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DIAGNOSTIC AND LIFE PREDICTION OF PUMPING UNIT REDUCERS BY VIBRATION ANALYSIS

The problem of determination of the technical state of pumping units reducing gears sharply is based on the estimation of their resource in the process of exploitation and after the repair in the conditions of repair base. Oil in Ukraine and Poland is produced mainly by pumping units, the whole amount of which in two countries exceeds 3000 items. It is especially needed to know descriptions of vibrations of reducing gears of pumping units by which it is possible to judge about the presence of defects, wear, damages or deformations of basic assemblies of reducing gears of different type (involute gearing or meshing of Novikov) or different production companies (Azerbaijan, Russia, Romania, USA, Ukraine and others like that). On the basis of classification of defects and connection them with vibroacoustic descriptions of reducing gears of pumping units the method of estimation of their technical state is developed and a remaining resource is forecast.It is needed also to estimate the state of reducing gears of pumping units after implementation of repair in the conditions of bases of repairs, for what it is suggested to develop stands for the tests of reducing gears and method of estimation of their technical state after repair. During the long term work of machine the change of its state is fixed on the basis of collection and treatment of statistical information about the parameters of vibration. As a diagnostic parameter the dispersion of level of vibration often is used in practice. Norms on possible vibrations for the separate types of mechanisms and machines are standardized, however much similar standards cause complication for reducing gears, as a level of their vibration to a great extent depends on loading of a shaft and speed of rotation, therefor it is more acceptable the procedure of comparison of spectrum of vibrosignal, measured on the diagnosed equipment, with the spectrum of vibrosignal, measured before on equipment, or on equipment in good condition with similar descriptions and perfomances.

Vibrodiagnostics is based on measuring of descriptions of oscilation processes (displacements, speeds or accelerations) which appear at interaction of details of working ma-

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chine or mechanism, and their analysis by different methods [1, 2]. The vibration signal has a complicated structure, that depends on the dynamics of mechanism and type and character of interaction of components which it is composed from.

Acceleration is derivative from the speed and it can be used for estimation of tendency of change of the technical state of machine. The change of magnitude of displacement (amplitudes of vibration) in the spectrum of frequencies is used in the tasks of search of various defects. On the basis of spectral analysis of vibration it is possible to define the wear of teeth of reducing gear, their damage and breakage, wear and failures of bearings, deformation of shafts, wheels disbalancing, defects of axes of shafts and others like that. Amplitude of impulses is straight proportional to the speed of shocks of contacting details, which depends on a size to the clearence in a kinematics pair.

We have conducted the diagnostic inspections on three oil wells in Oil company „Dolynanaftogaz", equipped by pumping units:

- well №40-D with the pumping jack UP-12T (reducing gear R-55 after repair),
- well №246-D with the pumping jack UP-12T (reducing gear R-55 after 8 years exploitations),
- well №58-ND with a pumping jack СК-8 (reducing gear Ц2НШ-750Б after 8 years exploitations).

The reducing gear R-55 has the involute meshing and the reducing gear Ц2НШ-750Б has the Novikov meshing (ОСТ 26-02-1200-75 and ТУ 26-16-5-76).

Oil wells №40-D and №246-D have been equipped by the pumping jack of identical type, with identical operating parameters (number of strokes per minute, mass and location of counterbalancing weights) and located on small distance one from other, that guarantees enough high similarity of character of loading of reducing gears, therefore comparison of vibration descriptions in this case allows correctly to define influence of time of work of the reducing gear R-55 on his vibration state.

Identical time of work for the reducing gears of oil wells №246-D and №58-ND in approximately identical terms allows also to conduct comparison of vibration descriptions of reducing gears with different types of meshing.

Technical descriptions of the reducing gears R-55 and Ц2НШ-750 (C2NSH-750) are presented in the Table 1.

Measurings of vibration descriptions were conducted by the informatively-measuring system, that contains a piezoelectric transformer of the increased initial signal that have been received by the linear entrance of audiosignal input (sound card) of notebook (Fig. 1). The record of signal was carried out by the CoolEdit Pro 2.1 program with frequency of discret equel to 44100 Hz and settling ability a 16 bit/counting t .

