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THE APPLICATION OF VIBRATIONAL-ROTATIONAL OPERATION MODE IN VIBRATORY DRIVE

In this paper an analysis of the resultant flux linkage vector ψ0 of double-way feed motor (DFM) in the vibrational-rotational mode is shown. It is used for vibration-based diagnostics of various equipment with AC drives. In the case of using DFM in the vibrational-rotational mode the accuracy of motion law implementation is higher than using the standart induction motor. The results of research obtained with the help of a mathematical model of the DFM that allows to explore the special operating modes such as oscillating, polyharmonical, vibrational-rotational and creeping speed ones. The urgency of DFM operational mode and its practical significance as a method of control for vibration-based diagnostics systems are also given herein. The influence of the load parameters on the dynamic parameters of the executive vibratory drive is shown.

Keywords: vibrational-rotational operation mode, vibration-based diagnostic, double-way feed motor, resultant flux linkage vector, damping torque, transient time.

Introduction

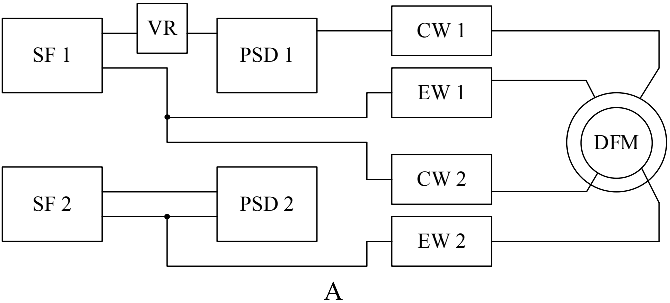
In modern industry many manufacturing processes are often accompanied by an intermediate estimation of product quality. In this regard, particular importance obtain the vibration-based diagnostic methods that enable to detect defects on the surface and also inside the product. Experience shows that the correct estimation organization and skillful using of different monitoring methods allow identify and assess the possibility of defects in testable objects with the high reliability [7]. One of the most widespread methods of testing a various equipment is vibration-based diagnostic. Some application areas of this method listed below:

– control and monitoring of the rotating equipment,

– test diagnostics and centering of cars,
– balancing of motors on the place of operation,
– diagnostics of rolling bearings,
– diagnostics of mechanical transfers,
– diagnostics of electrical motors.

The application of vibrational-rotational operation mode in vibratory drive. There are many requirements which is imposed to vibrational equipment, namely: vibration amplitude, vibration frequency, accuracy and many others [2, 3, 4, 6, 8 and 10]. In vibratory diagnostic platform for forming fluctuations, it is possible to use the oscillation generator based on DFM that operate in vibrational-rotational mode. Feature of the implementation of this mode is that stator windings are powered by currents of one frequency and the rotor windings are powered by currents of different frequencies or vice versa [3, 10]. In this article, the way of formation of a vibrational-rotational operation mode on the example of DFM is offered (figure 1). Experiments results at the different inclusions of magnetic fields are presented. The analysis of influence of load parameters on dynamic parameters of the executive motor was carried out. It is known that DFM is universal and has high output performance [1, 5].

Here SF1, SF2 – power supply feeders; PSD1, PSD2 – phase shifter devices; CW1, CW2 – control windings; EW1, EW2 – excitation windings, DFM – double-way feed motor, VR – voltage regulator. From power supply feeders (Current or Voltage) signal arrives to phase shifter devices, which creates a difference between frequencies in stator or rotor windings. Then the signal is divided on control windings and excitation windings. These windings form control of stator and rotor in double-way feed motor. At the same time, there is a rotating electromagnetic field from the stator and the shaking electromagnetic field from a rotor. Double-way feed motor represents the two-section in one motor case and can be considered as the motor with an additional fault tolerance reserve. In DFM using special control algorithms with implementation timely state control is possible [9].



A

Figure 1 – Structural scheme of electric drive with DFM in vibrational-rotational operational mode

At vibrational-rotational operation mode of DFM the following ratios are fair: $\omega_1=\omega_2=\omega_3=\omega$. At a ratio of initial phase shifts of the feeding currents (voltages) $\alpha=\gamma=\varphi=0$, $\beta=\frac{\pi}{2}$, the ratio will take a form $\omega_4=\omega`$.

