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A. Amin
Electrical Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

M. El-Shammoty
Electrical Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

S. El-Drieny
Electrical Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

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PERFORMANCE CHARACTERISTICS OF A SLOTTED-CAGE SOLID ROTOR THREE-PHASE INDUCTION MOTOR WITH CONSTANT-VOLTAGE SOURCE (EXPERIMENTAL INVESTIGATION)

خصائص أداء المحرك التأثيري الثلاثي الأوجه ذو بروزات سطحية وملفات قفص والمتصل

بمنبع ثابت الجهد (استقصاء تجريبي)

A. R. A. AMIN M. M. I. EL-SHAMMOTY S. A. EL-DRIENY

Electrical Engineering Department,

Faculty Of Engineering,

El-Mansoura University, El-Mansoura, EGYPT

الخلاصة - يهدف هذا البحث الى تحسين أداء المحرك التأثيري ذو العضو الدائر الحديدي وذلك من خلال تعديل تصميم العضو الدائر . ولهذا الغرض فقد تم تصميم ثلاثة أعضاء دوارة مصنوعة من الحديد مواصفاتها كما يلي : - العضو الدائر الأول لا يحتوي على مجاري سطحية بينما تم تزويده بثقوب لتركيب ملفات القفص السنجابي . بينما العضو الدائر الثاني والثالث يحتويان على مجاري سطحية عددها 32 مجرى ، 40 مجرى على الترتيب كما تم تجهيزه بثقوب لتركيب ملفات القفص السنجابي . وقد تم قياس أداء المحرك التأثيري للثلاثة أعضاء الدائرة المصممة ، وذلك في حالة تركيب ملفات القفص السنجابي وبدونها ، لحالات اللاحمل ، والقصر ، والتحميل لثلاثة جهود تشغيل وهي 70 V, 110 V, 130 V وقد أوضحت النتائج تأثير تغيير جهد التشغيل على درجة التشبع وعلى أداء المحرك التأثيري . كما أوضحت دراسة المقارنة للنتائج تحسن في أداء العضو الدائر الثالث نتيجة لقلة تيار المغنطة وتحسن معامل القدرة . كما أظهرت تحسن كبير في أداء المحرك التأثيري أثناء البدء والتحميل نتيجة لاضافة ملفات القفص السنجابي . وقد تم توضيح النتائج في شكل منحنيات وتدوينها في جداول لسهولة المقارنة . ولذا فانه يتضح من هذا البحث أهمية عمل تناسب في أبعاد المجرى وعددها على كل من العضو الثابت والدائر ، وذلك للحصول على أفضل أداء .

ABSTRACT:

The performance characteristics of a new form of a solid rotor, three-phase induction motor has been investigated. For this purpose, three differently slotted rotors were designed, and successively examined in the rotating field of a 36-stator slots. These rotors having noslot, 32-slot, and 40-slot. Comparing the performance of these rotors with and without cage winding, brought out clearly the influence of the various parameters that affect the performance of a slotted-cage induction motors. These parameters are the slot width, the slot depth, the slot numbers, and the saturation of the magnetic material.

It is noticed that the performance characteristics for a 40 slotted-cage induction motor have been improved considerably in comparison with the other two rotors. With this slotted-cage rotor the improvements are observed allover the torque/speed, and powerfactor/ speed characteristics. Thus, these investigations enable optimum design of the slotted-cage rotor for a given stator frame.

1. INTRODUCTION:

Interest has arisen for many years in the operating characteristics of the solid rotor three-phase induction motor ; notably with reference to starting and running performance. These motors show a useful reduction in the starting current, but the accompanied reduction in performance characteristics at rated voltage, owing to the inherent high resistance, is generally unacceptable [1, 2]. In addition, these motor suffer from the disadvantage of low power-factor and high slip when operating under full-load conditions. Techniques such as the fitting of copper end plates [3] or the machining of deep radial slits in the rotor surface [4] were introduced for relieving these problems, but they do not present entirely a satisfactory and practical solution.

