KÜLÖNBÖZŐ AUTÓIPARI CSAPÁGYAK ELEKTROMÁGNESES KOMPATIBILITÁSI HATÁSAI

ELECTROMAGNETIC COMPATIBILITY EFFECTS OF DIFFERENT BEARINGS IN AUTOMOTIVE INDUSTRY

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ABSTRACT

The effects of different bearings on EMC might be an uncommon idea, but in electric motors, it can be the source of unwanted electromagnetic radiation. This article is about a BLDC motor, where only with different type of bearings we could achieve decreasing of radiated electromagnetic waves. As this motor is part of a cooling fan for automobiles, we should consider other automotive applications. BLDC motors are widely used in modern vehicles, due to several advantages, but EMC might be their biggest issue in some applications if they are not properly designed.

1. INTRODUCTION

As a part of a bigger project, we were analysing an automotive cooling fan module. For us, EMC of the driving motor was in spotlight, but we should have work and consult with colleges with other specialization in order to achieve the best results. In this article a brief summary is about BLDC motors in general to learn about its working principle, then another short section is about EMC and finally our measurement method and results are written, we made on the mentioned driving motor.

2. BLDC MOTORS

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not produce “slip” that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used [1].

A brushless motor is constructed with a permanent magnet rotor and wire wound stator poles. Electric energy is converted to mechanical energy by the magnetic attractive forces between the permanent magnet rotor and the rotating magnetic field induced in the wound stator poles. *Figure 1.* shows a simplified illustration of BLDC motor construction.

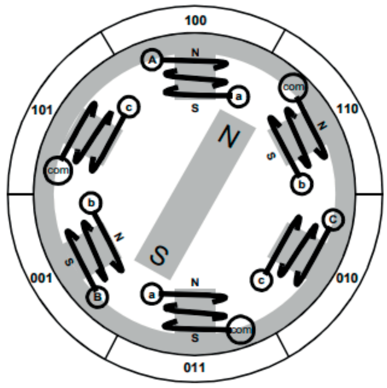

Figure 1. Simplified BLDC motor construction [2]

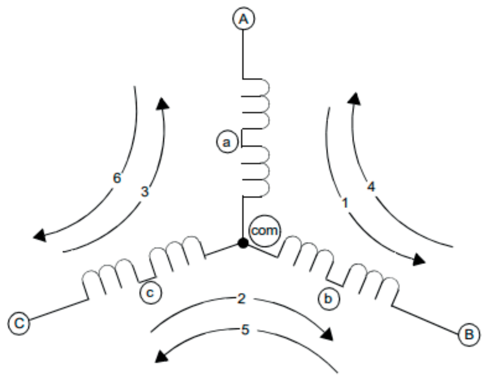

Figure 2 Three-phase windings with terminals [2]

Most BLDC motors have a three-phase winding topology with star connection. A motor with this topology is driven by energizing two phases at a time. The three-phase winding is feed by a three-phase inverter and the electronic commutation is implemented also by the inverter. *Figure 2.* shows the three-phase windings in star connection and the terminal names which are corresponding to *Figure 1.* Three-phase motors are better than two-phase design, because the rotating magnetic field is much more symmetrical. The three-phase windings make less EMC noise.

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive, but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to be compressed further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Neodymium (Nd), Samarium Cobalt (SmCo) and the alloy of Neodymium, Ferrite and Boron (NdFeB) are some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to compress the rotor further.

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into the stator.

Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever magnetic poles of the rotor pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

The Hall sensors increase the price of the motor. The sensors can leave, if we measure the motors back EMF. When a BLDC motor rotates, each winding generates a voltage known as back Electromotive Force or back EMF, which opposes the main voltage supplied to the windings according to Lenz's Law. The polarity of this back EMF is in the opposite direction of the energizing voltage.

2.1. The analysed BLDC motors

The motors of our project (*Figure 3.* shows) compliance the required emission rates, but in stricter conditions, for example in electric vehicles electromagnetic (EM) radiation of them should be reduced.

It has two phase winding, which is not the best choice if EMC is important. Next to the winding, the rotor has permanent magnets, 5 of them which can cause not some mechanical but also magnetic issues, because they are not so close to each other and the magnetic flux lines are not evenly distributed inside the rotor. The control electronics are on the back side, on a baseplate, which is also used for mounting the motor onto the whole fan assembly. The controlling here works with back EMF, so our motor doesn't contain Hall sensors [3].

