Design and Development of a Transmission System

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Abstract

The objective of this project was to design, develop, manufacture and test a five-speed transmission system that could be used for teaching and modeling in engineering classrooms. The gearbox was designed with several clear plastic viewing panels to observe the operation of the system. Furthermore, the components were designed for visual demonstration while running at lower speeds. Finally, a flywheel was added to the gearbox to measure rotational speeds. Most of the gearbox components were designed and manufactured using a 3D printer and computer aided design software. Material properties were verified using a tensile tester. The prototype assembly that was tested has met design specifications and required performances.

Introduction

The proposed project will develop a working model of a transmission to demonstrate the physics of a manual transmission. Per Spinka et al, "Complex physical models undoubtedly form an important educational tool in the engineering training process." Computer simulations are not enough to provide the experience and learning needed to develop good engineers. There is a real need for educational models like this gearbox, which helps students interact with equipment and machinery in engaging ways. The product will help to demonstrate features, such as shaft, gear, keyed shafts, bearing, and the interaction of different components in the transmission. Students will be able to measure the input power, speed and output speed by observing speed sensors attached to the assembly. The transmission model will also aid in classrooms labs, as students will be able to make predictions and test maximum speeds of the output shaft and compare it with the calculated speed of the car. The transmission will consist of five gears with ratios similar to that of a passenger vehicle, 3.12, 2.11, 1.60, 1.19, 0.86, first gear ratio to fifth gear ratio respectively, with a reverse gear ratio to be 3.17. This ratio is similar to that chosen by Noboru Hattori and other Nissan co-authors in their SAE paper[2]. The project activities include designing the gears, bearings and shafts, performing stress analysis and gear shape analysis, and building a CAD set. Finally, the product will be analyzed by Finite Element Analysis (FEA). The objective is to develop a model that will provide comprehensive knowledge and understanding of a five speed manual transmission system to science and engineering students.

Literature Review

Car engines have improved with combustion while electric engines have become integral to daily life making it frustrating not knowing the basics and mechanics behind how they work [3]. Along with engine combustion, a well-designed transmission plays a crucial role in making a vehicle perform perfectly. Several sources were useful in the design and analysis of many other aspects of the drivetrain.

Transmission technology has been developed through several decades, from manual transmission (MT) to automatic manual transmission (AMT), to continuously variable transmission (CVT), and to dual-clutch transmission (DCT). In addition to these popular designs, transmissions have been sometimes designed to perform particular functions. For example, if a transmission has 5 clutches and requires 3 of them to be engaged, there are a total of 10 possible combinations of gear ratios. The ZF 8HP and GM 8L transmission families have 5 clutches of which 3 are engaged for any gear state, but only have 9 out of these 10 states present (8 forward gear ratios along with 1 reverse gear ratio)[4].

Within the manual transmission, gear sets and dog clutches control the transmission ratios, which determine the ratio of input rpm and output rpm. Spur gears were selected for the application of this project. In order to perform an accurate spur gear design, several papers are studied, in terms of gear geometries, contact stresses, bending stresses, etc. Instead of using the C language to compute the contact stresses by varying the amount of profile shifts for a tooth-sum of 100 teeth (±4%) [5], FEA and hand calculations were applied, which will be covered in the method section. Furthermore, to simulate safely, plastic was selected as the material for all gears. The concept of plastic gears has been developed for years. For example, D.Laseinde studied the design process of plastic spur gears using virtual reality (VR). His study was aimed at developing a functional model and further validating the model for the production of plastic spur gears.[6] Related knowledge was gained by reading "Formulation for an optimal design problem of spur gear drive and its global optimization" [7], and "Design of spur gears using profile modification. Tribology Transactions" in which Zhang et al described several challenges they faced designing a gearbox cover.[8] Their article was useful in approaching the design and manufacturer of the clear case, but the educational model was also simpler in several ways.

