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DESIGN OF SWITCHED RELUCTANCE MOTOR FOR ELEVATOR APPLICATION

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ABSTRACT

This paper describes methodology to calculate required motor power rating for elevator and lift application. Switched reluctance motor an excellent candidate for traction applications contributes more in low speed-high torque application. Quality of lift is analyzed by its smoothness, without any jurg. Torque production in motor during acceleration and deceleration decides Smoothness of lift. In this paper a switched reluctance motor is designed and analyzed which gives precise control over its speed-torque profile.

Keywords: Switched reluctance motor, Smoothness, Speed-torque profile, Elevator and lift application.

INTRODUCTION

Selection of Traction Motors for Electric Propulsion Systems Is A Very Important That Requires Special Attention. The Traction Industry Is Still Seeking For The Most Appropriate Electric-Propulsion System For Hybrid Electric Vehicles (Hevs), Battery Electric Vehicles Bevs And Also For Elevators And Conveyors .Owing To A Rigid Structure And The Absence Of Magnetic Source on The Rotor; A Switched Reluctance Machine (SRM) Is Inherently Robust And Cost Effective. The Performance Of An Electric Machine Can Be Described By The Following Key Parameters: 1) Power Density; 2) Structural Integrity; And 3) Manufacturing Cost (Berker *et al.*, 2012). (Dinesh, 2013) Described Procedure to Determine Peak and Continuous Power Rating of Motor.

COMMERCIAL PASSENGER ELEVATORS

For most people residing in urban cities, elevators have become an integral part of their daily life. Simply stated, an elevator is a hoisting or lowering mechanism, designed to carry passengers that typically moves in fixed guides and serves two or more landings. The elevators can be broadly classified as either electric traction type or hydraulic type. Traction elevators have an elevator car and counterweight attached to opposite ends of hoist ropes. Traction elevators are most often used in mid-rise and high-rise buildings with five or more floors. Less maintenance is required for Traction elevators. Hydraulic elevators, on the other hand, are raised by forcing pressurized oil through a valve into a steel cylinder located above ground or underground. Hydraulic elevators are commonly found in low-rise buildings with two to five floors. The main design considerations for choosing electric traction drive for a particular project are the number of floors, the height of the building, the number of people to be transported, desired passenger waiting times and frequency of use. In this paper we have designed switched reluctance motor for commercial passenger elevator, selection and design is explained in (Bhatia).

SIZING OF MOTOR FOR ELEVATORS

A drive decides the performance of a propulsion system. For propulsion application two powers i.e., peak and continuous power has to deliver by same motor. Table1. Shows required power and speed-torque profile of required for acceleration, a=1.6 m/s^2.Energy is capacity to do work. Elevator is propelled vertically opposing gravitational force. Hence potential energy required should be high enough to oppose gravitational force and accelerate table 1.

Energy required for propulsion=mgh Joule (1)

$$\text{Power required for propulsion} = \frac{mgh}{\text{Time}} \text{ Watt} \qquad (2)$$

m- Total mass of lift with passengers

g- Acceleration due to gravity

h- Distance of propulsion

Force required for acceleration, F=ma N (3)

Drive Sheave is coupled with shaft of motor through sheave axle for handling rope of the elevator .gear ratio of 7:1 is kept between shaft connecting motor and sheave.

Sheave axle torque=force x radius of sheave

$$\text{Motor torque} = \frac{\text{sheave axle torque}}{\text{Gear ratio}} \qquad (4)$$

The speed of the elevator shall be within the following ranges and chosen to suit the specific building requirements as part of the elevator traffic analysis

1. Hydraulic passenger elevators - 0.28 to 0.79 m/s;
2. Geared traction passenger elevators - 0.52 to 2.4 m/s;
3. Gearless traction passenger elevators - 2.7 m/s and greater.

Table-1. Elevator Parameters

Parameters	value
Kerb weight of elevator	600 kg
Total weight of elevator	1350 kg
Maximum no. of passengers loaded	10 (75 kg/person)
Speed of elevator	8m in 5 sec
Acceleration, a	$1.6 m/s^2$
Gear ratio, G	7
sheave radius, r	0.4 m
Power required, p	32 HP
sheave axle torque	861 Nm
Motor torque	123 Nm
Motor speed	1880 RPM

DESIGN OF SWITCHED RELUCTANCE MOTOR

Torque in SRM is produced due to the force of attraction between magnetic field and magnetic materials.

