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THE CONCEPT OF CREATING NON-CONTACT DRIVE FOR WORKING BODIES IN MACHINES OF VARIOUS PURPOSE

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Summary. The problems of creating non-contact drive for working bodies of the machines was considered. The criteria of asymptotic stability of rotary movement of ring working bodies (RWB) and rectilinear movement of band working bodies assuming that there was no mechanical support were theoretically defined. The possibilities of applying research results for creating new efficient and secure machines with direct drive of the working body were pointed out.

Key words: rotary movement, non-contact drive, asymptotic stability.

INTRODUCTION

Within the conditions of market economy working machines are being highly upgraded in order to provide new consumer (functional) features and to maintain their competitive ability. Upgrade is performed on the basis of implementing new engineering solutions, applying modern technologies and scientific achievements.

A typical example can be the non-contact supports that keep the rotating shafts in space without stiff mechanical contact. They allow to rotate the ring working bodies of the machines (RWB) and to pass torque strength to them thus providing the reduction of oscillation load (up to 30%) and component deterioration. This idea gives the possibility to considerably increase the working frequency of RWB rotation and to extend the machines' durability. However the use of non-contact support does not allow to significantly reduce the number of rotating parts and mass: the power consumption, weight, dimension and in general cost of the machines remain almost the same.

A drastic effect can be reached by excluding the details which pass torque strength, and, in addition, keeping the working bodies without mechanical contact to implement passing the torque to them similarly in order to perform effective work. Thus power shaft, bearing and seal units are eliminated, and the working body of the machine is rotating only. In such a way one can realize a possibility of optimal design of the machine with direct drive of working bodies on the basis of multidimensional minimization by mass, dimen-sions, power consumption, power stream path, number of rotating details etc. Under constraints in the process of synthesis on torque, speed of rotation, proper frequencies of oscillations and stability of rotary movement rational distribution of constructive power and kinematical parameters is achieved [Nosko, 1999].

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

The machine's functioning implies precise positioning of the working body of the machine, stability concerning motive forces, processing forces and detrimental resistance. In non-contact drive on purpose of maintaining the RWB stability during rotation the reactions of mechanical support and torque on the power shaft are substituted by forces of different nature – electrodynamic combined with gas- or hydrodynamic forces and processing resistance forces acting directly on the RWB.

Maintaining by distributing forces a specific mode of motion when the movement of working bodies remains stable and their position is space can be predetermined is an important scientific and technical problem when creating a non-contact drive of working bodies in machines of various purpose.

The research conducted in the field of applied mechanics and theoretical engineering allowed to theoretically define the criteria of asymptotical stability of plane-parallel rotation of working bodies without mechanical contact.

Since the stability of the movement depends on many factors, the desired criterion of stability should interlink different controllable parameters (factors) which determine the stability of rotary or rectilinear movement. Their values should unambiguously indicate the kind of movement concerning its stability: stable, unstable or neutral (according to classical definition of stability suggested by A.M. Lyapunov); the criteria should be shown in such a form where the physical meaning of the items is evident; this is especially important for designers and engineers because it will allow to adjust the stability via changing the design factors. Such approach to the choice of criteria may be considered rather justified since it is first of all aimed at quick and qualitative development of fundamentally new working machines of various purpose. In this article we discuss the questions of creating centrifugal and inclined rotor pumps, machines for cutting semiconductor monocrystals with working bodies drive of new type – without mechanical support [*Breshev 2007*].

DEFITION AND ANALYSIS OF THE CRITERION STABILITY OF ROTATION

Stable movement of the ring working body means that it is stably rotating and maintains its position in space. Under the influence of external resistance forces (incidental or regular) which create the displacement of the working body without mechanical support the latter should resist the displacement and when the external disturbance disappears it should return to starting position.

Then for any given area $\boldsymbol{e}$ of acceptable deviations from the equilibrium position there will exist the area $\boldsymbol{\delta}(\boldsymbol{e})$ of starting disturbances; the movement of the working body (its centre of mass) started inside this area will never reach the limits of the area $\boldsymbol{\varepsilon}$, i.e. for any $\boldsymbol{t} > \boldsymbol{t_0}$ the inequality will hold:

$$\sum x_j^2 < e . \tag{1}$$

It is important for working machines that in the course of time the displacement of the working body will tend to its undisturbed position, i.e. to zero:

$$\lim_{t\to\infty} \sum x_j^2 \ (t) = 0 . \tag{2}$$

Such movement is considered to be asymptotically stable [*Merkin 2003*].

