Characteristics of Reduction Gear in Electric Agricultural Vehicle

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Abstract. In electric agricultural machine a reduction gear is needed to convert the high speed rotation motion generated by DC motor to lower speed rotation motion used by the vehicle. The reduction gear consists of several spur gears. Spur gears are the most easily visualized gears that transmit motion between two parallel shafts and easy to produce. The modelling and simulation of spur gears in DC motor reduction gear is important to predict the actual motion behaviour. A pair of spur gear tooth in action is generally subjected to two types of cyclic stress: contact stress and bending stress. The stress may not attain their maximum values at the same point of contact fatigue. These types of failure can be minimized by analysis of the problem during the design stage and creating proper tooth surface profile with proper manufacturing methods. To improve its life expectation in this study modal and stress analysis of reduction gear is simulated using ANSYS workbench based on finite element method (FEM). The modal analysis was done to understand reduction gear deformation behaviour when vibration occurs. FEM static stress analysis is also simulated on reduction gear to simulate the gear teeth bending stress and contact stress behaviour.

1. Introduction

Electric vehicles are an alternative solution to fuel engines for transportation vehicles due to advances in batteries, increasing oil prices, and the desire to reduce greenhouse gas emissions [1]. Many electric vehicles have been applied in industrial, logistics, and agricultural applications as material handling systems [2-5]. Electric vehicles are an important tool in agricultural modernization. With the rapid development of the economy, electric vehicles are widely used in agriculture. Electric agricultural vehicles are kind of mechanical and electrical integration of transportation vehicles. In this research, a small electric vehicle with lift and dump capabilities was developed. To achieve high quality and high productivity, a well-designed electric agricultural vehicle is needed.

One of important part to support an electric vehicle operation is a reduction gear. The reduction gear has been a research point of interest for many decades especially in agricultural vehicle. Gears can be defined as toothed member which is transmit power or motion between two shafts without any slip. Spur gears are the most recognized and common type of gears. Spur gears have their teeth parallel to the axis and are used exclusively to transmit rotary motion between two parallel shafts, while maintaining uniform speed and torque. They have high efficiency and excellent precision rating. The

involve tooth form being the simplest to be manufactured permits high manufacturing tolerances to be attained.

There are several research related to the reduction gear. Wada [6] proposed method to investigate the failure condition on reduction gear operation. Badkas [7] proposed static and dynamic analysis of two spur gears. Jie [8] investigate the interfacial contact temperature based on FEM. Patil [9] studied about frictional tooth contact along line of a spur gear. Parra [10] investigates the gear condition based on the vibration occurs during operation. Li [11] and Zhao [12] proposed a fault diagnosis scheme for reduction geares using modified multi-scale symbolic dynamic entropy and mRMR feature selection. CAD object and computer software for simulation helps designer to analyzes, optimize design, reducing cost and time efficiency in physical prototype making [13].
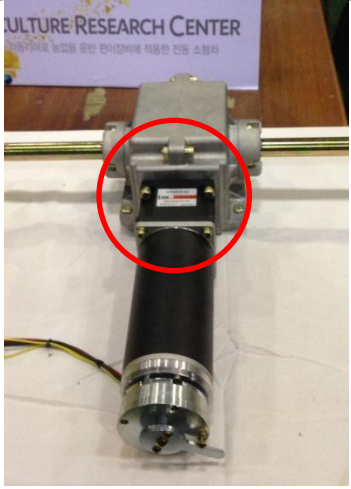
To improve the strength of reduction gear, in this research some parameters of gear are modified. In this paper the static analysis was done to evaluate the stress and total deformation improvement. This analysis was done to prevent the gear failure caused by deformation during operation [14]. Furthermore, the modal analysis was performed to find out the natural frequency of the reduction gear.

