Structural Analysis on the Separated and Integrated Differential Gear Case for the Weight Reduction

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Abstract The development of lightweight vehicle components has been studied for a long time due to strict exhaust emission regulations and fuel efficiency. The purpose of this study is to improve the performance and weight reduction of the differential gear case due to the change from the conventional type to the integrated type. Through the 3D modeling and the finite element analysis, the static stress analysis was performed for each load condition. Based on the results, the structural safety analysis results confirmed that the collision criteria were satisfied and the possibility of improving the performance and lighter weight of the products was confirmed.

Keywords Differential case · Integrated diff.case · Structural analysis · FEM analysis

1 Introduction

The vehicle differential gear is a device that distributes the number of revolutions of different wheels properly when the car moves forward or turns on the uneven surface of the road. It is a device that equally distributes the number of revolutions of the left and right driving wheels or the front and rear drive axles for smooth driving or transmits an equal torque to the rotating shafts during steering. The differential gearcase is a device that protects the differential gear from impact and moves with

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the ring gear of the differential. Differential gears and differential gear cases have many different shapes and sizes according to the shape of structure and type of the vehicle, and there are various design variables to improve the driving stability and ride comfort of the vehicle.

Many researchers have worked in the area of include differential gear in different applications [1–14] i.e. vehicle [15–24], gear system [25–35], etc. A differential gear for vehicles is a combination of four rotating bevel gears (two pinion gears, two side gears), which are connected to the drive shaft of the car to control the rotation of both wheels as the car progresses. Looking at the principle of the differential gear, when driving straight, only the left and right two side gears rotate and the pinion gear does not move. When the vehicle moves forward on the uneven surface or rotates in a curved section, the pinion gear existing above and below rotates to adjust the rotation speed and rotation speed of the side gear. The vehicle differential gearcase is a device that protects the differential gear from impact and moves with the ring gear of the differential. When power is transmitted from the power shaft to the ring gear, the ring gear rotates and the vehicle moves while rotating the side gears on both sides of the case [1, 2].

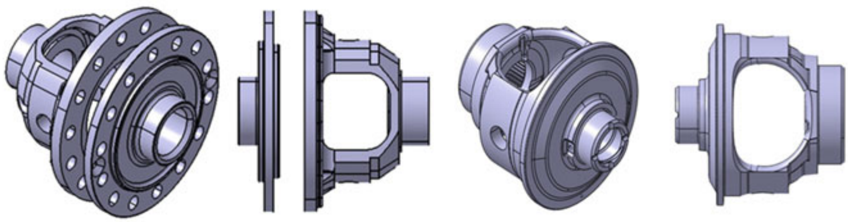
In the case of the separated differential gear case, the upper and lower parts are manufactured by casting process of spheroidal cast iron, respectively, and then manufactured through surface assembly and assembly process. There are many parts and the production process is complicated and heavy. There is a possibility of defects due to manufacturing defects and human error that can occur during assembly. In order to overcome the disadvantages of the separate differential gear case, the integrated differential gear case was designed. In the case of the integral differential gear case, there is a possibility of defects because it is difficult to accurately manufacture the internal and external shapes through the casting process due to the characteristics of the bending. However, since the integral differential gear is made of a single part, the structure is simple and lightweight, and the mechanical properties are improved [3].

In this study, the integrated differential case is designed to improve the structural properties and reducing weight for improving fuel efficiency. The integrated differential case is analyzed with load cases which are simulated for impact cases.

2 Differential Gearcase Design and Modeling

The manufacturing of the differential gear case for the vehicle is finalized through the necessary machining process according to the internal and external positions such as turning, grinding, and planar processing. In the case of the separate differential gear, the tolerance of the upper and lower parts of the differential gear case manufactured through the casting process is checked to determine whether there is a step, and the inner and upper gears are assembled to complete the final differential gear. In the case of the integral differential gear, it is not divided into upper and lower parts, so the gear is inserted into the integral differential gear manufactured through the casting process and fixed by using laser welding together with the fixing part. The material used for the integral differential gear is spheroidal cast iron, HB 170–241. The material is mainly used for the power transmission system of the vehicle, and the shape is manufactured through the casting process, and the connecting part is processed by grinding.

