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STATOR POLE ARRANGEMENT OF THE PERMANENT MAGNET STEPPER MOTOR WITH ASYMMETRIC STATOR FOR ACHIEVING THE UNIFORM STEP

Abstract: A special type of a two-phase permanent magnet stepper motor with asymmetric stator was constructed for the specific purpose. The structural design was based on a modified geometry of standard stator and a functional motor prototype was built. The measurement of the step uniformity reveals irregular step size for half-stepping driver. This paper presents the approach to find proper stator pole dimensions to achieve uniform step in half-stepping regime of permanent magnet stepper motor. The simulation of a magnetic circuit was used. The measurement on the prototype and the simulation of the motor angle for different stator arrangement are presented.

Keywords: *stepper motor construction, asymmetric stator, magnetic circuit simulation, Finite Element Method, step angle*

1. Introduction

There are many different constructions of electric motors, which serve various purposes. High volume manufactured standard motors do not fulfil all requirements sometimes. Therefore, the standard construction of rotary motors is modified and new types of motors for pumps, fans, home appliance, washing machines, etc. are designed. One of the design criteria is a mechanical dimensions restriction. Bogusz, Korkosz, and Prokop in [1] build motor where asymmetric stator geometry was dictated by economic considerations, i.e. the need to fit external dimensions of the motor to the drive of already existing food processor. FEM (Finite Element Method) software is successfully used for the design and optimisation of the permanent magnet motors. Both magnetic field ([2]-[6]) and heat distribution [7] can be modelled.

2. Stepper motor construction

Special requirements lead to the creation of stepper motor with an asymmetric stator. The footprint of entire motor must not be more than the side view of the rotor disc, which should be visible. Therefore, the construction with external asymmetric stator similar to a linear motor was chosen (Fig. 1). The prototype was built to prove the motor functionality. Fig. 2 shows the prototype of the bipolar two-phase stepper motor with permanent magnets. The diameter of the rotor disc is 16 mm and it contains ten ferrite magnets. The footprint of the motor allows stacking and more motors can create a counter shown in Fig. 3. This type of device is embedded into flight instrument of a flight simulator and is controlled by computer.

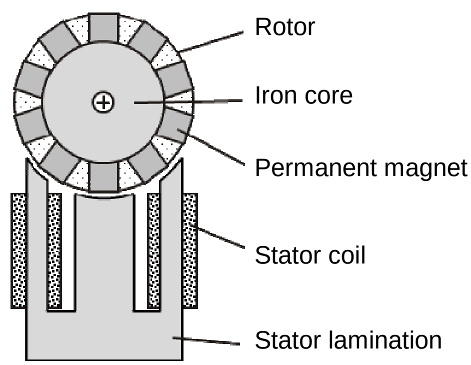

Fig. 1. Construction of stepper motor

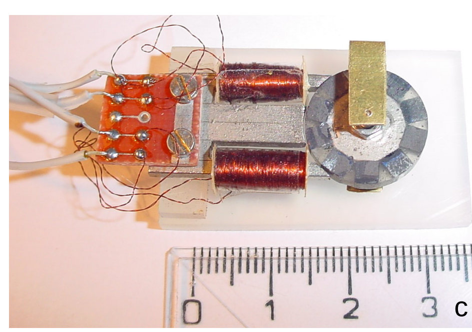

Fig. 2. Prototype of stepper motor

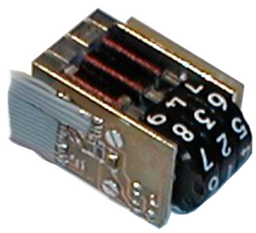

Fig. 3. Counter with three stepper motors

3. Step angle measurement on prototype

Designed motor is driven by a standard driver for bipolar two-phase stepper motors. Full step drive, half stepping, and microstepping are possible.

