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PARAMETRIC OPTIMIZATION OF SHOCK-DAMPER BY IMPULSIVE FORCE ACTION

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Summary. For the modular construction objects, as oil-gas damper (OGD), the method of optimization of functional parameters in the conditions of shock influences is developed. On the example of damper diagrams of specific shock damper the great quantity of Pareto-optimum values of quality criteria has been got that are represented as a system of algebraic equation. Possibility of estimation of shock damper capacity with working liquid losses is offered here.

Key words: shock, damper, criterion of quality, model, optimization

INTRODUCTION

When the vehicle on a high speed collides with road unevenness its shock dampers, especially front ones, are undergone to powerful shock influence with subsequent considerable growth of pressure overfall of working liquid and resistance force. Almost instantaneous; growth of resistance force results in the increasing of friction forces between shock-damper rod, compression and the guide, and between a piston and a cylinder. Because of increasing of working liquid temperature and diminishing of its viscosity the loses increase through the clearances in rubbing pairs and valves, the mean value of resistance force decreases at the subsequent unstressed motion. As a result the damping quality, capacity and service life of shock-vibrations safety system (SVS) has become worse. The objective reflection of these are longitudinal angular vibrations of a carriage, steering vibrations, decreasing of motion safety at the turns and high wear of tires. Influence of shock force increases in the conditions that become possible during shock absorber installing and subsequent operation of joint ears defects that reach +(-) 4% [Reimpell 1989]. To the present the mecanism of shock affecting indexes of quality of SVS and capacity of modern constructions of shock absorbers is not studied sufficiently that limits possibilities of their further technical perfection.

OBJECTS AND PROBLEMS

Important description of modern constructions of shock dampers is instantaneous power of the perceived vibrations. The least materialing and most compact at identical instantaneous power there are [Derbaremdiker 1985] modern constructions of oil-gas damper (OGD), that provide possibility of adjusting of workings descriptions and stability in the wide range of frequency of vibrations, to 20 Hertzs.

As a criterion index of capacity of SVS in the conditions of shock influences it is accepted to use the coefficient of overload

$$k_f = \frac{\max F_c}{H_0}, \tag{1}$$

where: $max\, F_c$ is a maximal value of force of resistance for the chosen model of OGD, H_0 is amplitude of shock force.

For complete description and optimization of working process in OGD enough for the cycle of shock influence, the indicated descriptions are not.

The most informing index is duration of the τ stage of complete renewal of parameters of OGD after a shock, and it is expedient to accept a dimensionless coefficient as the proper criterion of quality of construction

$$k_t = \frac{[\tau]}{\tau}, \tag{2}$$

where: τ and [τ] are maximal and nominal (tabular) values of duration of the stage of complete renewal of OGD parameters after a shock.

The out of control parameters of oscillating process of SVS are mass of the object of defence, amplitude of shock force, duration of blow, frequency of free vibrations.

For the simulating of working process under OGD at shock influence, description of resilient forces is linear, and forces of resistance – part-linear, where the followings areas are marked: first is the stage of compression, corresponding to the passing of liquid through the calibrated openings with the coefficients of resistance η_{11} and η_{12}, and second is the stage of tension, corresponding to the work of unloading valves of direct and reverse motion with the coefficients of resistance η_{21} and η_{22}. In denotation η: the first index specifies the mode of operations of OGD (1 is a compression; 2 is retreat); second — the area of power description (1 — initial; 2 — valvular).

As a result of analysis of power descriptions of OGD of the known firms-producers, the limit values of speed of piece-linear areas, coefficients of forces of resistance on the stages of compression of both retreat and nominal forces of resistance (table) are determined.

As the guided parameters on the stage of planning of OGD it is expedient to accept : coefficient of ansymmetry of power description k_a and coefficient of non-linearity of power description on the stage of compression k_n

$$k_a = \frac{\eta_{22}}{\eta_{12}}, \qquad k_n = \frac{[\eta_{12}]}{\eta_{12}}, \tag{3}$$

where: [η_{12}] is a basic (tabular) value of coefficient of resistance of the second (valvular) piece-linear area of power description of shock damper.