In order to eliminate the unnecessary elements of existing differential gear case models and to manufacture an integrated differential gear case for miniaturization and lightweight, miniaturization and lightening of differential gear proceed and through structural design program before production of a prototype to examine its stability [4, 5]. The integrated differential gear case was 3D modeled. In addition, 3D modeling was conducted to compare the stability of the separate and integrated differential gear cases. The separate differential gear case model measures 138 mm and 162 mm in weight and 6.137 kg in weight, respectively, and uses CATIA V5 R20 for the structural design program (Fig. 1). The all-in-one differential gear case model weighs 169 mm and 156 mm, respectively, and weighs 4.4 kg. Although there was little change in size, it satisfied the conditions when lightweight was advanced. At this time, the weight could be reduced by 28% (Table 1).



(a) (b)

Fig. 1 Differential gearcase modeling **a** separated differential case and **b** integrated differential case

Table 1 Material properties of separated and integrated differential cases

Part name	Material	Young's Modulus (GPa)	Poisson' ratio	Density (kg/m^3)	Tensile strength (MPa)	Yield strength (MPa)
Cup cover	FCD600	200	0.275	7.86	600	370
Integrated diff case	GCD500	169	0.27	7.10	500	320

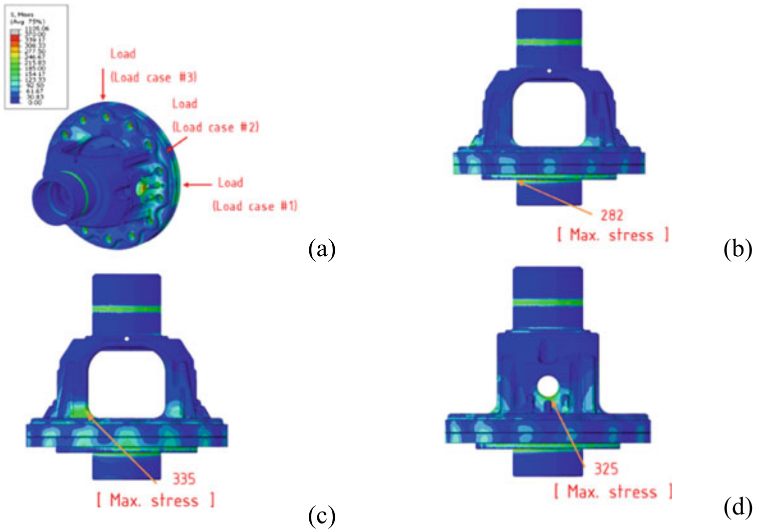


Fig. 2 Separated differential gearcase structural analysis with respect to loadcase: **a** loading information for loadcase, **b** loadcase#1analysis result, **c** loadcase#2analysis result and **d** loadcase#3analysis result

3 Differential Gearcase Structural Analysis

3.1 Separated Differential Gearcase Analysis

The maximum stress was calculated when the differential gear case and the ring gear were connected with fixed boundary conditions and additional loads were applied to the ring gear in three directions of 0, 45, and 90 degrees along with the boundary conditions. The maximum stress locations and stress values occurring in the separate differential gear case for each external force are shown in Fig. 2. The results of the stress analysis showed that the maximum stress was the highest in the case of Load case # 2, and the part that received the maximum stress in each case appeared differently according to the shape of the product.

3.2 Integrated Differential Gearcase Analysis

Since the boundary condition is given by pressure, the pressure corresponding to the external force is set based on the area of each region. After adding each boundary condition, additional fixed boundary conditions for structural analysis are added. A boundary condition was added to fix the displacement in the *z*-axis direction so that rotation did not occur at the ring gear connection. In addition, considering the rotation