Methods

This product is targeted at filling a need for a low cost manual transmission demonstration to educational institutions such as high schools, trade schools, community colleges, universities, and museums. The product demonstrates the mechanics of the five-speed transmission. Because the target market includes students, the product must be safe for use and vivid for observation. A motor with 100 watts was selected as an appropriate power source for this product. The motor will be operated at 6000 rpm, controlled by a foot pedal. A rubber band will be placed between motor output and transmission input in order to reduce the rpm by a factor of 20 which results in 300 rpm as input speed. Plastic gears are able to withstand the reduced input power and torque. In order to obtain the properties of material, 10 tests were performed. 10 standard bars made by the same material were individually tested on the Ultimate Tensile Strength (UTS) testing machine. The average UTS of 3D-Printing material among these 10 tests was calculated to be 25.15 MPa.

No friction and power loss were considered, simplifying the calculations, although in reality, the theoretical power losses of the spur gear occur in various conditions, in addition to mechanical losses and pump losses.[9] Designing a gear was the most technically challenging aspect of the design process. To better design a set of gears, an example of two spur gears will be calculated step by step with the writing of the basic formulas. For example, the pinion will have 17 teeth and the gear will have 52 teeth. This pair of gears will provide a reduction ratio of 52 divided by 17 = 3.059. The equations can be used interchangeably between spur and helical gears since the helical angle of a spur gear is zero and the cosine of zero degrees is one. Even though the calculating of one gear could illustrate the utilization of the gear design equations, two gears were selected for calculations to show how to modify the addendum to eliminate undercut on the pinion and because contact ratio and operating stresses require the use of two gears to achieve power transfer. Once the gear reduction ratio was made, the diametral pitch, normal pressure angle, and the helical angle were selected. This is a trial and error selection based on availability of parts or tooling and calculated estimations. If the selection is not suitable for the required performance, the calculated results may be compared with the allowable stresses for the respective materials and a second set of calculations may be initiated making the gears larger or smaller as desired to obtain the recommended operating stress levels.

Based on the assumptions and material property and using equations 1 and 2 below, gear bending and gear wear were analyzed to achieve the safety factor. The results show all the gears have at least 7.75 as a safety factor.

Gear wear: $\sigma = W * K_0 * K_v * K_s * K_H * \frac{K_B}{b * m_t * Y_J}$ Eq. 1

Gear bending: $\sigma_{bending} = W * K_v * PD * \frac{K_m}{F * J}$ Eq. 2

Design Tools/Processes

After selecting the size of the gear sets, design for the housing and shift mechanism were done using CAD. This software was helpful in making many of the necessary calculations. The 3-D printer was used to printout sample gears.

Overall, it was surprising to experience firsthand how complex the manufacturing process actually is. There were a vast number of parts required for the gear box as well as pages of calculations. The biggest challenge evolved from the interaction between parts. The meshing of the gears, meshing of the dog clutch with the gears, and the shaft's interaction with the mount all required a tremendous amount of coordination and detail in order to get the design to act properly. It was here, coordinating moving parts, which required the most time during the project.

In addition to the hand calculations, FEA was performed on all the gears and dog clutches. Examples are shown as Figures 1 & 2. For gears, contact stress and bending stress were analyzed. Meshing for contact analysis is complex and requires more refined meshing tools for accurate solution.[10] In this application, due to the limited technique issue, basic meshing tools were applied in this analysis. For dog clutches, in addition to stresses analysis, fatigue analysis was also performed.

