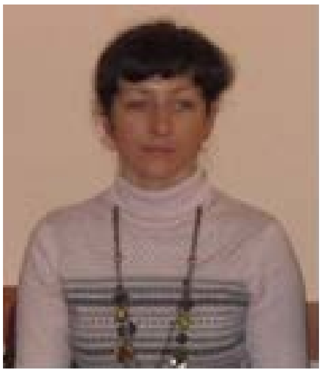
Fixed mining machines operating condition control automation



Elena Bondar

Senior Lecturer
State Higher Educational Institution " Kryvyi Rih National University"
Kryvyi Rih, Ukraine

Abstract
New diagnostic features of instance detecting of operational defects occurring and significant impact on the fixed rotary machines loads growth, which cause a sharp reduction in their life, were developed, explored and suggested. The automation module of rotary machines operating condition control on the base of dynamic misalignment fact discovery was suggested. The module allows applying of unit maintenance circuit according to real situation, avoiding of unauthorized stops, examinations and interference in serviceable equipment, and thus eliminating of additional service costs. The calculations of economic benefits of the fixed diagnostic module use, profit from the implementation and payback period were carried out.
Key words: OSCILLATION, SUPPORT, MODULE, AUTOMATION, DIAGNOSTIC, LIFE

Fixed mining machines (FMM) providing service to ore mining complex Krivoy Rog basin are an essential part of any ore processing plant, mine, etc. These machines are critical equipment as the continuity of the entire mining complex production cycle depends on their normal operation, and failures can cause production downtime, serious losses of hundreds of millions. Based on statistical data analysis, it was found that one of the main causes of FMM failures is the rotor system units defects, namely, dynamic misalignment of shafts and unbalance, which is due to the additional loads under the effect operational defects, which negatively affect the working capacity reducing turnaround time.

As it is known [1], the increase of the second harmonic of rotation frequency in radial, and to a greater extent, axial directions in the spectra from the bearing supports is a characteristic feature of the misalignment between two shafts connected by rigid or semi-rigid couplings. This condition is true for rotary systems of linear or weakly nonlinear recuperative characteristic. Thus, there is the necessity for automation of the FMM operational condition control on the basis of a fixed module for diagnostics and monitoring of fixed rotary machines in order to measure and analyze the pump unit vibration.

The module work is provided on the basis of recording of multisupport fixed rotary machine supports defects impact determined upon the angular displacement of hodograph plane of the rotor axis precession. The application task is solved by the continuous recording of rotor axis oscillation amplitude on the support at the center point within the range the informative frequencies, in the plane perpendicular to the shaft assembly axis, hodograph of the rotor axis precession recording. In the acting force system, rotor 8 (Fig. 1) [2] with a mass m_p has two front supports (I and II) and two back ones (III and IV) with rotor 9 supports rigidity c_1 and c_2, c_3 and c_4 respectively. At that, the rotor rotates with angular frequency ω and receives vibrational excitation with an amplitude y from the effect of centrifugal force F_c. In the car without operational defects, the rotor precession (rotor axis hodograph) is of a vertical ellipse shape, as only force of gravity is added to the action forces. If the supports have the defects, the rotor support rigidity is changed in the direction of service damage. It is conducive to rotor support vibration increase towards the defect and deviation (displacement) of the rotor axis towards the damage, in other words, it changes the rotor precession nature and, consequently, the rotary machine axis hodograph.

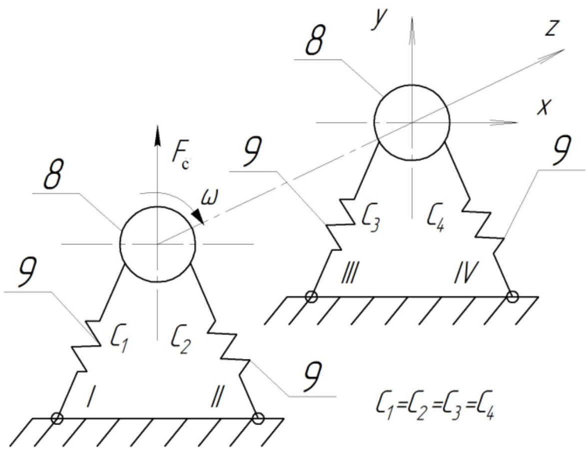


Figure 1. System of the FMM rotor action forces

The equilibrium condition formula is of the following form

$$m_p\ddot{y} + c_1 \cdot y_1 + c_2 \cdot y_2 + c_3 \cdot y_3 + c_4 \cdot y_4 = F_c \quad (1)$$

where m_p – rotor mass, ω - rotor rotation angular frequency; *y* - rotor oscillation amplitude in the force F_c direction; F_c - unbalance force vector; ; I and II, III and IV – two front and two back supports of FMM respectively; c_1, c_2 , c_3 , c_4 – rigidity characteristic of respective supports I, II, III and IV.

