ESTIMATION OF DYNAMIC CONDITIONS OF ROLLING STOCK. STRUCTURAL METHODS AND INTERPRETATIONS.

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Abstract: Features of procedures of dynamic synthesis are considered at use of various interpretations or models of processes in mechanical oscillatory systems. Methodological bases for research of the wave processes develop, allowing receiving some features of distribution of indignations. Authors offer scientifically-methodical bases for the decisions received analytical by.

Keywords: dynamics, mechanical circuits, structural interpretations, vibroprotection.

1. INTRODUCTION

Modern direction of machine dynamics as interdisciplinary area of a science and techniques, it is closely connected with problems of maintenance of reliability and safety of technological processes in many branches of economic activities, manufacture, transport, extraction and enrichment of raw material, etc.

2. DYNAMIC ESTIMATION

I. Mathematical models. Mathematical modeling is widely used in search and development of nonproduction decisions. As a rule, analytical models in dynamic calculations are representing mechanical oscillatory systems with one or several degrees of freedom. Complex designs are displayed in the form of systems with the distributed parameters.
The existing mathematical device allows to estimate dynamic properties of the systems reflected in analytical models practically at any kinds of external influences. The approaches realizing ideas of optimization, the account of nonlinear properties, dynamic synthesis and maintenance of technological quality are develop [1].

The base analytical model for the majority of practical problems represents system with one degree of freedom. Its complication and transformation can be presented by table 1. The modern theory of vibration allows considering in oscillatory systems various kinds of connections, generated by typical set of elements. It is defined so-called baricentric parts, elastic parts and damp parts.

Not stopping on details, we shall note, that greater potential opportunities in search of new approaches are incorporated in structural interpretations of known in the theory of vibration of mathematical models.

Structural interpretation of the equations on fig. 1b can be presented by the scheme equivalent in the dynamic attitude by system of automatic control in which entrance and target signals correspond to the certain kinds of external influences on the settlement scheme (fig. 1a). The basic for the subsequent reasonings is that circumstance that such approach allows to pay attention to existence in structure of model of straight lines and feedback, opportunities of the organization of management on relative and absolute deviations of object of protection, and also on external indignation.

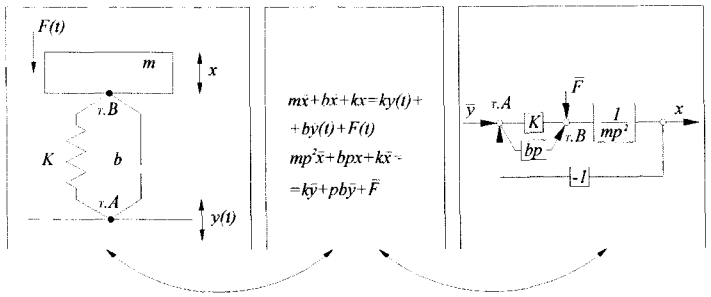


Figure 1. The Analytical Mode (a), mathematical model (b), its structural interpretation (c) for system about one degree of freedom

If the analytical model represents oscillatory system with final number of degrees of freedom the block diagram of system will be displayed by the system consisting of several blocks. Each block is fractional subsystem, being a typical fragment of system. For example, the system with two degrees of freedom beam type (fig. 2) has structural interpretations in two kinds which correspond to two systems of the generalized coordinates: x, φ (fig. 2b) x_1, x_2 (fig. 2c).

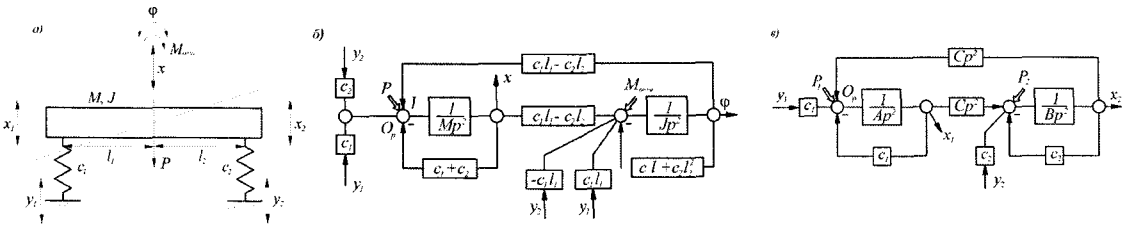
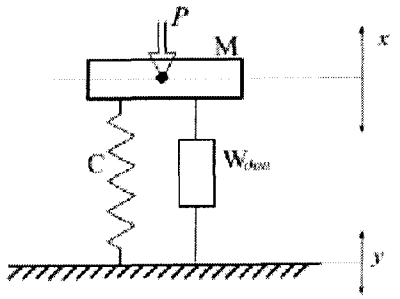
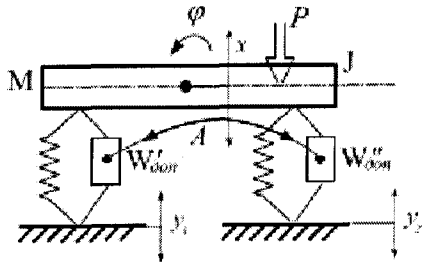
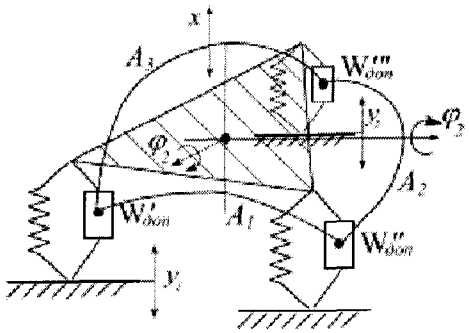


Figure 2. Base Settlement Two-dimensional Model (a) for Research of Dynamics of Vehicles,
A - The block diagram in system of coordinates x and φ
B - The block diagram in system of coordinates x_1, x_2

$$A = \frac{Ml_2^2 + J}{(l_1 + l_2)^2}; B = \frac{Ml_1^2 + J}{(l_1 + l_2)^2}; C = \frac{Ml_1 l_2 + J}{(l_1 + l_2)^2}$$

Table 1. There is Change of Opportunities of Use of Additional Ties at Transition to the Complicated Schemes of Vibroprotection.