In real situation the RWB placed in a rotating force field is influenced by potential forces of the moving field and resistance forces. Generally, external forces can be reduced to principal moment ***M*** and principal vector ***F.*** Being exposed to the former one, the working body is rotating; the principal vector defines its position relative to the plane of rotation and can be reduced to radial $\boldsymbol{F}_r$ and tangential $\boldsymbol{F}_\tau$ components. The projections of the principal vector constituents were defined analytically [Eroshin, Breshev 2005]. If the RWB is in the plane force field and under the actions of the forces is set to parallel-sided movement, then the movement of its center of mass can be described by the well-known system of equations. The movement is influenced by radial stabilizing forces and tangential forces which have a destabilizing effect on RWB:

– along ***OX*** axe – forces $F_{rx} = -D_r x_0$ and $F_{\tau x} = -D_\tau y_0$;

– along ***OY*** axe – forces $F_{\tau y} = D_\tau x_0$ and $F_{ry} = -D_r y_0$,

where: D_r и D_τ are the rigidity of non-contact RWB support in the radial and tangential line, respectively. Besides, the RWB is rotating in the medium the contact with which generates resistance forces $\boldsymbol{F}_c$ proportionate to the rate of relative motion. Such resistance forces are specific for the movement of bodies in flow or gaseous medium. The value of resistance forces can be evaluated through tenacity coefficient ***V***; then their projections onto coordinate axes can be evaluated as $F_{Cx} = -V\,x'$ and $F_{Cy} = -V\,y'$. If we define $D_r/m = a$, $D_\tau/m = b$ and $V/m = v$, then disturbed plane-parallel motion of the centre of mass of RWB can be described by the following system of second-order linear homogeneous differential equations with constant rates:

$$\begin{cases} x'' + vx' = -ax - by \\ y'' + vy' = bx - ay \end{cases}. \tag{3}$$

The general solution of the system (3) is:

$$x_i = \sum_{j=1}^{n} c_j \cdot h_{ij} \cdot e^{k_j \cdot t}, \tag{4}$$

where: C_j is an arbitrary constant;

h_j is a vector corresponding to the root of characteristic equation.

The stability theory states on the basis of (4) that if all the real components of all roots are negative, then the motion is asymptotically stable; it is easy to determine using the criteria of Gurvitz [*Merkin 2003*].

The Gurvitz determinant for the characteristic equation for the system of equations (3) is given by:

$$\begin{vmatrix} 2v & 2av & 0 & 0 \\ 1 & (2a+v^2) & (a^2+b^2) & 0 \\ 0 & 2v & 2av & 0 \\ 0 & 0 & (2a+v^2) & (a^2+b^2) \end{vmatrix} \tag{5}$$

The condition of asymptotic stability according to Gurvitz criteria is given by:

$$\Delta_3 = 2v(2a+v^2)\cdot 2av - 4v^2(a^2+b^2) - 4a^2v^2 > 0. \tag{6}$$

After transforming the expression (6) we obtain an inequality which defines asymptotic stability of rotation of a ring working body without mechanical support:

$$v > \frac{b}{\sqrt{a}} \text{ или } \frac{D_\tau \sqrt{m}}{V\sqrt{D_r}} < 1. \tag{7}$$

Criteria (7) shows that the stability of RWB rotation rises simultaneously with an increase of viscous medium resistance $\boldsymbol{V}$ and stiffness of non-contact RWB support in radial direction D_r (determined by the stabilizing force $\boldsymbol{F}_r$) as well as with decrease of stiffness in tangential direction D_τ (determined by the destabilizing force $\boldsymbol{F}_\tau$) and with increase of RWB mass.

This criteria is convenient because it interlinks the main factors which the engineer uses to design a new machine.

Computational solutions of the system of differential equations (3) provided that the criteria of asymptotic stability holds are shown in Fig. 1.

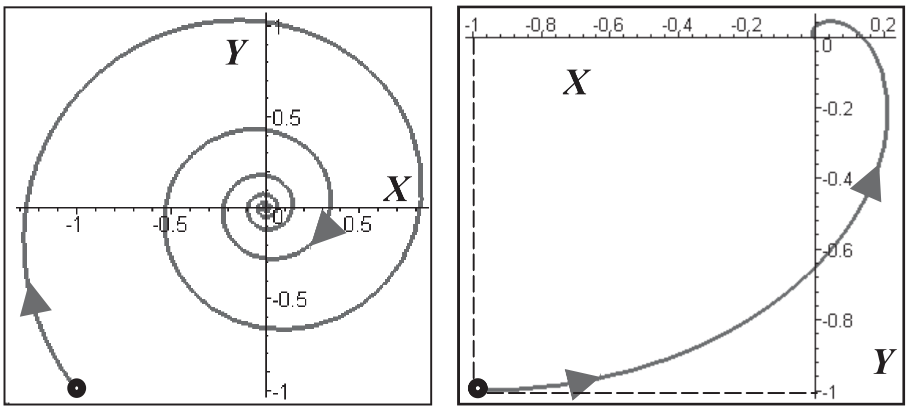

Fig. 1. Trajectories of centre of mass of RWB during rotary motion with different level of asymptotic stability

According to the initial conditions, the centre of mass of rotating RWB is not located in the coordinate origin (–1, –1), but in the course of time it approaches its central position (coordinate origin). The higher the level of stability is, the faster it happens, and the smaller is the value of the stability criteria.

