Design of a BLDC motor for low cost and low noise application

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***Abstract*—In HVAC applications, blower motors must be high efficiency, low noise and low cost. Brushless dc (BLDC) motors gain more and more interest in this application field. This paper deals with a BLDC motor design process. The design process integrates an optimization algorithm to minimize cost and reduce vibration and noise, coupled with analytical motor design software. Preliminary optimal results are then analyzed using high fidelity electromagnetic field and structural finite element analysis (FEA) software tools. Finally, a prototype has been manufactured. Motor efficiency and acoustic noise were measured on the prototype.**

***Index Terms*—permanent magnet motors, optimization, acoustic noise.**

I. INTRODUCTION

Brushless dc (BLDC) motors have shown their potentials in many applications especially in small to medium size units for HVAC. High efficiency is the first advantage being sought. This is to comply with more strict energy efficiency standard. BLDC motors can achieve high efficiency mainly due to the use of permanent magnet (PM) instead of short circuit bars as in induction motors. Other advantages are low audible noise and vibration. Motors used in indoor units must produce as low as possible acoustic noise. A design process of induction motors including noise analysis has been described in [1]. In this paper, a BLDC motor is developed for blower application. The BLDC motor is designed to reduce manufacturing cost and to be high efficiency. An optimization algorithm is used in the design process in order to reach these goals [2]. A prototype is build. The efficiency and acoustic noise of the prototype are then measured.

II. DESIGN OF BLDC MOTOR

This section describes the design process. First, an optimization design has been carried out. Prototype is then manufactured and tested. Noise is also measured on the prototype.

A. Design criteria

For HVAC application, blower motors must be high efficiency and low noise due to their indoor operational condition. Furthermore, manufacturing cost must be as low as possible. Some design considerations such as material selection, economy of scale by sharing parts between several models, are put forward to reduce cost. This can be translated into:

- Use ring magnet for flexible number of pole design,
- Use multiple stacked ring magnets for scaling power rating of motors,
- Use bonded NdFeB, PM which is advantageus in terms of price per performance ratio, instead of ferrite PM or sintered NdFeB,
- Use the lowest possible air gap length.

In air moving application like blower, air cutting by blower blades is the principal source of noise at high speed. However, the electromagnetic noise can dominate the air noise in lower speed. The electromagnetic noise is caused by many factors such as combination of number of slot and pole [3], dimension of stator and rotor, eccentricity, incomplete magnetization of ring magnet [4], current waveform, PWM frequency and so on. This study will focus on designing a BLDC motor from an existing stator already available in the production line.

B. Electromagnetic design

A preliminary design has been conducted using analytical software: SPEED PC-BDC to achieve the specifications as described in Table I. The preliminary design result is then analyzed using a FEA software, Ansoft Maxwell, to confirm local magnetic field saturation and cogging torque.

SPEED PC-BDC has been coupled with an optimization process using a genetic algorithm (GA), where the rated efficiency is used as the optimization objective. The following five design variables are considered: magnet height, number of ring magnet (step stack height), number of turns, number of strands and wire gauge. Other motor dimensions are fixed beforehand as the existing or sharing parts are used. There are several constraints such as flux density in yokes and teeth, winding temperature, rated and maximum inverter currents, cogging torque, etc.

TABLE I
MOTOR SPECIFICATIONS

Parameters	***Unit***	***Value***
Rated power	W	900
Rated speed	rpm	1350
Number of slots	-	36
Number of poles	-	12
Stator outer diameter	mm	139
Maximum stack length	mm	90

The optimization process using SPEED PC-BDC allows fast and optimized preliminary design. However, it cannot compute local magnetic phenomena of motor. The FEA software, Maxwell, is applied to the motor obtained from the optimization process. FEA is used to analyze local magnetic

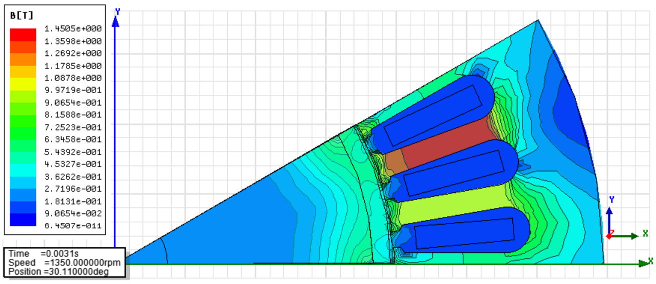

Fig. 1. Flux density at full load

saturation and to confirm the cogging torque. Flux density of the optimized motor at full load is shown in Fig. 1.