		
Change of dynamic properties is reached by change of parameters of base system: rigidity and weight of object of protection or introduction of additional communications. In the elementary cases it can be elastic, damping element and the mechanism for transformation of movement in the form of a kinematic circuit of the certain kind, since torque link up to a circuit with several degrees of freedom. However, in the latter case in structure of an additional circuit it is necessary to enter the elastic elements providing a certain configuration and static balance. Variants of escalating of complexity of additional communications are possible. Additional ties arm-link type allows to enter the centrifugal forces, capable to provide a mode of quasinull rigidity of system.	Change of dynamic properties in this class of vibroprotection systems also can be reached due to a choice of type of additional ties. Specific feature becomes an opportunity of the organization of interaction between two additional communications W'_{Ad} and W_{Ad} (it is designated by a branch).	Opportunities of change of dynamic properties are represented by wider in a problem of spatial vibroprotection (under the scheme with three degrees of freedom). There is additional ties if they are executed in the form of arm-link mechanisms, have wider spectrum: • Turn of a plane of the arm-link mechanism around of an axis which are passing through basic hinges; • There is use of centrifugal forces in additional ties; • Use of communications of interaction between W'_{Ad}, W''_{Ad}, W'''_{Ad} (branches A_1, A_2, A_3).

Such approach is interesting to that the idea is entered into consideration about power interchange between fractional blocks. Character of communications between blocks is distinguished and depends on a choice of system of the generalized coordinates that is from a way of consideration. Unfortunately, the mentioned approach of development in due time has not received, though in it the opportunity of transition to mechanics of wave movements, perhaps, consists.

Structural interpretations have allowed entering into practice of the decision of problems of vibroprotection, vibroinsulation, restrictions torsional modes, balancing, stabilization of technical objects, frequency methods of the analysis and synthesis from the theory of automatic control.

Generalization of the received results on the basis of structural interpretations can be presented as a consecutive process of introduction to base model of so-called additional communications. On fig. 3 some details of introduction of additional communications are shown.

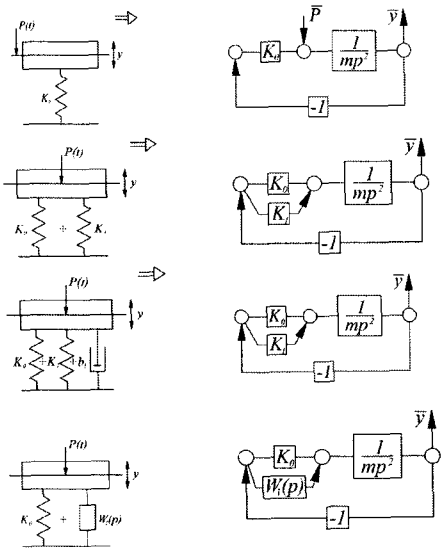


Figure 3. The Scheme of Introduction of Additional Ties

$$W_1(p)=\frac{a_0+a_1p+a_2p^2+\ldots+a_np^n}{b_0+b_1p+b_2p^2+\ldots+b_mp^m}$$

It has appeared, that additional ties can be presented in the form of is fractional-rational expression of a kind:

$$\bar{W}_1(p)=\frac{a_0+a_1p+a_2p^2+\ldots+a_np^n}{b_0+b_1p+\ldots+b_mp^m}; \qquad (1)$$

If index in this expression (1) are nulling and to move from consideration of the elementary combinations to more complex it is possible to find out, that private kinds of expression (a) have physical interpretation in the form of known (a spring, damper), and also there are new elements.

There is shown in table 2, that to separate private kinds of expression are correspond (1) not only separate parts, but also mechanisms (fig. 4,5,6).

