Designing Servo Motors Using JMAG-Express Online Version

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Abstract:- Servo motors are widely used in precision industries such as robotics where custom designed motors which meets the design requirements are essential. Further, small size servo motors which exactly fits to the requirement are hard to find. There are many software tools available to design servo motors like JMAG and ANSYS. This paper presents the conceptual design of a custom designed servo motor using the online JMAG-Express version.

Keywords:- *Servo Motor, JMAG.*

I. INTRODUCTION

Robot designs may require motors deviating from standard servo motors available in the market. Such deviations occur in motor sizes, torque, and speed specifications -specially for small size motors-. Designing servo motors for the required performance and dimensions can improve the quality of the overall design. For example, UR3e collaborative robot manufactured by Universal Robots use custom designed motors integrated into to the revolute joint. JMAG Express online version is a free software package which can be used to carry out designs of such motors quickly.

JMAG-Express online version allows user to select range of motor design templates like Interior Permanent Magnet Brushless Motor, Surface Permanent Magnet Brushless Motor etc. Further, it allows to set the basic motor target parameters like power, rated rpm, maximum rpm, torque and motor sizing parameters like number of poles, number of slots, power supply voltage, maximum current, maximum motor outer diameter, maximum motor height, winding pattern as well as magnet material in the Requirement pane and propose inner dimension, material, winding and driver parameters in the Dimensions, Materials, Winding and Driver panes to obtain minimum requirements for the selected motor template. Then the user can perform parametric analysis for the inner dimensions and drive parameters to improve the motor performance by using performance plots. This paper presents the motor design technique along with sensitivity analysis of critical dimension parameters.

II. MOTOR DESIGN REQUIREMENTS

A servo motor design as a substitution to the BRS2422A150 stepper motor is considered in this study. The BRS2422A150 stepper motor rated motor torque is 0.3 Nm at 1.5 A and 450 rpm. Brushless motor SPM type was selected as the motor template and the rotor type rsp_001 and stator type so_012 was selected for the study. Since the housing width of the BRS2422A150 is 42.3 mm [1], the stator outer diameter is fixed to 34.3 mm allowing 4 mm minimum housing thickness. The motor height is selected as 40mm. During the simulation, the continuous current is considered as 1/3 of the maximum current of the selected coil. Table 1 describes the fixed parameters set in the Requirement pane. The maximum revolution speed is limited by the hardware capabilities, and in this study, it is considered as 3500 rpm.

Table 1 - Fixed Parameters in the Requirement Pane

Parameter	Value
Rated Power (kW)	0.05
Rated Revolution Speed (rpm)	1600
Maximum Revolution Speed (rpm)	3500
Number of Poles	8
Power Supply Voltage (RMS) (V)	48
Maximum Outer Diameter of Motor (mm)	34.3
Maximum Motor Height (mm)	40
Magnet	Neodymium

III. MOTOR DESIGNING

The initial model was obtained by applying the Requirement pane data. As the online version of the JMAG Express only allows limited range of materials, 50A250 is used as the stator and rotor core material and NdFeB_Br = 1.4(T) was used as the rotor magnet material. The magnetization pattern is selected as Radial. This section explains the effect of each varying parameter towards changing motor performance using motor torque vs rpm graphs. Since the rated current of the BRS2422A150 type stepper motor is 1.5A, these simulations were started using 2.12 A peak current for AWG 23-gauge wire [2]. The orange color graph shown in all the Torque-Speed curves in this section represent the expected minimum performance graph according to the values set in the Requirement pane for Rated and Maximum Revolution Speed values.

A. Rotor Outer Diameter and Stator Inner Diameter

Fig 1 depicts the torque behavior when the rotor outer diameter is increased from 16mm to 17.2mm. In this case, the stator inner diameter is also increased to maintain the 0.5 mm airgap. We can observe that increasing the rotor outer diameter increases the torque while decreasing the rated and maximum rpm. It is advisable to keep the rotor outer diameter low as possible as low rotor inertia is required for servo motors.

