Operational optimization of the electromechanical system in non-deterministic conditions

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Abstract: - On the basis of theoretical and practical studies of the electromechanical system, the scientific and technical problem of improving the control system of the electromechanical system during the impact on it of multi-vector perturbations is solved. The result of the study is the integration of differential equations with coefficients dependent on the oscillations of the control object. In the theoretical part, the mathematical model of the electromechanical system was synthesized, which made it possible to investigate ways of minimizing the deviation angles and time intervals required to stabilize the motion of the electromechanical system, which allowed indirectly to realize the associated signal with the stochastic nature of the moment of oscillation of the control object on the coordinate plane. The method of parametric optimization of the mathematical model of the electromechanical system in the function of the angle of inclination is also improved and investigated. Based on the definition of the structure and algorithms of work, the efficiency of the control system of the electromechanical system increases in terms of reducing the stabilization time of the control object.

Key-Words: - electrical vehicle, control system, mathematical modeling, improvement, adaptability, stabilization

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1 Introduction

In order to improve the design of control systems for multi-mass electromechanical systems (MMEMS), methods of simulation design are applied [1]. The main advantage of simulation modeling is its versatility and the ability to ensure the high adequacy of the model of the real system under study. This is achieved due to the deep detail of the algorithmic description, which is impossible in the study by analytical methods, which are associated with the simplification of processes and tight restrictions on the conditions of use of the model. For example, the attempt to take into account the influence of random factors in the model of the MMEMS leads to considerable difficulties in the analytical study of systems, which cannot always be overcome. Simulation modeling in the study of systems under conditions of random influences is not complicated and is currently the most effective, and sometimes the only practically available means of obtaining information about the behavior of the system, especially at the stage of its design [2]. The random nature of the receipt of requests from multiple devices of the MMEMS is necessary in determining the required performance of processors of the control complex. Random values measured in the process of controlling values are the reason for the undetermined number of operations performed by the processor in the implementation of control algorithms [3]. The MMEMS consists of a large number of different devices and systems and is characterized by numerous external and internal random influences. Occasional perturbations are environmental disturbances, changes in the system characteristics related to the wear of the elements, the occurrence of their failures, which require fault localization to prevent the development of emergencies, and others. In this regard, the need to solve individual information processing problems and the time to solve these problems are also random [4]. Although many information processing tasks related to the control and control of a multi-mass electromechanical system (MMEMS) are cyclical, random influences on the control object cause access to devices that perform various functions. control and management, in general, is not regular [5]. Random value is also the time spent by the processor on the processing of information in the control process, as algorithms for solving problems have branching, containing cycles. The number of processor operations performed when implementing such algorithms depends on the random values of the measured values [6].

All this necessitates the use of probabilistic models in design (MMEMS). Such models are needed both in describing the processes of performing individual task algorithms and in describing systems that perform the certain set of control and control tasks [7].

2 Problem Formulation

Improvement of the strategy of control of a multi-mass electromechanical system by increasing the adequacy of the model of the system functioning intended to solve a certain set of computational problems in the control process by using queuing algorithms at the design stage with their further implementation in decision support systems [8].

3 Problem Solution

First, for the MMEMS backbone structure and the organization of distributed computing processes, in which the tasks are divided into separate stages performed by different processors, it is necessary to submit the MMEMSs functioning model in the form of interacting queuing systems (IQS) – a stochastic network. In this case, individual systems included in the network can be single-channel or multi-channel IQS [9]. The objective of this study is to evaluate the characteristics and select the parameters that provide the required quality of functioning of the projected complex MMEMS. Such studies are carried out on the basis of analytical models or by simulation (software) modeling [10]. Analytical models based on the application of queuing theory apparatus [11] are used in the initial stages of design. Such models allow to determine the device orientations and the organization of works in MMEMS to provide the necessary performance characteristics [12]. More accurate estimates of the system's characteristics will be obtained by simulation using the statistical test method (Monte Carlo method). Such research is a complex, time-consuming process that requires the development of specific simulation software. Simulation modeling will be carried out in the design of the MMEMS, the structure of which varies within the operational mode, taking into account identification factors [13]. The functioning of any queuing system is characterized by a number of indicators: the average time of the application being in the system; the average number of applications on the system; the average number of applications in the queue; average queuing times for applications and more. The values of these indicators depend on the organization of MMEMS, the parameters of its devices and the parameters of the application flows. After presenting the model of functioning of MMEMSs in the form of interacting IQS, they establish the relations that link the characteristics of the system with its main parameters. Accepting a number of assumptions about the parameters of the input flows and the nature of their maintenance allows us to build the model of IQS that is amenable to analytical research. This applies first of all to Markov systems that occupy the same place in queuing theory as linear systems in the theory of automatic control [14].

