AUTOMATION OF VIBRATION TESTING AT THE NATIONAL BUREAU OF STANDARDS

B.F. Payne, National Bureau of Standards

B. F. Payne : B.S. in physics Lynchburg College, and M.S. in physics The American University; joined the staff of the National Bureau of Standards in 1960; worked in the areas of developing test methods for accurate electro-mechanical measurements: vibration, force, acoustic, and fluids. Current work is in the area of vibration testing and calibration using real-time computer control .

KEYWORDS: Automation, calibration, computers, measurements testing, transducers, vibration

ABSTRACT

The National Bureau of Standards has been involved in vibration testing and calibration for many years. The developments in small computers in recent years have made possible a great improvement in the quality as well as the quantity of the experiments which can be performed in a laboratory with a given number of technical personnel. Often several experiments can be conducted simultaneously by using small dedicated computers. Laboratory automation has been efficiently employed in the evaluation and calibration of vibration transducers, using both comparison and absolute measurements. These measurements are fully automated, with interactive programs for controlling the test, setting test parameters, collecting and storing data and producing reports and graphs.

This paper discusses the types of experiments and tests which are automated at NBS in the area of vibration measurements. One area of importance in vibration testing is in characterization of shaker table motion. Some data are presented on piezoelectric shaker evaluation by mapping the motion of the shaker table by using a computer controlled displacement measuring interferometer developed at NBS. Plans for future testing include computer controlled high-g shock testing and dual centrifuge low frequency vibration testing.

INTRODUCTION

The improvements in and reduction in cost of small computers have made possible a greater potential for laboratory automation. Also a trend toward standarization of interfaces has made the automation more cost efficient. Some experiments which previously were not considered for automation are now being developed into automated systems. In our laboratory, automation has been efficiently used in vibration testing, calibration, and evaluation. Studies which would not have been considered possible a few years ago (because of limited technical personnel) are now becoming more feasible. The areas of automation presented in this paper are vibration transducer frequency response measurements, measurement of dynamic displacement of a vibration surface, and a project to evaluate piezoelectric shaker performance.

AUTOMATION OF COMPARISON METHOD FOR VIBRATION TRANSDUCER CALIBRATION

The first area of automation in our vibration laboratory was the comparison calibration of vibration transducers. Figure 1 shows a diagram for this setup. The purpose of this test is to measure the frequency response of a "test" transducer as shown in figure 1. The frequency response is measured by comparing the voltage output of the test transducer to the voltage output of an internal "standard" transducer which has been calibrated by an absolute method in reference to a fundamental unit [1]. This measurement is made at intervals throughout the useful frequency range of the system, (in this case 10 Hz to 10 kHz). A desktop computer is used for this setup. The computer is programmed to set the signal generator at the desired frequencies and amplitudes for the test points. (The power amplifier is set for constant gain.) A programmable switch selects the signal to be measured: first the "standard", and then the "test" for each frequency to be

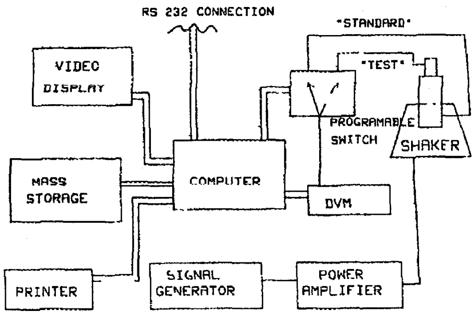

FIGURE 1 DIAGRAM OF AUTOMATED SYSTEM FOR TRANSDUCER CALIBRATION.

measured. The DVM is triggered by the computer to make measurements for each switch position. The DVM readings are stored in the computer. As the data are collected the sensitivity of the "test" transducer is calculated and displayed on the video terminal. The frequency response data are stored on the flexible disk storage at the completion of each test. The computer also prepares a test report showing the results of the test, the estimated accuracy, a general description of the test, and any comments or notes pertinent to the specific test. These comments are entered at the keyboard by an interactive program and inserted automatically into the report. The report is typed on a letter quality printer which is interfaced to the computer (RS-232C). The other equipment uses the IEEE-488 interface bus. The computer can also display the calibration in graphical form on the video display and a hard copy printer.

The system is a self-contained calibration and measurement system, programmed in BASIC, that completes the test automatically with only occasional operator checking to verify that the test is proceeding correctly. Other tasks can be performed while the testing is in progress, thereby increasing efficiency in the laboratory.

