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MODELING AND ANALYSIS OF ELEVATOR MOTOR FOR PASSANGER LIFT

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Abstract— **This report is a detailed theoretical analysis of permanent magnet synchronous motors (PMSMs) specifically designed for elevator systems. Elevators are crucial in modern urban infrastructure due to their high efficiency, reliability, and precision. PMSMs are a promising choice due to their superior efficiency, torque density, and controllability. The paper investigates the basic ideas behind PMSM functioning and uses electromagnetic theory to explain their behavior. It employs simulation techniques, including finite element analysis (FEA) and control algorithms, to evaluate motor performance under various operating conditions..The findings highlight the efficacy of PMSMs in elevators, highlighting their potential for optimizing energy consumption, enhancing ride comfort, and ensuring operational safety. The report includes calculations for motor design and machine test reports. The motor is successfully designed and tested for a passenger lift.**

Keywords— **Elevator, PMSM motor, IS17900**.

I. INTRODUCTION

Elevator systems form a vital component of contemporary urban infrastructure, enabling reliable vertical transportation within high-rise structures and supporting the smooth and efficient movement of passengers and materials. Among the various components that make elevators function seamlessly, the elevator motor stands out as the unsung hero that powers this extraordinary feat of engineering. Elevator motors are the driving force behind elevators, responsible for hoisting and lowering carriages while ensuring passenger safety, energy efficiency, and reliability.

An elevator, often known as a lift, is a vehicle that travels up a vertical shaft to carry people or goods between floors of building. The majority of today's elevators are powered by electric motors that are connected to a counterweight via a network of wires and sheaves (pulleys).Elevator systems are indispensable in the modern built environment, enabling the efficient and convenient movement of people and goods in tall structures. As buildings continue to reach greater heights and technology advances, elevator systems play a important role in the safe and reliable transportation of passengers and goods within these edifices. As urbanization accelerates the evolution of elevator technology continues to shape the future of vertical transportation.

A. Types of elevator system

1. Traction elevators: These use steel cables or belts to move the elevator car. They can be geared or gear-less.
2. Hydraulic elevators: They use a hydraulic piston mechanism to lift the elevator car, often used in low-rise buildings.
3. Machine room option

i. Machine room-less (MRL) elevators: These compact systems incorporate the motor and control systems within the hoist-way, saving space and energy.
ii. Machine room elevators-Hydraulic or traction are types of machine rooms. The machine room in traction elevators is usually situated above the hoist-way. The machine room, however, may also be found in a chamber or at the base of the hoist way.

B. Components of elevator system

1. Car
2. Counterweight
3. Hoist Way
4. Speed Governor
5. Cables
6. Controls Drive
7. Elevator Machine
8. Car Buffers
9. Guide Rails

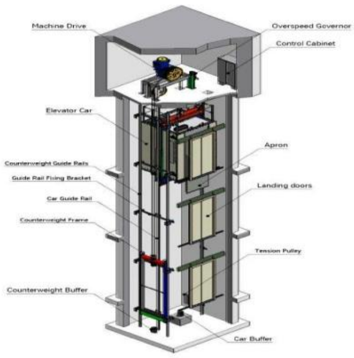

Fig. 1. Construction of elevator

C. PMSM elevator motor

A permanent magnet motor is a kind of electric motor that has a wound armature and permanent magnets for the field excitation. For a radial flux machine, the permanent magnets can be positioned inside or outside the armature, and for an axial flux topology, they can be stacked with the armature. Alternatively, the permanent magnets can rotate.

Working principle-The working principle of a permanent magnet synchronous motor (PMSM) is similar to that of a conventional synchronous motor. Its operation relies on the electromotive force generated at synchronous speed by the interaction of a rotating magnetic field. When a three-phase supply energizes the stator windings, it creates a rotating magnetic field across the air gap. As the rotor turns, the permanent magnet poles on the rotor lock onto this rotating field at synchronous speed, resulting in the production of torque.

Advantages of PMSM motor

1. At higher speeds provides higher efficiency
2. Available in compact sizes.
3. Compared to an induction motor, maintenance and installation are more simpler.
4. Able to sustain maximum torque at lower speeds.
5. Excellent reliability and efficiency
6. Delivers dynamic performance and smooth torque.

