Appendix F

Reference Papers

Library of Congress Catalog Card No. 73-647018
ISBN 0-931538-03-3
ISSN 0092-1661

Published by the Incremental Motion Control Systems Society
Post Office Box 2772, Station A, Champaign, Illinois 61820

A DISK-ROTOR PERMANENT-MAGNET STEP MOTOR

B. C. Kuo
Department of Electrical Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois

W. H. Yeadon
Warner Electric Brake and Clutch Co.
Marengo, Illinois

I. INTRODUCTION

The canned-type permanent-magnet (PM) step motors [1] have gained increased popularity commercially in recent years mainly due to their low cost, simplicity in construction, and light weight.

As the name implies, the housing of the canned-type PM step motor is a metal can. The stator teeth assemblies are punched out of metal sheets, and the stator windings are in the form of bobbin-wound coils. The rotor consists of a cylindrical piece of magnetic material which is magnetized with multiple numbers of poles with alternate polarities along the periphery of the rotor. Figure 1 shows the simplified cross-sectional views of the motor which has two stator sections. The teeth of one stator section are displaced from those of the other by one-half of a tooth pitch.

The stator coils are usually wound bifilar so that the motor can be driven by a unipolar driver as a four-phase motor, or, the bifilar windings can be so connected that the motor can be driven as a two-phase motor by a bipolar driver. Additional sections and phases can be added lengthwise to the motor to increase the torque output.

As shown in Figure 1, when one phase of the motor is energized, the magnetic flux is essentially confined to flow only within that section of the motor. Therefore, each section of the motor is essentially isolated from the other section(s) from a magnetic sense.

The purpose of this paper is to introduce a step motor that has a disk-shaped permanent-magnet rotor. The geometry, construction, principle of operation, and typical performance characteristics of the motor are presented. The analysis and computation of the magnetic circuits of the motor are given in another paper in these Proceedings.

The advantages of the disk-rotor PM motor are:

1. The motor diameter can be made smaller than a conventional cylindrical-rotor motor having similar performance characteristics.
2. Since the poles on the rotor are magnetized in the axial direction, oriented magnetic materials such as ceramic 5 or 8 may be used instead of the non-oriented materials such as ceramic 1, commonly used on cylindrical rotors with radial air gaps. The oriented material has a greater flux density which produces more torque per ampere of input current than a non-oriented material. As a result, the damping characteristics and the motor efficiency are improved.

II. CONSTRUCTION OF THE DISK-ROTOR MOTOR

Figure 2 shows the major components of the motor with four phases and a step resolution of 7.5 degrees (48 steps/revolution). As shown in Figure 2, the major components of the motor are:

a permanent-magnet rotor
two inner-pole assemblies
two outer-pole assemblies
two bobbin-wound coils
housing.

The two sets of inner-and outer-pole assemblies are positioned on opposite sides of the disk rotor. For the 48-step-per-revolution motor illustrated, the rotor is magnetized axially with 24 alternate North-South poles. There are 12 teeth on each of the inner- and outer-pole pieces. The tooth pitch of the inner-pole piece and the outer-pole piece is twice that of the rotor assembly. The relative positions of the inner-pole and the outer-pole assemblies on opposite sides of the rotor are offset by one-half of a tooth pitch. Figure 3 shows the relative positions between the rotor poles and the stator teeth of the two stacks. The two bobbin wound coils can each be wound with a single winding for bipolar driving, or with bifilar windings for unipolar driving.

As shown in Fig. 3, when the teeth of stack No. 1 of the stator are in alignment with the rotor poles, those of Stack No. 2 are in total misalignment. Thus, as the phase energization is switched from Stack 2 to Stack 1, the rotor will rotate one-half of a pole pitch of the rotor. The step angle of the motor is then given by

$$\theta_s = \frac{360}{2N_p} \text{ degrees} \tag{1}$$

where N_p is the number of poles on one side of the PM rotor. For the case illustrated in Figure 1, there are 24 poles on the rotor, and θ_s is 7.5 deg/step, or the step resolution is 48 steps per revolution. N_p is also equal to the total number of teeth on the inner-pole piece and the outer-pole piece on one stack of the stator.

Figure 4 shows two simplified cross-sectional views of the disk-rotor motor for the purpose of illustrating the main flux paths. The main flux-carrying ports of the motor include the PM rotor, the inner poles, the outer poles, the hub, and the housing. The spacer, which is located at the center of the motor, is non-magnetic and divides the motor into two sections magnetically. The main flux path of the motor is described as shown in Figure 4. If we start at the surface of a North pole on stack No. 1 of the PM rotor, as shown in Figure 4, the magnetic flux will typically go through the following parts of the motor in succession:

1. North pole on the left side of the PM rotor
2. Main air gap
3. Inner pole
4. Hub
5. Air gap between hub and housing
6. Housing
7. Air gap between housing and outer pole
8. Outer pole
9. Main air gap
10. South pole on the left side of the PM rotor, adjacent to the starting North pole.

