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Li Wei, S. Zinchenko, M. Geraimchuk, V. Zinchenko, I. Mukha

THE MEASUREMENT VECTOR QUANTITIES

Annotation: The analysis of problems of creation of vector converters of mechanical sizes is executed, their classification is resulted, the generalized mathematical model and mathematical models for converters direct and compensatory types is received. It is shown, that for construction of such converters it is necessary to use compensatory the circuit.

Keywords: vector converters, classification, mathematical model.

Introduction

Now there is a situation when, despite of as if the filled market different kinds of converters, demand for them constantly grows. Especially it concerns vector converters (VC) which should allow to define both modules, and a vector of physical sizes.

The requirement in VC is caused by modern development of information technologies (IT), manufactures, sciences, including development of navigating systems, carrying out seismic, gravitational and other similar researches. However world industry VC does not make, despite of existing interest of firms - manufacturers. Therefore development VC is an actual problem [1].

The analysis of the market of converters

The analysis shows, that in the market of converters (temperatures, pressure, acceleration are most widely submitted, to speed, moving, etc.) for measurement of one components of mechanical size which are constructed on the known physical phenomena [1, 2].

Separate direction are VC in which basis of construction the principle of integration of unicomponent converters is put, as defines their such lacks: complex algorithms of data processing of measurements, presence of errors of measurements because of distinction of metrological characteristics of separate converters, and also from deformation of the case and change of external parameters (temperature, indignation, pressure, etc.) [3]. The majority such VC belong to a class of the most investigated three - component converters.

Expansions of a scope, depreciation of operation and manufacture of converters are carried out in such directions:

- improvement of parameters and modernization;
- creation of systems of data processing and integration of sensitive elements with the electronic equipment;
- microminiaturization on the basis of technology iMEMS (integrated microelectromechanical systems), where known effects electronic a component and "know-how"are used in designing and manufacture of sensitive elements (SE) with the set characteristics.

The analysis shows, that manufacture of converters on the basis of processing technique iMEMS for measurement of pressure, force, speed, speedup, losses, etc. meanwhile restrains. Especially it concerns those cases when direct methods of transformation for measurement of mechanical sizes (for example use, pressure with the help membrane SE, or speedups when in quality SE the weight uses). Therefore an actual problem is design of new processing technique of engineering and manufacturing of converters on the basis of processing technique iMEMS.

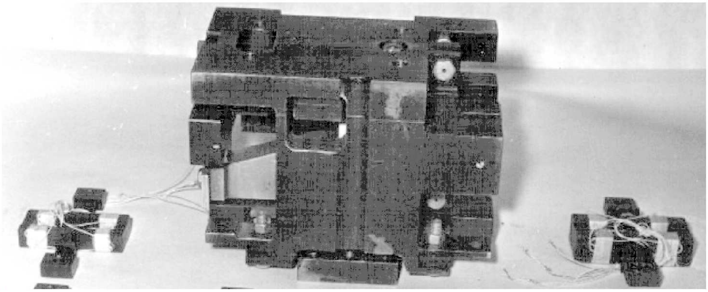

Figure 1 – Strain-gauge balances and strain-guage dynamometer

The analysis shows, that practically there are no publications under the theory, system probes and modelling multicomponent VC mechanical sizes, that, actually, and constrains their developing. For example, Ibragimova's work [4] is devoted basically to the theory of vector measurements with the help of unicomponent accelerometers. Known multicomponent converters of force and a driving torque are contact, executed as a platform, and have up to 6 level of freedom with resistive-strain sensor converters [5–7]. During too time introduction IT in process of creation of complex technical objects [8, 9] demand presence VC which represent the uniform technical arrangement, allowing to receive the full information on all components (for example, three linear and three angular conveyances) the gauged mechanical size (fig. 1). The present work is devoted to modelling and synthesis of such group VC.

