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Investigative Analysis for Material Characterization of SRM Rotor for Electric Vehicles

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Abstract: Switched reluctance motorrotor has significant influence in the field of electrical vehicles. The unique properties drive the researchers to enhance deep study and analysis towards materials characterization in performing dynamic analysis. In this research, an insight focus on the frequency analysis and thermal analysis is followed with different materials.

Keywords: *Rotor, dynamic analysis, material characterization, electromagnetic analysis.*

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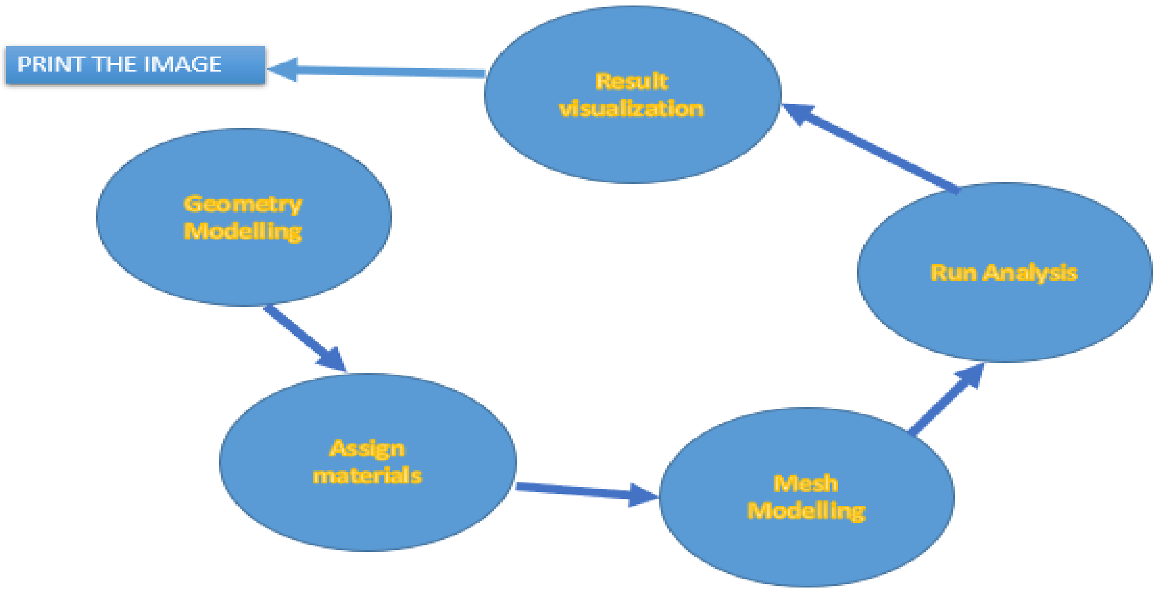

Fig: 1 Graphical Abstract

I. Introduction:

SRM (Switched Reluctance Motor) rotor technology contributes a predominant promise to electric vehicles. In electric vehicles, the sound and vibration is less comparatively with motor driven vehicles but still a lot of improvement is needed as light electrical vehicles design with moderating the battery capacity, cost[1].One of the key advantages of SRM technology is its mechanical simplicity. Since there are no permanent magnets or rotor windings, the rotor can be constructed with a simple geometry, making it more robust and easier to manufacture. Additionally, SRMs have a high tolerance for harsh operating conditions, such as high temperatures and vibrations, making them suitable for a wide range of applications, including electric vehicles, industrial machinery, and appliances[2].Mohd FairozOmaret al., developed new topology of single-phase segmented rotor FEFSM with a 12S-6P configuration is being introduced. This design offers numerous advantages, such as non-overlap armature and FEC windings, reduced weight, low copper loss, and high efficiency. The design, operating principles, and characteristics of torque, speed, and power have been thoroughly analyzed using JMAG-Designer via 2D Finite Element Analysis (2D-FEA). The fabrication process involves the use of Solid works software. The initial design allows for a maximum torque and power output of 16.6 Nm and 10.74 kW, respectively, making it highly suitable for high-density air conditioner applications[3].The performances of the FEFSMs, such as flux linkage, coil test, flux strengthening, torque, and power versus speed characteristics, have been investigated using 2D finite element analysis. A prototype of the FEFSM has been successfully developed using SolidWorks through 3D design. The fabrication process has reached 40% completion.Jianbin Liang et al., narrated the impact of the two-step skewed rotor on the harmonics of radial force density. Through the sound pressure level waterfall diagram and analysis of radial force density harmonics, it confirms the dominant vibration mode and harmonics of radial force density. This paper presents an acoustic noise analysis process that serves as the foundation for reducing noise by optimizing the rotor's stepped skew angles[4]. The result is revealing that the skewed rotor segment is beneficial in reducing the magnitudes of dominant radial force density harmonics of the stator, specifically the (48th, 0) and (24th, 0) harmonics, particularly between 3000 rpm and 6000 rpm and an acoustic noise analysis process that establishes the foundation for reducing acoustic noise by optimizing the rotor skew angles.Zahabi et al., studied and research have been conducted on various SRM topologies and structures to enhance their performance. These studies have demonstrated that by optimizing the design of SRMs, their efficiency can be improved by minimizing torque ripple. The findings from these designs can be extremely valuable for selecting an appropriate SRM structure for specific applications, such as EV applications[5].The predominant trend in motor topologies is shifting towards the use of permanent magnet synchronous machines, which offer high power density and cost reductions.Liquid cooling is an effective method for enhancing the performance of high-power motors. By incorporating a system of axial channels between the stator windings, the temperatures of the windings can be reduced by up to 60-80%. In comparison, a motor cooled with oil experiences a slower rate of temperature increase compared to a motor cooled with water.