METHOD OF MODELING

Quality of SVS and shock damper is characterized simultaneously by two criteria (1) and (2), therefore a task is taken to the setting of vectorial optimization with limitations [Gutyrya *et al.* 2004, Gutyrya and Yaglinsky 2006]

$$\min_{x \in R} f(x); \quad g_i(x) \le 0; \quad i = 1,...,m_g; \quad x_{min} \le x \le x_{max}, \tag{3}$$

where: $f(x) = \{f_1(x), f_2(x),..., f_k(x)\}$ is a vectorial goal function; x is a vector of project parameters, $g_i(x)$ are functions of limitations, m_g is an amount of limitations, k is a number of criteria of quality.

On the first stage of optimization a goal function can be presented as the weighed sum of two private criteria of quality

$$\psi_1 = f_j(x) = \alpha_{1j} \frac{max F_c}{F_n} + \alpha_{2j} \frac{T_0}{\tau}, \; j = 1,...,m_s; \; i = 1,...,m_T, \tag{4}$$

where: α_1 and α_2 are gravimetric coefficients of private criteria of quality, m_τ and m_s is an amount of points of trajectory and number of alternative variants of feasible solutions of task.

At variation of values of gravimetric coefficients α_1, α_2 in a range from 0.1 to 0.9 with a permanent step, realization of SVS, among which choose the most perspective for a further analysis variant, get the great number of alternative variants.

Basic descriptions of form of shock are duration of blow T_0 and amplitude of shock force h_0 attributed to mass of object.

SVS is represented by the model of Rusakova-Kharkevicha, with supposition, that harmonic shock operates force, the form of which is described by the equalization of semiwave of sine [Yaglinsky *et al.* 2006].

$$\ddot{x} + \omega_0^2 x + 2\lambda\dot{x} = h, \tag{5}$$

$$\begin{aligned} &h = h_0 \sin \omega t \quad npu \quad 0 \le t \le T_0, \\ &h \equiv 0 \qquad\qquad npu \quad t \ge T_0, \quad . \\ &h_0 = H_0/m_0; \quad \lambda = \eta/(2 \cdot m_0) \end{aligned} \tag{6}$$

$$\lambda = \begin{Bmatrix} \lambda_{11} \wedge \lambda_{12}; & 0 \le t \le T_0; & & \Leftrightarrow \textit{удар}, \\ \lambda_{21} \wedge \lambda_{22}; & T_0 \le t \le T_1; & h_0 = 0; & \Leftrightarrow \textit{отбой}, \\ \lambda_{11} \wedge \lambda_{12}; & T_1 \le t \le T_2; & h_0 = 0; & \Leftrightarrow \textit{сжатие} \end{Bmatrix}. \tag{7}$$

