Mechanical Regenerative Braking System for Higer Bus

Dabi Beyen, Ramesh Babu Nallamothu, Anantha Kamal Nallamothu, and Seshu Kishan Nallamothu

Abstract Many efforts have been made in finding alternative energy sources rather than based on petroleum fuels due to its intermittency and increase in price. The other approach is to use the available energy effectively by minimizing energy wastage and recycling energy by using regenerating devices. During braking the vehicle, the kinetic energy of the vehicle converted into heat energy and wasted to the environment. This braking energy can be stored in regenerating devices such as the flywheel, high voltage battery, and flat spiral spring before it converted into heat. The restored energy can be reused to restart the vehicle or for acceleration. This work aimed to design and analyze MRBS for Higer bus using a flat spiral spring as an energy storage device. This MRBS is designed for Ankai Higer bus operated in Addis Ababa that delivers about 55 passengers per trip beyond the manufacturer limit 40 passengers. According to the result, the energy stored in the flat spiral spring is inversely proportional to both spring length and the vehicle speed. The spring efficiency for the spring length of 2000 mm or 2 m moving at 40 km/h is greater than 45%. The CAD model of the planetary gear assembly was developed using CATIA VR5 and SolidWorks software and the model imported into ANSYS 16.0 for structural analysis in ANSYS workbench. From the analysis, the result for stress, strain, and deformation distribution had drawn. The AAK compact alternator is also connected to one end of the ring gear to get an output of around 1.7 kW (1680 W). The electric energy regenerated can be used to recharge the battery or to fulfill the electric need of the vehicle. It is recommended to the automotive industries, automotive manufacturers, and the universities to motivate and fund the researchers to investigate to develop environmentally friendly and technologically advanced regenerative brake system.

D. Beyen
Department of Mechanical Engineering, Wolkite University, Gubrei, Wabe Bridge, Ethiopia
e-mail: dabi.beyen@yahoo.com

R. B. Nallamothu (✉)
Mechanical Systems and Vehicle Engineering Department, SoMCME, Adama Science and Technology University, Adama, Ethiopia
e-mail: rbnallamothu@gmail.com; ramesh.babu@astu.edu.et

A. K. Nallamothu · S. K. Nallamothu
School of Industrial and Information Engineering, Politecnico di Milano, Milan, Italy

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1 Introduction

The regenerative braking system was a past idea and a recently focused researchable concept that needs more attention from automotive industries/manufacturers/and any other concerning bodies since it has its own contribution in combating the future energy demand deficiency problem that may occur due to intermittence of the fossil fuel. This system also needs a technological advance to give the necessary output and to bring a continuous solution to the problem. Regenerative braking is a device that helps to convert braking energy into another form of energy and stores the energy for later use by the driver to start the vehicle from rest or for accelerating vehicle. The amount of stored/captured/energy by the regenerative device depends on the efficiency of the device and the amount of braking torque/force [1–5]. On the other hand, a storage system is used to store a part of the kinetic energy of the vehicle for a shorter duration in a regenerative braking system. Power transmission is used to direct the energy which otherwise generally dissipated in the brakes storage system during deceleration [1, 6, 7]. In a conventional vehicle, due to the friction between brake pads and brake drums, the kinetic energy of the vehicle is converted into heat. This generated heat gets carried away by the wind stream into the atmosphere. Thus, vehicle kinetic energy gets wasted. More the amount of energy wasted more the duration of the application of the brakes and more the frequency of the application of brakes [1, 4, 6]. The energy storage system stores the energy for a shorter duration until the vehicle needs it back.

The conversion system converts the stored energy back into kinetic energy and used for restarting or accelerating the vehicle. The type of storage, the efficiency of the drive train, drive cycle, and inertia of the vehicle determine the amount of energy that can be stored. City-bound driving leading to very frequent braking has the higher potential of energy saving due to more energy wastage under normal conditions [1, 4, 5]. A successful regenerative braking system ideally should have the following properties [1, 3, 8–10]

- High energy conversion efficiency,
- High energy storage capacity per unit weight and volume,
- High power rating with short energy transmission time,
- No complicated control system,
- With higher smoothness of power delivery from the regenerative braking system,
- The rate of absorption and storage of energy is proportional to braking,
- With the shorter delay and less amount of energy loss over a wide range of road speeds and wheel torques.