Classification of vector converters

For unambiguity of process of synthesis and design VC it is offered to classify them by criteria depending on:

a) kind of the gauged size – VC conveyances, speeds, speedup, forces, gravitation and others;

b) quantities of gauged coordinates (component) - multicomponent VC from one up to six component;

c) circuits of construction - VC null-balance (with a back coupling, the closed circuit) and VC direct transformation (the openloop circuit) where in turn null-balance VC share depending on type of the circuit of a back coupling and a used adjuster - with analog steering and with steering from a computer / of the microprocessor;

d) kind of joint SE with the case - VC contact and VC contactless which in turn share on devices with electromagnetic, electromagnetic superconducting / cryogenic and electrostatic suspension;

e) the used indicator of a mismatch - VC with optoelectronic, electromagnetic, capacitor indicators;

f) Kind of a synthesised adjuster - VC with a usual or stochastic adjuster.

Let's note, that VC it is possible to classify and to the standard attributes: accuracy, a measurement range, area of use, etc.

The generalized mathematical model of vector converters

The generalized mathematical model (MM) VC, is received on the basis of equation Lagrange II style, the general theorem of dynamics and a principle Dalambera for a solid (a principle kinetostatics) in the following aspect [10]:

Generalized the MM is the basic for:

– the analysis of dynamics VC, synthesis of algorithm of handling of a signal and a management system of state SE (the network of compensating);

– definitions of MM of private designs VC of mechanical magnitudes.

Generalized in MM VC of a direct operation. In common VC it is possible to present as SE (absolute solid) the set mass and a pattern which is located in space on elastic and damping elements (fig. 2) which allow to move to it on three mutually translational and on three angular coordinates. Thus it is supposed, that: the center of driving coincides with the center of mass SE O1; shafts of coordinates OX, OY, OZ coincide with shafts of the principal central moments in rest; elastic elements are located in planes XOY, XOZ, YOZ; the mobile frame O1xyz, connected with SE, and O1 coincides with the center of its masses; motionless frame O1xy, is connected to case VC; shafts O1x, O1y, O1z are principal axis's of inertia SE; shafts of systems O1xyz and O1x'y'z' coincide during the initial moment of driving.

Originally, for a terminating connection generalized in MM VC of direct action, we consider movements SE, as solid in space, without taking into account its design. We receive such system of the equations:

$$M\ddot{x} = H_x^n - H_x^c + H_x(t),$$

$$M\ddot{y} = H_y^n - H_y^c + H_y(t), \quad (1)$$

$$M\ddot{z} = H_z^n - H_z^c + H_z(t),$$

where H^n, M^n – forces and the moments of a potential field of forces; H^c and M^c – forces and the moments of forces of elasticity; $H(t)$ and $M(t)$ – the set forces and the moments of external forces, as functions of time.

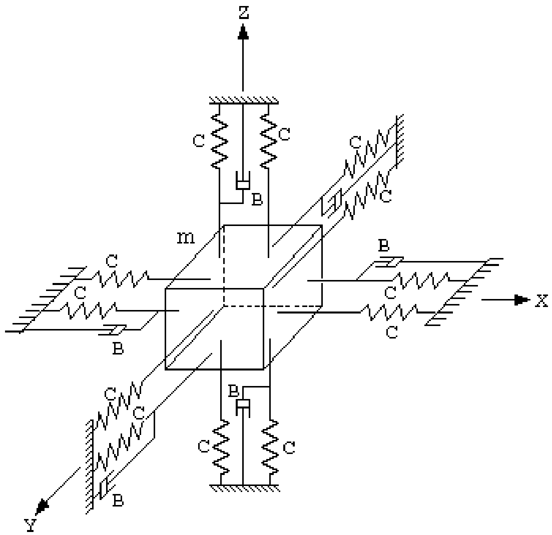

Figure 2 – The generalized circuit of the vectorial converters

Generalized in MM VC of the closed type. Taking into account, that driving SE in compensating VC is characterized small it both linear, and angular conveyances which in (1) them can be not taken into account. In this case the equations of driving (1) are linearized and shared on components that reduces in a system of simple equations (2) on which grounding it is possible to define MM for concrete designs VC:

$$M\ddot{x} = H_x^n - H_x^c + H_x^к + H_x(t),$$

$$M\ddot{y} = H_x^n - H_y^c + H_y^к + H_y(t),$$

$$M\ddot{z} = H_z^n - H_z^c + H_z^к + H_z(t), \qquad (2)$$

$$J\ddot{\alpha} = M_x^n - M_x^c + M_x^к + M_x(t),$$

$$J\ddot{\beta} = M_y^n - M_y^c + M_y^к + M_y(t),$$

$$J\ddot{\gamma} = M_z^n - M_z^c + M_z^к + M_z(t),$$

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where: H^k, M^k – forces and the moments of compensating accordingly.

