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Virtual Mechanical Engineering Education – A Case Study

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***Abstract*—**Virtual engineering technology has undergone rapid progress in recent years and is being adopted increasingly by manufacturing companies of many engineering disciplines. There is an increasing demand from industry for qualified virtual engineers. The qualified virtual engineers should have the ability of applying engineering principles and mechanical design methods within the commercial software package environment. It is a challenge to the engineering education in universities which traditionally tends to lack the integration of knowledge and skills required for solving real world problems.

In this paper, a case study shows some recent development of a MSc Mechanical Engineering course at Department of Engineering and Technology in MMU, and in particular, two units *Simulation of Mechanical Systems*(SMS) and *Computer Aided Fatigue Analysis*(CAFA) that emphasize virtual engineering education and promote integration of knowledge acquisition, skill training and industrial application.

***Keywords*—**Computational modelling and simulation, mechanical engineering education.

I. Introduction

VIRTUAL engineering technology has undergone rapid progress in recent years and has been widely accepted for commercial product development. Product design and manufacturing organizations are moving from the traditional, multiple and serial design-build-test cycle approach to simulation-led problem solving and performance validation using CAE and CAD tools [1]. One of the important factors that determine the possibility and the success of such paradigm shift is the availability of qualified virtual engineers. Large international OEMs in engineering industries such as automotive and aerospace have enjoyed the benefits of the application of virtual engineering technology in reducing the cost and increasing the competitiveness of their products. They have the capabilities to train the graduates that they employ to master virtual engineering technology through in-house career development system. On the other hand, the lack of qualified virtual engineers is becoming an increasingly acute problem that prevents small and medium sized engineering companies (SME) from moving towards simulation-led product design. Engineering courses in Higher Education are the vehicles to supply future engineers with suitable knowledge, skills and experiences [2]. Recognizing the current and future needs of industry, an MSc course was developed that aimed to equip the students with the knowledge of virtual prototyping process and related mechanical engineering subjects, the skills of operating a range of industry standard software for virtual prototyping and testing, the ability of updating their own knowledge of this fast evolving and diverse technological area, and the experience of industrial applications so that the students can take up the role of virtual engineers in industry after completing the course.

This paper is presented as a case study to show how the above objectives of the course are imbedded in the design of our MSc Mechanical Engineering course, and in particular, its two units *Simulation of Mechanical Systems(SMS)* and *Computer Aided Fatigue Analysis(CAFA).*

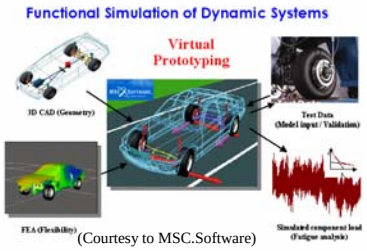
It is anticipated that virtual engineering education will be driven by the market demand for virtual engineers to expand dramatically in the next few years. One striking feature of this demand is its global-ness both in the geographical sense because of the global economy and in industrial discipline sense due to the generic powerfulness of the virtual technology. How to produce effective virtual engineers from our engineering courses is a timely issue for the engineering education practitioners in the higher education sector to address.

II. Rationale

Virtual prototyping is about functional simulation of mechanical systems under realistic operating conditions. Virtual prototyping involves integrated use of multibody system (MBS) / computer aided design (CAD) / finite element analysis (FEA) software and is a powerful tool for virtual design and testing which form the essential part of the virtual product development process. Figure 1 shows a virtual prototype of a car created by MSC.Software. Virtual mechanical engineers should have the ability of applying engineering principles in multiple disciplines and mechanical design methods in the commercial software environment in order to build and test virtual prototypes for commercial product development.

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(Courtesy to MSC.Software)

Fig 1 Schematic diagram of virtual prototyping

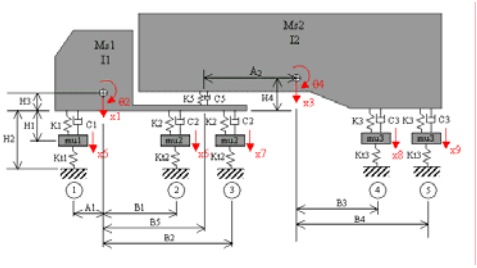
In our MSc course in Mechanical Engineering, units *Simulation of Mechanical Systems (SMS)* and *Computer Aided Fatigue Analysis (CAFA)*, in addition to four other units Finite element analysis *(FEA)*, Mechatronics *(MEX)*, Integrated management systems *(IMS)* and Product design and development *(PDD)*, provide a central theme of virtual product development.

