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INVESTIGATION OF THE VIBRATIONS OF AN AUTOMOBILE SUSPENSION USING THE THEORY OF EXPERIMENT DESIGN

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The author gives a mathematical model of the output characteristics of an automobile suspension for evaluating its elastic properties by magnitudes of the parameters that are characteristic of the actual operating conditions.

The development of the structures of automobiles involves improvement of their units, including the suspension, and is carried out in the direction of the most complete conformity of their characteristics to the operating conditions of the automobiles.

In evaluating the degree of perfection of an automobile's suspension and the conformity of its characteristics to the requirements placed on it the need arises to solve many interconnected problems, and by nontrivial methods too. The prerequisites outlined in [1] for a systems analysis in evaluating vibroloading and ways of improving quality determine the expediency of the use of mathematical methods of the theory of experiment design. To obtain a mathematical model of output characteristics that would allow evaluation of the elastic properties of automobile suspensions by magnitudes of the parameters and their changes that are characteristic of the actual operating conditions, it is expedient to apply methods of active experiment design.

An easy-to-use polynomial-type model was selected as the mathematical model. Having one and the same type of equations and invariable independent factors, the model makes it possible to easily compare different types of suspensions, having selected their qualitative and quantitative indicators as the response function.

In the first stage of the investigations a scheme classifying the models of suspensions in cushioning systems was developed. Then, based on an analysis of this information, the minimum required volume of tests was determined, designs of experiments were drawn up, independent factors were selected, and response functions and their characteristics were substantiated. Proceeding from the available possibilities and requirements placed on controlled parameters, the following independent factors were selected: the microroughnesses of the road x_1, the pressure in the tire x_2, the normal rigidity of the elastic element with allowance for the interboard asymmetry x_3, the speed of the automobile x_4, and the coefficient of inelastic resistance x_5. An example of coding the values of the independent factors (a working matrix) for a torsional suspension of a multidrive automobile is given in Table 1.

As response functions we took (in percent) the root-mean-square value of the vertical accelerations Y_1 (100% = 0.6g), the lateral-angular accelerations Y_2 (100% = 0.2g), and the axial-angular accelerations Y_3 (100% = 0.15g).

The second stage of the investigations was devoted to the development, construction, and evaluation of several versions of suspension regression models obtained as a result of implementation of an active experiment according to different designs. Since the single-factor relations between the independent parameters and the selected response functions turned out to be significantly nonlinear, the possibility of using experiment designs of higher order was studied.

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TABLE 1. Working Matrix

Factor	Upper level	Lower level	Ground level	Interval of variation of the factor
x_1, σ_q, m	0.22	0.18	0.2	0.2
x_2, P_0, MPa	5.0	3.0	4.5	1.5
x_3, C_n, N/mm	7.2	2.4	4.8	2.4
x_4, v, km/h	52	24	38	14
x_5, η	0.47	0.20	0.34	0.13

TABLE 2. Matrix of the Coefficients

Parameters	Regression coefficients		
	Y_1	Y_2	Y_3
x_0	28.1	20.4	24.0
x_1	–2.37	–0.65	–0.90
x_2	9.75	8.09	7.40
x_3	0.06	–0.71	–0.03
x_4	1.06	9.03	–2.09
x_5	–0.43	–2.84	6.46
x_1x_2	–0.81	0.53	–0.46
x_1x_3	–0.12	–0.78	–1.03
x_1x_4	–0.12	–1.15	–0.21
x_1x_5	0.12	–0.15	–0.78
x_2x_3	0.12	–0.40	–0.71
x_2x_4	0.75	6.46	–1.15
x_2x_5	0.12	0.84	3.40
x_3x_4	–0.06	–0.21	–0.46
x_3x_5	–0.06	–0.21	–0.40
x_4x_5	–0.06	–1.21	–0.59

Developed experiments according to designs on two levels and five factors [2, 3] and the performed comparative analysis of the results obtained showed that the regression model

$$Y = b_0 + \sum_{i=1}^{5} b_i x_i + \sum_{j,i=1}^{5} b_{ij} x_i x_j$$

is most convenient for evaluating suspension models and that the application of a higher-order model is not justified because of an increase in the volume of the experiment and the processing with an insignificant improvement in accuracy.

To construct the selected model, an experiment according to the design 2^{5-1} was realized. Results of the experiment were processed on a computer. Using the program developed we calculated a regression equation for each response function and checked the adequacy of the model (by F, i.e., by the Fisher number); we calculated the confidence interval for the regression coefficients (by t, i.e., by the Student number) and threw away insignificant factors. Table 2 gives as an example calculated data for the regression coefficients of the response functions on belonging to the input parameters x_1, x_2, x_3, x_4, and x_5.

From the data of Table 2 we can obtain regression equations for any of the prescribed response functions in polynomial form. Thus, for example, for the response function $Y_1(\sigma_z)$, in relation to the factors investigated

$$Y_1 = 28.1 - 2.37x_1 + 9.75x_2 + 0.06x_3 + 1.06x_4 - 0.43x_5 - 0.81x_1x_2 - 0.12x_1x_3 - 0.12x_1x_4 + 0.12x_1x_5 -$$

$$- 0.12x_2x_3 + 0.75x_2x_4 + 0.12x_2x_5 - 0.06x_3x_4 + 0.06x_3x_5 - 0.06x_4x_5 \, .$$

If the code variables (see Table 1) calculated as the ratio of the difference of the running value of the nominal level of the factor to the magnitude of the interval of variation of this factor are substituted into the regression dependence of Y_1, we obtain an interpolation formula for determining the radial deformation that occurs in complex force loading of a wheel on a bench with a prescribed combination of factor levels.

Similarly we can obtain calculated values of other output parameters of Y_2 and Y_3.

The interpolation formulas make it possible to calculate the magnitude of the investigated parameter of the response function, now using the natural values of the variable independent factors rather than the coded values. For example, for calculating σ_z in the case of tests the interpolation dependence has the form

$$Y_1 = 8.1275 + 0.475\sigma_q - 0.078P_0 + 0.416C_\mathrm{n} + 0.2v - 0.259\eta - 0.02\sigma_q P_0 - 0.26\sigma_q C_\mathrm{n} - 0.026\sigma_q v -$$

$$- 0.26\sigma_q \eta + 0.0025P_0 C_\mathrm{n} - 0.0015P_0 v + 0.00025P_0 \eta - 0.001C_\mathrm{n}\eta + 0.01vC_\mathrm{n} - 0.001v\eta \, .$$

The obtained relations of the force and deformation parameters are quite explicable physically and are confirmed by single-factor dependences.

Such an analysis of the functions of the output characteristics of a suspension by a set of output parameters using the evaluation of the calculated regression polynomial dependences can serve as a basis for certification of rigidity output characteristics of different models of suspensions with the aim of comparing them. Furthermore, regression models result from conducting a limited number of experiments (16 instead of many hundreds) and provide a basis for improvement of suspensions and optimization of the output parameters for a set of independent input factors with allowance for their mutual effect. In the case of the solution of particular problems associated with the determination of certain specific deformation force parameters, the number of experiments can be reduced.

NOTATION

σ_q, root-mean-square values of the microroughnesses (q is the microroughness height); C_n, normal rigidity of the elastic element; v, speed of the automobile; η, coefficient of inelastic resistance; Y, response function (root-mean-square value of the accelerations); b_0, residual term for $x_0 = 1$ (initial conditions); z, vertical accelerations; $q = 9.81$ m/sec^2, free-fall acceleration.

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