Torque is given by

$$T = \frac{I^2}{2} \frac{dL(\Theta, I)}{d\Theta} \qquad (5)$$

DL is change in inductance with different rotor positions. dΘ is change in rotor position, which should be as small as possible to reduce torque ripples in motor. Rise in inductance profile determines torque developed in switched reluctance motor.

Power developed in SRM is given by,

$$Pd = Ke * Kd * K1 * K2 * B * As * D2 * L * Nr \qquad (6)$$

Here the stack length is assumed to be as the multiple or submultiples of rotor bore diameter that is

$$L=K*D \qquad (7)$$

For non-servo applications the range of K can be

$0.25<K<0.7$

For servo applications it's usually the range given by

$1<k<3$

The specific electric loading is given by

$$As = \frac{\text{stator current x No. of conductors}}{\pi D} \qquad (8)$$

$$As = \frac{2Tph \times I \times m}{\pi D}$$

M is the number of phases excited at a time. In this design it is taken as m=1 and I is the rms Current through the phase. The specific electric loading in ampere conductors per meter is usually in the range of: 25,000 < As<90000.Selection of pole angle is important criteria and crucial part of design (Praveen, 2001). Constraints for rotor and stator pole Arcs are Minimum size such that the motor can produce torque in either direction for any rotor position. Maximum size such that flux is present in only one rotor pole when stator poles are energized (Iqbal). The two constraints on the arc widths limit the size of the arc widths within a defined area limited by the minimum and maximum arc widths Fig.1. In this section switched reluctance motors is designed by RMxprt. RMxprt uses a combination of analytical and magnetic circuit equations to predict the performance of this motor problem. RMxprt assumes the switched reluctance motor operates with shaft position feedback to synchronize the commutation of the phase currents with precise rotor position single pulse operation is used phase excitation. In the single pulse operation, each phase is energized at the turn-on angle and switched off at the turn-off angle. The difference between the turn-off and the turn-on angle is called the dwell angle. In fig.1 8/6 switched reluctance motor design and its parameters in Table II.

Table-2. Motor Parameters

Parameter	Rating value	Unit
Rated Power	32	HP
Rated Voltage	450 DC	V
Number of stator poles	8	-
Rated Speed	1880	RPM
Stacking factor of stator core	0.95	-
Number of rotor poles	6	-
Stator pole angle	21	Degree
Air gap	0.7	mm
Outer Diameter of stator	360	mm
Bore Diameter	241.3	mm
Length of stator core	339	mm
Inner Diameter of rotor	41.27	mm
rotor pole angle	23	Degree
type of material used	M22_24G	

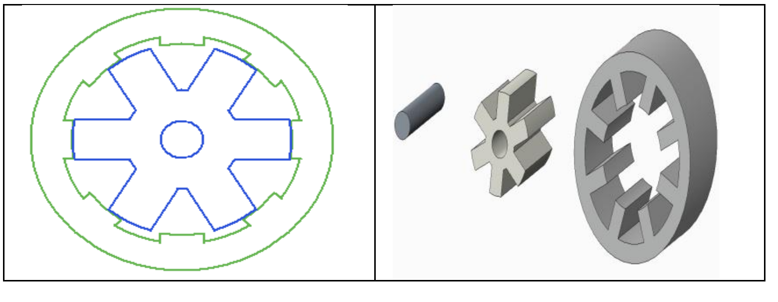
The aligned inductance value for this particular current is calculated as,

$$La = \frac{Tph \times \varphi}{I} \quad (9)$$

This calculated inductance should coincide with simulation output aligned inductance profile for analysis.