Table 1. Parameters of power descriptions of OGD

Firm-manufacturer, location of shock damper		Compression			Retreat			[τ], s	$max\,F_c$, kN, k_f	k_a
		η11, N·s/m	[η12], N·s/m	V_1, m/s	η21, N·s/m	η22, N·s/m	V_2, m/s			
Koni,	front	2000	430	0.1	2000	600	0.3	7.6	0.90, 0.18	1.40
	back	400	400	0.1	2900	1700	0.2	3.8	2.16, 0.43	4.25
Kamaz,	front	400	400	0.1	1300	500	0.3	8.2	0.75, 0.15	1.25
	back	2000	500	0.1	3000	2000	0.2	3.2	2.41, 0.48	4.00
Monroe Gazmatic,	front	2000	500	0.1	4600	660	0.1	6.3	0.95, 0.19	1.32
	back	1200	200	0.2	3500	1300	0.2	5.1	1.79, 0.36	6.50
Plaza,	front	2000	500	0.1	8000	3400	0.1	2.0	3.48, 0.70	6.80
	back	1000	500	0.1	8000	3400	0.1	2.0	3.48, 0.70	6.80
VASES 2108,	front,	3000	560	0.1	8000	1450	0.1	3.8	1.86, 0.37	2.60
	back	3000	780	0.1	9900	1780	0.1	3.2	2.12, 0.42	2.28
Delfi,	front	2500	300	0.1	6000	1250	0.2	5.1	1.71, 0.34	4.17
	back	1000	300	0.1	6000	1360	0.1	4.5	1.83, 0.37	4.53
Monroe Original,	front	2500	500	0.1	9000	1000	0.2	5.1	1.37, 0.27	2.00
	back	1800	300	0.1	7500	900	0.1	6.3	1.29,0.26	3.00
Delfi Duocontrol,	front	2500	230	0.1	8000	1300	0.1	5.2	1.78, 0.35	4.33
	back	2500	230	0.1	8000	1300	0.1	5.2	1.78, 0.35	4.33
Sachs Touring,	front	2500	500	0.2	5000	1400	0.2	3.9	1.82, 0.36	2.80
	back	2500	500	0.1	7000	1400	0.1	3.9	1.83, 0.36	2.80
Плаза “Sport“,	front	2500	630	0.1	7100	7100	0.4	1.5	5.05, 1.01	11.3
	back	2500	640	0.1	7100	7100	0.4	1.5	5.06, 1.01	11.1

Note: V_1 and V_2 is scope speeds of piece-linear descriptions

In calculations for all of OGD it is accepted : mass of the protected object, taken to one OGD m_0 = 500 kg, relative amplitude of shock force h_0 = 10 m/s^{-2}, duration of shock T_0 = 0.4 s. Angular shock frequency of process is equal to

$$\omega = \pi / T_0 \,. \tag{8}$$

Shock influences present the unstationary vibration phenomena, accompanied, with transitional processes. On the basis of the accepted model (5–7) the proper decision is got

$$\left.\begin{aligned} x = e^{-\lambda t}\left(x_0 \cos \omega_1 t + \frac{\dot{x}_0 + \lambda x_0}{\omega_1} \sin \omega_1 t \right) + \\ + Ae^{-\lambda t}\left(\begin{aligned} &\sin \varepsilon \cos \omega_1 t + \\ &+ \frac{\lambda \sin \varepsilon - \omega \cos \varepsilon}{\omega_1} \sin \omega_1 t \end{aligned} \right) + A \sin(\omega t - \varepsilon), \end{aligned}\right\} \tag{9}$$

$$\omega_1 = \sqrt{\omega_0^2 - \lambda^2}, \; tg\, \varepsilon = \frac{2\lambda\omega}{\omega_0^2 - \omega^2}, \; A = \frac{h_0}{\sqrt{(\omega_0^2 - \omega^2)^2 + 4\lambda^2\omega^2}}. \tag{10}$$

Using the method of docking, decision of equalizations (9) and (10) is got in supposition that a blow affects the system being in a state of the set motion, that is at zero initial conditions

$$x(0) = 0, \quad \dot{x}(0) = 0 . \tag{11}$$

First two elements of decision (9) correspond to free and free accompanying vibrations. The free vibrations of object corresponding only to the first element of decision, begin after expiration of time of blow T_0 (9). Scope terms at the end of shock are the initial for free vibrations in the phase of retreat. Like, the limit conditions at the end of phase of retreat $x(T_1) = x_1$, $\dot{x}(T_1) = 0$ are initial for free vibrations on the phase of compression and etc It is necessary to notice that in transition from the phase of retreat to the phase of compression, coefficients of resistances change and have different values on the piece-linear areas of power description of OGD.

RESULTS OF INVESTIGATIONS

For comparison of OGD constructions of different firms, design and calculation of criteria of quality of SVS is executed with identical mass of object. On the example of OGD model of firm Sachs Touring the damper diagrams of dependence of force of resistance F_c are made from moving of x stock (Fig. 1–3). The overhead part of diagrams corresponds to the phase of retreat, the lower part — to the phase of compression. The calculation values of parameters of τ and of $\max F_c$ for model shock dampers are resulted in the table.

