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전기강판 특성을 활용한 유니버셜 모터의 효율 개선

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Efficiency Improvement based on New Non-oriented Electrical Steel developed for Universal Motor

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Abstract – This paper presents efficiency improvement of a universal motor used in a vacuum cleaner. The transient computation is carried out by employing finite element analysis with nonlinear material curves. Working point of magnetic field is investigated and operating frequencies are analyzed using harmonics analysis. New non-oriented electrical steel is developed for the motor regarding permeability and iron loss at the frequencies. Accordingly, new electrical steel is applied to the motor, which leads to improve efficiency of the motor.

1. Introduction

In rotating machines, the Joule loss and core loss amount to 70~85% of the total loss with alternating supplies at 50 or 60 Hz. It is commonly desired to minimize both the Joule and core losses for improving the efficiency of the machines employing non-oriented electrical steel as a core material. In order to reduce both losses, two characteristics of the non-oriented electrical steel are required: 1) high magnetic polarization with high permeability and 2) low core loss. However, these factors are, in fact, inversely proportional in metallurgical viewpoint. Typical magnetic properties (average core loss of 1.5 T induction at 50 or 60Hz, magnetic induction at 5000 A/m) are paid attention in steel and motor community. It is noted that the typical magnetic properties is suitable to design induction motor with two pole configuration. Unlike the induction motor, however, the universal motor has various different working points in terms of the magnetic field of core material, which is discussed in this paper. The core material has diverse iron loss distribution in various frequencies and magnetic inductions.

Here, we computed 2D finite element (FE) model of a universal motor with electrical parameters composing an external circuit. In order for loss separation of the motor, working points of magnetic field were analyzed and operating frequencies were obtained by employing the Fast Fourier Transform (FFT). A new non-oriented electrical steel was developed for the motor regarding permeability and iron loss at the frequencies. The properties were measured by means of an Epstein frame [1]. From the test of vacuum cleaner, it is turned out that the average efficiency is raised by 0.61 %.

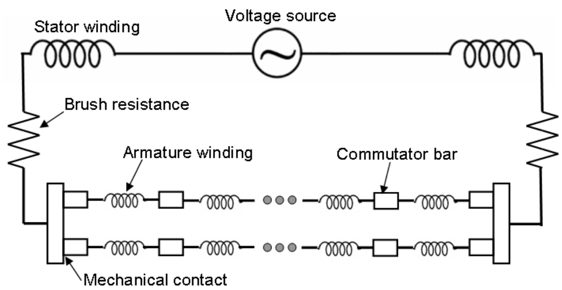
2. Analysis of Universal Motor

A universal motor used in a vacuum cleaner yields a mechanical output 1030 W at a rated speed of 36000 rpm, when input voltage 220 V with a frequency 60 Hz is applied. The universal motor has two-pole stator with a concentrated winding and 22 slots of the armature with a lap winding pattern. The FE model to be analyzed has a full geometry due to the lap winding of the armature. To drive the motor, an external circuit operated by a voltage source is constructed with the mechanical contact between brush and commutator bar. Fig. 1 presents the external circuit of the universal motor. It is noted that brush loss causing the Joule heat is unnegligible due to a large portion in the total loss [2].

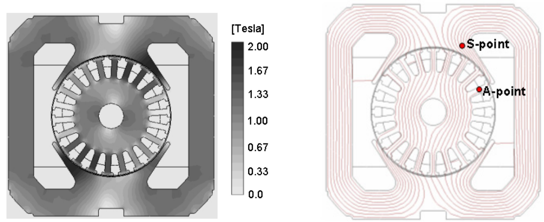
From the transient finite element analysis using the nonlinear material curve, torque and current profile were obtained at the rated speed. The electromagnetic torque was computed on a basis of the Maxwell Stress Tensor (MST) method. The pulsating component of the torque is caused by the mechanical contact between brush and commutator bar while the rotor revolves. Fig. 2 shows the magnetic flux density and magnetic flux contour lines when the rotor speeds up to the rated RPM. The magnetic flux density of the stator core is saturated around 1.8T~2.0T. In order to separate losses of the motor, the core loss is calculated as follows:

Step 1) Compute the nonlinear transient analysis using the external circuit with a voltage source.
Step 2) Obtain the magnetic flux density of the core versus time. See Fig. 2 and Fig. 3.
Step 3) Find working points of the magnetic flux density and operating frequencies by taking the FFT (Fast Fourier Transform). See Fig. 4.
Step 4) Measure iron loss data of the electrical steel using the Epstein frame method at the corresponding frequencies analyzed in the previous step.
Step 5) Estimate the coefficients of iron losses (such as the hysteresis and eddy current loss) by employing frequency separation method using losses at 50 and 60 Hz. The coefficients are a function of the magnetic flux density.
Step 6) Compute the core loss of each element in the FE model of the motor and integrate the losses.

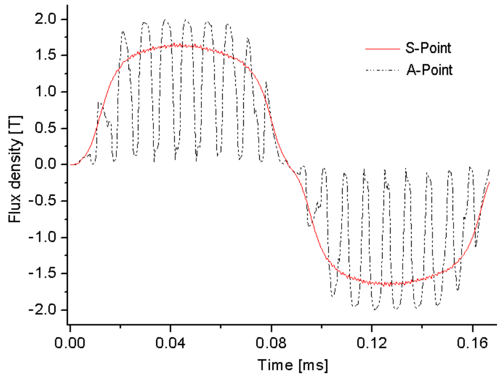
In order to verify the analysis result, the motor performances are measured by employing the acceleration method described in section 7.3.2.2 of IEEE std. 112-1996. The error between experiment and simulation is below 4%. Table I presents a comparison between the result of analysis and experiment. It can be seen that these results are in good agreement.



