Comparison of Torque between Different Diameters of Copper Rotor Bar Slot by Using FEM Software

I. Daut, Y. Yanawati, N. Gomesh, S. Nor Shafiqin, I. Pungut, and A. R. Rafidah

***Abstract*—This paper presents the comparison of different rotor slot diameter which is designed by using FEM software. The parameter is than taken from 0.5HP AC induction motor with a 10 rotor slot by means of hardware experiment. The Parameter is used as the input for FEM for simulation purposes. The 0.5HP three phase induction motor is investigated by the differences of starting torque. This is because the design with smaller rotor slot can produce high starting torque and this is essential for high-inertia loads such as flywheel-equipped punch press, elevators and hoist as required by NEMA design D. Simulation analysis shows that the 4mm diameter of rotor slots have higher starting torque than the rest of the rotor slots which is 3.4Nm.**

***Index Terms*—FEM, induction motor, torque, rotor bar slot, rotor bar diameter.**

I. Introduction

NEMA classifies polyphase induction motors according to locked rotor torque and current, breakdown torque, pull up torque and percent slip. Locked rotor torque is the minimum torque that the motor develops at rest for all angular positions of the rotor at rated voltage and frequency. Locked rotor current is the steady state current from the line at rated voltage and frequency with the rotor locked. Breakdown torque is the maximum torque that the motor develops at rated voltage and frequency, without an abrupt drop in speed. Pull up torque is the minimum torque developed during period of acceleration from rest to the speed that breakdown torque occurs.

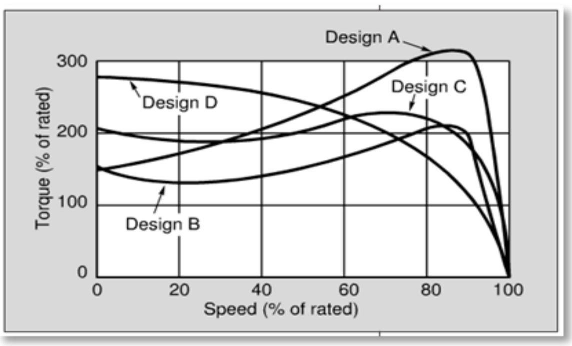

Fig. 1. Typical speed-torque characteristics for design A, B, C, and D motors

Fig. 1 [1] illustrates typical speed-torque curves for NEMA Design A, B, C, and D motors. Design A motors have a higher breakdown torque than the Design B motors and are usually designed for a specific use. Slip is 5% or less. Design B motors account for most of the induction motors sold. Often referred to as general purpose motors and slip is 5% or less. Design C motors have high starting torque with normal starting current and low slip. This design is normally used where breakaway loads are high at starting, but normally run at rated full load, and are not subject to high overload demands after running speed has been reached. Slip is 5% or less. Design D motors exhibit high slip (5 to 13%), very high starting torque, low starting current, and low full load speed. Because of high slip, speed can drop when fluctuating loads are encountered. This design is subdivided into several groups that vary according to slip or the shape of the speed-torque curve. These motors are usually available only on a special order basis [1].

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II. FEM Modelling

Fig. 2 shows the FEM design specification of the 0.5 HP induction motor in millimeters. The overall rotor radius is 33.75mm. The following design is constructed using 3D CAD software. The radius of the rotor and shaft remains the same but the rotor slot is altered by adding up the size from 2, 4, 6, 8, 10 till 12 to obtain the best design with the best efficiency as well as power factor and better starting torque. The design is then simulated using the FEM software. Certain aspect is considered such as the power factor, efficiency and starting torque which will be the point of discussion in this paper.

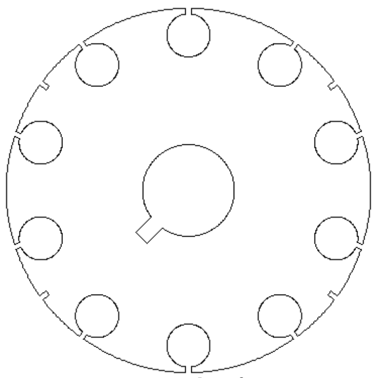


Fig. 2. Rotor slot of 10mm

TABLE I: Various Diameter of Rotor Slot

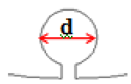
	Diameter (d)
	2mm
	4mm
	6mm
	8mm
	10mm
	12mm

Table I shows a round bar rotor slot type and the diameter of each slot that will be altered. The usage of this slot pattern is because it has a discrete 'starting bar' isolated from the main body of the conductor bar by a 'leakage slot', are applicable to motors with high conductivity material in the rotor cage [2]. Beside that, this design of rotor bar has a higher locked rotor torque and a high slip. Its principle field of application is in high-inertia loads such as flywheel-equipped punch presses, elevator, and hoists [3].

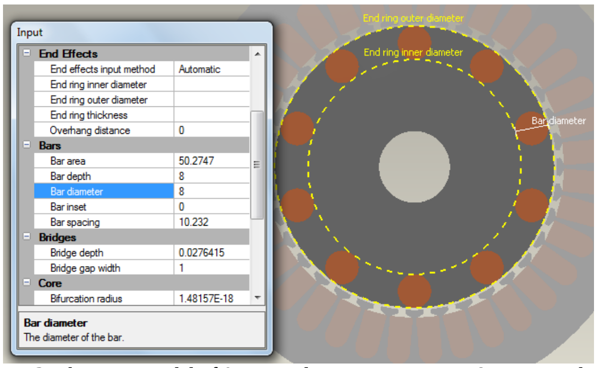


Fig. 3. The FEM model of 0.5HP Induction Motor using 8mm rotor slot size

Fig. 3 shows the FEM model simulated by using the AC Analysis solver. The result is then arranged to Table 2 which comprises of the nameplate data for 0.5HP induction motor. Input such as motor horse power, input voltage and frequency is inserted into the FEM software and the remaining result in Table 2 is the output from the FEM software.

