

DESIGN AND ANALYSIS OF MECHANICAL COMPONENTS IN THE ALTERNATOR

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Abstract

The alternator, a critical component in power generation and automotive electrical systems, relies on robust mechanical design to ensure efficiency and durability. This study investigates the design, material selection, and structural analysis of key mechanical components, including the rotor, stator, bearings, and housing. Advanced finite element analysis (FEA) and computational simulations are employed to assess stress distribution, thermal effects, fatigue behavior, and vibration characteristics under varying operational conditions. The study also explores the impact of load variations, rotational speed, and electromagnetic forces on the overall performance and longevity of the alternator. The results contribute to optimizing mechanical integrity, reducing wear and tear, enhancing energy efficiency, and minimizing maintenance costs. These insights provide a foundation for further advancements in automotive, industrial, and renewable energy applications, ensuring reliable and long-lasting alternator performance.

1. Introduction

1.1 Alternators

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. For reasons of cost and simplicity, most alternators use a rotating magnetic field with a stationary armature. Occasionally, a linear alternator or a rotating armature with a stationary magnetic field is used. In principle, any AC electrical generator can be called an alternator, but usually, the term refers to small rotating machines driven by automotive and other internal combustion engines. An alternator that uses a permanent magnet for its magnetic field is called a magneto. Alternators in power stations driven by steam turbines are called turbo-

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alternators.

1.2 Alternator Working Principle

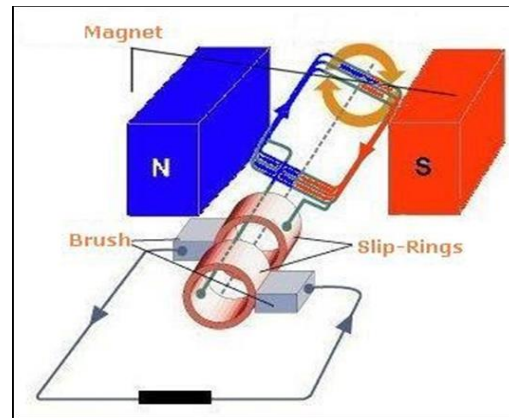


Figure 1. Basic Operation of Alternator [4]

Alternators generate electricity by the same principle as DC generators. When magnetic field lines cut across a conductor, a current is induced in the conductor. In general, an alternator has a stationary part (stator) and a rotating part (rotor). The stator contains windings of conductors and the rotor contains a moving magnetic field. The field cuts across the conductors, generating an electrical current, as the mechanical input causes the rotor to turn. A conductor moving relative to a magnetic field develops an electromotive force (EMF) in it, (Faraday's Law). This emf reverses its polarity when it moves under magnetic poles of opposite polarity. Typically, a rotating magnet, called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an induced EMF (electromotive force), as the mechanical input causes the rotor to turn.

2. Literature Review

The literature review is one of the important steps while doing any project. Before designing or manufacturing any component understanding the theoretical background behind the component is important. Oliveira et-al. [1] presents the main features of design, construction, performance analyses, and experimental studies of a brushless self-excited three-phase synchronous generator. The basic construction, principle of operation and exciting characteristics are described. In the proposed machine the rotor winding is shorted through diodes and the self-excitation is reached by a slip between the rotor and stator winding built with different pole numbers. Computer simulations performed with MATLAB® software were used to verify the mathematical model of the brushless self-excited synchronous generator and the achieved results showed similar behavior with experimental values. Adekunle et al. [2] studied the designs of shafts that were conservative

