A HANDS-ON STUDENT LAB FOR THE RELATION BETWEEN UNSTEADY AERODYNAMICS AND STRUCTURAL DYNAMICS

Johan Dahlqvist, Jens Fridh
KTH Royal Institute of Technology
Stockholm, Sweden

ABSTRACT

A small plate is excited with sound from a portable speaker. Strain gauges and a fast data acquisition unit are used to measure the variations in surface strain on the plate. This is the setup of a new student laboratory to combine theory and practice within unsteady aerodynamics and structural dynamics.

To clearly visualize and offer important hands-on lessons for graduate students in a master's program in aeromechanics, a lab facility has been put together for the participants to study the interaction between unsteady aerodynamics and structural dynamics.

The facility was run the first time with students during spring this year, with successful results both in terms of measurements and learning outcomes.

NOMENCLATURE

Symbol	Description
ρ [kg/m^3]	Density
A [m^2]	Cross-section area
E [Pa]	Young's Modulus
I [m^4]	Area moment of inertia
L [m]	Beam length

INTRODUCTION

In the latest issue of Mechanical Engineering, Michael Webber elaborates on the future of the engineering profession [1], rejecting textbooks and chalkboards and promoting interactive and digital learning, together with more hands-on labs and contact with real-world applications. At the division of Heat and Power and KTH extensive effort has been devoted to digital learning, including online distance-based labs. These have many advantages, mainly in the ability to server off-campus students as well as a reduced teaching effort. Evaluations are however showing that increased hands-on activities would be appreciated and necessary for increased understanding. With this background, the hands-on experience has been emphasized in a Master's level course in measurement techniques. Now the course labs have found an addition in as a strain gauge lab, discussed in this paper.

SCOPE

The practical part of the lab activity is intended to be performed during a 3-hour period, with additional time for preparation and evaluation reaching a total of 10 hours.

The target practitioners of the lab are graduate students, performing Master's studies within aero-elasticity. The lab is part of a measurement techniques course, and the students have by the point of the lab handled the fundamental theoretical points on the subject, and are hence prepared to utilize these skills. The level of practical experience on the other hand, varies greatly within the target group, and is not in focus in previous courses. It has thereby been identified as appropriate to at this stage emphasize further on practical experience and in combination give an opportunity to utilize obtained theoretical points.

METHOD

The lab procedure is defined as follows. Detailed instructions are sent to the participants well in advance of the lab. The instructions contain detailed step-by-step guiding of how the lab should be performed practically, but also the necessary theoretical background to calculate the Eigen frequency of a beam with one fixed end. Prior to performing the lab, it is asked of the participants to calculate the Eigen frequency of all the available specimens, which are defined in terms of material properties and dimensions. Also, a set of multiple-choice questions are given. The responses may be checked either interactively or in person as the lab occasion starts.

During the lab, students will themselves glue the strain gauges to the specimen, solder the connecting wires and connect the cables. They will then set up the data acquisition software according the given instructions. With the preparations ready, students will sweep through a relevant range of frequencies with the portable speakers. The frequency range is selected by the students, based on their calculations prior to the lab. Pinging the plate to excite the Eigen frequency is also recommended. The lab setup is seen in Figure 2.

Rudimentary post-processing tools are handed out to be run in MATLAB, allowing the students to evaluate the results and compare theory with practice in a report which is written and handed in to evaluate the complete understanding of the different lab elements.

Theoretical background handed to the practitioners include the derivation of the equation for calculating the Eigen frequencies of a cantilever with one fixed end as stated in Eq. 1.

$$\omega = \frac{\xi^2}{L^2}\sqrt{\frac{EI}{\rho A}} \qquad \text{Eq. 1}$$

Here, ξ can be obtained as a positive root of the transcendental equation (Eq. 2).

$$cos\xi cosh\xi = -1 \qquad \text{Eq. 2}$$

The first three roots 1.8751, 4.6491 and 7.8548, represent the first three harmonics, and are target of the investigation [2].

