Optimum Tooth-Geometry for Specific Performance Requirements of a Hybrid Stepper Motor

K. R. Rajugopal, B. Singh, G. K. Singh
Electrical Engineering Department, Indian Institute of Technology, New Delhi 110016, India

Abstract

Hybrid stepper motors are used in space, military and industrial applications. The design of the hybrid stepper motor for achieving a specific performance necessitates the choice of appropriate tooth-geometry. In this paper, a detailed account of the results of 2-D and 3-D Finite Element (FE) analyses, conducted with different tooth-width/tooth-pitch ratios (t/k) and also with various tooth/slot shapes such as rectangular, trapezoidal, triangular and circular, is presented.

2-D FE Analysis of Tooth-Geometry

A typical 18° hybrid stepper motor has been designed using the conventional design procedure. It is a 2-phase, bipolar, 8-pole motor, with 30 teeth on stator, and 5 teeth on each pole. Airgap has been 0.1 mm. The motor is designed to deliver a holding torque of 0.5 Nm at 28 V dc. In 3-D FE analysis, the motor design is tuned to reduce mass and volume. After several trials, an optimum motor geometry is achieved, in which the axial length of the motor has come down by 20% from the conventional design. 3-D FE analysis is carried out with different tooth-geometries. For a case with equal t and x on both stator and rotor, the detent torque peaks at t/k=0.5, and is of the order of 5% of the fundamental static torque (i.e., T/|/=14.3). Therefore, the holding torque peaks at t/k=0.38, when t/k=0.4. The first case of equal t and x provides more detent torque and better stiffness. But the static torque profile is not very smooth, and small dips are seen on the torque profile, thereby reducing the effective dynamic torque capability. Whereas the second case of equal tooth-width, but different tooth-pitch, provides less detent torque, moderate stiffness and a smooth static torque profile.

Development and Testing

Two hybrid stepper motors, Motor-1: 18°, 0.5 Nm with t/k=0.38 for stator and 0.4 for rotor, equal t and Motor-2: 0.5°, 1 Nm with t/k=0.5 and t/k=0.4 have been designed and developed. Fig. 1 & 2 show the measured static and detent torque characteristics of motors. The fundamental holding torques are found to be 0.49 and 1.05 Nm respectively for motor-1 & motor-2, against the designed values of 0.5 Nm and 1 Nm. The detent torques of motors, are 0.03 Nm and 0.084 Nm against the expected values of 0.0275 Nm and 0.09 Nm, respectively for motor-1 & 2. It is observed that for motor-1, having equal tooth-width, but different tooth-pitch on rotor and stator, the static torque profile is smooth, because of less harmonic torques present in it.

Conclusions

The rectangular tooth/slot shape is better with respect to torque density. The best results are obtained when t/k is kept between 0.38 and 0.4. Optimum slot depth is observed to be 0.5 x.

References