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Active damping vibrations of the inertia input for the asymmetric shaft supported on the bearings lubricate liquid

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The paper discusses some possibility of the arising damp vibrations under inertia input for asymmetric rotor supported in the cylindrical slide bearing lubricated by electro fluid. It is shown that the effect of the electric field on the individual bearings junction makes it possible to achieve similar vibrations for both journals bearing although with strong asymmetry. The phenomenon discussed that increasing intensity of the electric field causes a reduction of the forced vibration but the self - excitation threshold moves in direction to the lower rotation speed.

Keywords: slide bearing, damping effect, electrorheology fluids, Reynolds equation

1. Introduction

A significant problem which occurs when using rotors supported in the slide bearings is to ensure their stability in the event of an unpredictable excessive rise of the rotation speed. These cases can take place during over speeding failure of the generators or turbines. High speed rotors, which work in the range of supercritical speed and as a result cannot function normally without special stabilization methods or additional damping, also have to be considered. Technology is aware of many methods which allow the realization of the above mentioned tasks.

In recent years special liquids have been developed where their viscoelasticity properties change when a magnetic or electric field is used. The first one is called ferroliquids. These are suspensoid of the stable ferromagnetic molecule in the electric no active support liquid. Under the use of the magnetic field the ferro molecules magnetic dipoles are ordered, which consequently conduct to create the Lorentz mass force in the ferroliquide region. In the second case, we should define what electro viscosity means. The electro viscosity is described as a momentarily reversible change of the apparent viscosity liquid where the external electric field is applied.

The phenomenon of variations in apparent viscosity liquid affected by electric fields was used for the first time by A. W. Duff (1896). He was investigating influences of the electric field on glycerine and paraffin under viscosity changes. The idea of the electrorheology was first used by W. M. Winslow (1947) – the so called Winslow effect. That effect can be characterized by the increasing resistance of flow in relation to the electric field intensity. D. L. Klass and T. W. Martinek (1968) were investigating some electro viscosity properties of silicon and lime titanium compounds and they were set as functions of such parameters as a percentage, shearing velocity, electric field intensity, frequency of intensity change and fluid temperature.

In such a phenomenon, the electrorheology fluids have been used widely for different machines and devices, for example to control active slide bearing systems. Within the space of so many years, A. Kolias and A. D. Dimarogonas' (1994) work has evolved. They investigated partly slow – running slide bearing lubrication of the electrorheology fluids and compared the results with analytical models for Bingham materials and confirmed their statement. Nikolakopulos and Papadopoulos (1995) investigated high speed rotor lubricated with electrorheology fluids. They described such a quantity as the threshold of the shearing stress, dynamic of the yield stress, relative viscosity of the electric field at different concentrating conditions and values of the cut down velocity. The same authors in 1997 were investigating bearing capacity lubricating by ER fluid in the case of cross out rotor supported by them. ER fluid was used, not only as a base course, but also served to control systems.

The applied numerical procedure to solve Reynolds' main equation was based on Bingham's models. The tests carried out on different speeds of the cut down velocity pointed out that the electrical field can increase load capacity and align the rotor in relation to supports. The main purpose of this work is to investigate the possibility of the arising damp vibrations under inertia input for asymmetric rotor supported in the cylindrical slide bearing lubricated by electro fluid.

2. Model of the system

The model of the rigid asymmetric shaft supported in the slide bearings with circular profile under unbalanced forced according to rotation axis has been taken into account.

The model of the system is presented below.

where:

R_{oi} –bearing shell radius (i = 1,2),

R_i – journal radius (i = 1,2),

e_i – eccentricity (i = 1,2),

P_{ri} – circumferential component of the hydrodynamical uplift forces (i = 1,2),

$P_{\beta\,i}$ – radial component of the hydrodynamical uplift forces (i = 1,2),

ξ_i, η_i – Cartesian co-ordinate system for following bearing (i = 1,2),

τ_i, β_i – polar co-ordinate system for following bearing (i = 1,2),

α_i – specify angle of the line between the journal centre and the centre of the bush bearing following bearing (i = 1,2),

