RC-car as a Small-scale Measurement Setup for Physics Labotory Course

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Keywords: Physics laboratory, Oscillation, Engineeringeducation

INTRODUCTION

At Tampere University of Applied Sciences showing students the applicability of physics is seen as an important goal in engineering education. Physics lectures and laboratory exercises are tailored to the needs of different degree programmes as much as possible. A new laboratory assignment was designed for vehicle engineering students demostrating mechanical oscillation. In the assignment students measure spring constant, damping constant, and amplitude resonance frequency for a small RC-car suspension. Resonance frequency is measured with two different shock absorbers, ones without hydraulic fluid and ones properly filled with hydraulic fluid.

It is assumed that the RC-car suspension follows the equations of damped harmonic oscillator. These equations are difficult to grasp at first and it can be difficult to understand the meaning of different physical quantities and how they are related to each other. The main point of this new assignment was to concretize students' understanding on the significance of these quantities, which has been shown to be an important aspect for the students [1].

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In this article we describe the measurement setup and goals of the measurement and analyze students' apprehension on the subject. Common misconceptions and difficulties are collected and possible improvements are provided.

1 MEASUREMENT SETUP AND GOALS

1.1 Review of a forced oscillator

An oscillator with mass *m*, spring constant *k*, and damping constant *β*is forced to oscillate with sinusoidal force *F* that has an angular frequency ω. Second order differential equation describing its motion in *x* direction is

$$m \cdot \frac{\mathrm{d}^2 x}{\mathrm{d}t^2} + \beta \cdot \frac{\mathrm{d}x}{\mathrm{d}t} + k \cdot x = F \cdot \sin(\omega t). \qquad (1)$$

In this laboratory exercise the spring constant *k* is the effective spring constant for the whole back suspension of the RC-car, and the same applies to damping constant. Mass *m* is assumed to be axle load of the rear axle. The relevant particular solution to equation (2) for the underdamped case is

$$x(t) = \hat{x} \cdot \sin(\omega t), \qquad (2)$$

where the amplitude can be written as

$$\hat{x} = \frac{F}{m\sqrt{(k - m\omega)^2 + (\omega\beta)^2}}. \qquad (3)$$

From *Eq. (3)* it is apparent that amplitude of the oscillation depends on the frequency of the force and on the damping constant. Amplitude resonance occurs at frequency given by equation

$$f_R = \frac{1}{2\pi}\sqrt{\frac{k}{m} - \frac{\beta^2}{2m^2}}. \qquad (4)$$

As can be seen from *Eq.(3)* and *(4)*, increased damping constant *β*reduces the amplitude and causes the resonance frequency to decrease.

1.2 Measurement apparatus

Measurement setup is shown in *Fig. 1.*and 2. Front wheels of the car are kept in place with movable stoppers while the back end of the car is placed on a moving platform. Platform is moved up and down sinusoidally by a shaft connected to an electric motor with variable speed.

Motion of the car is measured with an ultrasonic motion sensor which is connected to a datalogger. Sensor detects the position of the rear spoiler that has a smooth surface.No remarkable interference of echoes from other surfaces were observed. Signal drawn by the datalogger represents *Eq. (2)* that is shifted vertically depending on the position of the sensor itself.For each different motor speed the frequency and amplitude values can be read from the datalogger screen.Example of the signal is presented in *Fig. 3.*It is also possible to export the data from the logger for further analysis on computer.

Fig. 1. Measurement setup.

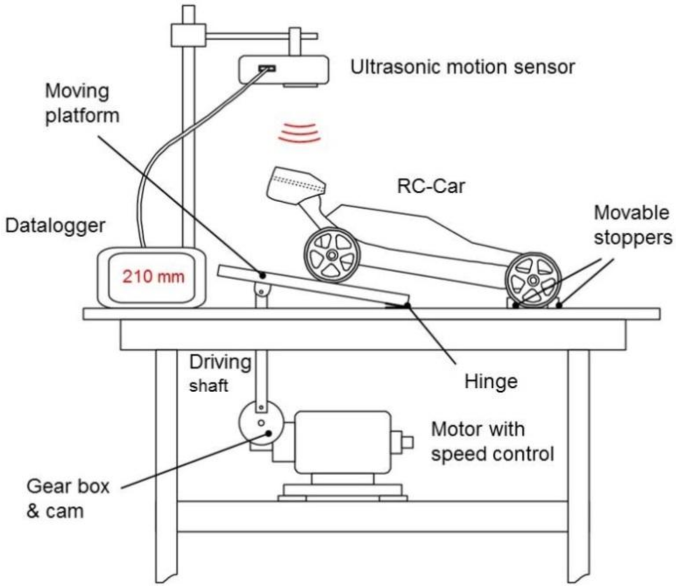

Fig. 2. Diagram of the setup.

