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SYNTHESIS OF CONTROL ALGORITHMS FOR ACTIVE VIBRATION ISOLATION SYSTEM CONSTRUCTED ON THE BASIS OF MECHANISM WITH PARALLEL KINEMATICS

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Abstract

In this article we considered a mehatronics system with parallel kinematics for vibration isolation for technological objects. This system includes executive drive mechanism, sensors of kinematics parameters and digital regulator. We synthesized control algorithms used to optimum control in coordinates of a condition. We received matrix of factoring of feedback from the decision of discrete algebraic Riccati equation. We used methods of reduce the state dimension of the system and got rid of superfluous feedback. We made model sample of one-dimensional vibration isolation system. And checked on this model our algorithms of optimum control. The breadboard model includes electromechanical drive mechanism, A/D-D/C converter, the gauge of moving and accelerometers. The results of experimental researches confirming an overall performance of system at various influences on the part of the basis are resulted.

INTRODUCTION

Now the increasing extending to the technician and manufacture is gained with technological systems with parallel structure, such as Stewart platform. A distinctive singularity of such gears is ability to perceive and transmit loading is similar to space trusses and to ensure six degree of freedoms to an output link in a combination to its precision positioning concerning the grounding. The platform and the grounding are connected by among themselves closed kinematic chain, each of which joining links contains the linear engine and two spherical kinematic pairs with limitation from twirl of a link concerning its direct-axis.

Gears with a parallel kinematics gain a wide circulation in cutting machines and in the rigs used in space, aviation and automotive industry, and hexapod can be used both in the capacity of a tool holder and in the capacity of a control linkage by a table. They can be used in metallurgy for conveyance and exact positioning of bar during rolling.

By wide circulation hexapods are obliged to presence of a lot of advantages. So, as against traditional multicoordinate sequential systems in which lapses on each of shafts are summarized, lapses in gears with a parallel kinematics can mutually be compensated, so the exactitude can attain long of a micron.

Other serious advantage hexapods consists in a volume, that the center of twirl can remain to constants in a time of all conveyance, i.e. the three-dimensional motion of a platform is ensured with a modification of length of rods. The rigid connection of a waste of rods ensures lack of "lost motion", and also heightened stiffness and a carrying capacity of a platform.

One more essential advantage hexapods is pinpoint accuracy of measurement of relative conveyances of a platform and the grounding that allows to apply them in especially exact rigs, robotic systems and in medicine; and as parrying of actions of low-frequency oscillations and impacts from the grounding to a platform and on the contrary, that allows to apply them in the process equipment and systems of an active vibration insulation.

STATEMENT OF PROBLEM

Let's consider use of space Stewart platform for problem solving a vibration insulation of technological plants from low-frequency vibrations on the part of the grounding. Thus the following problems are solved:

- sampling the scheme and a construction of the drive gear and such as transmitters;
- a system synthesis of steering.

There is a many of schemes and designs parallel kinematics mechanisms. We shall consider a solution of an electromechanical platform with a worm-gearing and the semirevolving gear. In the capacity of transmitters in sceme of a feed-back accelerometers and the displacement pick-up are used. This scheme simple enough design and indiscriminateness to actuating medium distinguishes, i.e. a possibility of maintenance in unfavorable mediums.

EXPOSITION OF A MOCKUP SAMPLE.

The experimental model of a bearing part of hexapod with a worm-gearing and the semirevolving gear is created. Its appearance and the block diagram are shown on figure 1.

The experimental model is consist of the mobile grounding 1 and platforms 2 on which the equipment is placed. Control of a platform is carried out by means of the electromechanical drive gear with direct-current electromotor and the lever gear. Control of the drive gear is carried out an adjuster on signals from accelerometers on plant 3 and the grounding (in figure it is not figured) and conveyances 4.

