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EMC Case Study: Using Resistors Instead of Ferrite Ring to Reduce Emission of Battery Powered Equipment

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***Abstract* – Electromagnetic compatibility levels of the electrical and electronic equipment limited by relevant standards has more and more importance with increasing number of device density. EMC basic concept states that the conformity of a product must be ensured at the design stage. Retrospective solutions are usually much more expensive. Nonetheless, numerous post-modification methods are used in many products. A typical example of these is the separately built-in mains interference filter, ferrite rings placed on wires, clamp on ferrites. This type of modifications incurs significant additional costs in mass production including not only the cost of the additional materials, parts or equipment but also the related services. Although several proven retrospective methods exist for reducing emissions afterwards, these are far not the optimal solutions in terms of the costs. This article describes a cost-effective solution for the retrospective EMC level reduction.**

I. INTRODUCTION

In 2021, we have performed a radiated emission measurement on a commercially available, battery-powered household appliance. The product met the requirements of the standard using ferrite rings placed on the most critical point of the wire [1]. The original aim of the measurements was comparing emission level reduction efficiency of ferrite rings from different suppliers and defining the cost reduction capability of different ferrite rings. We have to state, that exact technical and material specification of the ferrite rings were not available, but this information did not affect the evaluation of the original measurements or the evaluation of the measurements for further scientific research, and this information was not required to achieve the result. As the manufacturers are not public, the article refers only to the various ferrite rings in the numbering.

Results of the first set of measurements performed according to the original requirements, we have stated that there are no significant differences between the emission reduction levels of the three different ferrite rings. After performing the original tests we have received permission to perform further measurements with aim of scientific research and competence development.

We performed various measurements to determine and analyze effects of the incorporated ferrites, learned about the product, and then began systematic solution determination resulting neglection of the relatively expensive ferrites.

II. HARDWARE SITE OF THE MEASUREMENT

The measurement of the EMC emission of the battery household appliance was limited to the measurement “Radiated emission - 30 MHz to 1,000 MHz” according to the standard [1].

Measurements were performed in a SAC-3 type semi anechoic chamber with a measuring distance of 3 m (Fig. 1.).

The measuring antenna is an HL562E ultralog, to which a BBV 9744 preamplifier is connected. The end of the measuring chain is accompanied by ESR26 measuring receiver with K53 "Time domain scan" option, and an automated positioning system served the moving of the antenna and rotating of the product.

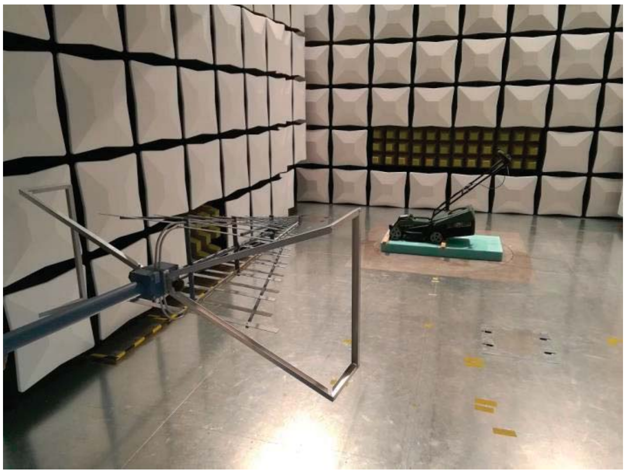

Fig. 1. Measurement setup of radiated emission measurement

III. SOFTWARE SITE OF THE MEASUREMENT

We have started the measurement planning with definition of our test procedure in the measurement control software. Radiated emission measurement for commercial equipment consists of several steps. The overview of this process can be seen in Figure 2. The purpose of multi-stage measurement is to find the most critical frequencies for EMC emissions and their most critical positions. Final measurements must be performed at these frequencies and positions. Otherwise, the standard does not provide an accurate description for determining the most critical points, leaving this responsibility to the person planning and performing the measurement. Accordingly, measurement settings not defined in the standard are usually determined jointly by the design engineer and test engineer.

A. Preview Measurement

Preliminary measurements were performed similarly to the final measurement with a quasi-peak detector, but with a much shorter measurement time. While 1 sec is used in final measurement, in preview measurement 50 ms was used. The standard allows the use of "Fast scan" or time domain-based measurement, which greatly reduces the time required to perform measurements. This is especially important for cordless machines, as the measurement time is limited by the accumulator capacity. The resolution bandwidth (RBW) is 120 kHz.

Preliminary measurements were performed with an antenna height of 1.5 m, in the 0 °, 45 °, 90 ° position of the turntable, in both horizontal and vertical polarization for the entire frequency range. The results of the total of 6 measured curves are combined into separate vertical and horizontal views.

