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Analysis of the efficiency of an automotive alternator by replacing Mild steel into aluminum as a material for rotor

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ABSTRACT

In real time automotive electrical systems, an alternator is usually used for charging the vehicle. The alternator generates AC voltage which is converted into DC voltage through rectifier of an alternator and this DC voltage helps to charging the vehicle's battery. The alternator further coupled with the vacuum pump, provides vacuum to the suction line of the vehicle's braking system. The rotor of the vacuum pump is made of mild steel which weighs high. Hence, it may act as a load to the alternator and reduces its efficiency. In the proposed model, efficiency and performance characteristics of the alternator are improved by reducing the mass of the rotor. Here, the mild steel is replaced by aluminum metal which weighs less. By using this, the mass of the vacuum pump is reduced, due to which the output power of the alternator gets increased. This increase in output power improves the efficiency of an alternator and subsequently the performance of the vehicle's charging system is improved.

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1. Literature survey

In [1], authors experimentally analysed the performance of camshaft mounted unit. They have simulated the vacuum pump with the presence of trapped volume of oil which creates overpressure in vacuum pump during cold starts of the lubricating fluid throughout the vacuum pump in order to take into account possible overpressures due to the presence of a trapped volume of oil, above all during cold starts. Simulation results considered mainly pressure vs. time characteristics and absorbed torque. In this case, the authors described the target equations for the behaviour of liquid and gaseous phases and also evaluated the current fraction of oil for each variable volume chamber. From this evaluation, the authors concluded that the proposed analysis able to simulate with an oil fraction ranging without discontinuities in the differential equations.

In [2–4], the authors studied their test equipment to measure the driving torque and time to attain the target pressure of the rotary vane vacuum pump of a brake booster and also analysed the effects of the several design variables on these parameters. From the results, it is inferred that the length and depth of grooves, thickness of an outlet check valve, and number of bypass holes. Further, they have proposed Optimal values of the design variables and to minimize the driving torque using the Taguchi method

In [5–7], the authors developed design base vacuum pump using Artificial Neural Network (ANN) model with two design parameters namely profile and performance. Then, prepared the proto samples with ANN model for certain range of vacuum pump. Finally, the model tested and results showed that the predicted values correlated with the actual values of proto samples.

In [8], the authors mathematically modelled for a different chamber profile of the vacuum pump to evaluate the evacuation time. Then experiments have been made with elliptical profile and compared with circular profile chamber of the vacuum pump. The performance evaluation results showed that the evacuation time with an elliptical chamber is lower than with a circular profile.

In [9–11], the authors designed an alternator by modifying the conventional Lundell alternator with dual-output extensions for

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jump charging. Then, they have experimentally validated this alternator with the particular high voltage of 42 V. finally, the authors achieved that tight load-dump transient suppression and low voltage of 12 V.

In [12], the authors experimentally focused on the performance metrics, including vacuum achievement time & power consumption to identify the optimum level of vacuum pump to improve the overall vehicle efficiency. Finally, they have concluded that the certain level of improvements is possible with these findings including in power consumption.

In [13], the authors analysed systematically the layout of vacuum pump performance specifically for brake and turbocharger applications. Initially, framed the steady state bench test condition to simulate the braking and turbocharger and also adopted the Taguchi's method.

Aluminium 6061T6 is another alternative material for vehicle body due to its higher yield strength with less dense than steel. The drawback of using thinner surface leads to buckling of the structure [14]. The vehicle subjected to impact load or overloading of weight was analysed by multiplying static load with a impact factor to obtain the impact load condition. In general impact factor is taken as 1.3 for low impact analysis and for higher loading condition it is in the range of 5 to 6 [15–17].

2. Objective

The main objective of the project is to improve the efficiency of the alternator by reducing the mass of the rotating part of the vacuum pump. The alternator discussed in this project is used in the diesel engine vehicle to charge the battery of the vehicle. Hence by reducing the mass of the vacuum pump the efficiency of the charging system of the vehicle gets improved. The mass is reduced by changing the type of metal used in a rotor. In existing vacuum pump the mild steel is used in a rotor which weighs high. In our proposed model the aluminum metal is used instead of mild steel. This proposed model the output power obtained is higher than the existing system.

3. Introduction

In this project the main aim is improving the alternator efficiency and there are some methods available for improving the alternator efficiency [18,19]. Those methods are known as a classical methods or conventional methods of improving the alternator efficiency (Fig. 1).