The rotor axis 7 hodograph (Fig. 2a) [3] is depicted in the rotary machine without supports damage under condition when $c_1=c_2=c_3=c_4$. If there are damages of the front supports $c_1 \neq c_2$ and defects of multisupport FMM distant supports $c_3 \neq c_4$, the position of rotor axis 10 hodograph is changed: it is deflected by the angel α from the plane perpendicular to the shaft assembly axis (Fig. 2b). If there are defects of multisupport FMM distant supports with the big difference of distant supports rigidity, i. e. $c_1 \neq c_2 \neq c_3 \neq c_4$, namely $c_{3>>}c_4$, the position of rotor axis 11 hodograph is changed: it is simultaneously deflected by the angel αfrom the plane perpendicular to the shaft assembly axis and by the angel β in the horizontal plane (Fig. 2c). When multisupport FMM support c_i reducing, which happens under partial or total support failure, y_i is increased in order to recover the balance. Due to irregular time change of c_i and consequently y_i, the rotor axis precession hodograph is deflected from the plane perpendicular to the shaft assembly axis, which causes the defect in the form of dynamic angular misalignment of the rotor unit coupling.

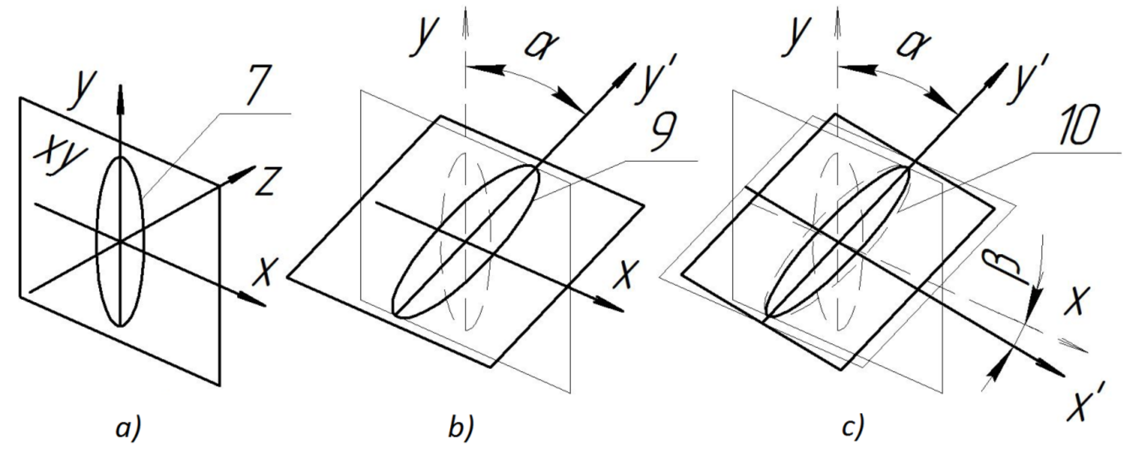


Figure 2. The rotor axis position change according to rigidity of its supports: a) when $c_1=c_2=c_3=c_4$ b) when $c_1 \neq c_2$ and $c_3 \neq c_4$; c) when $c_1 \neq c_2 \neq c_3 \neq c_4$, namely $c_{3>>}c_4$

If there are distant supports defects, the formula of the rotor equilibrium conditions is transformed into the following expression

$$m_p(\ddot{y}+\Delta y)+c_1\cdot(y_1+\Delta y_1)+c_2\cdot(y_2+\Delta y_2)+c_3\cdot($$

where Δy - the rotor oscillations amplitude increase in the direction of the additional force of defects ΔF_c; ΔF_c – the vector of additional force caused by the distant system supports defects. The fixed effect is the basis of the rotary unit dynamic misalignment detection method, which is implemented as follows (Fig. 3): a rotary unit installed on a foundation 1 and frame 2 consisting of two or more machines (for example 11 and 12) interconnected by means of rigid or flexible element 13 (coupling), in the working process, forms the mechanical rotor oscillations excitation, which are transmitted to the rotor 3 supports (fixed parts of the construction). If there are operational defects such as unfastening, supports cracking, frame destroying, foundation structure changes, and so on, the supports rigidity irregular change is observed. It causes the growth of an additional force ΔF_c, and leads to the rotor shaft precession hodograph change. It is shifted from the plane perpendicular to the shaft assembly axis towards the force action and obtains the slope towards the forces difference increase. This fact is recorded by vibratory displacement analyzer 6 installed on rotor support in the point of the rotary unit centering.