The transducer was set on the housing of reducing gear during testing near the end of output shaft. Mean frequencies of rotation at the entrance the shaft for reducing gears R-55 and Ц2НШ-750Б during conducting of measuring were equal accordingly to: f_{ent} = 3.9 Hz and f_{ent} = 3.53 Hz.

Treatment of results was conducted in the MathCad environment. Spectrums were built on the basis of selection by length near 1 million of values, that allows to attain settling ability on frequency near 0.04 Hz. The obtained spectral descriptions of vibration signal of reducing gears, resulted on Figure 2, testify to the substantial increase of level of vibration

practically in all range of frequencies for the worn reducing gear R-55 as compared to recently repaired one. Also there is a wide difference between amplitudes of vibration of reducing gears with the involute meshing and the Novikov meshing, which achieves 3...3.5 times. However much difficult character of spectrum of signals needs more detailed their research taking into account the structure and principle of work of all parts of pumping unit.

Table 1

Technical descriptions of reducing gears of pumping jacks

Indexes	R-55	Ц2НШ-750Б
Maximum torque, kN· m	55	40
Normal module: I stage II stage	 5,114 6,749	 5,000 8,000
Number of teeth of wheel: I stage Z1 II stage Z3	 20 27	 15 15
Number of teeth of wheel: I stage Z2 II stage Z4	 130 150	 94 89
Butt end module I stage II stage	 6 8	 – –
Corner I/ II stage	31º/32 º	–
Gear-ratio	36,100	37,180
Volume of oily bath, l	200	150
Mass, kg	4450	2820

