Investigating aids for teaching the balancing of rotating masses

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ABSTRACT: In this article, the authors describe the use of teaching aids for teaching the balancing of rotating masses. The objective was to equip the student with a three-dimensional visualisation of the topic, thus providing them with an in-depth understanding of the problem. The aids were designed and developed by final-year students of a Bachelor of Engineering (mechanical) programme as their final year project. The aids took the form of a physical and virtual model. The physical model was a toy-like structure that demonstrated important aspects of the topic, and the virtual model compared a balanced with an out-of-balance rotating shaft. An Excel workbook and a Matlab program were created to assist students. The aids were tested in the Mechanics of Machines class and the results indicated that students improved their interest and understanding of the balancing of rotating masses.

INTRODUCTION

Balancing of mechanisms is a well-known problem in mechanical engineering. The dynamic forces resulting from rotating imbalances are damaging to the rotor, bearings and the supporting structures of machines [1]. It may also be a source of noise, wear and fatigue of the machines. Rotating imbalance is the result of the unequal distribution of the mass of a rotor about its centreline. It is commonly encountered in rotating machinery in mechanical and electromechanical systems. It includes centrifuges, fans, pumps, machining tools, rotors of motors and engines, industrial turbomachinery, and many other rotating parts of systems [2]. Therefore, mass unbalance - the condition where the centres of mass and rotation differ - is one of the most common sources of vibration in rotating machinery.

Although vibration may be caused by a range of conditions, for example bent shafts, foundation failure, misaligned couplings or bearings, the unbalance is the most common source of high vibration that affects rotating equipment [1][3]. The resolution of this problem consists of the balancing of systems and components, which is vital to ensure reliable and safe operation.

Balancing is the process of improving the mass distribution of a body, so that it rotates in its bearings without or with much reduced, unbalanced centrifugal forces. The intention is to align the principal inertia axis with the geometric axis of rotation by the addition or removal of material [2][4].

A sound knowledge of the mechanics of rotating imbalance is crucial for an aspiring mechanical engineer. Balancing rotating machinery is a part of any classical course in the theory of the mechanics of machines [2][5-7]. However, despite many textbooks on balancing rotating masses, the students continue to have difficulty in understanding this problem.

MASS UNBALANCE AND CORRECTIVE PROCEDURES

Balancing requires removing or adding mass to reduce the imbalance in the rotating element (see Figure 1). Where the imbalance is sufficient to overcome friction, a rotating element will turn until its centre of mass sits directly below the axis of rotation.

By mass addition or removal, the centre of mass of the rotating element is moved closer to the axis of rotation, and therefore the rotating element will no longer move until the centre of mass is below the axis; it will stay still, since the centre of mass is located at the axis of rotation. This is called static balance. However, it does not eliminate any couples that are produced when the shaft rotates. In dynamic balancing of a system, corrections must be made to eliminate both the imbalance forces and moments (see Figure 2). Generally, alterations are carried out at two separate planes along the axis of rotation. Masses added off axis in two separate planes allow for any moment perpendicular to the axis to be cancelled.

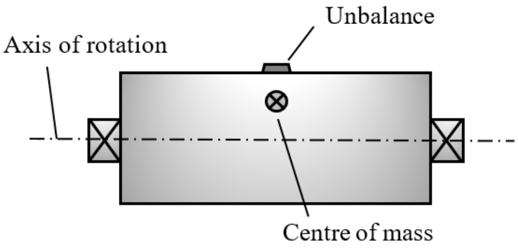

Figure 1: Static balance.

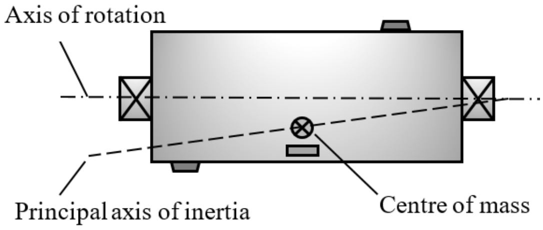

Figure 2: Dynamic balance.

The balancing of rotating masses is essential for rotating machinery in industry, e.g. the balancing of car wheels. There are commercial machines for balancing rotating systems. Although it may be useful for students to see such machines, it is inadequate for explaining the problem to students. Students need something with an educational purpose, to help them visualise and understand the problem.