Design Simulation Using Rmxprt

Fig. 1. 8/6 Switched Reluctance Motor



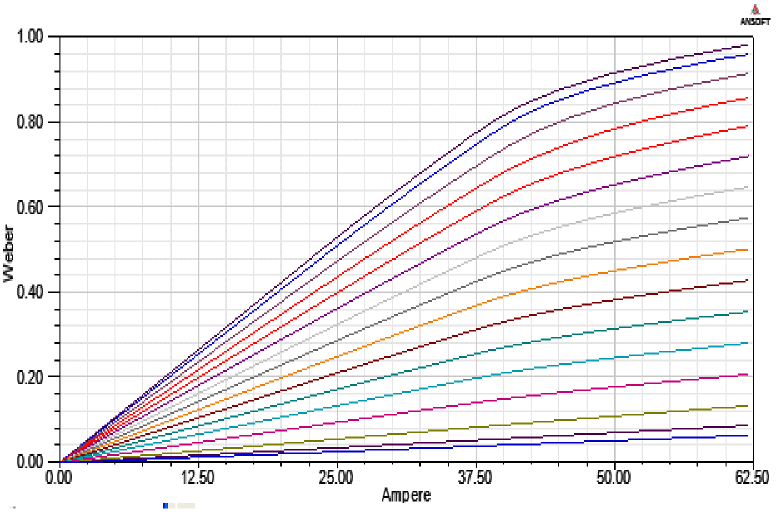


Fig. 1. Flux linkage from unaligned to aligned position

Fig.2 shows the magnetization characteristics of the propulsion SRM in 10 degree steps from the unaligned position (0 degrees) to aligned position (180 degrees).It is seen that in this design flux linkage reaches to 0.97 Weber.

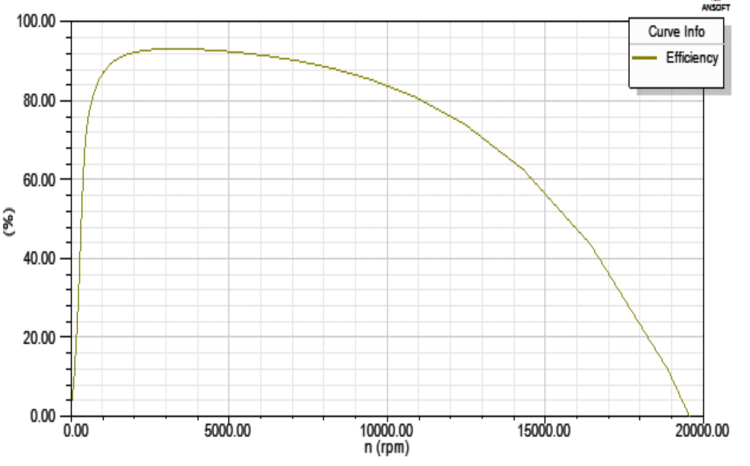


Fig. 2. Efficiency vs Speed

Fig.3 Shows efficiency at various speed and during acceleration efficiency is good maintained above 85% for different drive schedule efficiency is maintained minimum above 80%.efficiency can be increased by different optimization technique by reducing losses in motor. Losses include hysteresis losses, eddy current losses, switching losses in converter, winding copper losses and windage losses. By providing necessary cooling windage losses can be reduced.

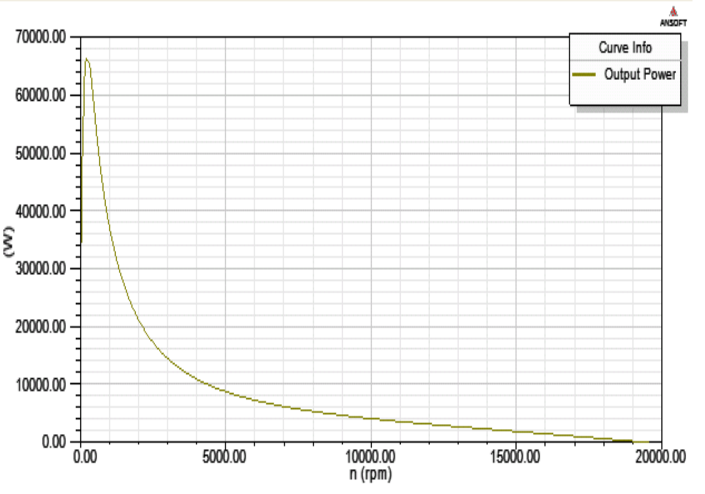


Fig. 3. Output power vs Speed

Fig.4 shows output power of motor power needed during acceleration in 32 HP but SRM machine is delivering 65 HP during acceleration which is enough to load 20 passengers.

Fig.5 shows torque-speed characteristics of switched reluctance motor. Chopper current control is applied to limit starting current and also torque to requirement. Initial torque is locked rotor torque which is limited because it causes sudden jurg in vehicle. Torque produced is 350 Nm during acceleration period; it varies for different road-load characteristics. For maximum load drive schedule enough torque is produced to propel elevator.