Fig. 1. Mild steel.

There are five types of losses in the alternator. These losses can be categorized into fixed losses and variable losses. When these losses can be reduced, the efficiency can be improved [20,21]. The Fixed losses are independent of load and the variable losses are dependent of load. The fixed losses are classified into two types they are Friction and Windage losses, and Core losses. The variable losses are classified into three types they are stray load losses, I2R losses in Armature field and Brushless exciter losses [22].

3.1. Reduction in mass of the rotor of the vacuum pump

This section discusses about the reduction in mass of the rotor of the vacuum pump. Analyses and use the different kind of metal to reduce the mass of the rotor of the vacuum pump. Finally decided to design the rotor in Aluminum, because of the aluminum has the less weight and it does satisfy the required mechanical stress for the rotor. The mass of the both rotor details are given below,

The mass of the Mild steel rotor = 194.7 g.

The mass of the aluminum rotor = 76.7 g.

Therefore, the overall reduction in mass of the rotor by changing the Mild steel into aluminum is given by

3.2. Analysis of mass and efficiency relation

The main aim of this project is to increase the efficiency of the alternator-increasing the efficiency means increasing the output power. For this attempt can try to analyze the mass and efficiency relation. Here, at present the vacuum pump is connected to the alternator which is used in the diesel engine vehicles [7–12].

The vacuum pump is used in the braking system of the vehicle which is connected to the shaft of the rotor, hence the vacuum pump act as the load to the alternator. The rotor used in the vacuum pump is made of Mild steel which weights high. When the vacuum pump is coupled with the rotor of alternator the efficiency of the alternator may get reduce due to high mass of the rotor.

So this study analyzed that reduction in mass of the rotor in the vacuum pump may increase the efficiency of the alternator. Hence by changing the rotor material which mass is lower than Mild steel's mass can be used. It has four veins. When the rotor rotates these veins only create the suction, by removing the air from the vacuum suction line and also reduce the heat of engine oil. The weight of the Mild steel is 194.7gms

4. New design

The new model of rotor is made up of aluminium, which is lighter than mild steel. It also has same four veins as that of Mild steel. The weight of the aluminium is 76.7gms. The aluminium rotor is made up of using CNC "wire cutting" machine with help of gear data. The aluminium rotor shown in Fig. 2. A two veins rotor in the new model of rotor. But it's not give same performance compares to four veins rotor. The gear data of new model of rotor is shown in Fig. 3.

The above shown diagrams are CAD diagram. This is used to design the rotor in the CNC machine. The total diameter of the rotor is 51 mm. the gap in veins is 5.1 mm.Totally it consists of four veins. The centre of the rotor is made hallow for fixing the shaft. The mass and efficiency relation and reduction of mass of the vacuum pump rotor have been analysed.The new model of the rotor has been designed. The relation between existing model and new model has been compared to show the benefits of newly proposed mode.

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Fig 2. Aluminium rotor.

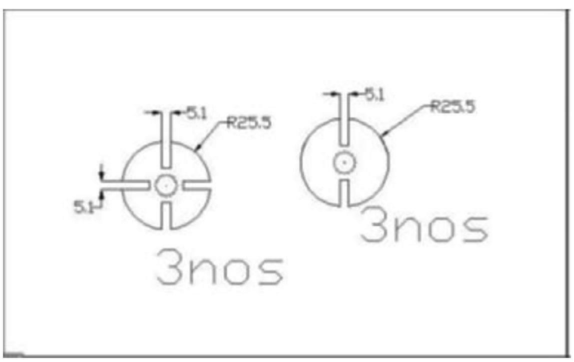

Fig. 3. Gear diagram of rotor.

5. Testing of vacuum pump

As the vacuum pump is the major part of the braking system in the vehicle, it is necessary to undergo various tests. When the rotor material of the vacuum pump is changed to aluminum instead of Mild steel, the new material should satisfy the various tests. Because the vacuum pump place the major role in the Braking system, if change in rotor material does not provide complete vacuum it may result in the failure of braking system. So it is necessary that the new vacuum pump should satisfy the following vacuum pump test.

5.1. Types of vacuum pump test

1. Over All Leak Test
2. Vacuum Leak Testing and Static Electric Testing
3. Dynamic Test of Alternator with Vacuum Pump (Oil Leakage Test)
4. Air pressure testing and fixing acceptance sticker

5.1.1. Overall leak test

This is one of the test to assure that a vacuum pump withstand a vacuum pressure of −731 mm of mercury for 20 s. The reading details are given below in the Table 1.

