A Study of Different Air Gaps on the Effect of Torque and Efficiency in Induction Machines

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Abstract- The air gap of induction machines is the most important design parameter. It simply affects starting torque, efficiency and also rated values. In this study, five asynchronous machines are used to examine the effect of different air gaps with the different armatures which have the same electrical properties. One of these is called standard rotor and the others are modified rotors which have different diameters. The torque, efficiency and mmf values of each machines are calculated in laboratory environment and compared with the traditional calculation techniques. Addition to these, the air gap voltage is analysed by using Fast Fourier Transform (FFT) to see its harmonic components. It is concluded that if the air gap increase the harmonic components of the mmf produced in air gap are reduced. Besides, copper and core losses are increased while the torque is decreased.

Key-Words: Induction Machines, Air-Gap, Efficiency in Induction Machines, Torque, MMF.

Notations:

s= Fractional slip,
n_s= Rev/sec synchronous,
f= Frequency in hertz,
n_r= Rev/sec of rotor,
p= Number of pole pairs,
R_m= Magnetising resistance, representing iron losses,
U_0= Line to line voltages,
P_0= No-Load input power,
S_0= No-Load apparent power,
Q_0= No-Load reactive power
X_m= Magnetising resistance,
R_e= Equivalent resistance referred to stator,
t_0= Room temperature,
X_e= Equivalent leakage resistance referred to stator,
t_1= Winding temperature,
R_{so}= Measured stator reactance at room temperature (20^{o}C)
R'_r=Rotor reactance referred to stator,
$X_{s\sigma}$= Stator reactance,
$X'_{r\sigma}$= Rotor reactance referred to stator,
T_c= Torque acting at mechanical shaft coupling,
T_e= Torque developed electromagnetically, in Newton meters,
ω_s= Synchronous angular velocity radians/sec.
U_{sc}= Measurement terminal voltage under short circuit test,
I_{sc}= Measurement current under short circuit test,
m_s= stator phase number,

1 Introduction

In the experimental study, the measure coils are placed on the stator coil and wave type of mmf in the air-gap is measured. Besides, the moment and efficiency values for each motor are obtained experimentally. As it can be seen from the results, As the air-gap in the induction machine increases, mmf wave type in the air gap, moment and efficiency change. This changing modifies the equivalent circuit parameters.

2 Theorical Examination of the Induction Machine

As it is known, in examination of induction machine, the general equivalent circuit is used. In this equivalent circuit, the equivalent circuit parameters occurring as a result of changing of rotor, stator and air-gap take place. While the stator circuit parameters, except the stator resistance, change depending on the air-gap, rotor circuit parameters change depending on the air-gap and sliding.

$$s = \frac{n_s - n_r}{n_s} \tag{1}$$

$$n_s = \frac{f}{p} \tag{2}$$

As the air-gap is a different, magnetizing current change. This situation a cause rises in loses. In this study, one stator is handled and the study is realized with various diameter rotors in different air gaps. For the motor used in the study, the friction and ventilation loses are deemed as fix and the variable equivalent circuit is given in Fig.1

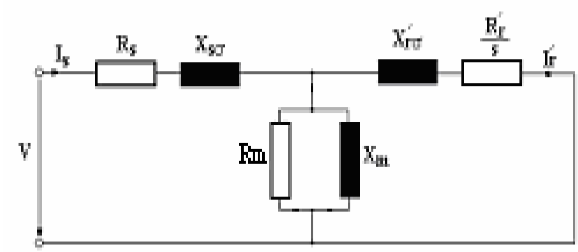

Fig.1 One phase equivalent circuit of induction machine

The circuit parameters in Fig.1 are calculated with the following equations by getting use of the no-load and short-circuit tests;

$$R_m = \frac{\left(\frac{U_0}{\sqrt{3}}\right)^2}{\frac{P_0}{3}} \tag{3}$$

$$S_0 = 3 \times \frac{U_0}{\sqrt{3}} \times I_0 \tag{4}$$

$$Q_0 = \sqrt{S_0^2 - P_0^2} \tag{5}$$

$$X_m = \frac{\left(\frac{U_0}{\sqrt{3}}\right)^2}{\frac{Q_0}{3}} \tag{6}$$

In the short-circuit test, the other parameters of the equivalent circuit are calculated as follows. However, stator resistance is externally measured.

$$R_e = \frac{P_{sc}}{3 \times I_{sc}^2} \tag{7}$$

$$Z_e = \frac{U_{sc}}{\sqrt{3} \times I_{sc}} \tag{8}$$

$$X_e = \sqrt{Z_e^2 - R_e^2} \tag{9}$$

$$X_e = X_{ss} + X'_{rs} \tag{10}$$

$$X_{1s} = X'_{2s} = \frac{X_e}{2} \tag{11}$$

$$R_e = R_s + R'_r \tag{12}$$

Stator resistance is found in the room temperature by means of ammeter-voltmeter method and the value of motor in nominal operation temperature is calculated with the following equations;

$$R_s = R_{s0} \cdot \frac{235 + t_1}{235 + t_0} \tag{13}$$

$$R'_r = R_e - R_s \tag{14}$$

The circuit parameters in equivalent with the equations given above are calculated and the results are given in Table 1. When the Table 1 is examined, it is found that the obtained results and experimental results conform to each other.

