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SOME PRINCIPLES OF OPTIMIZATION OF PARAMETERS OF VEHICLE'S PNEUMATIC SUSPENSIONS ON THE BASIS OF MODERN REPRESENTATIONS ABOUT CRITERION OF SMOOTHNESS OF THE MOTION

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To satisfy numerous, in many respects the inconsistent requirements, usually made to suspensions of vehicles, it is possible in any measure only with the help of means of active control's cushioning. Considering a suspension as system of automatic control, theoretically, for example, it is possible to take into account requirements to dynamics of a suspension during crossing of given macro irregularity with casual perturbations from microasperity, during body's rolls etc. [1].

Many researches in the field of active cushioning are limited only by theoretical researches, as difficulties of a material embodiment of such suspensions are obvious, which concerned with complexity of their designs and high cost of manufacture and exploitation. Nevertheless, real requirements of increasing an efficiency of vehicles have caused essential increase of a number of the constructive decisions which are not having a uniform theoretical basis and conceptually rather inconsistent. The researches theoretically proving an opportunity of sixteenfold improvement of a motion's smoothness with use of an active suspension with the preliminary control of a road's surface ("review" of a road's site before a suspension carry out with an advance 0,4…0,5 s, and the executive device of system of an active cushioning develops additional restoring effort) (Fig. 1) are known.

It is necessary to note, that the criteria used at estimation and designing of passive suspensions, not absolutely meet the requirements also to tasks of optimization active cushioning. From this point of view rather widely it is possible to apply mathematical models of systems active cushioning. And at all the opportunity of use of some conclusions and for the decision of tasks optimum cushioning "passive" suspensions is not excluded. So, for cushioning systems the regulations about of necessity are general to take into account at an estimation of efficiency cushioning expenses of energy at movement of the vehicle. Abundantly clearly, that the problem active cushioning should be considered from a position of a rational ratio of various aspects of optimization cushioning and opportunities of technical realization. That fact, that algorithms of cushioning management may provide use of means of digital processing of the information acting from gauges, predetermines an opportunity of use of the most perspective microprocessor element base for a material embodiment of control systems. Similar control systems are easier for combining with other possible control systems of a suspension of the vehicle.

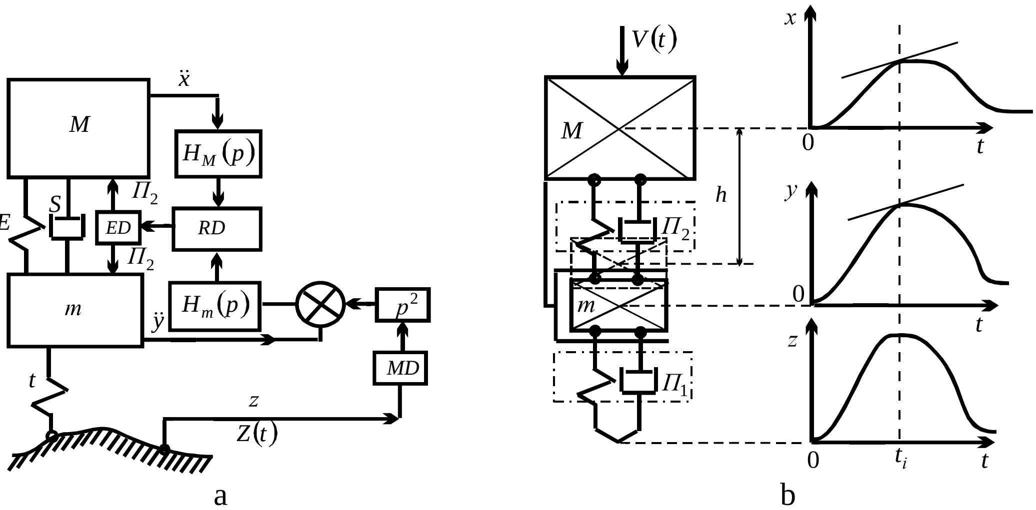


Fig. 1. The scheme of an active suspension of the vehicle (a) and classical two mass system with the limited general movement of a suspension (b):
M, m - sprung and unsprung masses; *EE* - an elastic element; *S* - the shock-absorber; *t* - the tire; *ED* - the executive device of system of an active cushioning; *MD* - the device measuring a road's profile; *RD* - the device reproducing the required law of control; $H_M(p)$, $H_m(p)$, p^2 - converters of signals; *p(d/dt)* - the operator of differentiation; *z(t)* - a profile of road; $\ddot{x}, \ddot{y}$ - acceleration of sprung and unsprung masses; Π_2 - active restoring force.

In our opinion, the most acceptable object for development of one of versions of an active suspension - a pneumatic adjustable suspension as it has some opportunities of characteristic's regulation depending on displacements and acceleration of sprung and unsprung masses.