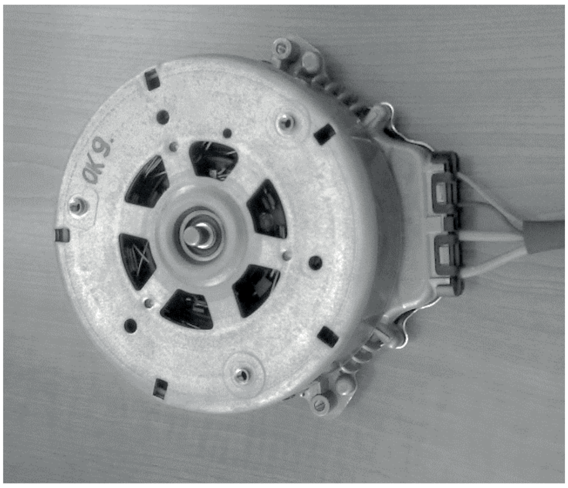

Figure 3 The driver BLDC motor of the cooling fan module

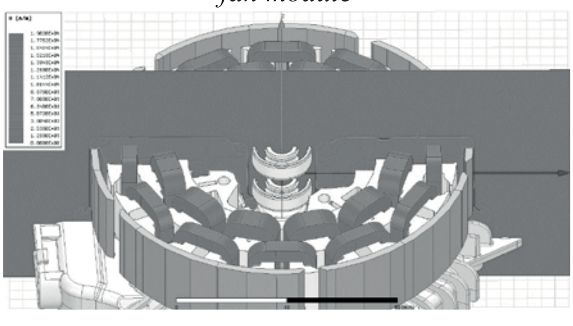

Figure 4 3D FEM analyses on the BLDC motor

It needs 12 V DC power and a simple 100 Hz PWM signal with 15-90% duty cycle to set the RPM. The rotor is connected to the shaft of the stator with a simple ball bearing. Before we have made modification plans, we had had to carefully analyse the source of the radiated electromagnetic waves. We also made 3D FEM analyses of the motor (*Figure 4.* shows), so we could learn more about the electromagnetic fields and how they change if we modify the motor.

Next to changing other parameters and parts, we made a choice to try other type of bearings. Different types of bearings have different electric conductivity, which is important for us, because of the shape of the rotor. The metal part of the rotor may work like an EM shielding, but if it is not properly connected, it causes other, unwanted problems. Charges can amass on the metal surface which, like a capacitor, can discharge in short periods, causing high frequency EM waves. The precision of the bearings influences the air gap between the rotor and stator, and magnetic flux could "escape" the motor, causing low frequency magnetics problem [4].

3. SHORTLY ABOUT EMC

Every electronic device radiates electromagnetic waves. Some of them might malfunction from a higher level of other devices radiation. These two properties are called electromagnetic compatibility or EMC. Emission rates, EM immunity and the different measurement methods are restricted by local and international standards. In automotive industry CISPR 25, CISPR 12 and ISO 11452-2 are the most important restrictions [5, 11, 12]. Engineers must make their plans, factories must produce devices, EMC laboratories must measure in a way, just like the restrictions say.

All kind of electric motors have different EMC problems. It depends on the size, the required voltage type, having brushes or not, how speed controlling work, how the stator and rotor produce the magnetic field, what materials are used in the construction and so on. We had a BLDC motor, which type has major advantages. The main reason it is used more frequently nowadays, the lack of brushes and wide variety of size and power, but it needs an electrical commutation, which can have EMC problems.

4. MEASURING TECHNIQUES AND RESULTS

We made the comparison measurements with the following settings and methods.

Evaluation method:

- Radial and axial measurements
- Horizontal and vertical antenna polarity
- The distance between the EUT (Engine Under Test) and the antenna is exactly 30 cm
- Duty cycle of the controlling PWM signal: 0%, 25%, 50%, 70%, 90%
- Measurement frequency range: 100-1500 kHz
- Evaluated frequency range: 900-1100 kHz
- 4 distinct frequency have been chosen to evaluate the amplitude: 900 kHz, 966,667 kHz, 1033,33 kHz, 1100 kHz
- In the examined frequencies RMS (Root Mean Square) value of the amplitude is calculated (1)
- We calculated the ratio between the RMS values of the original EUT and the modified EUT. It's marked with "H". If $H<1$, then the modification made an improvement, if H is about 1, there were no improvement and if $H>1$, that means the modified version performed worse.

$$RMS = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} x_i^2} \qquad (1)$$

where *RMS* is Root Mean Square, *N* is the number of samples, *i* is the index number, x_i is the i-th value of *x*.

