VIBRATION CONTROL FOR HIGH-RISE CONSTRUCTIONS

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The vibration control system for high-rise constructions presupposing foundation insulation with the help of roller supports and structural rigidity adjustment is proposed. Passive elements – diagonal links with hydraulic dampers. They supplement an active part of a control system, increasing reliability of control with construction oscillations. In the active system the oscillation control is executed by electric hydraulic actuators. The active system comprises a subsystem of measurement and estimation of state variables and of identification of disturbing effects at incomplete information. Control subsystem providing optimal the control law. Mathematical models of the object with built-in control links and electro-hydraulic actuators (EHA) have been set up. Method of arranging EHA in the structure has been proposed. Effectiveness of the proposed vibration control system under seismic impact on the structure and at different design concept of passive-active communication has been studied.

Keywords: high-rise structures, oscillation control system, seismic and wind loads, electric-hydraulic actuators

1. The urgency of the problem. Controlled structures are of current interest in high-rise building construction. Vibrations of high-rise buildings, pipes, TV towers are the result of seismic, wind, technological, and pulse pressures and can achieve several meters in the structure's high points. There are bending, vertical and torsional oscillations, with bending and torsional deformations being considered as the most dangerous.

Typical damages arising from these load impacts are as follows:

1) at a relatively moderate foundation and soft soil destruction comes from non-uniform yielding of foundation;

2) during the loading affect there may occur a phenomenon close to the resonance, which leads to strong rocking of structures, with the stresses in structural elements and at their joints exceeding the tensile strength, so the building collapses.

Control process consists of reducing vibrations to allowance or eliminating vibration amplitudes of the construction at minimum time and of eliminating resonance.

2. Development of the problem. In the process of working out the vibration passive control systems (VPCS) a device (a set of devices) with constant parameters that reduce the vibration amplitudes of high-rise buildings without an external energy source are used. VPCS are classified [1, 2] on the operation-based principle: damping, isolating, adaptive, inertial, aerodynamic, regulating construction rigidity. The last systems are considered most effective.

Each system has its advantages and disadvantages. However, all passive systems are simple and reliable, always ready for operation but they also provide an effective vibration control in the restricted range of disturbing frequency spectrum and need additional adjustment and control during building's vibrations.

Vibration active control systems (VACS) with external power supply operate according to a specific program and provide:

– installation of measuring devices and the use of algorithms or devices for optimal estimation of state variables and identification of external impacts;

– applying algorithms for calculating optimal control actions, analog-digital and digital to analog converters and computers;

– optimal placement of actuators in the design to ensure the generation of optimal control efforts.

Depending on the type of energy used we distinguish hydraulic, pneumatic, electrical, electromagnetic systems of active vibration control. Selecting the type system defines the required technical specification

3. Description of the VCS. We choose the combination system which comprises:

– insulating roller VCS, that reduces the cutting efforts in the object's foundation;

– electro-hydraulic system controlling rigidness of the construction enabling passive and active vibration control.

The main part of the insulating system is homogeneous roller moving **without sliding**. It is necessary because of the exact unwind specification before the seismic disturbance. Practical implementation is possible by using steel, cast iron rollers etc.

Passive link is made in the form of reinforced concrete or steel beam, with one end being rigidly connected to the structural framing assembly and the other one is adjusted to the piston (cylinder) of the actuators. Girder section meets the optimum operating conditions of additional links [3].

A positioning electro-hydraulic servo drives of translational motion on the basis of electromechanical transformer and hydraulic booster of the «nozzle-flapper» type and main shift feedback is accepted as a VACS actuator (Fig. 1).