Therefore, the authors have suggested to introduce the concept of the cage winding with either a smoothed or toothed solid iron rotors. The cage winding has been fitted into the solid iron rotor. Such configuration is denoted as a slotted-cage rotor. The analysis of this configuration from the field point of view is essentially a three-dimensional problem ; where the presence of slots alters the solid rotor magnetic properties, while the cage winding changes its electric properties. The field solution of the slotted-cage rotor configuration considering the effect of the slot depth, slot width, slot number, finite rotor length, and the nonlinearity of the material is very complicatted. Therefore, in order to bring out clearly the effects of variation in the physical dimensions of the slots and their numbers on the machine performance, three different rotors have been designed and tested. In addition, the saturation effect has been considered by recording the aimed results at three levels of supply voltage ; 70, 110, and 130 volt. Moreover, each of the three solid rotor has been equipped with a cage winding, in order to give an insight into its effect on the performance of the solid rotor induction motor.

2. THE SPECIFICATION OF THE PROPOSED ROTORS DESIGN:

The relatively high resistance of a solid iron rotor, compared with a laminated cage rotor, reduces the performance characteristics at rated voltage. The performance of a solid rotor induction motor in these respects can be improved considerably by introducing a conventional squirrel cage winding. Such slotted cage rotor may exhibit a more advantageous variation of effective impedance during running operation. The behaviour of the proposed slotted-cage rotor differs considerably as the terminal voltage varies. At reduced terminal voltage, the outer iron shell is designed to be of suitable thickness to carry the flux as the slotted-cage rotor will exhibit a solid rotor characteristics. However, at higher terminal voltages, the flux penetrates deeply into the inner surfaces and links with the squirrel-cage winding. Therefore, the cage winding comes into operation and the desired reduced resistance is achieved. Accordingly, a better performance would be exhibited by the slotted-cage rotor.

To verify these important knowledge three rotors are designed with different physical dimensions to reveal the influence of each of the slot depth, slot width, slot numbers on the machine performance. In addition, the effect of introducing the cage winding into these rotors has been illustrated. A proto-type induction motor, rated at 1.5 kw, 4-pole, 36-stator slot, 3-ph, 450 turns per phase, demonstrated the achievement of the predicted performance with each solid iron rotor. The rotors specifications are given in Table (1).

Table (1)
The Proposed Rotors Specifications

Name	Rotor No. 1	Rotor No. 2	Rotor No. 3
Rotor Diameter (D)	104	104	104
Air-gab Length	0.3	0.3	0.3
Effective Rotor Length (L)	54	54	54
Number of Spaced Slots (S)	0	32	40
Depth of Slots	0	6	6
Width of Slots	0	5	3
Width of Teeth	0	5.2	5.2
Mean Diameter of End Ring	89	68	68
End Ring Thickness	8.5 (copper)	8 (aluminium)	8
Number of Cage Bar	12	12	12
Diameter of each Bar	8	8	8

All the dimensions are in millimeters.

3. EXPERIMENTAL RESULTS AND DISCUSSION:

Experiments were conducted to measure and to predict the performance characteristics of the three solid rotors induction motor at strarting and running conditions. Load, no-load, and short-ciruit tests were carried out aimed at the measurment of the input power, and the input current and to predict the torque, and power-factor at various speeds for three levels of supply voltage. These results were given for three different rotors either equipped with cage winding arranged into the solid rotor, or with no cage winding. The results of these tests, Fig. (1), have shown to be varied considerably with a supply voltage and the type of the solid rotor configuration under test. These results have brought out clearly the influence of introducing the cage winding into the three designed rotors. The presence of the slots in the solid rotors is shown to improve the machine performance. However, the presence of the cage winding in the solid rotors is shown to have a significant influence allover the motor performance.

A comparitive study of the no-load, and short circuit test results presented for the three solid rotors were listed in Tables (2) to (4). These Tables contain and introduce the particular interesting values at starting and running light conditions for three levels of supply