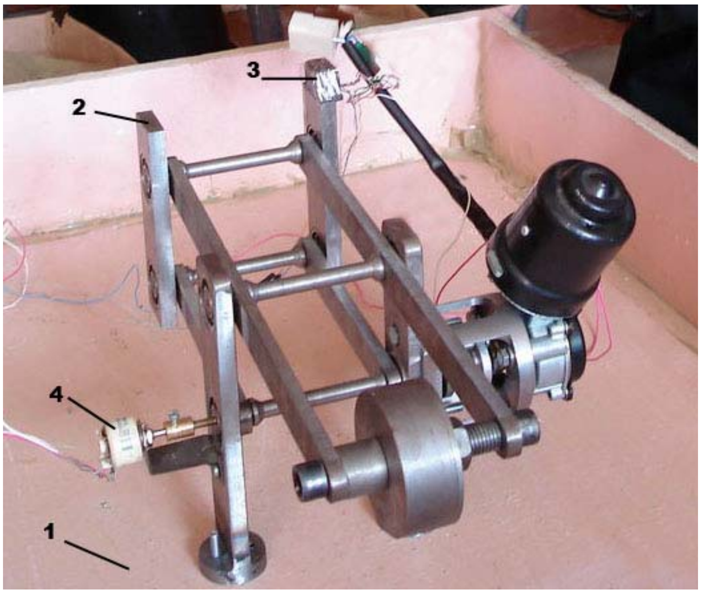

Figure 1. — An experimental model of a system of a vibration isolation

Base problem for ensuring functioning of such system, it's use of electric transmitters of kinematic parameters — a transmitter of relative conveyances and acceleration transducers.

Sampling transmitters of conveyances depends on an aspect of conveyances, and also from modes and the purposes of aftertreatment and filing of signals. In an experimental model in potentiometric displacement pick-up with linearly varying resistance is used.

The problem on application in a system of an active vibration isolation of accelerometers has a basic value as it grounded, primarily, on their use. For low-frequency and infralow frequency systems the most spread accelerometers grounded on piezoelectric effect as the range of their operation begins from 3 – 5 Hz cannot be used. Therefore it is necessary to apply low-frequency accelerometers to the given system with tenzometric, magnetic or capacity transformation of a mechanical signal of relative conveyance mass in electric.

In an experimental model accelerometer ADXL202 which can measure as dynamic speedup (for example, the vibration), and static (for example, a gravitation) is used. Output signals — the voltage proportional to speedup. The standard level of noise of a gear (150 $\mu g\sqrt{Hz}$) allows to trace speedups less than 1 mg at operation in a narrow-band condition (<10 Hz).

For microcircuit ADXL202 at turning on lowpass filter with frequency of a shearing, for example 10 Hz, the virtual value of noise on an exit of the filter will make 0.3 mg, and amplitude, with probability 0.997, — in limits 1 mg. As the full dial of this transmitter makes 1.5 g, the dynamic range is equal 20lg(1.5/0.001) =

= 63.5 dB

Signals from transmitters have a set frequency component. If the similar signal to discretize with frequency, its twice greater the high-frequenciest component, probably, is required unduly a high frequency of digitization. Limitation of a spectrum is made with the help of a filtering.

The filtering secures, that in a treated signal will not be high-frequency component which could reduce to aliasing. In our case frequencies above 5 Hz are undesirable, frequencies over 50 Hz can reduce in emersion of pseudo-frequency of oscillation of signals from transmitters 0–5 Hz that will make a system incontrollable.

Let's formulate some demands to performances of the filter: for maximum exact signaling in a filter transmission band there should not be pulsations, the filter should provide on frequency of a shearing of 5 Hz damping no more than 3 dB and on frequency of 50 Hz not less than 50 dB, at observance of first two conditions FRF of the filter should be maximum smooth.

The filter designed in view of showed demands can be described an aperiodic link of 4-th order. The given filter ensures frequency of a shearing of 5 Hz, damping 55 dB on frequency of 50 Hz and smooth enough FRF.