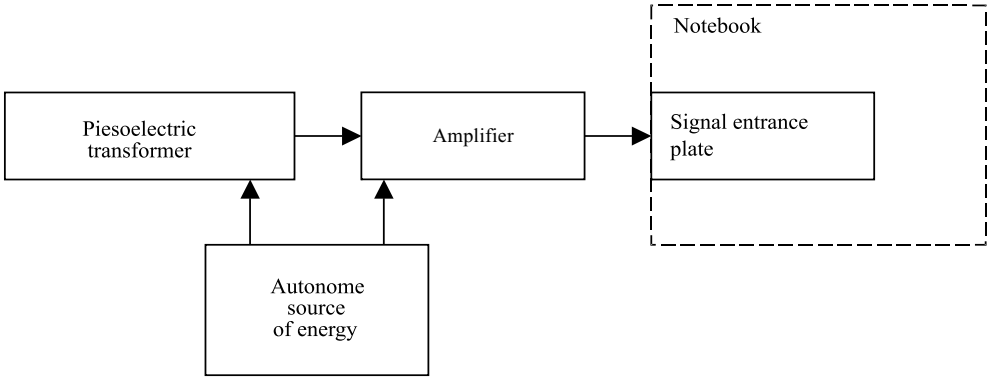

Fig. 1. Flow diagram of the vibration signal measuring system

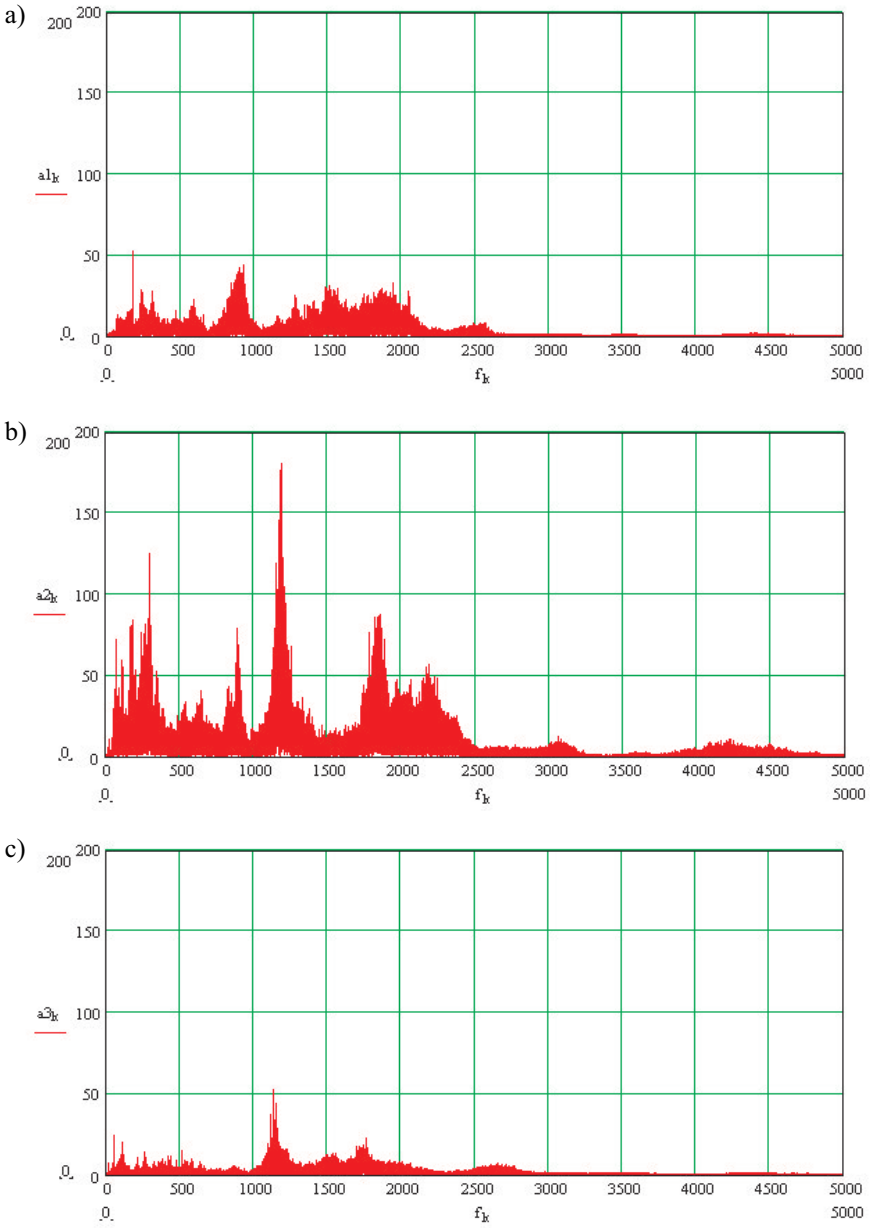

Fig. 2. Spectrums of vibration of the pumping unit reducing gears: a) R-55 (well №40-D), after repair; b) R-55 (well №246-D), worn; c) Ц2НШ-750Б (well №58-ND), worn

The spectrum of the vibration signals of gearing which is in the satisfactory technical state usually contains constituents on frequencies of rotation of entrance and output shafts, and also constituent on frequency of meshing [2].

The reducing gears of pumping jack are the two-stage transmissions, where two frequencies of meshing are generated f_1 and f_2:

– for the reducing gear R-55:

$$f_{з1} = 20 f_{ent} \text{ and } f_{з2} = \frac{Z_3}{i_1} f_{ent} = \frac{20}{130} \cdot 27 f_{ent},$$

– for the reducing gear Ц2НШ-750Б:

$$f_{з1}' = 15 f_{ent}' \text{ та } f_{з2}' = \frac{Z_3'}{i_1'} f_{ent}' = \frac{15}{94} \cdot 15 f_{ent}',$$

where:

i, i'_1 – are transmission ratio of the first stage,

z_3, z'_3 – are the number of teeth for the wheel of II stage.

Thus, for the reducing gear of R-55 meshing frequencies are equal to $f_{з1} = 78.1$ Hz and $f_{з2} = 16.3$ Hz, and for the reducing gear Ц2НШ-750Б – $f_{з1}' = 52.9$ Hz and $f_{з2}' = 88.5$ Hz accordingly.