The mechanical regenerative braking system (MRBS) is an assembly of planetary gear systems that contain sun gear in center, planetary gear in between, and ring gear

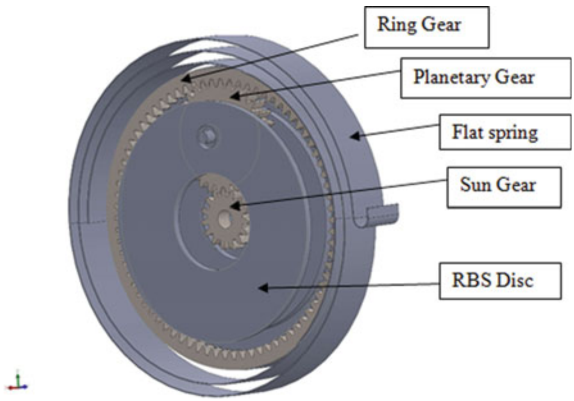


Fig. 1 MRBS assembly drawing

at the outside. The sun gear relates to the wheel axle in the wheel hub and transfers the axle rotation to the planetary gear. The planetary gear translates on the ring gear until the brake pedals depressed. As soon as the normal brake pedal depressed, the regenerative brake disk also depressed simultaneously. The regenerative brake depression stops the planetary gear from translating and transfers the motion to the ring gear. The ring gear on its turn starts to rotate on its axis and transfer to the external flat spiral spring. The flat spiral spring is attached to the outside of ring gear on one side, and the assembly covers on the other side. Following the turning of the ring gear, the spring winds up and starts to store the braking energy in the form of strain energy. The braking energy stored remains until it needs to start the vehicle from rest or to accelerate the vehicle. When the vehicle comes to rest finally the spring is controlled from returning by the mechanism allow the only a single direction of rotation the ring gear in the negative spin direction. This controlling mechanism/one-way clutch stays on until the accelerator pedal depressed. Model is shown in Fig. 1.

During the forward driving or accelerating the vehicle, the system is idling. This means the ring gear remains at rest, and the planetary gear translates on the stationary ring gear. At this moment, the system does not restore the energy, and this non-energy restoring cycle is known as idling time. This mechanism is an easy and simple mechanism which can be easily removed and inspected when failed it can be replaced with the new one.

The gear ratios between gears mate:

- Between the sun and planetary gear = 2
- Between the planetary and ring gear = 2.5
- The overall gear ratio = 2 × 2.5 = 5.

Higer bus is (Fig. 2) one of the transport means operated in our capital city Addis Ababa/Finfine and it is neighbor Oromia region cities. Specifications of Higer bus are given in Table 1.

Fig. 2 Higer bus

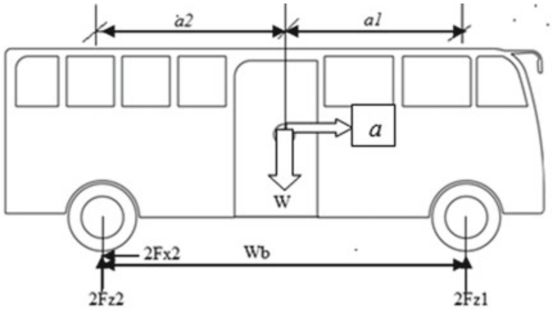


Table 1 Specifications of the Higer bus

Model	HK6669K
Overall dimensions (mm)	6620 × 2250 × 2795
Wheel drive	Rear-wheel drive (2RWD)
Type of fuel	Diesel
Maximum vehicle speed	120 km/h
Wheelbase (mm)	3308
Axle (front/rear)	Rated load 2500 kg/4500 kg

2 Braking Forces

Air Resistance (R_a) for a Rear-Wheel Drive (RWD)

$$R_a = \frac{1}{2} \times \rho_a \times C_D \times A_{FP} \times v^2$$

where, $\rho_a = \frac{p_a}{R_a \times T_a} \approx 1.05$ kg/m^3 is the density of the local air in k/m^3.