C. Modal analysis

Motor vibration generates acoustic noise. Sound pressure level (SPL) depends on frequency and amplitude of vibrating source. Stator and rotor deformations due to electromagnetic force are main vibrating sources.

Fig. 2 shows some preliminary modal analysis results obtained from ANSYS. The modal analysis determines natural frequency and deformation magnitude of each vibration mode. A significant SPL amplification can occur when harmonic frequencies resonate with natural frequencies.

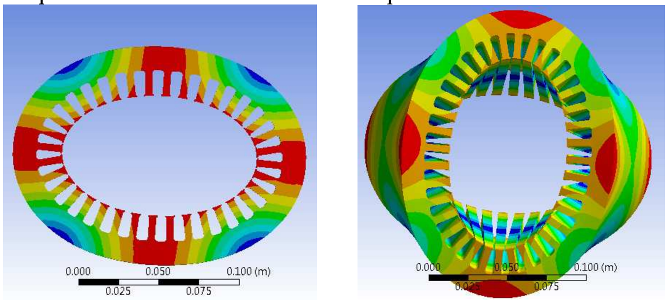

Fig. 2. Natural vibration mode shapes of a BLDC motor

III. EXPERIMENTAL RESULTS

A. Back EMF and efficiency

A prototype has been manufactured based on the optimal design result. Its back EMF and rated efficiency were measured. In the efficiency test, a BLDC sensorless drive provides 3-phase 120° square wave currents to the prototype motor. A dc motor was coupled to the prototype motor to apply a rated load torque. The efficiency was computed from the input electrical power and output shaft mechanical power.

A comparison between the computation and test results are shown in Table II, where SPEED PC-BDC results are reasonably close to the experimental results. Main discrepancies can be caused by the incomplete magnetized PM and under-defined mechanical losses.

B. Noise measurement

TABLE II
DESIGN AND TEST RESULTS COMPARISON

Parameter	***Unit***	***Design***	***Prototype***
Peak Back EMF at 1000 rpm	V	131	126
Rated efficiency	%	91	89.3

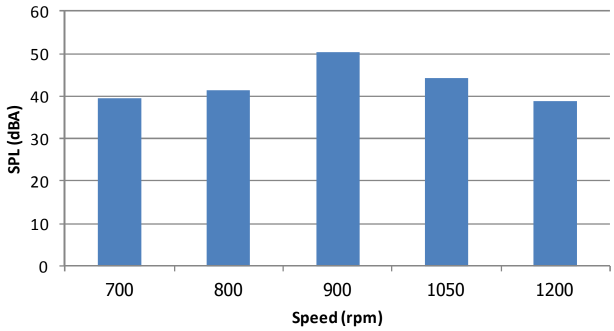

Fig. 3. Acoustic noise measurement

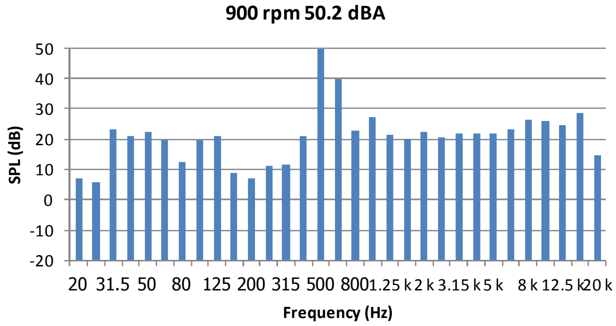

Fig. 4. FFT analysis on noise waveform at 900 rpm

The acoustic noise has been measured at different rotational speeds and at no load condition. A microphone was placed at 50 cm from the middle of the motor. The results are shown in Fig. 3. The BLDC motor produces low noise in general. It can be seen that a resonance occurred at 900 rpm. The FFT analysis at 900 rpm is shown in Fig. 4. The resonance frequency is around 500 Hz. This resonance cannot be avoided in the motor operation. However, this speed range can be passed rapidly by adjusting control parameters of drive.

IV. CONCLUSION

A design process has been described in this paper. It integrates the optimization algorithm in the preliminary design phase to maximize BDLC motor efficiency. The optimal result is further analyzed using electromagnetic and structural FEA tools. The optimization process ensures optimum motor efficiency. The natural frequencies are predicted by the modal analysis. Finally, the experiments, including efficiency and noise measurements, have been done on the prototype. The results are satisfied in terms of efficiency and noise level.

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