Research of the obtained spectrums in ranges near to frequencies of toothmeshing allows to expose the expressed maximums on frequency $f_{з1}$ (Fig. 3).

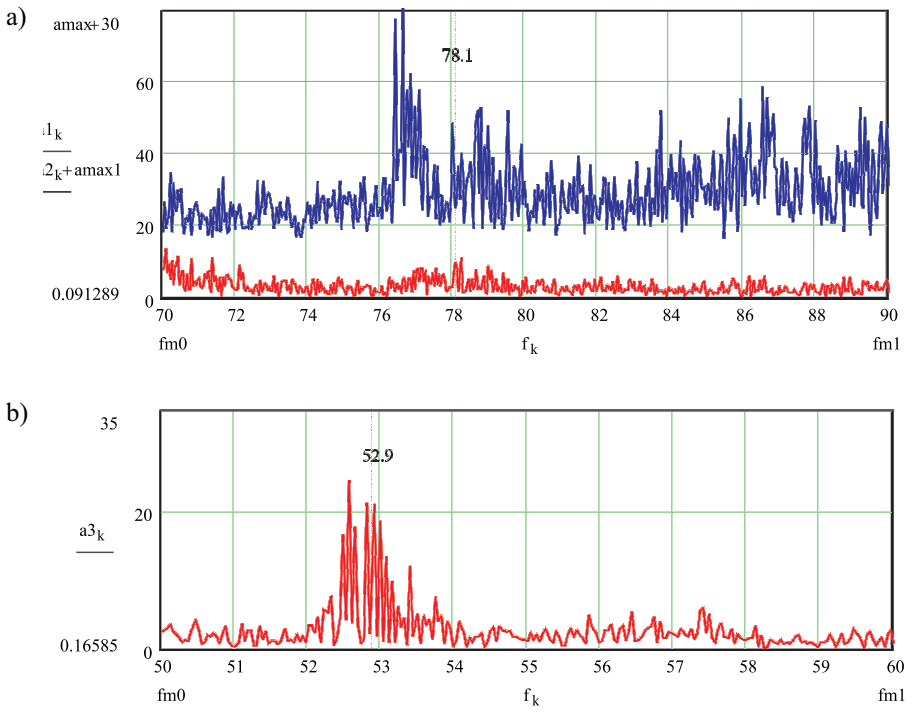

Fig. 3. Spectrums of vibration signals on frequency of toothmeshing (a) R-55; b) Ц2НШ750Б)

The spectrums for a new and worn reducing gear shown on Fig.3,a is presented on one graph. For a new reducing gear a maximum is not expressed clear enough and had small amplitude, contrary to worn one. Some fuzzy of maximum on the band of frequencies in the range 76.2...80.1 Hz comes into notice. It follows to notice that for asynchronous electric motors which are used as the prime mover of pumping jack, frequency of rotation poorly depends on loading on a shaft [3]. During the period of balancing, that corresponds to one turn of enter shaft of reducing gear, loading substantially differs for the first half-period (motion downward of the sucker rod column is unloaded) and second half-period (motion upwards of the column is loaded by weight of pumping liquid inside of the tubing). That, obviously, corresponds to two speeds of rotation of the motor and corresponds to two «humps» of frequency description on the left and to the rihgt from the middle frequency of toothmeshing. Also in both cases for worn reducing gears there are lateral bands remote from frequencies of toothmeshing on frequency of rotation of enter shaft of reducing gear, and, it is less expressed - on frequency of rotation of intermediate shaft. It is known [4] that the presence of such lateral accordions is the sign of defect of gear-wheel, that is revolved with the proper frequency (in this case initial and intermediate shafts). In the case of the reducing gear Ц2НШ-750Б it is confirmed by the sentineling diagram of vibration signaly, where shock impulses which follow with frequency of rotation of input shaft are expressly visible (Fig. 4).