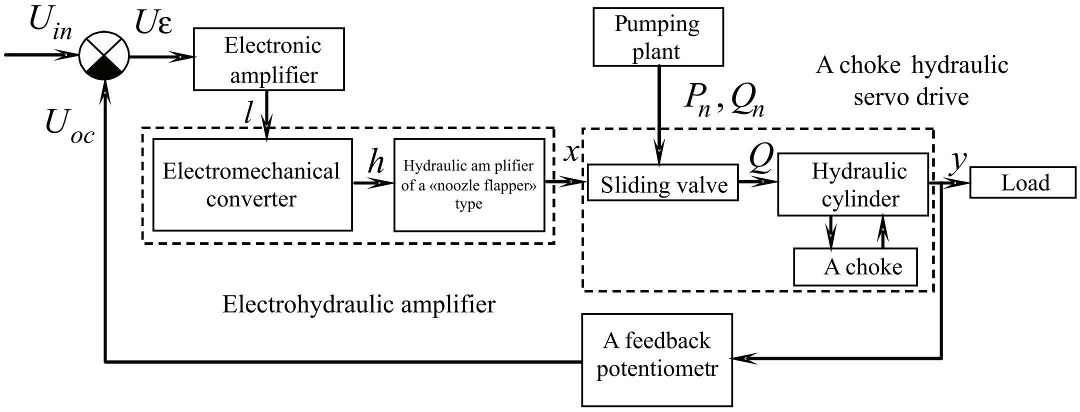

Fig. 1. Functional diagram of electro-hydraulic actuators

Further, during the study let's consider three types of passive link: tough; equipped with a «hydraulic spring», equipped with a hydraulic damper with communicating hollowness through an alternating choke with shift feedback.

The initial state of the actuator in the control system is characterized by: declutched electromagnets of electric-hydraulic distributor; filled pipes, hydraulic ram hollowness under pressure of hydraulic fluid in the hydraulic accumulator. As a result, we obtain the operating mechanisms' availability performance even under impulse loads on the controlled process.

At the passive control the electric unit of the actuator is switched off. Electromechanical converter and electro-hydraulic amplifier are in a neutral position. Fluid overflow from one hydraulic ram hollowness into another one is done by means of the choke.

With the active control by management signal from the computer U_{in} there appears current on the windings of electromechanical transformer that results in the shifting of the control sliding valve of the hydraulic booster and forces the hydraulic ram stock move together with the control object. The rod movement results in joint action of potentiometer lamellas that leads to development of current in the main negative feed-back circuit. This current is compared by adder in magnitude and sign with the control current i_{in}.

Thus, the translational motion of piston and hydraulic control cylinder is performed, the system of actuator working both in lengthening, and shortening of the additional link. Thereby the construction vibration control is available under disturbing force effect. Let's compile a mathematical model of a high-rise building with built-in passive-active links.

4. A mathematical model of the object with a built-in VCS. During modeling it is suggested that the internal forces and shifts caused by static lad component are given. Therefore, the model will describe small vibrations of the construction relative to stationary balanced state .In addition; we rely on the following assumptions.

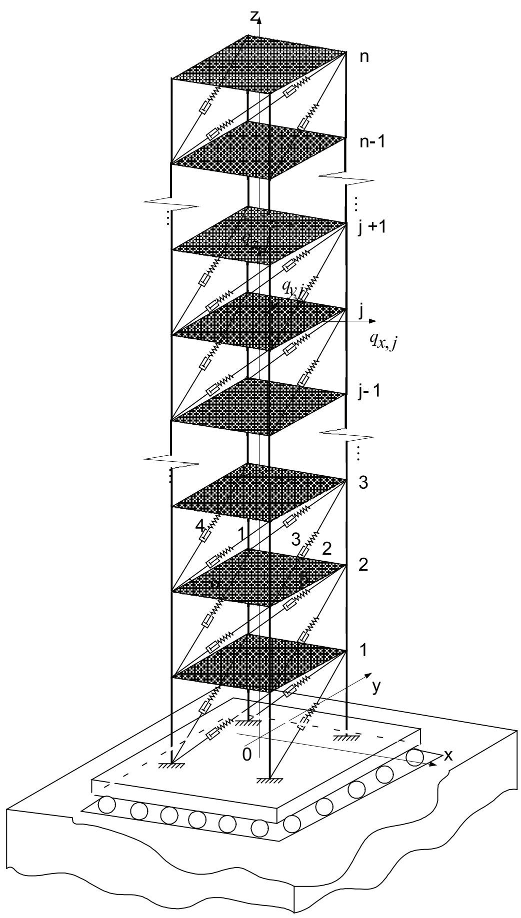

Fig. 2. High-rising construction scheme equipped by passive-active links and roller bearers

1. The high-rise building is set on roller bearings, according to the scheme shown in Fig. 2. Roller slippage is not observed. Restriction of the building horizontal motion of the building is performed mechanically and by means of springs and dampers.