ϕ, Θ – angles in the Cartesian co-ordinate system ξ, η,

Z – electro fluid voltage generator,

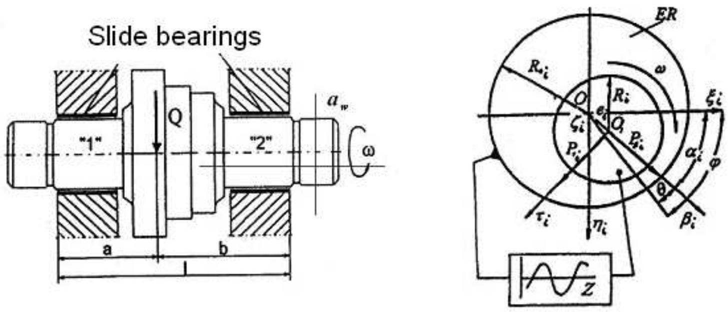

Figure 1 Model of the system

a, b – external load coordinates Q,

Q – external load.

This has been taken on the basis of the D.L. Klassa and T.W. Martinka (1967) as the basic properties for ER fluid, changes to its viscosity depending on the applied cut down velocity voltage and contents of components altering viscoelasticity properties. On the basis of the empirical results, it was possible to make approximation changes to the electro viscosity in relation to the electric field intensity and cut down velocity.

3. Equation of motion

For the considered system the bearing support model proposed by W.Kurnik and Z.Starczewski (1984) and electro fluid properties on the basis of Z. Starczewski's work (1999), the equation of motion proposed by W. Kurnika and Z. Starczewski(1994) can be written in the following form:

$$
\begin{aligned}
&\ddot{\xi}_1 = \frac{I_2}{I_1}\frac{a}{l}\omega\left(\dot{\eta}_2 - \dot{\eta}_1\right) + \left(\frac{1}{m} + \frac{a^2}{I_1}\right)\left(\frac{12\left(\mu_0 + B_1\frac{E_1^2}{v_s} + A_1\frac{E_1^4}{v_s^2}\right)R_1 L_1}{\delta_1}\right.\\
&\left\{\left(\frac{\beta_1^2(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)} + \frac{\beta_1\dot{\beta}_1}{(1-\beta_1^2)} + \frac{2\dot{\beta}_1}{(1-\beta_1^2)^{\frac{2}{3}}} arctg\sqrt{\frac{1+\beta_1}{1-\beta_1}}\right)\cos\alpha_1 + \right.\\
&\left. - \frac{3\pi\beta_1(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)}\sin\alpha_1\right\} + \left(\frac{1}{m} - \frac{ab}{I_1}\right)\frac{12\left(\mu_0 + B_2\frac{E_2^2}{v_s} + A_2\frac{E_2^4}{v_s^2}\right)R_2 L_2}{\delta_1} \qquad (1)\\
&\left\{\left(\frac{\beta_2^2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)} + \frac{\beta_2\dot{\beta}_2}{(1-\beta_2^2)} + \frac{2\dot{\beta}_2}{(1-\beta_2^2)^{\frac{2}{3}}} arctg\sqrt{\frac{1+\beta_2}{1-\beta_2}}\right)\cos\alpha_2 + \right.\\
&\left. - \frac{3\pi\beta_2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)}\sin\alpha_2\right\} + a_w\omega^2\cos(\omega t)
\end{aligned}
$$

$$\ddot{\eta}_1 = \frac{I_2}{I_1}\frac{a}{l}\omega\left(\dot{\xi}_1 - \dot{\xi}_2\right) + \left(\frac{1}{m} + \frac{a^2}{I_1}\right)\cdot\left(\frac{12\left(\mu_0 + B_1\frac{E_1^2}{v_s} + A_1\frac{E_1^4}{v_s^2}\right)R_1L_1}{\delta_1}\right.$$
$$\left\{\left(\frac{\beta_1^2(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)} + \frac{\beta_1\dot{\beta}_1}{(1-\beta_1^2)} + \frac{2\dot{\beta}_1}{(1-\beta_1^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_1}{1-\beta_1}}\right)\sin\alpha_1 + \right.$$
$$\left.-\frac{3\pi\beta_1(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)}\cos\alpha_1\right\} + \left(\frac{1}{m} - \frac{ab}{I_1}\right)\frac{12\left(\mu_0 + B_2\frac{E_2^2}{v_s} + A_2\frac{E_2^4}{v_s^2}\right)R_2L_2}{\delta_1}$$
$$\left\{\left(\frac{\beta_2^2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)} + \frac{\beta_2\dot{\beta}_2}{(1-\beta_2^2)} + \frac{2\dot{\beta}_2}{(1-\beta_2^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_2}{1-\beta_2}}\right)\sin\alpha_2 + \right.$$
$$\left.+\frac{3\pi\beta_2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)}\cos\alpha_2\right\} + \frac{Q}{m} + a_w\omega^2\sin(\omega t)$$