On the basis of the method, the module, which provides the fixed mining machines operational condition control automation, was suggested. The diagnostic task is implemented in real time using in-place-method and without fixed machines terminal from operation on the basis of vibroacoustic monitoring and technical conditions diagnostic detection, identification of defects, which cause dynamic misalignment.

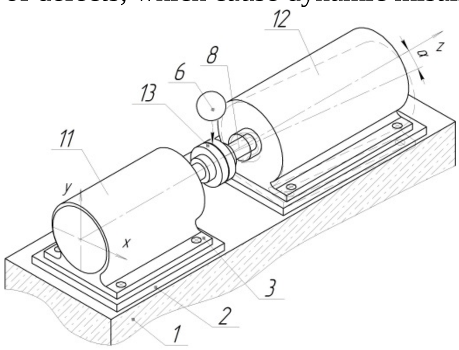


Figure 3. Diagram of the rotary unit dynamic angular misalignment detecting method

The module allows dynamic loads reducing, fixed machines resource characteristics maintaining or improving, the dynamic misalignment effect adjusting by planning of maintenance flexible regulations, which are adequate to equipment performance according to the diagnostic control data, and equipment and technological systems downtime reducing if there are objective data on their technical condition.

Operation algorithm of fixed mining machines operational condition control automation module is shown in Fig. 4.

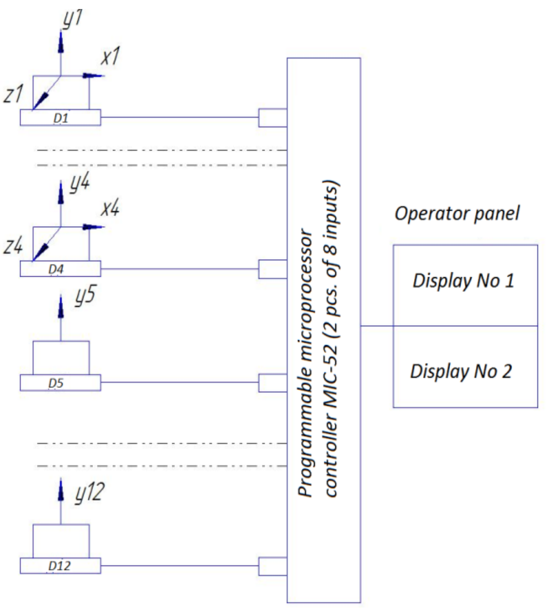


Figure 4. Operation algorithm of fixed mining machines operational condition control automation module, where D1-D4 - three-axis accelerometer of general purpose; D5-D12 - single-axis accelerometer of general purpose

The fixed module principle diagram for the fixed rotary machines diagnosis and monitoring is shown in Fig. 5. This module is designed for prevention from loads uncontrolled growth, reducing of equipment life from fixed machines dynamic misalignment occurrence and development. It occurs as a result of mounting hidden defects, operational damage occurrence and development and support structures destruction.

