Reform of a mechanical design course based on simulation software

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ABSTRACT: Given the importance of practical teaching in mechanical design courses, the authors of this article report on the teaching reform of a mechanical engineering course at Wuhan University of Science and Technology. The aim is to introduce case teaching in order to strengthen students' practical skills. Using a stress analysis model of a gear mechanism as an example, the work has highlighted the value of modern simulation technology in undergraduate teaching. The work also has expounded the relationship between modern simulation technology in the teaching of mechanical design courses and the outstanding engineer training concept. The results show that using simulations can improve teaching, while at the same time students can gain a deeper understanding of the course content. This improves student quality and better equips them to meet the demands of business and society.

INTRODUCTION

Industrial design is a profession most closely related to the manufacturing industry. Industrial designers have the responsibility for developing products and need a considerable understanding of mechanical mechanisms to ensure their products have a competitive advantage and to avoid infringing existing patents. Mechanical Design is a core basic course in teaching mechanical engineering [1].

The content of Mechanical Design lays the foundation for follow-up courses. The course requires students not only to master theoretical knowledge, but also to solve practical problems. Mechanical Design is about the design and working of machinery parts, as used in mechanical engineering [2].

The current curriculum has discrete units that are not directly correlated. Given the complexity of the engineering and design principles involved, many students find the course difficult.

The Mechanical Design course covers a broad field of knowledge. It is most important for students to be capable of innovative design and have the ability to solve practical production problems. This is also required for the Excellent Engineer Education and Training Plan, launched in 2010 by the Ministry of Education and the Chinese Academy of Engineering [3].

In teaching mechanical design, it is necessary to tackle the issue of how to effectively integrate theory and practice. In this article, the authors report on the use of computer simulation technology to simulate the process of mechanical design. A simulation involves the use of computers and special software to make a model of the physical system. The model can be used to research the design and behaviour of the physical system, which may not even exist.

PROBLEMS IN TEACHING MECHANICAL DESIGN

The traditional method of practical teaching was limited, making the course difficult to teach. Although some schools have better conditions, much of the equipment required is too bulky to be taken into the classroom. It is difficult to stimulate students' interest in learning with just the mathematics s and content of a textbook divorced from practical engineering applications.

Mechanical Design is a necessary foundation for follow-on courses, but has been hampered by a lack of support for practical teaching. Because of the extensive content some student self-study is required. But, students often cannot verify their learning content for the same reasons that hamper practical teaching. At present, most teaching material is traditional, subject-oriented and knowledge-based, but is not up-to-date and practical [4].

THE REFORM OF MECHANICAL DESIGN

Case Study Teaching for Strengthening Practical Skills

The reformed teaching programme uses a case-based method as the basic principle. Two reciprocal cases are used; referred to as perceptual-rational and rational-perceptual. In the perceptual-rational process, a mechanism is summarised by producing a kinetic sketch of the mechanism. The rational-perceptual involves conducting further design improvements; thus, implementing students' own design ideas based on mechanical theory [5]. The cases to be studied are classed at several levels, gradually advancing from easy to difficult. Simple cases include an umbrella, and speed-variable bicycle. More complex cases include clocks, computing mechanisms and special vehicles. The process cycle in case teaching is shown in Figure 1.

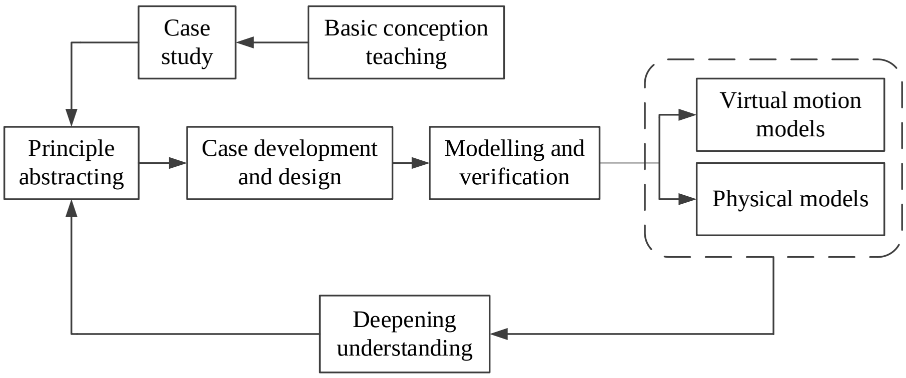

Figure 1: Teaching by case study.

