Algorithm development for finding the minimum level of noise immunity of an onboard electrical complex during control tests

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Abstract. An algorithm for finding the minimum level of noise immunity of the onboard electrical complex during control tests is developed in this paper. The expression is obtained for the frequency tuning step of a narrow-band electromagnetic action and an algorithm is developed that compared with the standard to more accurately find the minimum level of noise immunity of ETS.

Keywords: automobile, electrical on-board complex, electromagnetic compatibility.

1 Introduction

The existing requirements for the frequency adjustment step are not sufficient for a full assessment of electrotechnical systems (ETS) and on-Board electrical complex (BEC) of motor vehicles (MV) in the parameters of electromagnetic compatibility (EMC). In this case, it is possible to skip ranges with low noise immunity, and therefore inaccurately define minimum characteristics of noise immunity. This means that there are certain risks associated with their safe operation. Another problem is a long time to find the minimum noise immunity of ETS (BEC). Because, even if the frequency range is determined, in which there are malfunctions, then one has to look for the levels of noise immunity at each frequency.

 EMC problems are known to be occurred due to the parasitic resonant properties of electrical circuits. Hence the problem of more accurate and fast finding the minimum level of noise immunity of an electrical system is solved using the section of resonant circuits of the general theory of electrical circuits. The most difficult case should be considered when it is necessary to identify a frequency range with low noise immunity formed by one

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resonant circuit, because it is more difficult to find it than the range formed by several circuits.

2 The main part

Let's accept the condition: the passbands of the parasitic resonant circuits do not overlap. The bandwidth of the resonant circuit has to be greater than the frequency tuning step of the narrow-band action.

The resonant frequency of a circuit and its bandwidth are related by the expression:

$$Q = \frac{f_p}{\Delta f} \tag{1}$$

where Q – a figure of merit; f_p – resonant frequency of the oscillating circuit; Δf – bandwidth equal to

$$\Delta f = f_u - f_l \tag{2}$$

where f_l and f_u are lower and upper frequencies of the loop bandwidth.

Since

$$f_u - f_p = f_p - f_l \tag{3}$$

the expression (3) can be written as:

$$f_p = \frac{2Qf_l}{2Q-1} \tag{4}$$

The electromagnetic effect begins with the frequency f_1. If we assume that it coincides with the lower frequency of the first resonant circuit f_{l1}, i.e.

$$f_1 = f_{l1} \tag{5}$$

then the optimal frequency adjustment step should be such that the second frequency of the impact is resonant. According to this condition, the bandwidth of parasitic resonant circuits does not overlap. The noise immunity characteristic is complex and depends on many MV parameters. If EMC problems are detected during exposure, this range can be investigated in detail at any given step. But if there are no malfunctions, we assume that the second frequency of exposure falls on the lower frequency of the bandwidth of the second resonance

$$f_2 = f_{l2} = f_{p1} \tag{6}$$

Hence, the first step is, considering (3)

$$h_1 = f_{p1} - f_{l1} = f_{l2} - f_{l1} = \left(\frac{2Qf_1}{2Q-1} - f_1\right) = f_1\left(\frac{1}{2Q-1}\right) \tag{7}$$

Based on the arguments given above, let us write

$$f_2 = f_1 + f_1\left(\frac{1}{2Q-1}\right) = f_1\left(\frac{2Q-1+1}{2Q-1}\right) = f_1\left(\frac{2Q}{2Q-1}\right) \tag{8}$$

The second step of the impact adjustment is equal to

$$h_2 = \frac{f_2}{2Q-1} = f_1\left(\frac{2Q}{(2Q-1)^2}\right) \tag{9}$$

Similarly

$$f_3 = f_2 + f_1\left(\frac{2Q}{(2Q-1)^2}\right) = f_1\left(\frac{2Q}{2Q-1} + \frac{2Q}{(2Q-1)^2}\right) \tag{10}$$

Accordingly, the third step will be equal to

$$h_3 = \frac{f_3}{(2Q-1)} = f_1\left(\frac{2Q}{2Q-1} + \frac{2Q}{(2Q-1)^2}\right) \times \frac{1}{(2Q-1)} = \quad (11)$$

$$= f_1\left(\frac{2Q}{(2Q-1)^2} + \frac{2Q}{(2Q-1)^3}\right)$$

The fourth frequency of impact

$$f_4 = f_3 + h_3 = f_1\left(\frac{2Q}{(2Q-1)^2}\right) = $$

$$= f_1\left(\frac{2Q}{2Q-1} + \frac{2Q}{(2Q-1)^2}\right) + f_1\left(\frac{2Q}{(2Q-1)^2} + \frac{2Q}{(2Q-1)^3}\right) = $$

$$= f_1\left(\frac{2Q}{2Q-1} + \frac{4Q}{(2Q-1)^2} + \frac{2Q}{(2Q-1)^3}\right)$$

(12)

Formulas (6) - (12) show that the frequency adjustment is a geometric progression with the parameter $\left(\frac{2Q}{2Q-1}\right)$. From this

$$f_n = f_1\left(\frac{2Q}{2Q-1}\right)^{n-1} \quad (13)$$

where n=1, 2, 3….