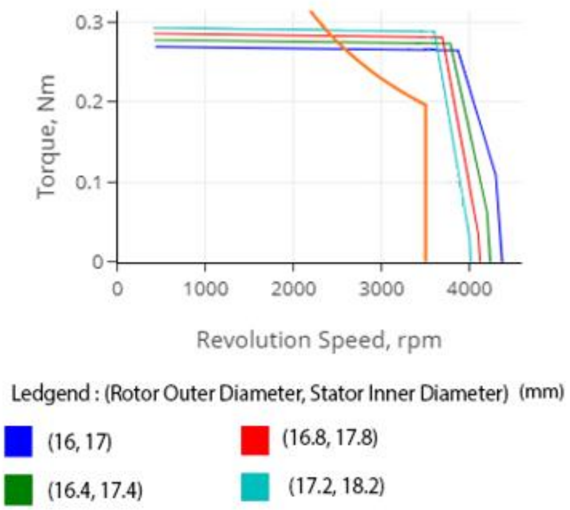

Fig 1 - Torque vs. Revolution Speed when Rotor Outer Diameter is Changed

B. Magnet Thickness

Fig 2 depicts the torque behavior when the magnet thickness is increased from 1.5 mm to 2.02 mm. Increase in the magnet thickness increases the flux density and hence the motor torque increases. The increase in flux density also increases the back emf which reduces the rated and maximum rpm. Since core saturations cannot be detected using conceptual design, it is essential to analyze the model using FEA method to verify that the stator core is not saturated at the expected speed.

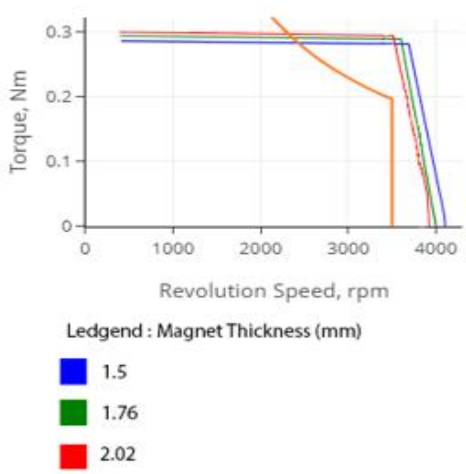

Fig 2 - Torque vs. Revolution Speed when Magnet Thickness is Changed

C. Air Gap

Fig 3 depicts the torque behavior when the airgap was increased from 0.5 mm to 1 mm. In this case the rotor outer diameter is decreased to increase the airgap. The airgap influences flux density in various locations and current density in slots [3]. When the airgap is increased the flux density is decreased. This reduces the torque and increase the rated/maximum rpm. The airgap should be selected in a way that saturation in stator tooth is minimized. This should be further analyzed with a FEA model.