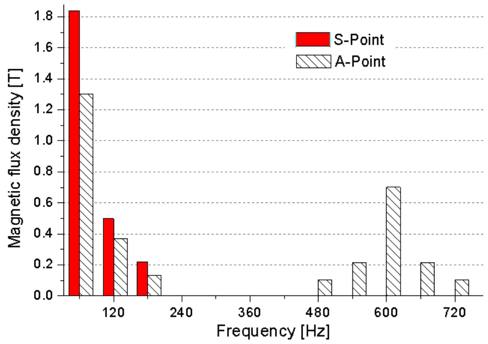
<Fig 1> External circuit of universal motor



<Fig 2> Plots of magnetic flux density (left) and magnetic flux line(right).



<Fig 3> Plots of magnetic flux density versus time.



<Fig 4> Spectral analysis of magnetic flux density.

<Table 1> COMPARISON BETWEEN NONLINEAR TRANSIENT FEA AND EXPERIMENT

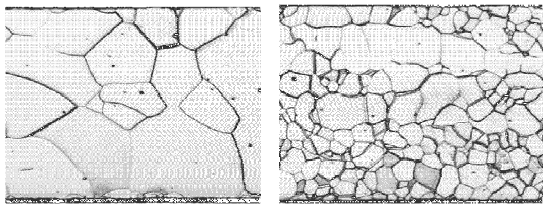
	RPM	Current [A]	Torque [N.m]
Experiment	36027	7.3	0.27
FEA	36000	7.3	0.26

3. NEW NON-ORIENTED ELECTRICAL STEEL

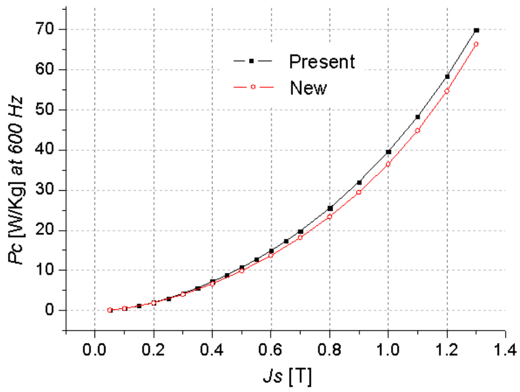
Authors emphasize that lower iron loss at high magnetic induction and higher permeability are contradictory properties for the non-oriented electrical steel in metallurgical viewpoint. Permeability of the core material is strongly related to the Joule loss (copper loss) since exciting current is proportional to the square of the reciprocal of permeability. The iron loss is able to be used to predict the core loss of a variety of motors. Silicon and aluminum additions to the non-oriented electrical steel cause reduction of the iron loss, but deteriorate its permeability at high induction levels. New 0.35 mm non-oriented electrical steel has smaller silicon content than the employed steel to increase its permeability. But manganese and aluminum contents are slightly greater. In high frequency region, the eddy current loss accounts for a large proportion of the total core loss. The smaller grain size means the lower eddy current loss induced in the steel. The grain size (or particle size) referring to the diameter of a grain of granular material has influence on the magnetic and mechanical properties [3]. The common grain size for high grades of the non-oriented electrical steel is ranged from 100 to 150 μm, but the new steel is 20~40 μm, as shown in Fig. 5. Fig. 6 shows iron loss curve measured at 600Hz in the Epstein frame method. Hence, the new steel yields lower core loss and better permeability in the motor at the operating frequencies.

4. REANALYSIS OF FE MODEL AND EXPERIMENTAL VERIFICATION

The motor performance using the new steel is reanalyzed in the nonlinear transient computation. It is found that the power loss due to the winding and brush was estimated to be 16.9 W lower than the present motor. Also, the core loss was 2.6 W lower. Consequently, 1% improvement is predicted in the motor efficiency. In order to verify these effects, 5 universal motors are manufactured using the new steel and launched in the vacuum cleaner. From the test of vacuum cleaner, it is turned out that the average efficiency is raised by 0.61 %. (The efficiency of vacuum cleaner is a ratio between suction power and electrically consumed power.)



<Fig 5> Picture of grain; high-grade steel (left) and new steel (right).



<Fig 6> Iron loss curve measured at 600Hz in Epstein frame method.

3. CONCLUSION

We investigated the magnetic working points of core material in the universal motor. The nonlinear transient computation and experimental results were in good agreement. A strategy to improve the efficiency is found; better permeability and lower iron loss around 480Hz~720Hz. Because most of the core loss is attributed to the eddy current loss caused in the armature. New non-oriented electrical steel was developed for the motor regarding metallurgic combination and grain size. Consequently, efficiency of the vacuum cleaner was increased by 0.61% in experiment.

[References]

[1] IEC 60404-2, Magnetic materials – Part 2: Methods of measurement of the magnetic properties of electrical steel sheet and strip by means of an Epstein frame.
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