The flux then traverses the depth of the rotor and exists at the North pole on the right side of the rotor, and then the same sequence as described above takes place in stack No. 2.

From Figure 4, we can see that one important difference between this disk-rotor motor and the conventional canned-type PM motor is that the flux paths of the former encompass the entire motor even when only one phase is excited, whereas the flux paths of the latter motor are confined to only the excited phase.

The coupling of both stacks of the motor by the magnetic flux also means that the torque developed by the motor will be affected by the stator teeth on both sides of the rotor.

III. PERFORMANCE CHARACTERISTICS

The performance characteristics of a typical disk-rotor PM step motor are presented in this section. The physical dimensions of the motor are: length = 2 in., outer diameter = 2.5 in.

The electrical properties and characteristics are:

Number of phases:	4	(bifilar wound)
Winding resistance:	1.6	ohms per phase
Rated current:	1.75	Amp. per phase
Inductance:	11	mH (0 Amp. DC at detent position)

The single-step responses with one-phase-on and two-phase-on excitations are shown in Figures 5 and 6, respectively.

Figures 7 and 8 illustrate the static torque curves with one-phase-on and two-phase-on excitations measured under the stated conditions. Figure 9 gives the torque-speed curves of the motor.

IV. REFERENCES

[1] Heine, Guenther, 'Small PM Stepping Motors as Dedicated Control Elements in Data Processing Technology," Proceedings of the Seventh Annual Symposium on Incremental Motion Control Systems and Devices, 1978, pp. 27-36.

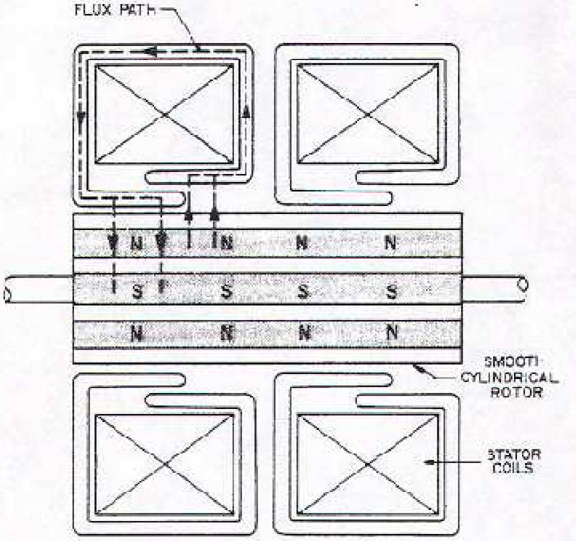

Figure 1. Cross-sectional view of the canned-type PM step motor.

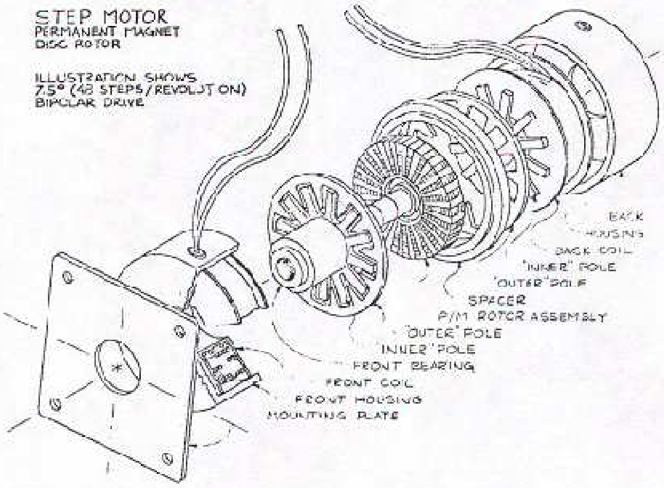

Figure 2. Principal components of the disk rotor motor.

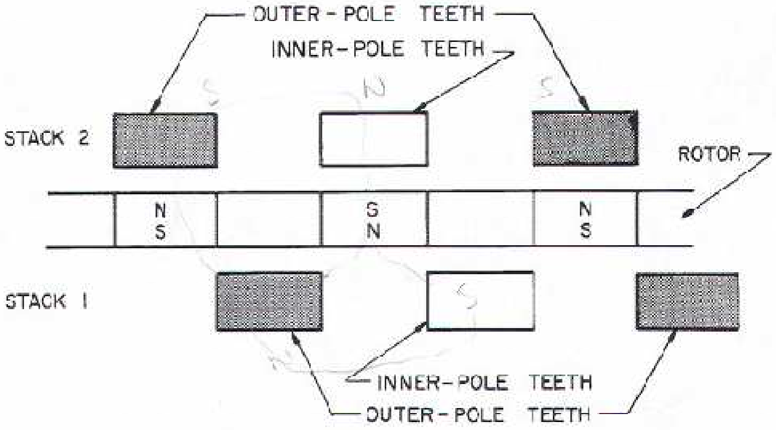

Figure 3. Inner-pole, outer-pole, and rotor relation.

