The following describes each of these major sub-packages in greater detail.

- Modeling, Set-up and Planning (Figure 4):

There are four major elements in the modeling, set-up and planning sub-package. These are: (1) model generation programs (SAP, NOVA/SAP, LSAP; LMG; and SPECIAL), (2) geometry and calibration set-up and modification programs XGEO and XCAL), (3) test planning (ANPLAN and LPLAN), and (4) response prediction (GENRSP, RSVP and LDS).

The model generation programs provide the theoretical model parameters (the mode shapes ϕ, the eigenfrequencies ω, the modal damping factors β, the modal effective masses W, and the modal participation factors Γ). SAP and NOVA/SAP are finite element model analysis programs.(4,5) SAP is the large core machine program and NOVA/SAP is the modified version of SAP converted for use on a minicomputer. The program LMG is used to interactively generate standard model data sets from hand calculations or other non-computer sources. The SPECIAL program is designed to take model parameters generated by other large core structural dynamic modeling programs (e.g., NASTRAN, EASE2, PIPESD, ANSYS, FLUSH, etc.) and convert them to the CVTAS standard model data sets.

The geometry and calibration set-up and modification programs generate the standard geometry and calibration data sets. The program XGEO converts geometry data tapes to the standard CVTAS geometry data set format and modifies existing geometry data sets for new test configurations. The XCAL program performs these same functions for the calibration data sets.

The test planning program ANPLAN uses the model data set input to provide the optimum locations for vibrators and accelerometers (or any other motion transducer, e.g., velocity or displacement), suggested frequency test range, and frequency step size for each mode of interest. The program ANPLAN also gives the best compromise for all of the modes so that vibrators and transducers are not required to be moved between mode identifications. The program LPLAN provides a scratch file (S_0) that can be used to simulate and verify the response of the test object using the optimized test plan.

- Transient Data Taking, Processing and Parameter Identification (Figure 5)

The primary sequence of programs for conducting transient tests (i.e., snapback, impulse, or explosive excitation) is to use the very flexible program XTAKE to obtain the conditioned measurement signals at up to 10,000 points through the analog-to-digital converters (ADC) and store the raw data in the scratch file S_3. The raw data in S_3 can subsequently be processed by the program XPROC to calibrate and adjust the data to obtain a standard time data set. After preliminary processing, the standard time data set can be Fourier transformed by means of a Fast Fourier Transform (FFT) algorithm and filtering performed to reduce out-of-range high and low frequency components in the program XFILT.(6) The inverse FFT can be applied to obtain a new filtered time data set. The inverse FFT can be applied to obtain a new filtered time data set. The frequency data set, obtained by the forward FFT, is used by the program PREPID to prepare a scratch file S_7. The S_7 file data are then used by the program ANTPI to obtain the experimental model parameters (mode used by the program ANTPI to obtain the experimental model parameters (mode shapes ϕ', eigenfrequencies ω', modal dampings β', effective modal masses W', and modal participation factors Γ').(7,8,9) These experimental model parameters can be listed directly or fed into the program LPID via the scratch file S_8 to obtain the standard model data set.

An alternate sequence of programs is to substitute the special purpose program XFAST for program XTAKE for obtaining transient measurements data at up to 25,000 points. The data from XFAST, stored in scratch file S_4, can be subsequently processed by program XPROS to obtain the standard time data set as was the case for program XPROC. The filtering and subsequent experimental parameter identification of the standard time data set is the same as for the previously described sequence using the programs XFILT, PREPID, ANTPI and LPID.

- Sinusoidal Data Acquisition, Processing and Parameter Identification (Figure 6)

The sequence of programs to be used for sinusoidal testing is similar to that for transient input testing except that the program XSINE is used in place of XTAKE (or XFAST) for obtaining the measurement data. In addition, XDARP is used to analyze the sine data in place of the programs XPROC (or XPROS) and XFILT.

The program XSINE provides calibration and correlation of data, unlike XTAKE (or XFAST) since frequency sweeps are slow enough to allow time for data reduction during the time the measurement data are being obtained. The programs following XDARP are similar programs to those used for transient data for parameter identification and output. For sinusoidal data, the program ANSPI is used in place of ANTPI for parameter identification. The program LPID is the same for both transient and sinusoidal test result output.