On a Fig. 1 the damper diagram of OGD base model of firm Sachs Touring (Tab. 1) is presented corresponding to the next values of criteria of quality

$$\begin{bmatrix} k_f = 0.36; & k_t = 0.11; \\ k_a = 2.80; & k_n = 1.00 \end{bmatrix} \Leftrightarrow \left\{ \begin{matrix} \lambda_{11} = 2.5\, s^{-1}; & \lambda_{12} = 0.5\, s^{-1}; & max\, F_c = 1.82\, kN; \\ \lambda_{21} = 5.0\, s^{-1}; & \lambda_{12} = 1.4\, s^{-1}; & \tau = 3.9\, s \end{matrix} \right\}.$$

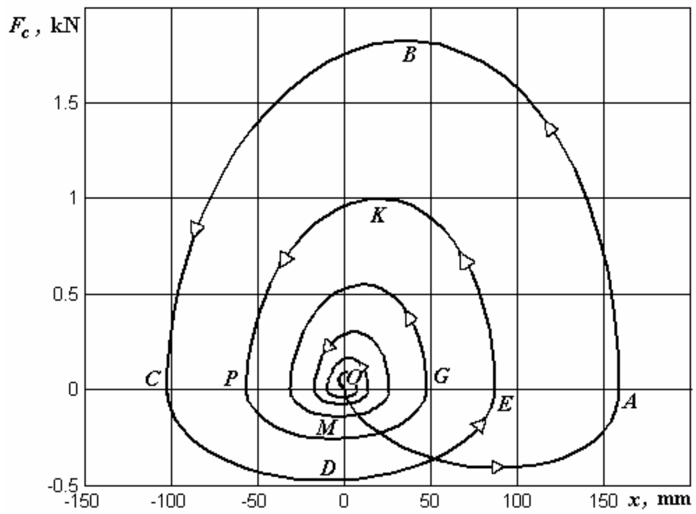

Fig. 1. The damper diagram of base model of OGD of firm Sachs Touring:
OA is a phase of shock, *ABC* is a phase of retreat, *CDE* is a phase of compression,
EKP is a phase of retreat, *PMGO* is motion to the stop

Managing the parameter of k_n, damper diagrams (Fig. 2) are built for OGD of firm Sachs Touring with the fixed values of the followings sizes: λ_{11} = 2.5 s^{-1}, λ_{21} = 5.0 s^{-1}, λ_{22} = 1.4 s^{-1}.

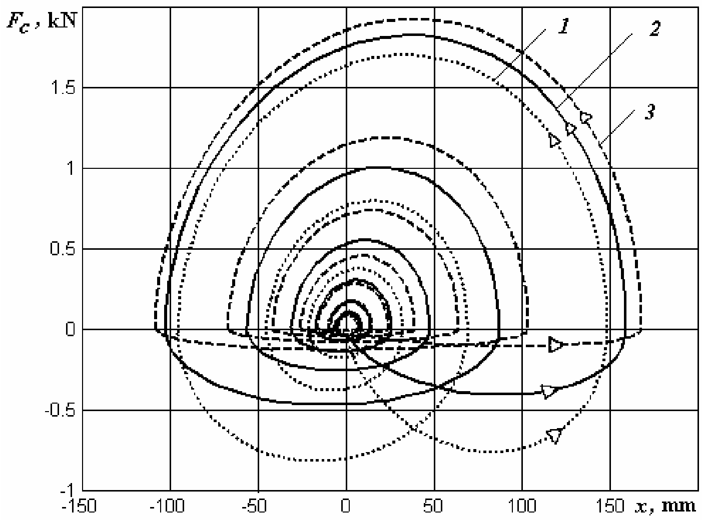

Fig. 2. The damper diagram at a management the parameter of k_n OGD of firm Sachs Touring