EXAMPLE - CARRYING CAPACITY OF A GEAR

Planetary gear trains are widely applied in the fields of aviation, shipping and metallurgy. It has many merits, such as small size, compact structure, high bearing capacity, large power transmission and high efficiency. The NGW (the model of a planetary gear reducer, N represents the internal gear, W represents the external gear, G represents the planetary gear) planetary gear train consists of a sun gear, a planetary gear and a fixed inner gear. It has the characteristics of being simple, with a small axial dimension, is easy to manufacture, and allows a large transmission ratio through multistage series. It is very widely used in driving devices. Therefore, the study of NGW planetary gear is highly relevant to understanding the technology of planetary gear trains [6].

RomaxDESIGNER is computer-aided engineering (CAE) software produced by Romax Technology, a British company specialising in the simulation, design and analysis of gear transmission systems. Romax Technology has more than 10 years' experience in the field of transmissions. Released in 1995, RomaxDESIGNER has become the industry standard in the gear transmission field. It is widely used in the automobile and wind energy industries, among others.

The RomaxDESIGNER provides support for the establishment of a conceptual model; components strength analysis through to reliability; as well as a system vibration and noise (NVH) prediction for the transmission system. The system constitutes a closed-loop solution mechanism of a gear transmission system. Functions include model analysis and optimisation for a variety of complex gear transmission systems. The conceptual model of a planetary gear as shown in Figure 2. As an example of using the system, Figure 2 shows a screen that can be used to complete the definition of a planetary gear by simply selecting *Concept Planetary* in the component list.

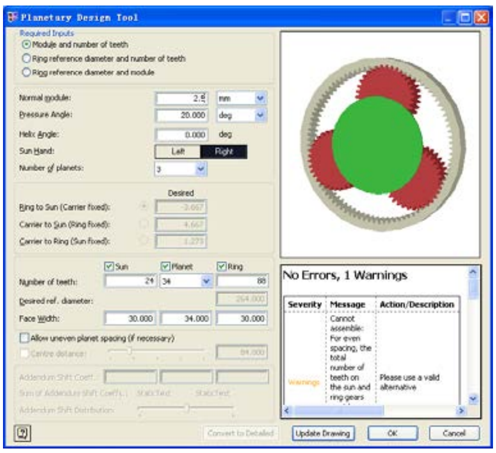

Figure 2: The conceptual model of a planetary gear.

To design a planetary gear using RomaxDESIGNER, three input parameters are required: module and number of teeth; ring reference diameter and number of teeth and ring reference diameter and module. Choose the first input mode, which produces the pressure angle; number of planetary gears; the gear tooth number and tooth width.

A gear strength check can be carried out after a conceptual gear model has been converted into a detailed gear. Some parameters need to be reset, and some parameters can use the default values before checking. It is necessary for the RomaxDESIGNER database to be modified according to the different model parameters. China's national standard GB/T3480-1997 was adopted from the International Standards Organisation standard ISO6336-1~6336-3:1996. Therefore, the ISO standard can be selected for calculations.

The following procedure applies when carrying out the simulation:

Select calculation standard: ISO 6336:1996 from the parameter list. Select ISO 1328:1995 as the quality standard. In the gear design parameters, select 7 for the grade precision. In the design requirements, select Flank Roughness = 1.6 μm for the input gear surface roughness. Choosing a thinner gear ensures good lubrication of gears in the meshing process and avoids blocking due to overheating.

According to the national standard GB/Z18620.2-2008, the tooth side clearance is determined by the following formula:

$$j_{b\min} = \frac{2}{3}(0.06 + 0.05a_i + 0.03m) \tag{1}$$

In the formula, a_i is the centre distance between the two gears and *m* is the module. Through calculation, the minimum clearance $j_{b\min}$ is 112.3 μm, and the circle diameter is 120 μm [7].

The experimental gear contact fatigue strength limit ($\sigma_{H\ lim}$) and the experimental gear bending fatigue strength limit ($\sigma_{F\ lim}$) are in the Material list, which showed the detailed parameters setting of a gear's material properties. The allowable tooth root stress can be calculated based on the strength of experimental gear in the standard used for strength calculation. Select the material quality level as MQ, according to ISO6336. $\sigma_{H\ lim}$ and $\sigma_{F\ lim}$ of sun gear and planetary gear's material $20CrNi2MoA$ are $\sigma_{H\lim} = 1{,}450MPa$, $\sigma_{F\lim} = 400MPa$. $\sigma_{H\lim}$ and $\sigma_{F\ lim}$ of the ring gear's material $42CrMo$ are $\sigma_{H\lim} = 750MPa$, $\sigma_{F\lim} = 280MPa$. Use the parameter menu Analysis Settings to define the viscosity of the lubricating fluid and reducer operating temperature. Lubricant viscosity should be 160 mm^2/s at 40 degrees Celsius, and for the reduction box at 120 degrees Celsius.