Equations of flux linkage for stator and rotor windings in the transformed coordinate system with accepted assumptions at vibrational-rotational operation mode of DFM take a form (1):

$$\begin{aligned}
\psi_{\alpha s} &= \psi_{ms}\sin(\omega t);\\
\psi_{\beta s} &= \psi_{ms}\sin\left(\omega t+\frac{\pi}{2}\right);\\
\psi_{\alpha r} &= \psi_{mr}\sin(\omega t)\cos\chi+\psi_{mr}\sin(\omega` t)\sin\chi;\\
\psi_{\beta r} &= -\psi_{mr}\sin(\omega t)\sin\chi+\psi_{mr}\sin(\omega` t)\cos\chi,
\end{aligned} \tag{1}$$

Where: ψ_{ms},ψ_{mr} – amplitude values of stator and rotor windings flux linkages; t- time; ω, ω` – angular rotation frequencies of magnetic fields of stator and rotor on axes α and β; ω≠ω ; χ – law of the movement of a movable element of the executive motor.

Equations for squares of a real and imaginary part of the generalized flux linkage vector take a form (2):

$$\begin{aligned}
\psi_{\alpha}^2 &= (\psi_{ms}\sin(\omega t)+(\psi_{mr}\sin(\omega t)\cos\chi+\psi_{mr}\sin(\omega` t)\sin\chi))^2 =\\
&= (\psi_{ms}(\sin(\omega t)+\mu(\sin(\omega t)\cos\chi+\sin(\omega` t)\sin\chi)))^2,\\
\psi_{\beta}^2 &= (\psi_{ms}\cos(\omega t)-(\psi_{mr}\sin(\omega t)\sin\chi+\psi_{mr}\sin(\omega` t)\cos\chi))^2 =\\
&= (\psi_{ms}(\cos(\omega t)-\mu(\sin(\omega t)\sin\chi+\sin(\omega` t)\cos\chi)))^2,
\end{aligned} \tag{2}$$

Where: $\mu=\psi_{\alpha r}/\psi_{\alpha s}$ – relation between the flux linkages of stator and rotor on an axis α.

Equation of resultant flux linkage vector at vibrational-rotational operation mode (3):

$$\psi = \sqrt{\left(\psi_{ms}\left(\sin(\omega t)+\mu(\sin(\omega t)\cos\chi+\sin(\omega` t)\sin\chi)\right)\right)^2 + \\ +\left(\psi_{ms}\left(\cos(\omega t)-\mu(\sin(\omega t)\sin\chi+\sin(\omega` t)\cos\chi)\right)\right)^2} = \\ = \psi_{ms}\sqrt{\left(\sin(\omega t)+\mu(\sin(\omega t)\cos\chi+\sin(\omega` t)\sin\chi)\right)^2 + \\ +\left(\cos(\omega t)-\mu(\sin(\omega t)\sin\chi+\sin(\omega` t)\cos\chi)\right)^2}. \tag{3}$$

Equation for the law of movement of a spatial vector of flux linkage in an air gap at vibrational-rotational operation mode (4):

$$\chi_0 = \operatorname{arctg}\left(\frac{\psi_{ms}\cos(\omega t)-\psi_{mr}\sin(\omega t)\sin\chi+\psi_{mr}\sin(\omega` t)\cos\chi}{\psi_{ms}\cdot\sin(\omega t)+\psi_{mr}\sin(\omega t)\cos\chi+\psi_{mr}\sin(\omega` t)\sin\chi}\right) = \\ = \operatorname{arctg}\left(\frac{\cos(\omega t)-\mu(\sin(\omega t)\sin\chi+\sin(\omega` t)\cos\chi)}{\sin(\omega t)+\mu(\sin(\omega t)\cos\chi+\sin(\omega` t)\sin\chi)}\right). \tag{4}$$

Hodograph of a resultant vector of flux linkage are given below (figure 2) at feeding the windings of the stator and a rotor from current source and voltage source.