However, the topology of SRM rotor must exhibit exceptional qualities like low noise, less vibration and high heat dissipation with its unique running capabilities. These aspects could be investigated from the frequency analysis and thermal analysis by choosing different materials used in the industry.

II. Material And Methodology:

The ideal characteristics of an SRM motor are specifically tailored for high-performance rotors, especially in applications such as automotive or industrial machinery, where factors like noise, vibration, and heat dissipation are of utmost importance. Attaining these qualities necessitates a careful balance of material selection, design optimization, and manufacturing precision.The selection of materials for SRM (Switched Reluctance Motor) rotors is crucial for achieving the desired performance characteristics. In this context,a few commonly used materials and their properties in the construction of SRM rotors are selected for the frequency analysis and thermal analysis in Table: 1.

S.No.	Material	Young's modulus, E in N/mm^2	Poisson's ratio	Density, in Kg/m^3	Yieldstrength, in N/mm^2
1	AISI 4130 steel	$2.05x10^5$	0.285	7850	460
2	1060 Aluminum alloy	$0.69x10^5$	0.33	2700	27.57
3	Copper- Aluminium-Bronzealloy	$1.1x10^5$	0.3	7400	275.74

The selection of rotor materials for SRMs in EVs ultimately depends on various factors. These factors, include performance requirements, cost considerations, environmental impact, and technological feasibility. As EV technology continues to advance, ongoing research and development efforts focus on identifying novel materials and manufacturing techniques. The goal is to enhance the performance and efficiency of SRMs in electric propulsion systems.

The frequency analysis of a switched reluctance motor (SRM) rotor aims to investigate the vibration characteristics of the rotor and the methodology is as shown in block diagram fig:1. This analysis helps in understanding the dynamic behavior of the rotor, identifying potential sources of noise and mechanical stress, and optimizing the motor's design for enhanced performance and reliability[6].Modal analysis is a widely used technique for determining the natural frequencies and mode shapes of a rotor system. In the case of SRMs, modal analysis helps identify the vibration modes of the rotor structure under different operating conditions. By applying an external force or impulse to the rotor and measuring its response, engineers can accurately characterize the fundamental and higher-order vibration modes of the rotor assembly[7].

The modal Analysis is a numerical method used to simulate the structural dynamics of complex systems, such as SRM rotors. FEA software enables engineers to model the rotor's geometry, material properties, and boundary conditions. They can then solve the governing equations to predict the rotor's natural frequencies and mode shapes[8]. FEA is valuable for assessing the impact of design modifications on rotor vibration characteristics and optimizing the rotor's structural integrity. The model for the analysis with boundary conditions is as shown in fig:2. Then the FEA model is performed the frequency analysis and thermal analysis.

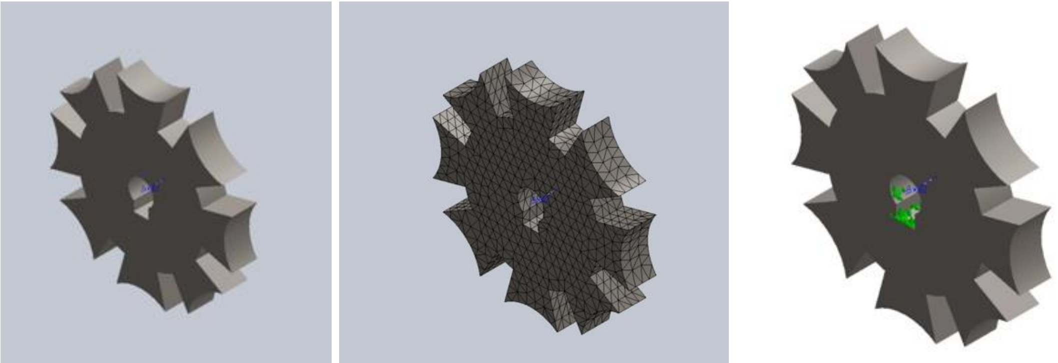

Fig 2: FEA model of SRM Rotor

Thermal analysis is performed to assess the temperature range for oil cooling methodology at the shaft, starting from 32 degrees Celsius.A convection coefficient of 0.8 W/m^2 °C is applied to the model to incorporate the convection attributes.

