Brushless DC Motor Ringing Noise: A Case Study

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1. INTRODUCTION

A brushless DC motor ringing noise case study is described in this paper. The motor analyzed is a 400 W brushless DC motor with 5 phases unipolar sensorless drive, 6 poles, 20 slots and external rotor configuration. It is used in the automotive industry to drive an engine cooling fan. The problem studied is a ringing noise that occurs at various speeds during wind up and wind down. This tone seriously affects the module's sound quality and has to be eliminated or significantly reduced.

2. EXPERIMENTAL INVESTIGATION

The SPL of the complete assembly (motor, fan and shroud), shown in Figure 1, has been recorded at 1 meter from the motor's side during a run up. This measurement shows that the module's SPL increase by more than 10 dB(A) at certain speeds. A colormap of the same measurement is presented in Figure 2 with the ringing noise highlighted. It clearly shows that the structure is excited at various orders, which tends to indicate that many forces are exciting it. One can also conclude from the colormap that the ringing noise is due to a resonance in the system because its frequency doesn't change with speed. This conclusion correlates very well with the subjective evaluations performed in conjunction with digital filtering that located the ringing noise around 1600 Hz.

3. MODAL ANALYSIS

A good understanding of the ringing mode's modal properties is necessary to eliminate the problem at a low cost. The analysis has been done with the motor mounted on a suspended shroud ring. A small shaker has been used to excited the motor while the input force was measured with a B&K 8200 force transducer and the response velocity with a Polytec scanning laser vibrometer. A natural frequency has been identified at 1592 Hz which is in the frequency range of interest. The associated damping was around 0.15% and the mode shape is shown in Figures 3 and 4.

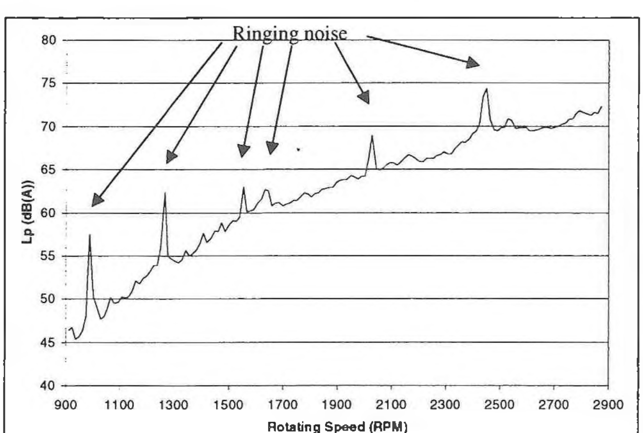

Figure 1 SPL vs speed

The mode shape is of the second order with a shape similar to a vibrating bell. As for a bell, it will create a quadrupole noise radiation [1]. The nodes are located near the end of 4 magnets and none is located between magnets or in the middle of a magnet. As shown in Figure 5, the rotor's side follows the same shape with larger amplitudes near the free extremity than near the front face.

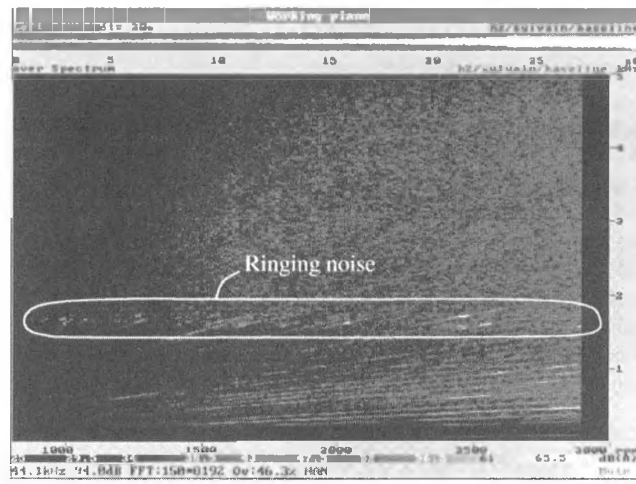

Figure 2 Colormap of a production module

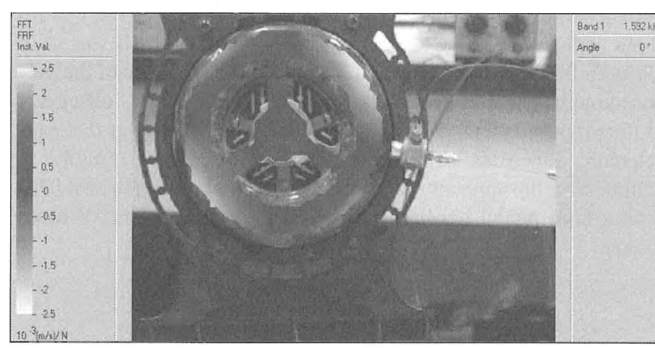

Figure 3 Front view of the 1592 Hz mode shape

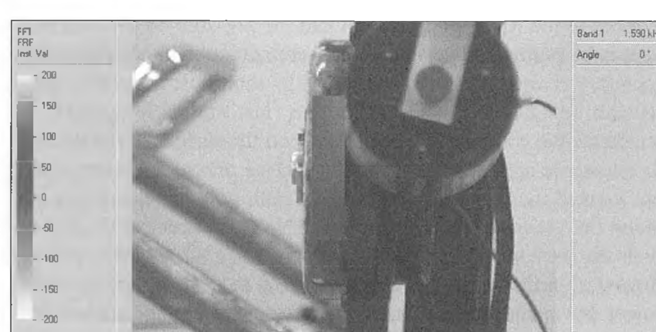

Figure 4 Side view of the 1592 Hz mode shape

4. DESIGN MODIFICATION

It is obvious from the experimental investigation and the modal analysis that the ringing noise problem is due to the resonance of the 1592 Hz mode. It is useless to attempt changing the mode's frequency because the resonance would only occur at a different speed. A more appropriate modification is to increase the damping to reduce the noise radiated at that frequency.