Functional testing reveals the irregular step size in half stepping case. Therefore some measurements of the step angle were carried out on the motor. Fig. 4 shows the measurement of rotor angle in static positions with zero torque. There are eight positions in half stepping excitation modes indexed from 0. Even indexes (0, 2, 4, 6) corresponds to the full step mode. Measurements were made for two different rotor positions respect to the stator.

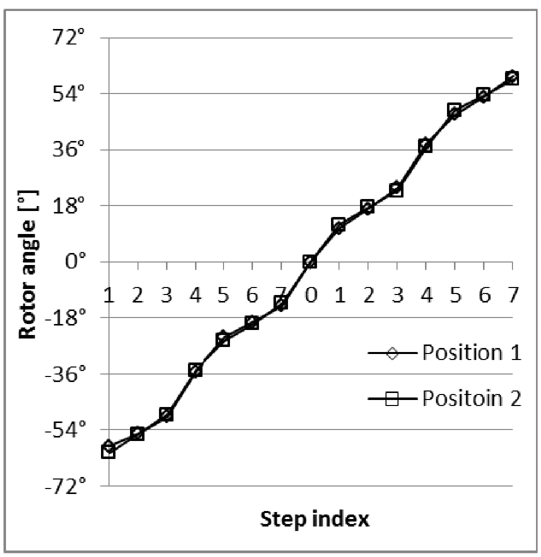

Fig. 4. Static positions of rotor for different step index (motor prototype measurement)

Fig. 4 shows irregular angle for even and odd steps for bought initial rotor positions. Fig. 5 shows relative angle error from calculated step angle (9° for half step, 18° for full step). The error is different for different positions due to not precisely manufactured prototype dimensions and the magnets strength. However, the significant difference can be seen between even and odd step indexes. It means that excited windings create asymmetric forces.

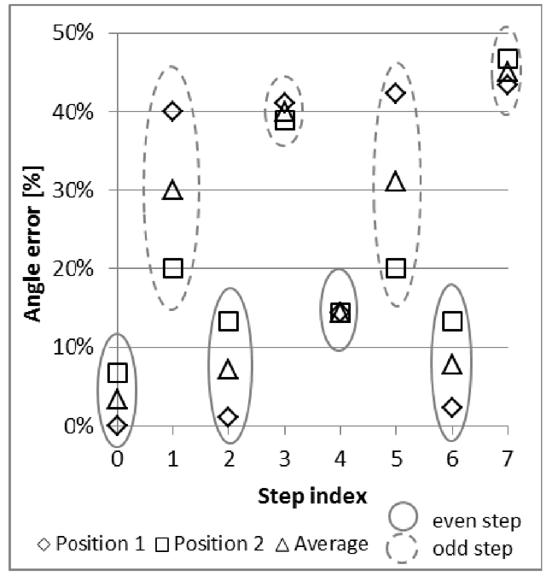

Fig. 5. Angle error of the rotor position for even and odd step index

4. Motor models

Several models of the stepper motor were made to analyse possibility to balance the step size. Fig. 6 shows vector of magnetic flux density in the 3D model. The ANSYS MAXWELL 16 software transient solution was used. The model is parametric and Optimetrics module is used to calculate magnetic flux and motor torque for different motor dimensions. Construction material has nonlinear properties.

The calculations of step angles of the model agree with the prototype measurement, what is illustrated in Fig. 7. Thus, the model is valid and can be used to study the influence of construction changes on the step irregularity.

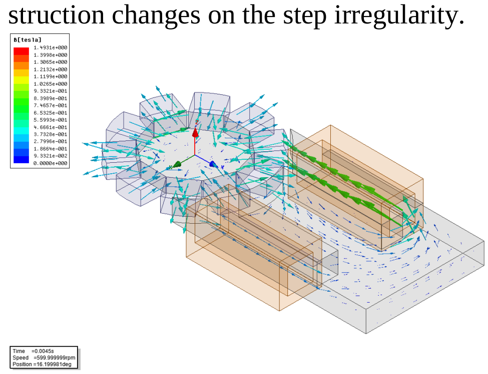

Fig. 6. Magnetic flux density vector in 3D model of stepper motor (current in one coil)