Mechanical components of motor

1.Stator, 2.Rotor, 3.Endshield, 4.Shaft, 5.Traction sheave, 6.Housing(Body)

Fig. 2. Gearless elevator motor

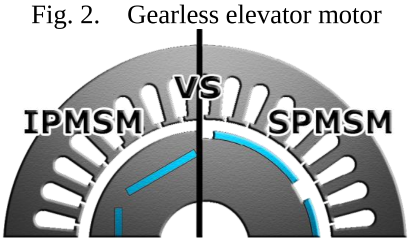

Fig. 3. IPMSM VS SPMS motor

II. LITERATURE REVIEW

Xiaohu et al.(1) studied the rapid development of elevator control systems in China, focusing on PLC control systems for lower maintenance costs. They tested hardware and software designs and implemented the system in high-rise buildings. Yao et al.(2) examined a failure monitoring system for elevators that is based on Internet of Things to avoid safety mishaps. The system uses Relief-F algorithm to evaluate factors, with accuracy increasing with batch size and time step. The system has several potential application and high research value. Shubham et al.(3) found elevator-related accidents are rare but can cause significant injury. They suggest compiling and analyzing accident data to reduce these risks, focusing on safety systems and new ones. Sadafale et al.(4) studied elevator systems, highlighting their safety risks and the need for fall protection, backup systems, and IoT-based operation to ensure smooth and convenient transportation between floors. Abhijaya et al.(5) analyze elevator safety in the US, highlighting the importance of safe and reliable operation for urbanization and accessibility. They evaluate maintenance and safety practices, highlighting vulnerabilities in passenger safety and the need for advancements in technology. Yetis et al.(6) investigate the design of interior permanent magnet synchronous motors (IPMSM) for gear-less elevators, addressing high performance, high power density, efficiency, and torque ripple. They use ferrite magnets and Motor Solve BLDC software for low cost, high efficiency, and torque density. Sharkawy et al. (7) developed a prototype of an elevator control system, with careful consideration given to its mechanical structure, dimensions, and weight specifications. The system employs an MG996R servo motor, known for its high torque, metal gears, and dual ball bearings. An Arduino Uno serves as the primary controller, while user input is managed through a 4x4 matrix membrane keypad. The prototype was tested with various load conditions (0.3 kg, 1.0 kg, and 2.5 kg), and the results demonstrated reliable performance during both ascending and descending operations. Huang et al. (8) introduced an innovative warning system designed to detect elevator power failures. This system utilizes an STM32 microcontroller to gather operational data through a CAN bus interface, transmitting the information to a remote monitoring platform via an NB-IoT module. By extracting various signals from the CAN bus, the system can identify power outages or instances where the elevator becomes trapped, enhancing safety through prompt fault detection. Ulu et al. (9) designed a 115 kW squirrel cage induction motor intended for use in electric vehicles. The design process focused on identifying key constraints and performance goals, followed by computer-aided engineering to refine the motor. Finite element analysis (FEA) was applied to validate the motor's performance, with further adjustments made based on these findings to enhance efficiency. Electromagnetic and thermal characteristics were evaluated using Maxwell and ANSYS software, ensuring the motor could withstand temperature limits in accordance with its insulation class. The final design met the required specifications, making it well-suited for electric vehicle applications. Shen et al. (10) explored motor design using the RMxprt module, which relies on magnetic circuit methods to study how rotor slot geometry affects motor performance and to fine-tune slot parameters. Using an electric vehicle induction motor as a case study, the rotor slot was first optimized within RMxprt. The motor’s characteristics before and after optimization were then compared using An soft Maxwell 2D.

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The improved design demonstrated noticeable gains in both power factor and starting torque, contributing to enhanced vehicle performance.

A. Theoretical calculations

1. Static load equation

SL= $\left(\frac{W1}{2} + W_R + \frac{W2}{2}\right)$ ………….(i)

Where,
W_1=W_{CAR} + $W_{PASSANGER}$
W_2=$W_{COUNTERBALANCE}$

For 10 passenger lift.
$W_{PASSANGER}$ =68X10=680 Kg (Rated load)
(Weight consideration - India-68 Kg , US=75 Kg)

W_{CAR} =1.2X Rated load
=1.2X680=816 Kg
W_1=680+816=1496 Kg
W_2= $W_{COUNTERBALANCE}$
= $W_{CAR} + \frac{W_{PASSENGER}}{2}$
= $816 + \frac{680}{2}$=1156 Kg
From (i)
Static load
SL = $\left(\frac{W1}{2} + W_R + \frac{W2}{2}\right)$
= $\left(\frac{1496}{2} + 30 + \frac{1156}{2}\right)$ =1356 Kg
= 1.25X1356 =1700Kg (FOS= 1.25)

2. Factor of safety

FOS = $\left(\frac{F\,X\,n\,X\,i}{SL\,X\,9.81}\right)$ ………….(ii)