Mathematical models of vectorial converters of mechanical magnitudes

Let's consider MM VC with elastic, electromagnetic, electromagnetic superconducting and electrostatic suspension which take into account singularities of everyone suspension, and are quotients a case generalized in the MM.

MM VC with elastic suspension. Let's put, that: K_x^i, K_y^i, K_z^i – linear stiffness of elastic elements in a direction of shafts O_1z; O_1y; O_1z; C_x^i, C_y^i, C_z^i – rotating stiffness of elastic elements in a direction of angle of rotations α, β, γ (see fig. 2). Taking into account that $J_x = J_y = J_z = J$ for designs SE and using the equation Lagrange II style, let's receive the system of the quasilinear equations circumscribing driving of a solid in a field of potential forces:

$$
\begin{gathered}
M\ddot{x} = H_x^n - H_x^c + H_x(t),\\
M\ddot{y} = H_y^n - H_y^c + H_y(t),\\
M\ddot{z} = H_z^n - H_z^c + H_z(t),\\
J\ddot{\alpha} + J\left(-\frac{1}{2}\ddot{\alpha}\beta^2 + \ddot{\gamma}\beta + \dot{\beta}\dot{\gamma} + \dot{\beta}\dot{\alpha}\beta\right) + M\left(y\ddot{z} - z\ddot{y}\right) = M_x^n - M_x^c + M_x(t),\\
J\ddot{\beta} + J\left(\ddot{\gamma}\alpha + \dot{\alpha}\dot{\gamma}\right) + M\left(z\ddot{x} - x\ddot{z}\right) = M_y^n - M_y^c + M_y(t),\\
J\ddot{\gamma} + J\left(\tfrac{1}{2}\ddot{\gamma}\alpha^2 + \tfrac{1}{2}\ddot{\gamma}\beta^2 + \ddot{\alpha}\beta + \dot{\alpha}\dot{\beta} + \dot{\alpha}\dot{\gamma}\alpha + \dot{\gamma}\dot{\beta}\beta\right) + M\left(x\ddot{y} - y\ddot{x}\right) =\\
= M_z^n - M_z^c + M_z(t)
\end{gathered}
\tag{3}
$$

The set of equations (3), describes driving SE with spring suspension in broken/not compensating state. This mode of behavior VC is characterized by the big conveyances / by modifications of coordinates that does not allow to execute a correct linearization (3), and (3) cannot be used for the analysis of influence of cross connections and selection of components because, complicated association between angular conveyances is observed and essential interferences of components take place.

Because of complexity of MM (3) it is impossible to allocate the information from each component, therefore constructive circuit VC with seating elastic elements on shafts is unsuitable for practical realization.

Therefore for construction VC it is necessary to use other circuits which would allow to share strains on coordinates and it is essential to reduce interferences of components, including with the help of algorithm of handling of a signal on each port. Such approach is realized with the circuit shown on fig. 3. In it, as against the circuit shown on fig. 2, elastic elements are allocated in a plane which is parallel to a coordinate axis and is perpendicular shafts, the angle of rotation around of

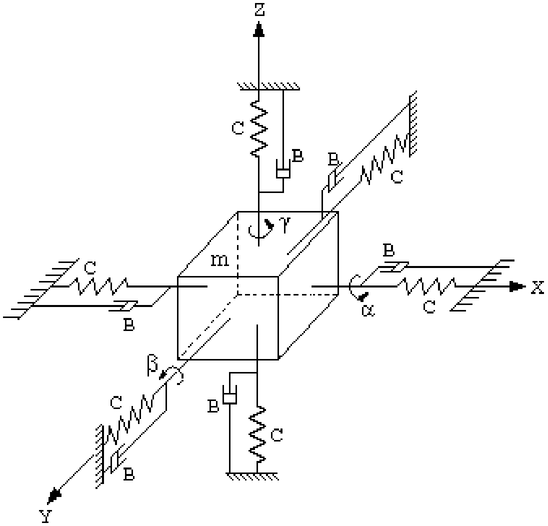

Рис. 3 – The improved circuit of the vectorial converters.