BALANCING ROTATING MASSES IN ENGINEERING CURRICULA

Balancing of rotating masses is a well-known problem in the field of mechanical engineering; the dynamic loads cause noise, wear and fatigue of the machines. It is one of the classical elements of mechanical engineering curricula.

Balancing of rotating masses may be taught as a separate topic, normally part of a course on the theory of machines [8]. The topic covers fundamental vibration concepts, design, experimental techniques, data analysis and dynamic balancing to convey machine vibration concepts [8]. Balancing is also used as an example in some applications, such as Matlab [9] or may be used in design projects [10].

Experiments play a major role in engineering curricula. Learning through experiment gives students a chance to learn from experience, which is more persistent than learning through theory. Experiments relate scientific theories to real life.

There is ready-made material, provided by the education and training service industry for experiments on the balancing of rotating masses. However, students have the tendency to use these as *black boxes*, where they simply follow the manual, without deeper thought and analysis of the concepts.

IMPROVING THE TEACHING

A survey was conducted of teaching the balancing of rotating masses. The survey was undertaken on two cohorts of students (in two consecutive years) in the Mechanics of Machines year-three course in the BEng (mechanical) programme at the University of Botswana. Out of 70 students registered for the course, 64 responded to the survey (91% response rate). The great majority of students (87%) found it challenging to visualise rotating systems in three dimensions.

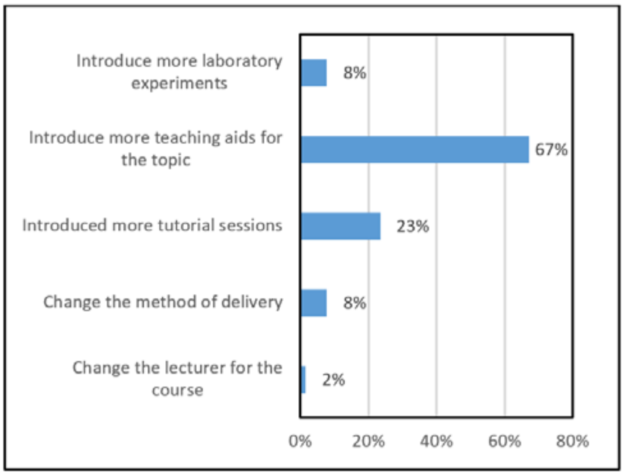

Figure 3: Methods to improve the teaching of balancing rotating masses.

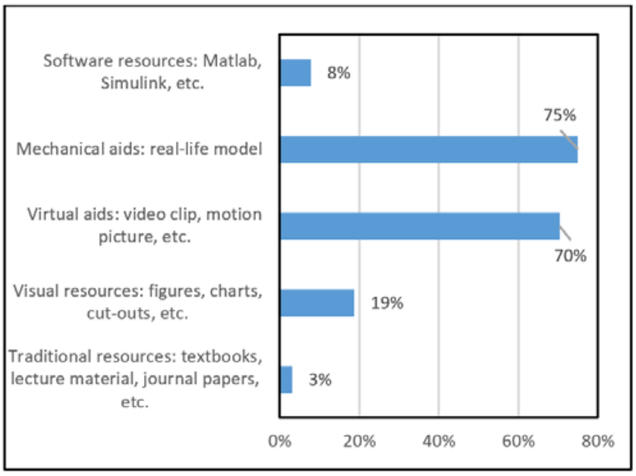

Figure 4: Teaching resources most likely to improve the understanding of balancing rotating masses.

The survey sought the students' opinions on methods to improve the teaching of balancing rotating masses. Most of the students (67%) supported the introduction of more teaching aids (Figure 3); 75% and 70% of students opted for the introduction of a mechanical aid (a model) or a virtual aid, respectively (Figure 4). The other options in Figure 4 - visual resources, traditional resources and software resources - were much less preferred.

Based on the results of the survey (Figures 3 and 4), a real-life model and a virtual model (video clip) were developed. The design specifications for both models are presented in Table 1.

Table 1: Design specifications for a mechanical model and for a virtual model.