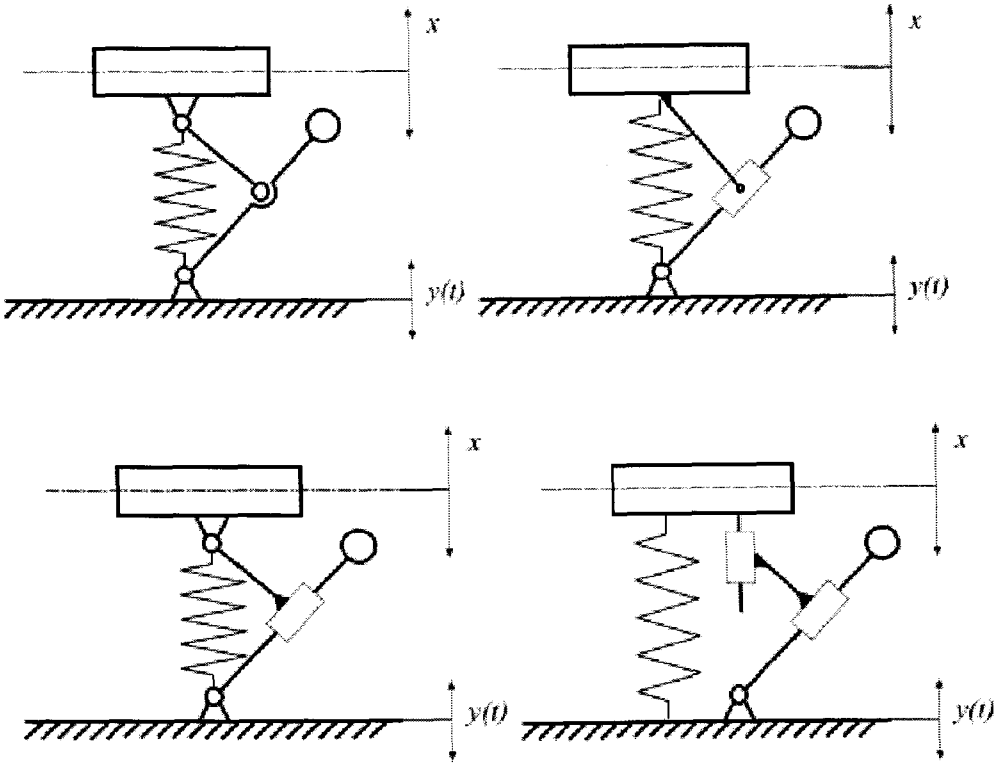


Figure 4. Opportunities of Construction of a Class of Vibroprotection Systems by Means of Change of Kinematic Pairs

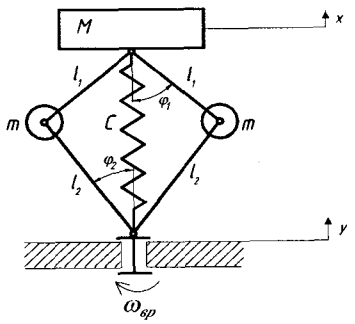


Figure 5. The Analytical Mode of Vibroprotection Systems with Additional Ties of Rotary Type

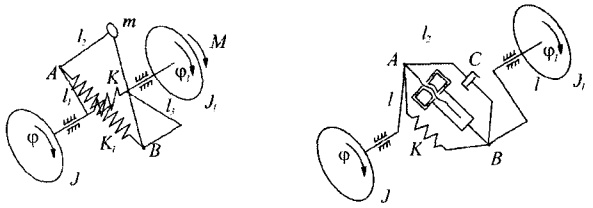
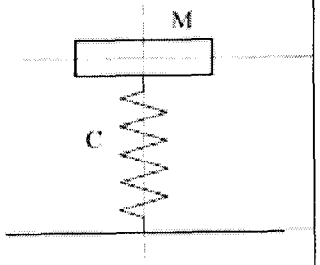
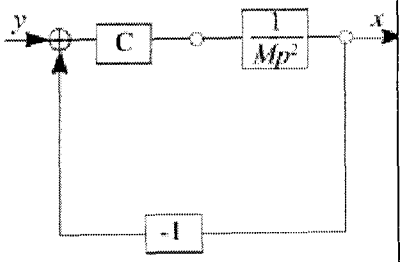
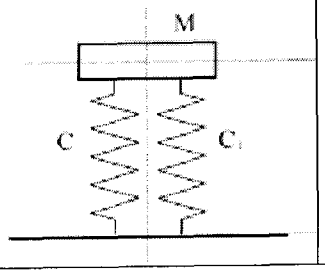
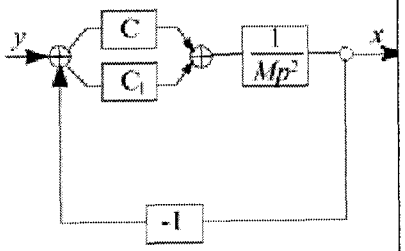
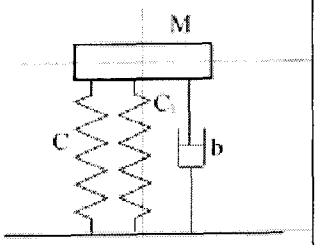
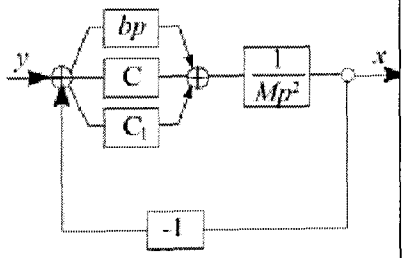
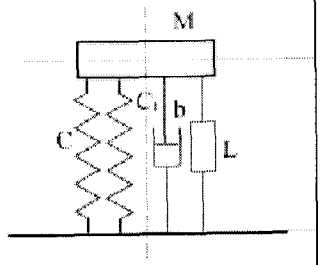
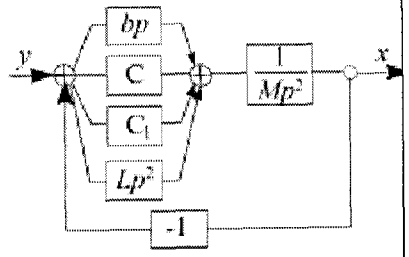
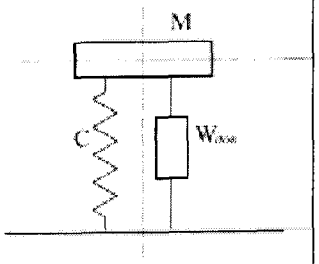
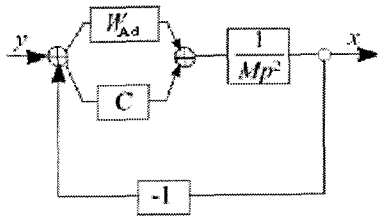
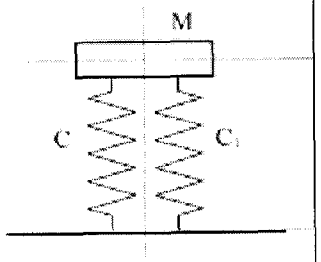
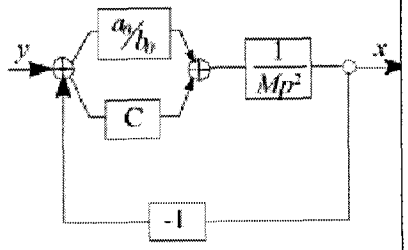