The trajectories of depicting points correspond to the next values of criteria of quality

$$1 — [k_f = 0.34; k_t = 0{,}9; k_a = 7;\ k_n = 2.5] \Leftrightarrow \{\lambda_{12} = 0.2\ s^{-1}; max\,F_c = 1.7\ kN; \tau = 4.5\ s\},$$
$$2 — [k_f = 0.36; k_t = 1; k_a = 2.8; k_n = 1] \Leftrightarrow \{\lambda_{12} = 0.5\ s^{-1}; max\,F_c = 1.82\ kN; \tau = 3.9\ s\},$$
$$3 — [k_f = 0.4; k_t = 1.2; k_a = 1.4; k_n = 0.5] \Leftrightarrow \{\lambda_{12} = 1.0\ s^{-1}; max\,F_c = 1.9\ kN; \tau = 3.2\ s\}.$$

The different values of relative coefficients of resistance of λ_{12} under the shock and compression result in the fork of curves 1, 2, 3 on diagrams at once at the beginning of the shock.

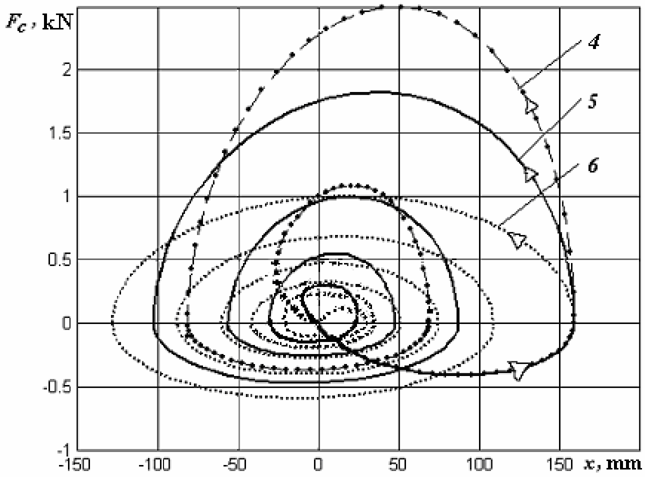

Fig. 3. The damper diagram at a management a parameter k_a OGD of firm Sachs Touring

Managing a parameter k_a (varying value of coefficient λ_{22}) the damper diagrams of OGD of firm Sachs Touring are built (Fig. 3) at the unchanging values of parameters: λ_{11} = 2.5 s^{-1}, λ_{12} = 0.5 s^{-1}, λ_{21} = 5.0 s^{-1}, k_n = 1.0. The trajectories of depicting points correspond to the next values of criteria of quality

$$4 — [k_f = 0.48;\ k_t = 1.3;\ k_a = 4] \Leftrightarrow \{\lambda_{22} = 2.0\ s^{-1};\ max\,F_c = 2.4\ kN;\ \tau = 3.0\ s\},$$
$$5 — [k_f = 0.36;\ k_t = 1;\ k_a = 2.8] \Leftrightarrow \{\lambda_{22} = 1.4\ s^{-1};\ max\,F_c = 1.82\ kN;\ \tau = 3.9\ s\},$$
$$6 — [k_f = 0.27;\ k_t = 0.8;\ k_a = 2] \Leftrightarrow \{\lambda_{22} = 1.0\ s^{-1};\ max\,F_c = 1.37\ kN;\ \tau = 5.1\ s\}.$$

On the phase of shock curves 4, 5, 6 coincide before the beginning of retreat, and go away further (Fig. 3). With diminishing of parameter k_a the maximal value of reaction goes down and fading time is simultaneously increased.

The construction of phase diagrams evidently demonstrates the process of renewal of the system after a shock and enables to make selection of such parameters of SVS, at which free after shock vibrations go out slowly during one period.