which would cause the greatest strains of elastic elements. In this case: a strain of an elastic element along X- axis essentially big, than on a Y-axis; strains on a X- axis increase twice as the top of the first element is squeezed (a strain decreases), and the second is stretched (a strain increases); on other coordinates elastic elements are deformed in one direction.

Therefore it is possible to note with the account before the accepted assumptions and labels of MM VC having 12 elastic elements, 6 and 12 snubbers [11]:

$$m\ddot{x} + h_x\dot{x} + \sum_{i=1}^{4} k_x^i x + \sum_{i=1}^{4} k_x^i y\gamma - \sum_{i=1}^{4} k_x^i z\beta = Q_x,$$

$$m\ddot{y} + h_y\dot{y} + \sum_{i=1}^{4} k_y^i y + \sum_{i=1}^{4} k_y^i z\alpha - \sum_{i=1}^{4} k_y^i x\gamma = Q_y,$$

$$m\ddot{z} + h_z\dot{z} + \sum_{i=1}^{4} k_z^i z + \sum_{i=1}^{4} k_z^i \beta - \sum_{i=1}^{4} k_z^i x\alpha = Q_z, \qquad (4)$$

$$J\ddot{\alpha} + h_\alpha\dot{\alpha} - \sum_{i=1}^{4} k_y^i zy + \sum_{i=1}^{4} k_z^i yz +$$
$$+\alpha\left(\sum_{i=1}^{4} c_x^i - \sum_{i=1}^{4} k_y^i y^2 - \sum_{i=1}^{4} k_y^i z^2\right) + \sum_{i=1}^{4} k_z^i xy\beta + \sum_{i=1}^{4} k_y^i xz\gamma = M_\alpha,$$

$$J\ddot{\beta} + h_\beta\dot{\beta} - \sum_{i=1}^{4} k_x^i zx - \sum_{i=1}^{4} k_z^i xz + \sum_{i=1}^{4} k_z^i yx\alpha +$$
$$+\beta\left(\sum_{i=1}^{4} c_y^i - \sum_{i=1}^{4} k_x^i z^2 - \sum_{i=1}^{4} k_z^i x^2\right) - \sum_{i=1}^{4} k_x^i yz\gamma = M_\beta,$$

$$J\ddot{\gamma} + h_\gamma\dot{\gamma} - \sum_{i=1}^{4} k_x^i yx + \sum_{i=1}^{4} k_y^i xy + \sum_{i=1}^{4} k_y^i zx\alpha + \sum_{i=1}^{4} k_x^i zy\beta +$$
$$+\gamma\left(\sum_{i=1}^{4} c_z^i - \sum_{i=1}^{4} k_x^i y^2 - \sum_{i=1}^{4} k_z^i x^2\right) = M_\gamma$$

If to enter the following matrix of factors $k_{ij}(i,j=\overline{1.6})$ (see a matrix of factors) then we shall receive the system of the differential equations circumscribing driving SE in the broken condition:

$$m\ddot{x} + h_x\ddot{x} + k_{11}x - k_{15}\beta + k_{16}\gamma = Q_x,$$
$$m\ddot{y} + h_y\ddot{y} + k_{22}y + k_{24}\alpha - k_{26}\gamma = Q_y,$$

$$J\ddot{\alpha} + h_\alpha\dot{\alpha} - k_{42}y + k_{43}z + k_{44}\alpha + k_{45}\beta + k_{46}\gamma = M_\alpha, \qquad (5)$$

$$J\ddot{\beta} + h_\beta\dot{\beta} + k_{51}x - k_{53}z + k_{54}\alpha + k_{55}\beta + k_{56}\gamma = M_\beta,$$
$$J\ddot{\gamma} + h_\gamma\dot{\gamma} - k_{61}x + k_{62}y + k_{64}\alpha + k_{65}\beta + k_{66}\gamma = M_\alpha,$$