The simulation is based on a rigid model. The simulation does not take gear meshing dislocation into account. The simulation results are shown in Figure 3, Figure 4 and Figure 5.

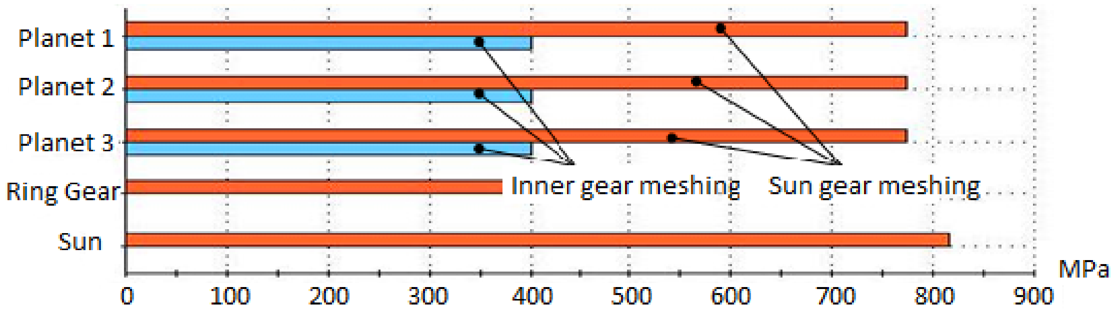

Figure 3: Maximum contact stress of gear.

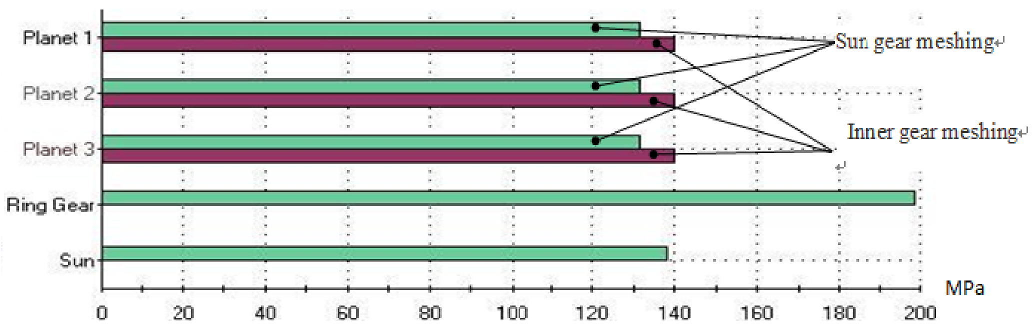

Figure 4: The maximum bending stress.

Figure 3 shows the maximum calculated stress for each gear contact. Planet 1, Planet 2 and Planet 3 refer to the three planet wheels' maximum contact stress when the reducer and the annular gear and the sun gear are meshed. The ring gear result shows that the maximum contact stress of the annular gear occurs when the annular gear and the three planetary gears are meshed. The sun result shows that the maximum sun gear contact stress occurs when the solar sun wheel and the three planetary gears are meshed.

Figure 4 shows the maximum calculated bending stress for each gear. Planet 1, Planet 2 and Planet 3 refer to the maximum bending stress of the maximum contact stress of the three planetary wheels when the speed reducer, the annular gear and the sun gear are meshed. The ring gear result represents the maximum internal bending stresses when the annular gear and the three planetary gears are meshed. The sun result shows the largest solar wheel bending stress when solar sun wheel and the three planetary gears are meshed.

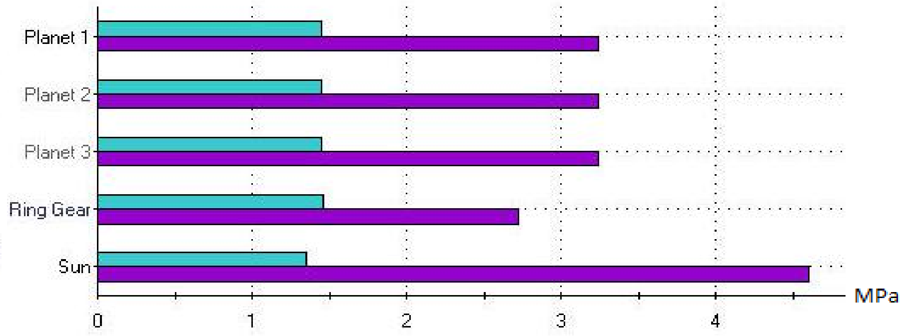

Figure 5: Gear contact safety factor and bending safety factor.