The working principles of strain gauges are covered in the course which the lab takes place. The specific variant selected for the exercise is LY11-6/120A from HBM; a 120 Ω strain gauge with a grid dimension of 6 mm x 2.7 mm. Distinguishing feature compared to a standard strain gauge is that this variant, instead of incorporating soldering points, has fine leads to be soldered on a separate substrate, as shown in Figure 2b. The mounting operation is similar to standard, but since the soldering is not done on the strain gauge itself, this is more suitable for beginners. A mistake does not mean that the strain gauge needs to be replaced.

Common practice in wiring resistive sensors is covered, where the strain gauges should be arranged as Wheatstone-bridges. It was identified as beneficial to use two sensors in tandem to increase signal strength and quality, as shown in Figure 1. Also single-sensor including bridge balancing with a variable resistor is covered in the preparation.

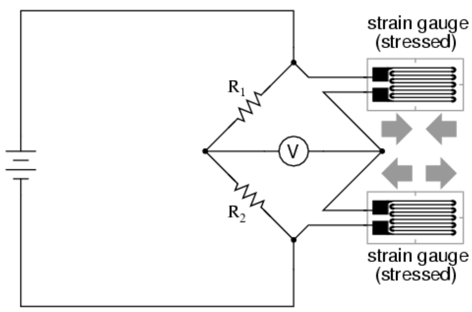

Figure 1: Strain gauges Wheatstone bridge arrangement

The data acquisition is performed with a DTS Slice Pro unit allowing up to 1 MHz sampling frequency and internal amplification. A sampling rate of 20 kHz has been selected for this application.

The excitation source used in this experiment is simple USB-powered portable speaker with 3.5 mm connection to a computer. The labeled frequency range is 100 to18000 Hz and a power of 4 W. These are powered by a laptop computer, which is also used to control the data acquisition system. The frequency source is obtained through a website which allows simple frequency sweeps [3].

Specimens which have been used in this iteration of the lab have been steel plates of 0.65 mm thickness and 25 mm height, with lengths varying between 100 to 160 mm.

RESULTS

The lab was successfully carried out during spring 2016 for a batch of 12 participants. The participants were divided into groups of 3-4 persons. A separate preparation event was included, offering the possibility to glue and solder the strain gauges. This was found highly necessary, since it took around 2 h to instrument the two specimen, for participants without previous practical experience. Later, the measurements could be completed within 1 hour.

To present an example, the results of one group will be shown [4]. Table 1 shows the obtained frequencies of one of the specimen. A highly satisfactory resemblance between theory and measurements is obtained. Calculated frequencies are consistently slightly higher than measured, which is also by the group elaborated to be due to the influence of the strain gauge itself. Also, material in terms of density and Young’s modulus are also given with a similar order of accuracy.

Certain resonances could not be picked up, and is elaborated to be due to the placement of the strain gauge coinciding with a resonance node. Figure 3 shows a FFT of a particular measurement from the series. Clear spikes are coinciding with the calculated resonance frequencies. A series of additional low-frequency spikes are seen together with the 1st harmonic, and may be the result of a truncated signal being used.

Table 1: Example results of identified resonance frequencies found through frequency sweep and ping test, compared to calculated resonances. [4]

Blade 2	ω_1 [Hz]	ω_2 [Hz]	ω_3 [Hz]
Calculated	40.7	250.1	713.8
Sweep	39.65	245	697.6
Ping	39.8	-	695.8

A course evaluation was filled in by the students for the first course event when the lab was utilized. Results are summarized in the diagram in Figure 4, with the question categories along the edge, and the deviation from the average result highlighted in red or green.