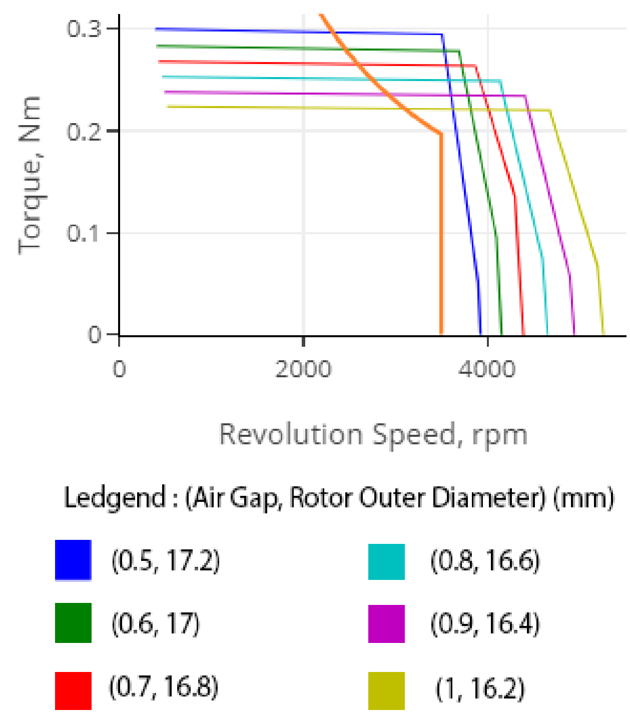

Fig 3 - Torque vs. Revolution Speed when Airgap is Changed

D. Slot Opening width

Slot opening width has many impacts on motor performance specially on cogging torque as well as airgap magnetic field distribution [4]. The cogging torque decreases when the slot opening width decreases [5]. Further, there are some points of slot opening width which maximizes the EMF [6]. Therefore, the effect of the slot opening should be analyzed more carefully using a FEA model as these behaviors cannot be captured using a conceptual design. JMAG Express model the slot opening behavior considering the airgap change. When the slot opening is increased, the flux density decreases as the air gap is increased near the slot. Therefore, the torque decreases and the rpm increase with the increasing slot opening as shown in Fig *4*.

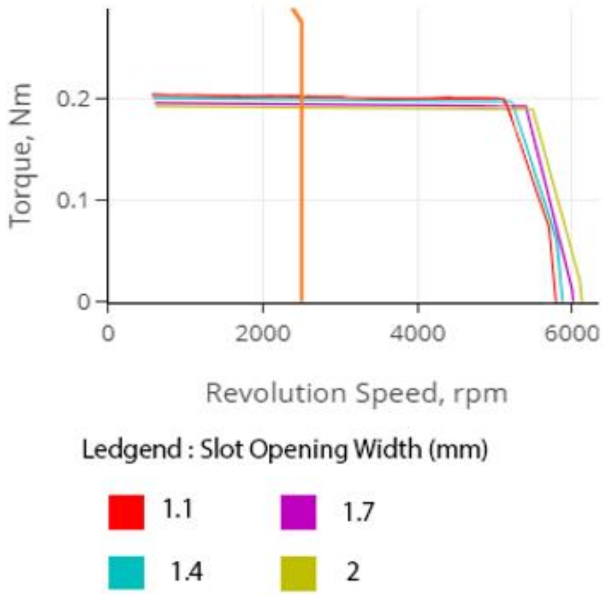

Fig 4 - Torque vs. Revolution Speed when Slot Opening Width is Changed

E. Slot Height and Slot Bottom Width

Increase in the slot height decreases the stator yoke width (gap between the slot bottom and outer of the stator) and increasing the stator bottom width decreases the stator tooth width (gap between two slots). Overall, increasing one of these parameters increases the slot area allowing number of coil-turns to be increased. Hence the current can be reduced to maintain torque or torque can be increased while maintaining the current. In this case it is essential to observe stator tooth and stator yoke saturations using a FEA model.

F. Coil Gauge, Number of Turns and Phase Current

The number of turns is a key component which decides the motor torque speed profile after the magnet thickness [3]. Fig 5 presents the torque behavior when the coil gauge, number of turns and phase current is changed. When the coil gauge is reduced, the diameter of the coil increases while increasing the slot fill factor. Since low gauge coils can carry high currents, the continues torque (obtain by 1/3 of maximum current of the coil) can be increased. But this may be an issue when developing the driver for the motor as high currents need to be supplied to the motor. By using high coil gauges, the number of turns can be increased while reducing the continuous current. As the number of turns increases, the back EMF increases resulting in decrees in the rated and the maximum rpm of the motor.

