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SUCCESFUL TEACHING OF EXPERIMENTAL VIBRATION RESEARCH

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Abstract

For more than 20 years, master students have been offered a practical training on experimental vibration research by the Structural Dynamics & Acoustics Section of the University of Twente. The basic theoretical knowledge, necessary to attend this practical training, is provided for the Master part of their study and it consists of a series of lectures on advanced dynamics, measurement techniques and the concept of modal analysis. The practical training consists of performing vibration experiments on a well defined simple structure. Use is made of a digital signal processing (DSP) Siglab system, together with ME'scope as analysis tool. In order to guarantee maximal transfer of knowledge toward the participants, small groups consisting of two students are formed. These groups are supervised by an experienced tutor, who intensively monitors the progress of the practical training. It lasts one day and the students have to write down their findings in a report. In order to attend the practical training in an efficient way, students have to study the theoretical basics of experimental vibration research in advance. In order to achieve an optimal preparation to the practical, a 'virtual' vibration measurement based on Labview is developed for the next academic year. Students will thus be able to run this experiment remotely from behind their PC by activating a real-life test case placed in the laboratory. In this paper the content and execution of the practical training is described. The experience of the authors is that the vast amount of interesting educational ingredients contributes to a profound understanding of both theoretical and experimental vibration research for Mechanical Engineering students.

1. INTRODUCTION

Any motion that repeats itself after an interval of time is called vibration or oscillation. The motion is then called periodic. The swinging of a pendulum, the motion of a plucked string are typical examples of vibration. Vibrations of a mechanical system about an equilibrium position are caused by restoring forces or moments within the system. The energy delivered by an external source on such a system leads to vibrations and, if uncontrolled, may result in failure. In literature a lot of examples can be found of system failures due to so-called resonance. Mechanical failure of machinery and structures due to vibrations is a major cause of large industrial damage contributing towards 38% of all accidents. Since the collapse of the Tacoma Narrow Bridge in the USA in 1940 vibration research (especially the theory) had advanced so much, that engineers and scientists are now able to control or eliminate the harmful effects [1]. Also vibration measurements have become a standard procedure in the design and development of engineering systems. A good understanding of physical phenomena related to vibration is essential in engineering practice. These phenomena are most often studied by assuming a mathematical model whose characteristics have to be determined by measurements on the system under consideration. During the last decades the design tools have been changed radically by the appearance of sophisticated computer-based tools for both experimental investigations and mathematical modelling. The so-called experimental modal testing and modal analysis techniques were introduced. Therefore it is necessary for mechanical engineering students to become familiar with these techniques [2].

2. A BRIEF HISTORY OF VIBRATIONS

People became interested in vibrations when the first music instruments, probably whistles and drums, were discovered. Since then people have applied cleverness and critical investigations to study the phenomenon of vibrations. As early as 4000 B.C., it is believed that in India and China there was an interest in understanding music, which is described as a pulsating effect due to rapid change in pitch [3]. The Greek Pythagoras (582-507 BC) is responsible to be the first person to investigate music sounds on a scientific basis. He discovered the relation between the length and the vibrating of a string. Galileo Galilei (1564-1642) wrote the first treatise on modern dynamics in 1590. His work on the oscillations of a simple pendulum and the vibration of strings are of fundamental significance in the theory of vibration. He was inspired to study the behaviour of a simple pendulum by observing the pendulum movements of a lamp in the church. Galileo’s writings also indicate that he had a clear understanding of the relationship between the frequency, length, tension and density of a vibrating stretched string. Sir Isaac Newton, (1642-1727) was important for the theoretical description of vibrations. Newton’s second law of motion $\mathbf{F} = \mathbf{m} \cdot \mathbf{a}$ is routinely used in modern books on vibration. After Newton many scientists made big steps in the developing of the description of vibration and sound [4]. Kennedy and Pancu (1947) developed a method to separate the different vibration modes for problems containing multiple ‘degrees of freedom’, as well as several eigenfrequencies that are close together. During the beginning of the 1970s the Fast Fourier Transformation (FFT) was introduced. This very efficient algorithm, developed by Cooley and Tukey in 1965, enables digital calculators to execute the Fourier transformations very quickly. Since the beginning of the 1980s, complete systems consisting of a FFT-analyzer, a computer for post-processing the measurement data and software for performing modal parameter estimation from a set of Frequency Response Functions (FRFs) on a so-called modal model, are available. This software contains options to ‘control’ this model. This means that changes in mass, mass distribution and damping can be simulated. The effect of different kinds of excitation, as well the location of this excitation on the response of the structure can then be examined. So the modal model is an important tool to simulate different possible design changes on a computer in advance [2]. This prevents the need for a time-consuming and costly ‘trial and error’ approach.