Table 1 Calculated equivalent circuit parameters

Motors	R_m	X_m	R_s	$X_{s\sigma}$	$X'_{r\sigma}$	R'_r
Standard Motor	956,291	155,00	11,145	6,440	6,440	7,887
1.	674,766	101,67	11,145	6,107	6,107	8,476
2.	263,985	59,251	11,145	5,250	5,250	9,335
3.	154,109	45,472	11,145	4,906	4,906	10,546
4.	96,718	37,918	11,145	4,756	4,756	12,955

By getting use of the equivalent circuit parameters, the moment values of motor in nominal operation are found according to the following equation;

$$T_c \cong -m_s \cdot \frac{R'_r}{s \cdot w_s} \cdot \frac{\left(\frac{U_0}{\sqrt{3}}\right)^2}{\left[R_s + \frac{R'_r}{s}\right]^2 + \left[X_{ss} + X'_{rs}\right]^2} \tag{15}$$

The moment values obtained according to the above equation are given in Table 2.

Table 2 Calculated moment values of motors

Induction Motors	Torque (Calculated) Nm
Standard Motor	5,789
1.Motor	5,453
2.Motor	4,980
3.Motor	4,525
4.Motor	3,807

Motor Number	1.HAR.	3.HAR.	5.HAR.	7.HAR.	9.HAR.
	Sin	Sin	Sin	Sin	Sin
Standard	14,1524	1,3300	0,3988	0,4918	0,5161
1	31,9688	0,7038	0,0652	-0,1108	-0,0484
2	14,2156	0,6783	-0,0189	0,0165	-0,0180
3	20,9747	0,5435	0,0148	-0,0634	-0,0469
4	23,7066	0,3153	0,0376	-0,1137	0,0249
	Cos	Cos	Cos	Cos	Cos
Standard	0,4643	0,1389	0,1270	-0,0105	-0,1401
1	-0,9911	-0,1119	0,8621	-0,0730	0,0577
2	-0,2194	-0,1215	0,2491	-0,0646	0,1213
3	-0,6809	-0,0766	0,5947	-0,0352	0,0708
4	-0,4553	0,0039	0,6001	0,0153	-0,0156

Table 3 Harmonic Amplitude

3 Experimental Study

In this experimental study, three-phase 0.75 kW, 50 Hz, 380 V., wyes connected, 4 pole, 2.10 A., 1440 rpm, cage-type induction motor is used. The air gaps of the motors used in the study are obtained as follows. While in the standard motor the air gap is 0.38 mm, it is 0.603 mm in the 1'st rotor, 1.15 mm in the 2'nd rotor, 2.105 mm in the 3'rd rotor and 2.15 mm in the 4'th rotor. MMF wave types obtained from the measure coil on the stator winding during the tests realized in the laboratory medium for the induction machine with different air-gap and squirrel cage are given in Fig.2. When the FFT of wave types in Fig.2 is realized, the upper harmonic values are found as given in Table 3.

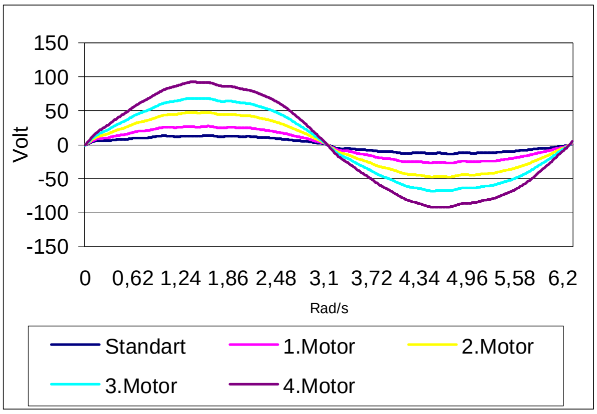

Fig.2 MMF Wave Types

In the upper harmonics; 3. and 5. Harmonics are effective and as it can be seen at the end of the examination, these values are high in the standard motor and as the air-gap increases, these values decrease.

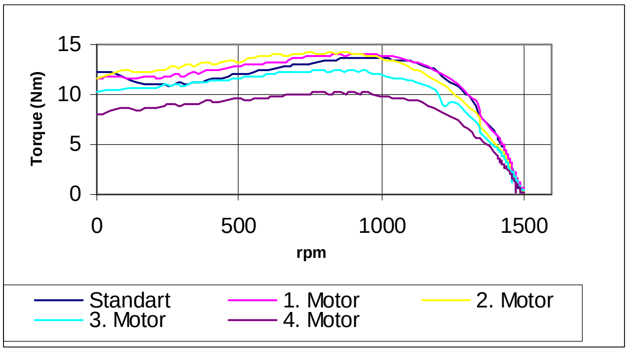

Fig.3 Moment Change

As it can bee seen from the torque change in Fig.3, the change in air-gap modifies the torque characteristics. The measured torque values are given in Table 4.