$C_D \approx 0.3$ to 0.6 is the drag coefficient (0.42 for Higer Bus).

$A_{FP} = SF \times W_2 \times H$ is the projected frontal area in m^2.

where, $SF \approx 0.75$ to 0.85 is the Shape Factor.

Rolling Resistance (R_{rl}) for a Rear-Wheel Drive (RWD)

$$Rxf + Rxr = fr(Wf + Wr) = fr \cdot W$$

where

Rxf Rolling resistance of the front wheels,
Rxr Rolling resistance of the rear wheels,
fr Rolling resistance coefficient,
W Weight of the vehicle.

Grade Resistance (*R*g) for a Rear-Wheel Drive (RWD)

$$R_g = mg \times \sin\phi = W \times \sin\phi$$

where

W is the weight of the vehicle in '*N*',
ϕ is the angle of inclination or slope.

3 Spur Gear Structural Analysis (ANSYS 16.0)

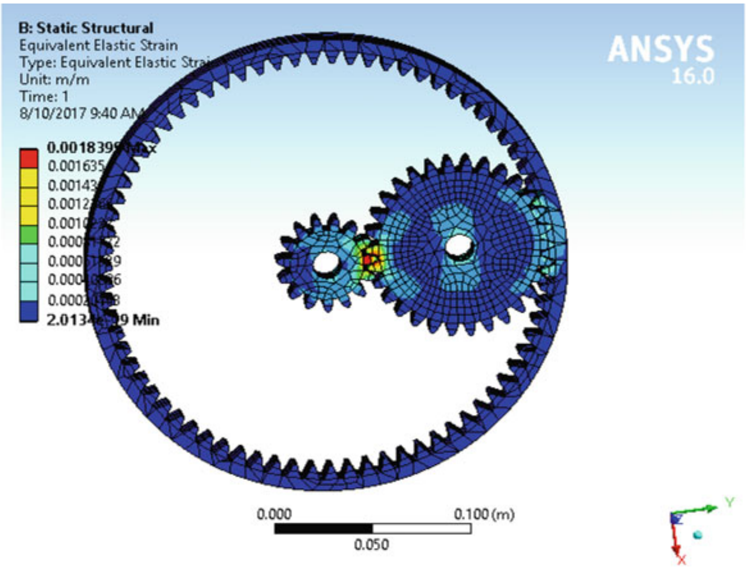
(i) The stress, strain, and deformation analysis of sun, planetary, and ring gear is making the ring gear fixed support. ANSYS analysis results are shown in Fig. 3a–d.

(ii) The stress, strain, and deformation analysis of sun, planetary, and ring gear is making the ring gear frictionless support. ANSYS analysis results are shown in Fig. 4a–d.