2. System Design

The developed electric vehicle is shown in figure 1. This vehicle is basically a cart powered by an electric motor. The operator controls the vehicle velocity and direction from behind the vehicle through the control panel on the handle. The optimal dimensions of the vehicle were calculated to maximize the capacity and the material strength. The vehicle was designed with a total body weight of 330 kg. The frame is made of high-quality structural steel. The length of the vehicle is 1760 mm and the width is 830 mm. The cargo size is 1220 mm (L) x 800 mm (W) x 220 mm (H), and the total load capacity is 300 kg. With this amount of load space, bulky crops and vegetables can be loaded easily. Moreover, the cargo can be opened at the back, left, and right sides of the vehicle.
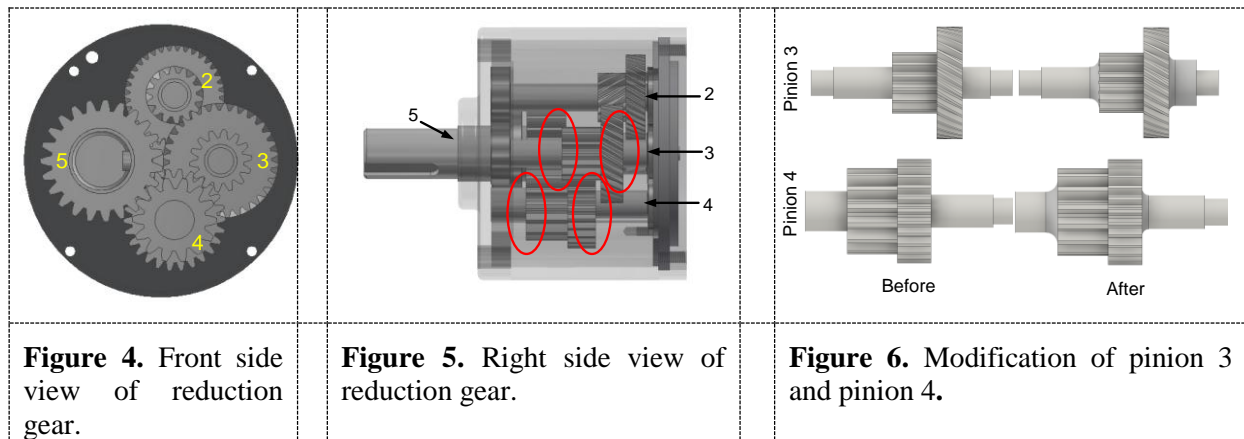
As shown in figure 2, this vehicle powered by two DA4A-29B4-ML57 24 V 400 W DC motors produced by Daehwa E/M Co. LTD from Korea. The rated angular velocity is 2900 RPM, the rated current is 23 A, the model size is 90 mm, and the shaft specification is powerful tooth cutting. To increase the torque and reduce the motor speed, a reduction gear was used. The D9K030US-S346 reduction gear was made by Daehwa E/M Co. LTD from Korea. The gear ratio is 30:1. The permissible overhang load is 55 kgf, and the permissible thrust load is 15 kgf. The maximum permissible torque is 300 kgf.cm. The output rotation direction is the same direction as the motor. Each motor was used to power the front wheels and rear wheels.

Figure 3 shows the failure condition of gear caused by contact stress and bending stress. The purpose of this paper is to improve the gear strength by modifying the gear parameter.

| **Figure 1.** Developed electric vehicle. | **Figure 2.** DC motor - reduction gear system. | **Figure 3.** Failed gear. |

3. Method

The structure of reduction gear used in this research as shown in figure 4 is consists of 5 pinions. To improve the strength of reduction gear, the pinion 3 and pinion 4 as shown in figure 5 are modified. The improvement are consists of gear shaft diameter increment and groove addition. The final form of reduction gear is shown in figure 6.

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Figure 4. Front side view of reduction gear.	**Figure 5.** Right side view of reduction gear.	**Figure 6.** Modification of pinion 3 and pinion 4**.**

In this research the stress and modal analysis was done to evaluate the reduction gear performance. Stress analysis was done to clarify the design of reduction gear can withstand a specified load, using the specified amount of material or that satisfies some other optimality criterion. Modal analysis is a kind of linear analysis technology, used to determine the structure of the natural frequency and vibration mode. First natural frequency or resonance is one of the contributing factors for vibration and noise related problems that occur in structures and machineries.