When the Table 4 is examined, it is found that the starting torque decreases depending on the air-gap of motors. As it is known, the air-gap change affects the stator and rotor reactance. As a result of this, while in the motor with low air-gap the highest torque is obtained, and as the air-gap increases, moment values decrease.

Table 4 Moment Values

Motors	T_s	T_c
Standart Motor	12,186	5,786
1. Motor	11,602	5,775
2. Motor	11,624	4,867
3. Motor	10,220	4,511
4. Motor	8,025	3,598

The starting and nominal torques of induction motors and as well as their efficient are important parameters in selection of motors. For this purpose, induction motors are loaded in their nominal loads and change in efficient values are obtained experimentally and given in Fig.4. These values change in parallel to torques.

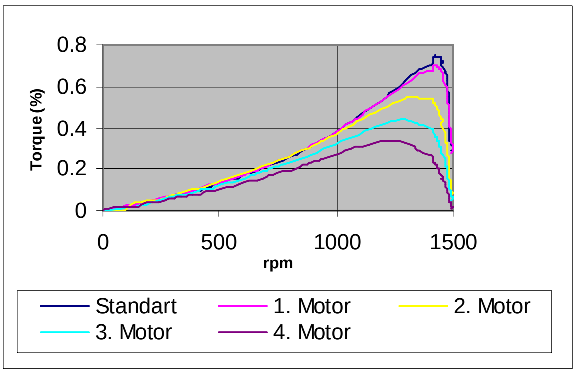

Fig.4 Changing of efficient in different air-gap motors

The efficient values in nominal operation are given in Table 5. When the results in Fig.4 are examined, nominal moment (T_c), nominal rpm (n_r) and efficient values are given in Table 5.

Table 3.3 Efficient Values

Motors	Air-gap (mm)	Torque (T_c)	Efficient (%)
Standard Motor	0,38	5,786	72,70%
1. Motor	0,603	5,775	67,60%
2. Motor	1,15	4,867	53,60%
3. Motor	2,105	4,511	39,80%
4. Motor	2,15	3,598	25,30%

The most important reason of decreasing of the efficient values in Table 5 is rising in magnetizing reactance and iron loses and in parallel to this, rising of gap losses in motor. The additional losses decrease as the air-gap increases.

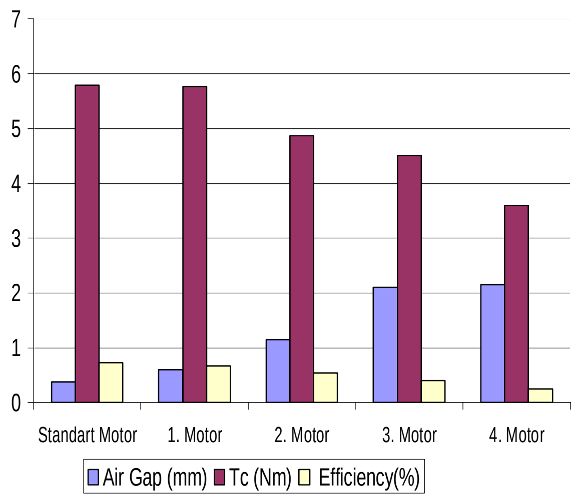

Fig.5 Air-gap, Torque and Efficient Changes

When the Table 5 is examined it is found that the efficient change in nominal torque and nominal revolution is the highest in the standard rotor and increasing of the air-gap causes changes on the efficient and torque.

4 Results

The affects of changing of air-gaps in 0.75 KW squirrel cage induction motors on the torque and efficient of motor are examined. As a result of this examination, the starting torque is in the highest value in standard motor and as the air-gap increases, the changes of this value according to the standard motor is 4.79 % decrease in the 1'st motor, 4.61 % in the 2'nd motor, 16.13 % in the 3'rd motor and 34.15 % in the 4'th motor.

When it is evaluated with regard to 1423 rpm (approximate nominal torque) , while it is observed that the nominal torque of the 1'st motor is 2.87 % higher than the standard motor , the efficient is 5.75 % lower than the standard motor. In the 2'nd motor, nominal torque is 13.9 % lower than the standard motor and efficient is 31.37 lower than the standard motor. The torque and efficient changes in the other motors when compared to standard motor show decrease, in the 3'rd motor 8.75 %, efficient change is 50.54 %, in the 4'th motor 34.70 % and efficient change is 70.11 %. In this study, it is observed that increase of the air-gap in induction machines causes decrease in moment and efficient.

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