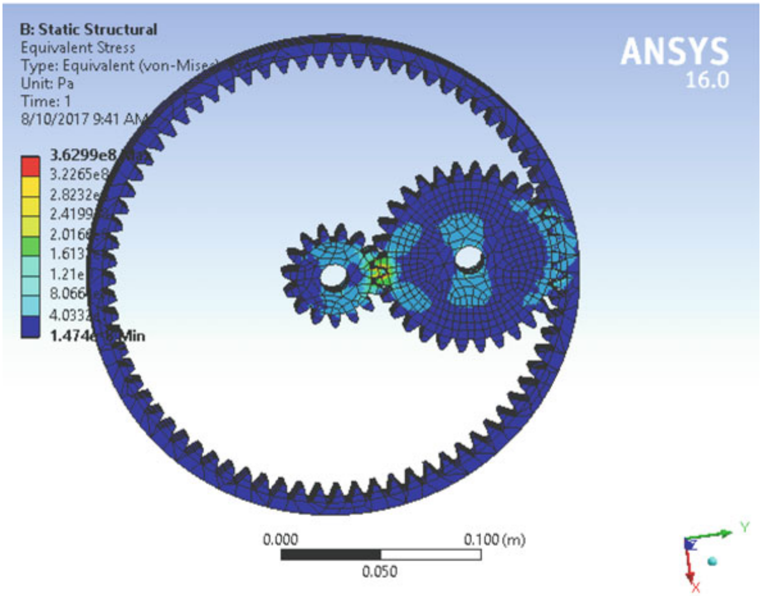
4 Conclusion

This work aims to explore, analyze, and improve the brake efficiency, fuel economy of the vehicle, and reduce emission without affecting/compromising/the vehicle performance by restoring the braking energy in the flat spiral spring and using it during restart from rest or acceleration. This MRBS is designed for Ankai Higer bus operated in Addis Ababa, Ethiopia. The bus delivers about 55 passengers per trip beyond the manufacturer limit 40 passengers due to the transportation facility shortage in Addis. There is a repeatedly braking and releasing of brake pedal during the delivery of passengers on the trip that causes much energy to lose as a form of heat to the environment. The mechanical regenerative braking system is the system designed to recover, permanently store, and release the energy safely when needed.

According to the result, the energy stored in the flat spiral spring is inversely proportional to both spring length and the vehicle speed. The spring efficiency for the spring length of 2000 mm or 2 m for the bus moving at 40 km/h is greater than 45%. But the efficiency drops when the length of the spring exceeds 2000 mm or 2 m. The finite element analysis of the designed components is done using ANSYS 16.0,

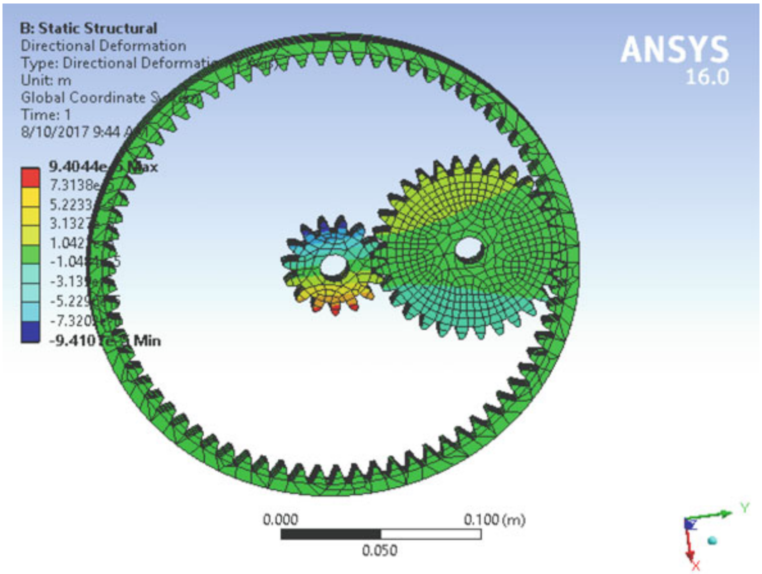


a) Equivalent strain

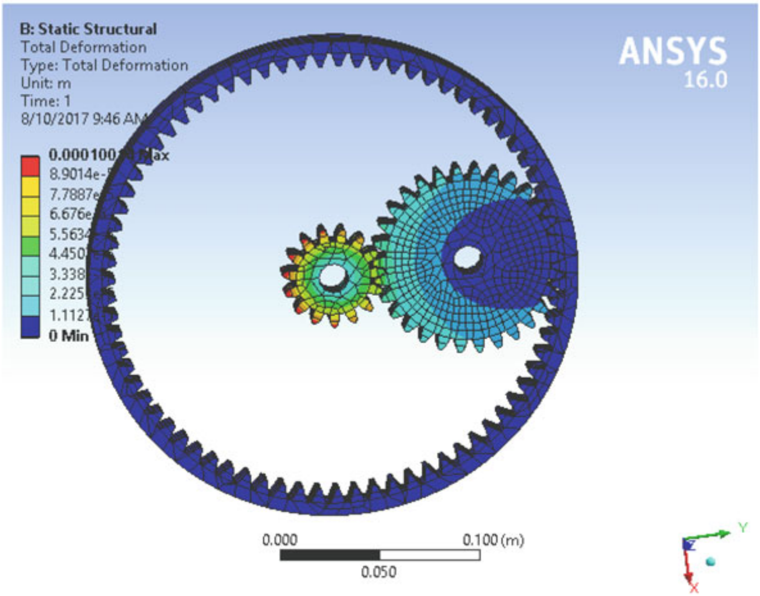


b) Equivalent Stress

Fig. 3 Structural analysis (ring gear fixed)