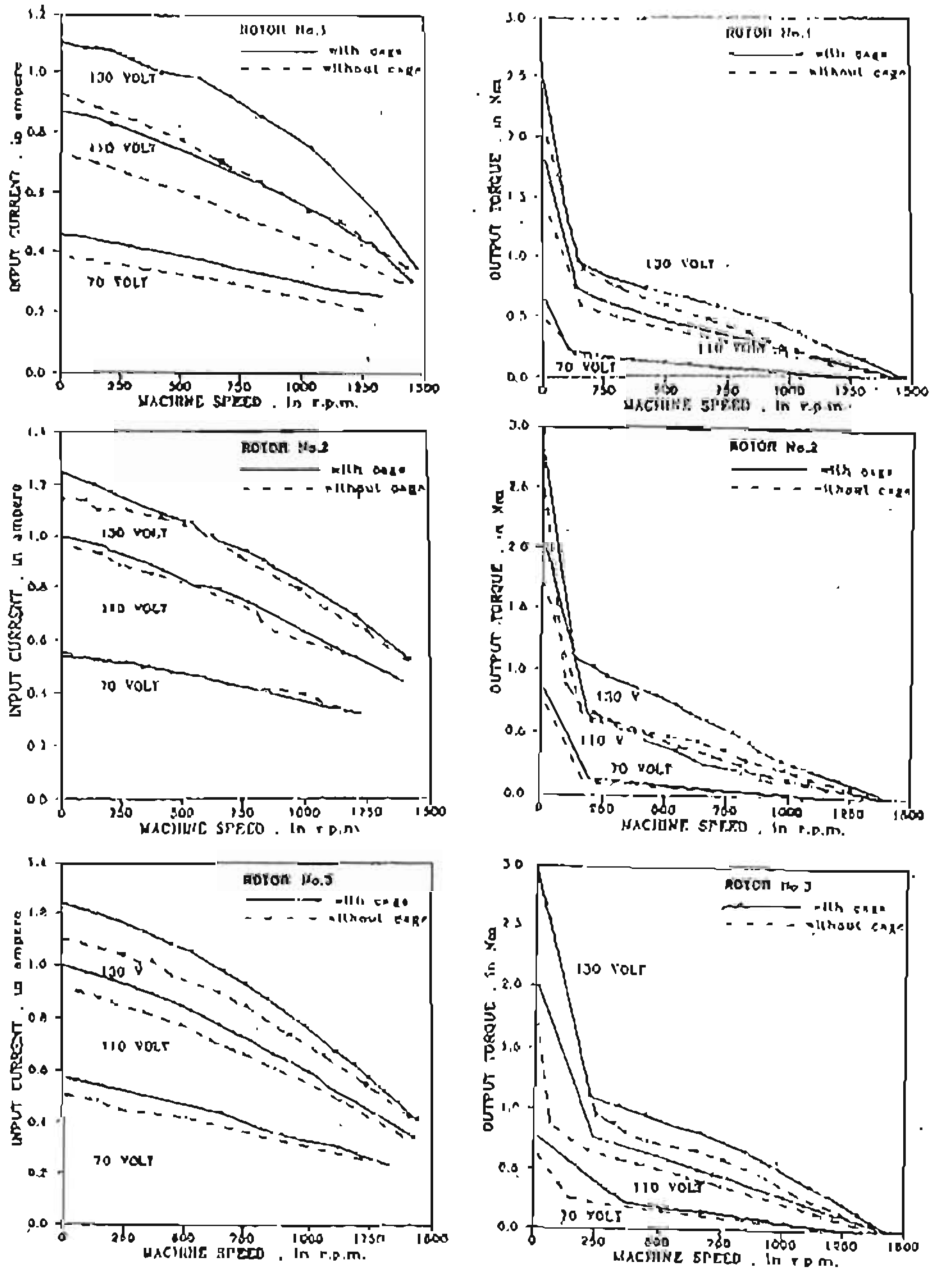

Fig. (13) The Effect of Introducing the Cage Winding on the Performance Characteristics for the Three Proposed Solid Rotors with Three Levels of Constant-Voltage Source.