$$\ddot{\xi}_2 = \frac{I_2}{I_1}\frac{b}{l}\omega\left(\dot{\eta}_1 - \dot{\eta}_2\right) + \left(\frac{1}{m} - \frac{ab}{I_1}\right)\cdot\left(\frac{12\left(\mu_0 + B_1\frac{E_1^2}{v_s} + A_1\frac{E_1^4}{v_s^2}\right)R_1L_1}{\delta_1}\right.$$
$$\left\{\left(\frac{\beta_1^2(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)} + \frac{\beta_1\dot{\beta}_1}{(1-\beta_1^2)} + \frac{2\dot{\beta}_1}{(1-\beta_1^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_1}{1-\beta_1}}\right)\cos\alpha_1 + \right.$$
$$\left.-\frac{3\pi\beta_1(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)}\sin\alpha_1\right\} + \left(\frac{1}{m} + \frac{b^2}{I_1}\right)\frac{12\left(\mu_0 + B_2\frac{E_2^2}{v_s} + A_2\frac{E_2^4}{v_s^2}\right)R_2L_2}{\delta_1}$$
$$\left\{\left(\frac{\beta_2^2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)} + \frac{\beta_2\dot{\beta}_2}{(1-\beta_2^2)} + \frac{2\dot{\beta}_2}{(1-\beta_2^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_2}{1-\beta_2}}\right)\cos\alpha_2 + \right.$$
$$\left.-\frac{3\pi\beta_2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)}\sin\alpha_2\right\} + a_w\omega^2\cos(\omega t)$$

$$\ddot{\eta}_2 = \frac{I_2}{I_1}\frac{b}{l}\omega\left(\dot{\xi}_2 - \dot{\xi}_1\right) + \left(\frac{1}{m} - \frac{ab}{I_1}\right)\cdot\left(\frac{12\left(\mu_0 + B_1\frac{E_1^2}{v_s} + A_1\frac{E_1^4}{v_s^2}\right)R_1L_1}{\delta_1}\right.$$
$$\left\{\left(\frac{\beta_1^2(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)} + \frac{\beta_1\dot{\beta}_1}{(1-\beta_1^2)} + \frac{2\dot{\beta}_1}{(1-\beta_1^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_1}{1-\beta_1}}\right)\sin\alpha_1 + \right.$$
$$\left.-\frac{3\pi\beta_1(\omega - 2\dot{\alpha}_1)}{(1-\beta_1^2)(2+\beta_1^2)}\cos\alpha_1\right\} + \left(\frac{1}{m} + \frac{b^2}{I_1}\right)\frac{12\left(\mu_0 + B_2\frac{E_2^2}{v_s} + A_2\frac{E_2^4}{v_s^2}\right)R_2L_2}{\delta_1}$$
$$\left\{\left(\frac{\beta_2^2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)} + \frac{\beta_2\dot{\beta}_2}{(1-\beta_2^2)} + \frac{2\dot{\beta}_2}{(1-\beta_2^2)^{\frac{2}{3}}}arctg\sqrt{\frac{1+\beta_2}{1-\beta_2}}\right)\sin\alpha_2 + \right.$$
$$\left.+\frac{3\pi\beta_2(\omega - 2\dot{\alpha}_2)}{(1-\beta_2^2)(2+\beta_2^2)}\cos\alpha_2\right\} + \frac{Q}{m} + a_w\omega^2\sin(\omega t)$$

Because the motion of the journals centre are analysed in the Cartesian co-ordinate system ξ_i, $\eta_i$it is necessary to complete equation (1) by expression (2).