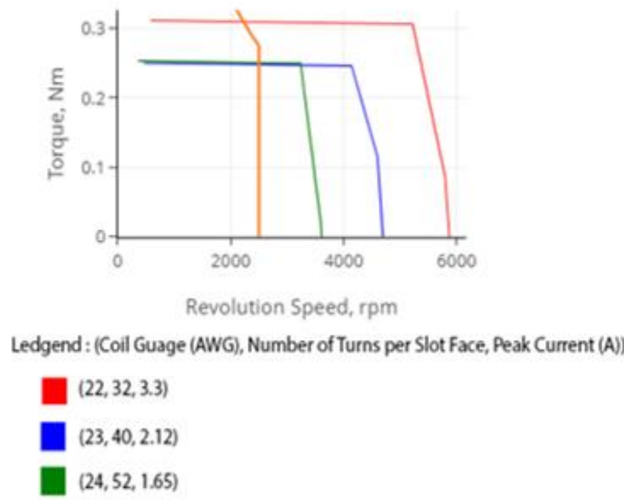

Fig 5 - Torque vs. Revolution Speed when Coil Gauge, Number of Turns and Phase Current are Changed

IV. OPTIMIZED DESIGN GEOMETRY PARAMETERS, PROPERTIES AND MACHINE CONSTANTS

Table 2 shows the geometry parameters of the model obtained after performing parametric simulation. Fig 6 shows the geometry of the model. For each slot face, 32 coil turns from gauge 22 coil is used in this design, meaning that number of turns for each stator tooth is 16. Since the maximum current of the selected coil gauge is 7A, the continuous current for this design is 2.3 A.

Table 2 - Geometry Parameters of the Optimized Model

Parameter	Value
All	
Outer Diameter (mm)	34.3
Gap Length (mm)	0.75
Stack Height (mm)	40
Stator: so_012	
Number of Slots	9
Stator Outside Diameter (mm)	34.3
Stator Bore Diameter (mm)	18.5
Angle of Slot (degrees)	38
Depth of Stator Slot (mm)	5.3
Width of Stator Slot-Bottom (mm)	8
Width of Stator Slot-Opening (mm)	1
Height of Stator Tooth-Tang (mm)	0.6
Angle of Stator Tooth-Tang (degrees)	0
Fillet Radius at Stator Slot-Bottom (mm)	1

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Fillet Radius at Stator Slot-Top (mm)	1
SPM_Rotor: rsp_001	
Number of Poles	8
Rotor Outside Diameter (mm)	17
Shaft Diameter (mm)	7
Magnet Thickness (mm)	1.9

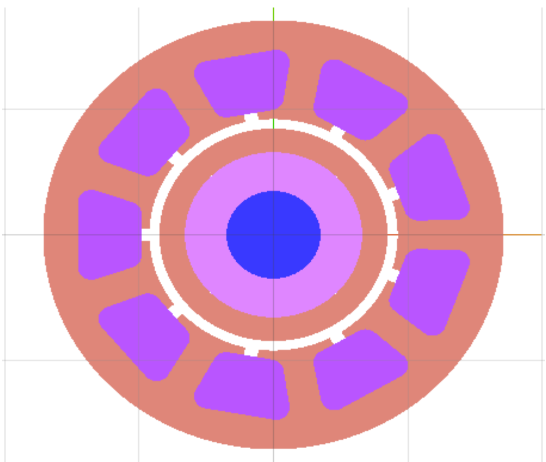

Fig 6 - Geometry of the Model

Table 3 shows the motor properties obtained from the Machine Constant and Mass Property tables in the Characteristics pane of the JMAG Express.