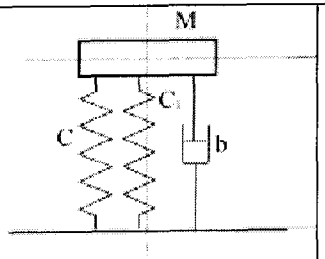
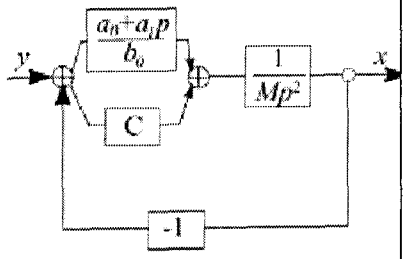
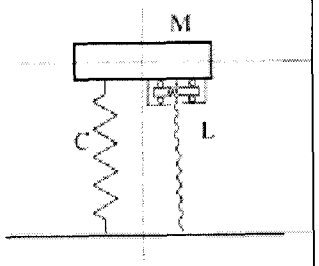
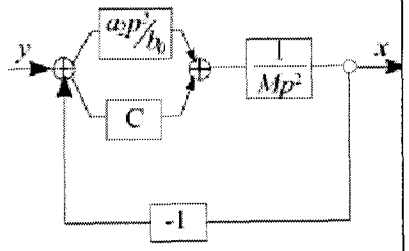
Figure 6. The Analytical Mode of Torsional Systems with Additional Ties in the Form of: two driving groups and additional weight *m* to which centrifugal forces are enclosed; the mechanism of transformation of movement and in parallel entered by a spring and damper

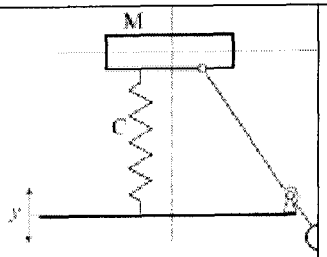
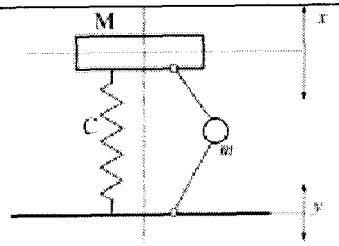
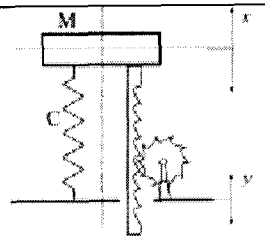
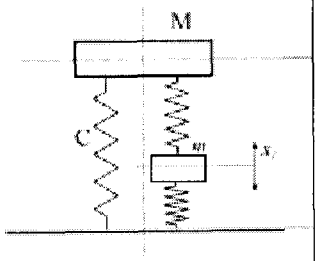
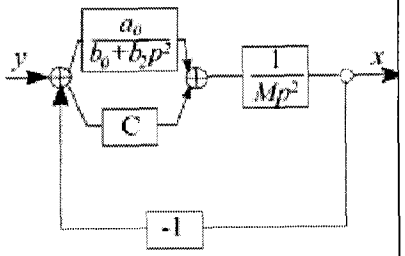
Table 2. The Table of Various Forms of Additional Ties in Problems of Vibroprotection at Kinematic Indignation.

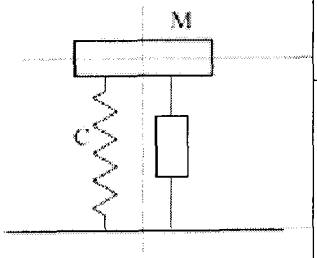
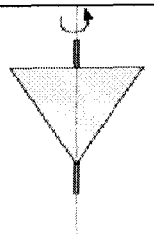
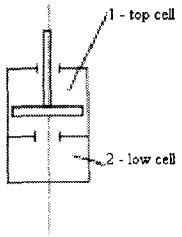
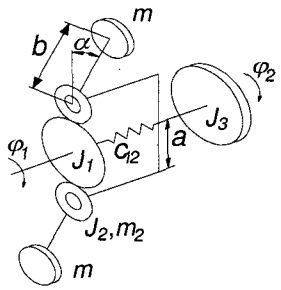
№	Kind of additional tie	Transfer function of system	Effects	Block scheme	Note
1	2	3	4	5	6
1	The basic or base scheme 	$W = \frac{C}{Mp^2 + C}$	Resonance, (break of 1-st sort in AFC)		$\omega_{рез} = \sqrt{\frac{C}{M}}$. $p \to \infty \quad \lvert W \rvert \to 0.$
2		$W = \frac{C + C_1}{Mp^2 + C + C_1}$	Resonance, shift aside higher frequencies		$\omega_{рез} = \sqrt{\frac{C + C_1}{M}}$. $p \to \infty \quad \lvert W \rvert \to 0.$

