Noise Analysis and Noise Reduction of Small DC Motors

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Abstract

The research was targeted on seat positioning motors used in higher category cars. First, noise evaluation method used by the manufacturer during the end-control is investigated and compared with laboratory measurements. In the second part, a complex vibration/noise generation model is set up, possible vibration and noise transfer paths are analyzed and the dominating path identified. In the final part, some modifications made on groups of motors and their noise reduction effect is described. Cumulative application of the most effective changes led to about 6-8 dB(A) average noise level reduction.

1. Introduction

With the growing demand of comfort of passenger cars, the number of small electric motors used for adjustments of different functional units is steadily increasing. To adapt their power demand to the accumulator voltage, these motors are usually DC-driven brush motors of a relatively high speed (~4500 rpm) thus producing not only torque desired by a certain unit but also a considerable amount of noise. Besides the structure of the motor and the precision of its parts and that of the assembly, the noise also depends on the total running time, rotational direction, as well as how the motor is fixed and loaded under real operating conditions. Before being equipped by additional parts (e.g. by a gear-box) and mounted into the car, motors have to be tested for noise on their own right after assembly. Noise limit generally accepted by the end-users (car manufacturers) is 42 dB(A) measured at the distance of 50 cm from the motor while the background noise shall be at least by 10 dB(A) lower. Since this latter requirement can not be fulfilled under manufacturing conditions, instead of noise, radial and axial accelerations are measured on the motor housing by magnetically attached accelerometers.

2. Evaluation of Quality Control (QC) Measurements

For the sake of statistical evaluation, 200 motors have been selected and arranged into four groups of 50 motors each, on the basis of QC measurements made by the manufacturer. Motors have been identified by a letter according to the outcome of the end-control vibration test (P-passed, F-failed), by an other letter indicating absence or presence of a Hall-sensor (N or H) and by a serial number (01-50).

Factory measurements contained only two sets of data for each motor (radial and axial accelerations of right rotated motors measured in 14 third-octave bands ranging from 400 to 8000 Hz). Acceleration measurements at the Vibroacoustic Laboratory of BUTE have been made in the same frequency bands. Moreover, the noise has also been measured and measurements have been carried out in both rotation directions.

As a typical example of the results, axial accelerations of the PN01-PN50 group rotated right are compared in Figures 1.a and 1b. Most striking is that while the factory measurements expose quite uniform behavior of the motors and show very small accelerations above 2500 Hz, the laboratory measurements present the motors as being very different and the accelerations have vivid spectra exactly at the high frequency range. This can be explained by the differences in the measurement methods. In the factory, the motors were fixed during the measurement in a rigid fixture and large-size accelerometers are attached to them by magnets. As the result, instead of measuring the motor itself, the motor-driven fixture is measured and because of the relatively large mass of the fixture, the high frequency acceleration components are suppressed. In the laboratory measurement, the motor was laid into a soft rubber 'cradle' and light-weight accelerometers were attached by bee-wax. It is also obvious that the tolerance limit given on the figures has been specified and adopted to the factory measurement method on statistical basis and has nothing in common with the weighted [dB(A)] requirement.