Suppose the simplest (Poisson) nature of the flow of applications and laws of service in MMEMS. Then, the flow of events in the BMEMS must have three properties:

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ordinariness, no aftereffect, and stationarity, and obey Poisson law of distribution [15]:

$$P_n(\tau) = (\lambda\tau)^n \cdot e^{-\lambda\tau} / n!, \qquad (1)$$

where: $P_n(\tau)$ is the probability of occurrence of n homogeneous events in the time interval τ;

λ is the constant positive number that defines the average number of events per unit of time.

Time intervals between events in MMEMS, taking into account probabilistic operational factors, are distributed according to the exponential exponential law [16]:

$$F(t) = P\{T \le t\} = 1 - e^{-\lambda t} \qquad (2)$$

with the probability density distribution of a certain operational factor

$$f(t) = \lambda e^{-\lambda t} \qquad (3)$$

For MMEMS, many typical situational factors will have intersections, that is [17]:

$$\begin{gathered}\overline{C}_{ik} \cap \overline{C}_{ij} = \not\subset,\ k = 1,2,...,L; \\ j=1,2,...,L;\ k \ne j.\end{gathered} \qquad (4)$$

where: $\overline{C_i}$ is the set of situational factors of the operating mode;

L is the subset $\overline{C_i}$, k = 1, 2, ..., L, relevant to typical situational factors. All current situations are evaluated for belonging to a particular set $\overline{C_{kj}}$, k = 1, 2, ..., L, and the task is replaced by the task equivalent to the typical situation $\overline{C_{kj}}$,.

In case the typical situations will not have overturning, that is:

$$\begin{gathered}d_i=0;\ a_{ij}=0;\ j=0;\ j=1,2,...,L; \\ \exists k = 1,2,...,L;\ p_{is} \in P_{ik},\ s=1,2,...,S \Rightarrow \\ \Rightarrow d_i=1;\ b_{ks}=1;\ a_{ik}=1; \\ \overline{C}_{ik} \cup \overline{C}_{ij},\ j=1,2,...,L;\end{gathered} \qquad (5)$$

where: d_i, b_{ks} and a_{ik} are auxiliary indicator variables of the iterative process;

p_{is} is s-th sign of the situational factor;

P_{ik} is the set of characteristic features of the k-th typical situation factor for the i-th operating mode identifier;

$\overline{C}_{ik}$ is set of variables taken into account in the modified task;

$\overline{C}_{ij}$ is an average set of typical situational factors for which $a_{ij} \ne 0$,

the mathematical expectation of the occurrence of the certain situational factor, which will lead to the withdrawal of MMEMS from the stable state, will be [18]:

$$M(t) = \int_0^\infty t^2 f(t)dt = 1/\lambda \qquad (6)$$

and variance in the time zone of the situational factor

$$D(t) = \int_0^\infty t^2 f(t)dt = 1/\lambda^2. \qquad (7)$$

In approaching steady-state operation without significantly changing the state of MMEMS in terms of energy consumption during multi-vector perturbations, applications for these or other situational factors tend to cluster in areas of short intervals, since

$$P\{\tau<1/\lambda\} = 1 - e^{-1} \approx 0.63 \qquad (8)$$

that is, a large proportion of disturbance applications follow each other at intervals less than the average $1/\lambda$.