RC-car used was given to the Physics Laboratory by the laboratory staff of the Vehicle Engineering programme. Model of the car was 1:10 scale Kyosho Inferno VE Race Spec and the rear suspension set model was Kyosho MT113B, which has a hydraulic mono-tube shock absorber. Specific silicone oil produced for RC-cars was used as hydraulic fluid. Datalogger was Vernier LabQuest 2 and the ultrasonic motion sensor attached to it via USB-cable was Texas Instruments DBR2 with the resolution of 1 mm.

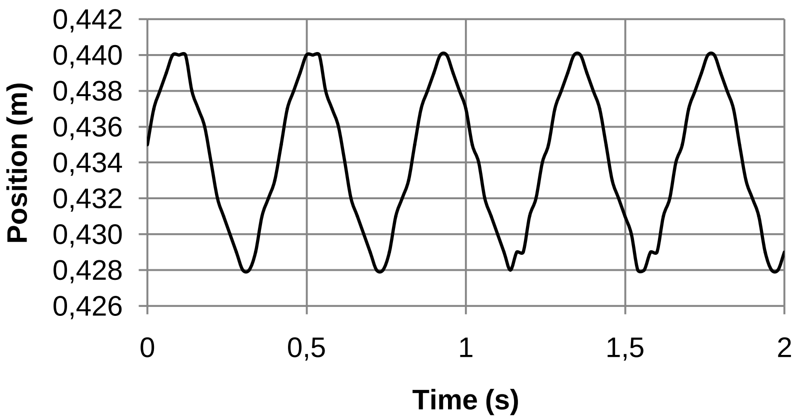

Fig. 3. Example signal for the spoiler position.

1.3 Carrying out the laboratory exercise

The students were required to read the laboratory instructions beforehand so they would already be familiar with the assignment before the actual measurements. Instructions were available online and usually students had either printed copies or looked up the instructions with a tablet or a mobile phone. As there was only one apparatus the students were required to work in groups of 6 to 8 people. Even when they all had the same measurement data, they handed in their laboratory reports as pairs.

Teacher only gave brief instructions and practical tips before the measurement. This was done deliberately to later analyze if the students themselves are able to associate the phenomena they've seen with the equations they should be familiar with. After this students completed the measurements independently with the written instructions, but before they left the laboratory the instructing teacher checked their results to see if some parts had to be repeated or if some important detail was missing. Teacher was available at all times in case the students had any questions or problems.

Students started the assignment by measuring the effective spring constant for the whole back suspension of the RC-car by measuring how much the chassis is displaced by different weights. Main part of the measurements was studying the resonance frequency with two sets of shocks absorbers. First the students made a series of amplitude measurements with different frequencies of the driving force with poorly damped suspension. After this they repeated the measurement with properly damped suspension.

1.4 Exemplary data from the measurement

Before giving the assignment to students the authors ran the measurements themselves and the results for the resonance frequency measurement can be seen in *Fig.4*.

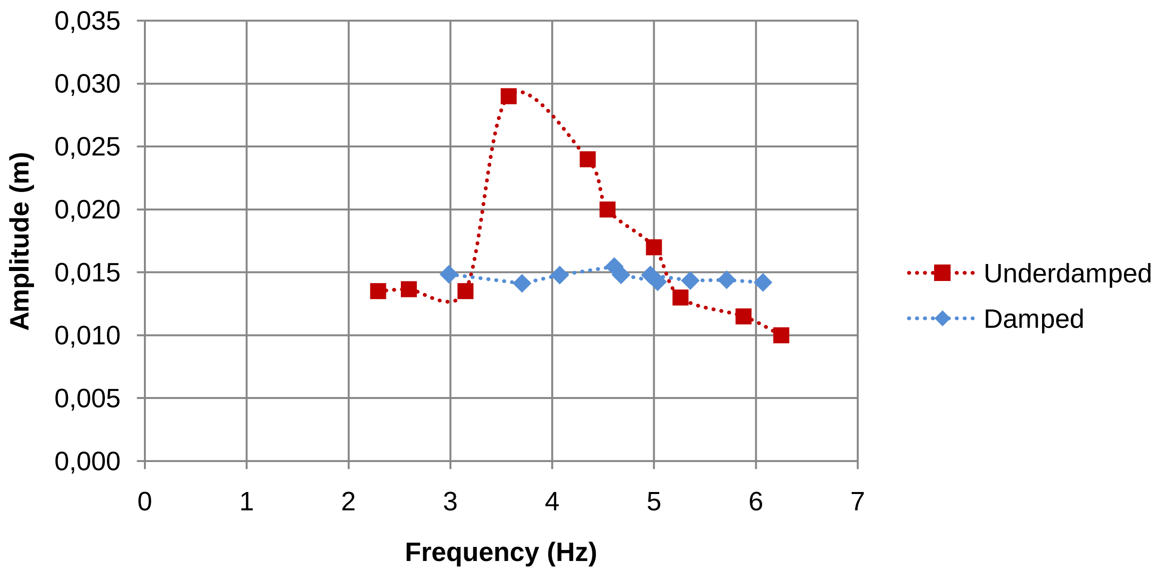

Fig. 4. Amplitude resonance measurement data for damped and underdamped suspension. The sharp resonance peak is difficult to capture completely. Dotted lines are drawn here as a visual aid and do not represent physical behavior.