IMPROVEMENT OF NON-CONTACT DRIVE AND EXPANSION OF ITS FIELD OF APPLICATION

Above we have discussed the direct drive of rotating ring working bodies. There are a lot of machines where non-direct drive is used and besides rotary movement the working bodies (or certain details) are in rectilinear motion or in plane-parallel motion. Such kinds of motion are typical for an absolute majority of working machines.

The concept of creating non-contact drive with plane-parallel motion of working bodies can be used in view of the following facts:

1. Progressive rectilinear motion (or back-and-forth motion) can be regarded as rotary motion when the radius of rotation tends to infinity. It is not more complicated to maintain its stability by the parameter $\boldsymbol{e}$ (***OY***-direction) of the displacement from rectilinear trajectory of movement (***OX***-direction) than during rotation (Fig. 2).

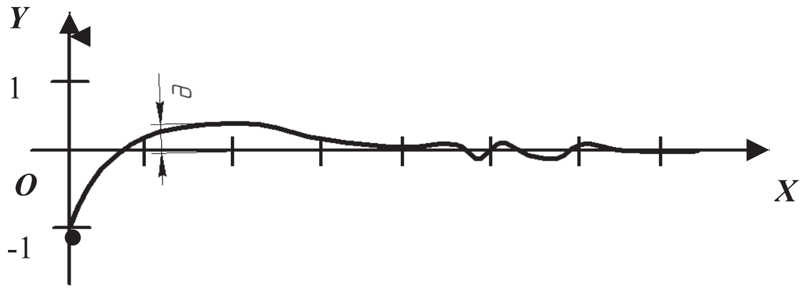

Fig. 2. Disturbances during stable rectilinear motion

When the principal moment of the motive forces is infinitely removed from the centre of rotation, it acts as a rectilinear moving force which always coincides with tangential component during rotation. The latter defines the stiffness of non-contact RWB support in tangential direction D_τ (7).

The tangential component itself stops its destabilizing influence, because it is directed in the line of principal rectilinear motion, and what is most important – it does not tend to increase the displacement *e* during disturbance.

By analogy with rotary movement, the radial component of motive forces determines the stiffness of non-contact support D_r in the direction orthogonal to the direction of rectilinear movement (*OY*-direction). If the radius of rotation infinitely increases, it maintains its principal stabilizing action, because it is always directed against the displacement ***e*** of the body (working body of the machine) from its starting position during disturbances. Abstract transition from a ring of infinite radius to a straightforward line allows to preserve the idea of evaluating elementary forces acting on a basic area element. In this case the criteria of stability of rectilinear movement can be obtained from the criteria of stability of rotary movement. If $D_\tau \to 1$, the stiffness of the support in tangential direction is eliminated according to (7), and the criteria of asymptotic stability of rectilinear movement is already is by:

$$\frac{\sqrt{m}}{V\sqrt{D_r}} < 1 . \tag{8}$$

2. In the case when the plane-parallel motion of the body along its trajectory consists of rotary and progressive rectilinear movement, the solution of the problem of asymptotic stability is generally evident. The most difficult are the moments of transition from rotary to rectilinear movement and conversely. In such situations the stabilizing action of other factors like resistance forces, special mass distribution, changes of velocity mode, selection of optimal curvature gradient etc.

APPLICATION OF RESEARCH RESULTS

There are machines where using non-contact RWB drive is technically possible and economically efficient. First of all, these are the machines for cutting semiconductor monocrystals, centrifugal and inclined rotor pumps, separators, and machines for treating interior surface of tanks.

In the laboratory environment on the working model of a machine for cutting semiconductor monocrystals there has been done cutting a silicon ingot by a diamond saw (RWB per se) which is set to rotary motion and preserves its stable position in space without contacting the machine mechanically [*Eroshin, Breshev 2005*]. Fig. 3 shows how a diamond saw with inner cutting edge at the speed of rotation around 1000 revolutions per minute cuts a plate from monocrystal 76 mm in diameter without mechanical contact with the rest of the machine. The ledge of the cutting disk is 46 mm in length and during rotation is totally plunged into the slot.