Figure 5 shows the safety factor for each gear. There are two bars for each element. The top bar shows the contact safety factor. The bottom bar represents the safety factor for the bending of each gear. Each gear of the reducer is listed on the ordinates of Figure 3, Figure 4 and Figure 5, and the abscissa represents the stress in Figure 3 and Figure 4, but in Figure 5 the abscissa represents the numerical factor of safety [8].

In order to compare the traditional rigid model with a rigid flexible hybrid model using RomaxDESIGNER, the rigid flexible hybrid model should be built taking into account the influences of the flexible structure, the axial, the bearing clearance and the bearing stiffness. The simulation results are shown in Figure 6, Figure 7 and Figure 8. The physical meaning of the graphs is the same as for the previous section [9].

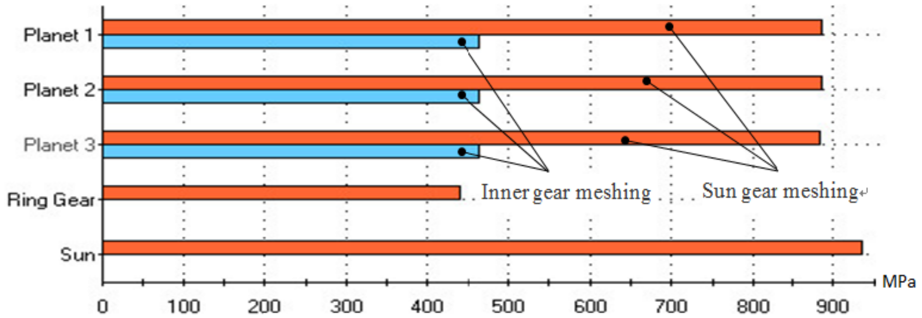

Figure 6: Maximum contact stress of gear.

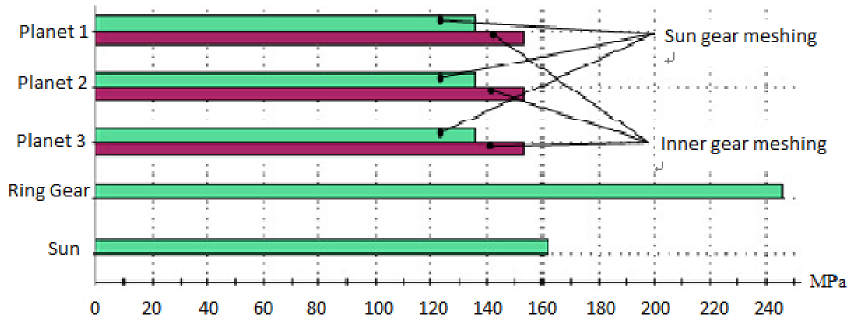

Figure 7: The maximum bending stress.

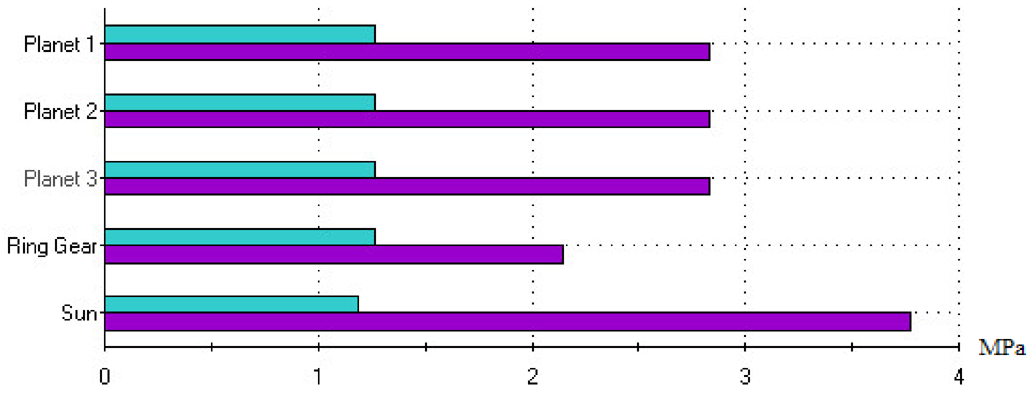

Figure 8: Gear contact safety factor and bending safety factor.

