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Analysis of the possibility of using LC passive filtration methods in reducing the radiated emission of brushed universal motors

Abstract. The influence of electromagnetic fields on human organisms is currently a popular direction of research in numerous research centers around the world. The article deals with the measurement of the radiated component of the electromagnetic field, which accompanies the operation of the still popular universal commutator motors and the passive method of its reduction. The research on the radiated component of the electromagnetic field was carried out with the aim of exposing users of home appliances and power tools, especially those located in the immediate vicinity. The measurements were carried out in two stages. Initially, emission parameters were acquired without LC elements, limiting the radiated components of the electromagnetic field. Then, these elements were introduced and the effectiveness of emission reduction was analysed. The results were briefly analyzed and referred to the currently applicable legal acts.

Streszczenie. Oddziaływanie pól elektromagnetycznych na organizm człowieka jest obecnie popularnym kierunkiem badań w licznych ośrodkach naukowych na całym świecie. W artykule zaprezentowano wartości składowej pola elektromagnetycznego towarzyszącej pracy wciąż popularnych uniwersalnych silników komutatorowych oraz pasywną metodę jej redukcji tej składowej. Badania promieniowanej składowej pola elektromagnetycznego przeprowadzono w celu narażenia użytkowników sprzętu AGD i elektronarzędzi, zwłaszcza tych znajdujących się w bezpośrednim sąsiedztwie użytkownika. Pomiary przeprowadzono w dwóch etapach. Początkowo parametry emisyjne pozyskiwano bez elementów LC, ograniczających komponenty promieniowane pola elektromagnetycznego. Następnie wprowadzono te elementy i przeanalizowano skuteczność redukcji emisji. Wyniki zostały poddane krótkiej analizie i odniesione do aktualnie obowiązujących aktów prawnych. (Analiza możliwości zastosowania metod filtracji pasywnej LC w ograniczaniu emisji promieniowanej silników uniwersalnych szczotkowych)

Keywords: Universal Commutated Series-wound Motor , Electromagnetic Field (EMC), Exposure,
Słowa kluczowe: uniwersalny silnik szotkowy, pole eletromagnetyczne, ekspozycja.

Introduction

Pulse changes of the value and the direction of the current caused by commutation accompany the process of energy conversion in universal commutator motors. They are related to the generation of electromagnetic disturbances. Due to the good proportions of mechanical parameters and weight, the use of such engines in the 1990s and 2000s was almost without alternative. Universal commutator motors appeared in power tools, household appliances and high-speed electric drives. It should be noted that the construction of such a motor is similar to the construction of DC commutator motors. However, the DC brush motor technology is accompanied by the fact that the source of energy for them are often electrochemical cells or simple systems of DC installations. Motors connected to the AC power mains operate on the basis of a much more extensive electromagnetic environment. They should be designed and constructed in such a way that they are not a source of these disturbances in a normal environment and are resistant to a certain level of disturbance. The issues of modern electric drive technology prove that this problem is important not only in AC universal brush motors, but also appears on a large scale in BLDC brushless motors. Despite the implementation of commutation with the use of semiconductor switching devices, the mechanism of generating disturbances remains unchanged. The commutation of the armature current is similar as a result and is the basis of motor operation. This fact gains particular importance when considering the exposure of users of the equipment in which they are the source of propulsion [1-5].