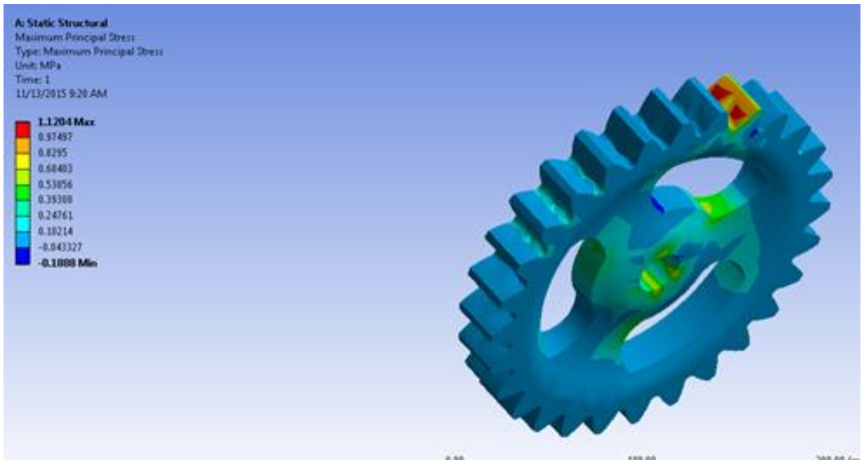

Figure 1 gear FEA Max Principal Stress

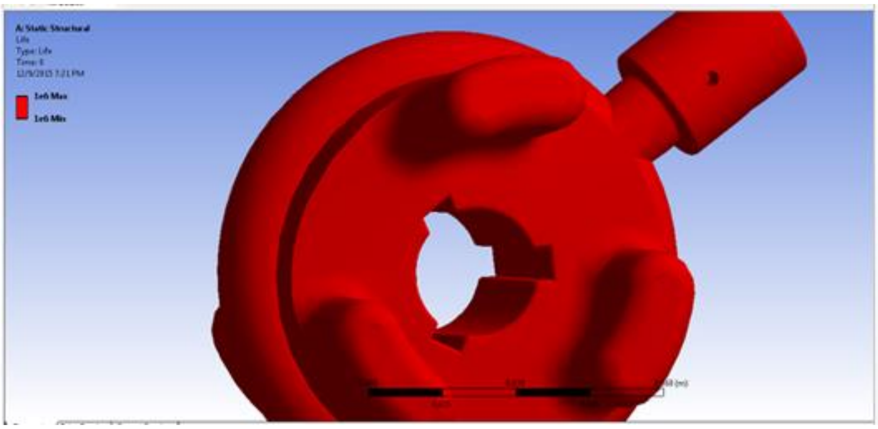

Figure 2 dog clutch FEA fatigue

Results

Table 1: Finite Element Analysis Results

								Brittle coulomb-Mohr			Factor of safety
Shear plane r θ normal to z	Contact r z normal to θ	Distance of peg to center	In shear plane on gear z θ normal to r			Shear normal to z	Normal to θ	Normal to r	σ a	σ b	n
Area1 (m^2)	Area2 (m^2)	Distance (m)	Area3 (m^2)	Force (N)	Torque (Nm)	Stress (Pa)					
9.87E-04	7.38E-04	1.10E-01	5.51E-04	9.13E+01	10	9.25 E+04	1.35 E+04	1.66 E+05	9.95 E+04	-8.60 E+04	136
8.96E-04	8.62E-04	1.08E-01	3.90E-04	9.26E+01	10	1.03 E+05	1.16 E+04	2.37 E+05	1.09 E+05	-9.7 E+04	121
8.93E-04	7.76E-04	7.50E-02	3.52E-04	1.33E+02	10	1.49 E+05	1.29 E+04	3.79 E+05	1.56 E+05	-1.43 E+05	84.2
8.93E-04	7.76E-04	7.50E-02	4.23E-04	1.33E+02	10	1.49 E+05	1.29 E+04	3.15 E+05	1.56 E+05	-1.43 E+05	84.2
4.53E-04	6.54E-04	6.50E-02	5.00E-04	1.54E+02	10	3.40 E+05	1.53 E+04	3.08 E+05	3.48 E+05	-3.32 E+05	37
4.53E-04	6.54E-04	6.50E-02	5.00E-04	1.54E+02	10	3.40 E+05	1.53 E+04	3.08 E+05	3.48 E+05	-3.32E+05	37

One of the analysis tables is shown as table 1, with analyzing all the relevant variables above, the minimum safety factor was 37.