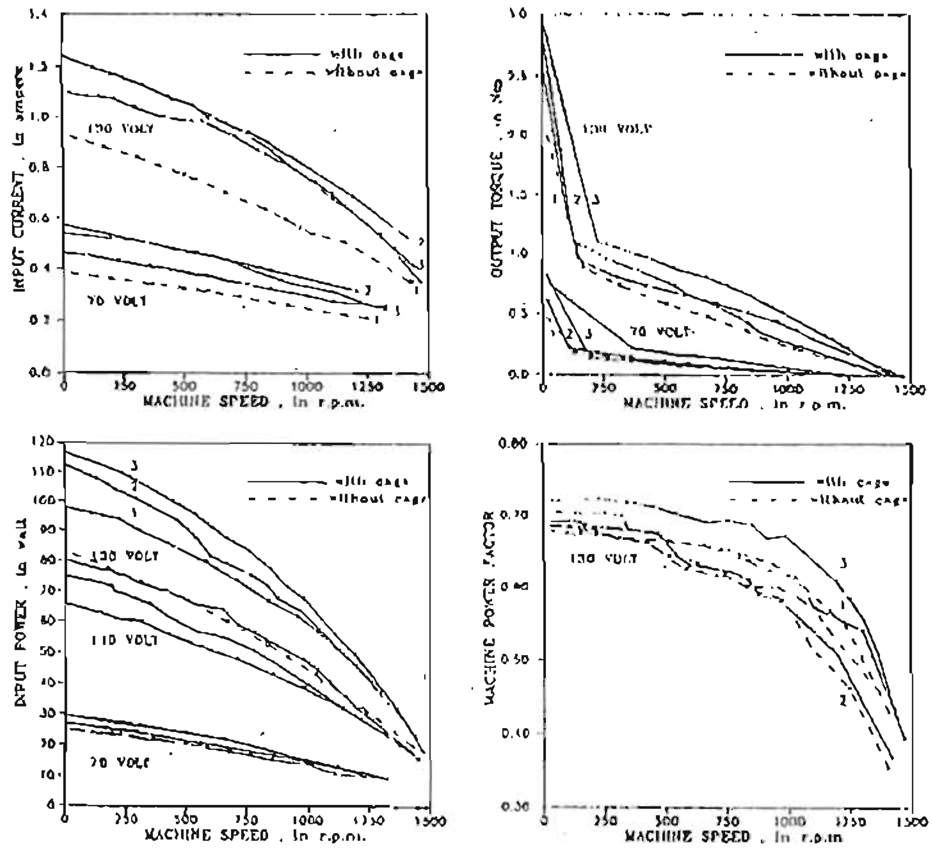

Fig. (3): The Effect of Changing the Physical Dimensions of the Slots, and their Numbers on the Performance Characteristics for Three Proposed Slotted-Cage Rotors. The Smoothed Rotor One is Provided for Comparison.

voltage ; 70, 110, and 130 volt. It is shown that, from locked rotor tests at three constant-voltage sources, introducing the axial slots in a solid rotor, increases the periphery path of the eddy current [5], thereby markedly reducing the effective resistance and reactance. Consequently, the machine will exhibit more reduction in their effective resistance and reactance, when either the smoothed or slotted rotor is equipped with cage winding. Accordingly, a high power-factor is obtained, with high voltage, especially with rotor No. 3. On the other hand, at reduced voltage, the power-factor for the unslotted rotor was high. However, it has been noticed that, with the no-load test, slotting the iron rotors implies an increases in magnetising current. Where, rotor No. 2 with wide slots dimensions, requires an increase in magnetising current in comparison with rotor No. 3, since the wide slot rotors require a definite value of magnetising force to drive the flux through the teeth due to the increasing in radial flux density. Furthermore, the presence of slotting in the rotor itself increases the effective air-gap which also requires additional magnetising ampere-turns. Tables 2 to 4 illustrate all the phenomena, which have been explained.

A compartive study of the load test results presented in Fig. (2) reveals that, the performance of the 32-slot machine was intermediate between the smoothed rotor and 40-slot one. Moreover, experimental evidence shows a variation of the power-factor with speed, this variation being large at very low slip. In addition, a significant improvement on the performance characteristics with a cage winding is revealed.

Furthermore, this investigation indicates the influence of reducing the slot width, with maintaining the teeth physical dimensions constant. Thus these investigation enables optimum design of the solid iron rotor for a given stator frame.

Table (2)
The No-load and Short-circuit Results
at Supply Voltage/ph = 70 volt.

	Rotor No. 1		Rotor No. 2		Rotor No. 3	
	without cage	with cage	without cage	with cage	without cage	with cage
Slip at no-load	0.167	0.117	0.187	0.193	0.187	0.117
N.L. current	0.210	0.255	0.320	0.317	0.263	0.240
S.C. current	0.385	0.460	0.555	0.540	0.510	0.575
N.L. power factor	0.629	0.532	0.547	0.507	0.597	0.565
S.C. power factor	0.723	0.777	0.69	0.714	0.728	0.733
Starting torque(Nm)	0.515	0.698	0.787	0.883	0.760	0.890
S.C. reactance	125.500	95.820	91.310	90.230	94.060	82.830
S.C. resistance	131.560	118.220	87.01	92.590	99.96	89.220

Table (3)
The No-load and Short-circuit Results
at Supply Voltage/ph = 110 volt.

