Loss Reduction of Vehicle Horn Employing Rolled Silicon Steel Sheets

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Carbon-steel-based solid cores, such as SK5, SWCH10A, and GI1t, have typically been used in vehicle horns, thanks to their superior cost-effectiveness and productivity. Such cores, however, induce high eddy current loss and generate the corresponding thermal energy in a time-varying magnetic field. Consequently, the conventional vehicle horns are usually exposed to a high temperature environment and their efficiency is also deteriorated. Thus, this paper proposes a novel configuration of vehicle horn employing rolled silicon electrical steel sheets as a solution for the aforementioned phenomena. The silicon electrical steel sheets, 50A470, are rolled around pole and armature of a conventional model to pass through a time-varying magnetic flux, prevent its eddy currents from flowing in closed loops, and reduce the consequent eddy current loss. Moreover, such steel sheets also reduce the input current and the joule loss in copper winding by means of the increased equivalent iron loss resistance. As a result, the novel vehicle horn produces a lower iron loss and joule loss than the conventional model while generating a similar electromagnetic force acting on itself. Additionally, its analytical approach called as the coupled electromagnetic circuit is developed for the repetitive design procedure. Finally, an optimum prototype is manufactured and tested so as to validate its effectiveness compared with the conventional vehicle horn.

***Index Terms*—Coupled electromagnetic circuit, eddy current loss, iron loss, joule loss, rolled silicon steel sheets, vehicle horn.**

I. Introduction

VEHICLE HORN is a sound-making electromagnetic device which can be equipped with a variety of sorts of vehicles i.e. automobiles, motorcycles, trains, and trams. It plays a role in warning other people of a vehicle's approach and presence, or in calling attention to a collision hazard. A lot of countries legally restrict that all the vehicles should install the horns. As a result, their demand and supply become gradually high as the number of the vehicles increases every year [1], [2].

The vehicle horns typically employ solid cores, particularly carbon-steel-based solid cores, i.e. SWCH10A, SK5, and GI1t, in body, diaphragm, pole, and armature parts. Such solid cores are excellent in terms of cost-effectiveness and productivity, but exhibit higher electrical conductivity and lower skin depth than the silicon-steel-based laminated cores [3]-[5]. In other words, it implies that the carbon-steel-based solid cores result in higher eddy current loss and lower inductance when they are exposed to a time-varying magnetic field. Such phenomena eventually exposes the vehicle horns to a high temperature environment and deteriorates their performance and efficiency. Furthermore, only few academic papers have discussed the electromagnetic characteristics of the vehicle horns [6], [7].

This paper suggests a novel configuration of the vehicle horn employing rolled silicon electrical steel sheets. The silicon electrical steel sheets are rolled around pole and armature of a conventional prototype to penetrate the time-varying magnetic flux, prevent its eddy currents from flowing in closed loops, and decrease the consequent eddy current loss. In addition, such steels reduce the input current and the joule loss in copper winding by means of the increased equivalent iron loss resistance. Consequently, the novel vehicle horn generates a lower iron loss and joule loss than the conventional vehicle horn while producing a similar electromagnetic force acting on itself. Furthermore, its analytical approach called as coupled electromagnetic circuit is developed for the repetitive design process. Lastly, a prototype is manufactured and experimented to verify its effectiveness compared with the conventional vehicle horn.

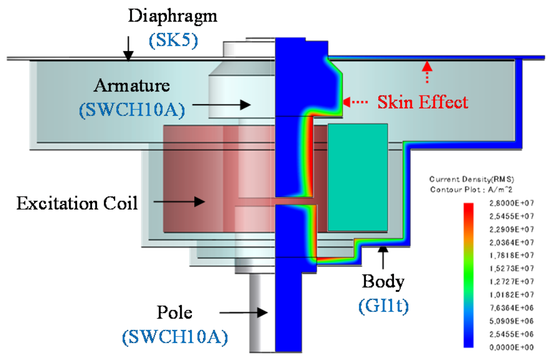

Fig. 1. Conventional vehicle horn and its current density distribution.