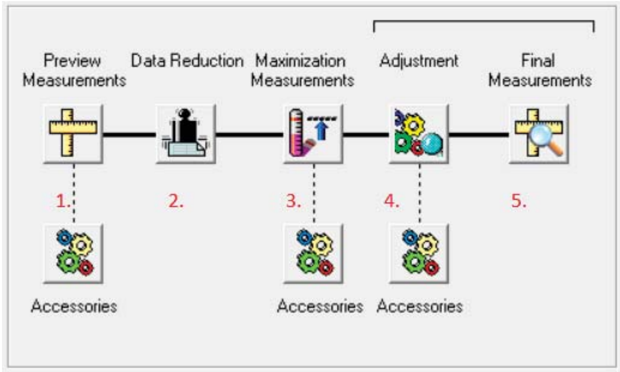

Fig. 2. Simplified measurement process in EMC32

B. Data Reduction

The software offers several automated options for selecting the points to be measured in detail, i.e. a given antenna height and position with a given product position pairs results a test setting for final measurement. In our setting definition we only used the "Peak Search" function with a relative threshold level of 6 dB. It should be noted, however, that "Interactive data reduction" is always active, meaning that after automated evaluation, we have the option to manually delete the suggested points and add points that we find interesting. According to our experiences, we typically pass on 6 points, unless the pre-measurement justifies clarifying additional points. Number of test point passed to final measurement highly increases the testing time, therefore six points proved to be a good compromise for cordless machines.

C. Maximization Measurement

The purpose of this test step is to determine direction in which the emission of the product is the highest. The standard [1] gives several recommendations for positioning of the turntable. We decided to position the table in every 15 degrees and to perform the measurement at rest, which means tests are performed in 24 positions. Measurements were performed in both vertical and horizontal positions. This means 48 positions were tested and analyzed. At each position, the critical frequencies determined in the previous step are measured with a measurement time of 50 ms. It means that the clear measurement time is much less, then the positioning of the turn table. The net measuring time is about 300 ms at each position while the time of the turning is about 3 sec. In this test step, the height of the antenna is not changed, mainly because this would mean an unacceptably long measurement time for a battery-powered machine. For some types of battery-powered machines, it is still necessary to replace the battery several times during the test process.

D. Adjustment and Final Measurements

In the flowchart, the adjustment and the final measurement are shown as two separate steps, in reality they take place directly one after the other at each critical point.

Each critical measurement point has an antenna height (which in this case is 1.5 meters), a polarization state, and a rotary table angle from the previous step. The "Adjustment" step is used to refine this worst case. First, the rotary table is turned slowly in the range of ± 15 ° from its pre-existing position, while the interference emission is continuously measured using the polarization inherited from the previous step. This process provides detailed environment checking of each critical point which was defined in the previous step. From this we get the worst-case scenario of the turntable position.

Next step is the changing the height of the antenna from 1 m to 4 m to find the worst-case height. After defining the worst-case antenna position and worst-case product position on the turntable, the positioning system adjusts these positions and the "Final Measurement" is performed.

IV. UNCERTAINTY, LIMIT AND MARGIN

In the field of EMC, several sources [2][3][4] deal with the professional determination of the measurement uncertainty of different measurements. The measurement uncertainty of emission measurements performed with antennas is relatively high, the standard also estimates a value of around 6 dB. The research team has calculated the measurement uncertainty of their own system, and the result was slightly below 6 dB.

The calculations are very complicated and not scope of this paper, however we would like to give an overview which type of uncertainty should be taken into account. First we need to know the parameters of receiver. These data mostly come from datasheet of the unit and in some cases from the calibration certificate. Parameters of the receiver include the receiver reading, sine wave accuracy, pulse amplitude response, pulse repetition rate response, noise floor proximity, and frequency step. Other group of parameters concerns the uncertainty of the measurement path. The focus is on the transmissions and reflections caused by mismatches but also need to deal with antenna factor, frequency interpolation and cross polarization parameters. Finally, we need to calculate with stability of measurement system in other words measurement system repeatability. This item describes what happens when the measurement system is disassembled and reassembled. Value between 1 and 1.5 dB of the stability is relatively high in most of laboratories.

It means that the highest permitted emission level defined by the standard as limit is minus 6 dB if one piece of sample is tested. Approach to the limit and margin at the automotive and commercial assets is surprisingly different. While the automotive standard [5] always defines values for one product, the standard for hand tools [1] allows statistical determination. For example, if one piece of lawn mower is measured, the margin should be at least 6 dB, but if 3 or 6 pieces are measured, 3.8 dB and 0.7 dB margins are sufficient for each piece. Products of this type are typically tested in numbers of 3 to 6. For the results reported below, the 3.8 dB margin is relevant.