= $\left(\frac{25\,X\,10^3\,X\,4\,X\,2}{1700\,X\,9.81}\right)$
= 12

Where,

F = minimum breaking strength of one rope;($25\ X\ 10^3$ Kn for ϕ8)
n = number of ropes
i = roping ratio, 1 for 1:1, 2 for 2:1
SL = maximum static load

3. Speed

V=$\left(\frac{\pi\,X\,D\,X\,N}{60\,X\,i}\right)$ ………….(iii)

Where,
D=Traction sheave diameter in m.
N=rpm, i= Roping ratio
For V=1m/s
N=$\left(\frac{1\,X\,60\,X\,2}{3.142\,X\,0.320}\right)$ =120 rpm

4. Motor torque

MT=$\left(\frac{(\text{Rated Load X }9.81)X\left(\frac{D}{2}\right)}{\text{Roping Ratio X (Counterweight)}}\right)$ ……….(iv)

Where,
D= Traction sheave diameter in m.

Motor Torque =$\left(\frac{(680\,X\,9.81)X\left(\frac{0.320}{2}\right)}{2\,X\,2}\right)$=267 Nm
(For 80 % shaft efficiency)

=267 / 0.80 =334 Nm.

5. Minimum no. of ropes.

FOS=12 =$\left(\frac{F\,X\,n\,X\,i}{SL\,X\,9.81}\right)$ ………….(v)

=$\left(\frac{1700\,X\,9.81\,X\,12}{25\,X\,10^3\,X\,2}\right)$ = 4 Nos

a) Suspension ropes standard IS 2365, IS 14665 (Part 4 Sec 8) , ISO 4344.
b) As per new standard IS17900 FOS should be 12. (11)
c) As per IS 14665 minimum rope for ϕ8 is 4 and ϕ10 is 3. (12)
d) The FOS of the ropes shall not be less than as following (12):

Table 1: Factor of safety

Rope Speed M/S	FOS
≤ 2.0	10
2.0 to ≤ 3.0	11
3.0 to ≤ 7.0	12

6. Braking torque
i. Without compensating chains

BT =$\left(\left(\frac{1.25Q + K - Z}{i} + m_{ropes}\right) X9.81X\left(\frac{D}{2}\right)\right)$……….(vi)

BT =$\left(\left(\frac{(1.25\,X\,680) + 816 - 1156}{2} + 30\right) X9.81X\left(\frac{0.320}{2}\right)\right)$
=447 Nm=0.80X 447
(For 80 % shaft efficiency)
=357.6 Nm
Where,
Q=Rated load in Kg.(125%)
K= Weight of car in Kg
Z= Counterweight in Kg
D=Traction sheave diameter in m.
i= Roping ratio
n=No. Of ropes
H=Height of travel in meters
Mropes=Total mass of ropes in Kg.
Mropes_specific= Specific weight of ropes in Kg/100 m of length.

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7. Output power

$$P(kW)=\left(\frac{2\pi NT}{60 \times 10^3}\right) \ldots\ldots\ldots\ldots(vii)$$

$$=\left(\frac{2 \times \pi \times 120 \times 334}{60 \times 10^3}\right) = 4.2\ kW$$

In HP

=4.2X1.34=5.63 HP

8. Load calculation

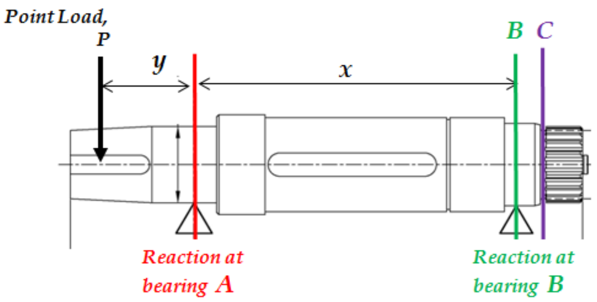

Fig. 4. Load Calculaton

Selection of Critical Sections:-
Section A-Reaction at pulley side bearing
Section B-Reaction at brake side bearing

Static load=1700 Kg
Point load=1700X9.81=16677 N
Bearing dynamic and static load capacity.

Table 2: Dynamic and static load capacity.

Bearing	Dynamic	Static
6313	97500	60000
6013	31900	25000

Table 3: Distances of shaft.