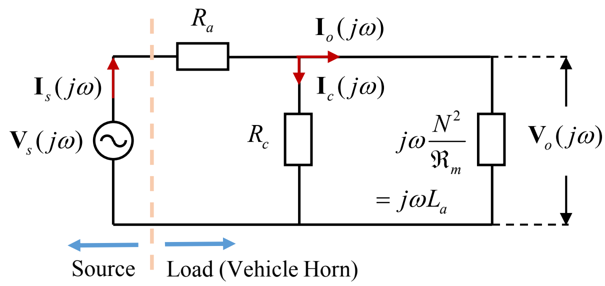

Fig. 2. Simplified coupled electromagnetic circuit in phasor forms.

II. Rolled Silicon Electrical Steel Sheets

Fig. 1 describes the configuration of the conventional vehicle horn and its current density distribution. As shown in Fig. 1, the eddy current mainly flows in pole and armature and the corresponding loss is induced. It indicates that the eddy current also flows at the skins of the solid cores due to their low electrical resistivity. The silicon-steel-based rolled lamination cores show lower electrical conductivity and higher permeability than the carbon-steel-based solid cores. It mentions that a time-varying magnetic flux and the consequent eddy current pass not through the solid cores, but the rolled lamination cores. The lamination cores are also coated to enhance electrical resistance between the laminations and reduce the eddy currents. They surround the pole and armature of the conventional model as in Fig. 4.

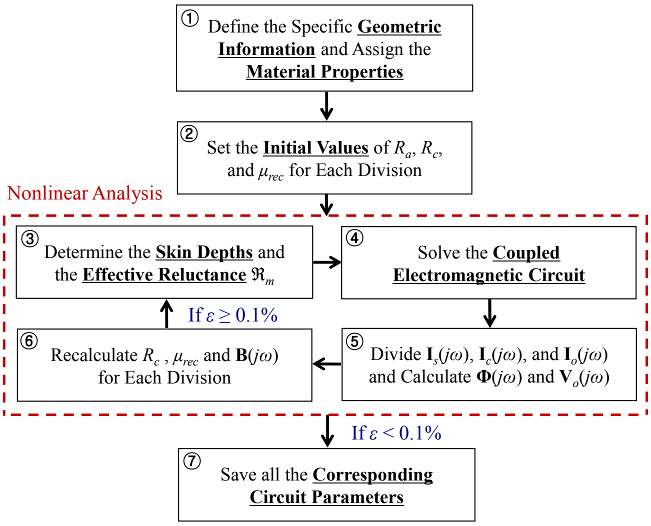

Fig. 3. Analysis procedure of the coupled electromagnetic circuit.

III. Parametric Design Based on Coupled Electromagnetic Circuit

The coupled electromagnetic circuit is introduced to express the magnetic field distribution of a vehicle horn and its connected AC voltage source. Fig. 2 describes its simplified schematic representation. The coupled electromagnetic circuit is especially represented in phasor forms because the sinusoidal time variations of voltage source of a given frequency, $\mathbf{V}_s(j\omega)$, will generate the sinusoidal variations of electric and magnetic fields with the same frequency in the steady state. In the circuit, the axisymmetric vehicle horn or the load is represented by the excitation coil resistance R_a, the equivalent iron loss resistance R_c, and the effective reluctance $\Re_m$. The specific descriptions of those parameters are being covered in the full paper. Fig. 3 shows an overview of the analysis procedure of the coupled electromagnetic circuit which is based on the homogeneous Helmholtz's equations (1) and (2) in lossy media to reflect the skin effect. Using the developed analytical approach, the parametric design is being accomplished to determine a specific geometry.

$$\mathbf{E}(j\omega) = E_0 \cdot e^{-\alpha z} \cdot e^{-j\beta z} \quad (1)$$

$$\mathbf{H}(j\omega) = \frac{E_0 \cdot e^{-\alpha z} \cdot e^{-j\beta z}}{(1+j)\cdot\sqrt{\frac{(\mu_0 \cdot \mu_{rec})\cdot \pi \cdot f}{\sigma}}} \quad (2)$$

where $f = \omega / 2\pi$ and $\alpha = \beta = (\mu_0 \cdot \mu_{rec}) \cdot \pi \cdot f \cdot \sigma$ (3)

IV. Experimental Verification

The experiment was conducted so as to verify the validity of the analytical approach and the effectiveness of the novel configuration of the vehicle horn under the rated conditions. The active power, the reactive power, the magnitudes and the phases of the input voltage and current were measured for the condition above. The measured data could be used to compute the system resistance, the system inductance, the copper loss, the iron loss, and the back electro-motive force, which were compared with those from the analytical approach. Such validation gives the accurate estimation of the performance and the effectiveness of the novel vehicle horn compared with the conventional model.

