SWITCHED RELUCTANCE MOTOR OPTIMAL GEOMETRY DESIGN

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Abstract: *This paper deals with the Switched Reluctance Motor (SRM) analysis using Finite Element Method (FEM) for geometrical optimization in terms of volume ratio of torque on the rotor, the so-called specific torque. The optimization parameter is the pair: stator and rotor pole angles, which forms a crucial part of the design process.*

1. INTRODUCTION

In the world market for electrical drives applications some domains, such as electric traction motor, pumps and compressors at high speeds, robots and numerically controlled machine tools, aeronautics and space technical, computer peripherals, etc., became clearly dominated by the stepper motor - electronic converter assembly, known as SRM.

These led, unsurprisingly, to a huge interest from researchers, in obtaining a more efficient motor and electronic converter and in development of design methods less influenced by simplified assumptions with a high generality.

2. SRM PRELIMINARY DESIGN

SRM design should be initiated with a first step, so-called pre sizing, which provides an initial set of geometric data.

Obtaining the diameter and length of stepper motor is considered in several works [1], [2], [3] stems from the recommendations, in accordance with ISO, of the International Electrotechnical Commission (IEC), by assimilation with asynchronous machine. The preliminary selection of frame size goes automatically at the outer diameter of the stator. The outer diameter of the stator is fixed in millimeters:

$$D_e = (framesize - 3) \cdot 2\,, \tag{1}$$

The rotor diameter is initially considered as the frame size, the feed-backs from design procedure leading to required changes.

Once established these key dimensions it'll proceed to calculate the stator, β_S and the rotor, β_R, pole arcs both expressed in radians, which is recommended to satisfy the following relationships [2], [3], providing a maximum torque without engine to remain locked or to lose steps:

$$\beta_S \le \beta_R\,, \tag{2}$$

$$\beta_S > \theta_p\,, \tag{3}$$

$$\beta_S + \beta_R < \frac{2\pi}{Z_R}\,, \tag{4}$$

The three relations describe a triangle so the SRM will function optimally only if the stator and rotor pole angles will be found in this triangle. Fig.1. shows feasible triangle for a 8/6 machine. The region below OE represents condition 1, the region above GH represents condition 2 and the region below DF represents condition 3. For example, if $\beta_S = 20^0$ then $20^0 < \beta_R < 40^0$.

Identification of optimal values for arcs involves calculating the maximum torque for different combinations, as long as relations (2) - (4) only set some restrictions. Since determining the maximum torque is subject to there overall package size of the resulting motor, this step is one that sends to the initial phase of design for each new tested value of the arc.

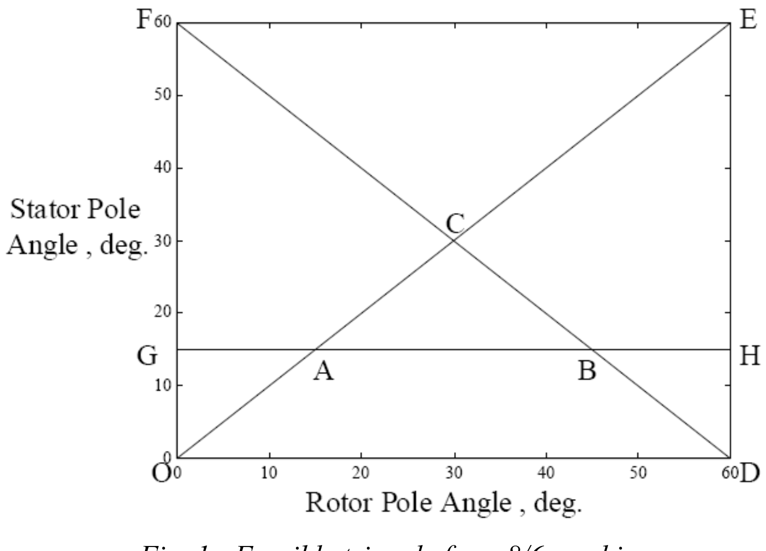

Fig. 1 - Feasible triangle for a 8/6 machine

Determination of machine torque can be done analytically from a number of simplifying assumptions and magnetic equivalent circuit models.