Mechanical model	Virtual model
• Easy to carry (light weight), but large enough to be seen, held and manipulated by students. • Inexpensive, but appealing and professional in appearance. • Durable and easy to assemble. • Easy to interpret but accurate and realist.	• Should be a simulation/video. • Should relate to reality. • Should be in three dimensions. • Use software with a friendly interface. • Easy to use (for both the lecturer and students).

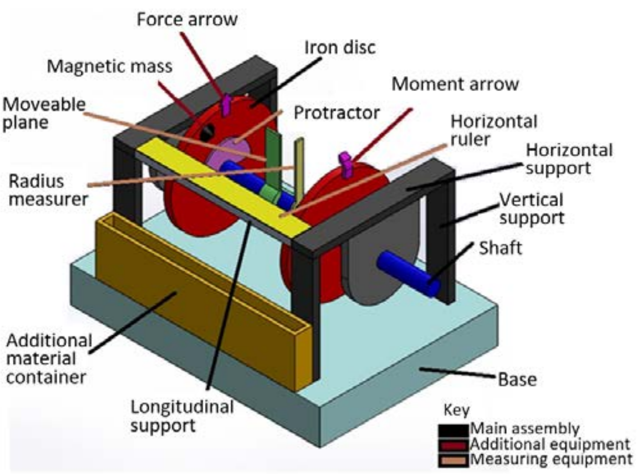

Figure 5: Mechanical model design.

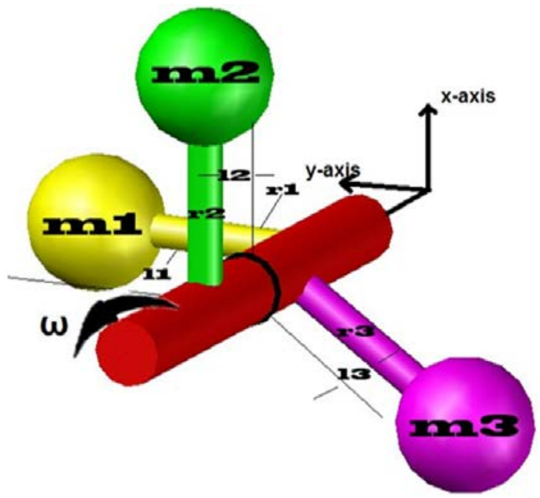

Figure 6: Virtual model.

Figure 5 and Figure 6 show the designs of the mechanical and virtual model. The mechanical model was designed through SolidWorks software and manufactured in the University of Botswana workshop. The material used was wood and polyvinyl chloride (PVC), with metal screws and bolts. The virtual animation model was developed using a written script for Autodesk Maya software.

With Autodesk Maya, it is possible to create a mini world that mimics the real world through the addition of gravity and centripetal forces. A video was developed to display how the members react in the real world. This was achieved by selecting *gravity*, and nominating active and passive rigid bodies as the moveable and immoveable parts; the rotating object is the active and the ground is the passive rigid body.

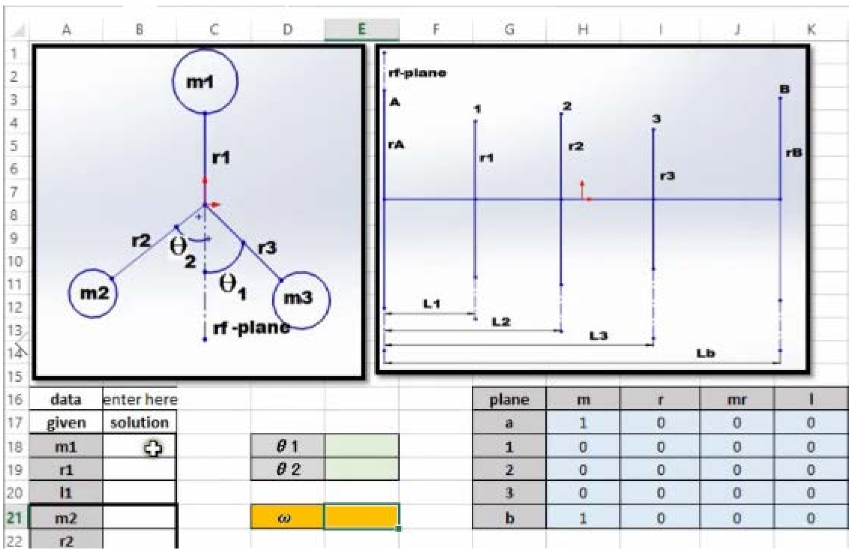

Figure 7: Instructional video spreadsheet (snapshot).