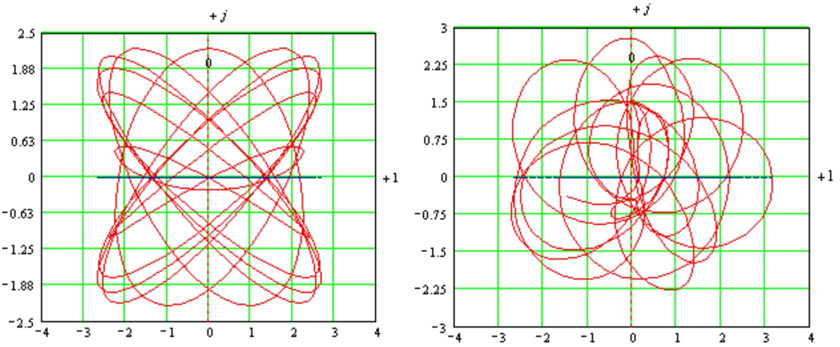


Figure 2 – Hodographs of a resultant vector of flux linkages ψ_0 at feeding the windings of the stator and a rotor: a) from current source b) from voltage source, at $\omega_1=\omega_2=\omega_3=1$; $\omega_4=1,1$

At vibrational-rotational operation mode the hodographs of the generalized resultant flux linkage vector ψ_0 (figure 2) represent fluctuations of the rotating magnetic field around the point 0.

This mode is realized at creation of the rotating electromagnetic field from the stator, and an oscillatory electromagnetic field from a rotor.

Vibrational-rotational operation mode in DFM can be created in two cases:

1. Creation of the vibration mode from a rotor – $\gamma_1=\gamma_2=1$; $\gamma_3=\gamma_4=1{,}225$;

$\omega_1=\omega_2=\omega_3=1$; $\omega_4=1{,}1$; $\alpha=\gamma=\varphi=0$, $\beta=\frac{\pi}{2}$.

Voltages on plugs of windings of the stator and a rotor in the transformed axes α,β,0 the following form (5):

$$\begin{aligned}
U_{\alpha s} &= U_{ms}\sin(\omega t);\\
U_{\beta s} &= U_{ms}\sin(\omega t+\beta);\\
U_{\alpha r} &= U_{mr}\sin(\omega t)\cos\chi + U_{mr}\sin(\omega' t)\sin\chi;\\
U_{\beta r} &= -U_{mr}\sin(\omega t)\sin\chi + U_{mr}\sin(\omega' t)\cos\chi.
\end{aligned}\tag{5}$$

2. Creation of the vibration mode from a stator – $\gamma_1=\gamma_2=1$; $\gamma_3=\gamma_4=1{,}225$;

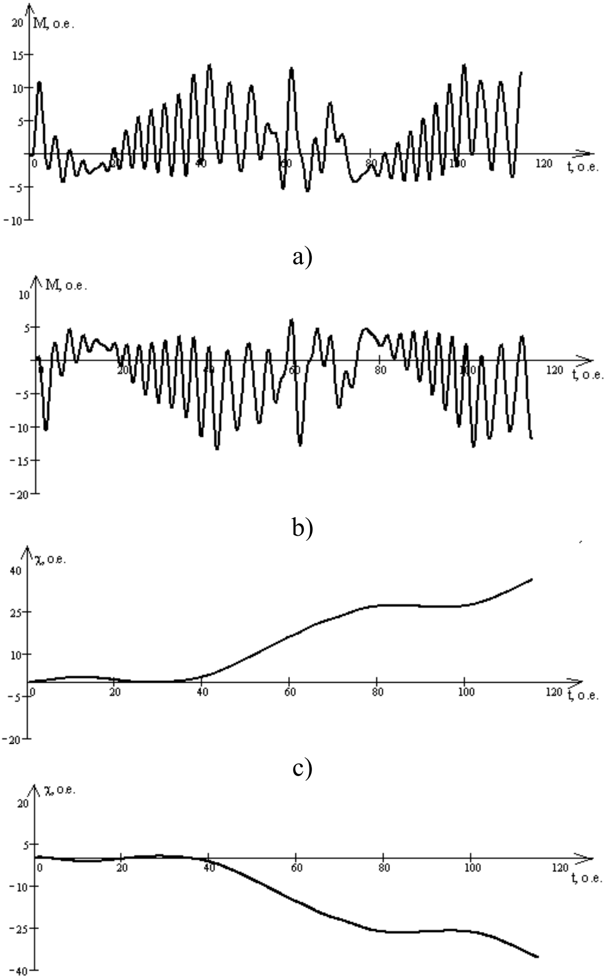
$\omega_1=\omega_3=4_3=1$; $\omega_2=1{,}1$; $\alpha=\beta=\gamma=0$, $\varphi=\frac{\pi}{2}$.