Distance between Reaction Forces	300	mm
Distance between bearing and pulley C2C	70	mm
Length of the shaft	480	mm

Reaction at A = - 20658.30 N
Reaction at B = -3891.30 N

9. Bearing life calculation

$$\text{Life in hours}=\left(\left(\frac{C}{P}\right)\right)^K \times \frac{10^6}{60\ n} \ldots\ldots\ldots\ldots(viii)$$

Where,
C=Dynamic load capacity of bearing. In N
P=Equivalent dynamic load in N
K=for
ball bearing=3 , roller bearing=10/3
N=No of revolution (rpm)

$$=\left(\left(\frac{97500}{20658.30}\right)\right)^3 \times \frac{10^6}{60X120} = 31065\ hrs.$$

For Continuous duty (24 hrs a day -S_1 duty)
=(31065)/(365X24)=4 years for 6313ZZ bearing.
= (95646)/(365X24)=11 years for 6013ZZ bearing.
For periodic duty (8 hrs a day S_3 duty)
=31065/(365X8)=8years for 6313ZZ bearing
=(95646)/(365X24)=32.8 years for 6013ZZ bearing.

As per IEC60034-1, minimum life of bearing for S_1 duty should be 40K hours. Therefore bearings is safe as per theoretical calculation. (13)

B. Results and discussion

I. Structural analysis of casting components-

The structural evaluation of casting components, such as the motor body and endshield, is essential to ensure the motor's durability and efficiency. Finite Element Analysis (FEA) using ANSYS software is conducted to assess stress distribution, deformation, and safety factors under real-world loading conditions. This simulation considers mechanical loads, thermal expansion, and operational forces to validate the structural integrity of the components. Identifying stress concentration areas allows for necessary design improvements, optimizing performance and reliability. By performing virtual testing, potential failures can be mitigated before physical manufacturing, leading to a more robust and efficient motor design.

Material properties and computational approach
The motor's body and endshield are typically manufactured from GG20 gray cast iron, a material known for its superior damping capability, wear resistance, and load-bearing properties. This material exhibits a tensile strength of about 200 MPa, Brinell hardness in the range of 180-230 HB, and a density of approximately 7.2 g/cm³. With a Young's modulus between 100-120 GPa and a Poisson's ratio of 0.26-0.30, GG20 is well-suited for applications requiring structural stability.
In the ANSYS simulation, core mechanical principles—such as Hooke's law—are implemented to compute the stress-strain relationship within the material under analysis.

$$\sigma = E \cdot \varepsilon \ldots\ldots\ldots\ldots(ix)$$

where σ denotes stress, E is the elastic modulus, and ε represents strain. Furthermore, the von Mises stress criterion is applied to assess material yielding under complex loading conditions, expressed as:

$$\sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \ldots\ldots\ldots\ldots(x)$$

where σ_1 , σ_2 , and σ_3 are the principal stresses. These computational methods help in refining the design, ensuring optimal performance and longevity of the elevator motor components.

Fig 6 shows maximum and minimum stress developed in casting components, Fig 7 shows maximum and minimum strain developed in casting components. It highlights the variation in parameters providing insights to material behaviour under different loading condition.

i. Equivalent stress

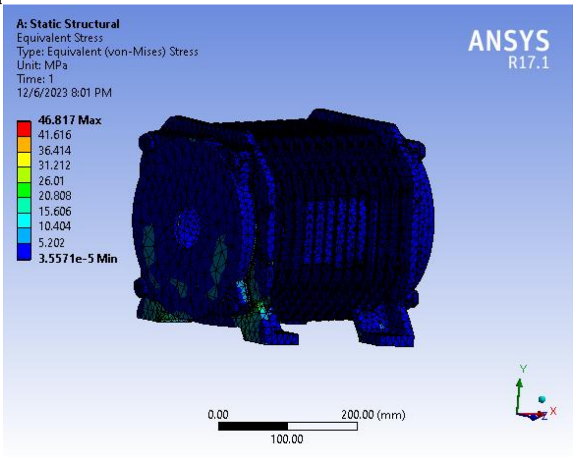

Fig. 5. Equivalent stress

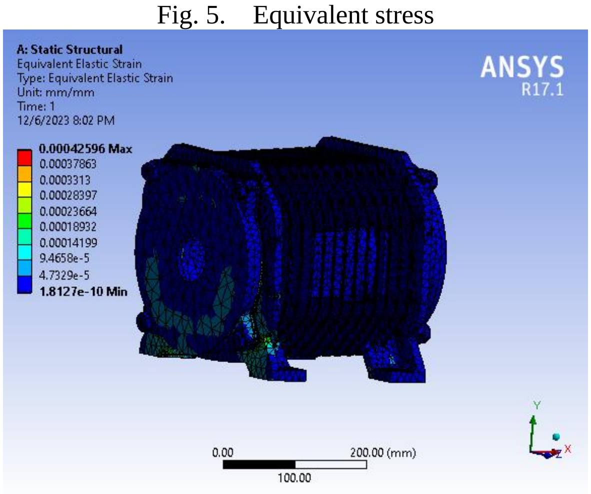

Fig. 6. Elastic strain

Results.
Nodes-199007, Elements -108958
Material used-FG200(Cast iron).(14)
Tensile strength of FG 200=200 MPa
FOS=200/46.817=4.271
Stress developed is within the limit,and strain and deformation is also very less. Therefore design is safe as per structural analysis.