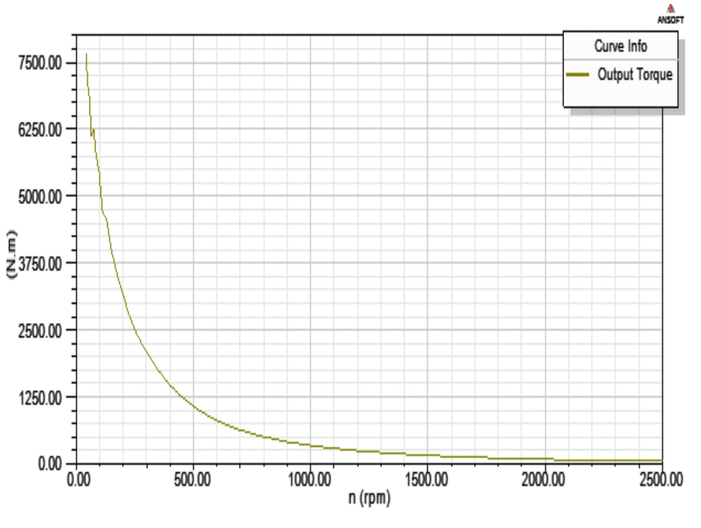


Fig. 4. Output Torque vs Speed

IMPORTANCE OF TRIGGER PULSE WIDTH AND LEAD ANGLE TRIGGER

Stroke angle is minimum conduction angle causes transverse of rotor when particular phase is excited. Stroke angle is given by,

$$\varepsilon = \frac{2\pi}{P*Nr} \quad (10)$$

In 8/6 configuration stroke angle is 15˚.therefore for every excitation rotor moves an angle of 15˚.fig.6 Shows Maxwell control circuit of switched reluctance motor with 450 V split DC arrangement. By keeping pulse width we can maintain speed of motor constant during acceleration and deceleration of elevator.

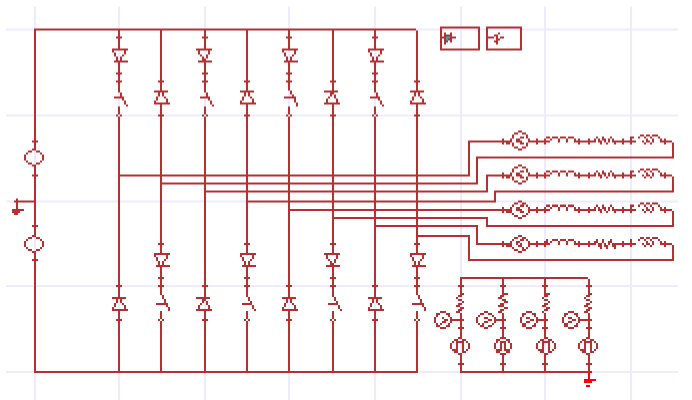


Fig. 5. Maxwell control circuit editor for trigger pulse width control

inductance profile repeats for every 45 degree in 8/6 configuration.βr>βs,θ3-θ4>0 to eliminate negative torque production by making current to zero during this period.Rotor pole arc is made greater than stator pole arc to eliminate negative torque caused by fall in current during decrease in inductance profile. Negative torque will lead to generation thus increases hysteresis and eddy current losses in motor.

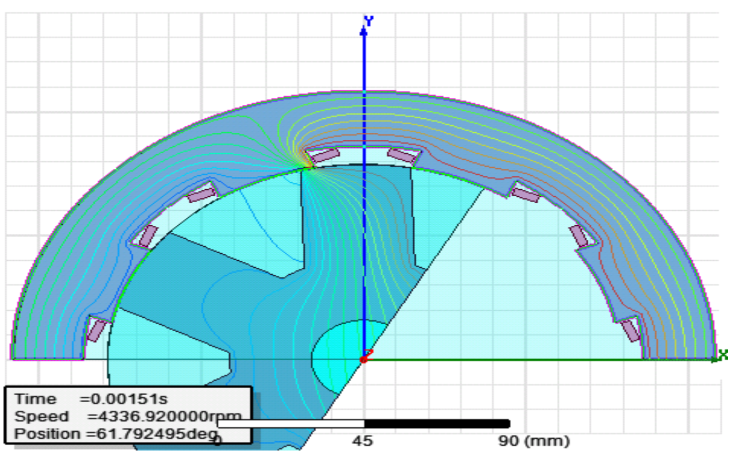


Fig. 6. Flux tubes with 7.5˚ lead angle trigger

This can also be controlled by applying excitation in advance to stator pole and bringing current to zero at aligned position. Advance excitation should be within stroke angle less than 15˚ shown in figure and Corresponding flux tubes shown in fig. 7.fig.8 shows phase excitation with respect to stator pole angle for motoring operation by providing lead angle trigger and negative torque can be eliminated..this negative reduces average torque and causes iron losses.saturation occurs in rotor core and degrades efficiency and life of machine.