In SMS unit, MBS and FEA are used to build virtual prototypes that simulate the systems' dynamic performance and generate component load. FEA takes the component load to carry out detailed component design and generate stress/strain distribution reflecting the geometric variations of the component. In CAFA unit, the component load and the stress/strain distribution from the previous steps are used as inputs to the fatigue analysis software to carry out fatigue design of the component. These processes are taught in classes and are built into the students' assignment projects.

The key teaching and learning strategy adopted is project-led knowledge-pulling, skill-drilling and student-centred learning. The projects center on design problems. During the development of solutions using virtual technology, some new knowledge has to be learned as well as existing knowledge is applied, which are directly related to the projects. The knowledge covers many academic subject disciplines in mechanical engineering. Similarly various skills are developed and practiced. The skills range from physical testing for acquiring modeling information and virtual model validation, building the virtual prototype, to virtual testing for correlation with physical test and system performance evaluation. Such a setting closely resembles what engineers have to do in their professional jobs. The student-centred learning is facilitated by setting staged targets and deliverables. The intended outcome is integrated learning of knowledge, skills and their applications as opposed to subject separated knowledge learning, unit separated skills training and practical application being as the tail section of the learning curve. Beside the teaching and learning oriented projects in the first part of the academic year, the students spend the latter part of the course working on an industrially oriented project. This provides the opportunity for the students to appreciate some real issues that companies face when migrating from traditional product development process to the simulation-led approach. This prepares students for a job as a virtual engineer or other roles in companies able to facilitate the implementation of simulation-led product design process.

III. Details of Students' Assignment Projects within SMS and CAFA Units

In SMS, assignment projects are used as the main threads to develop students' knowledge and skills in virtual prototyping. For example, one project was to model a nine-degrees of freedom truck semi-trailer baseline model using MBS software ADAMS*. The descriptive model and the ADAMS model of the system are shown in Fig. 2(a) and 2(b) respectively.



(a) Descriptive model



(b) ADAMS model

Fig 2 A 9 DOF truck semi-trailer model

During this project, the students went through a series of activities. These activities and the main knowledge and skills that are required to carry out each activity are shown in Table I.

The students were provided with project specifications at the start of the unit. The lecturer covered the related topics shown in Knowledge/Skills column using other examples but highlighted their relevance to this project. The students spent their student-centred study time to do their assignment project. In addition to what the lecturer taught, the students had to acquire more knowledge and skills for using the software packages and completing the project by using textbooks, on-line help and other resources. It has been observed that in this way the students became more motivated and active in their learning.

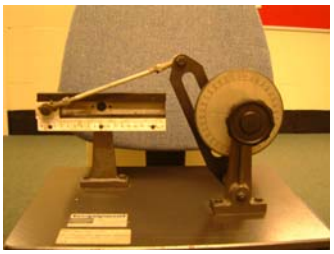
Another assignment project in SMS focused on the process of developing a virtual prototype. This included modelling an existing physical system, and once the virtual model was validated using the measured data from the physical system, further developing a virtual prototype of a machine that satisfies a set of design specifications. In addition, FEA was used to design some component to satisfy the strength and buckling requirements. The physical system is a quick return (QR) mechanism which has been used as a teaching aid for design classes.

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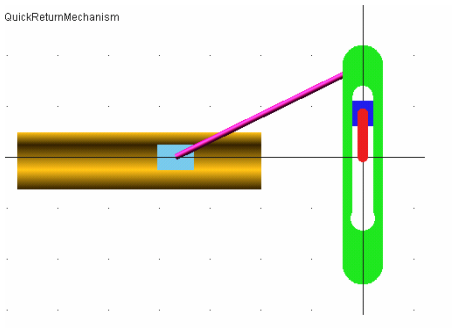
TABLE I
ACTIVITIES AND LEARNING POINTS FOR TRUCK-SEMITRAILER PROJECT

	Activity	***Knowledge/Skills***
A	Model dynamic systems in ADAMS/View such that the system has the required DOFs and does not have redundant constraints	Model building techniques in ADAMS
B	Determine the dynamic properties of the system such as the natural frequencies, the normal modes and modal damping	Modal analysis
C	Verify the computer model by comparing the modal results with theoretical solution which was derived from first principles	Theoretical vibration analysis Model verification
D	Once the computer model has been verified, explore the dynamic behaviour of the system under different excitations by simulation	Numerical integration methods, parameter settings and error control
E	Determine the frequency response function of the system using FFT	Fourier transform
F	Perform sensitivity analysis of vibration responses with respect to design variables	Design study

A photo of the physical model and an ADAMS model of the mechanism are shown in Fig. 3(a) and 3(b) respectively. A virtual prototype representing a concept design of a shaping machine is built using the same topology as the validated QR model as shown in Fig. 4. The link connecting the rotating arm and the translating slider is modeled as a flexible component with a FE representation. The dimensions of the link are designed by considering the strength and buckling performance requirements when subject to the component loads from the system simulation. The virtual prototype of the shaping machine is tested under a representative but simplified operating condition that the material being shaped provides a resistance force. Design studies are carried out to explore the scenarios with different machine dimensions, and different resisting force from the material being shaped, etc.. This project demonstrates a typical virtual prototyping process in industrial applications.