Universal commutated series-wound motor

The history of the idea of AC power supply for a single-phase brushed motor with a leakage commutator in which the excitation windings are connected in series to the commutating brushes began in the mid-1880s. It is obvious that in a series motor, the change in the direction of the current occurs simultaneously in the armature and the excitation circuit. Due to that fact the electromagnetic torque

of such a machine results from three components: structural constants, product of current and magnetic flux. The torque vector does not depend on the direction of the current. This situation strongly distinguishes these motors from the group of motors excited by permanent magnets. The main excitation magnetic circuit is made here as a sheet metal construction. The motor, operating on the voltage from the power grid, emits to it the harmful consequences of current pulsations caused by the commutation of the armature and the alternation of the supply current. There are also shunt commutator motors - the excitation winding is connected in parallel with the armature commutating brush system. Repulsion motors are a variation of commutator motors. In repulsion motors, there is no galvanic connection between the armature and the excitation. Energy is transported only by electromagnetic means. The armature is usually short-circuited by closing the circuit through the brushes. Changing the position of the brushes relative to the magnetic axis of the stator allows you to adjust the speed of the direction of rotation [6-10].
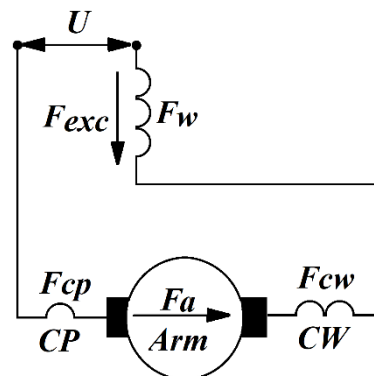

Fig. 1. Classic scheme of a series universal motor, taking into account the inductance of the commutation and compensating poles

In classical terms, the series circuit shown in Fig. 1. was given as the correct schematic representation of a universal

motor. It consists of an excitation winding *FW* and an armature *Arm*. In the circuit, the armature is preceded by a *CW* inductance, used as a winding to compensate for the effects of commutation current pulsation and to improve the power factor. Due to the widespread use of commutation poles, the diagram was supplemented with the *Cp* element and the *Fcp* parameter. The fact that the excitation current is also the armature current causes the electromagnetic torque of the machine to fluctuate in each half-period of the supply voltage without reversing the direction of the torque vector. Sharma S., Manna M., in publication titled *Finite Element Electromagnetic Based Design of Universal Motor for Agro Application* they publish equivalent diagram of universal motor according to Fig. 2 [15].
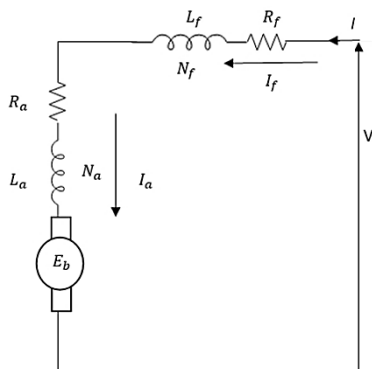

Fig. 2. Equivalent circuit of universal motor, where: *V* - supply voltage, *I* - load current, E_b - back emf, I_a - current of armature, I_f - field winding current, R_a - resistance of armature winding, R_f - resistance of field winding, L_a - inductance of armature winding, L_f - inductance of field winding, N_f - field winding number of rotational turns, N_a - number of turns of armature winding. $I = I_a = I_f$

The disadvantage is that theoretically such a motor cannot run without the load, because zero braking torque will result in an increase in rotational speed indefinitely. This problem is usually solved by mounting a fan for mechanical cooling on the rotor shaft. An increase in speed then causes an increase the braking torque in cubic function, unless the motor load itself represents an incremental characteristic as a function of rotational speed. Importantly, at high rotation speeds, due to the very complicated commutation process and the increasing importance of parasitic parameters, such machines with a power of several hundred watts do not have commutation poles. The transformation voltage generated in the commutating turns partly compensates for the rotation and self-induction voltage[16].