$$\begin{aligned}&\beta_1 = \frac{\sqrt{\xi_1^2+\eta_1^2}}{\varepsilon_1},\ \dot{\beta}_1 = \frac{\xi_1\dot{\xi}_1+\eta_1\dot{\eta}_1}{\beta_1\varepsilon_1^2},\ \dot{\alpha}_1 = \frac{\xi_1\dot{\eta}_1-\eta_1\dot{\xi}_1}{\beta_1^2\varepsilon_1^2},\ \cos\alpha_1 = \frac{\xi_1}{\beta_1\varepsilon_1},\\ &\sin\alpha_1 = \frac{\eta_1}{\beta_1\varepsilon_1},\ \beta_2 = \frac{\sqrt{\xi_2^2+\eta_2^2}}{\varepsilon_2},\ \dot{\beta}_2 = \frac{\xi_2\dot{\xi}_2+\eta_2\dot{\eta}_2}{\beta_2\varepsilon_2^2},\ \dot{\alpha}_2 = \frac{\xi_2\dot{\eta}_2-\eta_2\dot{\xi}_2}{\beta_2^2\varepsilon_2^2},\\ &\cos\alpha_2 = \frac{\xi_2}{\beta_2\varepsilon_2},\ \sin\alpha_2 = \frac{\eta_2}{\beta_2\varepsilon_2}\end{aligned} \tag{2}$$

where:

$\ddot{\xi}_1, \ddot{\xi}_2, \ddot{\eta}_1, \ddot{\eta}_2$ – acceleration in direction ξ, η in bearings ,,1” and ,,2”,
$\dot{\xi}_1, \dot{\xi}_2, \dot{\eta}_1, \dot{\eta}_2$ – velocity in direction ξ, η in bearings ,,1” and ,,2”,

$\xi_1, \xi_2, \eta_1, \eta_2$ – relocation in direction ξ, η in bearings ,,1" and ,,2",
$\varepsilon_1, \varepsilon_2$ – clearance in bearings ,,1" and ,,2",
β_1, β_2 – relative eccentricity in bearings ,,1" and ,,2",
$\dot{\beta}_1, \dot{\beta}_2$ – radius velocity in bearings ,,1" and ,,2",
ω – rotor rotation speed,
m – rotor mass,
μ_0 – absolute viscosity lubricate factor,
$\frac{E_1^2}{v_s}, \frac{E_2^2}{v_s}$ – electro field intensity and cut down velocity ratio,
δ_1, δ_2 – absolute clearance in bearings ,,1" and ,,2",
A_1, B_1, A_2, B_2 – constant coefficients,
$\dot{\alpha}_1, \dot{\alpha}_2$ – tangential velocity in bearings ,,1" and ,,2",
I_1, I_2 – moment of inertia for the rotor in relation to rotation axis and perpendicular axis in relation to rotation axis,
a_w – unbalance radius,

4. Numerical results

The system of the equations is described by four ordinary differential equations with constant coefficients strongly out of line and also coupled to each other as, therefore it is impossible to answer them in an analytical way. That is why for these analyses we are obliged to use digit simulation methods. The results are presented below in figures 2 – 7.