Earlier we consider a reaction of pneumatic suspensions on 1) change of sprung masses by respective alteration of characteristics, 2) efficiency of oscillation's damping by toughening of characteristics during a rebound stroke, 3) cross rolls of the vehicle with the help of use of high-speed regulators of a body's position [1, 2].

Optimization of characteristics of the vehicle's pneumatic suspension

In many aspects the problem of optimization of a motion's smoothness of vehicles with pneumatic suspensions is considered during discussion. For the past period of time are much more deeply investigated directions and means of suspension's perfection, opportunities of technical realization of difficult constructive decisions have increased, and the main thing - the need for synthesis of optimum systems cushioning has essentially grown.

Optimization of characteristics of a vehicle's suspension can be interpreted as process of revealing of potential opportunities, and not just as search of technically realizable constructive decisions improving its properties. In this case an optimization assumes a synthesis of a potential cushioning system, overstepping the limits of real system.

More often as the optimum characteristic of an elastic element accept the continuous nonlinear progressive characteristic providing equifrequently, i.e. ability of a suspension to keep free oscillations of sprung masses with identical frequency at various static loadings [1].

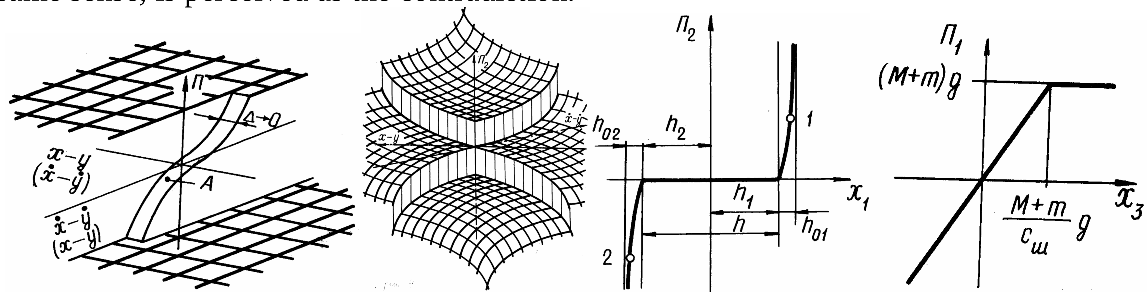
Such treatment of optimality follows from the analysis of existing cushioning systems.

One of principles of optimum cushioning's control, according to this treatment, demands a realization of the elementary inertial characteristic. Other principle provides one of the following laws of control of cushioning systems (Fig. 2, a):

$$\Pi = \begin{Bmatrix} n_2Mg, & x-y \geq 0 \\ \Pi(x-y), & x-y=0 \\ n_1Mg, & x-y \leq 0 \end{Bmatrix}; \quad \Pi = \begin{Bmatrix} n_2Mg, & \dot{x}-\dot{y} \geq 0 \\ \Pi(x-y), & \dot{x}-\dot{y}=0 \\ n_1Mg, & \dot{x}-\dot{y} \leq 0 \end{Bmatrix}, \tag{1}$$

where *x, y* - displacements of sprung and unsprung masses: $(\dot{\cdot}) = d(\cdot)/dt$; *П* - the restoring force arising in a suspension. (Index *П* as against the standard unequivocal index *P* used during getting the characteristic of a suspension, has always an opposite mathematical character and carries wider information on the energy sources used for effective work of an active suspension).

The ideal characteristic (Fig. 2, a) is the standard for selection of characteristics of the real suspensions close to optimum in sense of minimization of the maximal relative displacements of sprung and unsprung masses. However, in the first place, such precondition is not obvious; secondly, that fact, that characteristics, which are absolutely different, may serve as the standard for selection of characteristics of real suspensions, and optimum in the same sense, is perceived as the contradiction.



a b c d

Fig. 2. The characteristics of suspensions:

a - according to equation (1); b - piecewise continuous; c - opaque; d - piecewise-linear; h_1, h_2 - values of the maximal suspension movement determining its general movement $h = h_1 + h_2$; h_{01}, h_{02} - the maximal deformations of restraining arms accordingly a rebound stroke and a bump stroke in view of a pliability of director and elements of carrying body's system; 1, 2 - the points describing efforts, arising during full deformation of restraining arms

Already these examples show, that perception of an optimality of suspensions not uniformly. Typically also that in many respects the optimality is proved with the help of heuristic sendings and reasons. Taking into account above-stated, it is necessary to consider a problem of optimization of the suspension's characteristic, not basing beforehand on known treatment of an optimality, and being based in the greater degree on a mathematical formalism.