AUTOMATED MEASUREMENT OF VIBRATION DISPLACEMENT

The previous description for comparison measurements is a simple example of how a small computer can be efficiently used in a laboratory. The same work could be done manually at a cost of greater operator time. The following example of computer control illustrates an experiment in dynamic measurement not possible by manual operation.

Figure 2 shows a block diagram of this setup. The optical measurement system shown is a Michelson interferometer with one of the mirrors attached to the vibration surface to be measured. The transducer to be tested is mounted beside this mirror and the motion of the transducer is assumed to be the same as that experienced by the mirror. The forced vibration of the transducer and mirror is produced by a piezoelectric shaker. The reference mirror of the interferometer is attached to a small piezoelectric driver so that the path length difference Δ, of the two arms of the interferometer can be modulated by an oscillator tuned to a low frequency (0.4 Hz). The objective of the experiment is to measure the dynamic displacement to which the transducer is subjected. The low frequency terms of the photoelectric current produced in the detector [2] is given by:

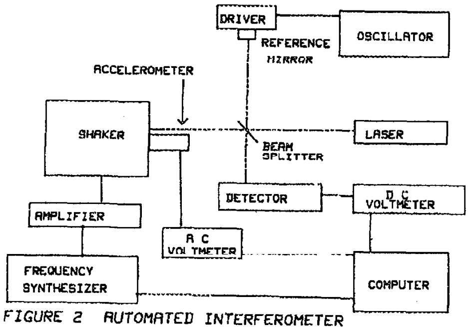

FIGURE 2 AUTOMATED INTERFEROMETER FOR DISPLACEMENT MEASUREMENT

$$I = A + B\,(\cos 4\pi\Delta/\lambda\,)\;J_0(4\pi d/\lambda\,).$$

A and B are contants, d is the displacement amplitude to be measured, λ is the wavelength of the laser light (632.82 nm), Δ is the optical path length difference of the two arms of the interferometer, J_0 is the Bessel function of the first kind of order zero.

It may be observed that for any fixed value of d, the range of variation of I is

$$I(\max)-I(\min) = 2BJ_0(4\pi d/\lambda\,) = \mathrm{Delta}(I)$$

since the cosine function varies from -1 to 1. This difference decreases as d approaches a value which makes

$$J_0(4\pi d/\lambda\,) = 0.$$

For a laser with λ = 632.82 nm, this value of d is equal to 121.1 nm, or the fringe-disappearance condition.

The procedure for automatic displacement measurement is as follows. A computer controlled, programmable digital synthesizer systematically varies d, the amplitude of vibration of the shaker, while a digital DC voltmeter reads Delta(V) from the photodetector circuit (corresponding to Delta(I) in the detector itself) and stores the data in computer memory. The synthesizer voltage is varied in small increments until Delta(V) reaches its lowest level or Delta(V) = Delta(min). At this condition the amplitude is 121.1 nm, or the fringe-disappearance condition.

The implementation of this theory is as follows. The synthesizer voltage range data for each test frequency is stored in memory of a desktop computer. The synthesizer is programmed to step through the range of voltages in 100 mV steps. At each step the Delta(V) is measured by sampling 100 dc voltage samples and finding the V(max) and V(min) and computing the

$$\mathrm{Delta}(V) = V(\max) - V(\min).$$

A dc voltmeter can be used for this purpose since, as pointed out above, the modulation frequency is only 0.4 Hz. The modulation frequency (0.4 Hz) is selected based on the sampling rate of the dc voltmeter so that the sampling window includes at least one cycle of displacement. Also at each step the transducer voltage output is measured on the ac-voltmeter and stored in memory. The range of the synthesizer voltage is selected so that displacement is less than the fringe disappearance condition on the initial voltage setting and passes through the fringe-disappearance condition at subsequent voltage settings. The final voltage steps correspond to a displacement greater than the fringe-disappearance condition. This is illustrated in figure 3a. The data are easily analyzed by reversing the sign of the Delta(V) for any value of Delta(V) past the minimum (figure 3b). The minimum measured value is not used in the analysis because it is uncertain on which side of the X-axis it belongs. (The experiment does not yield this information).

A straight line fit is used to determine the intercept corresponding to fringe disappearance. The transducer voltage for the fringe-disappearance condition is the x-axis intercept of this straight line fit.