Consider the case where homogeneous call applications from sensors that record certain perturbations with intensities within the error, whose service time is distributed by exponential law with exponent μ, are received at the system input. We denote by S the steady state of the system when it contains also and the applications. In the interval [t, t + dt], the probability of transition of the MMEMSs to the

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mode of compensation of the disturbing influence of the j-th situational factor is determined by the matrix:

$$P = \begin{array}{c|cccccc} & S_0 & S_1 & S_2 & S_3 & L & S_k \\ \hline S_0 & 1\text{-}\lambda dt & \lambda dt & 0 & 0 & L & 0 \\ S_1 & \lambda dt & 1\text{-}(\lambda+\mu)dt & \lambda dt & 0 & L & 0 \\ S_2 & 0 & \mu dt & 1\text{-}(\lambda+\mu)dt & \lambda dt & L & 0 \\ S_3 & 0 & 0 & \mu dt & 1\text{-}(\lambda+\mu)dt & L & 0 \\ \vdots & .. & .. & .. & .. & .. & .. \\ S_k & 0 & 0 & 0 & 0 & L & 1\text{-}\lambda dt \end{array} \qquad (9)$$

In constructing the matrix of the set of variables $\overline{C}_{kj}$, (4) the source of the applications can be considered as some system S_0. Applications coming out of the i-th system (i = 1, 2, ... j) with the constant probability B_{ij} are fed into the j-th system (j = 1, 2, ... L) (5) or leave the network (j = 0). In this case, the transfer matrix has the form

$$B_{ij} = \begin{bmatrix} 0 & \beta_{01} & \beta_{02} & L & \beta_{0j} \\ \beta_{10} & \beta_{11} & \beta_{12} & L & \beta_{1j} \\ \beta_{20} & \beta_{21} & \beta_{22} & L & \beta_{2j} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \beta_{i0} & \beta_{i1} & \beta_{i2} & L & \beta_{ij} \end{bmatrix}. \qquad (10)$$

In order to determine the throughput of the disturbance factor sensor network, it is necessary to determine the intensities of the applications in each of the MMEMS subsystems. Due to the fact that in the stable mode, the average number of applications leaving the system is equal to the average number of applications, the equality is true. Therefore, for λ (1) applications from sensors, given (5), we have:

$$\lambda_i = \sum_{i=0}^{L} \lambda_i \beta_{ij}, \quad j=0,1,2,...,L. \qquad (11)$$

To determine the architecture and load intensity of the MMEMS sensor network, it is necessary to determine the transmission coefficients and the characteristics of the sensors that form the network with the corresponding transmission ratios. The parameters of the individual sensors, calculated accordingly calculated in accordance with (11), must meet the following criteria:

- the speed of the device due to the parameters (8);

- the number of channels, which depends on the set of variables that are taken into account in the modified tasks $\overline{C}_{kj}$;

- the complexity of the stage;

- average service time (2);

- service intensity (3);

- transmission coefficient (7).

Therefore, for the system of values of the coefficients of the speed of the sensors, which are determined by the values of the transmission coefficients $b_0, b_1, \ldots, b_t$ with theoretical averages $\beta_0, \beta_1, \ldots, \beta_t$ (10), we form the matrix of central moments defining all the statistical properties of the coefficients B_{ij}, and hence, and the regression equation. We obtain the variance-covariance matrix M_{ij}, the principal diagonal of which are the estimates of the variances, and the rest of the seats are estimates for the variations of the regression coefficients:

$$M_{ij} = \begin{bmatrix} s^2\{b_0\} & \operatorname{cov}\{b_0 b_1\} & \cdots & \operatorname{cov}\{b_0 b_j\} \\ \operatorname{cov}\{b_1 b_0\} & s^2\{b_1\} & \cdots & \operatorname{cov}\{b_1 b_m\} \\ .. & .. & .. & .. \\ \operatorname{cov}\{b_i b_0\} & \operatorname{cov}\{b_i b_1\} & \cdots & s^2\{b_j\} \end{bmatrix}. \qquad (12)$$

From here we obtain the ratio for the variance estimation of the accuracy of the sensors and the covariance of the coefficients of the regression equations $s^2\{b_i\}=C_{ij}{}^2\{y\}$; $\operatorname{cov}\{b_i b_j\}=C_{ij}s^2\{y\}$.

Variance estimation of sensor accuracy of the reproducibility sensors $s^2\{y\}$, in respect that (4), is determined by the formula,

$$s^2\{y\} = \frac{\sum_{k=1}^{L}\sum_{q=1}^{L_k}(y_{kq}-\bar{y}_k)^2}{\sum_{k=1}^{L}(L_k-1)}, \qquad (13)$$

where $\bar{y}_k$ is the average value of y_k, determined from the M_{ij} data of repeated measurements.