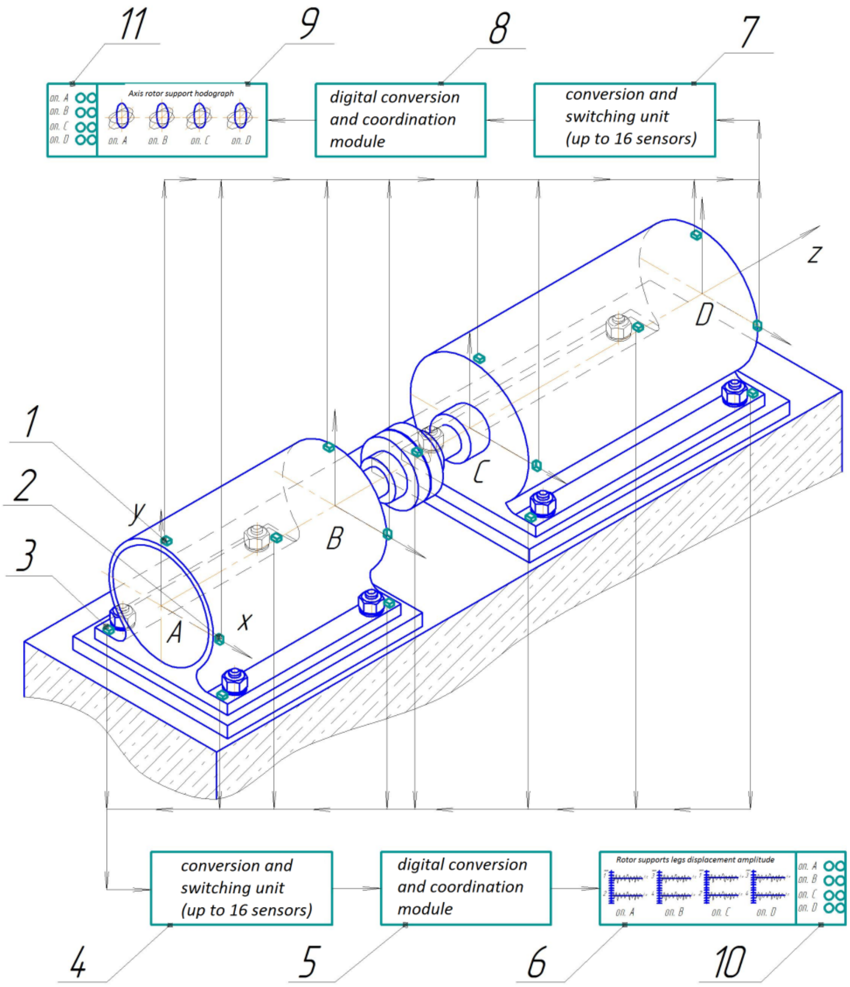


Figure 5. Diagnostic module principle diagram: where pos. 1, 2, 3 – accelerometers of determining of the vertical, horizontal and axial displacement on the supports and the vertical displacement of the rotor supports legs respectively; pos. 4,5,7,8 - programmable microprocessor controller; pos. 6, 9 – display for information output of the rotor supports legs displacement amplitude and building of hodograph rotor precession axis respectively; pos. 10, 11– means for signaling on the monitored parameters marginal error

Calculations of economic benefits from the fixed diagnostic module use for FMM were carried out [4]. The FMM servicing circuit of preventive maintenance was accepted as an analysis object (base case). This circuit involves, for example for K-500-61-1, 7 current maintenances and 1 general maintenance per 4 years; thus, current maintenance is carried out 2 times a year and general one is carried out in 4 years. The labor intensity of the current maintenance (equipment downtime) is 950 work hours. The cost of current maintenance is 120 000 UAH. The maximum allowable equipment life to general maintenance is 29 760 hours.

The value of annual economic effect is

$E_{an}= (E'_{an\,1}+ E'_{an\,2}+ E'_{an\,3} +E'_{an\,4})- E_{н}C_{ad}$

where C_{ad} – the module purchase costs, C_{ad}=43487 UAH; $E'_{an\,1}$ - annual savings from capital investments changes, $E'_{an\,1}$=12 000 UAH/yr; $E'_{an\,2}$ - operating costs for repairs and maintenance annual savings, $E'_{an\,2}$=144 000 UAH; $E'_{an\,3}$ - operating costs annual savings due to increase of structural elements durability, $E'_{an\,3}$=1000 UAH; $E'_{an\,4}$ - diagnostic services efficiency, $E'_{an\,4}$=80 000 UAH.

Then the annual economic effect from the FMM condition diagnostic module introduction and use is

$Э_{an}$=(12 000+144 000+1000+80000)-0.1·43 487 = 232 651.3 UAH

Profit from the module introduction is

P= $Э'_{an\,1}$+ $Э'_{an\,2}$+ $Э'_{an\,3}$ +$Э'_{an\,4}$=12 000+144 000+1000+80000=237 000 UAH

Payback period (years):

$$T = \frac{K_{ad}}{P} = \frac{43487}{237000} = 0.183$$

Thus, FMM operational condition control automation due to the use of fixed diagnostic module will allow: FMM servicing circuit using on the actual condition; avoiding of unauthorized stops, examinations and interference in serviceable equipment, and thus eliminating of additional service costs; increase in service life ensuring and corresponding decrease in renewal deductions during FMM operation; annual operating costs for repairs and maintenance reducing at a payback period 0.183.

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