Design, Construction, Calibration and Use of A New Type of Electromagnetic Brake

Miroslav Bjekic¹ Milos Bozic¹, Marko Rosic¹, Marko Popovic¹, Dragisa Petkovic²

Abstract – The paper presents a new type of electromagnetic brake, designed at the Laboratory of electrical machines, drives, and control at the Faculty of technical sciences in Cacak, Serbia. In laboratory testing, the brake is designed to be an adjustable load for an electric motor. Procedure of design and construction is described. Calibration of the brake and measuring apparatus are described in detail. The most important electromechanical parameters are identified. The authors describe the procedure for its use as a controlled load of induction motors up to 7.5 kW of power, in order to determine the energy efficiency class.

Keywords – *E*lectromagnetic brake, Design, Construction, Calibration.

I. INTRODUCTION

This paper presents the procedure of design, construction and calibration of new type of electromagnetic brake. The brake is made as controlled load for electrical motors up to 7.5kW.

II. DESIGN AND CONSTRUCTION

The brake has ferromagnetic disc with 8 ferromagnetic poles. Each pole has 690 winds of Cu wire (diameter of 0.95 mm). All conductors are in serial connection. Coils are powered with direct current. The direction of current should provide N-S poles cyclic. Brakes frame has two bearings, and they carry the shaft drive with disc. Between disc and poles is 0,8mm air gap. On the other side, the disc is attached to the motor shaft with footer.



Fig. 1. Parts of electromagnetic brake

Work principle: motor rotates disc. Disc is a part of magnetic circuit, also disc moves in a magnetic field. In the disc is induced emf and the current witch creates a braking torque.

¹Miroslav Bjekic, Milos Bozic, Marko Rosic, Marko Popovic are with the Faculty of Technical Sciences at University of Kragujevac, 65 Svetog Save 65, Cacak 32000, Serbia, E-mail: <u>mbjekic@gmail.com</u>

²Dragisa Petkovic is with the Masinsko-saobracajna skola, Dr Dragise Misovica, Cacak 32000, Serbia.



Fig. 2. Cross section and complete electromagnetic brake

During design, special attention was paid to the calculation of the axial electromagnetic force. This brakes construction is different from the standard brakes and it creates an unwanted axial force with which poles attract rotating disc [1]. The construction does not contain poles on both sides, and does not have two rotating discs, so the axial forces are not mutually canceled.



Fig. 3. Result of FEM simulation

For checking of construction parameters, FEM simulation was also performed. Figure 3. shows the approximate

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distribution of the magnetic field in described magnetic system. For values of excitation current of 0.7 A (maximum current in calibration procedure) the axial force of $8 \cdot 2.1 = 16.8$ kN was achieved.

III. CALIBRATION

Induction motor 2.2 kW, with voltage of 380V was first connected to the brake. Modified equipment and software to determine the energy efficiency class of three-phase induction motors [2] was used. The motor was first in regime no load. Braking current was gradually increased for different values of the terminal voltage up to 7 A. In doing so, important parameters of electric motor are measured, and from them are directly calculated electromagnetic power and torque. Motors load is gradually increased until it stops.

Figures 4 and 5 show the results of measurements. From the figure can be observed, that the value of the breakdown torque achieved with brake was more than 70 Nm. A maximum power witch is motor achieved is over 6 kW.







Fig. 5. *n*=f(*T*), *U*=50-400 V, *I*_k=0-7A

However, for the calibration of brake DC motor was used. It has possibility of easier adjustment of mechanical characteristics: with voltage changing and decreasing the excitation current. Two DC motors were selected with powers 1.5 kW and 4.4 kW.

Several measurements were performed with different values of excitation current (up to a maximum nominal value), supply voltage (20V to 120V) and brakes current value from

0.2 A to 0.7 A. The results of the measurement are shown in the graph in Figure 8.



Fig. 6. DC motor1 P=1500 kW



Fig. 7. DC motor2 P=4400 kW



Fig. 8. Results of calibration with two DC motors

Motor 2 was adjusted two times for brake testing. That was the reason why these results are specifically separated: **mot2** i **mot3**.

Presented values are with accordance with expected values. Between the measured values the curve was drown and its discrete numerical values are shown in the Table I.