2. General lay-out of the links must: connect the adjacent sections of the structure in order to suppress the horizontal and vertical vibrations of the high-rise building, and satisfy the controllability criterion; should not disturb the structure's static equilibrium and interfere the control object technological process.

3. It is believed that the passive-active links located on all sections of the multidimensional structure, with the he vector of generalized coordinates being written in the following form

$$\mathbf{q}(t)=\left[\mathbf{q}_x^t(t) \,\vdots\, \mathbf{q}_y^t(t) \,\vdots\, \mathbf{q}_z^t(t) \,\vdots\, \mathbf{q}_{p_1}^t(t) \,\vdots\, \mathbf{q}_{p_2}^t(t) \,\vdots\, \mathbf{q}_{p_3}^t(t) \,\vdots\, \mathbf{q}_{p_4}^t(t) \,\vdots\, \mathbf{q}_{1c}^t(t) \,\vdots\, \mathbf{q}_{2c}^t(t) \,\vdots\, \mathbf{q}_{3c}^t(t) \,\vdots\, \mathbf{q}_{4}^t(t)\right]^t.$$

With the following marking-off vectors of the object's generalized coordinates in the respective directions are formed by the scheme

$$\mathbf{q}_w(t)=\left[q_{w,1}(t) \quad \ldots \quad q_{w,j}(t) \quad \ldots \quad q_{w,n}(t)\right],$$

$$w:=x,y,z.$$

Vectors of generalized moves of pistons (cylinders) HA

$$\mathbf{q}_{p(c)_w}(t)=\left[q_{p(c)_{w,1}}(t) \quad \ldots \quad q_{p(c)_{w,j}}(t) \quad \ldots \quad q_{p(c)_{w,n}}(t)\right],$$

$$w:=\overline{1,4}$$

where n – number of vertical sections of the construction; t – transposing sign.

To take into account inertial and dissipative characteristics of the passive-active link we use a four-mass mechanical model of a multivariable construction and the 2-type Lagrange equation at the disturbing efforts impact.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\mathbf{q}}}\right)-\frac{\partial L}{\partial \mathbf{q}}+\frac{\partial D}{\partial \dot{\mathbf{q}}}=\mathbf{F}.$$

Where the Lagrangian function $L=T-\Pi$ is a function difference of kinetic and potential energy of the construction; D is a dissipative energy function of the object; $\mathbf{F}$ – disturbing impact vector; $\mathbf{q}(t)$ – the generalized coordinate vector. The equation of the controlled high-rise building (see the paper) [1, 4] looks like

$$\mathbf{M}\ddot{\mathbf{q}}(t)+\mathbf{K}(t)\dot{\mathbf{q}}(t)+\mathbf{H}(t)\mathbf{q}(t)=\mathbf{B}_F\mathbf{F}(t), \quad \mathbf{q}(t_0)=\mathbf{q}_0, \tag{1}$$

where it is designated:

– inertia matrix

$$\mathbf{M}=diag\left[\mathbf{M}_x \,\vdots\, \mathbf{M}_y \,\vdots\, \mathbf{M}_z \,\vdots\, \mathbf{M}_1^p \,\vdots\, \mathbf{M}_2^p \,\vdots\, \mathbf{M}_3^p \,\vdots\, \mathbf{M}_4^p \,\vdots\, \mathbf{M}_1^c \,\vdots\, \mathbf{M}_2^c \,\vdots\, \mathbf{M}_3^c \,\vdots\, \mathbf{M}_4^c\right];$$