Metodology of research

The article describes research on the emission of radiated disturbances generated by a universal brush motor and the possibility of using a passive reduction of these disturbances by introducing a passive RC coupler as an armature shunting circuit. A modern universal motor with a power declared by the manufacturer of 280 W, which was commonly used in small household appliances, was selected for the study. The engine idling speed was set at 23 200 rpm. Commutator with the number of segments 10. During the tests, the motor was powered from the public power grid with a voltage in the range of 223-231 VAC and a frequency of 50 Hz and was loaded with the torque through a worm gear and its own fan, so as to maintain the rotational speed at about 20 000 rpm. The tests were carried out on a measuring stand equipped with a *Tesseq GTEM 1000* chamber with a *Gauss Instruments TDEMI 1G* measuring receiver connected. In the first round of measurements, the motor was not supplied with a set of

elements forming: the capacitor or LC resonat circuit, which paralel of the armature witch the nodes of the commutating brushes. In Figure 3. This parallel fragment is shown [17].
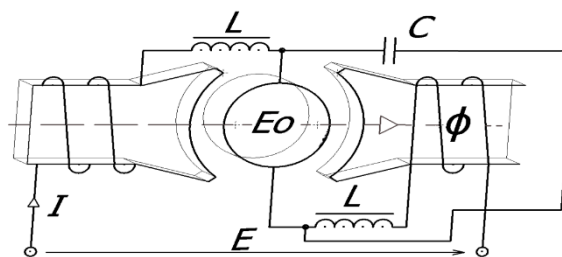

Fig. 3. Illustrative diagram of a universal AC motor with a damping capacitor in a parallel circuit of commutating brushes

In the next step, the measurements were repeated using filtration, according to the diagram in Fig. 3. A capacitor was used. It is worth noting that the use of small capacitance capacitors to filter radio interference in brushed motors is a popular practice. Interestingly, promising parameters for reducing the radiated components measured in the chamber were brought about by the use of more than just the capacitor. Better effects were observed when a series resonant LC circuit was installed in parallel with the armature. Various parameters of capacitance and inductance were used, leading to the initial selection, taking into account the commutation period. Corrections of the parameters: capacitance and inductance have already been carried out empirically, by repeatedly acquiring the level of disturbances in the *GTEM* chamber. Passive elements were used so as to keep the parasitic parameters to a minimum. *FERYSTER DTMSS-27 sendust power inductors* and *WIMA* Polyethylene Terephthalate capacitors. The minimum lengths of the connection wires of the branch with the brushes were maintained, at most several centimeters. Tests were carried out, in accordance with the PN-EN55014 standard, in the entire measurement range, i.e. from 30 MHz to 1 GHz, using the QP detector and the resolution bandwidth of 120 kHz. A class B household device was subjected to filtration analysis. Devices of this class are subject to more restrictive regulations than class A devices (commercial use). The difference between the test limit levels at 3 m and 10 m is 10 dB for the device under test. In order to reduce the emission of radiated components, the filtration method was applied by introducing L or LC passive elements into the armature circuit [18]. It is worth noting that there the method is not related to the shielding of elements or other direct methods compensating for the radiated components. By selecting the LC resonat circiut, which is an elementary countermeasure affecting the current derivatives during commutation. Used
Figure 5 presents the emission values of the radiated electromagnetic field component measured in the *GTEM 1000* chamber with reference to the limit values (PN-EN55014), as a function of frequency.

Results

The measurement of radiated disturbances was carried out several times. Very similar graphs were obtained. One of them is shown in figure 4. Exceeding the parameters contained in the legal standard is evident almost in the entire measurement range. The extremes of this graph are characterized by a certain regularity. They are around at 100 MHz, 150 MHz, 200 MHz, 250 MHz, 300 MHz of frequency. Another extreme is observed in the range of 460 - 500 MHz. In the upper part of the band, the fluctuation shallows out. However, there are exceedances- Fig. 4. This fact does not mean that the kitchen mixer appliance did not