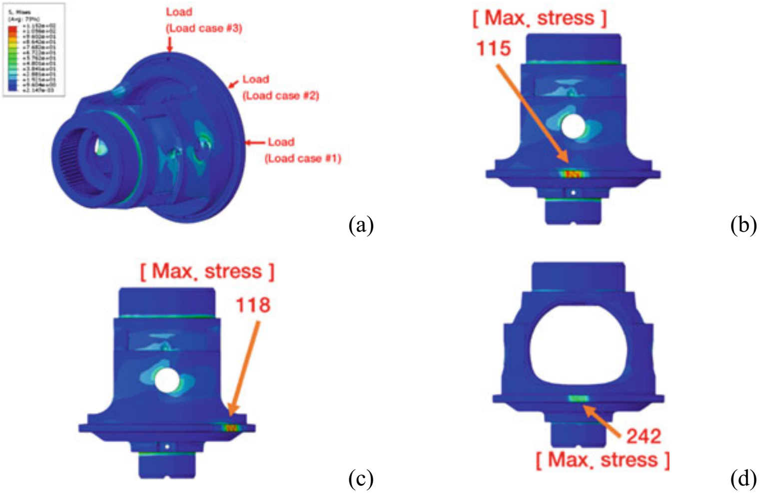


Fig. 3 Integrated differential gearcase structural analysis with respect to loadcase: **a** loading information for loadcase, **b** loadcase#1analysisresult, **c** loadcase#2analysis result and **d** loadcase#3analysis result

of the differential gear, an external force that gives torque to one of the rotating shafts was set.

The maximum stress was calculated when the differential gear case and the ring gear were connected with fixed boundary conditions and additional loads were applied to the ring gear in three directions of 0, 45, and 90° along with the boundary conditions. The maximum stress locations and stress values occurring in the integral differential gear case for each external force are shown in Fig. 3. The results of the stress analysis showed that the maximum stress was the highest in the case of Load case # 3, and the part under the maximum stress appeared in each case according to the shape of the product. Unlike the case of load case # 2 in the case of the separate differential gear case, the maximum stress is the highest in load case # 3 90° in the case of the integral differential gearcase. When compared with the model it can be seen that a significantly lower maximum stress value appears.

4 Conclusions and Discussions

The design change from the existing one-piece differential gear case model to an integrated differential gear case reduced the weight change by 28% while minimizing the size change. Structural analysis was performed to analyze the effect of structural safety due to the reduced weight, and as a result, the structural safety was confirmed. In addition, further research is needed to enable optimal shape design through structural optimization.

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References

1. Veeranjaneyulu C, Babu Hari U (2012) Design and structural analysis of differential gear box at different loads. Int J Adv Eng Res Stud 1:65–69
2. Khan A, Verma S (2015) Design and analysis of automobile central differential having two-different side gear. Int J Sci Res Dev 3(4):2321–0613
3. Chen L, Zhang D, Chen W, Hu F, Huang M (2013) Lightweight design of differential case based on particle swarm optimization algorithm. Trans Chin Soc Agric Eng 29(9):24–31
4. Güler T, Demirci E, Yıldız AR, Yavuz U (2018) Lightweight design of an automobile hinge component using glass fiber polyamide composites. Mater Test 60(3):306–310
5. Zhang Y, Lai X, Zhu P, Wang W (2006) Lightweight design of automobile component using high strength steel based on dent resistance. Mater Des 27(1):64–68
6. Bhardawaj S, Chandmal Sharma R, Kumar Sharma S (2019) A survey of railway track modelling. Int J Vehicle Struct Syst 11 (5)
7. Bhardawaj S, Sharma R, Sharma S (2020) Ride analysis of track-vehicle-human body interaction subjected to random excitation. J Chin Soc Mech Eng 41(2):236–237
8. Bhardawaj S, Sharma RC, Sharma SK (2020) Analysis of frontal car crash characteristics using ANSYS. Mater Today Proc 25:898–902
9. Bhardawaj S, Sharma RC, Sharma SK (2020) Development in the modeling of rail vehicle system for the analysis of lateral stability. Mater Today Proc 25:610–619
10. Bhardawaj S, Sharma S, Sharma R (2020) Development of multibody dynamical using MR damper based semi-active bio-inspired chaotic fruit fly and fuzzy logic hybrid suspension control for rail vehicle system. In: Proceedings of the institution of mechanical engineers, Part K: journal of multi-body dynamics
11. Dao DK, Ngo V, Phan H, Pham CV, Lee J, Bui TQ (2020) Rayleigh wave motions in an orthotropic half-space under time-harmonic loadings: a theoretical study. Appl Math Model 87:171–179
12. Goyal S, Anand CS, Kumar S, Chandmal R (2019) Thin-walled structures crashworthiness analysis of foam filled star shape polygon of thin-walled structure. Thin-Walled Struct 144
13. Kanth Choppara R, Chandmal Sharma R, Kumar Sharma S, Gupta T (2019) Aero dynamic cross wind analysis of locomotive. IOP Conf Ser Mater Sci Eng 691:012035
14. Lee J, Ngo V, Phan H, Nguyen T, Dao DK, Cho Y (2019) Scattering of surface waves by a three-dimensional cavity of arbitrary shape: analytical and experimental studies. Appl Sci 9(24):5459
15. Palli S, Koona R, Sharma SK, Sharma RC (2018) A review on dynamic analysis of rail vehicle coach. Int J Veh Struct Syst 10(3):204–211
16. Park J, Lee J, Jeong S-G, Cho Y (2019) A study on guided wave propagation in a long distance curved pipe. J Mech Sci Technol 33(9):4111–4117
17. Park J, Lee J, Le Z, Cho Y (2020) High-precision noncontact guided wave tomographic imaging of plate structures using a DHB algorithm. Appl Sci 10(12):4360
18. Park J, Lee J, Min J, Cho Y (2020) Defects inspection in wires by nonlinear ultrasonic-guided wave generated by electromagnetic sensors. Appl Sci 10(13):4479
19. Sharma RC, Palli S, Sharma SK, Roy M (2017) Modernization of railway track with composite sleepers. Int J Veh Struct Syst 9(5):321–329
20. Sharma RC, Sharma S, Sharma SK, Sharma N (2020) Analysis of generalized force and its influence on ride and stability of railway vehicle. Noise Vibr Worldwide 51(6):95–109