- Graphical Presentations (Figure 7)

As seen from Figure 7, there are three main types of graphical requirements: (1) general plotting of time dependent data (T) and frequency dependent data (S); (2) plotting of the test objects geometric configuration showing location of measurement transducers and input vibrations; and (3) plotting of response data giving the acceleration, velocity and displacement spectra as a function of frequency (tripartite graph).

The program XPLOT gives digital incremental plots of the standard calibration (C), frequency (F), time (T), or sinusoidal (S) data sets with titles and test designations. The program GPLOT not only plots the structure geometry for test documentation, but also can produce mode shape displacement plots superimposed on the original geometry to indicate the characteristic mode shapes for the complicated higher modes of vibration. An example of response output from the program XCETLDP is given in reference 1.

- Optional Programs

In addition to the above described programs, there are four other optional programs which can be used as part of the computerized vibration test and analysis system:

1) The program XRAND is used to gather and process random stochastic data. Some equipment vibration verification specifications require a random input for certain frequency and amplitude ranges.

2) The program XASHER is used to implement Asher's method with sine and transient data. Asher's method identifies the required force appropriation for multiple vibrators to isolate a single mode of vibration (appropriate position, phase and amplitude of each vibrator to optimally isolate the desired mode).(10)

3) The program TSA is available for time series analyses including filtering, power spectral density (PSD), correlation, coherence, autocorrelation, histogram analysis, probability intensity, statistical analysis, etc. Certain test requirements require this type of data analysis for reporting the test results.

4) The program BAYSIAN implements the method of Bayesian parameter and model modification. This technique employs Baye's Theorem for conditional probability to modify the original *a priori* model to best agree with the experimental model (obtained by parameter identification) by changing those parameters with least confidence values by the greatest amount, and changing those parameters of highest certainty (in the judgment of the model analyst) by the least amount. In this way, an intuitively optimum model can be achieved based on the tests which reflects the best judgment of the engineer and best reproduces (fits) the experimental data.(11)

SUMMARY AND CONCLUSIONS

A comprehensive computer based vibration tests and analysis system has been developed and the system described by high-lighting the main features of the hardware components and the software elements. The CVTAS has application to both laboratory shake table testing of movable equipment and *in-situ* testing of large stationary structures. Report-ready graphs of reduced and analyzed data are available within a few hours of test completion for review and subsequent test modification decisions. Complete and accurate documentation of all phases of testing, data analysis and presented results assures the reproducibility of tests, and the accuracy of test conclusions regarding the dynamic behavior of equipment and structures to mechanical vibration or seismic qualification specifications.

ACKNOWLEDGMENTS

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FIGURE 1. SHAKE TABLE INSTRUMENTATION