The vehicle we shall consider as system of points (the concentrated masses) or system of systems with one degree of freedom, but not system of linear systems. The system of points with one degree of freedom has that feature, that its movement analytically describes by normal system of the ordinary differential equations in a phase space, which dimensionality exactly twice exceeds number of points:

$$\frac{dx}{dt} = X(x, \Pi(x), t); x = (x_1, ..., x_k, ..., x_{2k}); X = (X_1, ..., X_k, ..., X_{2k}); \Pi = (\Pi_1, ... \Pi_k), \tag{2}$$

where $\Pi_1(x)..., \Pi_k(x)$ - characteristics of suspensions $\Pi_1..., \Pi_k$ *1-st..., k* masses.

The equation (2) describes anyone conceivable cushioning system of the concentrated masses, each of which has one degree of freedom. For definiteness all characteristics $\Pi_i(x)$ $(i=1..., k)$ accept nonrigid, because any number of the masses connected with each other by rigid suspensions, is equivalent to one mass. Characteristic $\Pi_i(x)$ it is possible to consider as the function, which dependent from any phase *m* coordinates and independent from others *2k - m* coordinates.

If as determining oscillatory parameters of the vehicle is chooses a sprung mass *M*, unsprung mass *m*, suspension Π_2 of sprung mass and suspension Π_1 of unsprung mass, object of optimization is a classical two mass system (Fig. 1, b), described by the equations such as (2):

$$\begin{aligned} &x_1 = x_2 = X_1; x_2 = -\left(\frac{1}{M} + \frac{1}{m}\right)\Pi_2(x_1, x_2) + \frac{1}{m}\Pi_1(x_3, x_4) = X_2, \\ &x_3 = x_4 = X_3; x_4 = \frac{1}{m}\Pi_2(x_1, x_2) - \frac{1}{m}\Pi_1(x_3, x_4) - \ddot{z} = X_4, \end{aligned} \tag{3}$$

where $x_1 = x - y,\ x_2 = \dot{x} - \dot{y},\ x_3 = y - z,\ x_4 = \dot{y} - \dot{z}$ - phase coordinates; *x, y* - geometrical coordinates (displacements of sprung and unsprung masses from position of static balance (Fig. 1), $z=z(t)$ - the process reflecting influence on oscillatory system of a road‘s microprofile. It is obvious, that processes of system’s movement in geometrical and phase space are interconnected linearly:

$$x = x_1 + x_3 + z(t);\ y = x_3 + z(t);\ x = x_2 + x_4 + z(t);\ y = x_4 + z(t). \tag{4}$$

Concerning systems (3) and (4) it is possible to formulate rather general an optimization task: to define the best in sense of a minimum of function a characteristic $\Pi_i(x)$ of suspensions of any mass with the given characteristics of suspensions of all other masses:

$$x_0 = \int_0^T X_0[x, \Pi_i(x), t]dt \to \inf. \tag{5}$$

In particular, for (3) $\Pi_1 = \Pi_2\ (x_3, x_4)$ - the characteristic of tires; we believe, that it is known and is not subject to optimization. Therefore for the given system an object of optimization will be only the characteristic of suspension $\Pi_2 = \Pi_2(\cdot)$ of sprung mass *M*.

If in a suspension the elastic element and the shock-absorber are loaded not in parallel or simultaneously show also elastic, and dissipative properties (for example, in pneumatic elastic elements the system providing throttling of air may provide, energy dissipation), the characteristic of a suspension is described by function $\Pi_2 = \Pi_2\ (x - y,\ \dot{x} - \dot{y})$. One of such piecewise continuous characteristics is shown on Fig. 2, b. Characteristic $\Pi_2 = \Pi_2\ (x - y,\ \dot{x} - \dot{y})$ generalizes the above-mentioned law of control described by expression (1).

If the elastic element is loaded in parallel with the shock-absorber, and the elastic element has no obviously expressed dissipative properties, and the shock-absorber – elastic properties, the suspension has additive characteristic $\Pi_2 = \Pi_{2y}\ (x - y) + \Pi_{2d} \times \times(\dot{x} - \dot{y})$, where Π_{2y} , Π_{2d} - the elastic and dissipative force arising in a suspension during relative displacements of sprung and unsprung masses. In pneumatic suspensions with valve regulators (the example considered by us - a pneumatic spring with an inertial regulator of rigidity) the characteristic is generally described by function $\Pi_2 = \Pi_2 \times (x - y,\ \dot{x} - \dot{y},\ \ddot{x} - \ddot{y})$.

