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Hands-on and Project based Learning in Noise, Vibration and Harshness (NVH) Course for the Undergraduate Students in Mechanical Engineering Program

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***Abstract*—The noise, vibration, and harshness (NVH) course is crucial for mechanical engineering undergraduate students since it covers a wide range of engineering applications. It makes students ready for their careers in the area of NVH which has received attention from industry. The traditional treatment in teaching the course is mathematically challenging and might not be helpful for some undergraduates who are kinaesthetic learners. The explanation of topics can be facilitated by modern computation tools with simulation and visual capabilities in NVH course. These contemporary simulation tools make it feasible to more effectively and engagingly teach mathematically complex subjects to students for better understanding. This paper describes teaching NVH course in the Mechanical Engineering department at the KLE Technological University. Course is taught in two parts at 5th and 6th semester level. The first course is Mechanical vibrations and the second one Noise, Vibration and Harshness (NVH). Hands-on lab sessions with the simulation tool are included in the second course to give student in-depth understanding of concepts.**

***Keywords*—Vibration; FEA; Course project.**

***JEET Category* – Pedagogy of Teaching and Learning.**

I. INTRODUCTION

NOISE, Vibration and Harshness (NVH) refers to a set of characteristics that describe the comfort and quality of a vehicle's ride. NVH is particularly important in the automotive industry but can also be relevant in other engineering fields. NVH is an essential aspect of vehicle development because it directly impacts the perception of quality and comfort by driver and passengers. Noise refers to any unwanted or unpleasant sound produced by a vehicle such as engine noise, road noise and interior cabin noise. Engineers work to reduce noise levels to create a quieter feel for passengers. Vibration of a vehicle's components, such as the engine, suspension, and wheels can affect comfort and the durability of vehicle components. Engineers aim to minimize vibrations to provide comfortable experience for passengers.

Harshness describes the discomfort or roughness felt by passengers due to road imperfections or vehicle vibrations. It includes both noise and vibration but focuses on their impact on comfort. Reducing harshness means improving the overall ride comfort of the vehicle. NVH engineering involves a combination of testing, analysis, and design modifications to achieve optimal levels of noise, vibration, and harshness. NVH is also important for compliance with regulations related to noise pollution and safety standards.

Mechanical vibrations and NVH are elective courses in the mechanical engineering curriculum at the KLE Technological University. These courses need to be taken seriously by undergraduate students whose line of work in the career will entail complicated system design and analysis [Liu, 2019 and Gürocak, 1998]. The foundational concepts learnt in the course provide insight into the design of machines to minimize undesired vibrations. Since course content in NVH typically needs more mathematical knowledge and problem-solving skills in linear algebra, calculus, differential equations and matrix calculation, which make NVH one of the difficult courses in mechanical engineering. Typically, a course instructor spends a more time explaining the theory with mathematical expressions in the theory classes. However, understanding the concepts is tough for students and also, unable to connect the content to real-world applications. As a result, a gap between theory and application occurs.

Different teaching-learning methods have been introduced and are satisfactorily received by student. For example, learning the course with simulation tool has been practiced in several courses in undergraduate engineering programs. Puente and Jansen [Puente, 2017] discussed design-based open-ended assignment are useful in improving the students' learning. Further, problem-based learning [Pinto, 2015] and professional practice [Magnell, 2019] included in the engineering education have received encouraging results.

Magana and de Jong [Magana, 2018] implemented modelling and simulation practices in engineering education that resulted in enhanced learning. The students' performance in science, mathematics, engineering and technology can be enhanced through active learning approach [Freeman, 2014 and Eddy, 2015].

In higher education, active learning has become a popular instructional strategy because it helps students to acquire new knowledge in addition to their prior knowledge [Hartikainen, 2019 and TeKippe, 2017]. An engineering student would benefit from working on a design-based project since it focuses on problem-based learning. In this approach, students work on the project from identification of problem, develop the solution and system design [Gómez, 2011]. Both of these instructional approaches attempted to change students' preconceived notions about NVH, that it is purely mathematical and impractical for engineering design and to increase interest in the course. In the paper, a new content designed for NVH course is introduced by including active learning component and course projects. The objective is to increase student performance and bridge the theory-practice gap. With this, students were able to understand better and also able to connect the learning to real-world applications. Instead of full theory class, instructor in this course merely gave students the fundamental information and theories they needed to grasp before asking them to start formulating ideas and getting ready for the course project.

