A Conceptual Mechanism Design Activity for an Introduction to Mechanical Engineering Course

Oziel Rios, Ph.D. and Dani Fadda, Ph.D., P.E.

Mechanical Engineering Department
The Erik Jonsson School of Engineering and Computer Science (The Jonsson School)
The University of Texas at Dallas
800 W. Campbell Rd., Richardson, TX, 75080, USA
E-mail: oziel.rios@utdallas.edu

Abstract

A conceptual design activity is presented in this paper to introduce freshman students to motion transmission with simple gear train mechanisms. The activity requires students to select components from a catalog and perform kinematic simulations using CAD software. The activity described in this paper was implemented in an introduction to mechanical engineering course but it could also be deployed in an upper-level, undergraduate mechanisms course. The activity was successfully administered to a class of 221 students during the Spring 2017 semester but can be administered to smaller classes as well. A description of the activity is presented along with a discussion of the resources and personnel required (instructors and teaching assistants).

The activity is considered simple to implement, requiring only a computer station with CAD software available in most engineering schools. Continuous improvements to the project are made based on faculty observations and assessments, as well as a survey administered to the students.

1. Introduction

At the University of Texas at Dallas (UTD), students take a two-course sequence of introduction to mechanical engineering courses. The first course is a 1 credit-hour course taken in the Fall semester where students work on activities related to team work, graphical communication, design methodology, project management, numerical analysis software, and ethics. The second course is a 2 credit-hour course typically taken in the Spring semester [1]. While the first course focuses on topics of relevance to all engineering majors, the second course focuses on design-related activities covering the topics of CAD [2], forces on structures [3], thermal energy and fluid systems, and mechanical components (this paper).

The design and operation of motion and power transmission systems is an important topic of study for mechanical engineering students. This topic is usually most closely associated with the mechanical engineering profession and is addressed in the first-year course by describing the need for such systems and investigating kinematic equations of gear trains composed of simple and compound spur gears [4]. For the conceptual design activity, students are given the functional requirements for the mechanism and design constraints. They are asked to select spur gears from an online catalog to achieve the requirement. The students are directed to download 3D CAD models of the gears from the online catalog, build a 3D assembly model of their design, and run kinematic simulation to ensure their design satisfies the functional requirement and constraints.

In the rest of this paper, a more detailed description of the activity is provide as well as observations and assessments of the activity. Results from a student survey are also presented.

2. Description of Project

Our objective when creating this activity was to provide a valuable learning experience to achieve the course learning outcomes while providing an engaging and enjoyable experience for the students.

An example of the mechanism the students were asked to design is shown in Fig. 1. This type of mechanism can be applied to milling machines, loading trays of Blu-ray players, and other applications. The conceptual design activity consisted of selecting four spur gears and a rack as shown in Fig. 1 to achieve an output linear speed of 0.25 in/sec (speed of the rack). An allowable range for the input motor speed was given. Students were asked to select from plastic molded gears available in the McMaster-Carr online catalog [5] to achieve the required output linear speed.

As an incentive to be mindful of costs, teams with the lowest cost for the gears were awarded bonus points. However, optimizing the design for achieving the lowest cost was not a requirement.

The kinematic equations for this mechanism are straightforward. Let r_i and ω_i be the radius and angular speed, respectively, of gear i (where i is 1, 2, 3, or 4), let v_5 be the speed of the rack gear 5 (the output speed). The velocity ratio of the mechanism is determined to be

$$\frac{v_5}{\omega_1} = \frac{r_1 r_3}{r_2}$$

where ω_1 is the input speed. Students had to use this equation to search the catalog for a set of gears that satisfy the requirements and constraints. The search is greatly simplified if students realize gear 4 is an idler gear and $r_1 < r_2$ for speed reduction.

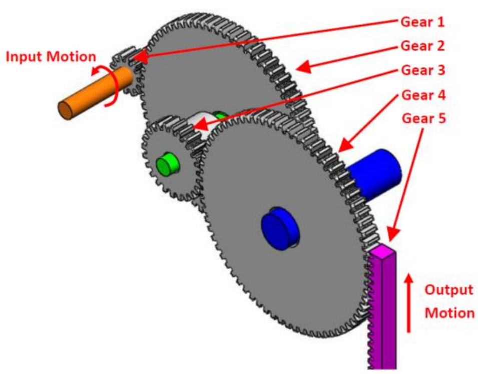

Fig. 1, Mechanism composed of spur and rack gears. Gears 2 and 3 form a compound gear.

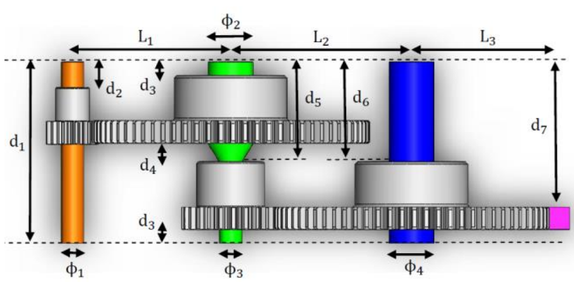

Fig. 2, Top view of the mechanism showing the parameters needed for the 3D assembly model.

Once the gears were selected, students downloaded 3D models of the spur and rack gears to create a 3D assembly model. Although the mechanism looks simple, many parameters must be determined before the 3D assembly model (Fig. 2) could be created. Some of the parameters need to be selected or determined by the students while others are based on their gear selections. The values of L_1, L_2 and L_3 are determined based on the pitch diameters of the gears. The value of d_1 (the shaft length) is selected to ensure that there is enough clearance in the shaft after the gears are assembled. The values of d_2, d_3, d_4, d_5, d_6 and d_7 are based on the overall width of the selected gears and to ensure that the gears mate. The values of ϕ_1, ϕ_2, ϕ_3 and ϕ_4 are based on the bore diameters of the selected gears. Based on these parameters, the students had to create 3D models of the shafts.