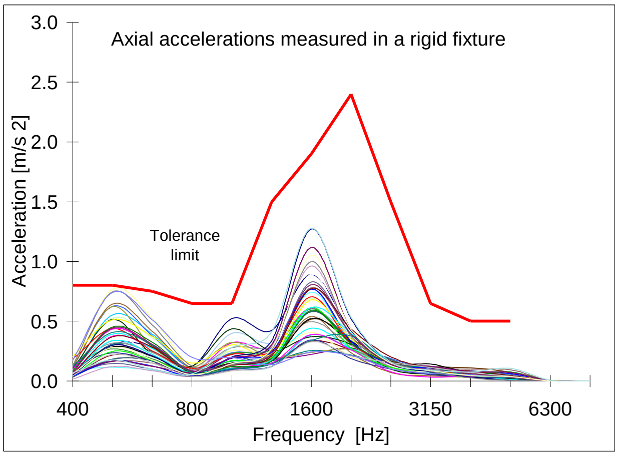

Figure 1.a Factory measurements of PN01-PN50 motors

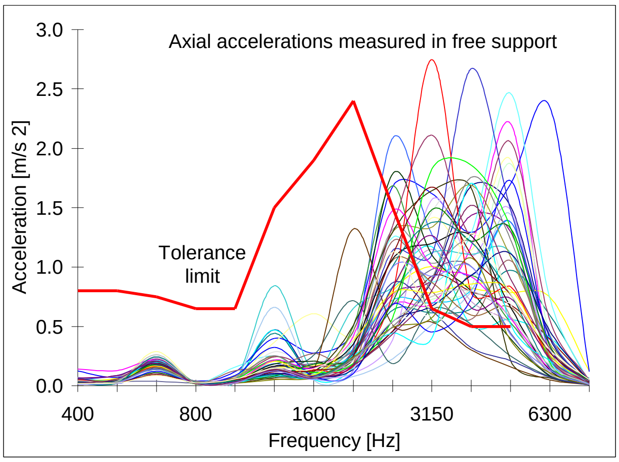

Figure 1.b Laboratory measurements of PN01-PN50 motors

The large differences in the autospectra of the freely supported motors foreshadowed that there might be several reasons of excessive noise generation.

Using the results of the laboratory noise measurements, Figure 2. shows the probability distribution for all tested groups as the function of noise level in dB(A). It is rather obvious from the figure that the vibration-based factory testing method is hardly suitable for noise evaluation, e.g. about 20 percent of PN group would have failed and about 75 percent (!) of the FN group would have passed in a real noise test.

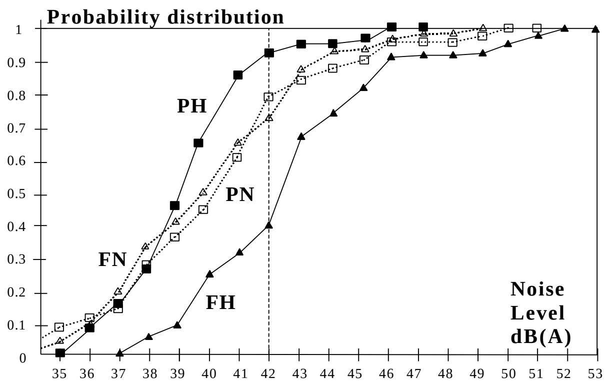

Figure 2. Probability distributions of motors vs. the noise level.

3. Transfer Path Analysis

A sample of the examined motors is shown in Fig. 3. The main part of the housing is made of a flat iron plate, folded to a cylinder and fixed by puzzle-like closings. On the right side, a metal conical cap with the rear bearing inside is attached while the left side is closed by plastic front bearing holder, containing the electrical connections, too.

Figure 3. The photo of the investigated motor

Numerous simple tests aiming at the rough localization of the main noise sources and transfer paths have been performed prior to the thorough investigation. Even by listening the loudness differences when hiding the cylindrical housing into the palm, covering the front bearing holder by the hand or squeezing the housing at different locations indicated that the noise is not generated by just one operating mechanism.

To provide for a systematic survey, a complex model of the noise generation and propagation has been established and further investigations and measurements have been made to prove the most probable assumptions. The complex model is shown in Fig. 4. The main parts of the motor are shown here as boxes while the lines indicate the magnetic, mechanical or acoustical connections between them. The bold lines show the assumed dominant paths.