In lab sessions, the following content related to the NVH coursedelivered is shown in Table I. Ten exercises were planned to perform in the lab which cover most of the course contents. Altair Hyperworks software is used for hands-on session.

TABLE I
CONTENT RELATED TO THE NVH COURSE

Sl. No.	NVH Analysis (Hands on Content)
01	Analysis of cantilevered thin and thick square plate (Free-Free and Forced-Fixed condition).
02	Analysis cantilevered thin and thick square plate with changes in design to increase the natural frequency.
03	Normal mode analysis of cylinder: Axi-Symmetric case
04	Normal mode analysis of a Bracket with design changes (Free- Free and Forced-Fixed).
05	Modal frequency response analysis of – (a) Thick square plate. (b) Frame assembly
06	Modal frequency response analysis of an automotive chassis.
07	Harmonic forced vibration response analysis of simply-supported thick square plate
08	Transient forced vibration response of a) Simply-supported thick square plate b) Monocoque chassis
09	Acoustic analysis of brake squeal and half car model
10	Optimize the rectangular box model for panel thicknesses to reduce the vibration level using what-if studies and optimization process

The interactive learning exercises helped the students comprehend the fundamental concepts of NVH. Course projects are assigned to work in a team of 4-5 students. Student feedback and results are analysed and discussed in order to assess the course's efficacy. With course projects, students had to gather the essential data and develop their models for carrying out the vibration analysis while the instructor guided in their active learning for design tasks. Further, students had the chance to get practical experience through course projects and also able to analyse the results and draw inferences. In this way, a link between theory and practice in the area of NVH was made. As a result, students' interest in the course increased and their learning also improved.

A. *Methodology for course project*

Course projects support students theoretical understanding and grow their ability to apply that knowledge for solving the real-world issues. A course project could be a plan for designs of structures, machinery/equipment, or a technical-economic analysis of various engineering or technical solutions.

The course projects for the team are having following activity.

- Defining problem statement,
- Scope, Objectives and Deliverables.
- Detailed methodology.
- Execution, Results and Discussion.
- Interpretations of the results.

Expectations:

- Apply fundamental concepts of NVH to solve the vibration problems in mechanical systems.
- Perform the different type of NVH analysis using FEA tool.
- Determine dynamic characteristics and natural frequencies of components/systems and make design changes to improve its performance.
- Prepare the technical report of the work.

Example of course project title: "Design and NVH analysis of bonnet of the small segment car".

The auto body of each unique car has a unique type of bonnet. The auto's bonnet is a crucial component that is used for a variety of purposes. The use of the bonnet gives the car an opulent appearance. It covers the radiator, the engine, and many more components. The route was then developed such that, at the moment where the hood opens, every support component should be available and have a fundamental impact on the motor. When an automobile is involved in an accident from the front, the hood structure is frequently damaged. Therefore, the dissection of the bonnet is necessary. This work focuses on the NVH analysis and methods used for bonnet.

B. *Sample course projects*

Three sample course projects of the students' team for the course are discussed below.

Project Title 1: "Dynamic Analysis of Coir Rope Rewinding Machine."

A coir rope rewinding machine rewinds bobbin-rolled coir rope. Due to their length and bulk, these bobbins cannot be offered directly in the market. Modal analysis of the entire assembly is performed in this work and pattern holder of a coir rope rewinding machine for machine vibration. Free-free modal analysis and fixed free modal analysis were performed. Figure 1 represents the complete CAD model and Figure 2 represents the FE discretised (Mesh) model of coir rope rewinding machine.

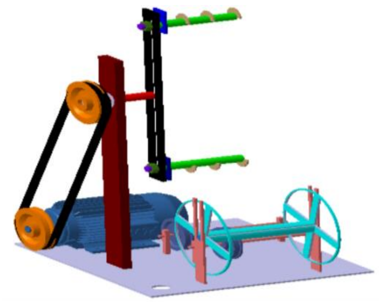

Fig.1. 3D Cad model of the coir rope rewinding machine.