On fig. 2 time charts, illustrating operation of the filter are reduced. On an input of the filter it was applied a signal, having sine wave component with frequency 50, 75, 100 and 200 Hz (fig. 2a) — noise (a spurious signal which is necessary for suppressing), and also sinusoids with frequencies of 2 both 5 Hz and a quantized signal with frequency of 1 Hz (fig. 2b) — a legitimate signal (should be passed by the filter with minimum distortions). On fig. 2c the commixed signal given on an input of the filter is shown. On fig. 2d a filtrated (useful) signal. The insignificant distortions being in the big extent a corollary of a diminution of an amplification of the filter on 3 dB on frequency of 5 Hz are appreciable.

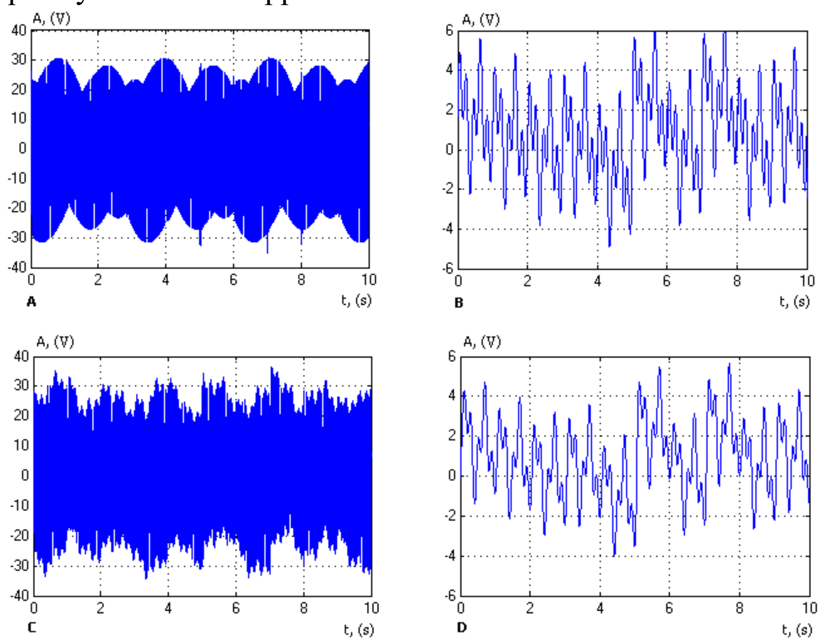

Figure 2. — Time charts of the filter

Transmitters through filters are connected to the computer by means of a board of water/output LCard L-154. On a board there is one analog-digital converter, on which input by means of a commutator move 16 (or 32) a signal from analogue inputs of a board. From the DAC of a board it is possible to remove a signal of steering shaped by a progamma.

Before connection of radiants of a signal the common earth loop of the computer and gears connected to it has been provided. For this purpose have connected contact piece 12 connectors of a board to an earth loop of gears.

At differential connection the noise suppression, originating on connecting leads, on 70 dB is ensured. The real relation makes signal/noise of datas of an analog-digital converter about 80 dB.

SYNTHESIS OF AN OPTIMUM DIGITAL ADJUSTER

On the basis of obtained from acceleration pickups and the displacement pickup of the information control action pays off. The control algorithm has been obtained by an electromechanical system from the analysis of feed-backs - control loops. In the capacity of base the optimum adjuster is considered.

In our case in view of electromechanical properties of the drive gear driving of one of bearing part is described by a set of equations in space of a condition