We made 24 different measurements on each EUT (4 different antenna arrangement and in one arrangement 6 different RPM). We created a specific excel sheet in order to do the mathematical calculations. We used only the data required for our evaluation method, because the measurement makes almost 15000 data points per EUT.

EMC measurements require precise measurement methods and equipment, showed on *Figure 5.*

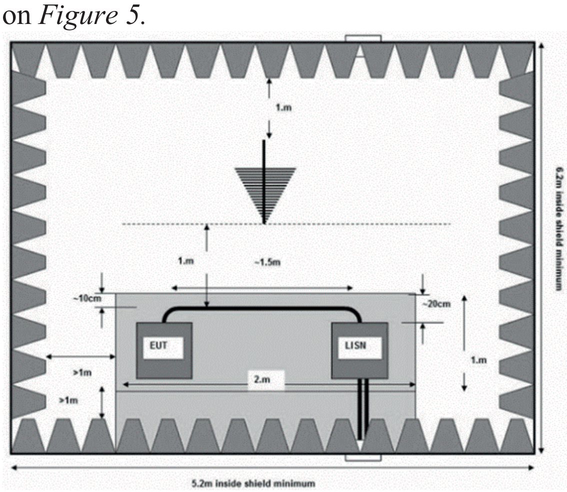

Figure 5.: Proper automotive EMC test method according to CISPR 25 [9, 10]

Our measurements were made in our EMC laboratory. This lab is owned by the University of Miskolc, Institute of Physics and Electrical Engineering, Department of Electrical and Electronic Engineering. It is in building A3, on the basement floor. This lab is not an accredited, proper EMC laboratory, but it has a good electromagnetic shielding, and we made our best to build the required test conditions. It must be mentioned that the later detailed measuring data is only for reference, it can't be used for qualification purposes. At earlier stages we used an old PMM 7000 emission precompliance system, but the lack of the suitable antenna and software support, we decide to use a more modern device [6].

We used a handheld spectrum analyser FSH-8 from Rohde & Schwarz for the measurements and a computer to collect the data with. The antenna was a HE300HF antenna. Its frequency range is from 9 kHz to 20 MHz [7, 11]. Other test equipment was an oscilloscope (to set the control PWM signal precisely), a simple analog PWM signal generator, a car battery (for supply DC power for EUT). The EUT was mounted with wooden blocks on a metal plate covered wooden table. The covering plate was grounded. We made an extra grounding pole into our lab to increase the grounding properties in order to achieve higher shielding factors [8]. One of the measurement arrangements is showed on *Figure 6.*

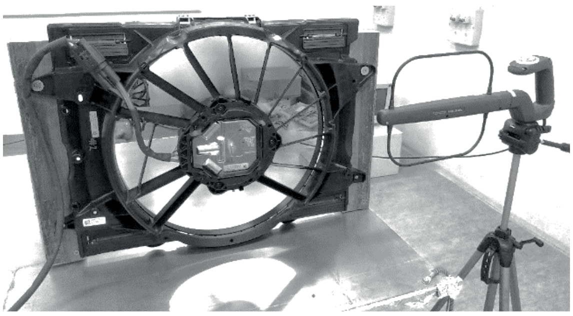

Figure 6.: Cooling fan module (EUT) under measurement

The results of our measurements lead to the fact, that in the radial direction modules produce less electromagnetic radiation in the full examined frequency range. Due to this fact, we used the axial directional data when comparing different modifications and modules. We made another simplification, not to use the horizontal data, because vertical radiation was much more intense at all modules.

(We made all the measurements, but at the final evaluation we used only the limited data). According to the usage of these modules, important PWM duty cycles are 25%, 70% and 90%, so we could ignore more data. All these considerations result in a massive decrease of evaluated data points. From the 15000 collected data, we only had to analyse 270. The settings of the spectrum analyser are in *Table 1.*

Table 1.: Applied settings on FSH8

Settings	Value
Middle Frequency	800 000 Hz
Frequency offset	0 Hz
RF dampening	manual
RF dampening	0 dB
Preamp	ON
RF input	50 Ohm
RBW	10 000 Hz
VBW	100 000 Hz
Sweep time	200 ms
Type of measurement	Average
Detection method	RMS
Primary transducer	HE300A-HF
Number of averages	10

The original module contains ball bearings. Modifications were used to test different bearing types (3 different types from the original).