Accordingly $f_n \in \lfloor f_{\min}; \ f_{\max} \rfloor$, where f_{min} and f_{max} are the minimum and maximum frequencies of the range in which the ETS (BEC) tests are performed.

From the experimental data presented below in the fourth chapter, the maximum figure of merit is found, which is 33.8. Then expression (13) takes the form

$$f_n = 1{,}015^{n-1} f_1 \quad (14)$$

Expressions (13) and (14) are derived for the case when the frequency of exposure coincides with the resonance.

The figure of merit parameter is defined either from the results of calculating the mathematical model of the tested ETS (BEC) or is selected from the statistical analysis of previously obtained experimental data of similar systems.

In practice, the frequency range in which there is a malfunction ETS (BEC) is formed by multiple resonant circuits and wider than the frequency adjustment step to an electromagnetic field.

The following algorithm is used for finding the minimum level of noise immunity of an electrical system. At the first iteration, the electrotechnical system installed in MV with the specified E_{ef1} is tested for electromagnetic effect. Frequency tuning is performed according to (14). There is a malfunction of the electrical system in this frequency range ΔF_1. If

$$\Delta F_1 > f_{n+2} - f_n \quad (15)$$

where

$$\Delta F_1 = \{f_n; f_{n+1}; f_{n+2}\}$$

then at the second iteration, the level is reduced to the value of E_{ef2}. Tests are carried out in the range ΔF_1 with this exposure level E_{ef2}. Based on their results, the frequency range of ΔF_2 is found. By analogy with (15), it is compared with the adjustment step of narrow-band electromagnetic influence.

Iterations continue to reduce the exposure level until the condition is met

$$\Delta F_j = f_{n+2,j} - f_{n,j} \quad (16)$$

where ΔF_j is the frequency range in which the electrical system is disrupted at the level of E_{efj};

$j = 1, 2, 3 …$ is the number of the electromagnetic effect level;

and

$$\Delta F_j = \{f_{n,j};\ f_{n+1,j}; f_{n+2,j}\},$$

$$\Delta F_j \subset \Delta F_1 .$$

The case $j = 1$ is a special one where iterations to reduce the exposure level are not performed. Changing the levels of subsequent impacts is made from the condition

$$E_{efj+1} = kE_{efj} \tag{17}$$

where k is the coefficient selected from the condition

$$0{,}71 \leq k < 1.$$

The coefficient k has the following physical meaning: the specified reduction in the level of electromagnetic influence should not be greater than the ratio of the induced interference at the resonance frequency to the induced interference at the extreme frequencies of the bandwidth of this resonant circuit.

If condition (16) is met, the minimum level of noise immunity is at the frequency

$$f_{min} = \frac{f_{n+2,j} + f_{n,j}}{2} \tag{18}$$

and equal to

$$E_{min} = E(f_{min}) \tag{19}$$

The proposed approach is explained in Figure 1, and the algorithm for finding the minimum level of noise immunity of an electrical system when testing for narrow-band effects is shown in Figure 2.
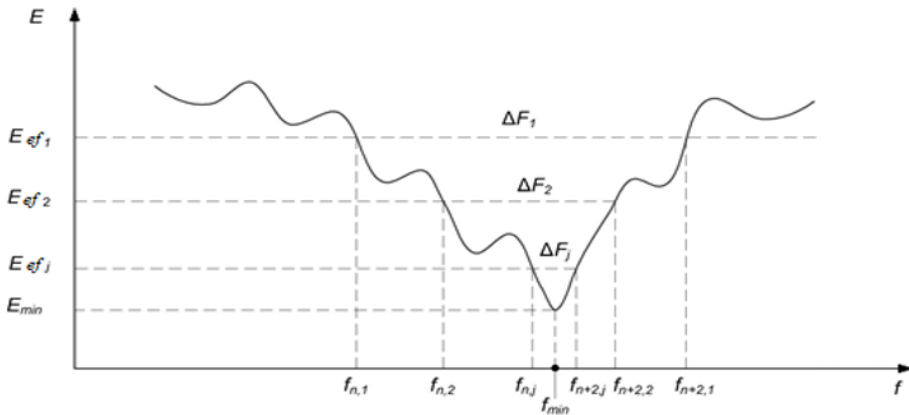

Fig. 1. Finding the minimum level of noise immunity of an electrical system

Experimental studies of the electromechanical power steering of a car of a well-known Russian brand using the proposed algorithm have shown that the accuracy of finding the minimum level of noise immunity increases in comparison with the standard algorithm (Fig. 3). In standard tests, the minimum level of noise immunity was 71 V/m, while the found level is 63 V/m using the proposed approach. The accuracy can be calculated using the known relative error formula

$$\delta = \frac{|E_{tr} + E_m|}{E_m} \times 100\% \tag{20}$$

where E_{tr} is the true level of noise immunity found by the proposed algorithm; E_m is the measured level of noise stability found by the standard algorithm.