Voltages on plugs of windings of the stator and a rotor in the transformed axes α, β, 0 the following form (6):

$$\begin{aligned}
U_{\alpha s} &= U_{ms}\sin(\omega t);\\
U_{\beta s} &= U_{ms}\sin(\omega' t);\\
U_{\alpha r} &= U_{mr}\sin(\omega t)\cos\chi + U_{mr}\sin(\omega t+\varphi)\sin\chi;\\
U_{\beta r} &= -U_{mr}\sin(\omega t)\sin\chi + U_{mr}\sin(\omega t+\varphi)\cos\chi.
\end{aligned}\tag{6}$$

Gabriel's Krone equations [3], which describe transformations of energy in the electrical machine, are the basis for the DFM mathematical model. They are the system of the differential equations consisting of the equations of voltages and the equation of the movement of a movable element of the executive motor, at the standard assumptions for electric vibratory drives [5, 6]. The mathematical model describing processes in DFM is written down concerning currents of the stator and a rotor of the motor in axes α, β, 0 in an iterative form, under zero initial conditions. The model is executed on the basis of the induction motor with a phase rotor of type 4AK160S8У3 with IP44 protection and the synchronous rotating speed n=750 rpm, P2=5,5 [kW]. This model allows to investigate the transient processes in DFM at different operation modes [5].

Shown the electromagnetic moment of the motor and the law of the movement of a movable element of the executive motor of figure 3 at different methods of forming the vibrational-rotational operation mode as results of modeling. Curves of figure 3 are received at the following load parameters: J_n= 63,34 r.u., C_m=*0* r.u., R_g=4 r.u.



a)

b)

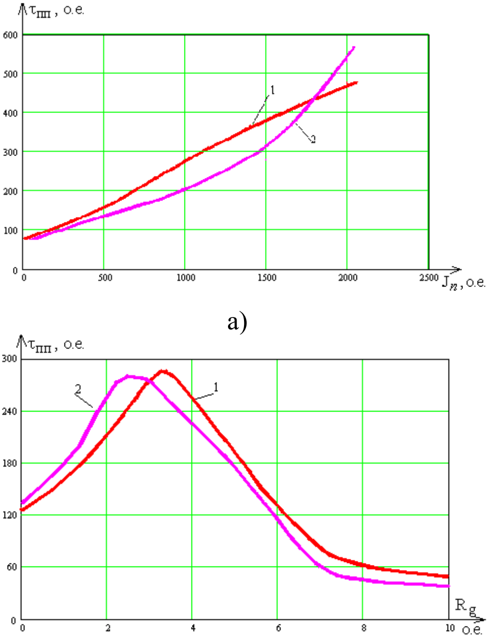
c)

d)

Figure 3 – Timing diagram: a, b) of electromagnetic moment;
c, d) the law of movement at different methods of forming
the vibrational-rotational operation mode

Behavior of change of the law of the movement of a movable element of the executive motor from time is same as during creation of the oscillatory electromagnetic field from a secondary element, and from primary element. At the same time it is overlap of a rotation field on an oscillatory field and has a vibration amplitude χm=4 r.u. It is necessary to add that in independence from a formation method of an oscillating field a modulation of the electromagnetic moment is created.