3. THE STUDY OF STRUCTURAL VIBRATIONS

The Department of Mechanical Engineering of the Faculty of Engineering Technology at the University of Twente believes that it is important for mechanical engineering students to have a thorough understanding of the principles, theory, and application of vibrations. Therefore, about twenty years ago, the course ‘Advanced Dynamics & Structural Vibrations’ for master students was started. Its objective was deepening and broadening the knowledge of dynamical systems within the area of mechanical engineering. This covers three fields of interest:

- The dynamics of non-linear systems.
- An introduction to modal analysis and experimental vibrations research.
- A practical experimental vibration research.

The first part focuses on the analysis of solution techniques for non-linear dynamical systems, qualitative and quantitative methods, stability, limit cycles, perturbation techniques, sub-harmonic vibrations and random vibrations. Use is made of the book of L. Meirovitch [5] and lecture notes [6]. In the second part the study on mechanical vibrations is considered from the experimental point of view. The following subjects are treated:

- The concept of Frequency Response Functions. (FRFs)
- An overview of the most important measuring methods. (Fast Fourier Transform)
- Data processing and transforming measurements into a mathematical model. (curve-fitting)

The lectures are summarized in a reader [2]. Students are taught to become familiar with the process and background of determining the eigenfrequencies, mode shapes and damping values of a construction.

In part three the practical takes place. The dynamic behavior of a construction is measured and the data is used to develop a mathematical model. This model can be used for:

- Verification of the mathematical model.
- Improvement of the mathematical model by means of measurement feedback.
- Improvement of the mathematical model of a part of the construction which is difficult to describe by means of mathematics.
- Examining the effect of changes in mass, stiffness and damping values on the dynamic behavior of the construction.
- Examining the response behavior to different kinds of external excitation with different points of application.

Use is made of the manual 'Experimental vibration research' [7]. With a good preparation and professional support, it is possible to complete the practical in one day. A tutor gives instructions on the use of the equipment and background information on how the measurements should be performed. In this way the student does not have to study the complex manuals of the used DSP SigLab [10] analyzer and the modal and structural analysis software of ME'scope [11]. So there is time for discussion during the practical. To complete the course, a report of the practical has to be written, which is part of the discussion during the oral exam.

4. PRACTICAL EXPERIMENTAL VIBRATIONS RESEARCH

The practical experimental vibration research deals with an experimental analysis of the modal behavior of a free vibrating structure [8], [9]. To be sure that the students focus their attention on the measuring techniques and the background of data processing the structure has a simple geometry: a rectangular PVC plate with a slit (0.6 x 0.4 x 0.03 m) is used (see figure 1) which has 15 eigenfrequencies and corresponding mode shapes in the frequency range of 0-1000 Hz. The material is PVC because the damping can be measured easier than for a steel or aluminum structure. The advantage of a plate like structure is the fact that response measurements in the direction perpendicular to the plate will give sufficient information on bending and torsion vibration.