A matrix of factors $k_{ij}(i,j=\overline{1.6})$.

$$\begin{bmatrix}
\sum_{i=1}^{4} k_x^i & 0 & 0 & 0 & -\sum_{i=1}^{4} k_x^i z & \sum_{i=1}^{4} k_x^i y \\
0 & \sum_{i=1}^{4} k_y^i & 0 & \sum_{i=1}^{4} k_y^i z & 0 & -\sum_{i=1}^{4} k_y^i x \\
0 & 0 & \sum_{i=1}^{4} k_z^i & -\sum_{i=1}^{4} k_z^i y & \sum_{i=1}^{4} k_z^i x & 0 \\
0 & -\sum_{i=1}^{4} k_y^i z & \sum_{i=1}^{4} k_z^i y & \sum_{i=1}^{4} c_x - \sum_{i=1}^{4} k_y^i z^2 - \sum_{i=1}^{4} k_z^i y^2 & \sum_{i=1}^{4} k_z^i xy & \sum_{i=1}^{4} k_z^i xz \\
\sum_{i=1}^{4} k_x^i z & 0 & -\sum_{i=1}^{4} k_z^i x & \sum_{i=1}^{4} k_z^i xy & \sum_{i=1}^{4} c_x - \sum_{i=1}^{4} k_y^i z^2 - \sum_{i=1}^{4} k_z^i x^2 & -\sum_{i=1}^{4} k_z^i yz \\
\sum_{i=1}^{4} k_x^i y & -\sum_{i=1}^{4} k_y^i x & 0 & \sum_{i=1}^{4} k_y^i zx & \sum_{i=1}^{4} k_x^i zy & \sum_{i=1}^{4} c_z - \sum_{i=1}^{4} k_x^i y^2 - \sum_{i=1}^{4} k_y^i x^2
\end{bmatrix}$$

MM VC with electromagnetic and electrostatic suspension. VC with elastic suspension have limited on exactitudes and sensitivity and consequently use for measurement of the big values, for example, speedups from 1 up to 5g. For construction highly sensitive VC use electromagnetic / magnetic and electrostatic suspensions.

For definition their MM use the equations of the Lagrange-Maxwell which describe driving SE which supplement component operations of the generalized magnetic forces on SE and a set of equations circumscribing processes in an electric part of the device. Substituting an elasticity of mechanical elements their electromagnetic analogs, that is a mechanical spring electromagnetic, and, vectorial reformers substituting corresponding values in (5) we shall receive a set of equations in such aspect:

$$m\ddot{x} + h_x\dot{x} + k_{11}x - k_{15}\beta + k_{16}\gamma = BlI_x + Q_x,$$
$$m\ddot{y} + h_y\dot{y} + k_{22}y + k_{24}\alpha - k_{26}\gamma = BlI_y + Q_y,$$
$$m\ddot{z} + h_z\dot{z} + k_{33}z - k_{34}\alpha + k_{35}\beta = BlI_z + Q_z, \quad (6)$$
$$J\dot{\alpha} + h_\alpha\dot{\alpha} - k_{42}y + k_{43}z + k_{44}\alpha + k_{45}\beta + k_{46}\gamma = BlI_\alpha C + M_\alpha,$$
$$J\ddot{\beta} + h_\beta\dot{\beta} + k_{51}x - k_{53}z + k_{54}\alpha + k_{55}\beta + k_{56}\gamma = BlI_\beta C + M_\alpha,$$
$$J\ddot{\gamma} + h_\gamma\dot{\gamma} - k_{61}x + k_{62}y + k_{64}\alpha + k_{65}\beta + k_{66}\gamma = BlI_\gamma C + M_\alpha,$$

where: $I_x = [i_1 + i_2 - (i_3 + i_4)]$, $I_y = [i_5 + i_6 - (i_7 + i_8)]$, $I_z = [i_9 + i_{10} - (i_{11} + i_{12})]$, $I_\alpha = (i_1 - i_2 + i_3 - i_4)$, $I_\beta = (i_5 - i_6 + i_7 - i_8)$, $I_\gamma = (i_9 - i_{10} + i_{11} - i_{12})$, i_i – controlling current in windings i=1, 2, ..., 12; I – it is defined by algorithm of handling and steering of state SE.