$$\dot{\mathbf{X}} = \mathbf{AX} + \mathbf{B}u + \mathbf{GY} \tag{1}$$

where $\mathbf{X} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} \dot{x} \\ \Delta x \\ I_a \end{bmatrix}$ — a vector of a condition, $\mathbf{Y} = \begin{bmatrix} \dot{y} \\ \ddot{y} \end{bmatrix}$ — a vector of perturbation, $\mathbf{A} = \begin{bmatrix} 0 & 0 & \dfrac{k_{em} r_1}{J_{em} + m r_1 r_2} \\ 1 & 0 & 0 \\ -\dfrac{k_{em}}{r_1 L} & 0 & -\dfrac{R}{L} \end{bmatrix}$, $\mathbf{B} = \begin{bmatrix} 0 \\ 0 \\ \dfrac{1}{L} \end{bmatrix}$, $\mathbf{G} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \\ \dfrac{k_{em}}{r_1 L} & 0 \end{bmatrix}$ — matrixes of fixed coefficients; m — a mass of plant; I_a — a current of a motor armature; k_{em} — electromechanical factor of the electric motor; J_{em} — a moment of inertia of a rotor of the electric motor; R — resistance of drive winding; L — inductance of the electric motor; r_1 and r_2 — gear-ratio reduction ratios of pair “screw–nut” on speed and force parameters accordingly.

Problem of synthesis of an optimum adjuster we shall solve in discrete area for what a set of equations (1) we shall transfer in the discrete form. In outcome we shall receive a set of equations

$$\mathbf{X}[i+1] = \mathbf{A}_{\Delta}\mathbf{X}[i] + \mathbf{B}_{\Delta}u[i] + \mathbf{G}_{\Delta}\mathbf{Y}[i] \tag{2}$$

where $\mathbf{A}_{\Delta} = \exp(\mathbf{A}T) = \mathbf{E} + \sum_{i=1}^{\infty} \frac{\mathbf{A}^i T^i}{i!}$, $\mathbf{B}_{\Delta} = \left(\int_0^T \exp(\mathbf{A}T)\, dt \right) \mathbf{B} = \left(\mathbf{E}T + \sum_{i=1}^{\infty} \frac{\mathbf{A}^i T^{i+1}}{(i+1)!} \right) \mathbf{B}$

In the matrix equation (2) $\mathbf{A}_{\Delta}$, $\mathbf{B}_{\Delta}$ and $\mathbf{G}_{\Delta}$ are analogs of matrixes $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{G}$ continuous system, and T — the period of digitization. In view of complexity of mathematical calculations is inexpedient to output a general view of matrixes $\mathbf{A}_{\Delta}$ and $\mathbf{B}_{\Delta}$. It is convenient to calculate matrixes $\mathbf{A}_{\Delta}$ and $\mathbf{B}_{\Delta}$ in a numerical aspect.

Let's define structure of an optimum discrete adjuster as a matrix relation

$$u[i] = -\mathbf{F}\mathbf{X}[i]$$

where $\mathbf{F} = \begin{bmatrix} f_1 & f_2 & f_3 \end{bmatrix}$ — a matrix of factors of closed loops on variables of a condition. For the decision of a problem of synthesis of an optimum adjuster we shall generate vector $\mathbf{Z}$ of controlled variables

$$\mathbf{Z} = \begin{bmatrix} z_1 & z_2 \end{bmatrix}^{\mathrm{T}} = \mathbf{D}\begin{bmatrix} x_1 & x_2 \end{bmatrix}^{\mathrm{T}} = \mathbf{D}\mathbf{X}$$

where $\mathbf{D} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$ — a matrix of link of coordinates of a condition and controlled variables.

For common expression of criterion of quality we shall accept an integral from quadratic forms of controlled variables and control action of an aspect

$$J = \sum_{i=0}^{\infty} \left(\mathbf{X}^{\mathrm{T}}[i] \mathbf{D}^{\mathrm{T}} \mathbf{Q} \mathbf{D} \mathbf{X}[i] + r u[i] \right) \to \min$$

where $\mathbf{Q} = \begin{bmatrix} q_1 & 0 \\ 0 & q_2 \end{bmatrix}$ — a matrix of weighting coefficients at controlled variables.

Thus, we have formulated a problem of control: to minimize amplitude of a velocity of driving of plant (so also amplitude of its speedup) and also to limit a level of conveyance of plant concerning the grounding, having limited thus to an off-the-shelf resource of control.