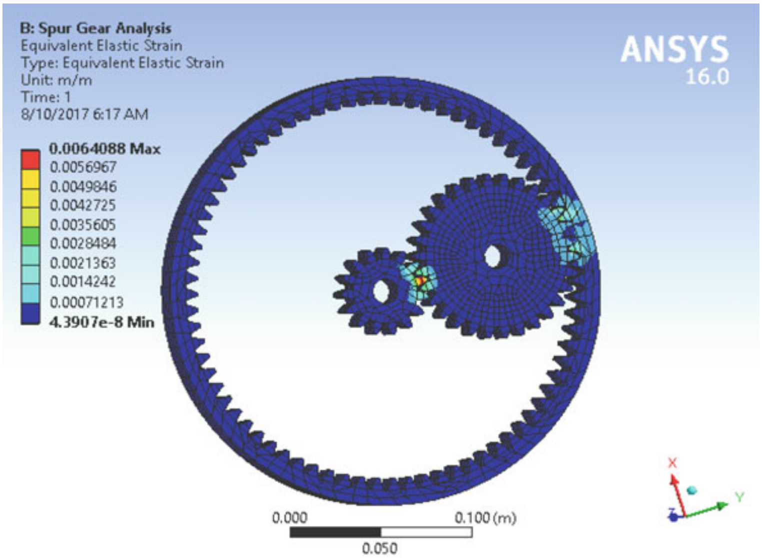


c) Directional Deformation

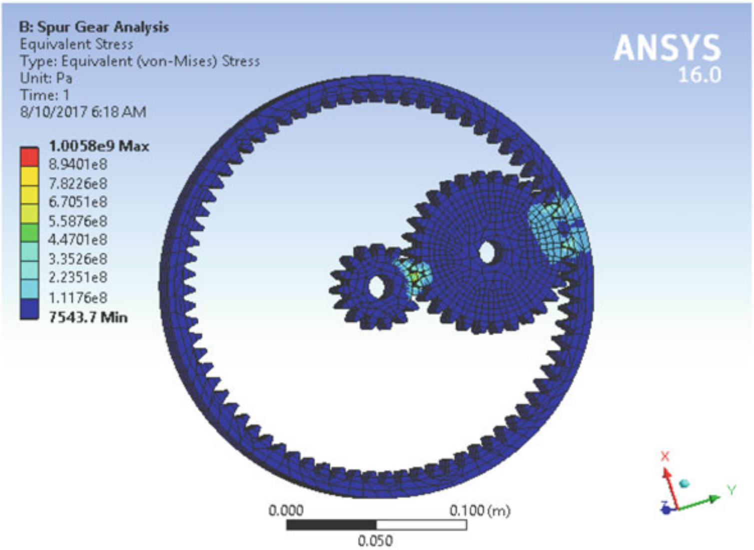


d) Total Deformation

Fig. 3 (continued)