Conclusion

The initial model for testing was constructed as a CAD assembly. The plan for making a physical prototype has already begun and is nearly complete. This model will include the first gear, first pinion, the second gear, second pinion and the dog clutch that mates with the first and second gears. These components will be assembled using 2” X 6” long 1” round shafts that are held in position by a wooden frame. This model will help generate an understanding of how well the dog clutch operation will work and how well the gears mesh. The mass moment of inertia can also be measured which will help obtain the limits of power input. There are more material properties that need to be obtained from testing. The most important property is impact resistance of the 3-D printed material. It would also be helpful to develop a better understanding of the materials reaction to sintering, like deformation and strength improvements. Pending the success of the test, the project is ready to be manufactured as a whole.

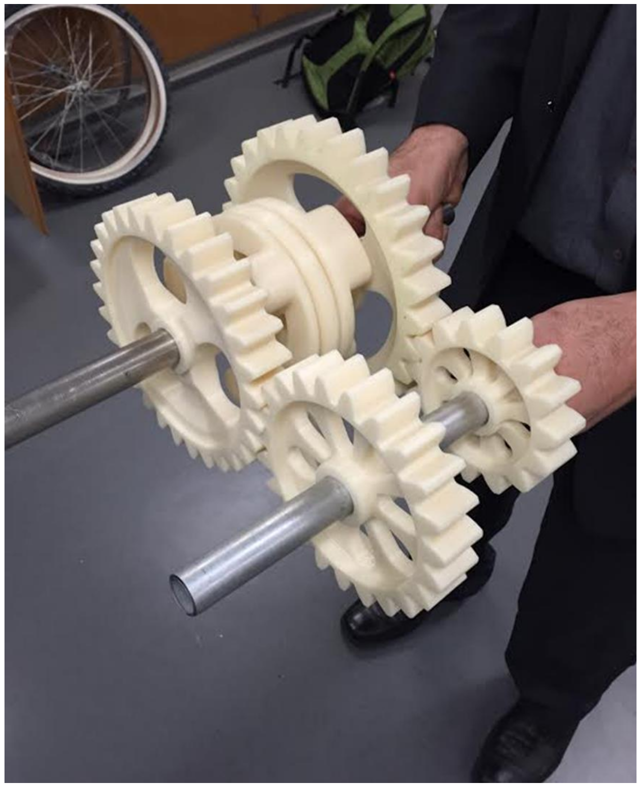

Figure 3 test procedure

References

【1】Spinka, O., Åkesson, J., Hanzálek, Z., & Årzén, K. (2010). Open physical models in control engineering education. International Journal of Electrical Engineering Education, 47(4), 448-459.
【2】Hattori, Noboru. "A New Five-Speed Nissan Automatic Transmission for Passenger Cars." SAE Technical Paper, February 01, 1990, 5.
【3】Ohtani, Masayaki. "How a 5 Speed Transmission Works Purpose." Engine Basics, 2015.
【4】Apakidze. "FORD 10 SPEED TRANSMISSION POWER FLOW." FEA Example, 2007.
【5】Sachidananda, H. K., K. Raghunandana, and J. Gonsalvis. 2015. "Design of Spur Gears using Profile Modification." Tribology Transactions 58 (4): 736.
【6】Laseinde, O. T. and S. B. Adejuyigbe. 2013. "Design of Plastic Spur Gears using Virtual Reality." International Journal of Computer Aided Engineering and Technology 6 (1): 48-61.
【7】Wan, Zhong and ShaoJun Zhang. 2013. "Formulation for an Optimal Design Problem of Spur Gear Drive and its Global Optimization." Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 227 (8): 1804.

【8】Zhang, Chunyan, Yinhu Qiao, Liang Sun, and Lizhong Wang. "Method of NC processing for the cover of auto gearbox."

【9】B. Wang. "Modeling and Analysis of the Dynamic Efficiency of Manual Transmission/reducer." ResearchGate Web of Science 16, no. 3 (2015): 417-26.

【10】Bommisetty, Karthik. "Finate Element Analysis of Spur Gear Set" May 2012, 40-41.