in approach as relatively low working stresses [1]. And where high stresses are involved, a greater shaft dimension is employed for such design. This approach necessarily made the production cost high, as quite a lot of materials are involved in such production. The primary reason for such an approach is to safeguard the shaft failure in most operations. Unfortunately, the mechanism of failure mode was not well understood because most of the applications in which shafts are employed are of great importance, which in some cases affects life negatively (i.e., involving loss of lives) and distorts operations. Despite all these developments, designers are still faced with the problems of working with large numbers of formulas, computations, and iteration procedures involved in the design of shafts. These have made the design procedures of shafts both cumbersome and rigorous, hence time-consuming. This problem becomes more pronounced if the designer is interested in seeing the effects of the variation of one or more design parameters, which means starting again from scratch. Mankar, [3] studied that quality is the prime concern for any industry to establish or remain in today's competitive market. Steel industries have 4-Hi reversible cold rolling Mills and cold rolling trimming Lines. The objective of the trimming Line is to remove excess unwanted edgy material from cold rolled coils before the galvanization process. Galvanizing lines have CGL-1 and CGL-2, which produce 20000 M galvanized coils per annum. Galvanizing is the practice of immersing clean, oxide-free steel into molten zinc to form a protective coating over the metal. This Paper deals with the redesign and analysis of the spindle shaft of a scrap winder machine to address all the problems found in the existing condition. It includes an analysis of the existing gearbox and present working conditions with the help of the FEA approach. The paper describes improving line continuity, uptime, and reducing production loss, maintenance cost, delay time, and chances of accidents. Sivaprakashan [4], investigates the aluminum-based composites, find their importance in the field of automobile and aerospace industries, owing to their improved mechanical and microstructure properties are utilized for producing cylindrical components in LM6 alloy. Among all types of metal matrix composites (MMCs), considerable attention has been paid to the synthesis and characterization of aluminum matrix composites due to their lightweight and ease of processing. Different types of dispersoids like SiC, alumina, Si₃N₄, TiO₂, etc., have been used as reinforcement materials in the form of fibers, whiskers, or particulates in an aluminum alloy matrix. Among all the available types of composite materials, particle-reinforced composites are the most promising ones owing to their isotropic material properties and low cost. Many researchers have reported that the addition of ceramic particles to aluminum matrix enhances its mechanical properties. Hence, aluminum reinforced with ceramic particles is one of the popular groups of MMCs. However, there exists still exist problems in producing good quality particle-reinforced MMCs. In this view, LM6 alloy with varying contents of Al₂O₃ and Si₃N₄ is going to be fabricated because of its excellent mechanical and microstructure properties, like strong bonding, high hardness, good thermal shock resistance, resistance to strong acid attacks, wear resistance, long life, and so on. In addition, LM6 alloys reinforced with Al₂O₃ and Si₃N₄ material were not fabricated previously through the squeeze casting method. Squeeze casting has its advantages, such as maximum utilization of material, low porosity, good surface finish, near net shape product, and so on. All these factors

motivate us to fabricate the alloy through squeeze casting and to study its characteristics. Bacchus et al. [5] identify the rotor inter-turn during short circuits of an alternator. The detection method is based on the analysis of a flux probe signal located in the air gap of the machine. Previous works have shown that pattern recognition can be applied to detect such a fault by using the experimental data as prototypes. A new method is developed here by considering a learning step based on simulation. Therefore, the machine is modeled and validated for that purpose. A feature selection is made by considering feature correlation. Cawthorne [6] studied the design approach for the alternator, which accounts for the characteristics of the engine used as the prime mover and the interactions between the engine and the alternator. First, models of the engine and the alternator are developed. These models will then be integrated to represent the overall system. Next, the models are simulated, and the results are compared to experimental data taken from the prototype system. The validated models are used in an optimization routine to maximize the efficiency and minimize the volume of the alternator. The results of the optimization provide the design parameters for the alternator that best satisfy the objective of maximum efficiency and minimum volume. Finally, these optimization results are discussed, and the explanations are interpreted. Pavana et al. [11] studied the structural analysis of the spring. The property-like stiffness of the spring was studied with finite element analysis. Structural analysis is done to validate the strength. Structural analysis has been conducted on the wave spring by varying the spring material, such as Structural steel and Beryllium Copper. For this analysis, loads are considered as bike weight, single person, and two-person. Structural analysis is done to validate the strength. Rahul et al. [12] studied the design and optimization of the Foot Bridge. The basic emphasis has been given to minimizing the total deformation of the structural member by optimizing the cross sections, material properties, and weight. Six different cross sections (circular, rectangular, and square with solid and hollow sections) of the beam with three different materials (Aluminum alloy, Structural steel, and Titanium alloy) were analysed in ANSYS 11.0 with similar loading and support conditions. A three-dimensional model developed in SolidWorks was imported to ANSYS, and then mesh generation and post-processing were done. Maximum deformation was observed for aluminum material, whereas it was minimum in the case of structural steel. SeidHajdarević et al. [13] investigate study of the stiffness analysis of a statically indeterminate wood-chair side-frame. Numerical calculations are carried out with a linear elastic model for orthotropic materials. The mathematical model is solved by a finite element method". The results revealed that the stiffness of joints in a frame had a considerable impact on the structure's deflection. Maximum deformation was obtained at the top portion. Translation displacement magnitude is considered to calculate the stiffness. The structure becomes stiffer as the position of the stretcher is lowered and/or the stretcher cross cross-section is increased. Ramesh [14] studied the casting properties of grey cast iron. Two important parameters for successful casting are the fluidity of molten metal and the cooling rate. These are also affected by thickness and variations in the thickness of the section of casting. The term section sensitivity, when used to define castability, is an attempt to correlate properties in the critical sections with composition and cooling rate. The fluidity of the molten iron is affected by the mold conditions, pouring rate, and amount of superheat above the freezing