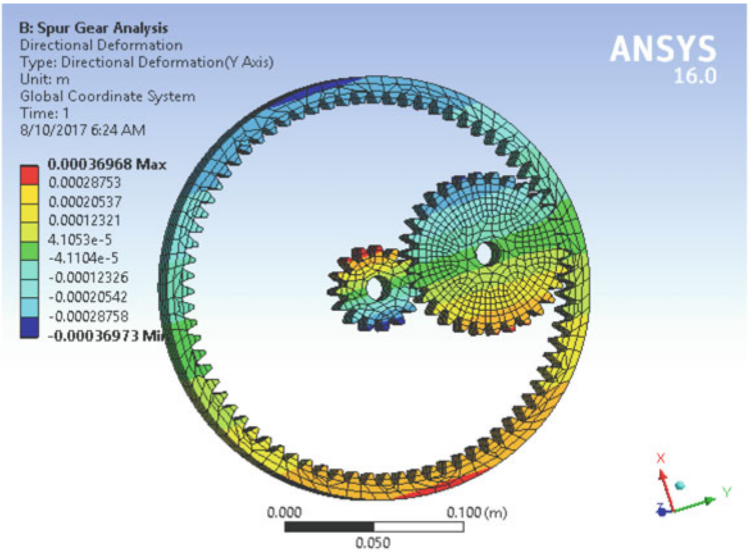


a) Equivalent Strain

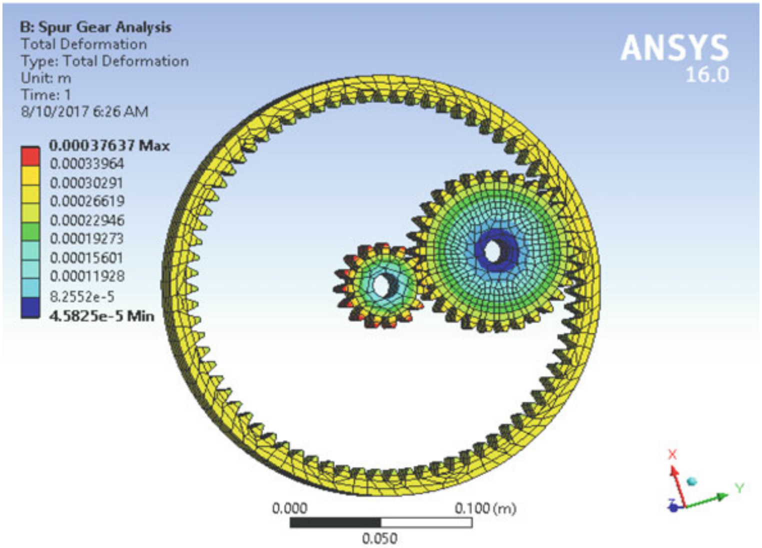


b) Equivalent Stress

Fig. 4 Spur gear structural analysis



c) Directional Deformation



d) Total Deformation

Fig. 4 (continued)

which shows that the stresses and strains developed are well within the permissible limit. From the AAK compact alternator, connected to one end of the ring gear 1.7 kW (1680 W) electric power is also captured. The electric energy regenerated can be used to recharge the battery or to fulfill the electric power need of the vehicle. The energy that is needed to be dissipated/lost/during braking is secured and stored in a flat spiral spring and the alternator in the form of torsion force and electric energy, respectively. The MRBS is a compact assembly and can be installed in the wheel hub. The operations of MRBS are done gradually by the use of one-way clutch to make sure the use of system safe and control the energy loss. Future study in this field will result in design which is environmentally friendly and technologically advanced system that electronically controlled. The energy storing capacity and the size of the device also can be improved by using supercapacitor in the future.

References

1. Clegg SJ (1996) A review of regenerative braking systems. The University of Leeds, Institute of Transport Studies, White rose, p 25
2. Khurmi RS, Gupta JK (2005) Machine design textbook, 1229 pp. Eurasia Publishing House (PVT) LTD
3. Veh Int J Innov Technol Res 2(30):981–984
4. Singh S (2004) Spur gears in “mechanical machine design-II,” 1st edn, pp 243–311. ISBN 98-93-5014-266-0
5. Mahadevan K, Balveera Reddy K (2014) Spring and gear design, design data handbook
6. Schmid H, Jacobson (2014) Fundamentals of machine elements, 3rd ed. CRC Press
7. Jazar RN (2012) Vehicle dynamics: theory and applications, Dept. of Mechanical Engineering Manhattan College Riverdale, NY 10471. springer.com, New York
8. Author Guide (2015) IskraAvtoelektrikad.d.ALTERNATORS, Manual of users, London
9. Karaveer V (2013) Modeling and finite element spur gear analysis. Int J Current Eng Technol
10. Gujar RA, Bhaskar SV (2013) Shaft design under fatigue loading by using modified goodman method. Int J Eng Res Appl (IJERA) 3(4):1061–1066. ISSN: 2248-9622, www.ijera.com