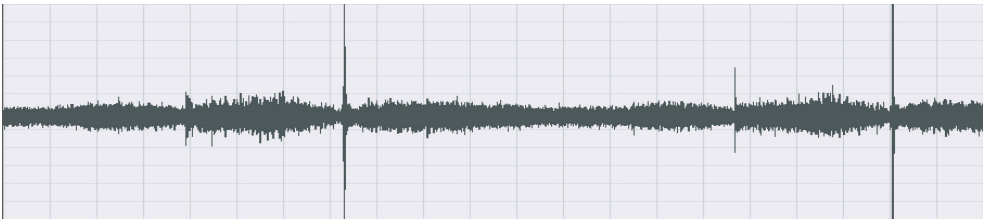

Fig. 4. Vibration signal of the reducing gear Ц2НШ-750Б

In the spectrum of vibration signals there are plenty of «peaks» and «humps», on the face of it, the origin of it is incomprehensible. The reason of their presence is oscillation of all elements of construction of pumping unit on own frequency of each of elements under the action of shock impulses , thus, as conducted researches show [3], vibration of separate elements of pumping unit and even underground part of pumping unit (reducing gear, crank, support, beam, polished rod), exposes correlation of the order 0.48...0.54. Maximal contribution to the vibration measured on the housing of reducing gear, except for own vibrations of shafts of gearings, own vibrations of bearings are brought in above all things, and also, probably, pulleys of v-belt transmission, and, by a less measure, all other transmitted elements.

Separately it follows to select the frequency band of 1100–1800 Hz, in which wide maximums in the spectrum of vibration appear. Accordant, for example, [4], this band of frequencies represents the processes of friction between the elements of construction of

bearings, thus at worsening of friction conditions as a result of hit of mechanical particles in lubricating oil (that it is conditioned by wear of elements) is substantially multiplied amplitude of spectral constituents. In this case it is possible to look after such band of frequencies in the region 1100...1300 Hz for the worn reducing gears of both types. At the same time for a new reducing gear R-55 substantially expressed maximum is absent.

The analysis of vibration descriptions of reducing gears of different types testifies that the general level of vibration for a reducing gear with the Novikov meshing in this case is substantially less, that testifies to his high operating reliability. In the well attached meshing Novikov teeth touch on a line, due to that the resulted radius of curvature in the cut perpendicular to the line of contact, in oftentimes (~100) exceeds the resulted radius of curvature of involute transmission. The area of spot of touch of teeth grows thus, that provides greater bearing strength of the Novikov meshing. However more difficult technology of manufacturing of gearing with the Novikov meshing is applied and needs high exactness of work.. In thhe practice of exploitation of reducing gears of pumping jacks there were their mass failures through low exactness of manufacturing. The number of the articles in which advantages and lacks of the Novikov meshing [4] are discussed that expedience of his use in different industries of industry was published in a recent year. From a discussion on pages and forum of site of the magazine “Reducing gears and drives” (http://www.reduktor-news.ru/forum/) it is possible to do a conclusion, that on condition of observance of the proper technology of manufacturing and with the use of some perfections this meshing indeed has the advantages above involute (promoted contact durability, more small mass and sizes at identical power, decrease of noise and so on.), although majority from them is substantial, for example, for an aviation technique for which similar reducing gears was developed. Factories of CIS continues to produce reducing gears with the Novikov meshing for pumping jack alongside with reducing gears with the involute meshing.

Development of stands of models for the tests of reducing gears of pumping units (Fig. 5) is conducted with the purpose of their accomodation and estimation of the technical state after repair, when on the basis of the vibroacoustic signal processing it is possible to define quality of repair.

The use of functional-cost analysis of reducing gears of pumping units is conducted for cutting of costs on their repair. On the basis of study of structural-element model in the process of functioning of reducing gear the main assemblies can be distributed between functions, the basic and auxiliary functions are determined, certain financial expences on implementation of each functions are calculated. After it is possible to define quality of their repair basis of the vibroacoustic signal of the repaired reducing gears processing.

The conducted researches allow to do a conclusion, that the increase of authenticity of diagnostics of reducing gears of pumping units can be attained by an account at the spectral analysis of deposit of own vibrations of all elements of the pumping unit construction and features of its work, which cause unstationary of vibration signals during the period of pumping.