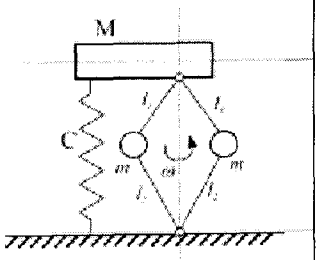
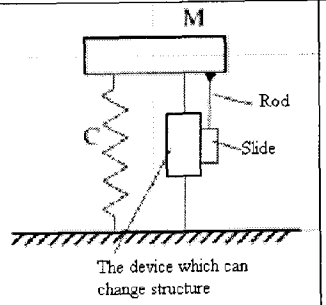
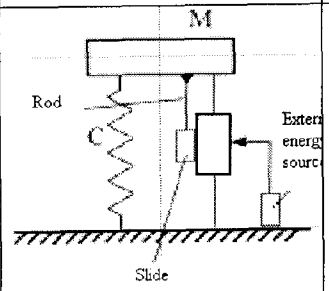
3	 b – damping coefficient	$W = \frac{C + C_1 + bp}{Mp^2 + bp + C + C_1}$	There is a resonance with restriction of the maximal amplitude of fluctuations		ω_{cut} - theret is defined from the frequency equation. $p \to \infty \quad \lvert W \rvert \to 0$
4	 L – there is resulted weight of the mechanism of transformation (for example, screw)	$W = \frac{C + C_1 + bp + Lp^2}{(M + L)p^2 + bp + C + C1}$	There is a resonance, mode of dynamic clearing, restriction of amplitude of fluctuations at a resonance, "lock-out" high frequencies.		*if* $p \to \infty \ \lvert W \rvert \to 0$ $\lvert W_{cut} \rvert = \frac{L}{M + L}$; *if* $b = 0$ $\omega_{dyn} = \sqrt{\frac{C + C_1}{L}}$; $\omega_{dyn} = \sqrt{\frac{C + C_1}{M + L}}$;

5		$W = \frac{C + W_{don}}{Mp^2 + W_{don} + C}$	The generalization of the approach and reception of results on poses is possible at the items 1-4 by reduction W_{Ad}		Common view $W_{Ad} = \frac{a_0 + a_1 p + ... + a_m p^m}{b_0 + b_1 p + ... + b_n p^n}$ $p = i\omega,\ i = \sqrt{-1}.$
6		$W = \frac{b_0 C + a_0}{Mb_0 p^2 + a_0 + Cb_0}$	$W_{Ad} = \frac{a_0}{b_0}$ $\frac{a_0}{b_0} = C_1$		$a_0 \neq 0,$ $a_1 = a_2 = ... = a_m = 0.$ $b_0 \neq 0,\ b_1 = 0,\ b_2 \neq 0,$ $b_3 = b_4 = ... = b_n = 0$

7	 b – damping coefficient	$W = \frac{b_0 C + a_1 p + a_0}{M b_0 p^2 + a_1 p + C b_0}$	$W_{Ad} = \frac{a_0 + a_1 p}{b_0}$ $C_1 = \frac{a_0}{b_0};$ $b = \frac{a_1}{b_0}$		$a_0 \neq 0, a_1 \neq 0$ $a_2 = ... = a_m = 0.$ $b_0 \neq 0,\ b_1 = 0,$ $b_2 = b_4 = ... = b_n = 0$
8		$W = \frac{b_0 C + a_2 p^2}{(M b_0 + a_2) p^2 + C b_0}$	$a_2 = L$ $(item\,4)$ $W_{Ad} = \frac{a_2 p^2}{b_0}$ $L = \frac{M b_0 + a_2}{b_0}$		$a_0 = 0, a_1 = 0, a_2 \neq 0,$ $a_3 = ... = a_m = 0.$ $b_0 \neq 0,\ b_2 \neq 0,$ $b_3 = ... = b_n = 0.$
9				There is a block diagram similar of item 8.	

					
10		$W = \frac{b_0C+b_2p^2+a_0}{Mb_0p^4+(Mb_0+Cb_2)p^2+Cb_0+a_0+cb}$	$W_{Ad} = \frac{a_0}{b_0 + b_2 p^2}$		For definition of transfer function of additional ties the scheme is used $W'_{Ad} = \frac{C_2}{mp^2 + C_1 + C_2}$ $W_{Ad} = \frac{C_2C_1}{mp^2 + C_1 + C_2}$ $W_{Ad} = C_1 W'_{Ad}.$

11			Parameters of system depend on conditions of external influence $W_{Ad} = ?$		The device of type «Whirligig» which cooperates with system at the certain parameters of relative movement
			$W_{Ad} = \frac{a_0 + a_1 p}{b_0 + b_1 p}$		At low frequencies cell 1 and 2 work. At high frequencies the top cell works.
			There are modes of dynamic clearing depending on speed of rotation.		Planetary mechanisms with levers and additional flyweights for creation of the forces depending on speed of rotation.