FEM remains the best analysis tool. The easy way to accomplish the non linearity and the complicated structure of the materials, great accuracy of the simulation, reduced costs, speed of analysis permit to take into account a lot of models and choose the best fitting of a desired imputed condition.

Will be considered a SRM prototype 8/6 which has the following characteristics:

Power output: $P_{kw} = 3728$ [W]

Speed: $N = 1500$ [$rot/\min$]

Peak current: $i_p = 13$ [A]

Input AC voltage $V_{ac} = 480$ [V]

The torque to be developed by the machine is:

$$T = \frac{P_{kw}}{2\pi\left(\frac{N}{60}\right)} = \frac{3728}{2\pi\left(\frac{1500}{60}\right)} = 23.7459\ [N \cdot m], \tag{5}$$

The machine will be designed with an IEC frame size of 100. The outer diameter of the stator is fixed as follows:

$$D_0 = (gabarit - 3) \cdot 2 = (100 - 3) \cdot 2 = 194\ [\text{mm}] \tag{6}$$

The maximum stack length for frame 100 is restricted to 200 mm: $L = 200$ [mm]

For a machine of this frame size, a practical air-gap length can be assumed to be: $\delta = 0.5$ [mm]

The bore diameter D equal to the frame size is selected: D=100 [mm].

The remaining sizes are determined based on relatively simple relations and are not elements of variability within the meaning of optimization in this paper.

So the only undetermined sizes are stator and rotor pole arcs. Using Fig.1, and considering only the integer values of the angles resulted from triangle ABC, a total of 496 possible combinations become valid. Removing the combinations when $\beta_s = \beta_r$ and all combinations over $\beta_r - \beta_s > 5°$, because it follows a very high torque oscillation it remain to be analyzed 80 possible combinations of rotor polar arc and polar arc stator, Fig. 2.

Arcul polar rotoric [°]

Arcul polar statoric [°]	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
15	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
16	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
17	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
18	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
19	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
20	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
21	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
22	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
23	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
24	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
25	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
26	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
27	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
28	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
29	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
30	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Fig. 2 - Combinations analyzed

3. SRM OPTIMIZATION

All 80 combinations of stator and rotor arc are carried out by FEM analysis using Infolytica Magnet V 7 [5].

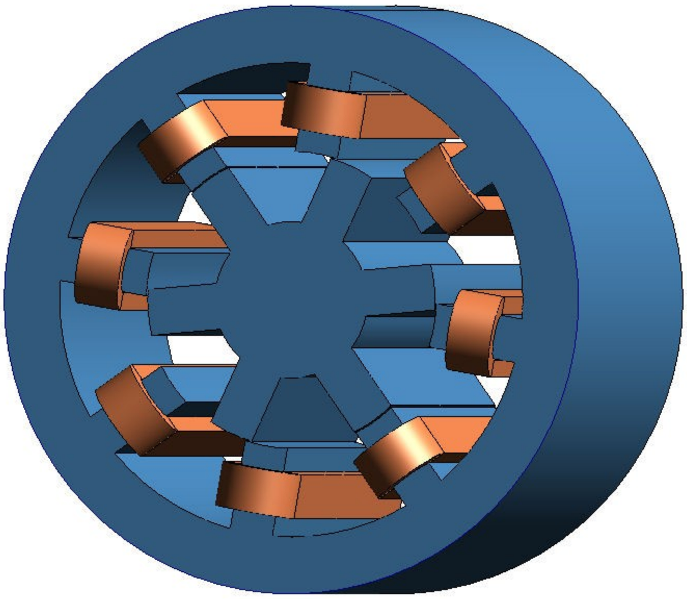

Fig. 3 – Optimized SRM

For example the geometry, final mesh and the magnetic field spectrum are presented for two combinations:

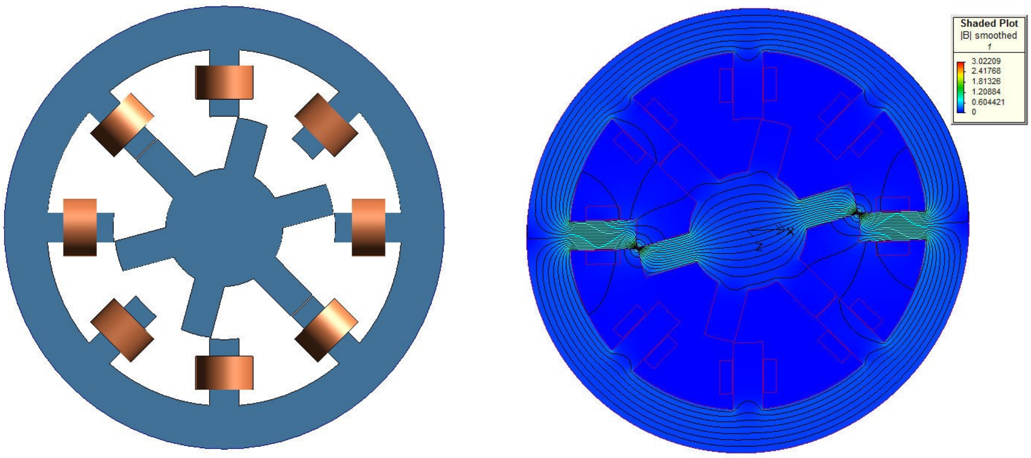

Fig. 4 – SRM with $\beta_s = 15^0$, $\beta_r = 16^0$. Resulted maximum torque of 22.37719369403 [Nm].

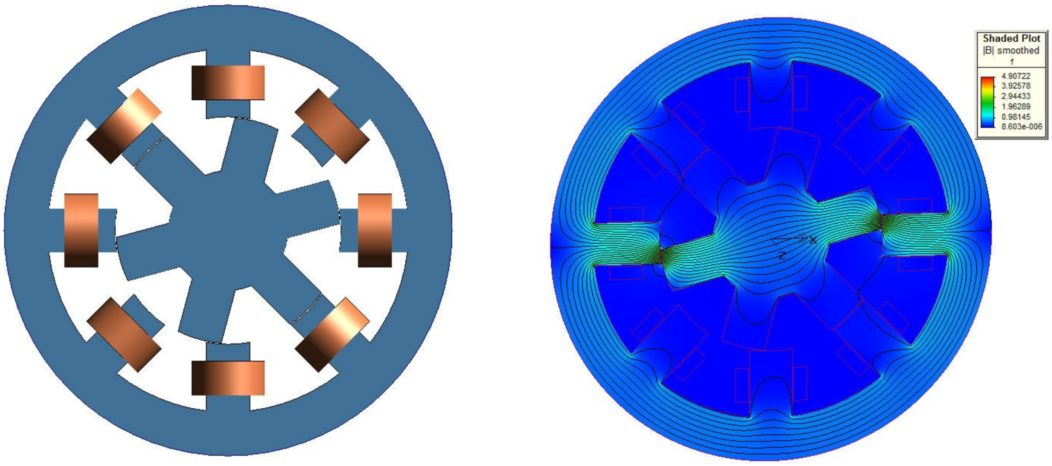

Fig. 5 – SRM with $\beta_s = 22^0$, $\beta_r = 23^0$. Resulted maximum torque of 22.96590710053 [Nm].

Below are presented, in graphical form, the values of maximum torque for the 80 analyzed combinations of arcs stator – rotor:

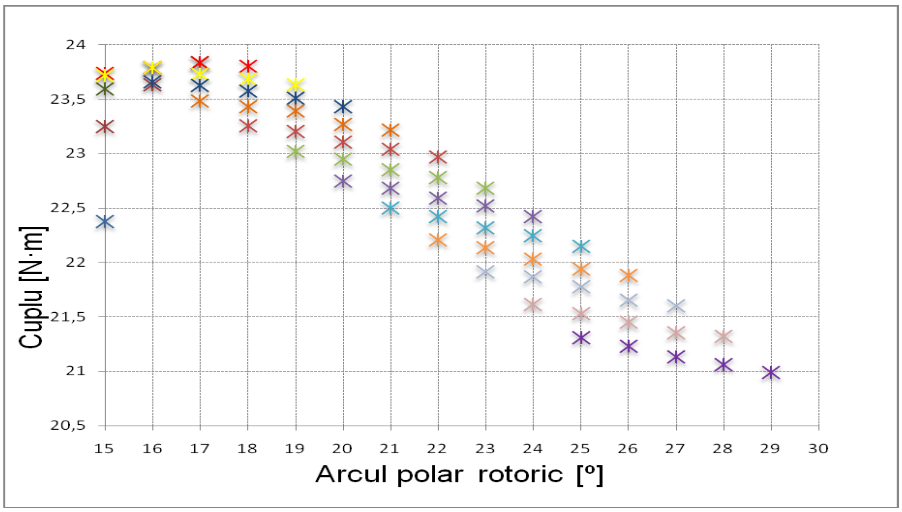

Fig.6. Maximum SRM torque

Choosing the optimal configuration implies to find the maximum of torque function, summarized below:

Table 1.

β_S[º]	β_R[º]				
	17	18	19	20	21
16	23.63229790367	23.79089221673	23.786169113	23.78645798388	23.65620882183
17	x	23.83713248871	23.837004845	23.729893902	23.62874549198
18	x	x	23.80226305215	23.68337550118	23.57710280044

Considering that the optimization process is done in terms of maximum torque, the optimum model produces a 23.83713248871 [Nm] torque for the stator pole arc, $\beta_S = 17^0$ and the rotor pole arc, $\beta_R = 18^0$.

Optimized model must be examined in detail to validate the results.

For these the maximum torque values, fig.5, respectively linkage magnetic flux values, fig. 6, for different rotor positions must be determined.

Using the same FEM software, Magnet, V. 7, these computations are realized in the post processing stage of analysis.