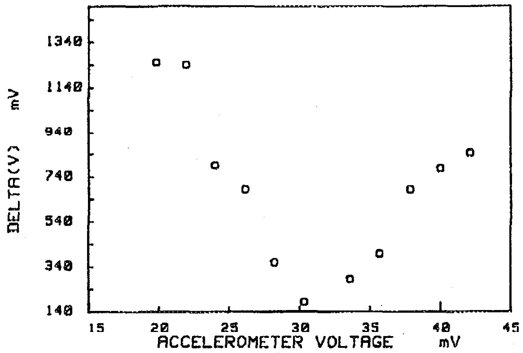

FIGURE 3A OBTAINING A MINIMUM FOR DELTA(V) USING 100 mV SYNTHESIZER INCREMENTS

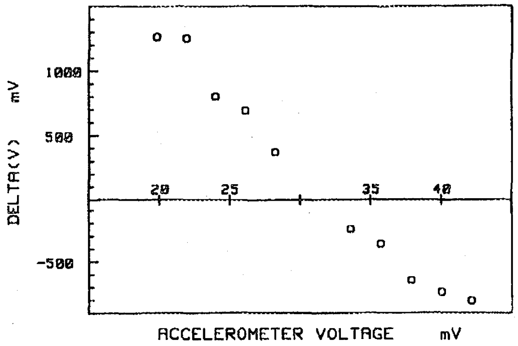

FIGURE 3B OBTAINING A MINIMUM FOR DELTA(V) USING 100 mV SYNTHESIZER INCREMENTS

Having determined a course fit using 100 mV steps, the process is repeated using 10 mV steps on the part of the cycle near the fringe disappearance as shown in Figure 4a.

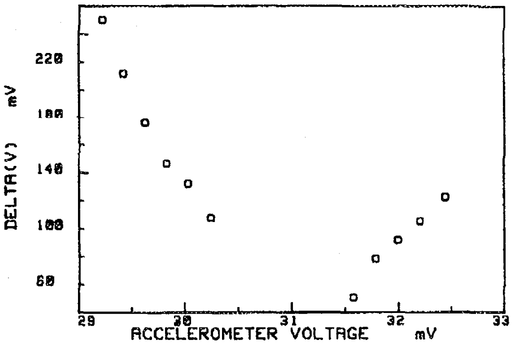

FIGURE 4A OBTAINING A MINIMUM FOR DELTA(V) USING 10 mV SYNTHESIZER INCREMENTS

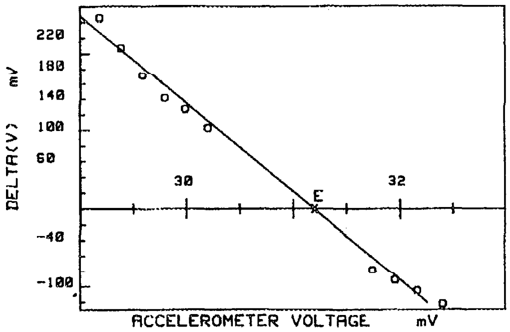

FIGURE 4B OBTAINING A MINIMUM FOR DELTA(V) USING 10 mV SYNTHESIZER INCREMENTS

The x-axis intercept of the straight line (as shown in figure 4b) gives the output from the vibration transducer at an amplitude of 121.1 nm. The acceleration is then easily computed from

$$\text{Acceleration} = (2\pi f)^2 d/g$$

where d = 121.1 nm, f is the forced vibration frequency in Hz, and g= 9.80665 m/s/s (standard acceleration of free fall). The sensitivity of the transducer is then computed from:

$$\text{Sensitivity} = \sqrt{2}\ E\ /\ \text{Acceleration}$$

where E is the rms voltage of the transducer, obtained by the intercept method given above (see figure 4b).

The transducer sensitivity is likewise determined for each frequency in the test. A typical range for the measurement system described here is 3 kH to 10 kHz.

Using this computer controlled experimental determination of transducer sensitivity to a sinusoidal forced vibration eliminates the need for many measurements using manually operated equipment [2]. The time savings for this one measurement process is impressive. The automated experiment using a relativily inexpensive desktop computer can perform measurements with the same accuracy as the manual experimental setups. The computer controlled experiment can be unattended after initial turnon, freeing time for other projects.