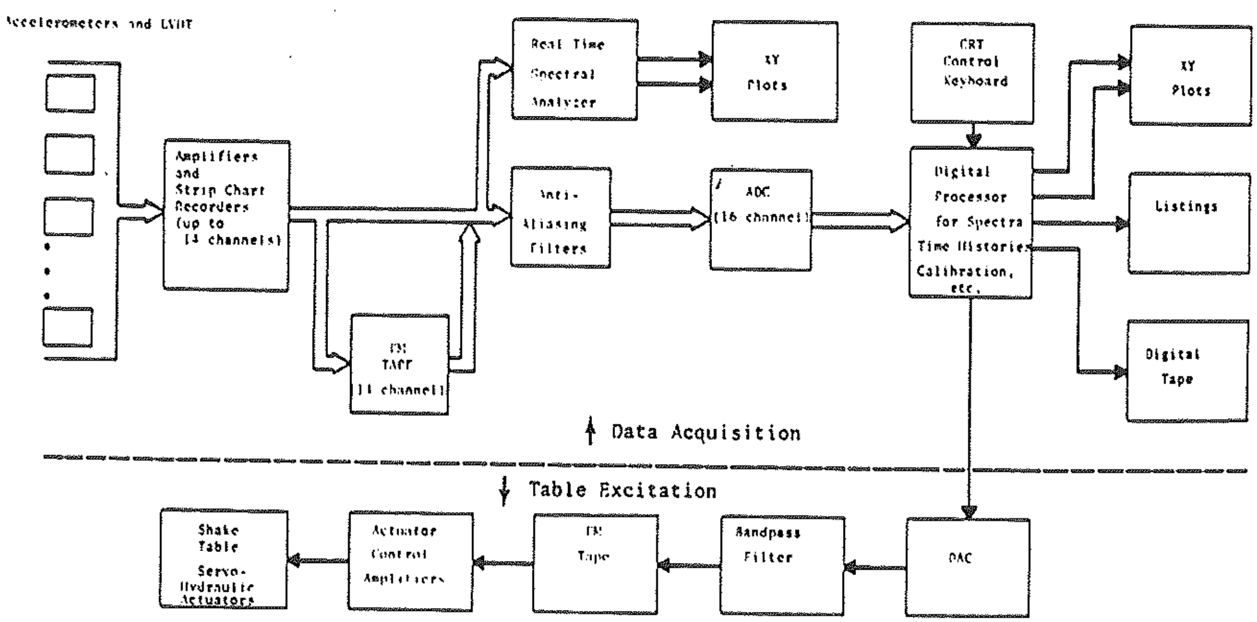

TABLE I. SYMBOL DEFINITIONS

[ALPHA]	a program, name ALPHA
(BETA)	a general purpose standard format data set, name BETA
(M)	model parameters, ϕ, β, ω, W, Γ
(G)	geometry and location description
(T)	time data set
(F)	FFT data set
(S)	sine step data set
(C)	calibration, attenuation, location reference data set
(I)	interactive input from CRT
(T)	tape input (e.g., other people's models)
(A)	analog data input
(L)	output listings for review
(XY)	Houston XY plots
(TEK)	Teletronics CRT/Hard copy plots
(S_i)	Scratch or intermediate special purpose purpose data file