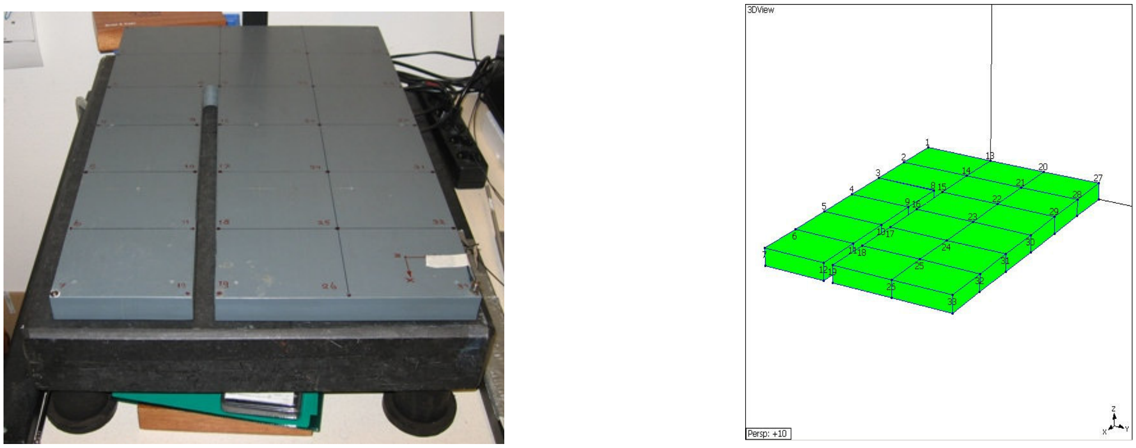
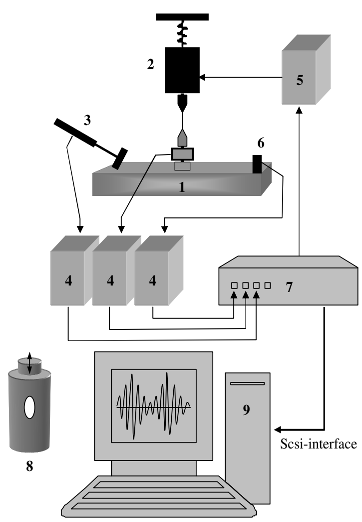


Figure 1. Picture and 3D wire frame of the rectangular plate with slit

First the students (in pairs of two) have to perform a modal analysis which consists of measuring the eigenfrequencies, damping and corresponding mode shapes of the structure. In the modal and structural analysis program ME'scope a '3D wire frame model' is built. The node points on the actual structure and on the wire model have the same location, number and direction. The rectangular structure vibrates due to force excitation at one or more points by a exciter (shaker) or an impact hammer. The response (acceleration) of the structure is measured at one or more points. To measure the Frequency Response Function (FRF) on different points of the structure the measurement setup depicted in figure 2 is used.



1-	Structure	Rectangular plate with slit of PVC
2-	Exciter	B&K 4810 / force-sensor B&K 8203
3-	Impact hammer	B&K 8202 / force-sensor B&K 8200
4-	Cond. Amplifiers	B&K NEXUS (4x charge input)
5-	Power Amplifier	B&K 2706 (for the shaker)
6-	Accelerometers	B&K 4393
7-	DSP	SigLab 4-channel Model 20-42
8-	Calibr. Exciter	B&K 4294
9-	PC with:	- MS-Windows XP;
		- Mat Lab version 6.5;
		- DSP-SigLab version 3.28;
		- MA software ME'scope VT-850;

Figure 2. Outline measurement setup

For the student it is important to have an impression of the mode shapes to be expected. Therefore FEM simulations using ANSYS are performed in advance. In figure 3 the first 5 mode shapes with their eigenfrequencies are depicted. In this way the student learns that a numerical simulation will help to prepare the experiment properly, e.g. to identify the most suitable locations for the response sensors and the excitation.

