The FFT Analyzer in Mechanical Engineering Education

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The use of an FFT analyzer as a teaching tool is reviewed. Lab experiments are described that provide a good foundation for future career applications in vibration dynamics and mechanical systems.

The Department of Mechanical Engineering is one of four departments within the Thomas J. Watson School of Engineering and Applied Science at the State University of New York (SUNY) at Binghamton. The undergraduate educational experience emphasizes the application of a wide spectrum of engineering fundamentals. Care has been taken to ensure a balanced integration of theory, design and laboratory practice through the selection and sequencing of courses within the curriculum. All undergraduates take a senior level course on Mechanical Vibrations which covers a wide range of analysis methods for multi-degree of freedom systems along with techniques for vibration control. A four semester course sequence in vibration is offered at the graduate level covering the analysis of continuous systems, noise and vibration control, random vibrations and nonlinear vibrations. The senior year mechanical engineering lab includes three experiments that provide "hands on" experience with the concepts covered in the Mechanical Vibrations course.

The Senior ME Lab Course

The laboratory course for Mechanical Engineering seniors is designed to encompass the range of subjects contained in the junior and senior year required courses. The topics addressed by the laboratory experiments cover thermodynamics and heat transfer, mechanics, dynamics, fluid mechanics, vibration and control systems. A series of twelve experiments is conducted that provide application and demonstration of the principles studied in the theory classes. One of the primary emphases of the experiments is to provide experience in the use of transducers and instrumentation in the observation and analysis of mechanical phenomena. The use of automated, computer based data acquisition systems and basic statistical methods for analyzing data are also addressed. Principles of instrumentation and measurement and the selection of appropriate instruments are additional topics covered in the process of conducting the experiments. Aspects of test methodology and experimental design are addressed in several of the experiments. Use of state-of-the-art electronic instruments such as oscilloscopes, FFT analyzers and PC based data collection systems is an important part of the senior laboratory experience.

Importance of the FFT Analyzer to Mechanical Engineers.

The FFT spectrum analyzer is an invaluable tool for mechanical engineers in today's world of measurement and analysis of mechanical systems. FFT analyzers are an essential tool in such fields as vibration and shock data analysis, machinery monitoring and analysis of complex waveforms. Use of the FFT analyzer is required in many industries, including military, transportation, aerospace, manufacturing and consumer products. Many mechanical engineers today make careers in the fields of vibration and machinery analysis; the knowledge of principles and applications of the FFT analyzer is essential for these disciplines.

FFT Analyzers in the ME Department.

The Mechanical Engineering Department faculty believes it is important for mechanical engineering students to become well grounded in the principles, application and use of FFT analyzers. The Senior Mechanical Engineering Laboratory emphasizes the measurement and analysis of mechanical phenomena and systems, including three experiments involving vibration. Two of these experiments, which involve the use of an FFT analyzer, are described later in this article. One Senior Laboratory objectives is familiarization of students with measurement transducers and analysis instruments prevalent in industry today. Training in FFT analysis techniques is an important part of meeting this objective. The FFT analyzer, along with associated transducers such as accelerometers, is the primary analysis tool used in the vibration experiments mentioned above. Additional experience in the use of FFT analyzers is obtained through work on research programs, senior projects and vibration test conducted for industry.

FFT Analyzer Requirements.

It was necessary to equip multiple experimental stations with a basic vibration oriented FFT analyzer to successfully conduct the vibration experiments. The analyzer needed to be capable of all basic FFT operations, including auto-spectrum, transfer function and coherence. It was important to have a simple man-machine interface that "spoke" in vibration analysis parameters that students could readily learn. It was desirable to have the FFT be PC based and operate in a familiar environment such as Windows 95. Operation in the PC environment would provide readily available data files or hard copy output. In view of the multiple station needs, purchase price was also a significant consideration.

The Data Physics ACE FFT Analyzer. The Data Physics ACE PCMCIA packaged 2-channel FFT analyzer met all our requirements. This analyzer is intended for use in a laptop PC, but can be installed in a desktop PC though use of a PCMCIA to ISA bus adapter from ANTEC Corporation. The ACE with the ANTEC card fit into existing desktop PCs and provided a basic FFT capability in the Windows 95 operating system environment that was familiar to students. The ACE provides an efficient man-machine interface that is specifically vibration oriented. Features of the ACE which are particularly useful in an educational laboratory environment include: 1. ability to store and recall complete experimental setups; 2. an easily understandable man-machine interface; 3. easily selected displays of analyses such as auto-spectrum, FRF and coherence; 4. the ability to store data for later analysis off-line; and 5. readily available displays of both time domain and frequency domain plots.