21. Sharma RC, Sharma SK (2018) Sensitivity analysis of three-wheel vehicle's suspension parameters influencing ride behavior. Noise Vibr Worldwide 49(7–8):272–280
22. Sharma RC, Sharma SK, Palli S (2018) Rail vehicle modelling and simulation using lagrangian method. Int J Veh Struct Syst 10(3):188–194
23. Sharma SK (2019) Multibody analysis of longitudinal train dynamics on the passenger ride performance due to brake application. Proc Inst Mech Eng Part K: J Multi-body Dyn 233(2):266–279
24. Sharma SK, Kumar A (2014) A comparative study of Indian and worldwide railways. Int J Mech Eng Robot Res 1(1):114–120
25. Sharma SK, Kumar A (2018) Disturbance rejection and force-tracking controller of nonlinear lateral vibrations in passenger rail vehicle using magnetorheological fluid damper. J Intell Mater Syst Struct 29(2):279–297
26. Sharma SK, Kumar A (2016) Dynamics analysis of wheel rail contact using FEA. Proced Eng 144:1119–1128
27. Sharma SK, Kumar A (2017) Impact of electric locomotive traction of the passenger vehicle Ride quality in longitudinal train dynamics in the context of Indian railways. Mech Indust 18(2):222
28. Sharma SK, Kumar A (2018) Impact of longitudinal train dynamics on train operations: a simulation-based study. J Vibr Eng Tech 6(3):197–203
29. Sharma SK, Kumar A (2018) Ride comfort of a higher speed rail vehicle using a magnetorheological suspension system. Proc Inst Mech Eng Part K: J Multi-body Dyn 232(1):32–48
30. Sharma SK, Kumar A (2017) Ride performance of a high speed rail vehicle using controlled semi active suspension system. Smart Mater Struct 26(5):055026
31. Sharma SK, Phan H, Lee J (2020) An application study on road surface monitoring using DTW based image processing and ultrasonic sensors. Appl Sci 10(13):4490
32. Sharma SK, Saini U, Kumar A (2019) Semi-active control to reduce lateral vibration of passenger rail vehicle using disturbance rejection and continuous state damper controllers. J Vibr Eng Tech 7(2):117–129
33. Sharma SK, Sharma RC (2018) An investigation of a locomotive structural crashworthiness using finite element simulation. SAE Int J Commer Veh 11(4):02–11-04–0019
34. Sharma SK, Sharma RC (2018) Simulation of quarter-car model with magnetorheological dampers for ride quality improvement. Int J Veh Struct Syst 10(3):169–173
35. Sharma SK, Sharma RC, Kumar A, Palli S (2015) Challenges in rail vehicle-track modeling and simulation. Int J Veh Struct Syst 7(1):1–9