– the object mass matrixes

$$\mathbf{M}_w=diag\left[m_{w,1} \,\vdots\, \ldots \,\vdots\, m_{w,j} \,\vdots\, \ldots \,\vdots\, m_{w,n}\right], \quad w:=x,y,z;$$

$m_{w,j}$ – section mass of the construction j;

– piston (cylinder) mass matrixes with associated mass of additional link

$$\mathbf{M}_l^{p(c)}=diag\left[m_{l,1}^{p(c)} \,\vdots\, \ldots \,\vdots\, m_{l,j}^{p(c)} \,\vdots\, \ldots \,\vdots\, m_{l,n}^{p(c)}\right];$$

– dissipative $\mathbf{K}(t)$ and rigidness $\mathbf{H}(t)$ matrixes are described in details in paper [1, 4],

– block matrix of disturbing efforts «distribution»

$$\mathbf{B}_F=\left[\begin{array}{c:c:c:c:c:c:c:c:c:c:c} \mathbf{B}_F^x & & & \mathbf{0} & & & \cdots & \cdots & & & \mathbf{0} \\ \hdashline & \mathbf{B}_F^y & & \vdots & & & & & & & \vdots \\ \hdashline & & \mathbf{B}_F^z & \mathbf{0} & & & \cdots & \cdots & & & \mathbf{0} \end{array}\right]^{\mathrm{T}}$$

– $\mathbf{B}_F^x, \mathbf{B}_F^y, \mathbf{B}_F^z \in R_{n\times v}$ – disturbance «distribution» matrixes over the building;

– disturbing effort vector

$$\mathbf{F}(t)=\left[a_x(t)\mathbf{M}_x \quad a_y(t)\mathbf{M}_y \quad a_z(t)\mathbf{M}_z\right],$$

where $\mathbf{a}(t)=a_x(t)\,\mathbf{i}+a_y(t)\,\mathbf{j}+a_z(t)\,\mathbf{k}$ – priming coat acceleration vector at seismic activity.

So, the mathematical model of a controlled space multidimensional modeling (see equation (1)). has been obtained. Its feature is a registration of inertia and dissipative characteristics of actuators of a passive-active vibration control.

5. Actuator mathematical model. At drawing up a deterministic vibration model for a loaded choke hydraulic control one relies on the following assumptions [3, 5]:

1. The choke hydraulic control is considered as a system with lumped parameters.
2. Hydraulic control power supply is performed at a constant pressure from an unrestricted consumption source.
3. Hydraulic accumulator capacity is matched on the basis of supplying the entire control process.
4. Hydraulic accumulator, spool-type distributer, electromechanic convertor are located near the hydraulic control. Therefore, due to short hydraulic lines wavelength processes do not make significant impact on the hydraulic control dynamics.
5. Hydraulic ram is located in the middle of additional link , with symmetry being assumed for study simplification.
6. The piston and the cylinder move right and left relative to mid-(zero)position.
7. During transient analysis the inertia, dissipative and position load is considered.
8. Metering -difference characteristic of the flow controller (control valve) is approximated by the parameter with zero values in the neighborhood of datum origin.
9. The flow control windows have equal specific consumptions.
10. Hence the vibration control system operation is momentary the hydraulic fluid temperature variation is neglected.
11. In the study of dynamic processes in the hydraulic control the adiabatic fluid elastic modulus F_{zh} is taken which is considered to be constant in the service pressure range, hydraulic fluid being clean.
12. Pressure being changed, hydraulic fluid specific density is neglected and variation rate is considered by the following relation

$$\frac{dP}{dt} = \frac{E_{zh}}{V}\frac{dV}{dt} \triangle ABC.$$

13. In the study of hydraulic control dynamics gas-air phase occurrence and dissolution in the operating fluid is considered.
14. Volume strain of pipes and building chamber curtains are noted by the reduced elastic modulus E_{pr}.
15. Hydraulic head losses in the connecting flues are negligible.
16. Acoustic effects in the connecting flues and time lag in the transmission lines are not considered.
17. Hydraulic flow inertia in the connecting lines and in the hydraulic control chambers are not considered due to pipelines being short and filled with hydraulic fluid.
18. In the hydraulic control the viscous and dry friction are considered. The dry friction characteristics are taken as linear. Fluid viscosity index is constant.