The matrix of factors of feed-backs is defined by expression

$$\mathbf{K} = \left(r + \mathbf{B}^{\mathrm{T}} \mathbf{P} \mathbf{B} \right)^{-1} \mathbf{B}^{\mathrm{T}} \mathbf{P} \mathbf{A}$$

where $\mathbf{P}$ — a square positive definite supplementary matrix a size, in our case, 3×3. The matrix $\mathbf{P}$ meet requirements to discrete Riccati equation [1].

$$\mathbf{P} = \mathbf{D}^{\mathrm{T}} \mathbf{Q} \mathbf{D} + \mathbf{A}^{\mathrm{T}} \mathbf{P} \mathbf{A} - \mathbf{A}^{\mathrm{T}} \mathbf{P} \mathbf{B} \left(r + \mathbf{B}^{\mathrm{T}} \mathbf{P} \mathbf{B} \right)^{-1} \mathbf{B}^{\mathrm{T}} \mathbf{P} \mathbf{A} \qquad (3)$$

The solution of Riccati equation is numerically with the help of the procedures included in package MATLAB. Thus, we obtain the law of steering as a feed-back on a condition of a system

$$u[i] = -k_1 \dot{x}[i] - k_2 z[i] + k_3 I_a[i] \qquad (4)$$

It is necessary to pay attention that the magnitude of current of a motor armature I_a is difficultly accessible to measurement, therefore it is expedient to express it through other measured magnitudes. From the first equation of exposition of a system in coordinates of a condition we have

$$I_a = \frac{J_{em} + mr_1r_2}{k_{em}r_1}\ddot{x} - \frac{J_{em} + mr_1r_2}{k_{em}r_1}\ddot{y}$$

Then the law of controlling of an optimum adjuster (4) will become

$$u[i] = -k_1\dot{x}[i] - k_2 z[i] + k_3'\ddot{x}[i] - k_3'\ddot{y}[i],$$

where $k_3' = \frac{J_{em} + mr_1r_2}{k_{em}r_1}k_3$. Besides the signal of control should not exceed as much as possible admissible voltage of the electromotor.

Structure of the adjuster implementing optimum steering by this criterion, it is shown on fig. 3.

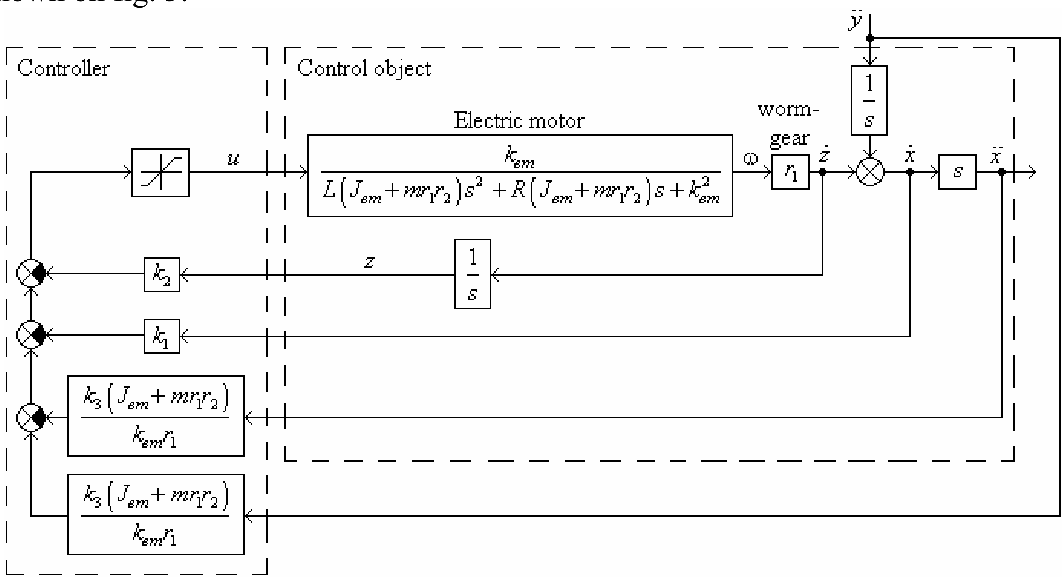

Figure 3. — Structure of an electromechanical system with an optimum regulator

EXPERIMENTAL RESEARCHES

We did full-scale tests with mockup sample..