Despite students' preferences, as shown in Figure 4, a Matlab program was prepared, as well as a simple Excel spreadsheet for the students to check their manual calculations on balancing. Matlab programming and the Excel spreadsheet were included in an instructional video; snapshots of those video clips are presented in Figures 7 and 8.

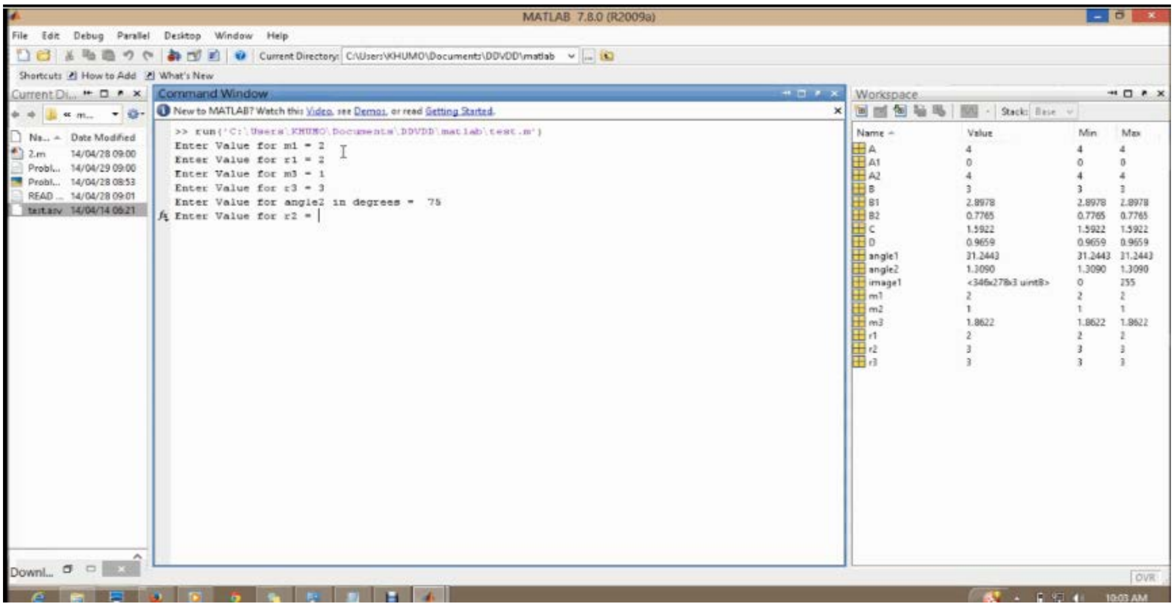

Figure 8: Matlab programming (snapshot).

A laboratory exercise required students to prepare their own spreadsheet and write their own Matlab program. Students were required to submit both the Excel spreadsheet and the Matlab program as part of their laboratory report. The intention was to encourage students to check their calculations against results.

RESULTS

The results of tests and continuous assessment for the course balancing of rotating masses, are presented in Figure 9.

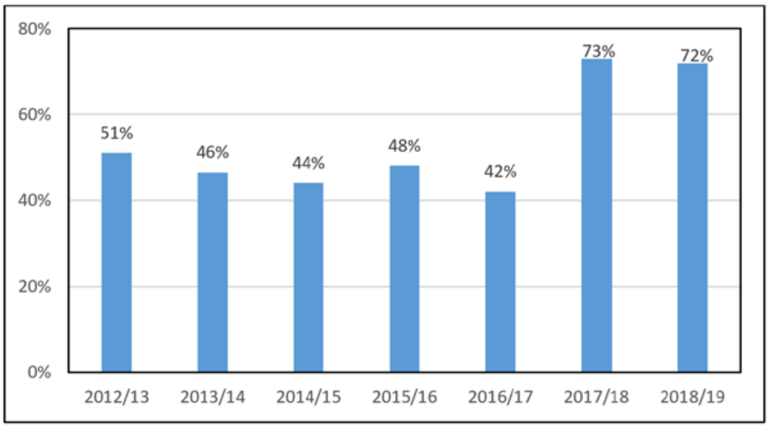

Figure 9: Test average results for the balancing of rotating masses.