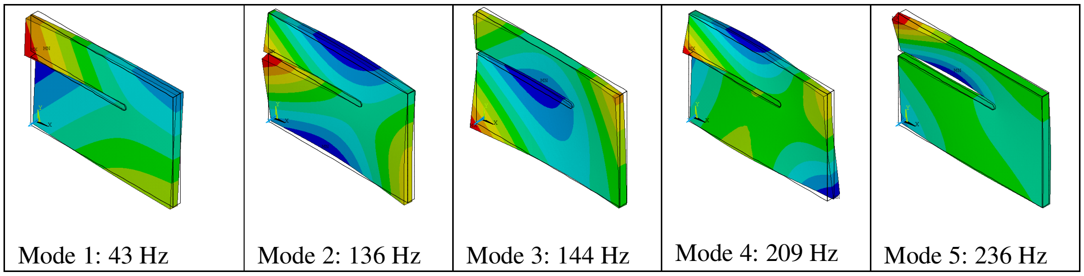


Figure 3. FEM calculation of the PVC plate with slit

Figure 4. Overview of the practical

The students learn to check for reliability with the coherence and to get a first impression of the eigenfrequencies from the imaginary parts of the FRFs. Further they have to store the data in the DSP Siglab analyzer for post-processing purposes. To determine the mode shapes the modal analysis package ME'scope is used. With this package the students have to generate a mathematical model of the structure such that the dynamic behavior of the structure can be analyzed. The modal parameters are estimated by curve fitting the set of FRF measurements. For the student it is important to know be aware of the need of curve fitting. The outcome is a set of frequencies, their corresponding mode shapes and the damping values. Each mode shape can be animated on the screen. To understand the concept of modal analysis a simple modification with a known mass is performed and simulated with ME'scope. The simulated and experimentally obtained results have to be compared and discussed. In this way the student gets a good understanding of the possibilities, the accuracy and the limitations of the measuring and (numerical) analysis techniques.

5. LEARNING ON DISTANCE

Figure 6. Measuring setup with clamped beam

To be able to optimally prepare the practical and to get experimental experience during the course the student can carry out a 'virtual' vibration measurement in advance. This service will be offered in the near future. Via internet the student can then log in on a server. Via a webcam an experimental set up can be observed, consisting of a clamped aluminum beam with a shaker provided with a force sensor and an accelerometer connected to the beam. With the Labview multifunction DAQ the shaker can be activated and the frequency response functions can be measured and compared with calculations.

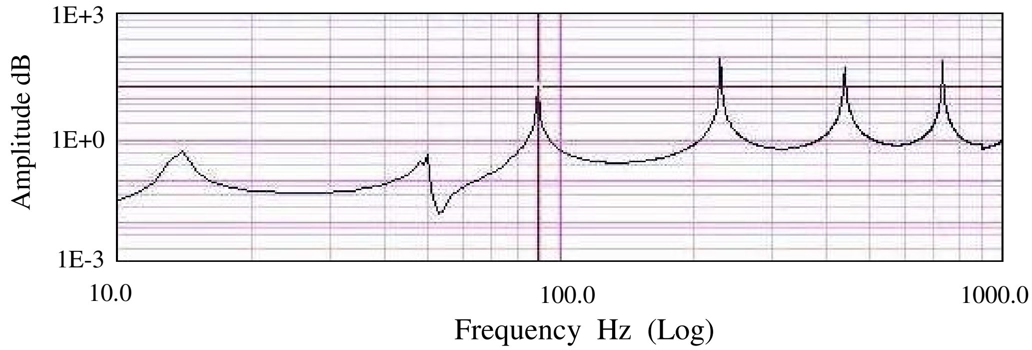


Figure 7. Display Labview: Measured frequencies of the beam

6. CONCLUSIONS

In this paper a survey of the entire course 'Advanced Dynamics & Structural Vibration' has been presented. It can be is concluded that the subsequent steps in the process lead to a profound knowledge of both theory and practice for the students. The surplus value of this one-day practical lies in the immediate application of theory and practice during the course. For the experiments, use is made of the most up-to-date hardware and software. Students are urged to prepare themselves thoroughly for this day, so that an effective exchange of knowledge is guaranteed. The active contribution of the tutor is, of course, of vital importance during this session. The experience of the authors is that this approach of the practical is mostly appreciated by the students.
In the new academic year students will become familiar with the concept of modal analysis via a 'learning on distance' practical by connecting an introductory real-life experimental set-up for measuring vibrations. The setup will be located in the laboratory and can be observed via a webcam. Several experiments can thus be performed remotely and obtained data can be post-processed by the students at home.

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