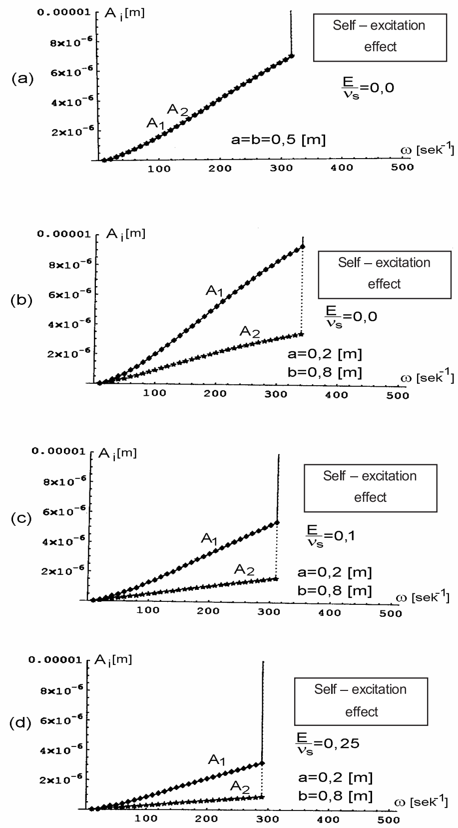

Figure 2 Changes of the amplitude of the self – exited vibration A_1, A_2 for bearing journal 1 and 2 in relation to rotation speed and different electric field intensity and cut down field. Data: R_1=R_2=0.05[m], L_1=L_2=0.05[m], $\mu_1 = \mu_2$=0.005[Pa·s], $\varepsilon_1 = \varepsilon_2$=0.0003[m], m=50[kg], Q=500[N], a_w=0.00001[m]

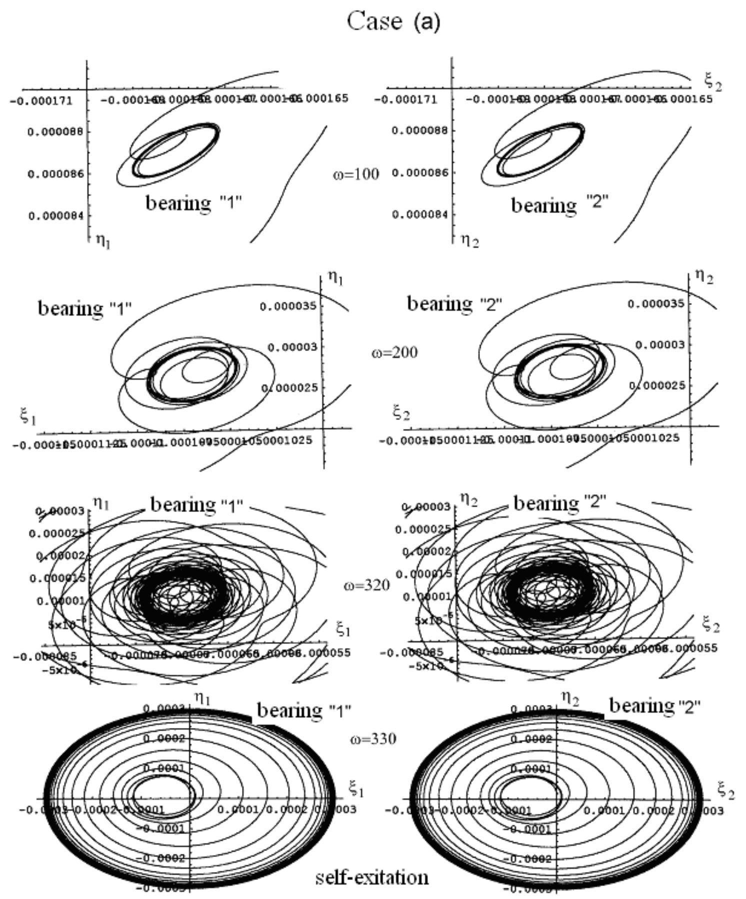

Figure 3 Example of the vibration trajectory of the bearing journal 1 and 2 for different frequency force (rotation speed) and trajectory for the self – excitation effect (case a from figure 2)