High scores were received on questions related to how the course activities helped with the learning, understanding of key concepts, as well as learning from concrete examples. Also the learning was done through collaboration with others, as seen under Belonging (Figure 4). The strain gauge lab may have some part in these results. Unfortunately, the same evaluation was not performed for the course event before the lab was implemented, and a comparison is hence not possible. Lower results were obtained on questions regarding the individual work and exploration of the subject, as seen under Self Exploration in Figure 4. This may indicate that the preparation work and evaluation of the results may be further extended, leading to a deeper self-obtained understanding. The immediate feedback from the students as they were performing the lab showed a positive and enjoyable experience, with appreciated hands-on elements.

FUTURE WORK

In coming iterations of the lab activity, several modifications are planned to be implemented. A simple yet beneficial addition, both for the understanding of the results, as well as improvement of the measurements, is that the participants perform a FEM analysis of the specimen, in preparation. This will allow visualization of the vibration modes, but more importantly, the measurement location may be selected precisely to an area of high predicted strain.

A second improvement is a more emphasized focus on the strain amplitudes, which then should be translated to stress. This information may be used to practice HCF predictions according to the standard methods used for stressed components such as turbine blades. In the current iteration, strain amplitudes were mainly used to identify the harmonic modes, and the levels were not further discussed.

An additional improvement of the measurement setup is to monitor the excitation signal. A simple variant would be to extract the signal input to the speaker for monitoring in the DAQ. It is however not certain that the signal would correspond to the excitation, due to both the speakers' properties and the physical distance between speakers and the specimen. A more accurate method could be to monitor the sound with a microphone or unsteady pressure transducer.

CONCLUDING REMARKS

In summary, a successful lab facility has been developed and tested. Relatively simple improvements have been identified, and may be implemented in future iterations. A positive impact on the learning experience of the group of students first to test the lab could be seen. The ambition with this paper is thereby to inspire similar labs to be developed where appropriate.

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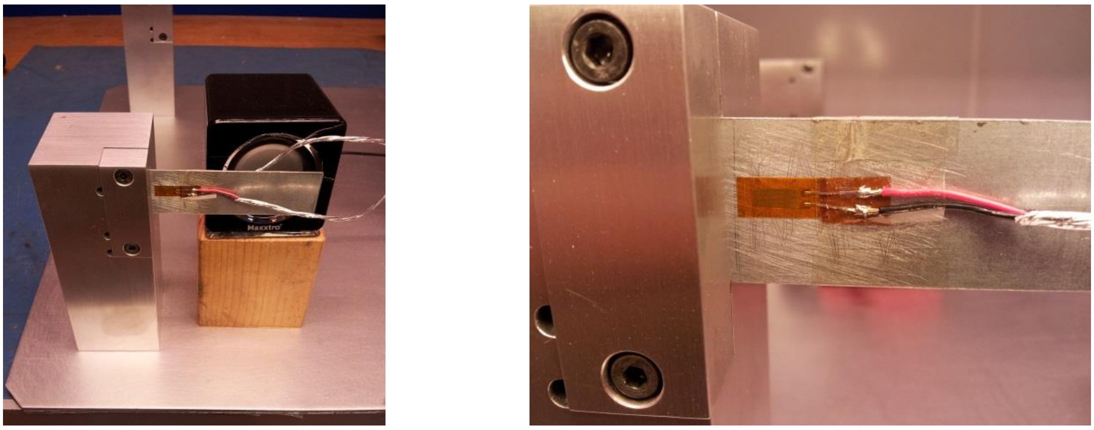


(a) *(b)*

Figure 2: Strain gauge lab setup (a) with speaker and instrumented specimen, and one strain gauge on each side of the specimen. Detail of instrumentation shown in (b).