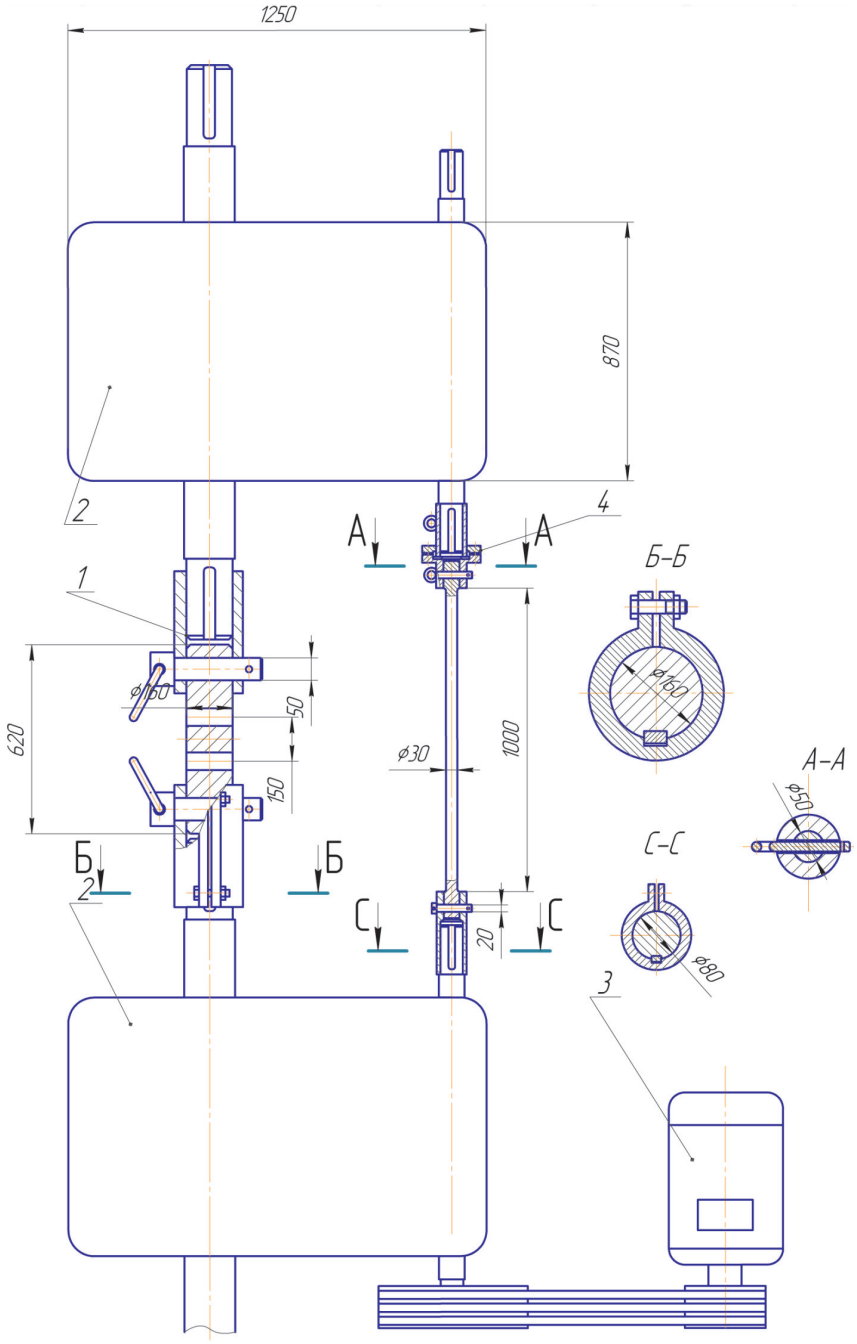

Fig. 5. Stand for the reducing gear Ц2НШ-750 testing.
1 – clutch; 2 – reducing gear; 3 – electric motor; 4 – springing shaft

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