The new teaching aids, the mechanical and virtual models, were introduced from the 2017/18 academic year. The results showed a substantial improvement in marks for the topic from the 2017/18 session, which continued in the following academic year when the aids were again used. However, the improvement could be attributed to the additional attention being devoted to the topic. The additional elements, such as the spreadsheet and Matlab, may have been a contribution to the improvement.

Students generally preferred the virtual model to the mechanical model, as reflected in Figure 10; 66% of the respondents had positive opinions about the virtual model compared with 49% for the mechanical model. Interestingly, the students appreciated both writing the Matlab program, as well as creating their own spreadsheet to understand the problem (Figure 11).

Creating their own tool to check manual calculations made students better understand the problem. These teaching resources were used despite not being preferred by the students (Figure 4). However, according to the responses, those two resources did not help the students in the visualisation of the problem.

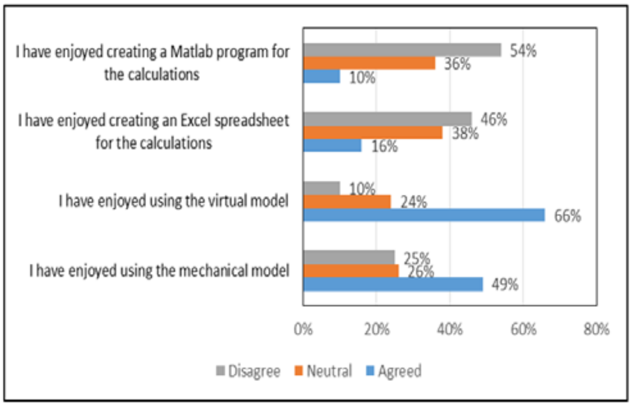

Figure 10: Students' satisfaction with the teaching tools.

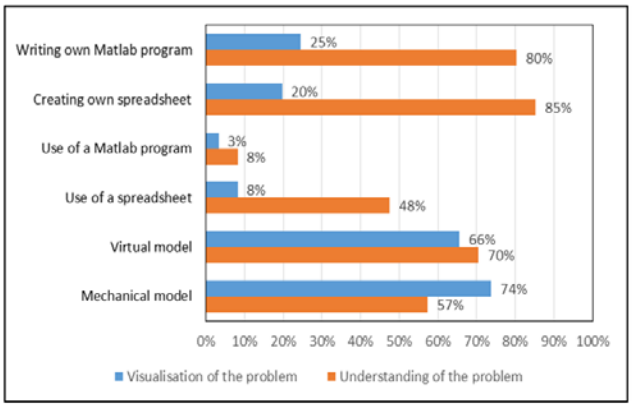

Figure 11: Students' appreciation of various teaching aid tools.

The mechanical model (74% positive answers) was the best aid for visualisation, followed by the virtual model (66%) (see Figure 11). Both of these were assessed positively for understanding, but were not as good as students' efforts in creating their own Matlab program and spreadsheet. Applying the spreadsheet was considered a good tool by which to understand the problem, but not one for visualisation.

The Matlab program was rated very low in visualisation and for understanding the problem. It may be that the students treated the Matlab program as a *black box*, simply putting in input data and receiving the answers without understanding the problem. The spreadsheet may have been better because the students could see progressive changes reflected in the calculations.

CONCLUSIONS

The authors in this article have described the application of teaching aids to give an insight into the topic of balancing rotating masses. The main objective was to provide students with a three-dimensional visualisation of the topic, thus equipping them with an in-depth understanding of the problem. The teaching resources developed included a mechanical toy-like model, a virtual model, in the form of a video clip, a spreadsheet and Matlab program, for students to check their manual calculations.

All aids were used in the teaching of the balancing of rotating masses. In addition, a laboratory exercise was performed by students. As part of the laboratory, the students were asked to prepare their own spreadsheet and Matlab program.

Efforts to understand the problem were successful, because the test marks for the topic increased considerably after the introduction of the teaching aids. The mechanical and visual models helped visualisation of the problem and students enjoyed using them. Even though students did not enjoy creating their own spreadsheet or writing their own code in Matlab, these helped in their understanding of the problem.

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