EVALUATION OF VIBRATION SHAKERS UNDER COMPUTER CONTROL

The computer controlled displacement measuring interferometer as described in the previous section was used to evaluate the performance of piezoelectric shaker designs. The shakers were designed to give uniaxial motion over the frequency range of 3 to 10 kHz or higher. In the interferometer described above, the assumption was made that the mirror experienced the same motion as the transducer mounted beside it. For piezoelectric shakers this is usually not the case. Due to the complex nature of the composition of the shaker, the surface of the shaker will not usually move uniformly. One of the design goals is to produce a shaker that will give uniform motion over the mounting surface [3]. Figure 5 shows the top surface of such a shaker with reflecting mirrors around the surface perimeter, the center section reserved for transducer mounting. By measuring the sensitivity of the transducer mounted at the center with reference to the 121.1 nm displacement of each mirror, one can effectively map the motion of the surface of the shaker. The spread in the sensitivity values for the six positions monitored is shown in figure 6 for two shakers with quite different design. The design goal of course would be to obtain the same motion at all points on the surface. Figure 6a shows the results of testing a rather simple shaker design consisting of two piezoelectric discs, a steel base, and a single piece of ceramic for the top mounting surface. The spread in the data shown in figure 6a is typical for a simple design (about 15% at 10 kHz). Figure 6b shows the results of an evaluation of a shaker of more complex design, sometimes referred to as a stagger-tuned shaker and described in detail in ref 3. The data in figure 6b show a maximum spread of less than 2% for any frequency tested. The automated interferometer makes the evaluation of these shaker designs possible since only a small amount of time is necessary to set up the test, the bulk of the tedious work being under computer control.

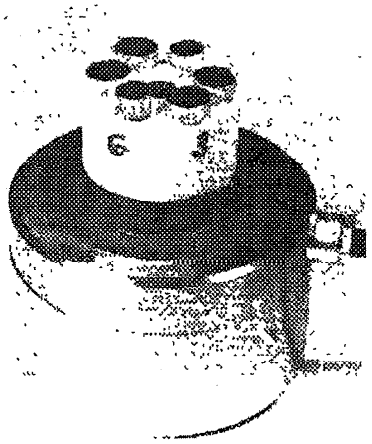

FIGURE 5 PIEZOELECTRIC SHAKER WITH MIRRORS ATTACHED.

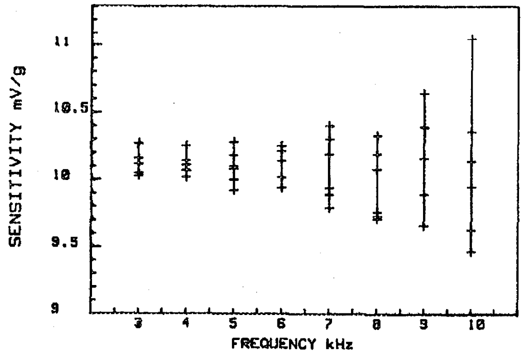

FIGURE 6A RANGE OF SENSITIVITY FOR SHAKER 1.

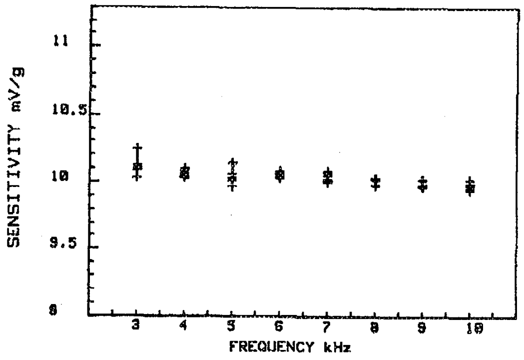

FIGURE 6B RANGE OF SENSITIVITY FOR SHAKER 2.

SUMMARY AND CONCLUSIONS

Developments in lower cost desktop computers with interfaces that readily adapt to many types of test equipment have made possible a greater potential for laboratory automation. In the area of vibration measurements, routine calibrations are automated with high level language programs that provide a convenient and self contained calibration system. Programs are quickly and easily modified as new needs arise.

A computer controlled displacement measuring interferometer has been developed that has useful applications in transducer response measurements and shaker evaluation. Under computer control, many measurements that were previously impractical are now feasible. Plans for future testing facilities include computer controlled high-g shock testing and dual centrifuge low frequency vibration testing.

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