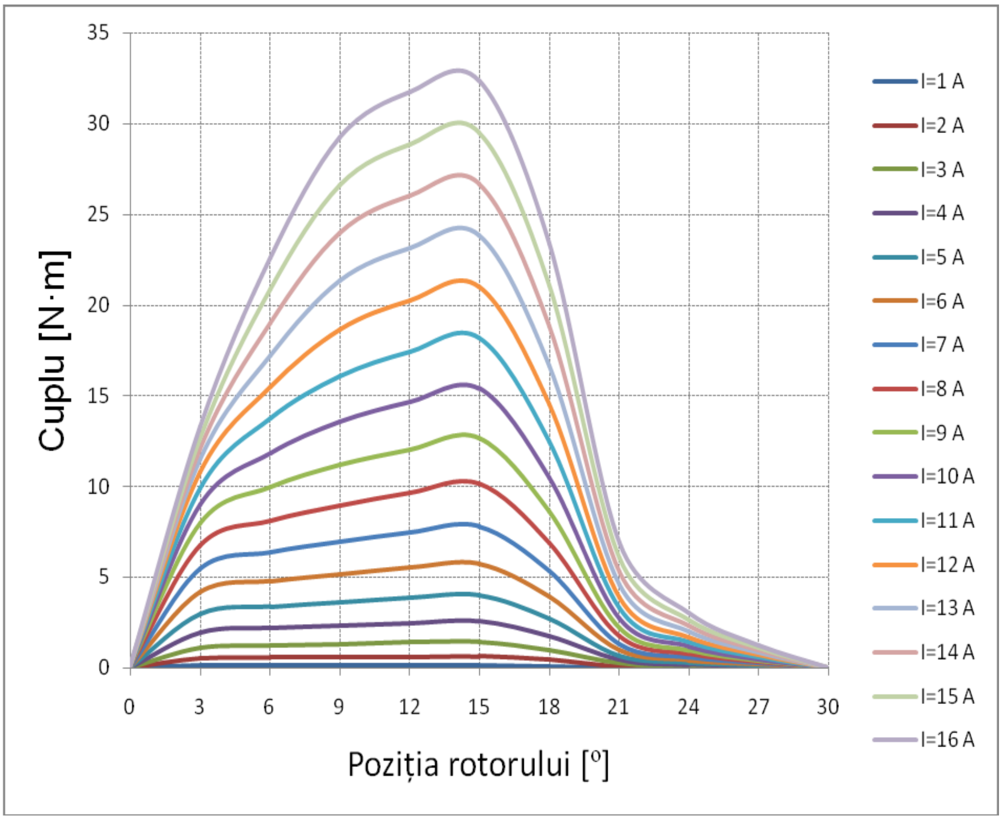

Fig.7. Maximum torque depending on rotor position

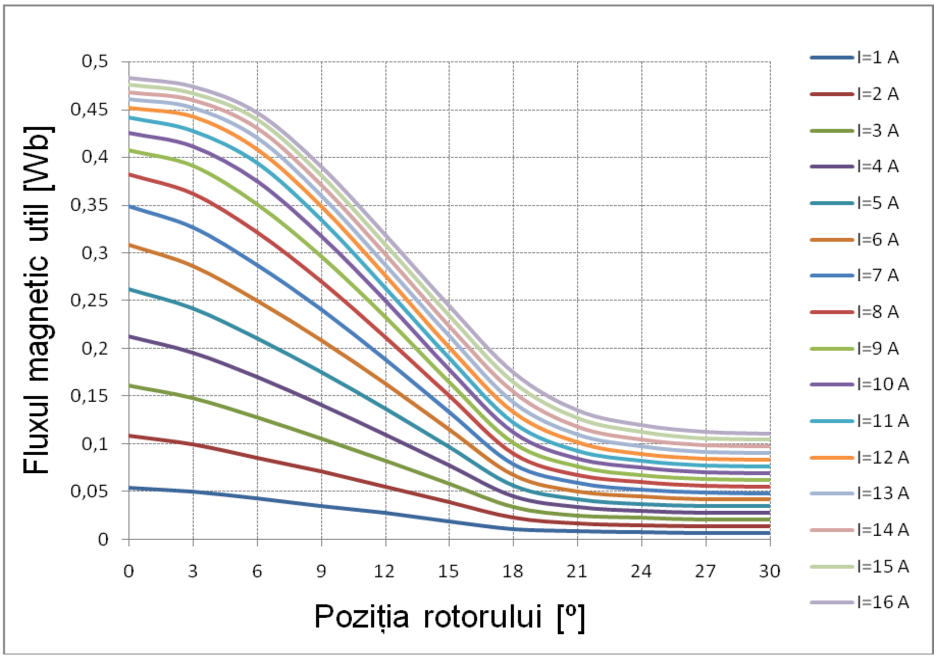

Fig.8. Linkage magnetic flux depending on rotor position

4. CONCLUSIONS

It was presented a FEM based design methodology to obtain an optimum combination of stator and rotor pole angles for a 8/6 SRM in terms of maximum torque for one phase fed at a time.

This start with classical pre sizing of the machine for establishing basic geometry of a basic SRM model. Based on "feasible triangle" and other restrictions the basic SRM will generate a number of available configurations.

FEM analysis of these models and maximum torque computation will identifies the optimum model of the SRM.

Of course a complete analysis of the resulted optimum SRM must be done to certify the choice.

REFERENCES

1. Praveen V, *Design of Switched Reluctance Motor and Development of a Universal Controller for Switched Reluctance and Permanent Magnet Brushless DC Motor Driver,* Ph.D. Dissertation, Blacksburg-Virginia, 2001.

2. Krishanan R, *Switched Reluctance Motor Drives: Modeling,. Simulation, Analysis, Design, and Applications*,CRC Press, 2001.

3. Miller, TJE, S*witched Reluctance Motors and their Control*, Magna Physics Publishing and Clarendon Press, Oxford, 1993.

4. Torkaman, H. Afjei E, *Comprehensive study of 2-D and 3-D finite element analysis of a switched reluctance motor***.** J. Applied Sci**.,** 8: 2758-2763, 2008.

5. Magnet CAD Package, *User Manual*. Infolytica Corporation Ltd., Montreal, Canada, 2007**.**

6. Faiz J, Ganji B, De Doncker R. W, Fiedler J.O, *Electromagnetic Modeling of Switched ReluctanceMotor Using Finite Element Method***,** IEEE Industrial Electronics, IECON 2006.

7. Lee J. W, Kim H. K, Kwon B. I, Kim B. T, *New Rotor Shape Design for Minimum Torque Ripple of SRM Using FEM,* IEEE Transactions on Magnetics, Vol. 40, No. 2, March 2004.