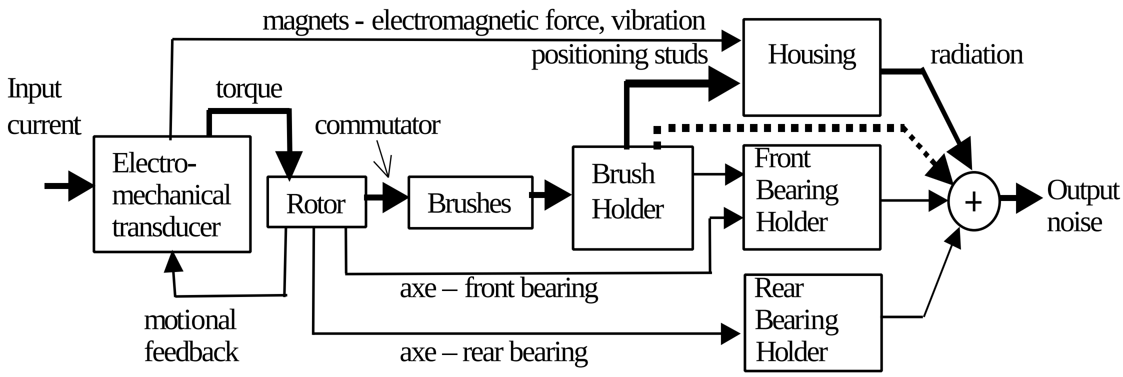

Figure 4. Noise generation and propagation model

Detailed vibration and noise analyses have been made on motors randomly selected from the mass-measured groups. Vibrations of the housing have been measured by accelerometers, vibrations of the brushes, brush holder, axis-ends and bearing holders by Doppler-laser interferometer. Measurements have been evaluated both in time and frequency domain by using wire frame animation and modal analysis, respectively.

Table 1. Modal analysis results

Empty housing		Complete motor	
Eigenfreq. [Hz]	Damping [%]	Eigenfreq .[Hz]	Damping [%]
(2490)	(0.9)	2492	3.8
(3267)	(3.3)	3130	8.0
(3580)	(0.3)	3306	3.7
(5758)	(3.5)	3723	3.2
(5761)	(3.3)	5547	5.1
(6473)	(0.3)	6573	4.2

One of the most important goals was to prove the dominance of the brush-generated vibration over the effect of magnetic forces. For this reason, two motors have been mechanically interconnected via a short Bowden cable and measured in the setup as given in Figure 5.

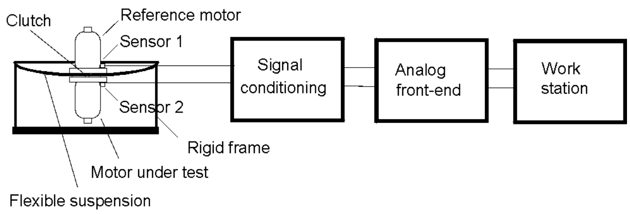

Figure 5. Experimental setup for two motors operated in tandem

Firstly, the tested motor was assembled and measured without the magnets and without the brush holder. Then the motor was completed one by one by the missing parts and finally it was the driving one. Having compared acceleration spectra measured by sensors 1 and 2, it turned out that the vibrations of the tested motor were stronger when the incomplete motor was driven with only the brush holder inserted, than the vibrations measured when the tested motor was the driving one!

The major role of brushes has also been proven by measuring the noise level with one minute periods on some newly assembled motors in the first 20 minutes of their operation (see Figure 6.). Although the changes are not monotonic, the decreasing tendency is unanimous for each case.

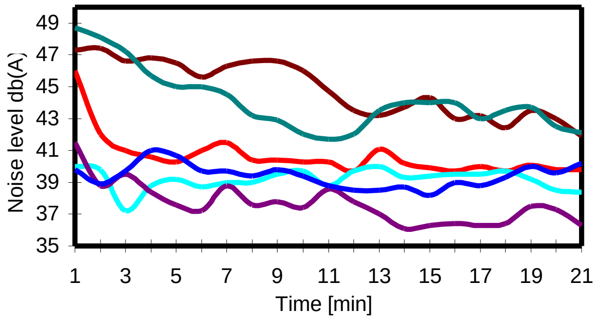

Figure 6. Variations of the noise level due to changes in brush-commutator contact