Vibration Mass Absorber Experiment

This experiment was developed to demonstrate the principles of a dynamic mass absorber in reducing the response of a cantilever beam to induced vibration. The experimental apparatus simulates the vibration of an airplane wing resulting from forcing functions present in the motor/propeller system. In the process of the experiment the students find the maximum vibration response of the "wing" as forced by the rotation of an out of balance motor/propeller system. The mass damper is then tuned to this frequency and mounted on the "wing." The vibration response of the "wing" with the absorber mounted is then run to show the vibration reduction effects of the absorber, and also the occurrence of new resonances below and above the original natural frequency of the "wing" system. The laboratory setup, shown in schematic form in Figure 1, consists of a 1.5 by 0.25 in. cross-section steel beam that is 24 in. long. A small electric motor (RC car motor) with an out of balance propeller is mounted near one end of the beam and the other end is rigidly clamped to the bench top. The masses and beam...
length are sized to provide a system natural frequency around 20 Hz. The motor is driven by a variable voltage power supply. Varying the supply voltage causes the forcing frequency to vary over the range of 10 to 50 Hz. Provision is made to attach the mass damper, a 100 gram mass at the end of a 1/8 in. diameter steel rod 3 in. long, to the ‘wing’ motor system at a point below the motor. The natural frequency of the absorber is changed by altering the mass or the length of the rod. An impact hammer is used to excite the mass absorber during the tuning process, with the ACE FFT being used to observe the vibration response of the absorber. This operation provides a brief introduction to the use of an impact hammer in exciting mechanical systems. Accelerometers are mounted to record the response of the wing system and of the absorber mass. An oscilloscope was formerly used to measure the output of the accelerometers. Use of the ACE FFT in the sine sweep peak hold mode provides a much more efficient means of vibration data collection than the former method of manually recording oscilloscope waveform amplitudes and frequencies. The experimental procedure consists of the following steps:

1. Measure the vibration response of the ‘wing’ system over a 10 to 50 Hz range.
2. Tune the mass absorber to the natural frequency of the ‘wing’ system.
3. Mount the tuned absorber to the ‘wing’ system.
4. Rerun the ‘wing/absorber’ system vibration response.
5. Observe the phase relations of the ‘wing’ and absorber vibration over the range of 10 to 50 Hz and note the new resonant peaks above and below the original natural frequency.

Some typical test results (1998 fall semester) are shown in the frequency versus vibration amplitude plots of the ‘wing’ system shown in Figures 2 and 3. These figures are copies of actual plots from a typical student report and were generated off-line using Windows Paint functions to print data files exported from the DP ACE FFT (accelerometer calibration was 100 mV/g). This experiment has provided a good demonstration of the operating principles of a dynamic mass absorber. Observation of the ‘wing’ system and the mass absorber vibration signals shows the 180° out-of-phase relationship which provides the vibration response reduction at the original natural frequency of the ‘wing.’ Observation of the vibration response of the ‘wing’ with the absorber mounted shows the new resonances introduced and points out that mass absorbers are only useful for reducing vibration at a critical frequency and may cause undesirable response at other frequencies.

**Vibration Isolation Material Characterization**

This experiment provides students with experience in characterizing the performance of various vibration isolation materials (see Figure 4). Isolator performance parameters such as
transmissibility, natural frequency and crossover frequency are evaluated through the use of a small vibration shaker with random vibration and the ACE FFT analyzer. Learning objectives of the experiment include: criteria for determining isolator effectiveness, test procedures for measuring isolator material response, use of vibration shakers, application of accelerometers and use of an FFT analyzer to measure frequency response functions and coherence. The experiment provides an overall experience in vibration test procedures, equipment and instrumentation, along with education in determining the performance of vibration isolator materials.

The test setup is shown schematically in Figure 5. A 2 in. square section of an isolator material is secured to the top of a 100 lb force vibration shaker. The shaker is driven by the random vibration signal from the ACE FFT analyzer. The typical frequency range is 5 to 500 Hz. Accelerometers (PCB miniature units with integral electronics) are mounted on the shaker head and on top of the isolator. Very light top loading (on the order of 10 to 30 grams) is used to reduce shaker input power requirements. The ACE FFT analyzer is used to measure the transmissibility (FRF of the shaker output to isolator top) and coherence.

The experimental procedure calls for each group of 3 to 4 students to determine the transmissibility of 6 different isolating materials. They are asked to measure the frequency and amplitude of maximum transmissibility and to measure the crossover frequency and verify that the test setup exhibits good coherence. From the test data the students are to calculate the spring constant and damping ratio of each material and draw some conclusions about the effectiveness of the material as a vibration isolator. A typical isolator FRF plot from the ACE FFT analyzer is shown in Figure 6. This plot was taken from a typical student report for the fall 1998 semester.

Prior to the 1998 fall semester, this experiment was conducted as a demonstration by the instructor due to limited availability of a stand-alone 2-channel FFT analyzer. Purchase of the ACE units and additional accelerometers and vibration shakers has provided equipment for multiple experimental stations. Now the students can get valuable “hands on” experience with use of an FFT analyzer. In previous years, students had stated that the learning experience would be enhanced if they could actually conduct the experiment themselves. Experience has shown that the students almost always learn more if they actually perform the experiment as opposed to observing a demonstration by the professor.

Future FFT Analyzer Applications

The availability of the ACE FFT analyzer at multiple experimental stations in a desktop or laptop PC configuration opens up a wider range of possible future experiments and vibration data collection applications. Some possible future uses for the ACE analyzers are: 1. data collection and analysis for vibration and shock tests; 2. collection of vibration or shock data at remote locations; 3. creation of experiments to demonstrate modal analysis techniques; 4. experiments in some of the more advanced techniques of FFT analysis; and 5. use of the FFT analyzer in machinery monitoring applications.

Conclusions

The use of an FFT analyzer in vibration experiments provides students with experience in the application of modern mechanical systems analysis tools. A primary skill developed is the ability to think in both the time and frequency domains - which seems to be a new experience for most mechanical engineering seniors. The understanding of FFT analysis tools for vibration dynamics and mechanical systems will be valuable to many of these students as they go into the workplace. The use of the ACE 2-channel FFT analyzer enables us to meet our goal of providing hands-on experience in FFT analyzer principles and operation. This educational experience provides our engineers with a good foundation for future career applications in the field of FFT analysis of vibration waveforms.