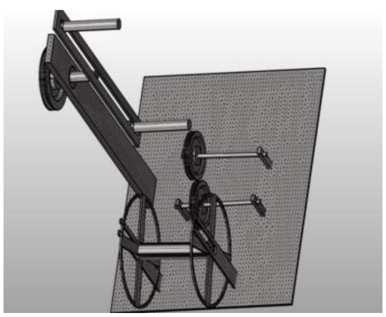

Fig. 2. Mesh model of Coir Rope Rewinding machine complete assembly.

TABLE II
NATURAL FREQUENCIES OF FREE-FREE MODAL ANALYSIS FOR COMPLETE ASSEMBLY

Mode Number	Frequency (Hz)	Eigen Shape
7	367	Z-Bend
8	535	Y-Oscillation
9	579	X-Oscillation
10	897	Y-Expansion
11	1410	X-Y-Expansion
12	1689	Mixed Modes

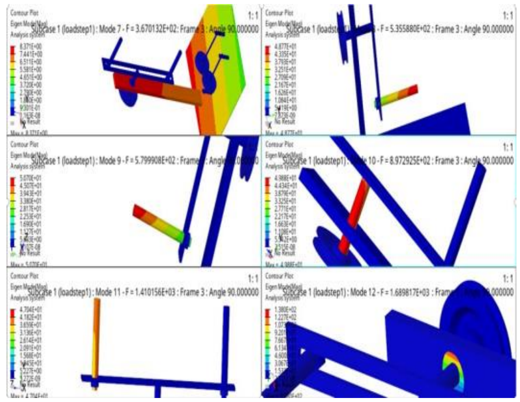

Fig. 3. Different modal frequencies of complete assembly.

Natural frequencies of free-free modal analysis [Sivakumar, 2021] for complete assembly are shown in Figure 3. Table-1 represents the first six natural frequencies of free-free modal analysis for complete assembly of the coir rope rewinding machine. The results are ranging between a value frequency of 367 Hz to 1689 Hz for full assembly. The frequency parameters are to be reduced for better working and long life of the machine. This data could be very helpful in the redesign or development of the machine. Additionally, the machine's health improves and failure is less likely as a result of the vibration being reduced.

Project Title 2: "Design optimization and vibration study of multi-functional E-cart chassis".

The chassis is an important component in the design of a vehicle. The chassis is essential to the handling and stability of the vehicle in addition to providing structural support. Its design and performance have a considerable influence on the vehicle's safety, handling, and comfort. The chassis must be sturdy enough to resist bending under load while minimizing vibration transfer to the passenger compartment. The FEA analysis of chassis is performed in the study for different thicknesses. Based on the least amplitude of vibration, the thickness is selected and the design is modified. Figure 4 represents the complete CAD model of the three wheeled electric cart and Figure 5 represents methodology used for the project work.

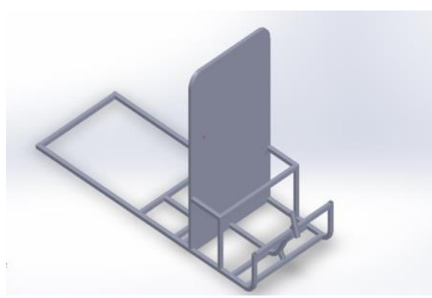

Fig. 4. CAD model of Chassis of the three-wheeled electric cart.

GUIDELINES FOR MANUSCRIPT PREPARATION

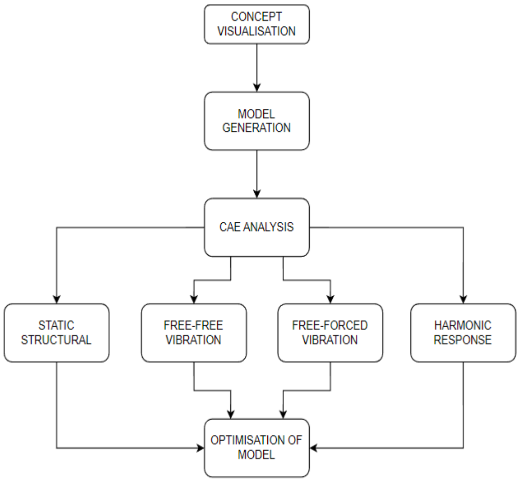

Fig. 5. Methodology

Free-forced modal analysis:

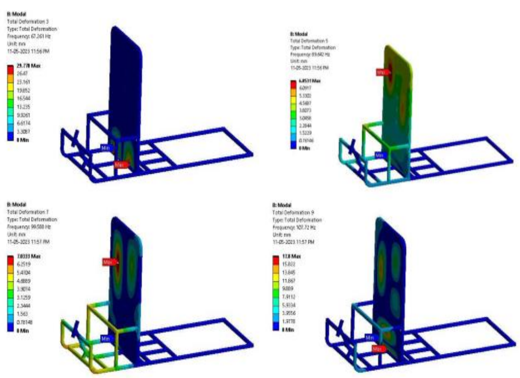

Fig. 6. Different modal frequencies of chassis assembly.

TABLE III
FREE-FORCED MODAL VALUES OF THICKNESS OF 3 MM

Mode Number	Frequency (Hz)
1	30.13
2	37.52
3	67.26
4	76.34
5	89.64
6	91.54

The mode shapes of free-forced modal analysis [Senthil kumar, 2013] of the chassis having thickness 3 mm are shown in Figure 6. Supports are given at the members where wheels are mounted. Table III represents the natural frequencies of the chassis when boundary conditions are imposed and external forces are acting on the entire assembly. The mode shape is the shape of the model deformation that the component would show when vibrating at the natural frequency. The results are ranging between a value frequency of 30.13 Hz to 91.54 Hz for whole assembly.

Project Title 3: "Vibration analysis on propeller shaft of heavy-duty vehicle".

A universal joint with intersecting axes connects the transmission shaft to the propeller shaft. Drive shaft model is created in Solidworks 2021 and imported to ANSYS 2023 R1 workstation. The present work is on finite element analysis of Tata vehicle 1210 drive shaft.

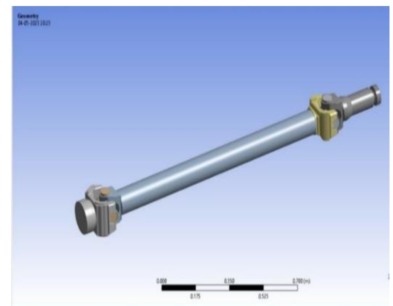

Fig. 7. CAD model of propeller shaft.

Modal and transient analysis [Raju, 2022] of a drive shaft was performed and determined intrinsic frequencies, vibration mode forms, and deformation. Figure 7 represents the complete CAD model and Figure 8 represents FE discretised model of propeller shaft.

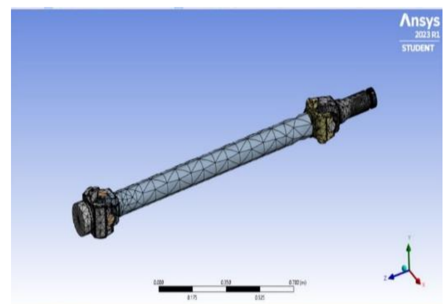

Fig. 8. Mesh model of Propeller shaft.

Transient Analysis:

The overall deformation and equivalent stress of the propeller shaft are determined through transient analysis.

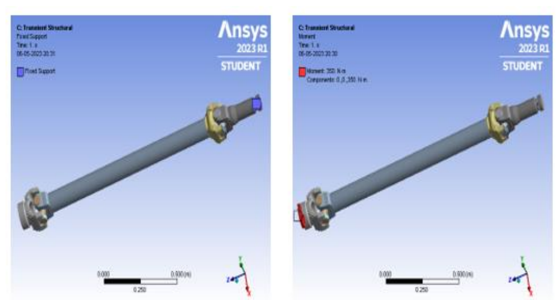

Fig. 9. Propeller shaft subjected to fixed support and moment.