TABLE II: 0.5HP INDUCTION MOTOR NAMEPLATE FOR BOTH DIAMETERS

Diameter of rotor slot (mm)	2	4	6	8	10	12
Phase (ϕ)	3	3	3	3	3	3
Frequency(Hz)	50	50	50	50	50	50
Voltage(V)	415	415	415	415	415	415
Speed (r.p.m)	1425	1425	1425	1425	1425	1425
Current (A)	0.52	0.55	0.65	0.84	1.08	1.33
Horsepower (HP)	0.5	0.5	0.5	0.5	0.5	0.5
Starting Torque (Nm)	3.15	3.4	2.0	1.2	0.75	0.55

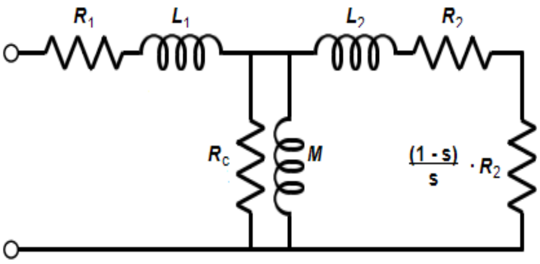


Fig. 4. Equivalent circuit of 0.5HP induction motor

The motor are design to have 36 stators and 10 rotor slots each with various diameter of rotor slot using copper; the FEM uses steady-state AC analysis solver for various diameter of rotor slot design. Based on simulation, results from both diameters rotor slots are analyses and its properties differences are stated. In this simulation, copper conductivity is 5.77×10^7 sm^{-1}.

The BH curve used for the 0.35mm thickness of non oriented electrical steel modeling has shown as Fig. 5. The BH curve assigned to the FEM design is below 1.8T.

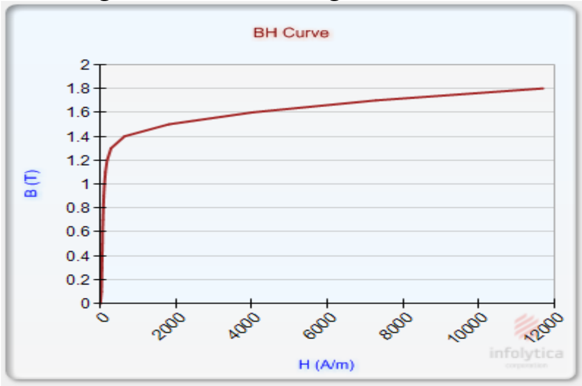


Fig. 5. BH curve for 0.35mm thicknesses and both diameters of material

III. TORQUE

The comparison between different diameters of Copper Rotor Bar is shown in Fig. 6. Fig. 6 which is the torque of various diameter of rotor slot using copper and the maximum magnetic flux density of both diameters is 1.8 Tesla base on the BH curve assign in Fig. 5. Rotor bars made of copper conduct high ampere flow. An example is the small copper rotor bars that are used in high-slip motors. Their small gives them high resistance, which limits the amperes in the rotor winding this mean the diameter 4mm has a very high locked-rotor torque and high slip. It means the small rotor bars, located close to the surface of the rotor, will have ampere flow that nearly matches (in time) the stator amperes [4]. The rotor slot type called the round bars is Design D where representative cross sections of some NEMA-design rotors. The design D motor has a very high locked-rotor torque and high slip. Fig. 6 shown that diameter 4mm has relatively high resistance, low-reactance rotor bars close to the surface.

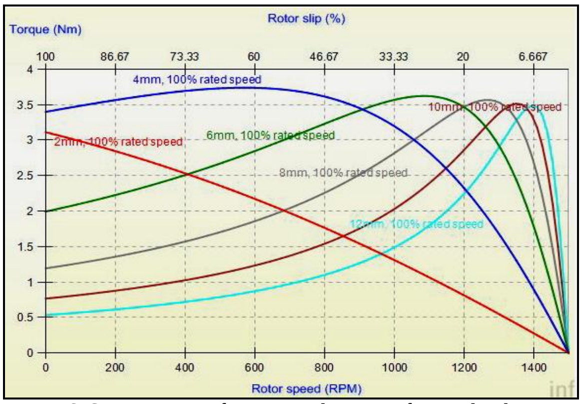


Fig. 6. Starting torque for various diameter of rotor slot design

IV. CONCLUSION

From the analysis, it shows that 4mm diameter of slot rotor has 3.4Nm higher starting torque compare to other diameter rotor slot. Small rotor slot, located close to the surface of the rotor, will have ampere flow that nearly matches the stator ampere. When this happen, the motor has a good phase angle (near 90°) between stator and rotor windings. Large rotor slot are surrounded by a lot of iron. Magnetizing the surrounding iron causes a delay current flow in the bars. This delay in current flow in the rotor slot causes peak magnetism to occur later in the rotor poles than in the stator poles. The result from these activities is a poor phase angle. Starting torque is a very important value when fitting a motor to a load and so it is proven by simulation that a rotor with a smaller rotor slot can produce high starting torque. This advantage makes rotor frame using 4mm slot rotor with copper a best choice for implementation of higher starting torque in the induction motor.

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