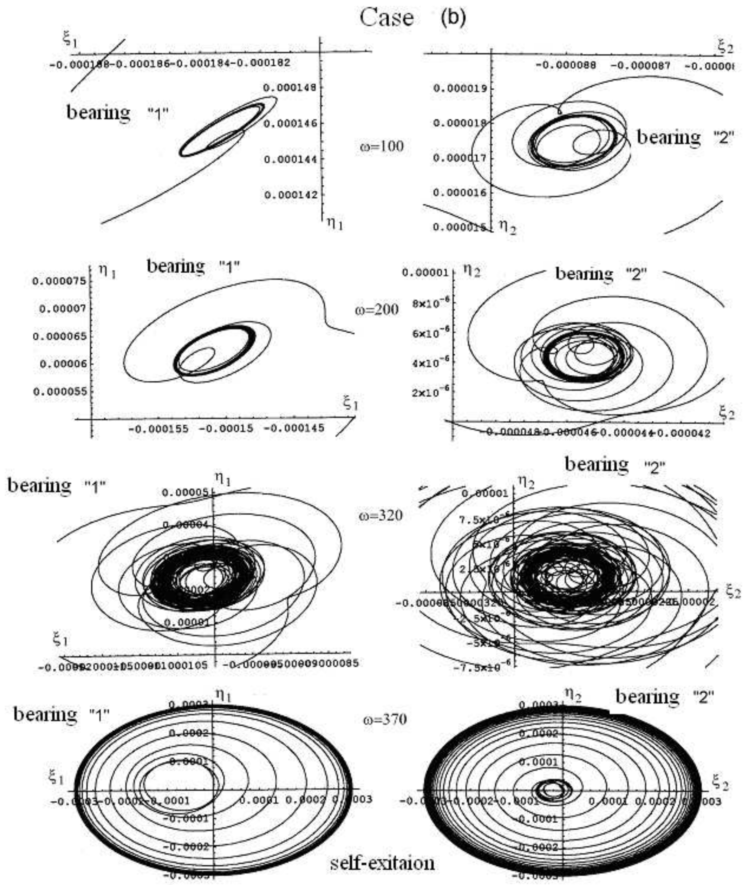

Figure 4 Example of the vibration trajectory of the bearing journal 1 and 2 for different frequency force (rotation speed) and trajectory for the self – excitation effect (case b from figure 2)

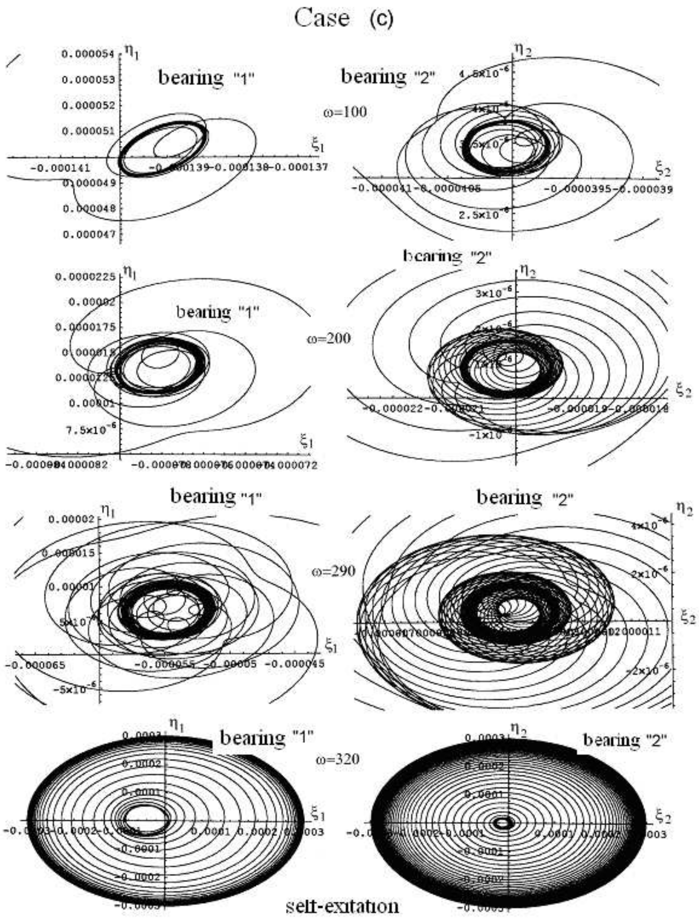

Figure 5 Example of the vibration trajectory of the bearing journal 1 and 2 for different frequency force (rotation speed) and trajectory for the self – excitation effect (case c from figure 2)