12		Transfer function of system includes parameters of rotation - ω. There is use of centrifugal forces for change of a vibrating condition of system is possible.	There is effect of management in the resulted weight of system. There is quasinull rigidity.		Frequency of a resonance and dynamic clearing depend on angular speed of rotation.
13		Transfer function corresponds to transfer function of system with variable structure.	There is a management of a vibrating condition depending on parameters of movement of system $W_{Ad} = \frac{a_0 + a_1 p + a_2 p^2}{b_0 + b_1 p + b_2 p^2 + b_3 p^3}$		There are special properties in transient. Energy of external sources is not used.
14		The system passes in a class of systems of automatic control.	Management on a relative deviation, y - an entrance signal, x - a target signal is carried out. $W_{Ad} = \frac{a_0 + a_1 p + a_2 p^2}{b_0 + b_1 p + b_2 p^2 + b_3 p^3}$		Stable change of parameters of a vibrating condition with use of active means (active vibroprotection system).

Thus, finally, structural interpretation is allows to enter into practice of search and a choice of decisions on change of a dynamic condition of oscillatory systems the new concept - change of dynamic properties by introduction of additional ties. These ties can be physically realized. Examples are resulted in table 2. The part of such realizations became a subject of inventions, and the base model has got a number earlier not found out dynamic properties. We shall result some examples: original modes of dynamic clearing, deny systems on high frequencies.

There is important that circumstance, that introduction of additional ties now can be correlated and to way (or a principle) managements of a condition: A - on an absolute deviation, B - on a relative deviation and C - on external influence. Elsewise, the base model possesses an opportunity to unite in itself information properties (parameters of a condition) and physical representations of realization of concrete elements of physical object.

There is possible to note this circumstance in the special image as such approach allows to pass easily to systems of active type in which additional ties represents a chain of consistently connected touch means, devices of processing and transformation of the information, the amplifier and the executive mechanism. The titled circumstance demands special consideration because of necessity to consider so-called internal constructive communications in system. The last are arise, and they are necessary for considering, when information channels are disconnected, however, servo-drivers, by virtue of specificity of their work, have their the «internal connections».

Development of the offered approach is perspective that allows to generalize the results received earlier in considered area on a uniform methodological basis and to make a number of conclusions about directions of possible researches (table 3).

1. Existing results of the applied theory of vibroprotection and vibroinsulation can be received as special cases more the general approach (from positions mechatronic).
2. The known set of typical elements of oscillatory systems can be expanded by introduction new.
3. Representation of transfer function of additional ties in the form of is fractional-rational expression (1) gives the tool of search and formation of new and original physical realizations. Therein plan table 2 can be carried to toolkit of prediction in search of new decisions.

II. There is consider, how it was already mentioned, an opportunity of expansion of a class of typical elementary parts. In table 3 it is shown, that as such new parts can act

- A part of double differentiation,
- A part of integration,
- A part of double integration,
- A part of pure delay.

Perhaps, the most remarkable is that circumstance, that transfer functions of these elementary types of parts (we shall name their typical elementary parts of 1-st level) can be received from the analysis of expression (1). On all the mentioned parts extend rules of switching links structures (a rule of consecutive and parallel connection of springs).

The opportunity of granting of a mechanical circuit as forms of realization of additional ties is expressed and is shown on the scheme (fig. 4,5,6). The big interest represents generalization of concept of a mechanical circuit as to some series-parallel combination of two-poles. Last, in this case represents a typical elementary part of the first level. By such approach is ample opportunities of physical realization of a greater part of transfer functions of additional communications on the basis of consideration of special cases of expression (1) are shown.

In summary it would be desirable to note, that the approach based on structural interpretations, for last years began to develop intensively, that it is possible to reflect the scheme on fig. 7, 8 reflecting specificity of approaches.

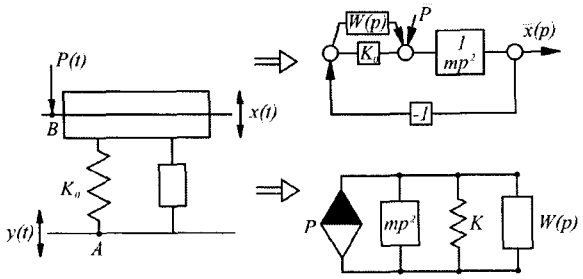


Figure 7. The Analytical Mode: Two Kinds of Structural Interpretations

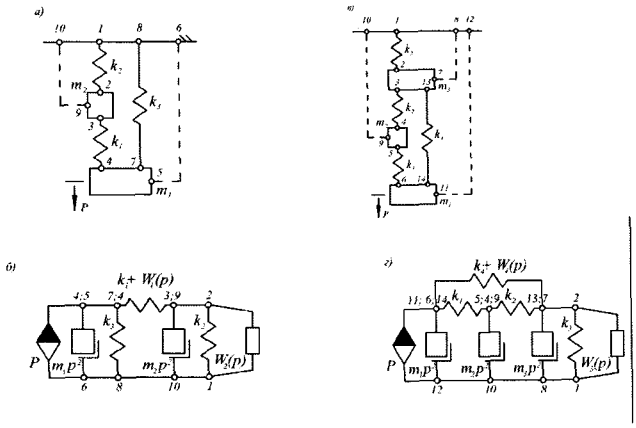
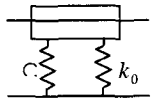
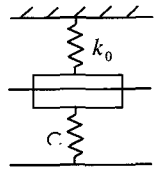
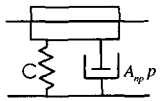
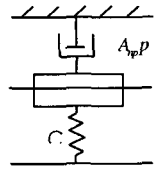
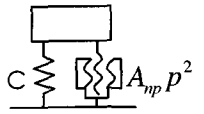
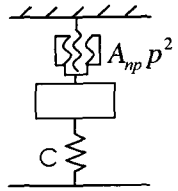
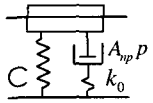
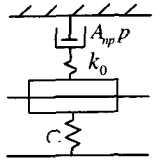
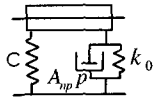
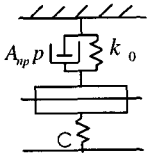
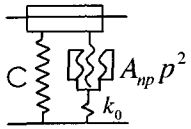
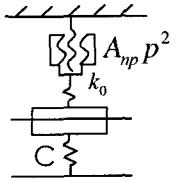
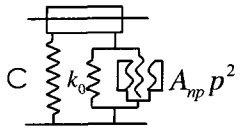
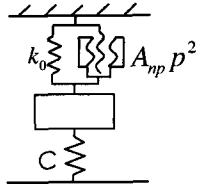
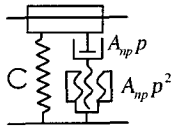
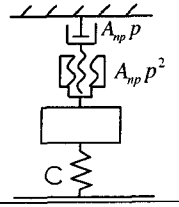