comply with the applicable legal directive at the stage of its introduction to the market. The device was tested after a certain interval of use, where the commutator, brush set and bearings were characterized by some wear. The operation of the rotor could be characterized by a certain eccentricity, which worsened commutation and favored disturbances. The engine was tested only, so the speed control system and EMC capacity was also removed.
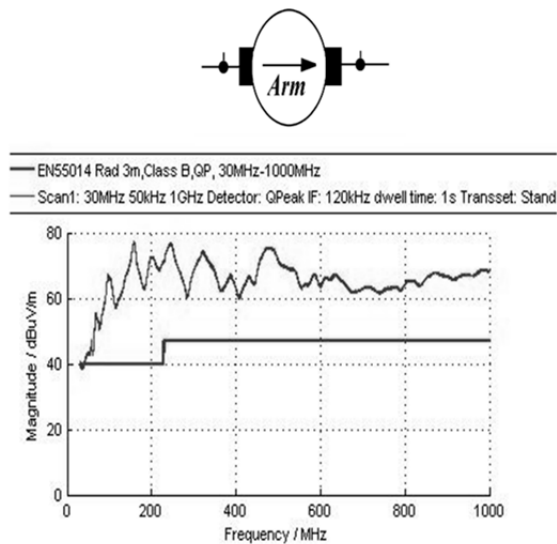

Fig. 4. Diagram of disturbances radiated by the motor without the passive EMC filtration system

Then, attempts were made to limit the disturbances by placing a capacitor. In these operating parameters, the reduction was provided by the capacitance of 470 nF. Figure 5 shows this situation. There were also attempts to build an rc snubber parallel to the commutator brushes, using resistances in the range of several to several dozen ohms.The frequency response of the attenuation changed. exceedances remained.
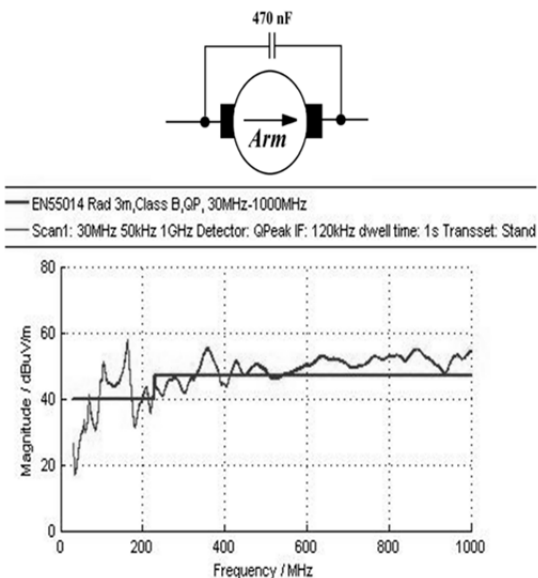

Fig. 5. Diagram of disturbances radiated by the motor with the paralel capacitor

Figure 5. shows this situation. A large part of the radiated emission has been reduced. The extremes we see occur again around the100 MHz, 150 MHz, 350 MHz points.

The next measurement steps show that promising electromagnetic properties are obtained by placing a series resonant LC circuit in parallel with a set of commutating brushes. These situations, with the graphs and parameters of the elements, are shown in the figures 6-9

Characteristics for the component set: The capacitance of 470 nF and inductance of 30 μH are shown in Figure 6
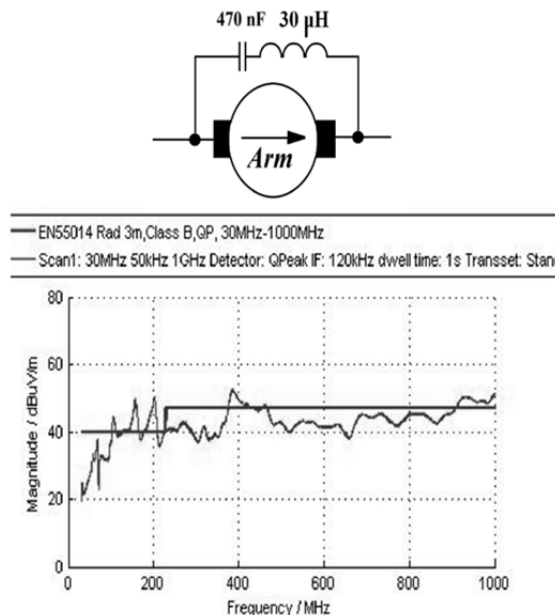
Fig. 8. The capacitance 1000 nF and 33 μH of inductance