(a) Photo of the physical model



(b) ADAMS model
Fig. 3 A quick return (QR) mechanism

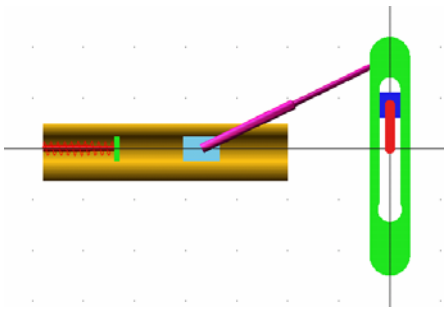


Fig. 4 Shaping machine concept design

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Unit CAFA runs after the SMS unit. The assignment project in CAFA implements partially a computer aided fatigue analysis process as described by the schematic diagram in Fig. 5.

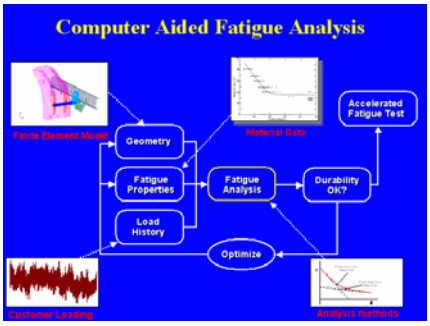
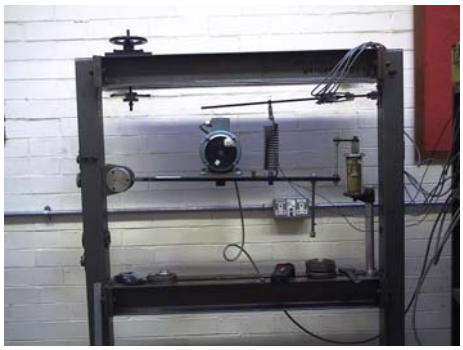
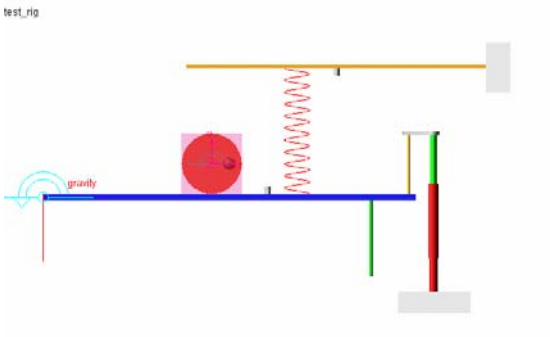


Fig. 5 Virtual fatigue design process

The system used in this project is shown in Fig. 6(a) and its virtual model in Fig. 6(b).



(a) Photo of the test rig



(b) ADAMS model

Fig. 6 A vibration-fatigue test rig

The pivoted main beam is connected to a cantilevered beam above it via a spring. The cantilevered beam has a hole drilled in it to represent fatigue features. When the motor on the main beam runs, due to an off-centred nut on the rotating plate that causes an out-of-balance force, the whole system vibrates and therefore the cantilevered beam is subject to a cyclic fatigue loading of the spring force. In carrying out this project, the students need to use several software packages in an integrated manner. ADAMS is used to build a virtual model of the whole system to simulate the spring force which is the component load of the cantilevered beam. ANSYS** is used to provide the stress/strain distribution within the cantilevered beam due to a unit load. FE-Fatigue*** is used to apply the dynamic stresses which result from the above component load and stress distribution to the material fatigue model and the selected fatigue analysis methods to calculate the fatigue damage distribution and fatigue life at the critical locations which are at the hole rim. Further more, design studies are carried out to investigate the variation of the fatigue performance with respect to different design variables such as the out-of-balance mass, spring stiffness, damping coefficient, etc..

In addition to the virtual fatigue design practice as described above, the students are required to use theoretical methods to verify the computer simulation results whenever appropriate. For example, the natural frequency of the system when the cantilevered beam is locked up as a rigid support is calculated from first principles. Also the fatigue life at the hole rim of the cantilevered beam under the cyclic spring force and a mean stress loading is calculated using both the stress-life and strain-life methods.

For all the projects described above, there is an emphasis on the verification and validation of the virtual model. This is carried out by using test data, theoretical solutions or results obtained from other independent software, depending on the particular scenario. It is considered to be of fundamental importance that the students develop the awareness and the ability of carrying out model verification and validation from the earliest stage of their learning and practice of the virtual technology.