(liquids) temperature. It may be noted that as the total carbon decreases, the liquid temperature increases, and the fluidity at a given pouring temperature also decreases. Cast iron is a form of material that is favored by foundrymen over cast steel because of the ease of production by Cupola furnace, lower melting temperature than steel, and excellent fluidity of molten cast iron. Yasser et al. [15] studied the response surface methodology for modeling and optimizing tensile and impact strength properties of fiber-orientated quaternary hybrid nanocomposites. Central composite design (CCD), which is a subset of response surface methodology, has been employed to present mathematical models as a function of physical factors to predict tensile and impact behavior of the newly mentioned hybrid nanocomposite and optimize the mentioned mechanical properties. Totally 20 experiments were designed with 6 replicates at the center point. Carmita Camposeco-Negrete, [16] investigates the Optimization of cutting parameters using the Response Surface Method for minimizing energy consumption and maximizing cutting quality in turning of AISI 6061 T6 aluminum. A set of experimental runs is established using a Central Composite Design, and the Response Surface Method was employed to obtain the regression model for the energy consumed during machining, specific energy, surface roughness, and material removal rate. The adequacy of the model is proved by Analysis of Variance. Chatterjee et al. [17] studied the Prediction of hardness for sintered HSS components using the response surface method. The percentage of alumina, sintering temperature, and sintering time were considered as the controllable process parameters, while the hardness of the sintered components was considered as the response variable. A 23 full factorial design of experiments (DOE) was used to collect experimental data to statistically analyze the effect of process parameters on the hardness of sintered HSS components. It has been observed that the percentage of alumina, sintering temperature, and their interaction affect the hardness very significantly, while the duration of sintering temperature does not affect the hardness significantly. An order response surface model (RSM) has been used to develop a predictive equation of hardness based on the data collected by a statistical design of experiments known as the central composite design (CCD). The analysis of variance (ANOVA) shows that the observed data fit well into the assumed second-order RSM model [18-20].

3. Materials and Methods

3.1. Load on the shaft

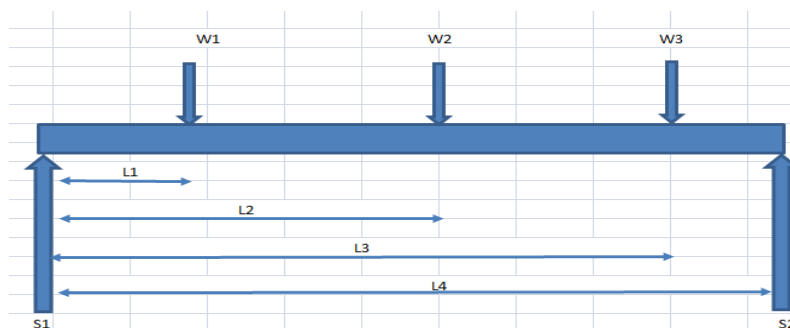


Figure 2. Free body Diagram of Shaft

W_1 = Weight of Excitor Rotor=120.46N

W_2 = Weight of Main Rotor + Self Weight +UMP= 1567N W_3 = Weight of the Fan=54.24N

S_1 =Bearing Support S_2 = Coupling Support

L_1 = Distance between exciter rotor and bearing support = 45.5 mm L_2 = Distance between main rotor and bearing support = 369 mm L_3 = Distance between fan and bearing support = 629 mm

L_4 = Distance between coupling support and bearing support = 796.5 mm

3.2 Material Properties

Material properties of C40E hot rolled normalized steel is as follows: Ultimate Tensile strength: 550 N/mm²