The number of degrees of freedom of the variance estimation of the accuracy of the sensors, which allows to determine the significance of the coefficients, i.e. to specify the structure of the MMEMS model, is determined by the expression:

$$f_y = \sum_{k=1}^{L}(L_k-1) \qquad (14)$$

The variance estimate of the predicted value of the response of the sensor s2 {ŷk} is determined by the law of making errors

$$s^2\{\hat{y}_k\} \approx \sum_{i=0}^{n}\left(\frac{dy}{db_i}\right)_k^2 s^2\{b_i\} + \sum_{i=1}^{t}\sum_{j=0}^{t}\left(\frac{d^2y}{db_i db_j}\right)\mathrm{cov}\{b_i b_j\}, \qquad (15)$$

or in matrix form, taking into account (12):

$$s^2\{\hat{y}_k\} = X_k^L (X^L X)^{-1} s^2\{y_k\} X_k = X_k^L M_{ij}^{-1} X_k, \qquad (16)$$

where X_k is the coordinate vector of the k-th point of the experiment.

The estimation of the variance of adequacy is determined by the expression

$$s_{ij}^2 = \frac{1}{N_{jk}-L_{ij}}\sum_{k=1}^{L}(\bar{y}_{jk}-\hat{y}_{ij})^2, \qquad (17)$$

where L_{ij} is the number of coefficients included in the regression equation after discarding insignificant coefficients. The value of $f_{ki} = N_{jk} - L_{ij}$ is called the number of degrees of freedom of the variance of adequacy.

For example, to estimate the significance of the coefficients and the adequacy of the obtained MMEMS model, we will make the variance estimation of reproducibility according to 14 measurements of the values of the disturbance sensors. The largest error is 0.0308 from the maximum signal value. In this case, there is the uniform duplication of the measurements $L_1 = L_2 = \ldots = L = N$ and the variance estimation of reproducibility is in the form

$$s^2\{y\} = \frac{\sum_{k=1}^{N}\sum_{q=1}^{L_k}(y_{kq}-\bar{y}_k)^2}{N(L_k-1)} = \frac{0{,}0308}{14(5-1)} = 1{,}0967\times10^{-3}.$$

4 Conclusion

The proposed approach to refinement of MMEMS as the component of the design process allows to predict the total number of disturbing factors with the possibility of multiple changes to the MMEMS architecture, even with minimal data on an existing project, and can be used for virtually any type of MMEMS in terms of power supply. This approach also allows upgrading of various types of MMEMCs to adapt them to operational mode (eg dynamic positioning) and enables synthesizing recommendations for MMEMS developers, controllers and power systems. This is achieved by the fact that the proposed approach is based on the cognitive (in synergy with engineering) research decision-making process, which includes the stepwise improvement of the data that comes from the study of a specific operational mode of operation of MEMMS.

The possibility of iterative optimization of MMEMS parameters allows to use the developed methods as a means of intellectual design, the result of which is the improved adjusting, and therefore the operational characteristics of MMEMS. The proposed strategy, compared to existing systems, has a higher speed of detection of the risk of loss of position MMEMS, greater reliability and accuracy of positioning.

The ratios of coefficients d_i, b_{ks}, and a_{ik} (5) correlate better with probability coefficients, suggesting that MMEMS reliability is increased in operational modes, one of which is dynamic positioning, and allows the results to be added to the database of various decision support systems to provide developers and researchers with the information they need to create new MMEMS concepts or modify existing ones. Determination of the values of the probabilistic coefficients of the disturbing factors applied to MMEMS, and the formation of a configuration matrix of the compensating forces with determining the distance from the place of application of the individual disturbing factor to the projection of the force vector on the plane of motion MMEMS possible on the basis of the identifying relevant identification factors. Obtaining correction factors that affect the components of forces and moments, proportional to the size of the MMEMS model and the real object bound to the original geometry, is possible by formalizing physical models of MMEMS with means of identifying disturbing factors on the lines of the compensating efforts of the calculators. Increasing the statistics of the frequency of significant identification factors of process characteristics in MMEMS during iterative procedures is proportional to the sample size and does not increase the variables and coefficients of the regression model. The random values of the variables of disturbing influences are not correlated, which is evidence of the prerequisite for the application of the developed principles of composition of regression models according to the results of experimental studies.

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