V. RESULTS OF MEASUREMENTS

A. Measurement of the product with original ferrite ring

The product with original ferrite ring (hereinafter "Ferrite 1.") fully met the expectations, with the value closest to the limit of 136 MHz, where the margin was 7.03 dB (Fig. 3). The other two test pieces gave very similar results. One showed a margin of 5.64 dB at 147 MHz and the other a margin of 6.64 dB at 142 MHz.

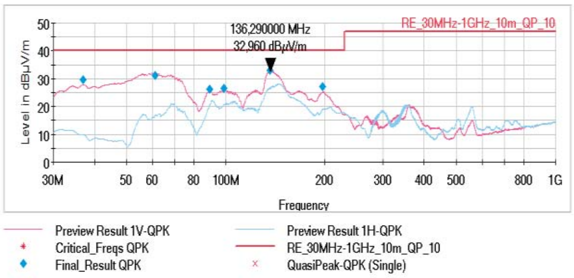

Fig. 3. Emission diagram of testing the product with Ferrite 1.

B. Other ferrite rings

After measuring the product with Ferrite 1, we have tested the product with two other types of ferrite rings (hereinafter "Ferrite 2" and "Ferrite 3. "). The measuring system was not modified or reassembled, all measurements were performed with the same measurement set-up. This is important when comparing the results because the mounting error can be neglected in the measurement uncertainty. Measurements of products using Ferrite 2. and Ferrite 3. produced slightly worse results, with a margin of 3.9 dB at 156.2 MHz in the worst case (Fig. 4). Summarizing the results appropriateness of all tested ferrites can be stated, if the statistical principle of 3 samples is considered. This point is the end of the official tests, however, the partner company approved further studies for research purposes.

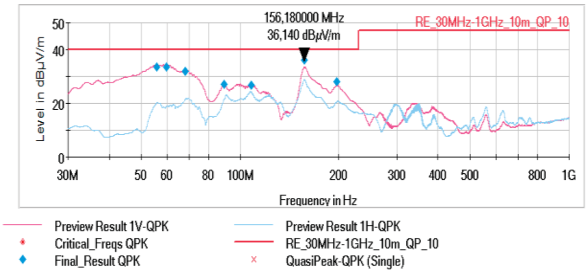

Fig. 4. Emission diagram of testing the product with Ferrite 2.

C. Study of the emission levels without ferrite

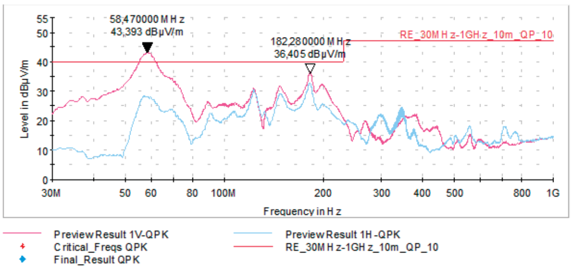

Fig. 5. Emission diagram without ferrite

The first step in the study was to determine exact effect of the use of ferrite on the product, so the ferrite was removed from one of the products. The result is shown in Figure 5. It can be stated that the use of ferrite is mainly necessary due to the emission in range of 50-60 MHz. A value of 36.405 dB (~ 3.6 dB margin) measured at 180.28 MHz with an even larger sample size would be acceptable without the use of ferrite.

D. Study of emission without antenna

The subject of the research is a battery-powered garden machine, in the construction of which the main components, the electronics, the battery, the motor are essentially integrated in one place, in the body of the device. However, due to safety features and convenient switch-on, a circuit loop must be built into the handle. In most cases, this circuit loop is just a wire with switches, which during operation forms a closed loop, i.e. an antenna. The aim of the following experiment is to determine the emission level added by this "antenna" to the complex interference emission of the product. Therefore, while meeting the safety conditions, the equipment was operated without a wire loop. The machine was started directly at the connector on the control panel.

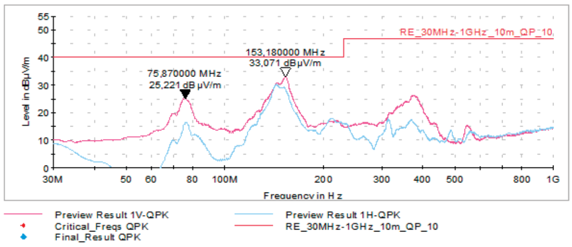

Fig. 6. Emission diagram without wire loop

The results show that the interference emissions are significantly reduced in both the 50-80 MHz and 100-200 MHz bands. However, it can also be stated that the device would meet the requirements without the wiring loop. Of course, it cannot be a solution because of security concerns. However, the use of a mechanical signal transmission, such as a Bowden cable, could also be a solution. It is also true that today's manufacturing industry prefers to avoid such elements and of course they are not advantageous in terms of design either. However, there are a few household appliances exist on the market where the control signals are transmitted via wireless communication from the handle to the device central unit and motor. At this point of the research the engineering team conducting the measurement attempted to come up with a different and cheaper solution if the original wire loop concept must be used, but the use a ferrite ring should be avoided.