The procedure of static analysis and modal analysis includes following steps as shown in figure 7. Firstly, the 3D model of important component of the reduction gear was created. In this research focused on the spur gears since this part affected by the loading condition. Secondly, the model was simplified to obtained geometry model. Thirdly, the mesh of the model was generated. Fourthly, the materials properties were defined. In this research the gear are made of AISI 4140. Fifthly, the boundary condition was defined. Finally, solve the problem, visualized and read the results. In this research the 3D model was build using inventor software and stress analysis and modal analysis was done using ANSYS 15.

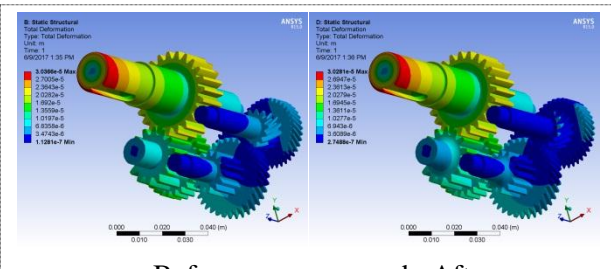**Figure 7.** Simulation analysis procedure.
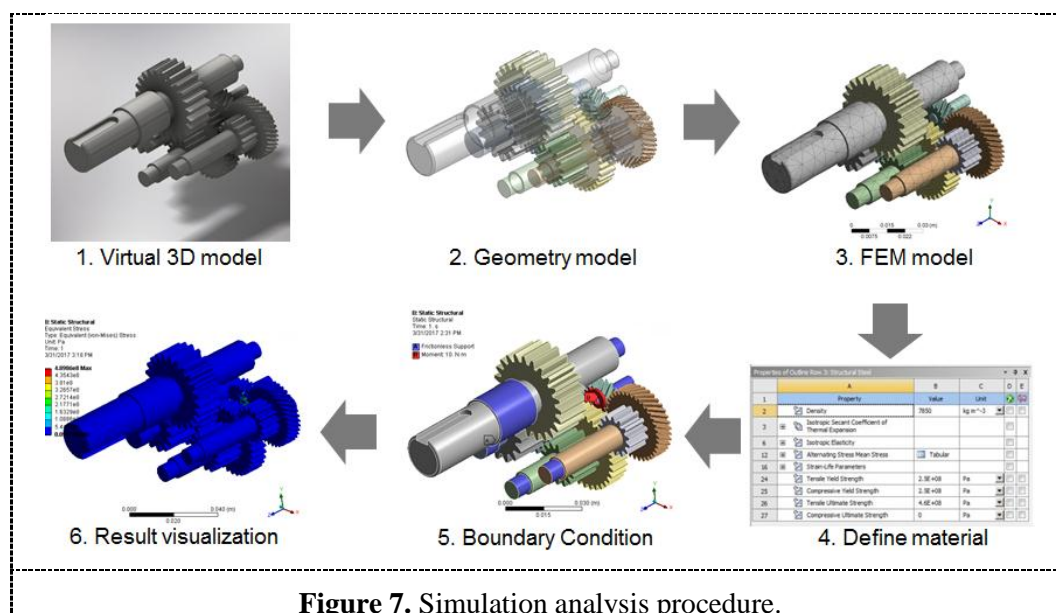
4. Result and Discussion