Hence

$$\delta = \frac{|63V/m - 71V/m|}{63V/m} \times 100\% = 12{,}7\%$$
.

As seen from the estimation, the accuracy with the application of the proposed algorithm increases by more than 12,7 %.
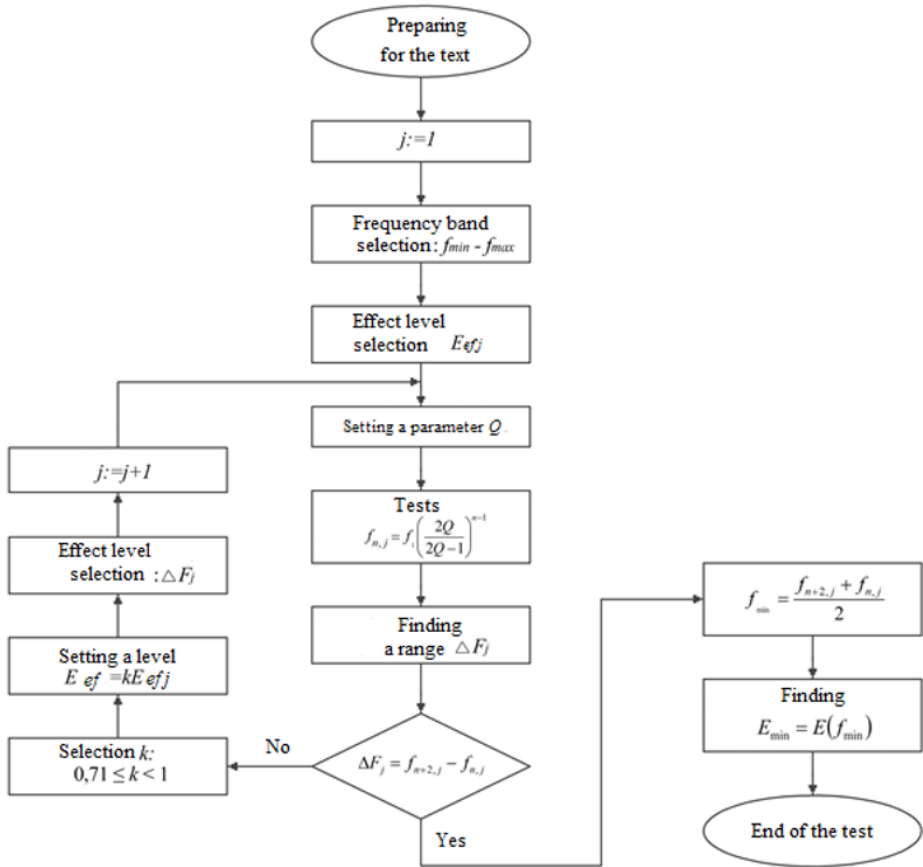

Fig. 2. Algorithm for finding the minimum level of noise immunity of MV (BEC) during narrow-band impact tests
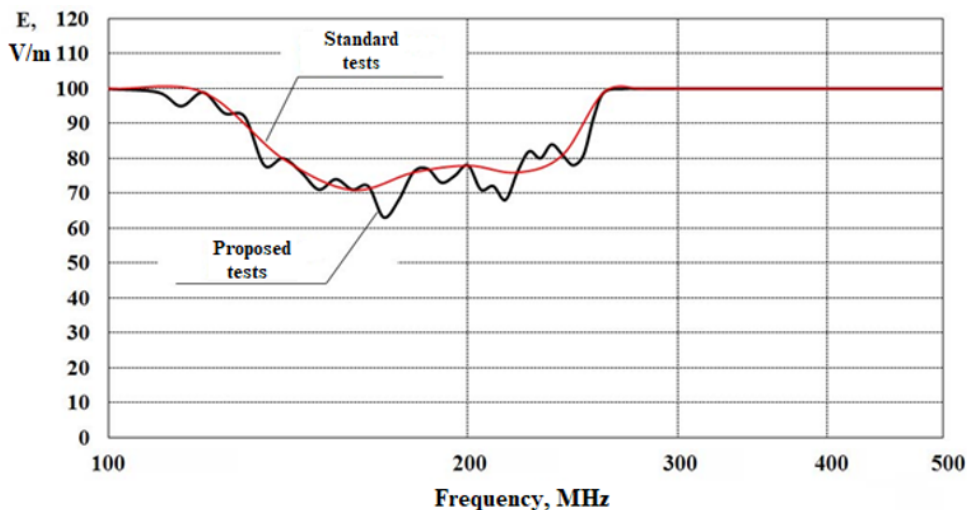
Fig. 3. Noise immunity of an electromechanical power steering of a car

3 Conclusion

The expression is obtained for the frequency tuning step of a narrow-band electromagnetic action and an algorithm is developed that compared with the standard to more accurately find the minimum level of noise immunity of ETS. The research results in the accuracy of finding the level of noise immunity increases by 12.7%.

Acknowledgment

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