IV. Degree Project with Industrial Application

As an important part of the course, each student carries out a major degree project after studying the taught units. Projects that are industrially based or with industrial applications are preferred. One of the industrially based projects is about computer aided fatigue analysis of a car suspension damper top [3]. The car company provided the CAD geometry and the load time histories measured during proving ground tests as well as the material information. The aim is to establish the extent and distribution of fatigue damage in the component due to each duty cycle represented by the provided load histories.

The student doing this project went through an exciting journey of problem solving. His main activities / achievements and the key issues involved are summarized in Table II.

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TABLE II
MAIN ACTIVITIES/ACHIEVEMENTS AND KEY ISSUES OF THE DEGREE PROJECT

	Activity / Achievement	***Key Issues***
A	Clean up the geometry in preparation for meshing.	Solving a typical problem in industry arising from the separation of design and analysis teams
B	Model the contacts and bolts/nuts in the assembly	Modelling the real condition based on a close examination of the physical model and the operating condition
C	Verify the quality of the mesh. See Fig. 7	Error control of FEA results
D	Design the validation test with the guidance of simulation results	Simulation guided testing scheme design
E	Validate stress results from FEA by experiment. See Fig. 8	Strain measurement, data processing and correlation with FE results
F	Predict fatigue performance of the component using FE-fatigue together with the stress distribution from ANSYS, the load time histories and the cyclic properties of the material. See Fig. 9, 10	FE based fatigue analysis
G	'What-if' study with respect to material type See Fig. 11	Fatigue design

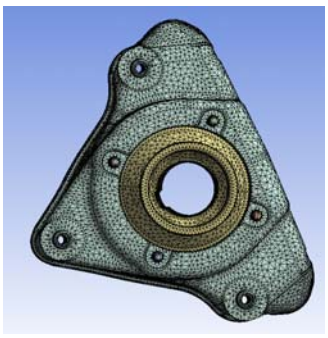


Fig. 7 Mesh

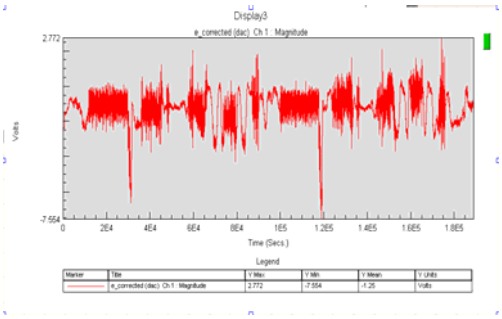


Fig. 9 Load time history



Fig. 8 Physical test to measure strains

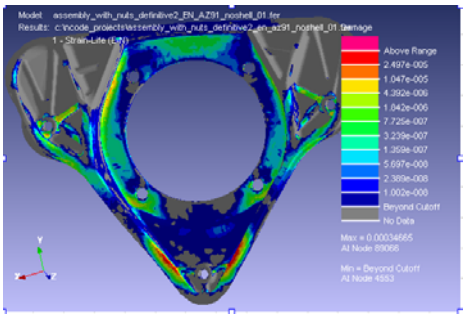


Fig. 10 Fatigue damage distribution

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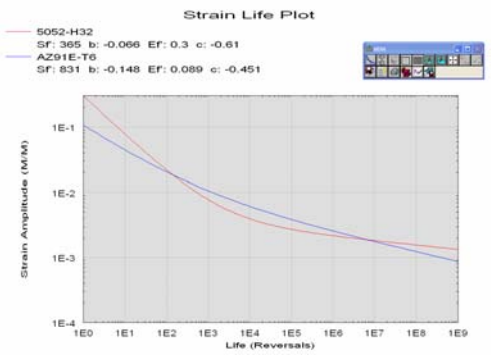


Fig. 11 Cyclic properties of two materials

Through doing such projects, students not only learn a lot more about the subject, but also often have to resolve some real problems in industrial applications of the virtual technology and thus gain valuable experiences. These make the students more confident and capable to pursue a career as virtual engineer.

V. Concluding Comments

This case study shows some attempt to develop engineering courses that promote the attitude and working style of professional engineers, provide effective training in technical knowledge and skills in virtual engineering technology and develop students to become desirable virtual engineers for industry.

It is the author's opinion that virtual engineering technology should become a new connecting point where Mechanical Engineering education in HE and the manufacturing industry hold hands and work together to achieve great benefits on both sides of the enterprise. The industry will gain competitiveness and better products through using a smarter way of developing products while the HE will produce better qualified and more desirable graduates by equipping the students with the required knowledge, skills and experiences. Closer collaboration between industry and HE as well as the software developers should be strongly encouraged.

* ADAMS – A MBS software from MSC.Software
** ANSYS – A FEA software from ANSYS Inc.
*** FE-Fatigue – A fatigue analysis software from nCode

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