In case of use of a design “pure” electromagnetic suspension (when there are no mechanical connections SE ith case VC in (6) it is necessary to exclude component a mechanical elasticity and damping. VC with moving coils that limitation, as current-carrying guides have, as influences their exactitude.

Development compensating VC with electromagnetic suspension is design VC with superconducting electromagnetic suspension. Structurally superconducting suspension it is possible to execute with use of effect of magnetic potential through (V.V. Kozorezom is open) which essence consists in existence of a minimum of potential energy between two magnetic elements or ideally master rings. Use of a superconductivity allows to raise considerably measurement accuracy of mechanical magnitudes due to lack of relaxational appearances and drops of temperature noise. Structurally circuit VC will consist of the superconducting electromagnetic circuits which have been powered up symmetrically to SE. In such VC there is a physical gear of support of steadfastness SE which speaks immutability of the full magnetic flux caused by ideality electrowire current of circuits. They have zero expenditures of power for work superconducting electromagnetic suspension, high stability and dependability. At construction VC it is possible to use two approaches. The first, uses for construction highly sensitive gravimeters and gradiometers, is founded on pure effect of magnetic potential through. In such VC there are no inverse/controlling networks. The system of the differential equations which describe driving superconducting electromagnetic VC mechanical magnitudes, coincides with a set of equations (6) and can be noted as:

$$\ddot{x}_1 = \frac{1}{M}(F_1^0 + K_{11}x_1 + K_{15}x_5 + K_{16}x_6 + Q_1),$$
$$\ddot{x}_2 = \frac{1}{M}(F_2^0 + K_{22}x_2 + K_{24}x_4 + K_{26}x_6 + Q_2),$$

$$\ddot{x}_3 = \frac{1}{M}(F_3^0 + K_{33}x_3 + K_{34}x_4 + K_{35}x_5 + Q_3), \quad (7)$$

$$\ddot{x}_4 = \frac{1}{J}(M_1^0 + K_{42}x_2 + K_{43}x_3 + K_{44}x_4 + K_{45}x_5 + K_{46}x_6 + M_1),$$

$$\ddot{x}_5 = \frac{1}{J}(M_2^0 + K_{51}x_1 + K_{53}x_3 + K_{54}x_4 + K_{55}x_5 + K_{56}x_6 + M_2),$$

$$\ddot{x}_6 = \frac{1}{J}(M_3^0 + K_{61}x_1 + K_{62}x_2 + K_{64}x_4 + K_{65}x_5 + K_{66}x_6 + M_3),$$

where $X_i = \{x, y, z, \alpha, \beta, \gamma\}$; F_i^o, M_i^o, K_i^o – composite functions which include separate derivative and integrated functions.

Let's mark, that for VC the compensating circuit, the system (7) is necessary for supplementing the equation controlling perturbations $U = \{U_1, U_2, \ldots, U_6\}$. Besides fulfilling a change of variables of a system of the differential equations (6) and (7) it is possible to note as the equations of space variables [12, 13].

For the analysis and synthesis driving SE VC with electrostatic suspension is possible to use a set of equations (7), only instead of an electromagnetic spring uses electrostatic. We shall mark, that use electrostatic suspension has a limitation which speak that for its work it is necessary to use the big voltages, it, at first, and, second - SE it is necessary to joint to a radiant with the help of guides which influence on driving SE and sink an exactitude and sensitivity. In other words presence of guides completely destroys advantages electrostatic suspension.

Resume

Thus, in work mathematical models VC which describe their driving are obtained and allow to facilitate process of their synthesis and construction of algorithms of handling of a signal. It is shown, that construction VC under the conventional circuit is unacceptable because of impossibility of the account of influence of one coordinate on another. The suggested circuit eliminates this limitation.

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