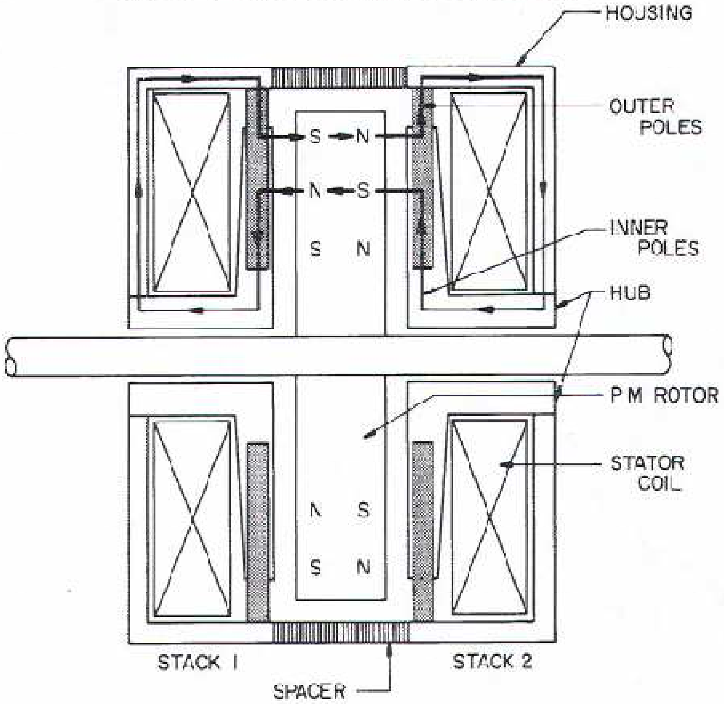

Figure 4. Cross-sectional view of the disk-rotor motor.

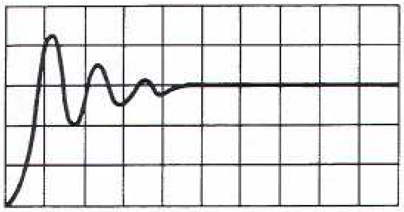

Figure 5. Single-step response.
One-phase-on excitation.
Horizontal: 10 msec/div.
Vertical: 1.25 deg/div.
30 Volts at 1.75 Amps.
8-ohm suppression.

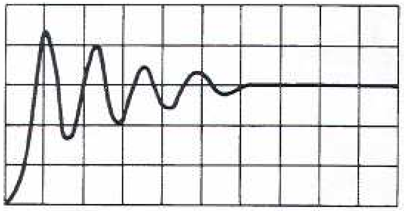

Figure 6. Single-step response.
Two-phase-on excitation.
Horizontal: 10 msec/div.
Vertical: 1.25 deg/div.
30 Volts at 1.75 Amps/phase.
8-ohm suppression.

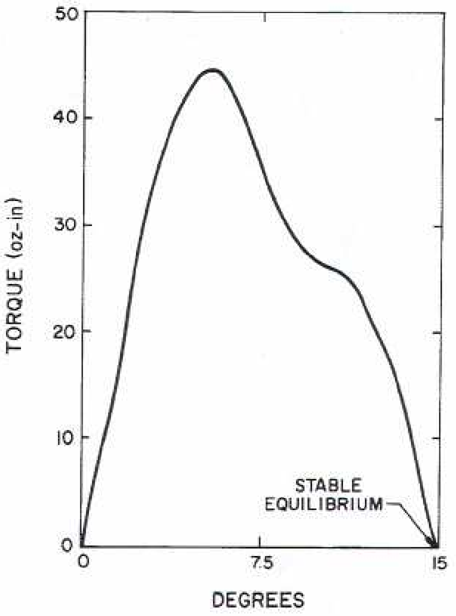

Figure 7. Static holding torque - one-phase-on.

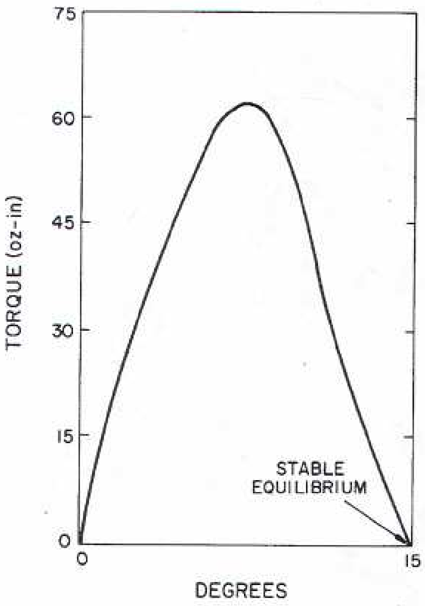

Figure 8. Static holding torque - two-phase-on.