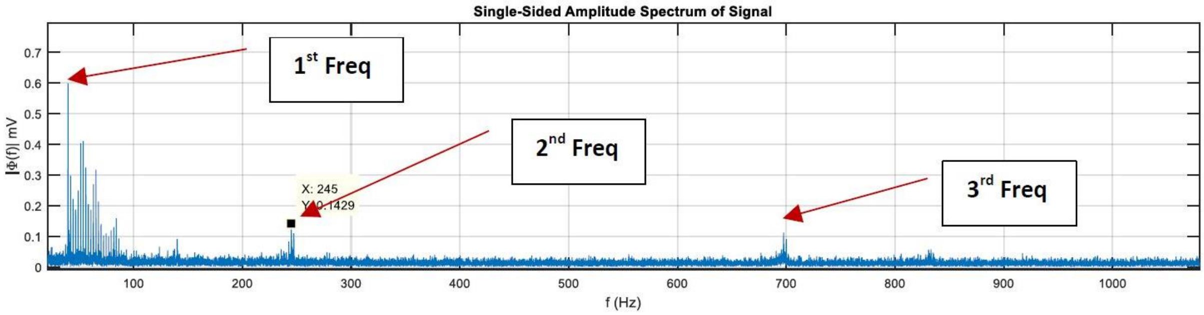
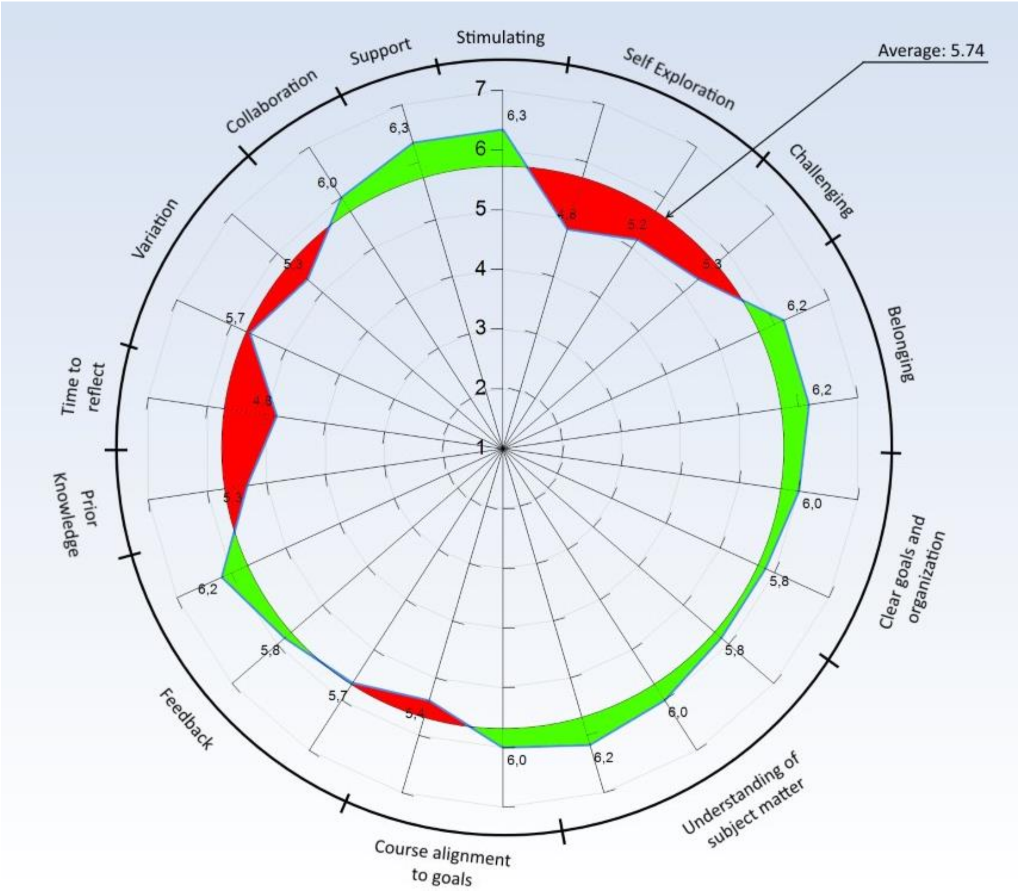


Figure 3: Lab group measurement result.



(a) *(b)*

Figure 4: Summary of course evaluation results.