Fig. 6. Diagram of disturbances radiated by the motor with the resonat circuit where L =30 μH, C =470 nF

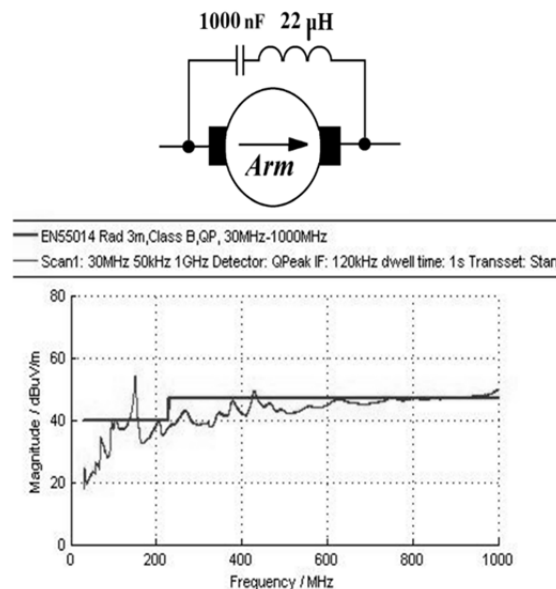Fig. 7. Characteristics for the component set: The capacitance of 1000 nF and inductance 22 μH

Fig. 7. Diagram of disturbances radiated by the motor with the resonat circuit L =22 μH, C =1000 nF

Fig. 8. Presents the result of using 1000 nF and 33 μH of inductance

Based on the measurements, it can be said that the lowest values of the radiated component parameter were provided by the set of elements shown in figure 7. There are no gross overshoots of the upper part of the range.
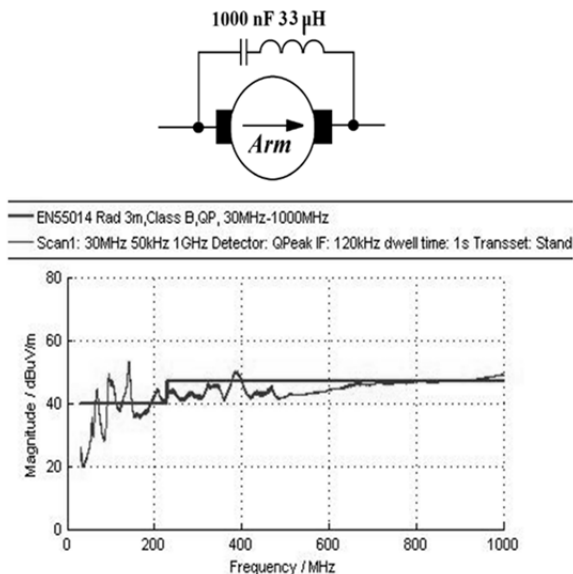
Fig. 8. Diagram of disturbances radiated by the motor with the resonat circuit (100 nF, 33 μH)

Summary

The article is a continuation of a research series devoted to the measurement of the emissivity of popular electrical devices, admitted to the market and operation. The measurements were carried out using the GTEM1000 chamber. It was assumed that the emission level recorded inside the chamber should reach the maximum value of min. 6 dB lower than the permissible values specified in the standard

The available measurement charts show that the transmission of radiated emissions under the control of the European Union is a non-trivial issue. A device that hits the market, after a certain interval of use, may show some discrepancies and exceedances.

Passive interference reduction is effective provided that a certain set of tuning works related to the selection of elements is carried out. The article uses an unusual method of a resonant system. Determining whether significant changes in the motor operating conditions, including load, power supply parameters will significantly deteriorate the EMC parameters, requires further research.

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