The results of all investigations were summarized as follows:

- The resulting noise is determined basically by the brush vibrations
- Brush vibrations originate in periodic nonlinear dynamic forces between the brushes and the edges of non-filled commutator grooves.
- Brush vibrations are partly radiated as a direct airborne sound through the holes of the front bearing holder (see the dotted line on Fig.4.). The main transfer path, however, leads via the brush holder to the housing which, being the largest surface, effectively radiates the noise if driven radially.
- Construction of the housing is partly favorable because the friction in puzzle closings effectively damp out the eigenfrequencies (see Table 1.). On the other hand, however, this is the way in which the tangential motion of brushes is converted to radial vibration of the housing.

4. Noise Reduction Experiments

To verify and to make use of the results obtained by analysis described in the previous section, several small modifications have been performed one by one on groups consisting of 5 motors each. The most effective modifications were as follows:

- attaching a reinforcement ring into the housing between the brush holder and the magnets (RR),
- filling up (stiffening) the brush-holder by resin (SB),
- keeping the brush vibrations away from the housing by weakening the brush holder's positioning studs and isolating them by plasticine (IBS, see Fig. 7.),
- eliminating the direct sound path by filling up the gaps of the front bearing holder by plasticine (FG),
- stiffening the housing by welding the puzzle-like closings (WP).

Figure 7. Front view of the motor (plastic bearing holder removed). Left: positioning studs weakened but still naked, right: studs isolated + rotor inserted.

It was previously verified (see Figure 6.) that the noise level tends to decrease if the newly assembled motors are run for some ten minutes to evolve a sliding layer on the commutator. Alike, slight hits on the motor housing relieve the stress in bearings. Modified motors have thus been measured twice, once immediately after being switched on for the first time and then - being hammered after a one-minute running - after ten minutes of running. The measurement was evaluated on group basis i.e. the average dB(A) noise level and its standard deviation has been calculated for each group and compared with a group of unmodified, factory assembled motors (REF). These values are given in Figures 8.a and 8.b.

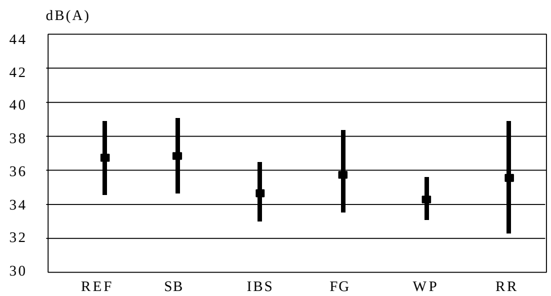

Figure 8.a Average noise levels and standard deviation of noise levels measured on modified motors after the first switching on.

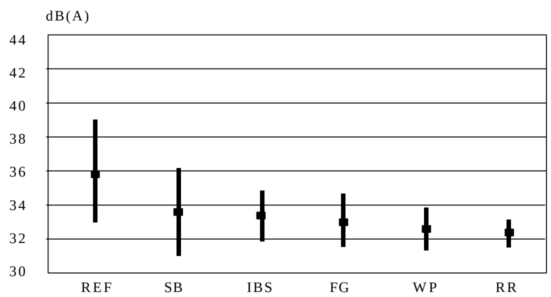

Figure 8.b Average and standard deviation of noise levels measured on modified motors after ten minutes run-in period

As can be seen from the comparison of figures 8.a and 8.b, differences due to modifications can hardly be observed immediately following the first switching on, but later, effect of all modifications presented here became quite significant.

5. Conclusions

As it had been previously expected, none of the modifications was enough on its own to reach sufficient and reliable noise reduction. This is because the behavior of these mass-produced, relatively cheap motors is not only time-variant but -due to relatively loose tolerances of components and that of their assembly- the significance of different vibration transfer paths is different for each produced sample, too. By combining some of the most effective modifications, however, motors having only 30-32 dB(A) noise level have been assembled.

6. Acknowledgements

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7. References

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