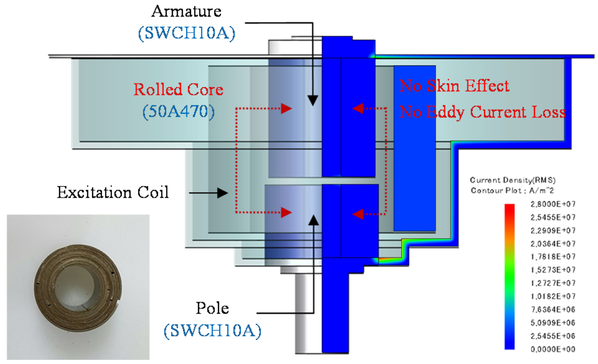

Fig. 4. Novel vehicle horn employing the rolled silicon steel sheets

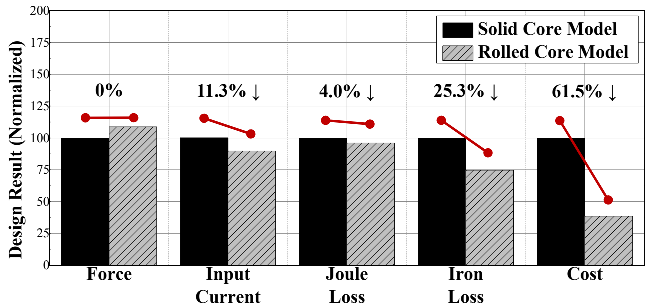

Fig. 5. Comparison of the conventional and novel vehicle horns.

V. Conclusion

This paper proposes a novel configuration of the vehicle horn employing the rolled silicon steel sheets to decrease the eddy current loss and the joule loss in copper winding as described in Fig. 4. Fig. 5 compares the conventional and novel vehicle horns in terms of electromagnetic force, input current, joule loss, iron loss, and manufacturing cost. The results above validate the loss reduction through the rolled silicon steel sheets.

References

[1] W. Wu, T. Hong, L. Liu, C. Chen, P. Zeng, and Z. Zeng, "Study on durability test bench of the automotive electric horn," in *Proc. IEEE ICAE*, Zibo, China, May 2011, pp. 180-184.

[2] J. Guo, W. Ren, G. Zhai, and H. Zhao, "Experiment research on high frequency making and breaking characteristics of automobile horn contacts," in *Proc. IEEE HOLM*, Charleston, U.S.A., Oct. 2010, pp. 1-6.

[3] L. Cheng, S. Sudo, Y. Gao, H. Dozono, and K. Muramatsu, "Homogenization technique of laminated core taking account of eddy currents under rotational flux without edge effect," *IEEE Trans. Magn.*, vol. 49, no. 5, pp. 1969-1972, May 2013.

[4] Y. Gao, K. Muramatsu, M. J. Hatim, and M. Nagata, "The effect of laminated structure on coupled magnetic field and mechanical analyses of iron core and its homogenization technique," *IEEE Trans. Magn.*, vol. 47, no. 5, pp. 1358-1361, May 2011.

[5] J. Wang, H. Lin, Y. Huang, and L. Huang, "Numerical analysis of 3D eddy current fields in laminated media under various frequencies," *IEEE Trans. Magn.*, vol. 48, no. 2, pp. 267-270, Feb. 2012.

[6] Y. C. Chen, W. C. Ko, H. L. Chen, W. J. Wu, P. Z. Chang, and C. K. Lee, "A thin light flexible electromechanically actuated electret-based loudspeaker for automotive applications," *IEEE Trans. Ind. Electron.*, vol. 59, no. 11, pp. 4140-4147, Nov. 2012.

[7] J. Usher and J. Benesty, "Enhancement of spatial sound quality: A new reverberation-extraction audio upmixer," *IEEE Trans. Audio, Speech, and Lang. Process.*, vol. 15, no. 7, pp. 2141-2150, Sep. 2007.