FIGURE 2. HARDWARE CONFIGURATION

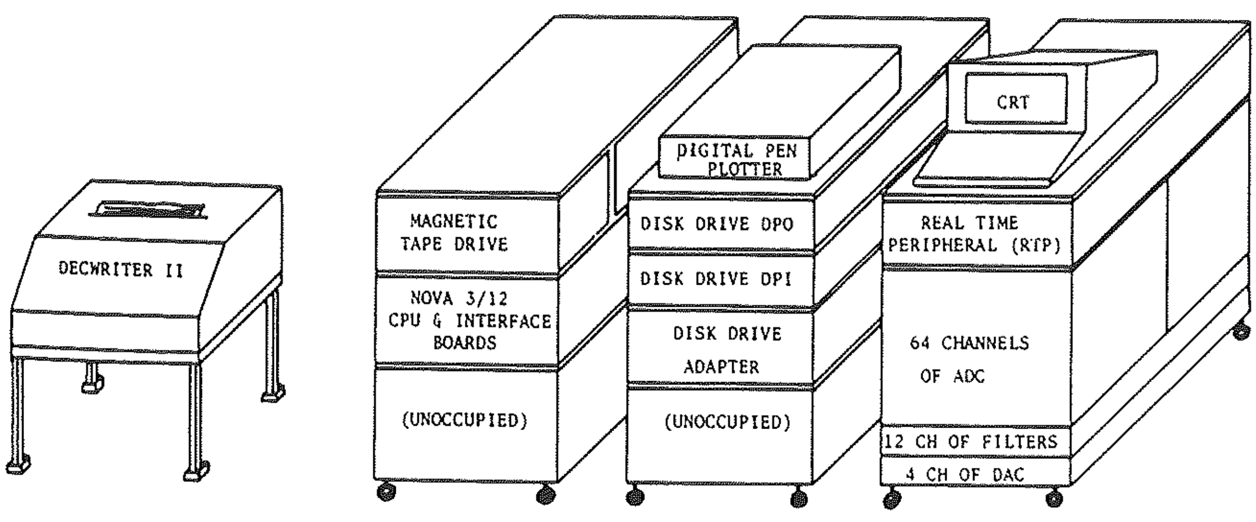

FIGURE 3. COMPUTERIZED VIBRATION TEST AND ANALYSIS SYSTEM OVERVIEW

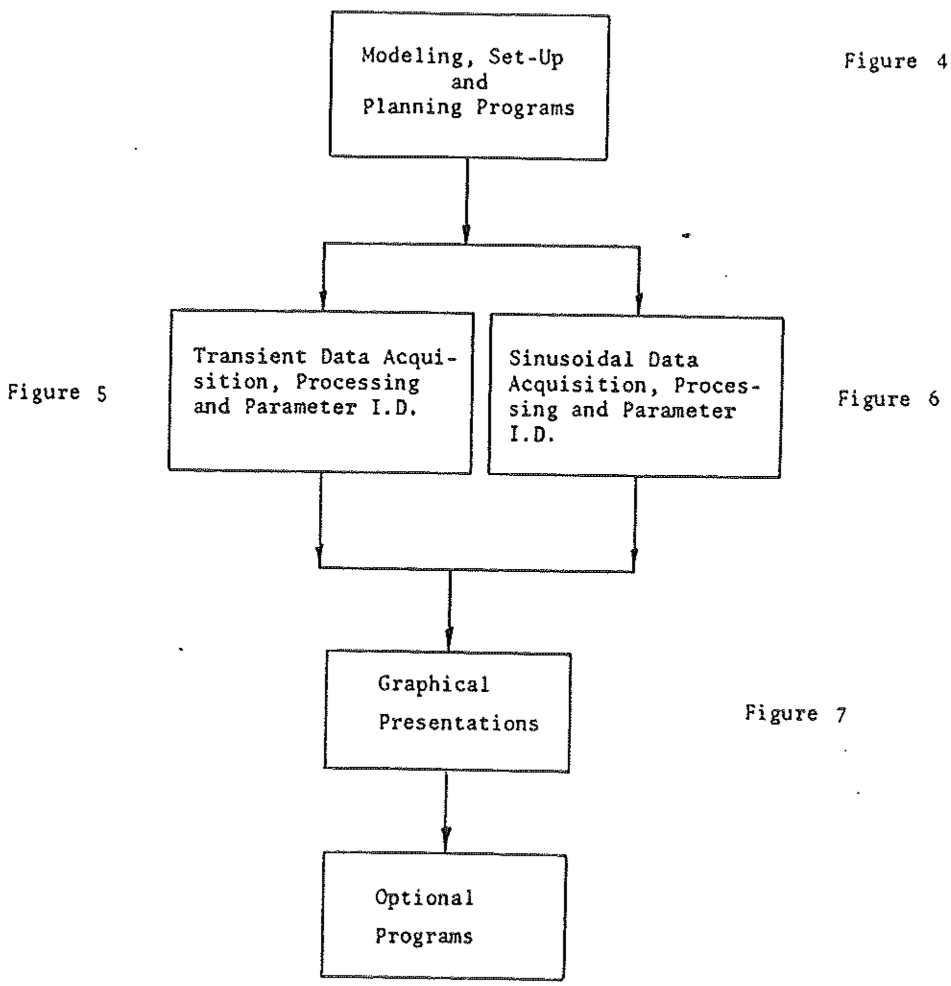