On fig. 4 signals from accelerometers on the grounding (curve 1) and on plant (curve 2) are reduced at action on the grounding of sine wave perturbation. On fig. 5 shown operation of a system (curve 1) at action on the grounding of a casual signal of low frequency (curve 2).

From reduced graphs it is visible, that the investigated system ensures suppression of vibrations up to a level about 20 % from magnitude of perturbation.

Voltage excursion of a feed of the electromotor changes the lower boundary of a frequency range of operation of the electromechanical drive gear, however at a source voltage less than 2 V, twirl of the shaft of the engine becomes inconsistent. At a trigger voltage less than 1 V the shaft of the engine it is not twirled (a starting current restricted 1.5 A). For a solution of a problem of a guard of plant from exterior perturbations on infralow frequencies magnification of factor of a reduction or application of other type of the electromotor is necessary.

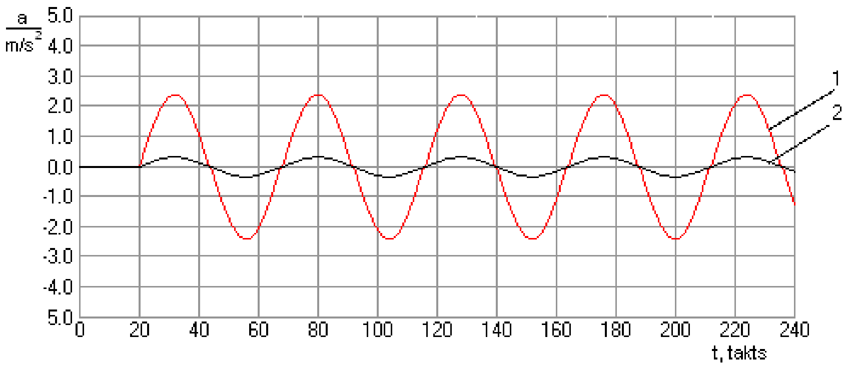

Figure 4. — A response of a considered system on a harmonic signal

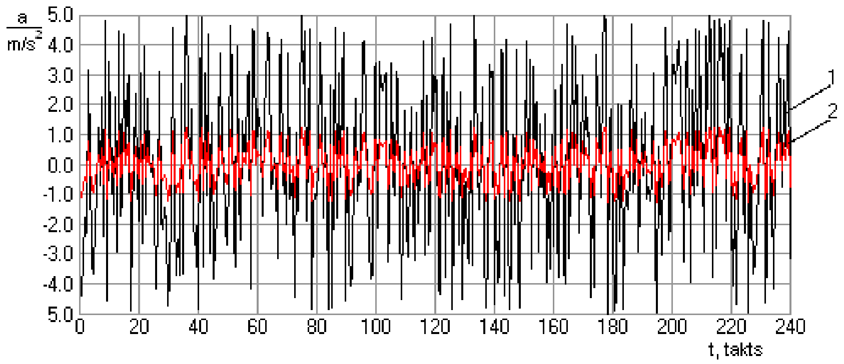

Figure 5. — A response of a considered system on a casual signal

SUMMARY

Application of the stepping motor will be perspectiv. Positioning by the stepping motor is fulfilled without a slippage and an override, also there is no dead zone. We shall mark, that sampling or development of the electromotor for application in similar a system demands special probe and searching of optimum solutions in view of development technicians.

Probes of a response on exterior perturbation have shown a high performance of the selected scheme of the electromechanical drive gear and the control algorithm, and also paths of the further probes and refinements of a system.

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