The results of stress analysis of the rigid flexible hybrid model and the traditional rigid model are as shown in Table 1 and Table 2, respectively.

Table 1: Stress analysis for the rigid flexible hybrid model.

Gear	The maximum contact stress (MPa)		Contact limited stress (MPa)		The maximum bending stress (MPa)		The ultimate bending stress (MPa)		Safety factor	
									Contact	Bend
Sun	932.79		1104.57		161.37		609.69		1.18	3.78
Ring	438.43		554.38		245.96		527.63		1.26	2.15
	left	right	left	right	left	right	left	right		
Planet 1	884.79	464.70	1,122.7	1,167.94	135.45	152.95	432.73	432.73	1.27	2.83
Planet 2	885.90	465.19	1,122.7	1,167.94	135.68	153.08	432.73	432.73	1.27	2.83
Planet 3	874.58	463.87	1,122.7	1,167.94	135.38	152.74	432.73	432.73	1.27	2.83

Note: the left column represents - meshed with the sun wheel; the right column represents - meshed with the inner gear ring.

Table 2: Stress analysis for the traditional rigid model.

Gear	The maximum contact stress (MPa)		Contact limited stress (MPa)		The maximum bending stress (MPa)		The ultimate bending stress (MPa)		Safety factor	
									Contact	Bend
Sun	814.92		1104.57		138.06		634.95		1.36	4.59
Ring	378.18		554.38		198.48		541.46		1.47	2.73
	left	right	left	right	left	right	left	right		
Planet 1	772.98	400.84	1,122.7	1,167.94	131.32	139.88	454.06	454.06	1.45	3.24
Planet 2	772.98	400.84	1,122.7	1,167.94	131.32	139.88	454.06	454.06	1.45	3.24
Planet 3	772.98	400.84	1,122.7	1,167.94	131.32	139.88	454.06	454.06	1.45	3.24

Note: the left column represents - meshed with the sun wheel; the right column represents - meshed with the inner gear ring.

From Table 1 and Table 2, it can be seen that the maximum contact stress for each gear of the gear box and bending stress are less than the allowable ultimate stress and, so would meet the design requirements. Referring to Table 1, in the rigid flexible hybrid model, the maximum contact stress for the three planetary wheels meshed with the sun wheel differ i.e. 884.79MPa, 885.90MPa and 874.58MPa, respectively. But, for the traditional rigid model (Table 2), the maximum contact stress is the same i.e. 772.98MPa.

The maximum bending stress of the three planetary gears both meshed with the sun gear and with the annular gear are the same. Therefore, the rigid flexible hybrid model takes into account the influence of structural flexibility, axial deformation, bearing clearance and bearing stiffness. Hence, the rigid flexible simulation closely models reality.

The simulation results for the rigid flexible hybrid model and rigid model show that the maximum contact stress and the maximum bending stress of the rigid model are much less than the rigid flexible hybrid model. The safety factors for the rigid model were significantly higher than that of the rigid flexible hybrid model. This is due to the rigid flexible hybrid model taking into account the effect of the flexible structure, the axial deformation, bearing clearance and the bearing stiffness. Once again, it shows the value of rigid flexible hybrid modelling.

TEACHING EFFECTS

The introduction of simulation technology into the Mechanical Design course has achieved remarkable results in the past five years. There have been more than 50 students who have won awards in innovative contests; students' innovation ability has significantly improved. Simulations using RomaxDESIGNER enable students to have a vivid understanding of mechanical designs, and to have a more profound understanding of mechanical structures commonly in use. The use of simulations has strengthened students' knowledge and has improved their ability to apply their learning. In addition, students are inspired to be more creative [10].

Upon completion of the training, students have not only mastered the basic theory of mechanical design, but also have a deeper understanding of the knowledge base. They understand how these theories are applied in practice and how to solve practical engineering problems. Hence, the training has inspired students' interest in mechanical design and produced high-quality graduates with the potential for ongoing self-development.

CONCLUSIONS

A comparative analysis of the traditional rigid model of a system of gears with a rigid flexible hybrid model using RomaxDESIGNER simulation software concluded that the hybrid model results are closer to actual working conditions and so validates the hybrid model. Such simulations can develop and improve students' engineering design abilities.

Wuhan University of Science and Technology has reformed teaching of the mechanical engineering courses. Combinations of traditional and new teaching methods are used. The latter includes the use of simulation software to model mechanical systems. The results show that teaching methods using modern simulation software benefit and stimulate students' learning and cultivate their ability to solve practical problems.

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