Various strategies have been considered to increase the damping at minimum cost and without major modifications to the motor. Knowing that a viscoelastic material submitted to shear is much more effective than one submitted to tension/compression, it has been thought that the magnets could be used as a constraining layer for the damping material. An original design[1] has been developed by replacing a small portion of the magnet adhesive by a very thin layer of viscoelastic material. In the present prototypes, a 10 mm wide and 0.127 mm thick band of 3M ISD 110 viscoelastic material [2] was installed between the magnets and the rotor beside the free edge to take advantage of the maximum shear stress. The remaining magnet surface area was used to bond the magnets to the rotor with a standard adhesive. The Figure 5 illustrates the concept with one magnet removed for clarity. A damping level of 0.8% was achieved with this design and a ringing noise reduction of more than 10 dB(A) as shown in Figure 6 where a standard production sample is compared to 5 prototypes with viscoelastic material.

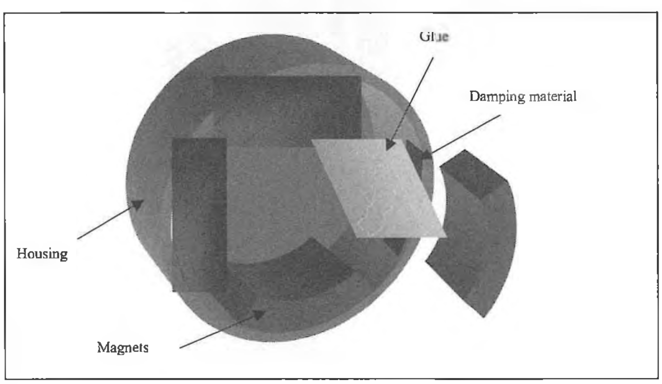

Figure 5 Illustration of the design modification

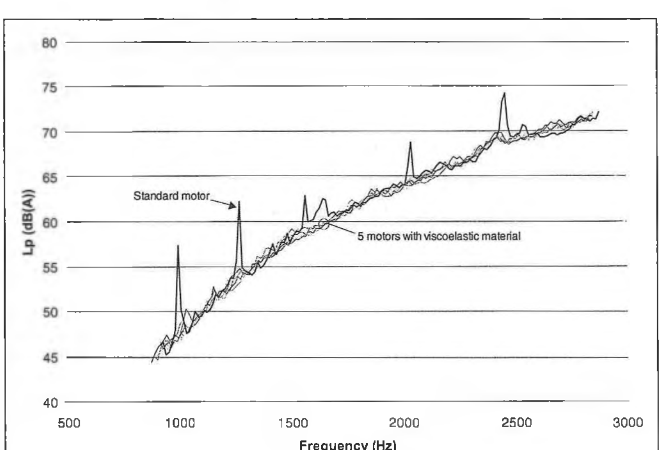

Figure 6 SPL comparison between production and prototypes

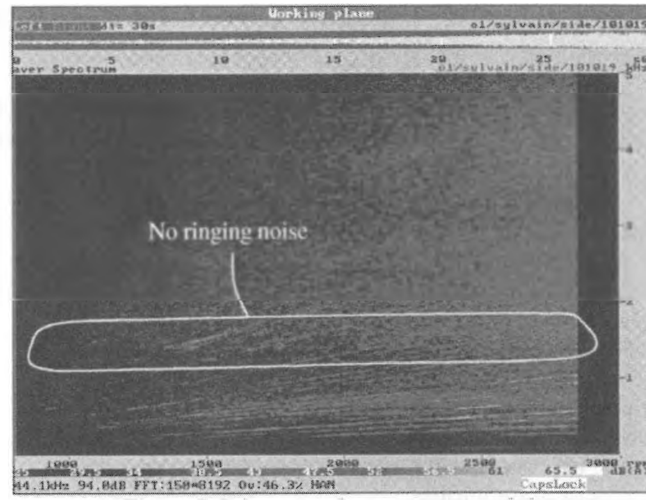

Figure 7 Colormap of a prototype module

A colormap of one of the prototypes is shown in Figure 7. As expected, the noise level around 1600 Hz has been significantly reduced without really reducing the noise level in the remainder of the spectrum.

5. CONCLUSION

A case study of a brushless motor ringing noise problem has been presented. It has been shown that a rotor's mode around 1600 Hz resonates at certain speeds due to various electromagnetic forces. A new design with viscoelastic material between part of the magnets and the rotor has been described. The experimental results have shown that the new design significantly increase the mode's damping and reduce the ringing noise by more than 10 dB(A). The addition of viscoelastic material between part of the magnets and the rotor offers a convenient way of reducing the ringing noise at a minimum cost and without any major modification to the motor itself.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Pierce, Allan D., "ACOUSTICS An Introduction to Its Physical Principles and Applications", Acoustical Society of America, Woodbury (1994).

[2] "3M Viscoelastic Damping Polymers 110- 112- 130-", Technical Data (February 1999).

[1] Patent pending