TABLE I BRAKING TORQUE VALUES

	<i>M</i> _k [Nm] for <i>I</i> _p =0,2-0,7A					
$n [\min^{-1}]$	0,2	0,3	0,4	0,5	0,6	0,7
0	0	0	0	0	0	0
50	0,12	0,35	0,71	1,06	1,76	2,35
100	0,2	0,6	1,2	1,8	3	4
200	0,5	1,1	2,2	3,3	5	6,5
400	0,8	2	3,3	4,8	7	9,45
600	1,2	2,6	4	6	8,5	10,9
800	1,4	2,8	4,4	6,5	9,2	11,5
1000	1,5	3	4,6	6,8	9,6	12
1200	1,55	3,1	4,7	6,9	9,7	12,3
1400	1,6	3,15	4,8	7	9,8	12,5
1600	1,65	3,2	4,85	7,1	9,8	12,6

Shown values, hereafter, will be used to determine the analytical expression of the braking electromagnetic torque as function of braking current and speed.

IV. DETERMINATION OF THE ANALYTICAL EXPRESSION OF THE BRAKING TORQUE

Here was used the MATLAB program and its application **cftool** with interpolation function (1).

$$M_{k}(n) = A \cdot e^{(B \cdot n)} + C \cdot e^{(D \cdot n)}$$
(1)

With this interpolation function dependence $M(I_k)=f(n)$ can be presented efficiently and with few variables.

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Fit options Immediate apply Cancel Apply					
Results					
General	model Exp2:				
$f(x) = a^* exp(b^*x) + c^* exp(d^*x)$					
Coefficients (with 95% confidence bounds):					
a	a = 3.391 (-2.491, 9.273)				
b	b = -0.0002657 (-0.0007967, 0.0002654)				
c	c = -3.421 (-9.27, 2.429)				
d	. = -0.001126 (-0.002223, -2.915e-005)				



Figure 9 shows an example of calculated parameters for braking current $I_k=0,2$ A.

Coefficients A, B, C and D were obtained for six values of braking current (0,2; 0,3; 0,4; 0,5 i 0,6 A).

Thereafter was made a new interpolation of interpolating coefficients with cubic polynomial (2):

$$y = p_1 \cdot I_k^3 + p_2 \cdot I_k^2 + p_3 \cdot I_k + p_4$$
(2)

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5th degree p	5th degree polynomial					
6th degree p	olynomial 👻					
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Linear m	odel Poly3:					
f(x	$f(x) = p1*x^3 + p2*x^2 + p3*x + p4$					
Coeffici	ents (with 95% confidence bounds):					
p	1 = -91.57 (-220.7, 37.6)					
p	2 = 148.4 (-26.81, 323.6)					
p	3 = -55.52 (-129.1, 18.09)					
p	4 = 9.36 (-0.03165, 18.75)					
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Fig. 10. Calculated coefficients of interpolation polynomial for determination of coefficient A

All results are presented in matrix form, suitable for programming:

$$\begin{bmatrix} A_1 & B_1 & C_1 & D_1 \\ A_2 & B_2 & C_2 & D_2 \\ A_3 & B_3 & C_3 & D_3 \\ A_4 & B_4 & C_4 & D_4 \end{bmatrix} = \begin{bmatrix} 91,57 & 0,0093 & 86,41 & 0,0452 \\ 148,40 & -0,1440 & -141,20 & 0,0672 \\ -55,52 & 0,0074 & 52,78 & -0,0358 \\ 9,36 & -0,0012 & -9,09 & 0,0037 \end{bmatrix}$$
(3)

$$A = A_1 \cdot I_k^3 + A_2 \cdot I_k^2 + A_3 \cdot I_k + A_4$$
(4)

$$B = B_1 \cdot I_k^3 + B_2 \cdot I_k^2 + B_3 \cdot I_k + B_4$$
(5)

$$C = C_1 \cdot I_k^3 + C_2 \cdot I_k^2 + C_3 \cdot I_k + C_4$$
(6)

$$D = D_1 \cdot I_k^3 + D_2 \cdot I_k^2 + D_3 \cdot I_k + D_4$$
(7)

The obtained results are shown in Figure 11. The figure shows set of analytical functions of electromagnetic braking torque as function of speed n and braking current I_k . Speed and braking current at some point define the braking electromagnetic torque at that point.

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Fig. 11. Set of analytical functions that describes electromagnetic torque for speed range of 0-1600 min⁻¹ and braking currents from 0.2 A to 0.7A

V. FUTURE STEPS

With described procedure it is possible to calculate the braking torque using the derived analytical expressions.

This means that the motor load (torque) can be determined, at any moment, if current values of only two parameters are known: speed of rotation and braking current.

The aim of further research can be introduced in this way: First, predefine motor load type: gravitational (constant load), fan or some other (variable load). Then, using feedback and new derived expression of required torque, braking current will be calculated considering the speed. By applying this current to the brake, motor will get the appropriate load.

VI. CONCLUSION

This paper describes the process of design, construction and calibration of electromagnetic brake. The analytical expression of braking torque was derived, considering speed of rotation and braking current.

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