The samples which are made of aluminium have satisfied the overall leak test in the vacuum testing Centre. The testing images are given below Fig. 4.

Table 1
Overall leak test.

No of samples	Vacuum (mmHg)	Duration (sec.)
1	−731	20
2	−731	20
3	−730	20
4	−731	20

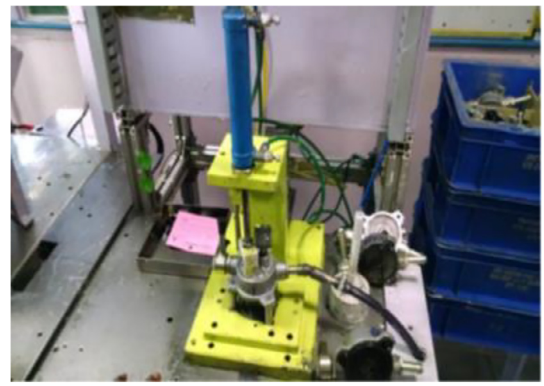

Fig. 4. Test bench of overall leak test.

5.1.2. Vacuum leak testing and static electric testing

In this test the vacuum pump is connected to the shaft of the alternator and the initial excitation is given to the alternator. After giving excitation the leak in the vacuum pump is detected. The reading details are given below in the Table 2.

When the leak is above 20 mmHg, the sample is rejected. The above sample's vacuum leak is minimum and maintains above the vacuum pressure of −700 mmHg for the duration of 20 s. Hence the samples satisfy the vacuum leak testing and static electric testing. The testing images are given below Fig. 5.

5.1.3. Dynamic test of alternator with vacuum pump

This test the alternator with the vacuum pump is connected to motor and the oil inlet valve of vacuum pump is connected to the oil valve and vacuum valve is also connected. Here the alternator is run at three speed levels for certain duration and vacuum pressure is checked. The reading details are given below Table 3.

The various speed specifications are given below

1. Speed 1000 rpm –vacuum pressure 500 mmHg-duration 35 sec. maximum
2. Speed5000 rpm-vacuum pressure 500 mmHg-duration 10 sec. max for big suction
3. Speed 5000 rpm-vacuum pressure 680 mmHg-duration 40 sec. maximum.

5.1.4. Air pressure testing and fixing acceptance Sticker.

In this the alternator connected with vacuum pump undergoes air pressure testing. The air pressure in the vacuum pump should maintain an air pressure between0.08 and 0.12 bar for the duration of 20 s. The reading details are given below Table 5. The test sam-

Table 2
Vacuum leak test.

No of samples	Vacuum pressure (mmHg)	Leak (mmHg)	Duration (sec.)
1	717–713	4	20
2	730–726	6	20
3	720–714	4	20
4	719–715	8	20

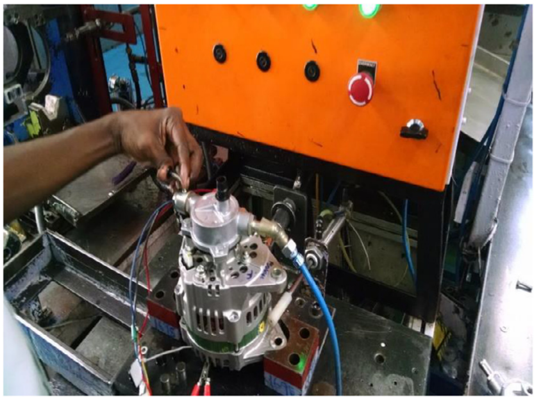

Fig. 5. Test bench of vacuum leak test.

Table 3
Air pressure test.

No of samples	Air Pressure (Bar)	Duration (sec)
Sample 1	0.10	20
Sample 2	0.09	20

ples also satisfy the air pressure testing and finally a acceptance sticker has pasted on the test sample. The testing images are given below Fig. 6.

5.1.5. Inference from vacuum pump Test.

The Aluminium rotor in the vacuum pump, which has been newly introduced instead of Mild steel, has overcome the entire above test successfully. The aluminium retains the same qualities of Mild steel, so it's safe to use in the Breaking system. After the modification aluminium rotor it does not reduce the efficiency of the breaking system, Here our ultimate aim is to increase the efficiency of alternator so these vacuum pump can be used further running test of alternator.