Mathematical model of a loaded electro-hydraulic actuator is described [2] by equations given in this table. The analog block diagram of the loaded electro-hydraulic actuators is shown in Fig. 3.

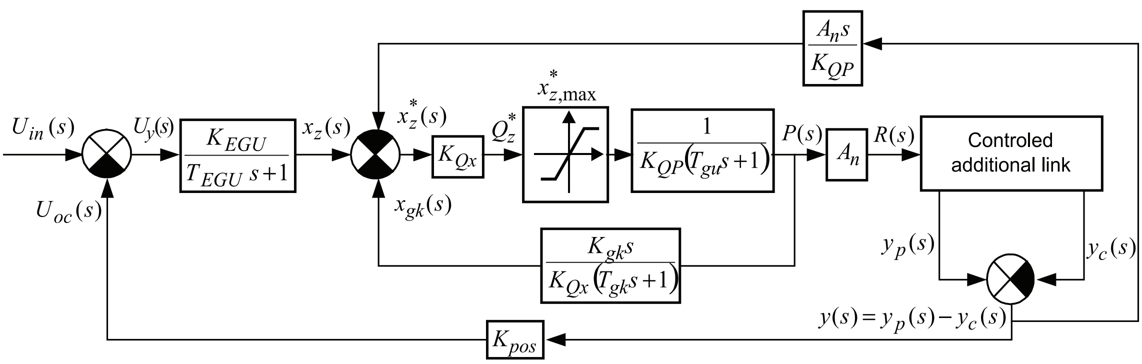

Fig. 3. Block diagram of a loaded electro-hydraulic actuator analog (Additional controlled link)

Mathematical model of a loaded electro-hydraulic actuator

Cauchy form	Standard image form
$U = U_{in} - U_{oc}$	$U(s) = U_{in}(s) - U_{oc}(s)$
$U_{oc} = K_{pos}\left(y^p - y^c\right)$	$U_{oc}(s) = K_{pos}\left[y^p(s) - y^c(s)\right]$
$T_{EGU}\dot{x}_z + x_z = K_{EGU}U$	$(T_{EGU}s+1)x_z(s) = K_{EGU}U(s)$
$K_{Qx}x_z^* - K_{QP}P = A_n\left(\dot{y}^p - \dot{y}^c\right) + \frac{V_{pol}}{2E_{pr}}\dot{P}$	$K_{Qx}x_z^*(s) = K_{QP}\left[T_{gu}s+1\right]P(s)$; $T_{gu} = \frac{V_{pol}}{2E_{pr}K_{QP}}$
$x_z^* = x_z - x_{gk} + \frac{A_n}{K_{Qx}}\left(\dot{y}^p - \dot{y}^c\right)$	$x_z^*(s) = x_z(s) - x_{gk}(s) + \frac{A_n s}{K_{Qx}}\left[y^p(s) - y^c(s)\right]$
$K_{Qx}\left(T_{gk}\dot{x}_{gk} + x_{gk}\right) = K_{gk}\dot{P}$	$K_{Qx}\left(T_{gk}s+1\right)x_{gk}(s) = K_{gk}sP(s)$

Here is considered that the piston and cylinder dynamics is described in the multidimensional structure mathematical model, with marking-off introduced:

U, U_{in}, U_{oc} – electro-hydraulic amplifier input voltage, input voltage, and feedback link voltage accordingly;

K_{pos} position feed-back ratio;

y^p, y^c piston and cylinder moving accordingly;

T_{EGU}, K_{EGU} – electro-hydraulic amplifier time constant and coefficient of amplification;

x_z, x_{gk} – sliding valve and hydro-condenser movement correspondently;

P – differential head in the hollowness of hydraulic vibration absorber;

R – hydraulic vibration absorber force;

A_n, V_{pol}, E_{pr} hydraulic vibration absorber piston area, hydraulic vibration absorber hollowness fluid volume, reduced elastic modulus correspondently;

K_{Qx}, K_{QP} – mutual conductance and и metering-difference characteristic correspondently;

T_{gk}, K_{gk} – hydraulic condenser time constant and coefficient of amplification.