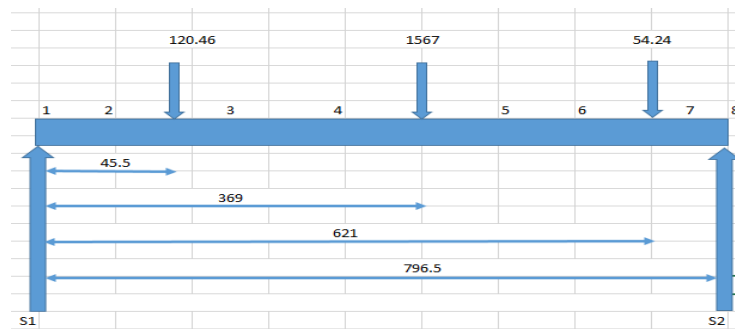
Ultimate yield strength: 290 N/mm² Modulus of Elasticity: 210 GPa Bulk Modulus: 160 GPa, Poissons Ratio: 0.3, Density: 7500 kg/mm³

3.3 Analysis of Shaft

According to Macaulay's method, the bending moment at any section distance X from bearing support B given by –

$$EI \frac{d^2y}{dx^2} = S_1(x) - W_1(x - L_1) - W_2(x - L_2) - W_3(x - L_3) \quad (1)$$

W_2 has large value as compared to W_1 and W_3 . So, it is obvious that deflection because of weight W_2 is maximum. Therefore, by integrating above equation and substituting the value one can get the maximum deflection value.

**Figure 3.** Free body diagram of Shaft (2)

3.4 Finite Element Approach

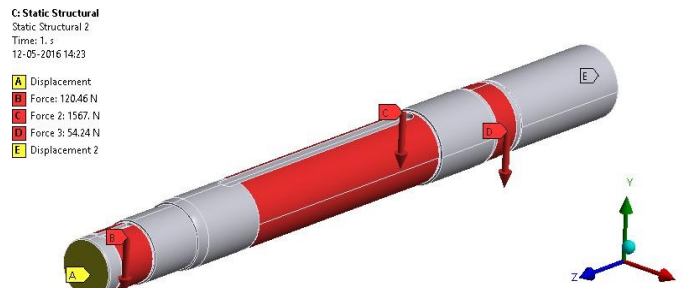
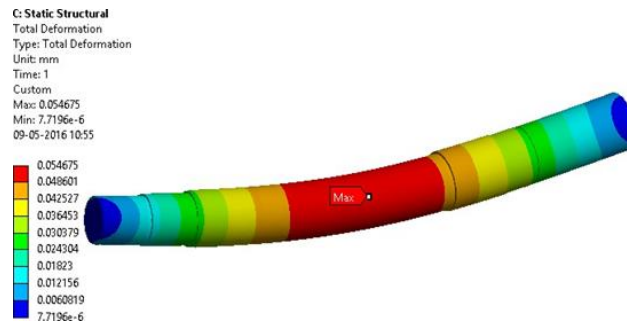


Figure 4. Loads and boundary conditions of shaft

The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Number of elements in model: 355611 Number of nodes in model: 249372 Loads and boundary conditions Loads like the weight of the Excitor rotor, main rotor, and Fan are applied on the shaft, Apart from these loads, two boundary conditions are applied at bearing location and coupling location. Figure 6 shows all the loads and support.

**Figure 5.** Maximum deflection of the shaft**Figure 6.** Maximum Stresses Induced in the shaft**Table 1.** Static result comparison

Item	Analytical	FEA
Stresses τ (N/mm ²)	11.309	11.689
Deflection y (mm)	0.0544	0.0546

5. Conclusions

The 160kVA alternator shaft is redesigned and validated analytically for static case and dynamic cases. Deflection, stresses, and transverse frequency are validated by FEA using ANSYS software. The maximum deflection and stresses in the shaft are observed at the main rotor location. The

values of maximum deflection and natural frequency are within allowable limits. Because of the redesigning of the shaft, Weight is reduced by around 8 kg which result in cost reduction. The size of the alternator can be reduced by eliminating landing bars. Different design concepts are studied. In-ring concept and cup cone concept. The advantage of making a 4 mm thick frame, along with the reduced size, is one can directly weld the foot to the barrel (frame). The barrel becomes more robust. In the tie rod concept, tie rods are inserted inside the stator core, which results in a reduction of size, and manufacturing is easier as compared to landing bars.

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