III. Results and discussion:

The SRM motor should be analyzed for its vibrations and natural frequencies in order to enhance its operational functionalities.An 8 fin SRM rotor with the adopted fixed geometry at the motor shaft location as a primary boundary condition and the natural frequency analysis is performed. A standard solid mesh is used to develop discretized model and 8041 elements are created with 13234 nodes are generated during the process. Adirect sparse solver is used to evaluate the natural frequencies of therotor. The natural frequencies in Hertz are tabulated and compared in Table 2.

Table 2 Materials mode(Hz) list for SRM motor

Frequency Number	AISI 4130 steel frequency	1060 Aluminum alloy frequency	Copper- Aluminum-Bronze alloy frequency
1	3878.6	3870.9	2934.1
2	4051.7	4044.8	3065.5
3	4192.3	4087.1	3147.2
4	4767.0	4775.5	3611.7
5	5283.6	5157.6	3968.2

The minimum natural frequency mode is observed from 2934.1 Hz to 3968.2 Hz for Copper-Aluminum-Bronze alloyand a maximum range from 3878.6 Hz to AISI 4130 steel material SRM rotor. The Aluminum alloy records moderate natural frequency range from 3870.9 Hz to 5157.6 Hz.Similarly, the thermal distribution is also moderate for aluminum alloy from the fig3 (a) & 3 (b).