FIGURE 4. MODELING, SET-UP, AND PLANNING PROGRAMS

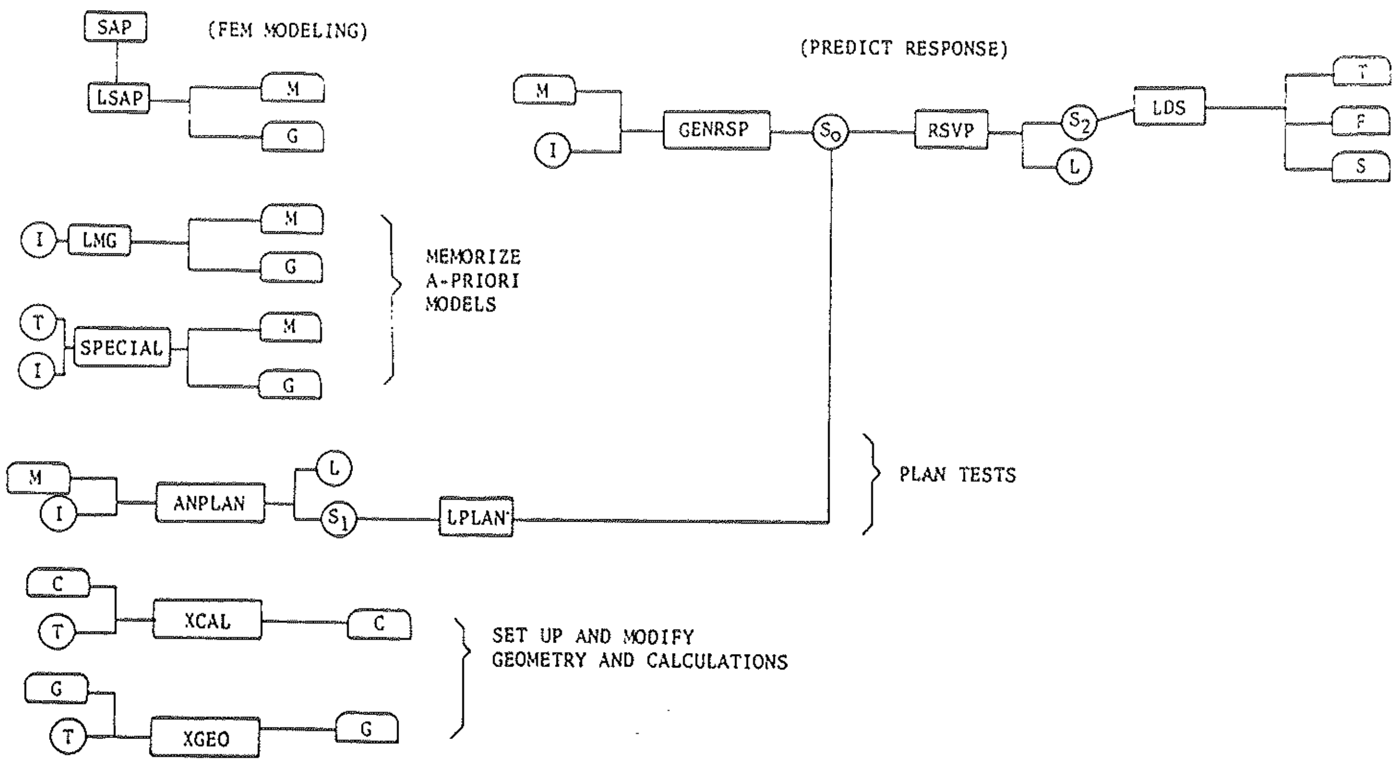

FIGURE 5. TRANSIENT DATA TAKING, PROCESSING, & PID