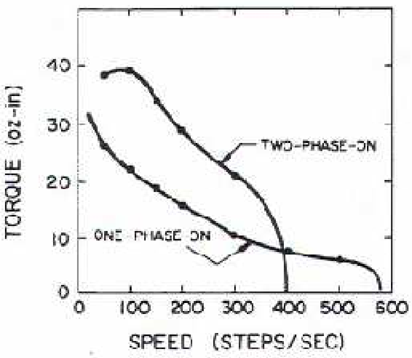

Figure 9. Torque-speed curves.

Ultimag® Size 4EM

Part Number: 199172-0XX

All catalogue products manufactured after April 1, 2006 are RoHS Compliant

Specifications

Dielectric Strength	1000 VRMS (23 awg): 1200 VRMS (24-33 awg)
Recommended Minimum Heat Sink	Maximum watts dissipated by the Ultimag are based on an unrestricted flow of air at 20°C with the Ultimag mounted on the equivalent of an aluminium plate measuring 15.9 cm square x 0.32 cm thick
Thermal Resistance	7.6°C/watt with heatsink ; 15.0°C/watt without heatsink
Rotor Inertia	8.43×10^{-7} (kgm²)
Peak Torque Rating (Tp)	0.32 Nm
Power Input	145 watts (stalled at Tp; 25°C; Pp)
Number of Phases	1
Static Friction (Tf)	7 mNm
-3dB Closed Loop	78 Hz
Maximum Winding	180°C
Number of Poles	6
Weight:	215 gms
Dimensions:	Ø41.66 mm x 26.3 mm L (See page B10)

Performance

Maximum Duty Cycle	100%	50%	25%	10%
K_M (mNm/√watt)	40.6	35.7	32.2	30.1
Maximum ON Time (sec) when pulsed continuously[1]	∞	40	15	4
Maximum ON Time (sec) for single pulse[2]	∞	108	34	9
Typical Energise Time (msec)[3]	6	5	4.5	3.5
Watts (@ 20°C)	14.5	29	58	145
Ampere Turns (@ 20°C)	510	721	1020	1613

Coil Data						
awg (0XX)[4]	Resistance (@20°C)	# Turns[5]	VDC (Nom)	VDC (Nom)	VDC (Nom)	VDC (Nom)
23	0.71	104	3.2	4.5	6.4	10.1
24	1.54	174	4.7	6.7	9.4	14.9
25	2.15	195	5.6	7.9	11.2	17.6
26	3.01	219	6.6	9.3	13.2	20.9
27	5.78	328	9.2	12.9	18.3	28.9
28	8.09	368	10.8	15.3	21.7	34.3
29	14.40	515	14.5	20.4	28.9	45.7
30	20.11	575	18.9	24.2	37.7	59.6
31	34.40	774	22.3	31.6	44.6	71.0
32	56.60	1008	28.7	40.5	57.0	91.0
33	91.40	1288	36.0	51.5	73.0	115.0

How to Order

Add the coil awg number (0XX) to the part number (for example: to order a 25% duty cycle rated at 18.5 VDC, specify 100172-027).

Please see www.ledex.com (click on Stock Products tab) for our list of stock products available through our distributors.

[1] Continuously pulsed at stated watts and duty cycle

[2] Single pulse at stated watts (with coil at ambient room temperature 20°C)

[3] Typical energise time based on no load condition. Times shown are for half of full rotary stroke starting at centre-off position.

[4] Other coil awg sizes available — please consult factory

[5] Reference number of turns

WARNING: Exposed Magnet may affect pacemakers.
In the event a product unit's magnet is exposed due to product disassembly, Pacemaker Wearers should distance themselves 3 metres from exposed magnet.

All specifications subject to change without notice.

References

Society., Incremental. 1981. Incremental Motion Control Systems and Devices: Proceedings, Tenth Annual Symposium, June, 1981. Champaign, Ill. Incremental Motion Control Systems Society.

Motor Engineering. Chatsworth: NMB Technologies Coporation. Accessed December 1 2007, from: <nmbtc.com>.

Condit, Reston. 2004. "Stepping Motor Fundamentals." [Available Online] [cited December 1, 2007] Available from www.microchip.com.

Solenoid Basic. Vandalia. Accessed December 1 2007, from: <www.ledex.com>.

Lazic, Anita, Browning, Bert, Nwabude, Tiffany, and Fallen, Tio. 2006. Axial Flux Permanent Magnet Micromotor Based on MEMS Technology. Thesis, Engineering, Florida State University, Tallahassee.