Figure 8 and figure 9 show the stress comparison before and after modification. The maximum stress occurred on the reduction gear before modification is 310.53MPa, and after is 288.42MPa. The safety factor of the gear can be improved from 1.33 to 1.43. The maximum deformation occurred on the reduction gear before modification is 30.36 μm, and after modification is 30.28 μm.
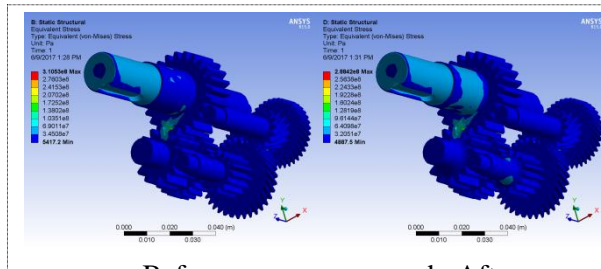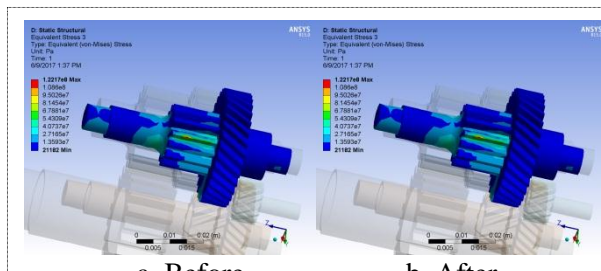

| a. Before | b. After | a. Before | b. After |

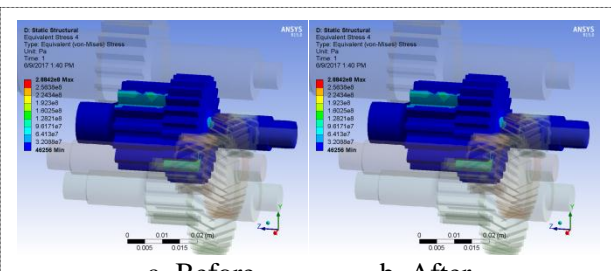**Figure 8.** Von-Misses Stress of pinion 3.   **Figure 9.** Total deformation of pinion 3.

Figure 10 shows the maximum stress occurred on the shaft 3 before modification is 158.47MPa, and after modification is 122.17MPa. The safety factor of shaft 3 can be improved from 2.618 to 3.396. Figure 11 shows the maximum stress occurred on the shaft 4 before modification is 310.53MPa and after modification is 288.42MPa. The safety factor of the gear can be improved from 1.33 to 1.43.


| a. Before | b. After | a. Before | b. After |

Figure 10. Von-Misses Stress of pinion 4.   **Figure 11.** Total deformation of pinion 4.

Figure 12 shows the result of modal analysis of the gear. The simulation result shows that the natural frequency of the gear is between 4559.6 Hz and 7592.2 Hz. This is higher than the operational frequency of the gear which is 50Hz when the motor operate at 3000 rpm. This should be the key consideration to avoid produce resonance. Therefore, the operation of the gear only generated small deformation.
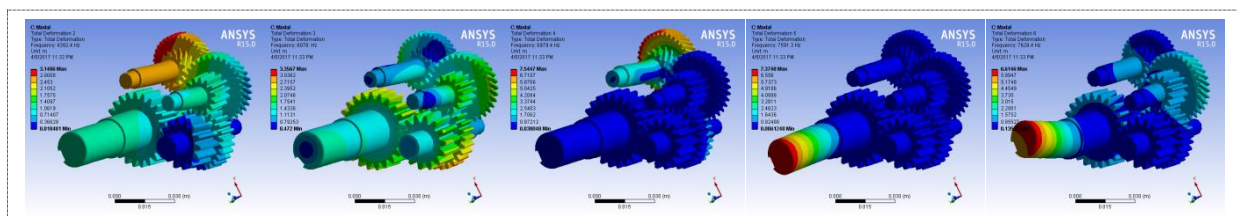
a. F=4559.6Hz   b. F=6145.9Hz   c. F=7063.8Hz   d. F=7573.9Hz   e. F=7592.2Hz

Figure 12. Modal analysis of reduction gear.

5. Conclusion

In this research the structure analysis was done to the DC motor reduction gear of electric agricultural vehicle. Based on this research following conclusion can be obtained:

1. By modifying shaft 3 and 4, the stress occurred in reduction gear can be reduced.
2. The safety factor of the gear can be improved from 1.33 to 1.43.
3. The natural frequency of reduction gear is between 4559.6~7592 Hz is higher than the operational frequency of the gear which is 50Hz.

Acknowledgments

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