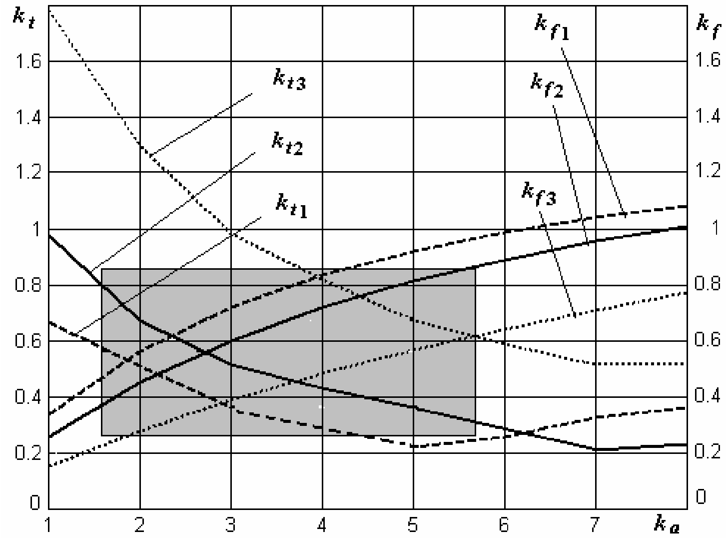

Fig. 4. Pareto-optimum great number of values (selected area) for the criteria of k_f, k_t

The followings values of parameters k_{n1} = 0.33, k_{n2} = 0.5, k_{n3} = 1.0 to the indexes 1, 2, 3 near the coefficients of k_f, k_t (Fig. 4) correspond.

The Pareto-optimum great number of values of criteria of quality of OGD is limited to the followings limits of values of parameters: k_a = 1.5÷5.5; k_n = 0.3÷1.5, which have the role of limitations during the constrained optimization with the developed algorithm. As a result of the selective calculations made with the developed method [Yaglinsky *et al.* 2006] for OGD the optimum values of managing parameters, providing the minimum value of goal of ψ_1 function, are: k_a = 2.5; k_n = 0.61. The values of criteria correspond to these parameters k_f = 0.62; k_t, = 0.62.

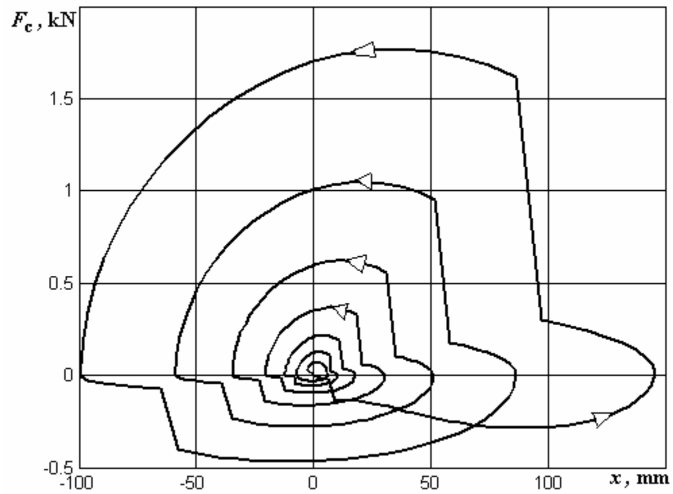

Fig. 5. The damper diagram of OGD at presence of 10% losses of working liquid of base model of OGD of firm Sachs Touring

It is possible that in the process of exploitation the appearance of losses of liquid changes character of damper diagrams and results in considerable growth of dynamic influences (Fig. 5).

Comparison of damper diagrams (Fig. 1, 5) for the base model of OGD of firm Sachs Touring testifies that 10 % losses of working liquid results almost in the double increase of reaction of the system on shock influence.

CONCLUSION

Calculations at shock influence on OGD with the use of the developed model allow substantially complement and specify the methods of the optimum planning of modern constructions of high-tense shock dampers of transport and technological machines, provide the increase of high-quality descriptions of SVS and operating reliability of OGD. Unlike the known decisions, the substantial influencing of losses of working liquid in the process of normative exploitation on quality of SVS is shown .

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