In RMxprt for four phase SRM maximum trigger pulse width is 90˚, i.e,21° angle of stator pole arc and lead angle is given by 7.5°.for rated rpm of motor(1880 rpm) pulse applied is 21˚ so that elevator propels at constant speed of 8 m/5 sec.if pulse width increases beyond this value causes negative torque and increase torque ripples which reduces efficiency of motor.hence by varying pulse width between 40˚ to 90˚ speed-toque can be controlled.

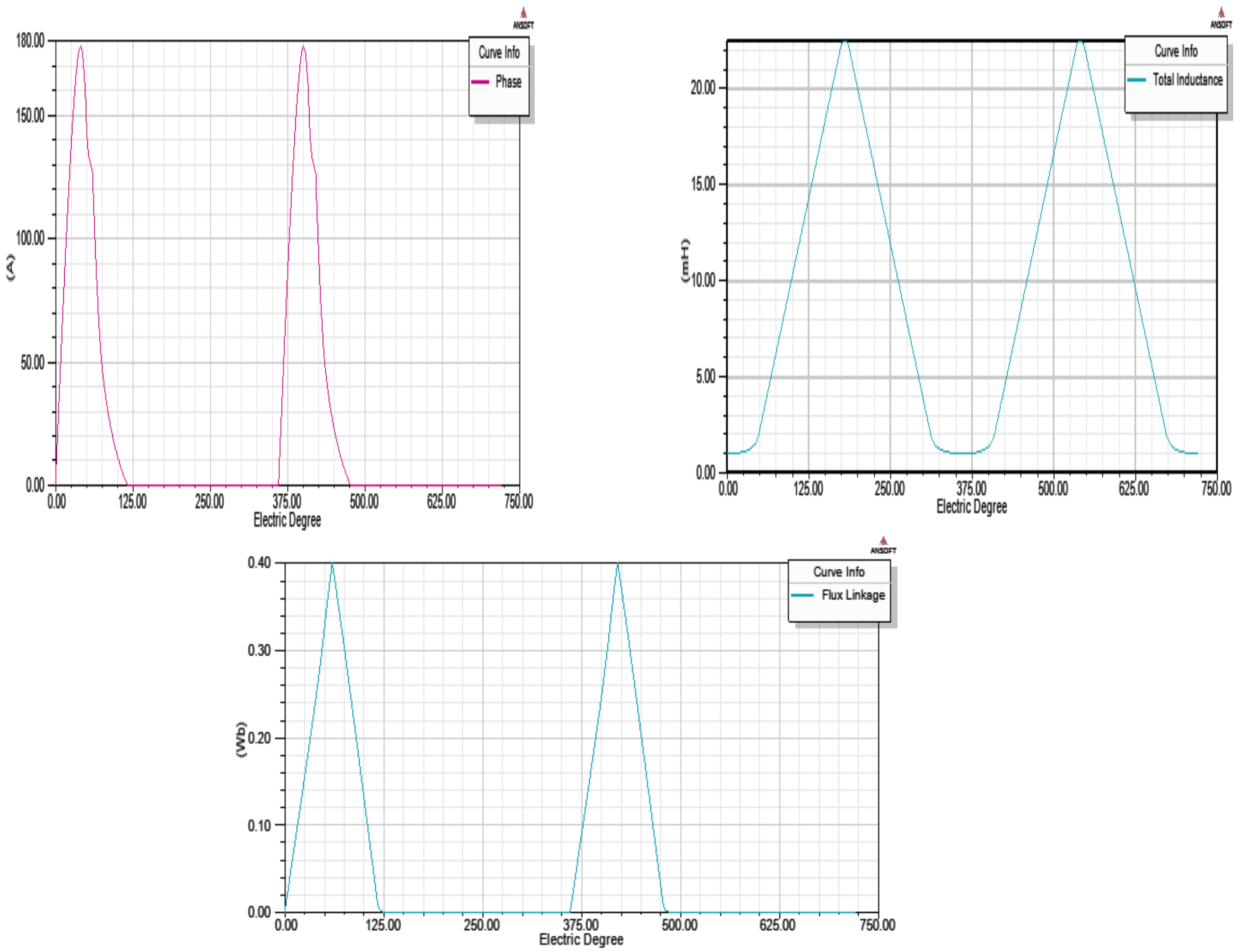


Fig. 1. phase excitation with stator pole angle and corrosponding inductance profile

SIMULATION DESIGN SHEET

As design and simulation process is completed data sheet of design is generated.