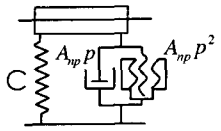
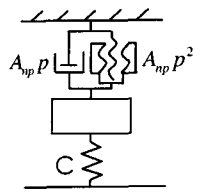
Figure 8. Examples of Oscillatory Systems and their Mechanical Circuit

Table 3. The Summary Table of Typical Elements for Block Diagrams of Mechanical Oscillatory Systems

№	Index of transfer function in table 4	Private kinds of transfer function of an additional circuit	Forms of physical realization of an additional circuit of a private kind	
			On a relative absolute deviation	On an absolute deviation
1	2	3	4	5
1	A-1	$W = \frac{b_0}{a_0}$	 Intensifying part, spring rigidity $k_0 = \frac{b_0}{a_0}$, C - rigidity of the basic spring (Fig .1).	
2	C-1	$W = \frac{b_1 p}{a_0}$	 There is a differentiating part of the first order, damper with damping coefficient $A_{np}p = \frac{b_1}{a_0}$.	

3	F-1	$W = \frac{b_2 p^2}{a_0}$	 There is a differentiating part of the second order, the device for transformation of movement. It is possible to present, as the lever mechanism or dynamic гаситель type the screw-nut.	
4	A-3	$W = \frac{b_0}{a_1 p}$	Integrating part of the first order, there is unknown physical realization.	There is unknown physical realization.
5	A-6	$W = \frac{b_0}{a_2 p^2}$	Integrating part of the second order, there is unknown physical realization.	There is unknown physical realization.
6	C-2	$W = \frac{b_1 p}{a_0 + a_1 p}$	 There is a consecutive connection of a spring and damper.	
7	B-1	$W = \frac{b_0 + b_1 p}{a_0}$	 There is a parallel connection of a spring and демпфера.	
8	F-7	$W = \frac{b_2 p^2}{a_0 + a_2 p^2}$	 There is a consecutive connection of a spring and differentiating part of the second order.	

9	G-1	$W = \frac{b_0 + b_2 p^2}{a_0}$	 There is a parallel connection of a spring and differentiating part of the second order.	
10	A-2	$W = \frac{b_0}{a_0 + a_1 p}$	There is a consecutive connection of a spring and integrated part of the first order, physical realization it is unknown. Aperiodic link. Probably, corresponds to introduction of additional communication of a kind e^{-ap}, at decomposition of exponential function in a number and deduction of the two first members.	There is unknown physical realization. Aperiodic link.
11	B-3	$W = \frac{b_0 + b_1 p}{a_1 p}$	There is a parallel connection of a spring and integrated part of the first order, physical realization it is unknown.	There is unknown physical realization.
12	A-7	$W = \frac{b_0}{a_0 + a_2 p^2}$	There is a consecutive connection of a spring and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
13	G-6	$W = \frac{b_0 + b_2 p^2}{a_2 p^2}$	There is a parallel connection of a spring and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
14	F-2	$W = \frac{b_2 p^2}{a_0 + a_1 p}$	 There is a consecutive connection of a differentiating part of the first order and differentiating part of the second order	

15	E-1	$W = \frac{b_1 p + b_2 p^2}{a_0}$	 There is a parallel connection of a differentiating part of the first order and differentiating part of the second order	
16	C-7	$W = \frac{b_1 p}{a_0 + a_2 p^2}$	There is a consecutive connection of a differentiating part of the first order and integrated part of the first order, physical realization it is unknown.	There is unknown physical realization.
17	G-3	$W = \frac{b_0 + b_2 p^2}{a_1 p}$	There is a parallel connection of a differentiating part of the first order and integrated part of the first order, physical realization it is unknown.	There is unknown physical realization.
18	C-13	$W = \frac{b_1 p}{a_0 + a_3 p^3}$	There is a consecutive connection of a differentiating part of the first order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
19	M-6	$W = \frac{b_0 + b_3 p^3}{a_2 p^2}$	There is a parallel connection of a differentiating part of the first order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
20	F-13	$W = \frac{b_2 p^2}{a_0 + a_3 p^3}$	There is a consecutive connection of a differentiating part of the second order and integrated part of the first order, physical realization it is unknown.	There is unknown physical realization.
21	M-3	$W = \frac{b_0 + b_3 p^3}{a_1 p}$	There is a parallel connection of a differentiating part of the second order and integrated part of the first order, physical realization it is unknown.	There is unknown physical realization.