For a vibrational-rotational operation mode changeable load parameters are load inertia moment J_n and load damping torque coefficient R_g. In Figure 4. the diagram of transient time ($\tau_{пп}$) from load parameters.



a)

b)

Figure 4 – Diagram of transient time from: a) load inertia moment J_n;
б) коэффициента load damping torque coefficient R_g

On the given diagrams (figure 4) the following designations are accepted: 1 – creation of the oscillatory field from a rotor; 2 – creation of the oscillatory field from the stator. In a vibrational-rotational operation mode, the transient time increases considerably. From figure 4. the transient time at the changing load damping torque coefficient has a resonance peak in points R_{g1}=3,5 and R_{g2}=2,5. During creation of the oscillatory field from a rotor and from the stator, respectively.

Conclusion

1 Change of load inertia moment J_n leads to increasing of transient time $\tau_{пп}$ what means that influence of this load parameter are significant.

2 Change of load damping torque coefficient Rg leads to reduction of transient time and to existence of resonance peak at concordant inclusion of electromagnetic fields in independence from side of formation the oscillatory field.

3 Practical application of DFM in vibrational equipment as a method element of a non-destructive testing perhaps if oscillation frequency does not exceed 10 Hz, and amplitudes of the feeding currents (voltages) shall not differ more than for 25 %.

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Дірілдеткіш жетекте тербелмелі-айналмалы жұмыс режимін қолдану

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Применение колебательно-вращательного режима работы в виброприводе

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Бұл жұмыста әртүрлі жабдықтардың дірілді диагностикасы үшін айнымалы ток электр жетегінің тербелмелі-айналмалы жұмыс режимін жүзеге асыру кезінде қос қуат беру машинасының ψ0 ағынның векторына талдау жасалды. Тербелмелі-айналмалы режимде жұмыс істейтін атқарушы қозғалтқыш ретінде қос қуатты машина жағдайында сериялық асинхронды қозғалтқышты пайдаланғанға қарағанда қозғалыс заңын пысықтау дәлдігі жоғары екендігі көрсетілген. Зерттеу нәтижелері осындай электромеханикалық энергия түрлендіргішінің арнайы жұмыс режимдерін, атап айтқанда: тербелмелі, полимармоникалық, тербелмелі-айналмалы және қозғалатын жылдамдықты зерттеуге мүмкіндік беретін қос қуатты машинаның математикалық моделін қолдана отырып алынды. Электр жетегінің осы режимінің өзектілігі және оның Бақылау әдісі ретінде дірілді диагностика жүйелері үшін тәжірибелік маңыздылығы негізделген. Діріл электр жетегінің атқарушы электр қозғалтқышының динамикалық көрсеткіштеріне жүктеме параметрлерінің әсеріне талдау жүргізілді

Кілтті сөздер: вибрациялық-айналмалы жұмыс режимі, дірілге негізделген диагностикалық, екі жақты қозғалтқыш, ағынды байланыстыратын вектор, демпфер моменті, өтпелі уақыт.

В данной работе был проведен анализ результирующего вектора потокосцепления $\psi 0$ машины двойного питания (МДП) при реализации колебательно-вращательного режима работы электропривода переменного тока для вибродиагностики различного оборудования. Показано, что в случае с МДП, как исполнительного двигателя, работающего в колебательно-вращательном режиме точность отработки закона движения выше, чем при использовании серийного асинхронного двигателя. Результаты исследования получены при помощи математической модели МДП, которая позволяет исследовать специальные режимы работы такого электромеханического преобразователя энергии, а именно: колебательного, полигармонического, колебательно-вращательного и ползучей скорости. Обоснована актуальность данного режима работы электропривода и его практическая значимость для систем вибродиагностики, как метода контроля. Проведен анализ влияния параметров нагрузки на динамические показатели исполнительного электродвигателя вибрационного электропривода

Ключевые слова: вибрационно-вращательный режим работы, диагностика на основе вибрации, двигатель двусторонней подачи, результирующий вектор потокосцепления, демпфирующий момент, переходное время.

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