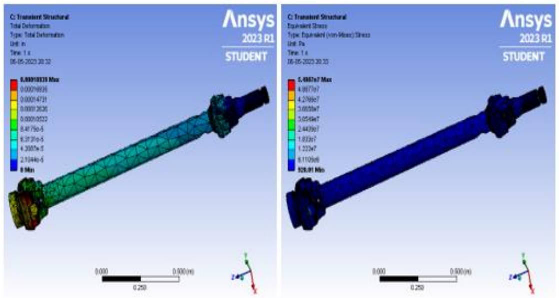

Fig.10. Result of transient analysis.

Figure 9 represents the loading and boundary conditions applied for propeller shaft for transient analysis and Figure 10 shows the results of transient analysis that is deformation and stress respectively. The maximum deformation is 0.18 mm and maximum stress that acts on the shaft is 54.98 MPa. It is observed that the maximum deformation occurs at ends of the shaft. Stress developed in the member is less and acceptable when material yield stress is considered. Also, deformation is found to be less for the applied loading conditions.

II. Assessment and Discussion

The course outcomes were measured by two written exams and one course project in the entire semester. In Semester Assessment (ISA) for 30% weightage and End Semester Assessment (ESA) for 50% weightage were scheduled, and questions are of descriptive type and numerical problems. The course project was assessed for 20% weightage. The course projects also meet the program outcomes (PO) 3 and 5 of mechanical engineering programs.

The focus of the course project is on the simulation of mechanical vibration problems that are relevant to various applications. This will be accomplished by using the Project Based Learning (PBL) technique. This has helped in attainment of PO3 and PO5 which are Design/development of Solutions and Modern tool usage. The project evaluation is conducted using a systematic assessment method that depends on predetermined rubric criteria. The factors in question have been specifically formulated to evaluate performance and are organized according to a 5-point Likert scale. This scale offers a complete and uniform approach for appraising the simulation results.

'PO3' is Design/Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations.

'PO5' is Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

Following questions were asked for students regarding hands-on sessions and course project.

1. The inclusion of hands-on sessions workshops has increased students' engagement with the NVH course.
2. In-depth knowledge provided through practical exercises and projects improved exam performance.
3. The course project helped students to enhance their critical thinking skills in developing the solutions.
4. Reflecting on the project, how well do you think you understand the principles and practical implications of Noise, Vibration, and Harshness in engineering?
5. The course project has enhanced students' capacity to work in teams and presentation skill.

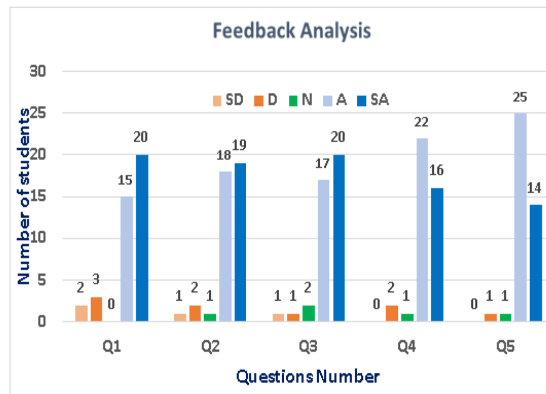

Fig.11. Feedback analysis

The student survey has shown positive feedback on the hands-on sessions and course projects experience. The hands-on sessions and course project feedback analysis is shown in Figure 11. Students' performance in the project was evaluated by the instructors as per the rubrics. There are 70% of students who have scored 60% and above in the project. The outcome is considered as satisfactory.

III. Conclusion

The present paper discusses re-designing the course 'Noise, Vibration and Harshness' by including new teaching methods of active learning and course projects. Such a teaching strategy aimed to provide students with a better knowledge of the course concepts, enhance problem-solving ability, and bridge the gap between theory and industry practice. All course project solutions were obtained using Finite Element Analysis (FEA) tools. Using these tools, students simulated, visualized, and enhanced operational aspects of selected course project problems. Details of a few students' course projects are discussed in the paper. The student outcome is analyzed and shows satisfactory results. Students' feedback shows that including hands-on sessions and course projects in the NVH course enhanced their learning and improved critical thinking. Further, the activity addresses Program Outcome 3 and Program Outcome 5. The current cycle's projects deal with vibration-related issues. However, further work on harshness and noise are planned for the upcoming cycle.

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