The students were given the steps to create the 3D assembly model in SolidWorks CAD software as well as the steps to setup and run a kinematic simulation to verify their results (see Figure 3).

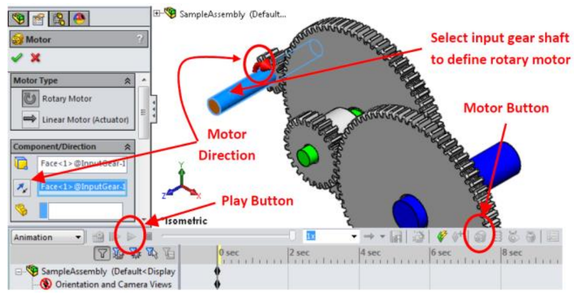

Fig. 3, Definition of a motor in SolidWorks.

3. Resources to Administer the Activity

The total enrollment for the Spring 2017 semester was 221 students and five lab sections capped at 48 students were offered. Students worked in groups of two and those sections with an odd number of students had one group of three. Each lab section was supported by one instructor and two graduate teaching assistants.

This activity required one computer per each group of two students equipped with 3D CAD software. SolidWorks was the CAD software implemented but it should be noted that the assembly model can be created in any 3D CAD software.

4. Observations and Results of a Student Survey

Overall, the activity was successfully implemented and the students responded to it well. Some students required some additional time, which was provided with extended office hours. In future implementations, the number of labs dedicated to this activity will be increased from 2 to 3.[1]

Students were asked to provide anonymous feedback on the activity in a survey administered at the end of the course. The survey includes the student's perception of their

[1] As described in [1], each week students have a 50 minute lecture and a 1 hour and 40 minute lab.

understanding of activity topics, the value of the activity for their future education, motivation, and their enjoyment of the activity. Specifically, the students were asked to respond to the following statements based on a 5-point Likert scale where a value of 1 meant they strongly disagreed and a value of 5 meant that they strongly agreed with the statement.

1) This activity helped me better understand aspects of the design process including motion analysis of simple transmissions and design under constraints.
2) After working on this activity, I understand simple concepts related to machine components including angular velocity, power transmission, velocity ratios, pitch of a spur gear, simple and compound gear trains.
3) Searching for components in a catalog to satisfy design requirements was a valuable activity.
4) Using SolidWorks to create a motion simulation was a valuable experience.
5) After working on this activity, I feel more confident using SolidWorks.
6) I was motivated to complete the activity.
7) I enjoyed working on the activity.
8) The concepts I learned while working on this activity will be of value to me in other engineering courses.

The results of these are plotted in a diverging staked bar chart [6] as shown in Fig. 4. The raw data is given in Table 1.

As can be seen from Fig. 4, over 71% of the students who responded to the survey either agreed (A) or strongly agreed (SA) with each of the statements. This indicates that the students not only thought the activity was a valuable learning experience but enjoyed it as well. Engineering reports and 3D models provided by the students indicated that they were able to understand the design problem and how to use the kinematic equation to search for a valid set of gears to produce the required output speed.

Students were also asked to provide free-response comments on any issues they faced and how to make improvements to the activity. Some students wrote: "it's a good introductory activity into simulations in solidworks," "it allows students to become more independent by selecting their own components for their projects," and "looking for different gears and comparing their physical properties and prices was a great learning experience." Some students wanted to go further with the project (beyond an introductory level course): "I feel there should be more emphasis on the CAD procedures for designing the gears," and "it may be beyond the scope of this class, but it would be more interesting to design a unique gear system." Another student wrote: "really interesting way to take what we learned in [CAD activity] to the next level." On the other hand, some students could have benefited from more lab time: "this was the most time consuming lab," and "need to make the lab time a little longer to learn all the concepts of the gears." To this end, as was previously mentioned the number of labs will be increased.

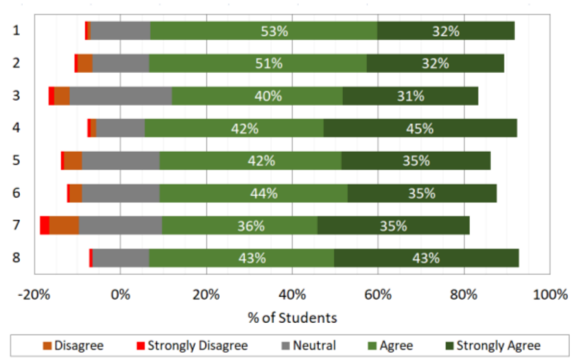

Fig. 4, Student responses to survey questions.

Table 1, Number of students who strongly disagree (SD), disagree (D), agree (A), strongly agree (SA) and where neutral (N) with the statements.

Statement	SD	D	N	A	SA	Total
1	1	1	20	76	46	144
2	1	5	19	73	46	144
3	2	5	34	57	45	143
4	1	2	16	59	64	142
5	1	6	26	61	50	144
6	1	4	26	63	50	144
7	3	10	28	52	51	144
8	1	0	19	62	62	144

5. Summary

In this paper, a conceptual mechanism design activity for a freshman mechanical engineering course was described. The resources to administer this activity were also presented. The activity was successfully administered to 221 students. Results from a student survey (144 respondents) indicate the activity was well received by the students. Engineering reports and 3D models submitted by the students also indicated a high-level of understanding of the concepts. Overall, the activity was successful in introducing concepts of motion and power transmission to the students.

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