Results in *Fig.4.* represent exactly what we wanted the students to see. With insufficient damping the car starts to resonate with the driving force and we see the peak in amplitude. When these shock absorbers are replaced with properly damped ones, we no longer get the resonance. Amplitude of the properly damped case is the amplitude of the moving platform. This difference between shock absorberswas also clearly visible to the naked eye.

2 ANALYZING STUDENTS' KNOWLEDGE

2.1 Student group

There were 39 students enrolled to this course implementation and all of them were second year students in the vehicle engineering degree programme. Side by side with the laboratory course they attended lectured course on oscillations and waves. All of the needed concepts and equations of oscillatory motion could be found from the text book used in the lectured course. Some of the equations were also given in the laboratory instructions.

2.2 Pretest findings

At the beginning of the laboratory course implementation 33 students answered to a short pretest about vehicle suspension systems and oscillatory motion. Questions where

1. What are the main purposes of a vehicle suspension system?

2. What is the meaning of a spring constant?

3. What is needed to produce an oscillatory motion?

4. How does increased damping affect the natural frequency of an oscillator?

5. What does resonance mean? How could you observe resonance in a passenger vehicle?

As was expected the answers varied greatly. Often students gave almost trivial everyday answers and very few gave answers that could be considered to be professional. Verbal answers from questions 1 to 4 were grouped in several categories and occurrence of each category can be seen in *Fig. 5-8.* Total number of answers for each question can differ from 33 as some students gave answers from several categories.

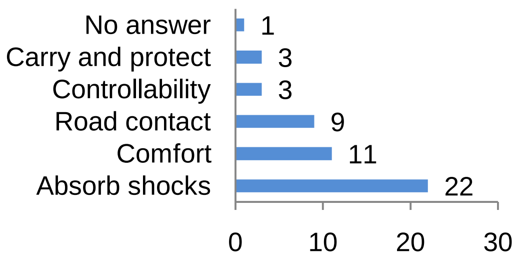

Fig 5. Purpose of suspension?

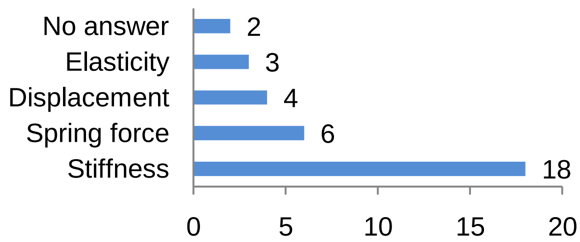

Fig 6. Meaning of spring constant?

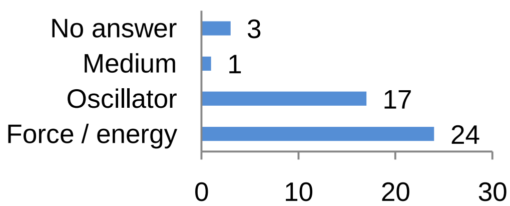

Fig 7. What is needed for oscillation?

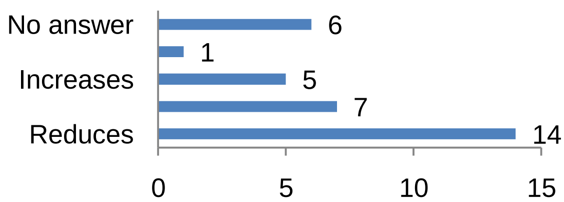

Fig 8. Increased damping and frequency?

Purpose of the vehicle suspension was seen simply to absorb vibration and increase ride comfort. About one third of the students included some type professional viewpoint by talking about the support and controllability suspension gives or about the importance of road contact. Perhaps it would've been a better idea to ask about the purpose of springs and shock absorbers separately. Spring constant was correctly understood to mean the stiffness of the spring, how easy or difficult it is to stretch or compress the spring. Few students described it as a some kind of internal force that the spring has at its use.

None of the students actually gave exact answer to the question about oscillatory motion and what is needed to create it. "Energy" is consider to be a trivial answer as is the fact that there needs to be something that oscillates. The fact that there has to be a restoring force that is trying to bring the oscillator back to equilibrium was missed in every answer. In about half of the answers the effect of increased damping on the frequency was correctly understood. Perhaps students didn't look this question from the vehicle viewpoint, as only one student commented specially on the vehicle suspension systems and said thatdamping should be critical.