22	F-28	$W = \frac{b_2 p^2}{a_0 + a_4 p^4}$	There is a consecutive connection of a differentiating part of the second order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
23	AB-6	$W = \frac{b_0 + b_4 p^4}{a_2 p^2}$	There is a parallel connection of a differentiating part of the second order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
24	A-5	$W = \frac{b_0}{a_1 p + a_2 p^2}$	There is a consecutive connection of an integrated part of the first order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.
25	B-6	$W = \frac{b_0 + b_1 p}{a_2 p^2}$	There is a parallel connection of an integrated part of the first order and integrated part of the second order, physical realization it is unknown.	There is unknown physical realization.

The note: the set of transfer functions of additional ties if the structure of transfer functions will contain numerator and a denominator with factors can be similarly received $b_0 \neq 0, b_1 \neq 0, b_2 \neq 0, b_3 \neq 0, b_4 \neq 0,\ a_0 \neq 0, a_1 \neq 0, a_2 \neq 0, a_3 \neq 0, a_4 \neq 0.$

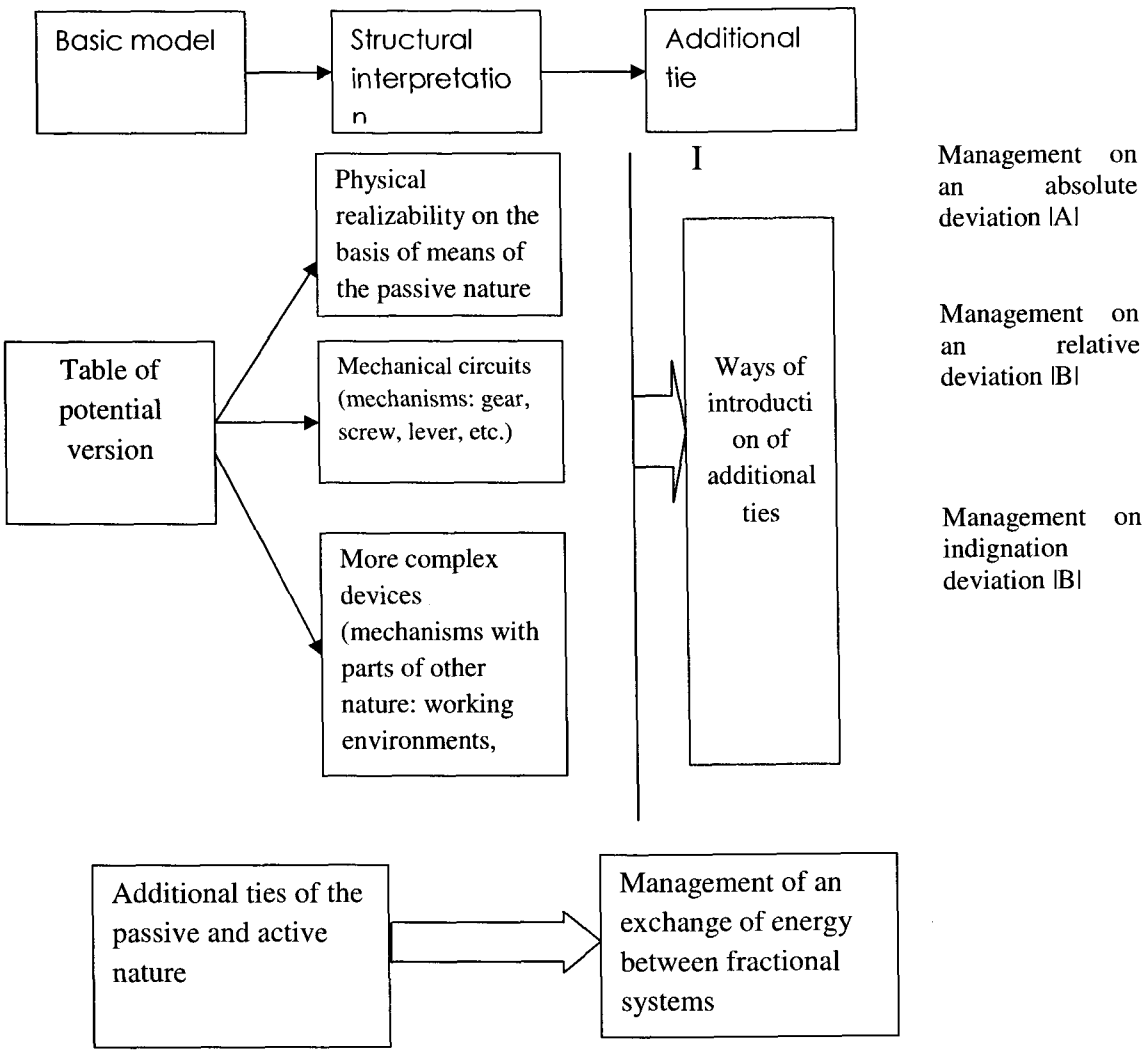


Figure 9. The Scheme of the Organization of Process of Research

At structural interpretations in the form of mechanical circuits from two poles of structure which have more simple appearance, and switching of elements submits to two rules of consecutive and parallel connection, convolution of circuits occurs definition of full complex resistance of a circuit becomes more rational, however, initial result more often. Both of a method yield identical results, and transfer function and full complex resistance are mutually defined the friend from the friend.

REFERENCES

Eliseev S.V., Lukyanov A.V., Reznik Yu. N, Khomenko A.P. Dynamics of mechanical systems with additional ties. Publishing of Irkutsk State University of Railway Engineering. Irkutsk.- 2006. pp.316.