5.1.6. Running test of the alternator with Mild steel as the rotor in the vacuum pump.

The alternator with existing Mild steel as the rotor in the vacuum pump is the taken as the test sample and running test has been done. The following reading are the results of the running test. This test is done at the following running speeds. The reading details are given below Table 4.

Fig. 6. Test bench.

Table 4
Running test with mild steel rotor.

Output	Voltage (V)	Current (A)	Speed (rpm)
0	0	0	0
1	14.1	0.9	1185
3	13.53	74.8	2022
4	13.40	99.9	6108

Table 5
Speed levels.

Output	Voltage (V)	Current (A)	Speed (rpm)
0	0	0	0
1	14.5	1.2	1205
2	13.59	78	2064
3	14.44	102.3	6158

5.1.7. Running test of the alternator with aluminum as the rotor in the vacuum

Here, the same running test is done as before but the rotor material used is made of aluminium. The alternator is run with high and low speed levels and the output obtained at those speed levels is given below in Table 5.

5.1.8. Comparison of Mild steel rotor output and aluminum rotor output

The above Fig. 7 clearly indicates the change in output of the alternator when the rotor material is changed to the aluminium. The output current increases while using the aluminium rotor in the vacuum pump compared to the Mild steel.

By using the aluminium as the rotor the mass decreases, as a result of it the output current increases. The increase in output current shows the increase in efficiency of the alternator. And also reduce the cost of production of the vacuum pump by using aluminium which is lighter and cheaper metal.

The Fig. 7 clearly says that after changing the cast-mild steel rotor into the aluminium rotor the output current given by the alternator increases. The increase in output current shows that there is increase in the efficiency of the alternator. The vacuum pump which is mainly used in the braking system of the vehicle, hence it should satisfy the vacuum tests. The test samples satisfied the all the four types of vacuum test. Then it has been connected to the shaft of the alternator and running tests has been done at various speed levels. During the running test the existing model of alternator provides the output current of 99.4 A at a speed of 6108 rpm. Our new model of alternator provides the output

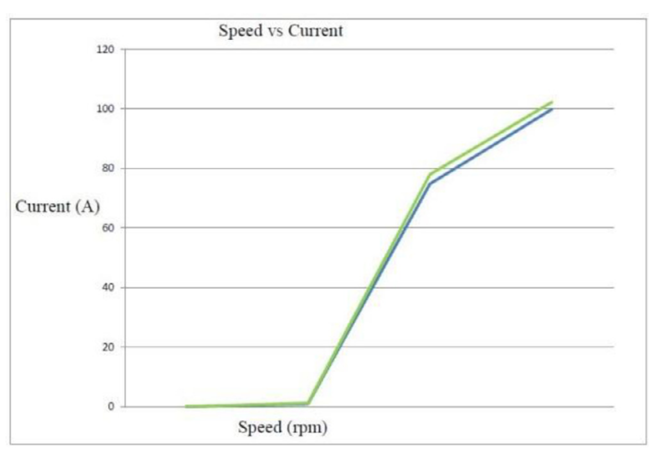

Fig. 7. Speed vs current graph for two different materials rotors.

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current of 102.3 A at a speed of 6158 rpm. By using this new model the output current is increased about 2.9 A then the existing alternator. The above results clearly indicate the increase in efficiency of the alternator is due to reduction in mass of the rotor in the vacuum pump. Hence, our statement has been proved by giving the expected results.

6. Conclusion

The efficiency of the alternator can be increased by reducing the mass of the rotor in the vacuum pump. The above results also prove that the efficiency can be increased by reducing the mass. The new design i.e. aluminium rotor can be used in the vacuum pump for the increased performance and efficiency of the alternator. The newly modified rotor which is made of aluminium has overcome the entire vacuum test successfully and it is safe to use in the braking system of the vehicle. And also during the running test of the alternator the output current and speed of the alternator with the aluminium rotor is high compared with the alternator with Mild steel rotor. This shows that the efficiency has been increased when the aluminium rotor is used in the vacuum pump.

7. Future scope

This study will play a major role in improving the efficiency of the alternator in future automotive world. In this study we have clearly proved that reduction mass can improve the efficiency. Hence, in future by reducing the mass of claws i.e. rotor poles can improve the speed of the rotor of the alternator. In future the study will be platform to manufacture weightless automotive alternators.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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