Question 5 is most closely related to the laboratory assignment and different answer categories for it are presented in *Fig. 9.* Resonance was often described simply as some kind of vibration or oscillation or something happening between two different objects. Only 9 students out of 33 said that a certain frequency is associated with resonance and few of them mentioned that there is a driving force that causes the resonance. Answers to the question how to observe resonance were usually along the lines of "I can hear a rattle". In a handful of answers certain parts of the vehicle were mentioned to vibrate.

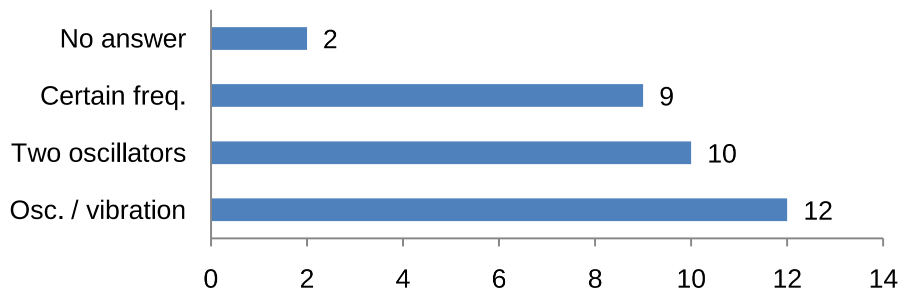

*Fig. 9.*What does resonance mean?

2.3 Findings from laboratory reports

Students are required to write a formal laboratory report where they present their results and theoretical background for the assignment. They are also asked to link the laboratory assignment to their own professional area. Formally they write excellent reports. They know the structure and format and usually their reports are presentable, but most often the problems are in the actual substance. Name of this laboratory assignment was Suspension of a RC-car, but almost no one mentioned vehicle suspension systems and their purpose in their reports. Discussion about these topics were covered in 3 reports out of 19.

Many of them presented few equations for the spring force and damping, but practically no one wrote explicitly about forced oscillation even if the *Eq. (4)* was presented. Students were also giventhe names of couple of road vehicle suspension testing standards as a hint for background material, but again those got even a mention in three different reports. Lastly students were asked to ponder how well the results of spring constant and resonance frequency can be scaled to a real vehicle. In only one report this was approached in a quantitative manner.

Importance of damping in vehicle suspension was not clearly understood. Often students came back to the instructing teacher with questions like “We didn’t see any resonance with proper damping installed, why!?” Not seeing the resonance was the whole point of the exercise. Many students saw the resonance in their data even if the imagined amplitude peak was almost within the margin of error for the measurement, and reported it as such. Teacher could have given this answer beforehand but taking away the students’ need to think for themselves renders the whole exercise a bit pointless.

3 DISCUSSION

3.1 Emerged challenges

Clearly students were not familiar with the concept of forced oscillation. They couldn’t connect the things they have been talking about in the lectured course to ones they saw in the laboratory exercise. They didn’t have the understanding how damping should affect the resonance. Students were often unable to link their results to the real world. They didn’t have a clear view on what kind of numbers should be correct for real vehicles. We believe the main problem is that most students aren’t really engaged in the laboratory work even when the assignment is tailored to support their professional growth.How could we make them try harder?

3.2 Suggested improvements

Students need to be better prepared for the laboratory assignments so they know what kind of phenomena they are going to study in the laboratory. If the students are not naturally engaged in learning, one possible solution is giving out mandatory pre-lab assignments that prepare them for the measurements and ease the reporting part of the assignment. Forced oscillation and resonance could be demonstrated in an undamped case with a mass on a spring at the beginning of the laboratory session. Simultaneously going through the equations describing the motion of the mass might put them in the right mindset. They could then try to work out the damped case by themselves. It is still important to make the applicability of physics clear to the students. The application message could perhaps be better blended into the theoretical part of the instructions [2].

There are a couple of potential methods to better engage students. In this implementation the laboratory assignment was given to the students in a cookbook format where students followed a well-written directions through the whole measurement. Instead we might present the assignment as a design lab [3] where the instructions would give the end goal and general guides on how to approach the experiment. This approach could also make students think about instrumentation and limitations of theoretical models which are both seen as fundamental objectives of engineering instructional laboratories [4].

Another alternative might be the recurrent method [5] where in the so called forward study students review the phenomenon, do the experiment and analyze their data to determine the value of an unknown constant. They would then do the backward study where they use their previous results to predict the value of a parameter that could finally be measured. As an example it would be possible to use the resonance frequency to find out the damping constant and then predict the frequency with different spring constant.

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