Hence, each of the listed characteristics can be accepted as object of optimization. However in that case the area of search of optimum properties of a suspension is narrowed, and more strongly, than function $\Pi_2 = \Pi_2(\cdot)$ has more particular kind. So, as the optimization problem is formulated in the determined form, it is expedient to count as a subject of search the program of control $\Pi_2 = \Pi_2(t)$ instead of function $\Pi_2 = \Pi_2(x)$. It is justified also by that methods of classical (a principle of optimality Eelier - Lagrange) and modern (a principle of a maximum, dynamic programming) calculus of variations serve as the powerful mathematical device for search of optimum programs of control. The general methods of mathematical synthesis of controls in form $\Pi_2 = \Pi_2(x, t)$ and the more so in form $\Pi_2 = \Pi_2(x)$ do not exist, that, in particular, was reflected in intensive development of methods of optimization of active cushioning systems and on rather weak development of methods of optimization of passive systems.

To give the full description of optimum work of cushioning system in enough simple terms, we shall consider a mode of transfer of perturbation to a sprung mass separately from a mode of restoration of its desirable movement. For ensuring of absolute smoothness of a motion, for example, the bus, the characteristic of a suspension should be opaque (Fig. 2, c). By the term of *opacity* usually designate that fact, that changing of any disturbing factors, which effect on one of system's elements, has not an effect in any way for the power factors influencing any other element of same system. In a considered case the condition of opacity of the characteristic is carried out, when $\Pi_2 = \Pi_2(x_1, x_2) = \Pi_2(x - y,\ \dot{x} - \dot{y}) \equiv 0$. Really, when $\Pi_2 \equiv 0$ always $\ddot{x} \equiv 0$. From here follows, that if at the initial moment of time $t = 0$ speed and displacement of sprung mass are equal to zero and at any other moment of time t they will be equal to zero: $\dot{x}(t) = \dot{x}(0) = 0,\ x(t) = x(0) = 0.$

Thus, it is enough for performance of a condition of opacity of the suspension's characteristic, that the characteristic of a suspension was described by equation $\Pi_2 = \Pi_2(x) \equiv 0$.

At the same time the characteristic of a suspension is absolutely transparent with enough big (as the movement of a suspension is always limited) displacements of sprung mass concerning an oscillating unsprung mass.

Transfer of disturbance to sprung mass from irregularities of road with the opaque characteristic of a suspension is possible only during its breakdown or then, when some disturbance $V = V(t)$ influences directly on sprung mass. In particular, if macro profile of road is not horizontal, the real reason of occurrence of disturbances $V = V(t)$ - big sluggishness of sprung mass: the mass M aspires to keep rectilinear forward movement while its centre should move by a trajectory reproducing a road's profile.

Pressing of wheels to road with constant effort $Mg = const$ guarantees an opacity of the suspension's characteristic. It is favorably reflected on stability and roadability of the vehicle, and also promotes an increasing of efficiency and fuel efficiency owing to decreasing of intensity of wheels spin and absence of energy dissipation in the suspension. Results of both theoretical, and experimental researches unequivocally confirm an optimality (and from the various points of view and for various roads) of suspensions with small rates, as they, in effect, opaque [1].

The more a suspension's movement, the in the greater degree positive properties of its opacity are shown. Therefore and non-rigid long-stroke suspensions have significant advantages, which are the more appreciably, than more their transparency and a movement is. But with decreasing of opacity at the limited movement of a suspension its lacks are more strongly shown, is especial at often breakdowns during movement of the vehicle on roads with a poor-quality covering.

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CONTRIBUTIONS CONCERNING VIRTUAL INSTRUMENTATION IN SPECTRAL ANALYSIS

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Spectral analysis is the most widely used technique in the extraction of information from measured signal patterns.

This paper presents virtual instruments for spectra estimation included in a more complex program that makes signal processing in time, amplitude and frequency domains.

The results of these studies can serve the projection of industrial equipment for the tool wear monitoring and for the creation of a database for automatic estimation of tool wear by vibration processing.

1. ***Introduction.*** Vibration monitoring is used both as a maintenance and as a production quality control tool for machinery systems.

While often similar in concept, these differ considerably in some aspects. Vibration monitoring as a maintenance tool, often called *condition monitoring*, enables the establishment of a maintenance program based on a early warning.

This can be of great value in cases involving critical machinery, where an unexpected shutdown can have disastrous economical or environmental consequences. In general, these cases involve the monitoring of a single or a few systems where continuing operation is imperative.

Applications involving quality control often deal with the opposite situation: a large amount of sometimes low-cost components have to be tested during production. The identification of faulty components not only reduces manufacturing cost, but often pinpoints production problems, which are then usually remedied.

The sensing feature of vibration monitoring make it a viable quality control tool, especially where other practical tools may be almost unavailable.

An unviable state of system may be recognized, even when there is no faulty component at hand. The recognition of an early failure prediction necessitates the identification of the state of the system, based on the variables monitored. The knowledge needed for such an absolute identification is often not available and continuous or regular measurements are collected during operations [1].

Frequency domain analysis is the most widely used method and many monitoring methods classify almost exclusively on the base of patterns in the frequency domain. This fact