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# Dynamic reduction of unbalanced magnetic force and vibration in switched reluctance motor by the parallel paths in windings

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**Abstract**

The influence of winding method counteracting unbalance forces on the rotor vibration behavior is investigated in this paper. Unbalanced magnetic force caused by rotor eccentricity may degrade the performance of motor, increasing vibration, acoustic noise, excessive wear of bearing and degree of eccentricity. This paper proposed a method to reduce the unbalanced magnetic force and vibration by introducing parallel paths in windings. The motor was simulated by using 2D transient magnetic FE analysis coupled with external circuits. Serial connection and various parallel connections of windings were modeled in the external circuit. It was found from the simulation results that the currents could be balanced in parallel paths and unbalanced magnetic forces could be reduced. Experiment results also reveal that the acceleration of stator surface is minimum with the proposed method.


*Keywords:* Winding connection; Rotor eccentricity; Switched reluctance motor; Vibration; Unbalanced magnetic force

## 1. Introduction

Acoustic noise and vibration in switched reluctance motors have been studied in various aspects in [2–4,9,12,14,15] in recent 30 years. In [3,9], the stator core shape was designed for high modal frequency using modal analysis. A longitudinal rib on frame was reported in [14] to reduce vibration. The mounting effects on mechanical resonant frequencies are analyzed in [14]. The control methods were proposed in [4,12]. But one factor to take into consideration is that the machine usually presents some changes compared to the original design. Due to the tolerances introduced during the manufacturing process, wear of bearings, and other reasons, some degree of rotor eccentricity is always present. The use of parallel paths in stator windings offers another way to reduce the vibration. The beneficial effects of parallel windings in reducing unbalanced magnetic force (UMF) and vibration have been discussed as long as 100 years. All of the researches have focused on induction motors [5,7] using analytical approaches or numerical approaches.

The air gap of SRM in fractional horsepower applications is usually 0.2–0.4 mm which is much smaller than PM motors and induction motors and is more sensitive to rotor eccentricity. A relative eccentricity between the stator and rotor of 10% is common [13]. It is therefore essential to keep the rotor eccentricity to a minimum by using strict control of manufacturing and assembling procedures. However, for economic reasons, and especially for mass produced machines, it is not always possible to do so.

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**Nomenclature**

| | |
|---|---|
| $\varepsilon$ | relative eccentricity |
| $g$ | air gap length |
| $r$ | eccentricity in the vertical direction |
| $g_e$ | nominal air gap |
| $g_{ecc}$ | eccentric error |
| $\omega_{ecc}$ | whirling angular speed |
| $\varphi_{ecc.0}$ | initial phase angular of the rotor eccentricity. |
| $\mu_0$ | permeability of air |
| $K_{fr}$ | constant for the fringing inductance |
| $N$ | number of turns |
| $D$ | stack length |
| $R$ | rotor radius |
| $\theta_0$ | overlapped angle of stator and rotor teeth |
| CCW | count clockwise |
| FEA | finite element analysis |
| UMF | unbalanced magnetic force |
| SRM | switched reluctance motor |

The air gap nonuniformity or rotor eccentricity has been studied in [6,8,13] mainly about the torque and flux density. However, connection methods of coils were ignored except in [11] and little attention in the literature has been paid to unbalanced magnetic force (UMF). This paper firstly proposed a method to reduce the UMF and vibration by introducing parallel paths and equalizer in windings. In this work, a 12/8 switched reluctance motor (SRM) with relative eccentricity is studied using time-stepping finite element analysis (FEA) coupling external circuits. Various arrangements of the parallel stator windings were modeled in the external circuit. The equalizing current in paralleling paths, torque profile and unbalanced magnetic forces are obtained and compared. The proposed method which has two parallel branches with neighboring coils in series and an equalizer was found to reduce torque ripple greatly, balance the radial force on symmetrically distributed stator poles.

## 2. Modeling of SRM with relative eccentricity

### 2.1. Motor specifications

The SRM studied in this paper is a three phase 12/8 motor. One phase has four stator poles and four coils as denoted A1, A2, A3, and A4.... The cross-section and distribution of coil groups are shown in Fig. 1. The specifications of motor are given as illustrated in Table 1.

Table 1
Motor specifications.

| Item | Values | Item | Values |
|---|---|---|---|
| No. of phases | 3 | Shaft diameter (mm) | 24 |
| No. of stator/rotor poles | 12/8 | Stack length (mm) | 80 |
| Stator diameter (mm) | 135 | Turns per tooth | 100 |
| Rotor diameter (mm) | 68 | Wire (mm) | 0.7 |
| Stator pole arc (°) | 14 | DC voltage (V) | 310 |
| Rotor pole arc (°) | 16 | Rated torque (N m) | 4.9 |
| Air gap length (mm) | 0.3 | Rated speed (rpm) | 3600 |