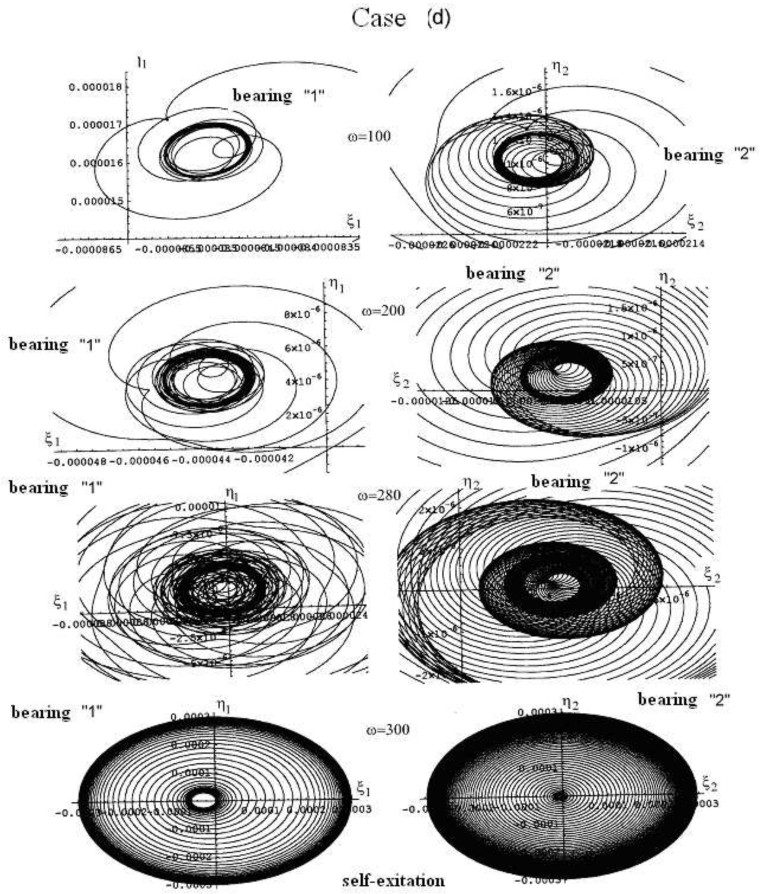

Figure 6 Example of the vibration trajectory of the bearing journal 1 and 2 for different frequency force (rotation speed) and trajectory for the self – excitation effect (case d from figure 2)

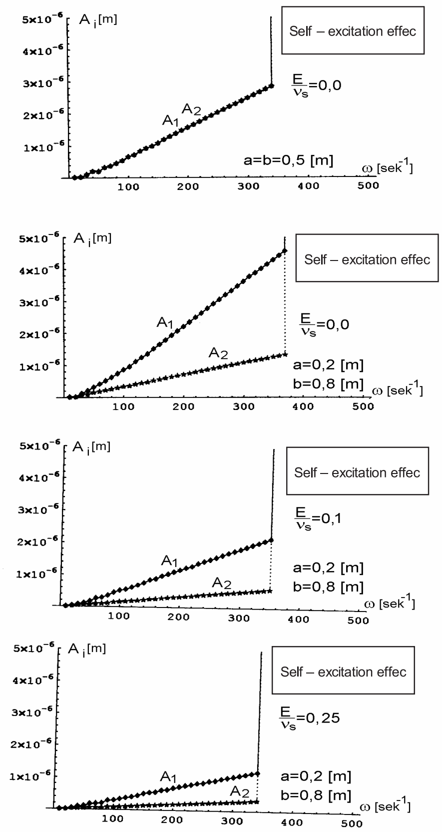

Figure 7 Changes of the amplitude of the self – exited vibration A_1, A_2 for bearing journal 1 and 2 in relation to rotation speed and different electric field intensity and cut down field. Data: R_1=R_2=0.05[m], L_1=L_2=0.05[m], $\mu_1 = \mu_2$=0.005[Pa·s], $\varepsilon_1 = \varepsilon_2$=0.0002[m], m=50[kg], Q=500[N], a_w=0.00001[m]

5. Final remarks

Taking into account the above results the final conclusion can be written down as:

- In whole range of the investigated bearings clearance and asymmetric coefficients some aspects of control vibration amplitude of the journal bearing in the case of the unbalance existence in relation to rotation axis has been presented.
- The affect of the electric field on the individual bearings junction makes it possible to achieve similar vibrations for both journal bearing although with strong asymmetry.
- The fficient effect of the electric field on the force vibration amplitude of the journal bearing can be recognized near lower rotation speed. According to high rotation speed self – excitation effect will appear.
- Increasing intensity of the electric field causes a reduction of the forced vibration but the self – excitation threshold moves in direction to the lower rotation speed.

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