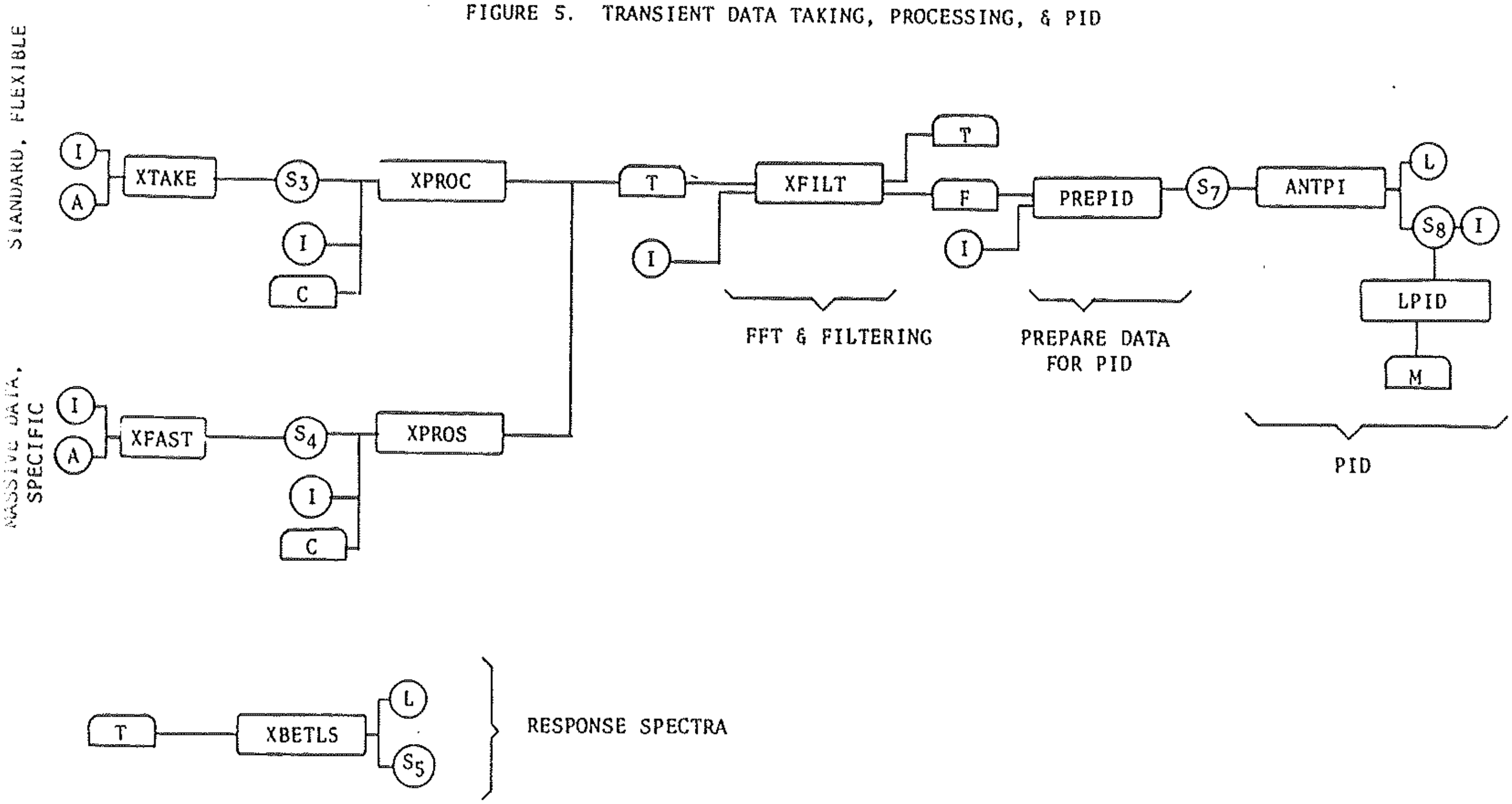

FIGURE 6. SINUSOIDAL DATA ACQUISITION, PROCESSING, AND PARAMETER I.D.

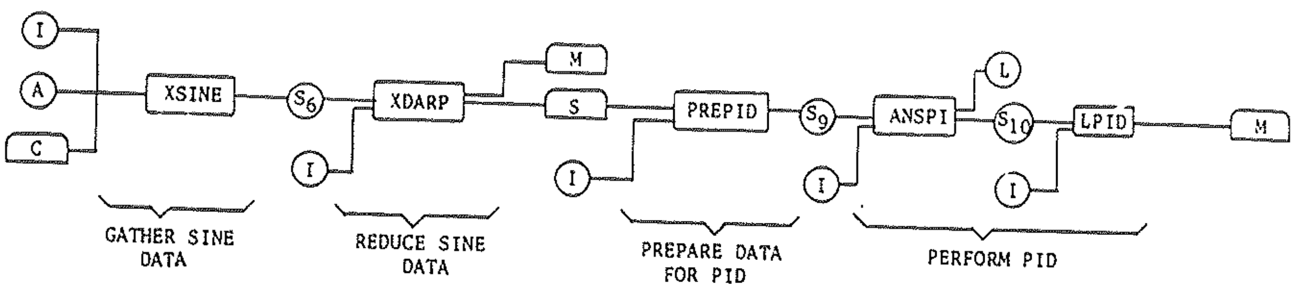

FIGURE 7. GRAPHICAL PRESENTATIONS