Equation conversion given in the table provides obtaining dependence of the control voltage and output force of the hydraulic vibration absorber with consideration of actuators location it can be written as

$$\mathbf{E}\ddot{\mathbf{R}}(t) + \mathbf{G}\dot{\mathbf{R}}(t) + \mathbf{L}\mathbf{R}(t) = \mathbf{N}\mathbf{U}(t),$$

where **E, G, L, N** are corresponding matrix coefficients. Further it is assumed that all actuators are similar.

6. VCS Performance study. Numerical study of control system is presented by the example of a high-rise structure – tower-type headgear. A mass reinforced concrete tower-type headgear erected in the sliding form 120 sm high and plan sizes 21×21 m was subjected to seismic impact with oscillation strength of 7 grades with direction cosines cos *x* = 35°, cos *y* = 55°, cos *z* = 45° elative to global coordinate system. Impact frequency resonates with the structure's main vibration tone. Control system sensors and additional links are set on the marks 12, 24, 36 m, providing its observability and controllability relative motion of the tower-type headgear on the mark *36 m by axes* ***x*** exceeds allowance by 8 times, by axes ***y*** – 6 times , by axes ***z*** – by 1,5 times; on the mark *24 m by axes* ***x*** – 7 times, by axes ***y*** – 6 times, by axes ***z*** – 1,3 times; on the mark *12 m* by axes ***x*** – 6 times, by axes ***y*** – 5 times, by axes ***z*** – doesn't exceed.

7. Conclusions. Analysis of numerical modeling outcomes provides the following conclusions:

– using rigid links and links equipped with «hydraulic spring» alternates frequency characteristics of a building and allows to avoid resonance by reducing vibration amplitude but it does not protect the structure from failure;

– using passive links with hydraulic vibration absorber changes the frequency characteristic of the structure reducing vibration amplitude significantly, That being provided, the links maintain serviceable condition and the building does not collapse. As a result of reducing general link rigidness the required full vibration suppression of the multidimensional structure is not achieved;

– using active links reduces vibration amplitude of the structure down to allowance level and maintains the building's integrity vibration amplitude significantly.

References

1. Kuzina O.A. The analyze of devices and systems extinguishing fluctuations of high-rise tower type constructions / South-Russian State Technical University – Novocherkassk, 2002. – 65 p. It is deposited at the International council for scientific and technical information (ICSTI) 23.05.02. – It is annotated in the Bulletin of account ICSTI «Deposited scientific works». – 2002. – №7–60.

2. Kuzina O.A. Sistema for oscillations damping of high-rise constructions. Dissertation on scientific degree competition a cand. tech. sciences on a specialty 05.13.01 – «The System analysis, control and information processing». – M/, 2003. – 290 p.

3. Kabelkov A.N., Kuzina O.A. Mathematical model of is passive-active system controling oscillations in multidimensional constructions / South-Russian State Technical University: The centre of operative polygraphy. – Novocherkassk, 2002. – 69 p.

4. Kanianthra J.N., Speckart F.H. A Technique for determining damping values and damper locations in multi–degree–of–freedom system // Works of the American Society Of Mechanical Engineers. – Series D., 1975. – № 4. – P. 99–105.

5. Kabelkov A.N., Kabelkov V.A., Burtseva O.A. Methods for Research of States and Control of Vibration of Nonconservative Systems // Mechanical Vibrations: Types, Testing and Analysis. – Hauppauge: Nova Science Publishers, Inc., 2010. – P. 4-60.