II. Machine test result

i. Weight of components

Table 4:Old machine component weight

Component	Weight (Kg)	Cost (Rs)
Body	40	5600
DE Endshield	10	1400
NDE Endshield	9.5	1330
Shaft	22.4	1845
Traction sheave	10.4	1456
Rotor stack	11.9	2050
Stator stack	15.72	3170
Fan	0.700	1156
Copper	5.2	5148
Total	120.62	23155

Table 5:New machine component weight

Component	Weight (Kg)	Cost (Rs)
Body + DE ES (2 in 1)	43	6020
NDE Endshield	9.5	1330
Shaft	20.2	1700
Traction sheave	10.4	1456
Rotor stack	7.2	1250
Stator stack	13.5	2570
Fan	0.400	300
Copper	4.4	4356
Total	104.2	18982

Graph indication
Body + DE ES (2 in 1)-a, NDE Endshield-b, Shaft-c, Traction sheave-d, Rotor stack-e, Stator stack-e, Fan-g, Copper-h

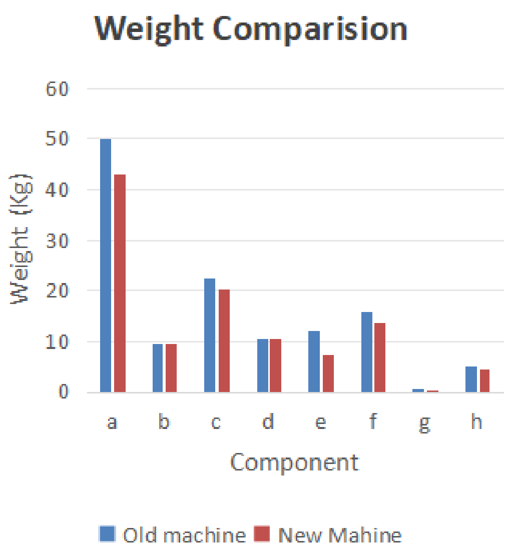

Fig. 7. Weight comparison of old & new machine

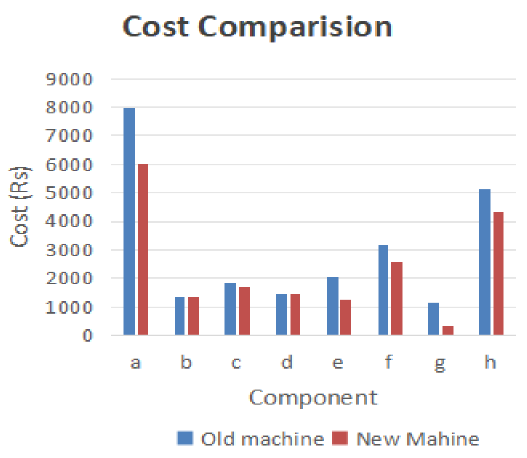

Fig. 8. Cost comparison of old & new machine

III. CONCLUSION

The elevator motor design process involved meticulous planning, analysis, and innovative design. The motor meets industry standards and pushes the boundaries of efficiency and reliability. The design phase involved understanding requirements, safety, energy efficiency, and performance optimization. The 3D modeling stage enhanced visualization, facilitated virtual testing, optimized before physical prototyping, accelerated development, and resulted in cost savings and streamlined manufacturing. The stator body/housing and end shields were evaluated for safety and integrity, demonstrating their robustness in construction. After calculations, analysis, and 3D modeling, the elevator motor design was finalized and sent for manufacturing. Motor is assembled and tested successfully for given rated load (680 Kg) and parameter. Total motor weight is reduced by 16 kg, resulting in 4100 rupees of cost savings per machine. Components like end-shield, body, shaft, bearing, are standardize for 6,8,10 passenger motor. Temperature rise of motor is 80°C.(Stable temperature after loading). Back emf is 340 volt. Motor is successfully designed and manufactured for passenger lift.(10 Passenger).With the successful completion of all phases, from conceptualization to manufacturing the designed motor is now prepared for seamless integration into passenger lift systems. This report presents a detailed theoretical analysis of essential parameters involved in the motor design.

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