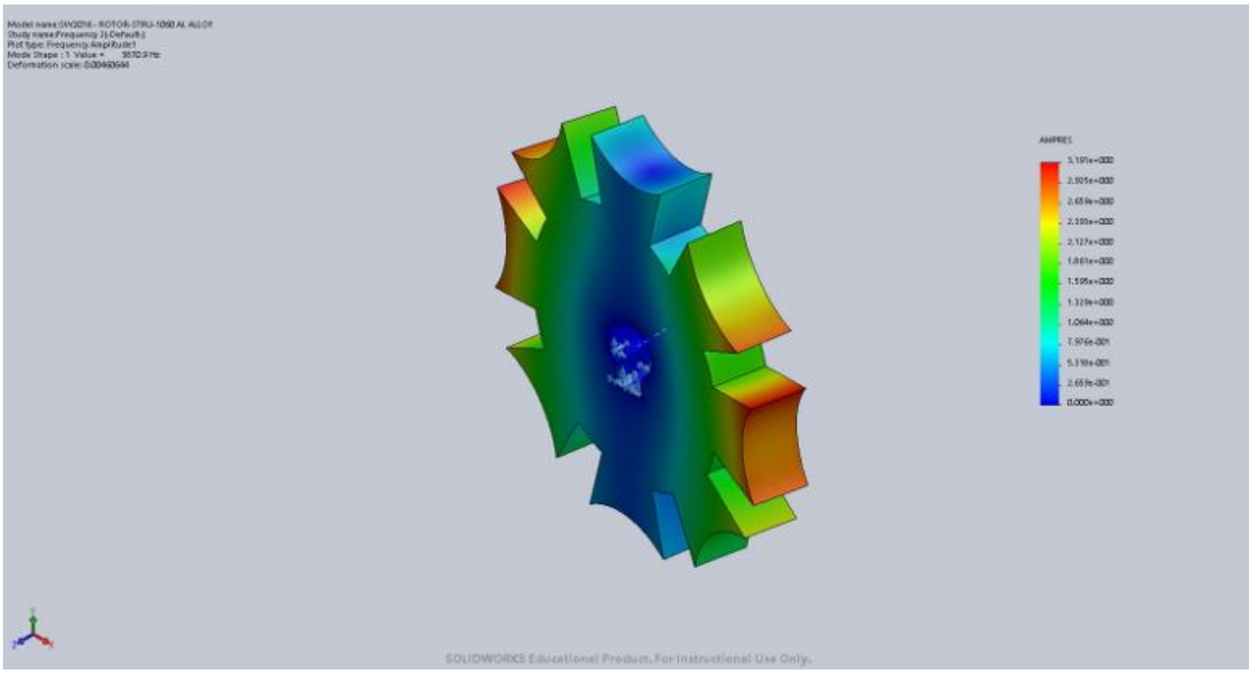

Fig 3(a) Natural frequency mode shape – 1 for 1060 Al Alloy

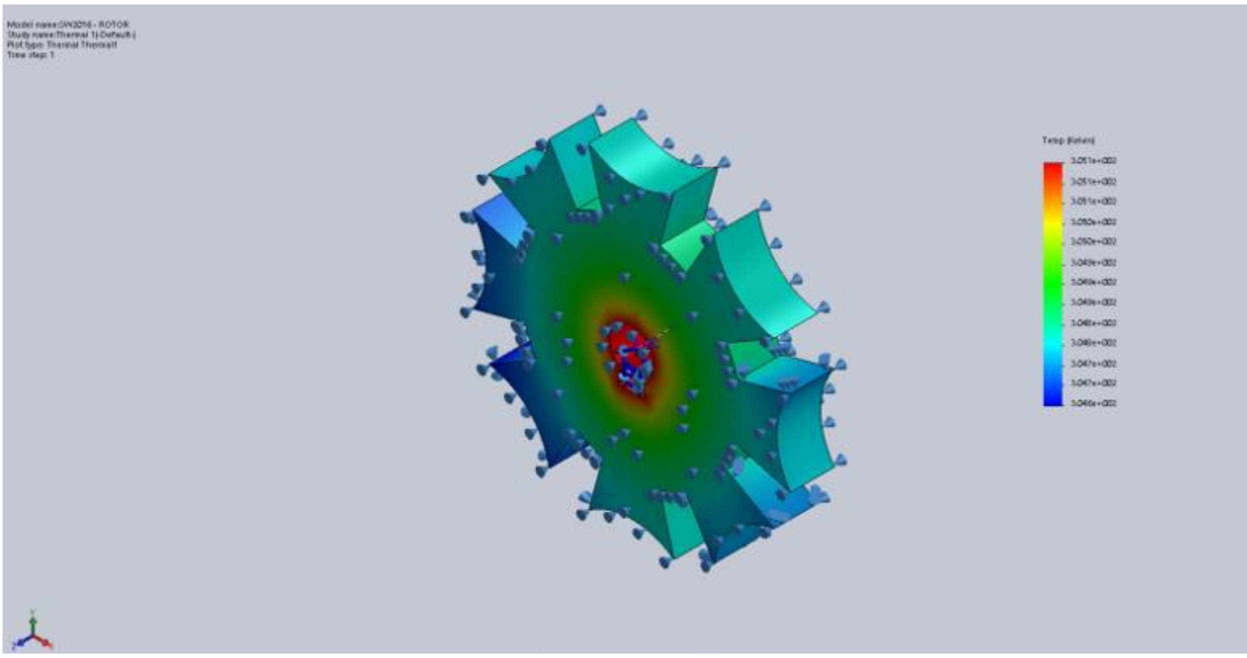

Fig 3(b) Thermal distribution contour for 1060 Al Alloy

IV. Conclusions:

In order to minimize operational failure, it is important to accurately predict the natural frequencies of the rotor during the design stage. In this paper, the researchersutilize the finite element method (FEM) to predict these frequencies for a designed rotor and proved the 1060 Aluminum alloy is the best choice to use it as the SRM rotor for its stability and sustainability based on the material properties taking account of weight of the rotor. Thermal analysis can be performed to determine the distribution of temperature, temperature gradients, and heat flow within the model, as well as the heat exchanged between the model and its surroundings.It is also observed that the thermal distribution is also stable to prove that 1060 Al alloy is the best choice for the SRM rotors.

Future scope: Thermal testing is a method used to test the ability of a material to operate safely at various temperatures. The data collected through thermal tests helps users of products understand the material's safe operating limits, as well as provides insights into its general characteristics and potential lifespan and it has to be carried out with proper test facilities. Ultrasonic fatigue testing is one of the few methods that allow investigation into fatigue properties in the ultra-high cycle region and this method is based on subjecting the specimen to longitudinal vibrations at its resonance frequency with proper equipment.

List of abbreviations

FEA	Finite Element Analysis
FEFSM	Field Excitation Flux Switching Machine
12S-6S	12 Slip rings (fins) and 6 stages
FEC	Field excitation coil
EV	Electrical Vehicles

Declarations

Availability of data and material

The material properties are chosen from the Solidworkssoftware [Dassault Systems SolidWorks Educational Edition 2016-17].

Competing Interests

Title of the Manuscript: "Investigative Analysis for Material Characterization of SRM Rotor for Electric Vehicles".

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We are also confirming that the manuscript has been read, accepted and approved by all named authors. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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Author's contributions

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Raja Govindan[1], Kadirvel Manikandan[1], Abdulbasith Mohammed[1], Nidamanuri Sreenivasa babu[1], Nidamanuri Surekha[2]

Raja Govindan: Methodology and Data Analysis.

Kadirvel Manikandan: Materials selection and Formal Analysis.

Abdulbasith Mohammed: Data compilation and visualization.

Nidamanuri Sreenivasa babu: Conceptualization, Investigation, Writing -Original Draft

Nidamanuri Surekha : Project Idea and model implementation.

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