(Extended annotation)

MOVEMENT CONTROL OF FLEXIBLE MECHANICAL SYSTEMS WITH VARIABLE PARAMETERS AND VARIABLE DEGREES OF FREEDOM

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The paper discusses some of the control problems of moving mechanical objects that clearly exhibit the properties of flexible multi-frequency oscillating systems with discretely time-varying number of freedom degrees.

Typical examples of such mechanical objects are the orbit-assembled large space structures (LSS) [1] and space and underwater robotic modules that have long flexible manipulator links. The flexibility of such links as well as transferred payloads should be taken into account.

Similar dynamics exhibit exotic multistory buildings that are constructed on moving basements with active stability systems [2]. These objects are erected in earthquake-prone zones.

A principal feature of such mechanical systems is a rigid carrier body (main body) and some flexible elements (carried bodies) that are attached to this main body.

Such construction makes it possible to solve the control problems of discretely changing objects with the use of equations that are shaped as a sequence of modal-physical models (MPM) [3]:

$$(1) \qquad \mathfrak{M}_n : \quad \begin{array}{l} \ddot{\bar{x}} = m_n(u); \quad \ddot{\tilde{x}}_i + \tilde{\omega}_i^2 \tilde{x}_i = \tilde{k}_i m_n(u), \quad i = \overline{1,n},\ n \in (1,N); \\ x^{\Sigma} = \bar{x} + \tilde{x}, \qquad \tilde{x} = \sum_{i=1}^{n} \tilde{x}_i; \qquad m_n(u) = M(u)/I_n , \end{array}$$

where $x^{\Sigma} \doteq \vartheta \in q$ is the controlled coordinate of the carrier body; $\bar{x}$ is the coordinate of the transfer (rigid) motion; $\tilde{x}$ is the disturbance due to the influence of the flexible elements motion; $\tilde{\omega}_i, \tilde{k}_i$ are the fundamental frequencies and the excitability coefficients of the elastic modes; *n* is the number of the flexible carried elements at the *n*-th stage of the assembly; *N* is the number of the flexible carried elements of the completed construction; $M(u)$ is the control action; *u* is the input signal of the orientation system actuator device; I_n is the inertia moment of the construction at the *n*-th stage of the assembly. $\mathfrak{M}_n$, $(n=0,1,2,...,N)$ defines MPM of the object at the *n*-th stage of its assembly in the orbit. Index $n=0$ identifies the main body moving model ($\mathfrak{M}_0$: $\ddot{\bar{x}} = m_0(u)$, $m_0(u) = M(u)/I_0$). In particular, this model corresponds to the initial stage of the LSS assembly in the orbit. At this stage, the construction carrier body is set up, oriented and stabilized with the accuracy, which is needed for the next assembly stages. With increasing the value of *n*, the model (1) becomes more complicated since the number of freedom degrees and the inertia moment also increase. According to the general Rayleigh's theorem, an increment of the inertia moment leads to decreased frequencies $\tilde{\omega}_i$. They close with the frequency of the main ("rigid") controlled motion. It is well known that, as a result, a quality control becomes problematic and motion instability may arise. This instability can be caused by the "capture" of the regulator by elastic oscillations.

The above discussion suggests that, when designing the control system, the following three qualitatively different types of the controlled object condition should be distinguished.

1. The initial type ($n = 0$) involves the carrier body orientation with respect to the required direction and its stabilization with accuracy that is necessary for the further assembly.
2. Once the first construction flexible element ($n = 1$) and some other flexible elements ($n \le n^* < N$) are attached to the assembled object that begins exhibit the properties of a flexible mechanical system, which is characterized by the presence of one or several comparatively high-frequency (~1÷10 *Hz*) elastic modes.
3. As the number of the flexible elements increases ($n^* < n \le N$), the assembled construction turns into a hard-to-control system. Such system is distinguished by a big inertia moment of the attached bodies and low elastic modes frequencies (<0,1 *Hz*). These frequencies close with the fundamental frequency of the "rigid" motion of the object.

The paper considers the transformation of dynamical properties of a discretely evolving structure that is being changed in accordance with a prescribed construction assembly sequence.

The proposed solution breaks down the transformation process into clearly defined steps.

The task on determination of the transformation boundaries is solved. Between the boundaries the assembled construction retains the properties that correspond to one of three aforementioned types of the system condition:

-rigid body

-flexible object with insignificantly affected system dynamics of the construction elastic oscillations

-flexible multi-frequency construction that requires an extension of the observation vector, so that the desired controlled dynamics can be achieved

An approach to solving the control problems of discretely evolving flexible objects is suggested.

This approach uses a sequence of algorithms that correspond to the object condition and implement a stable control of the main body with regards to elastic oscillations and provide a high accuracy on all stages of the assembly. The block-diagrams of the control system for three types of object condition are suggested.

As an example, the block-diagram of the control system for the third type of the object condition ($n \geq n^*$) is shown in Fig 1. This control algorithm uses the information about the dominant elastic mode phase (phase control) [4].

The main loop of the control system is depicted by a dotted line. The main algorithm is chosen without considering the influence of the elastic oscillation. There exist a link with the two tuning parameters K_m and τ .

The first parameter K_m is the tuning amplification coefficient that is needed for the maintenance of the constant level of the control action $m_u = M_u K_m I_n^{-1}$ with the variable mass-inertia properties of the assembled object. The second tuning coefficient τ_β implements the control by the time-delay of the relay control action, which switches with respect to the base algorithm requirements. The control switching action must be delayed until the dominant mode phase reaches the value corresponding to the optimal switching condition.

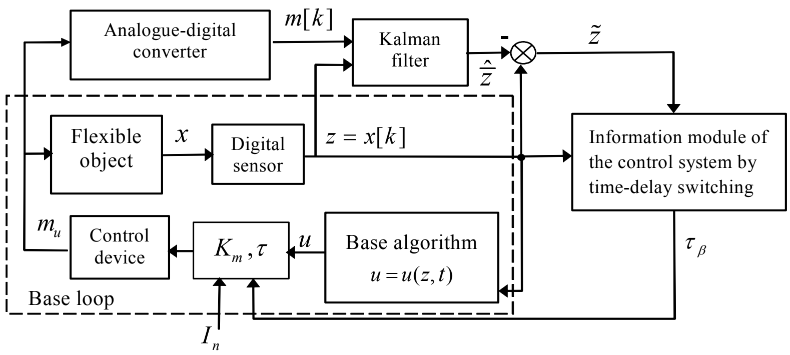

Fig. 1. Block-scheme of the phase control by flexible object.

The results of computer simulation are given in the full paper. These results support both the operability of the suggested algorithms and high quality of the control of discretely evolving objects.

References

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