Material Consumption

MATERIAL CONSUMPTION	
Stator Copper Density (kg/m^3):	8900
Stator Core Steel Density (kg/m^3):	7650
Rotor Core Steel Density (kg/m^3):	7650
Stator Copper Weight (kg):	13.6459
Stator Core Steel Weight (kg):	121.11
Rotor Core Steel Weight (kg):	69.2941
Total Net Weight (kg):	204.05
Stator Core Steel Consumption (kg):	207.534
Rotor Core Steel Consumption (kg):	112.292

Sator and Rotor Data

STATOR CORE DATA	
Number of Stator Poles:	8
Outer Diameter of Stator (mm):	360
Inner Diameter of Stator (mm):	242
Yoke Thickness (mm):	44.32
Pole Embrace:	0.4666
Length of Stator Core (mm):	339
Stacking Factor of Stator Core:	0.95
Type of Steel:	M27_24G
STATOR COIL DATA	
Slot Insulation Thickness (mm):	0.09
End Length Adjustment (mm):	0
Number of Parallel Branches:	1
Number of Turns per Pole:	20
Number of Wires per Conductor:	1
Wire Diameter (mm):	2.743
Wire Wrap Thickness (mm):	1.8
Slot Fill Factor (%):	100.57
ROTOR CORE DATA	
Number of Rotor Poles:	6
Length of Air Gap (mm):	0.7
Inner Diameter of Rotor (mm):	41.27
Yoke Thickness (mm):	45
Pole Embrace:	0.3833
Length of Rotor Core (mm):	339
Stacking Factor of Rotor Core:	0.95
Type of Steel:	M27_24G
Magnetic Shaft:	Yes

Full-Load Operation Data

FULL-LOAD OPERATION DATA	
Input DC Current (A):	57.919
Phase RMS Current (A):	56.496
Phase Current Density (A/mm^2):	9.56041
Frictional and Windage Loss (W):	3.49399
Iron-Core Loss (W):	509.703
Winding Copper Loss (W):	1520.53
Diode Loss (W):	44.5915
Transistor Loss (W):	160.429
Total Loss (W):	2238.75
Output Power (W):	23824.8
Input Power (W):	26063.6
Efficiency (%):	91.4104
Rated Speed (rpm):	1754.99
Rated Torque (N.m):	129.636
Flux Linkage (Wb):	0.399457
Stator-Pole Flux Density (Tesla):	0.703234
Stator-Yoke Flux Density (Tesla):	0.34983
Rotor-Pole Flux Density (Tesla):	0.646507
Rotor-Yoke Flux Density (Tesla):	0.236223
Coil Length per Turn (mm):	810.815
Winding Resistance in Phase (ohm):	0.119097
Winding Resistance at 20C (ohm):	0.0979667
Winding Leakage Inductance (mH):	0.145168
Iron-Core-Loss Resistance (ohm):	459.633
Frequency of Phase Current (Hz):	175.499
Maximum Output Power (W):	66255

No-Load Operation Data

NO-LOAD OPERATION DATA	
No-Load Speed (rpm):	19549.4
No-Load DC Current (A):	6.04553
No-Load Input Power (W):	2720.49
START OPERATION DATA	
Estimated Start Torque (N.m):	8490.95
Estimated Start DC Current (A):	2002.09
Maximum Start Current (A):	3761.65
TRANSIENT FEA INPUT DATA	
For Armature Winding:	
Number of Turns:	40
Parallel Branches:	1
Terminal Resistance (ohm):	0.119097
End Leakage Inductance (H):	5.36796e-005
2D Equivalent Value:	
Equivalent Model Depth (mm):	339
Equivalent Stator Stacking Factor:	0.95
Equivalent Rotor Stacking Factor:	0.95
Estimated Rotor Inertial Moment (kg m^2):	0.869915

CONCLUSION

An approach to design and control switched reluctance motor according to speed-torque characteristics of elevator. By varying trigger pulse width with stator pole angle speed-torque profile is controlled. Further work to do flux analysis where we can reduce losses in motor and optimization of stator and rotor pole angle to improve torque profile.

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