Name of the analysed samples:

- **A0, B0, C0 samples**: these were original products, each of them has been modified after the measurement.
- **A1 sample**: modified with higher grade precision bearing
- **B1 sample**: modified with needle roller bearing
- **C1 sample**: modified with angled bearing

Table 2.: Normalized amplitude of electromagnetic emission of ***A0 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	8,591	15,425	2,379
966 666,67	7,675	16,324	2,503
1 033 333,33	8,201	16,601	1,482
1 100 000,00	7,307	17,121	1,603
RMS	6,800	15,361	1,934

Table 3.: Normalized amplitude of electromagnetic emission of ***A1 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	7,646	11,736	1,412
966 666,67	6,385	14,747	1,399
1 033 333,33	7,515	15,966	2,429
1 100 000,00	8,442	14,285	2,424
RMS	7,322	13,854	2,104

Table 4.: Emission ratio between the original (A0) and modified (A1) modules

Ratio	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	0,890	0,761	0,594
966 666,67	0,832	0,903	0,559
1 033 333,33	0,916	0,962	1,638
1 100 000,00	1,155	0,834	1,512
RMS	1,077	0,902	1,088

Table 5.: Normalized amplitude of electromagnetic emission of ***B0 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	8,724	13,492	2,908
966 666,67	9,385	16,785	3,656
1 033 333,33	9,887	14,304	3,551
1 100 000,00	7,651	14,322	2,617
RMS	7,516	14,094	3,176

Table 6.: Normalized amplitude of electromagnetic emission of ***B1 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	6,719	15,894	2,554
966 666,67	8,294	13,124	3,081
1 033 333,33	8,893	13,520	2,056
1 100 000,00	7,195	14,925	2,674
RMS	6,912	13,016	2,567

Table 7.: Emission ratio between the original (B0) and modified (B1) modules

Ratio	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	0,7702	1,1780	0,8782
966 666,67	0,8838	0,7819	0,8428
1 033 333,33	0,8995	0,9452	0,5791
1 100 000,00	0,9404	1,0421	1,0219
RMS	0,9196	0,9235	0,8083

Table 8.: Normalized amplitude of electromagnetic emission of ***C0 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	9,207	14,327	2,628
966 666,67	8,609	15,133	3,042
1 033 333,33	10,352	15,261	3,098
1 100 000,00	9,767	15,297	3,793
RMS	8,110	13,553	3,006

Table 9.: Normalized amplitude of electromagnetic emission of ***C1 sample***

[dBμV/m]	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	6,129	11,317	2,078
966 666,67	5,949	13,888	5,345
1 033 333,33	6,704	14,889	2,029
1 100 000,00	6,684	13,062	2,086
RMS	5,740	12,282	2,687

Table 10. Emission ratio between the original (C0) and modified (C1) modules

Ratio	PWM		
Frequency [Hz]	**25%**	**70%**	**90%**
900 000,00	0,6657	0,7899	0,7908
966 666,67	0,6910	0,9177	1,7570
1 033 333,33	0,6476	0,9757	0,6547
1 100 000,00	0,6843	0,8539	0,5499
RMS	0,7077	0,9062	0,8938

With the acquired data we could calculate an approximated measurement error and determine the linear and RMS value of changes. *Table 11.* shows that measurement error was less than 2% at all measured modules, furthermore negative percentage means that underestimation is common.

Table 11.: Results of the evaluation method

	„A”	„B”	„C”
Approximated error percentages	-1,036%	-0,653%	-1,947%
Linear value of changes	-4,37%	-9,83%	-17,66%
RMS value of changes	-7,46%	-8,74%	-15,68%

From linear and RMS changes, RMS values are more representative due to our evaluation method mentioned before. Signs in these rows shows the direction of change, so a negative sign means improvement. The results show that C1 sample performed the best, so the angled bearings have the best EM emission levels.

Higher grade precision bearings in A1 sample worked well, because it produced a better dynamical balancing, which affect the EM radiation. Airgap between stator and rotor can change less due to the better balancing, so magnetic force lines scatter less. Needle roller bearing and angled bearing can decrease not only the dynamic balance, but also improve conductivity between the stator and rotor.

This reduces the shock-like electrical pulses between the two parts, which significantly reduces the pulsing EM emission. As a result, time-based emissions are also reduced.

5. SUMMARY

The goal of the whole project is to reduce the EM emission rates of this automotive cooling fan module. The driving BLDC motor have minor EMC problems and this article was about only one part, the ball bearings. We tried different type of bearings and as a result we can say that it is possible to reduce electromagnetic noise by changing the bearings in this motor.

6. ACKNOWLEDGMENTS

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