Fig. 3. Cutting a monocrystal (1) by a diamond cutting saw (2) which is rotating without contacting the machine mechanically

Thus the dimensions of the diamond cutting saw have been reduced by a factor of 2 and more, and the masses of rotating details have been reduced be a factor of approximately 100 (from 30..70 kg to 0,2..0,4 kg). It has been shown that the new design of the machine allows to reduce the power consumption of the machine by 1,5..2 times and its mass – by 5..10 times (from 2000…4000 kg to 200…300 kg), thus significantly reducing the cost.

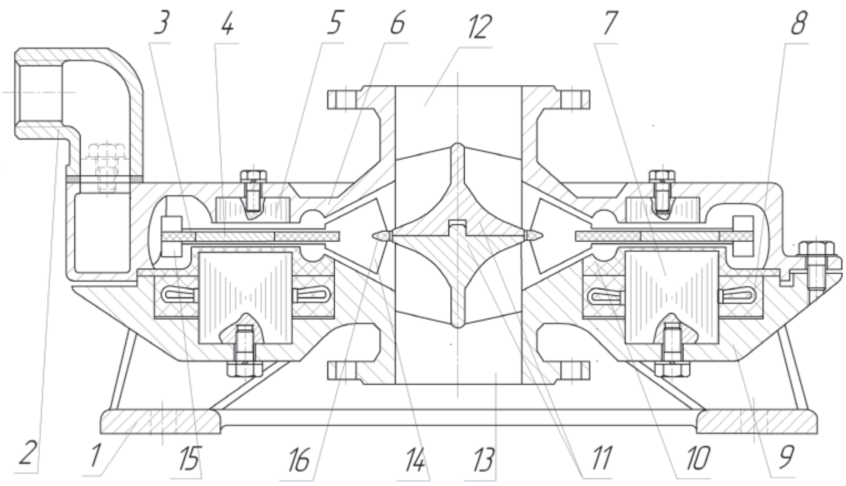

Fig. 4. Inclined rotor pump with non-contact drive of the working wheel

The new construction of an inclined pump rotor with non-contact drive of a working wheel has been suggested (applied for a patent of Ukraine). It does not have a shaft, bearings and seals on the moving surfaces; its working wheel is rotating without mechanical support, "levitating" in a fluid flow.

Such pump has a maximal level of airtightness, and hence it provides maximal security while working with corrosive and dangerous medium. An increase of security and life time is conditioned by working wheel only and the absence of mechanical contact during its rotation in a fluid flow.

The simplicity of the pump's construction allows to reduce its mass and dimensions by 1,2…1,5 times as well as to reduce the prime cost and operating costs (Fig. 4).

The pump works in the following way. The working wheel 3 with metallic core 4 is located inside the working area of the pump which consists of the case 9, insulating partition 10 and cover 6. There the force (magnetic) field is rotating; this field is created by the active component 7 with electric winding 8 intensified by the inactive element 5 of disk stator. The influence of magnetic field on the metal core 4 creates motive forces of electrodynamic nature which set the working wheel 3 into rotary motion.

The fluid flows to the pump from two directions through the entries 12 and 13, cools the case 9, where electrical windings 8 are placed, and the wicket gate uniformly directs the fluid to the working wheel 3 from below and from above. Then from both sides it is captured by centrifugal blades 14, which are symmetric relative to the mean plane of working wheel 3. The fluid flows in identical conditions from above – between the working wheel 3 and cover 6, and from below – in the gap between the working wheel 3 and insulating partition 10.

Such uniform motion of fluid from the centre to the periphery provides the "levitation" of the working wheel in the flow. Then the fluid falls onto rotational blades 15 the influence of which rises the fluid pressure; after that the fluid flows out of the pump through a delivery dome.

CONCLUSION

1. The concept of non-contact drive of working bodies for machines of different purpose was suggested.

2. The criteria of asymptotic stability of working bodies during rotary and rectilinear movement without mechanical support were theoretically defined.

3. The criteria interlink principal constructive and power parameters and their values indicate the type of stability of the motion.

4. Using non-contact drive allows to develop working machines on a high technical level using the principles of resource saving, maximal security and efficiency. New machines can be used in different fields of application.

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TEORIA KONSTRUKCJI BEZSTYKOWEGO NAPĘDU CZĘŚCI ROBOCZYCH W MASZYNACH WIELOFUNKCYJNYCH

Streszczenie. Rozważono możliwość konstrukcji bezstykowego napędu dla części roboczych maszyn. Zdefiniowano teoretycznie kryteria asymptotycznej stabilności ruchu obrotowego części pierścieniowych (RWB) oraz ruchu czworokątnego części roboczych taśmy, zakładając brak wspomagania mechanicznego. Otrzymane rezultaty badań mogą posłużyć do stworzenia nowych, efektywnych i bezpiecznych maszyn z bezpośrednim napędem części roboczych.

Słowa kluczowe: ruch obrotowy, napęd automatyczny, stabilność asymptotyczna.