The wiring diagram of the tested machine is not known for the research group, but the measurement results show that the battery voltage is applied to one endpoint of the switch line. Presumably, the other end activates a switching element, such as a MOSFET, when it is turned on. Ideally, this wire is at a constant potential, meaning it should not act as an antenna at all.

Because the motor drive circuit is constantly switching, it causes a fluctuating supply voltage, which means that it causes a constantly changing battery voltage. This fluctuating voltage is applied to the switching line, which thus becomes the transmitter of the electromagnetic waves. In essence, the ferrite ring placed on the wire is also designed to reduce this fluctuation. The question for researchers to answer is whether this fluctuation can be reduced by any other cheap, passive element. Since the total length of the built-in switching line is approximately 2.5 meters, based on the wavelength-frequency relationship, this corresponds to approximately 120 MHz, while the half-wavelength corresponds to 60 MHz.

E. Study of using additional resistors

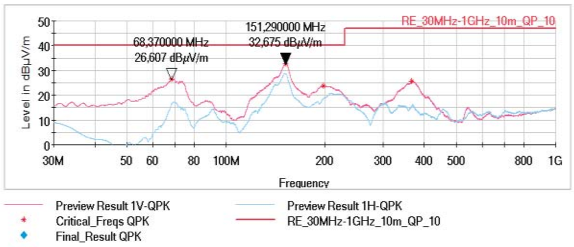

Fig. 7. Emission diagram with two resistors

The basic idea was to modify the impedance of the "antenna" effect caused by the wire to some extent. It has been assumed that the supply voltage must be in a certain range to turn on the device, so increasing the resistance of the wire presumably should not cause any problem. According to calculations, 1.2 kΩ resistors were built at both ends of the switch wire. The result is shown in Figure 7.

Based on the 13.4 dB margins obtained at 68.4 MHz and the 7.32 dB margins obtained at 151.3 MHz, it can be concluded that better results were obtained with the two resistors than with any of the ferrite rings. It is important to mention that both resistors are required to achieve the result. Leaving it at either end of the wire gives a result substantially free of the ferrite ring.

F. Method of antenna splitting

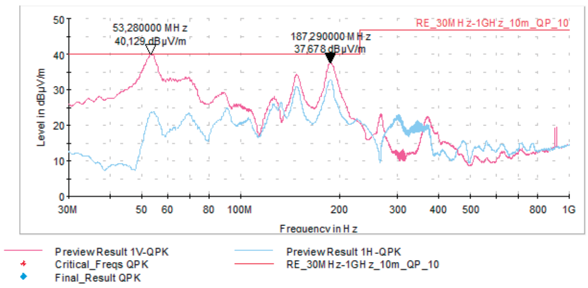

Fig. 8. Emission diagram with one resistor at switch

In one step of the systematic scientific test design, analyzing the length of the switch wire, a resistor was installed in the center of the antenna, which point practically is located at the switch of the device.

Analyzing Fig. 8, although the level of interference emission decreased by a few dB compared to that shown in Fig. 5, it did not prove to be as effective as the two resistors used at the ends.

VI. CONCLUSION

In ideal case, the EMC compliance of a product is ensured at the design stage. However, due to the complexity of the topic and possible unexpected situations, the product may fail during the EMC test despite best intentions. As the product is usually already on the verge of production, the well-known quick solutions, ferrites, interference filters and possibly special coatings and absorbers come to the force. These are usually quick procedures, as they can be retrofitted (even into products that have already been manufactured) without major modifications, but these are relatively expensive methods. The costs of retrofitting increase in nearly proportion to the number of pieces of the product. However, with analyzation and accurate understanding of the disturbance phenomenon, application of a specific, low-cost solution may become available, even if cost of test development and performance and cost of analysis procedure are also calculated and added.

The results of research summarized in this paper proved, that using two low-cost resistances ensure higher emission limitation capability, than the originally used and widely accepted methods with ferrite rings. In the industrial practice the retrofitting methods are very often supplemented with additional enhanced power limitation, in order to achieve further emission limitation. The research will be continued in the future to analyze if the enhanced power limitation in the products may be avoided by using the two-resistance method for emission lowering. The use of low-cost, low-conversion solutions can lead to significant savings in industry, which is of paramount importance in mass production.

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