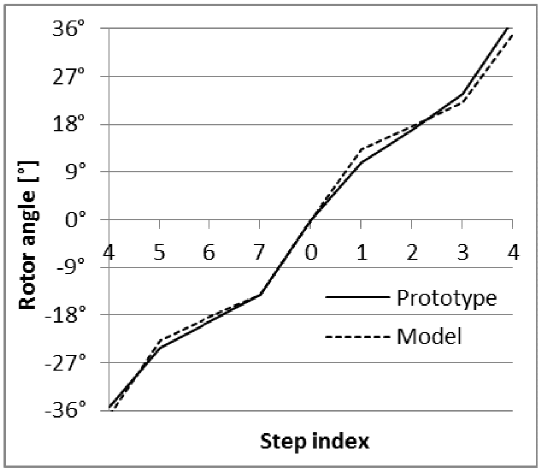

Fig. 7. Comparison of static positions of rotor for different step index for prototype and model

The estimated precision of the calculated rotor angles is less than 0.5° due to simulation grid of finite element method.

Fig. 8 shows cogging torque if there is zero current in coils, Fig. 9 shows static torque for one energised coil and Fig. 10 for two energised coils.

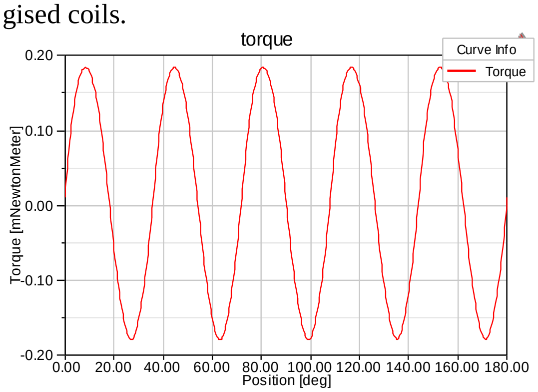

Fig. 8. Cogging torque, no current in coils

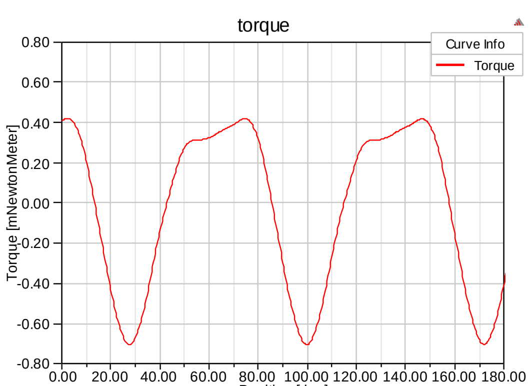

Fig. 9. Static torque, current in one coil

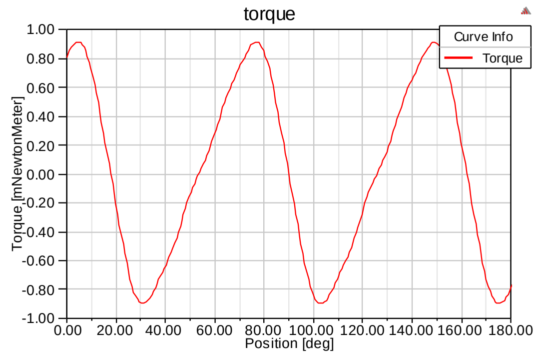

Fig. 10. Static torque, current in bought coils

5. Construction modification

Fig. 11 shows the stator dimensions *d1*, *d2*, and *d3* which were considered for change. The dimension *d1* was set to original value 14 mm after some preliminary dimensions changing experiments and combination of *d2* and *d3* was investigated only.