Table 3 - Properties and Machine Constants of the Optimized Model

Parameter		**Value**
Properties		
Inertia	Rotor Magnet (kg m^2)	1.566e-06
	Rotor Core, (kg m^2)	8.344e-07
	Total, (kg m^2)	2.4e-06
Machine Constants		
Inductance	Ld, (H)	6.919e-04
	Lq, (H)	8.765e-04
	Self-Inductance, (H)	5.228e-04
	Mutual Inductance, (H)	-2.614e-04
Torque Constant	Kt, (Nm/A)	0.0945
Voltage Constant	Ke, (V s/rad)	0.1091
Magnetic Circuit	Average Teeth Flux Density, (T)	1.114
	Average Back Yoke Flux Density, (T)	0.5199
	Average Gap Flux Density, (T)	0.8728
	Magnet Flux Linkage, Wb	0.01918

V. MOTOR PERFORMANCE COMPARISON

Table 4 shows the key performance parameters of the optimized model at the 1600 rpm. Fig 7 shows the efficiency plot for the operating range. From Fig 7, it can be observed that the rated and maximum rpm is approximately 4200 & 4800 respectively. Fig 8 presents the toque speed curve of the BRS2422A150 stepper motor. Comparing the performance of both BRS2422A150 and simulated motor, it can be observed that the simulated motor has approximately the same torque as the BRS2422A150, and rated and maximum rpm is greater than the BRS2422A150 motor.

Table 4 - Key Performance Parameters at Operating Speed

Parameter	**Value**
Torque (Nm)	0.298
Power (kW)	0.05
Efficiency (%)	85.82
Copper Loss (W)	7.62
Iron Loss (W)	0.622

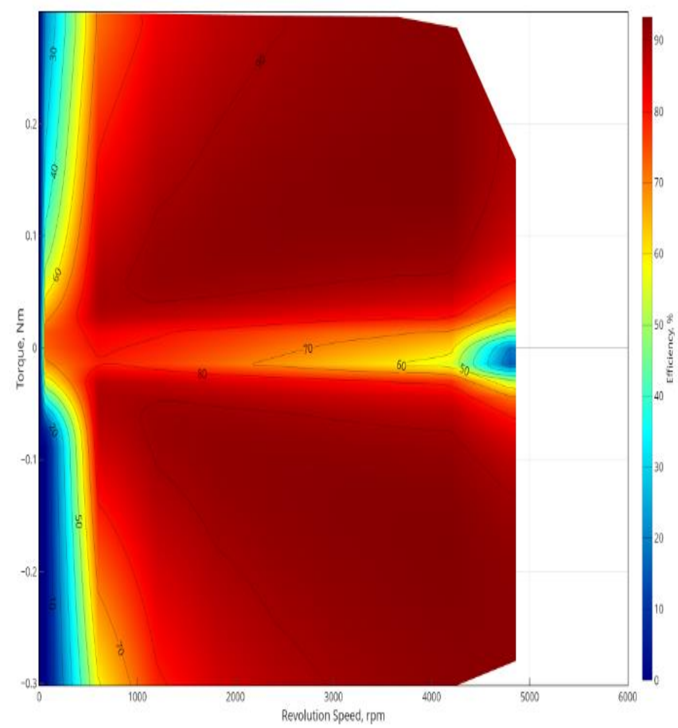

Fig 7 - Efficiency Map of the Model at 48V and 3.3 A Current

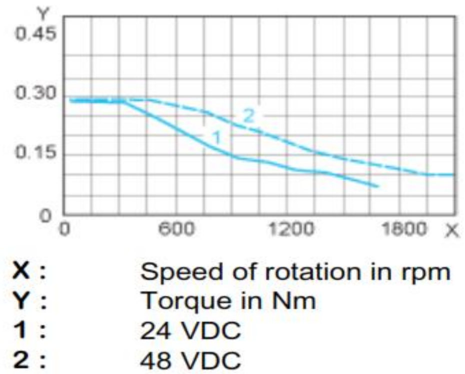

Fig 8 - Torque Speed Graph of BRS2422A150 Stepper Motor

VI. CONCLUSION

JMAG Express online software is a great tool to develop a conceptual design for a motor quite easily which allows user to have an idea about rough dimensioning and allows to analyze sensitivity of motor geometry, material, and winding parameters towards the motor performance.

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