	Rotor No. 1		Rotor No. 2		Rotor No. 3	
	without cage	with cage	without cage	with cage	without cage	with cage
Slip at no-load	0.060	0.033	0.077	0.083	0.077	0.053
N.L. current	0.300	0.505	0.440	0.450	0.352	0.350
S.C. current	0.730	0.870	0.970	1.000	0.920	1.000
N.L. power factor	0.485	0.476	0.413	0.404	0.490	0.468
S.C. power factor	0.697	0.689	0.656	0.682	0.697	0.730
Starting torque(Nm)	1.520	1.912	1.760	2.130	1.830	2.160
S.C. reactance	108.000	91.560	85.580	80.470	86.340	75.180
S.C. resistance	105.080	87.200	74.400	75.000	76.090	80.300

Table (4)
The No-load and Short-circuit Results
at Supply Voltage/ph = 130 volt.

	Rotor No. 1		Rotor No. 2		Rotor No. 3	
	without cage	with cage	without cage	with cage	without cage	with cage
Slip at no-load	0.048	0.020	0.063	0.053	0.060	0.040
N.L. current	0.352	0.350	0.520	0.525	0.430	0.417
S.C. current	0.930	1.100	1.150	1.250	1.100	1.240
N.L. power factor	0.437	0.395	0.355	0.370	0.430	0.424
S.C. power factor	0.676	0.679	0.679	0.692	0.705	0.724
Starting torque(Nm)	2.133	2.570	2.660	2.870	2.900	2.990
S.C. reactance	101.640	86.060	83.000	75.050	83.820	72.320
S.C. resistance	95.970	81.000	76.750	72.000	83.310	75.900

4. CONCLUSION:

This paper brings out the effects of varying the physical dimension of the slotted rotor, as well as the effect of including cage winding into the rotors on the machine performance ; through an experimental investigation. A comparative study of the test results leads to some interesting conclusions.

1) It is established that the provision of axial slot on the rotor has a considerable influence on the performance characteristics. Moreover, the cage winding presents a further reduction in the rotor impedance and the current/speed and torque/speed curves exhibit steeper characteristics for the same applied voltage.

2) As the rotor-tooth dimension is kept constant, the magnetising current required by a wider dimensions of the slotted rotor increases. Where the effective air-gap for such rotor is increased. Accordingly, the power-factor for this case is lower than that of the smoothed solid rotor at low slips, but improves with increasing slips. The addition of the cage winding to the rotor provides a considerable improvement in the power-factor ; especially with rotor No. 3.

3) It is noticed that, there is a further reduction in the slip with the rotors equipped with a squirrel cage winding ; especially with the smoothed rotor as the mechanical friction is very small.

4) Finally, a better performance characteristics of the solid rotor is obtained by increasing the periphery path of the eddy current. Therefore, increasing the slot depth is recommended with high number of slots. Moreover, a significant improvement on the machine performance is revealed when the cage winding comes into effect. Therefore, a compromise between the number of slots, slot width, slot depth, and the cage winding becoms essential for optimum design.

REFERENCES:

1. Finzi, L.A., Paice, D.A.: "Analysis of solid iron rotor induction motor for solid-state speed controls", IEEE Trans., PAS-87, pp. 590-596, 1968.

2. Chalmers, B.J., Herman J.: "Induction motor fan drive with unlaminated rotor and heat-pipe cooling", Proc. IEE, 124, (5), pp. 449-453, 1977.

3. Woolley, I., Chalmers, B.J.: "End effects in unlaminated-rotor induction machines", ibid, 120, (6), pp. 641-646, 1973.

4. Dorairaj, K.R., Krishnamurthy, M.R.: "Poly-phase induction machine with a slitted ferromagnetic rotor. Pt. 2-analysis", IEEE Trans., PAS-86, pp. 844-855, 1967.

5. Rajagopalan, P.K., Balaramamurty, V., Sarma, P.S.: "Tooth-flux distribution in slotted solid iron rotor", Proc. IEE, Vol. 117, No. 1, pp. 101-108, 1970.