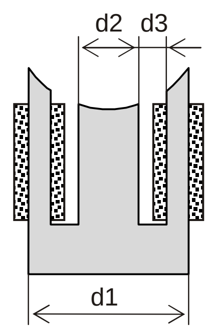

Fig. 11. Dimensions considered for modification

The dimensions change influences only half step. Full step angle (0°, 18°, 28°,…) is not changed due to symmetric stator shape. Fig. 12 shows region, where the deviation from 9° half step is minimal. The dimension step was 0.1 mm. It can be seen that the correct half step angle can be obtained with many different combination of parameters *d2* and *d3*. For that reason further criteria must be introduced to select the right combination. The maximum torque and the iron volume were chosen as criterion. Results for several dimension combination with smallest half step deviation are listed in Tab. 1. Simulation results have finite precision because of finite element method and the dimensions step 0.1 mm. Therefore, results are indicative. Identifying the precise dimensions requires more calculations for lower dimension step.

The combination of values 4.3 mm and 2.35 mm has maximum torque and combination 4.1 mm and 2.65 mm has minimum iron volume. These combinations seem to be suitable for further investigation.

Despite of limited simulation precision, it is clear, that dimension *d2* should be reduced from original value 5.2 mm to 4.3 (4.1) mm to achieve 9° half step.

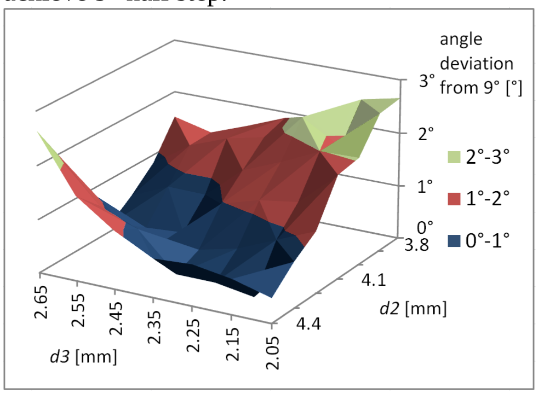

Fig. 12. Angle deviation from half step 9° for different combination of d2 and d3

Tab.1 Four best dimension combinations

d1 [mm]	d2 [mm]	d3 [mm]	Half step [°]	Deviation from 9° [°]	Max torque [10^{-3}Nm]	Iron volume [$10^{-7}m^3$]
14	4.3	2.15	8.95	0.05	513.4	5.764
14	4.1	2.65	9.13	0.13	497.0	5.453
14	4.3	2.35	9.17	0.17	548.1	5.638
14	4.3	2.25	8.83	0.17	524.1	5.701
Original dimensions						
14	5.2	2.45	14.0	5.0	702.8	5.547

Fig. 13 shows a magnitude of magnetic flux density in original (5.2, 2.25 mm) and new design (4.3, 2.35 mm).

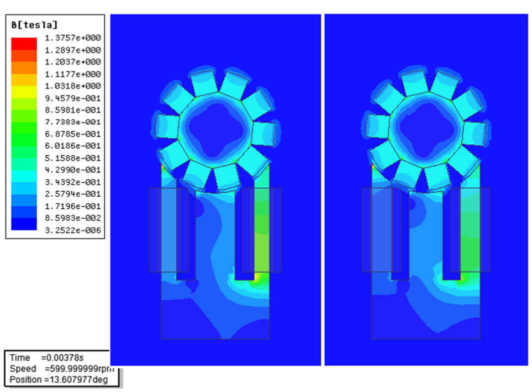

Fig. 13. Magnitude of magnetic flux density in original (left) and new (right) design

6. Conclusion

This paper describes searching for best stator pole arrangement of the two-phase permanent magnet stepper motor with an asymmetric stator. Original functional prototype does not have uniform step in half step mode. Therefore, the computer model of the motor was built and verified so different dimension combinations could be investigated. Simulation results show that a regular step size can be achieved by many different dimension combinations. Hence maximum torque and minimum iron volume were chosen as additional criteria. The reduction of *d2* dimension was suggested as a result of presented procedure. Offered technique can be used for further motor dimension and weight reduction.

7. References

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