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B.V. Kopey*, O.I. Stefanyshyn, S. Bednarz*****

ANALYSIS OF PUMPING UNIT REDUCERS DIAGNOSTIC ALGORITHMS BY FORMALIZED METHODS

1. INTRODUCTION

In domestic and foreign petroleum the oil production by pumping units is the most widespread method and plays a leading role in comparison with other methods of petroleum production through the simplicity of its design and simplicity in operation. Ukraine and Poland operate a significant number of oil wells equipped by pumping units, with an increase in the number of failures and emergency states, due primarily to a long term of operation (more than 30 years).

Reliability – ability to perform specified functions of the object, preserving the value of its performance indicators in the set limits that meet the specified regimes and conditions of use, maintenance, repair, storage and transportation. Reducer of pumping unit (Fig. 1) is the least reliable of ground equipment [1–4].

An important feature of pumping units reducers is reliability, which is measured by indexes such as infallibility, durability, maintainability, conservation.

One of the main reasons for slow performance of pumping units' reducers is a significant deterioration of working surfaces of the teeth, so we need to analyze factors that influence the wear of tooth surfaces and choose the working methods and technical means to monitor their condition. An effective method of predicting and preventing of wear is the use of diagnostic algorithms by formalized methods.

* IFNTUOG, Karpatska str., 15, Ivano-Frankivsk, 76019; e-mail: kopeyb@nunq.edu.ua
** TSBVO "Ukrnafta" Shevchenko str. 77-a, Borislav, Lviv region., 79760
*** AGH University of Science and Technology, Krakow

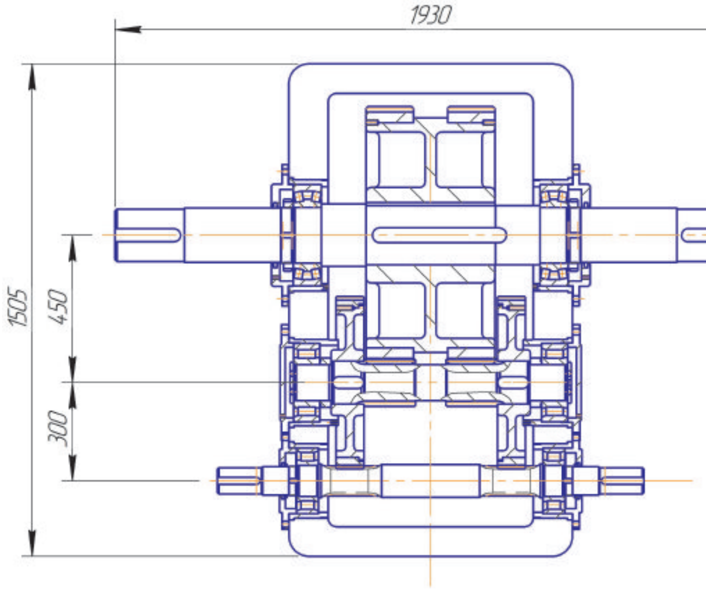

Fig. 1. Reducer TS2NSH-750 of pumping unit

2. RESULTS AND DISCUSSION

Diagnostic model is designed for the construction and analysis of algorithms by diagnosing formalized methods. The using of the diagnostic model allows us to ease and formalize decisions on the diagnostic problem.

In [5, 6] are described the most common forms of diagnostic models:

- Analytical form of diagnostic models, which are the result of the analytical description of processes of passing signals, or systems of equations that solve the parameters of the object;
- The graph model to represent a description of the object under investigation based on set theory and graph theory as a way of visual representation of objects;
- Functional and logical models that are built on the basis of logical analysis of the functional diagram of the object of research.

The presence of a large number of links between structural assemblies of pumping unit's reducers complicates the detection of certain analytical patterns in the transfer and change of diagnostic signs [7, 8, 9]. Pumping units reducer can be attributed to a complex oscillatory system with distributed parameters, so accurate analytical modeling of processes in the same vibration reducers is a complex task. The problem of modeling is complicated by the presence of linear and nonlinear relationships between assemblies of reducer, a significant inertia of the facility and many other factors. In order to find ways [10] to reduce the intensity of vibration of reduction gear drive we considered its simplified linear analytical model and the possibility of system simplifying or splitting it into parts.

Therefore, for the synthesis of algorithm for diagnosing the functional-logical model has been selected, which allows to consider the links between individual elements and nodes of the object by simple means and consider the impact of these items on measuring diagnostic features.

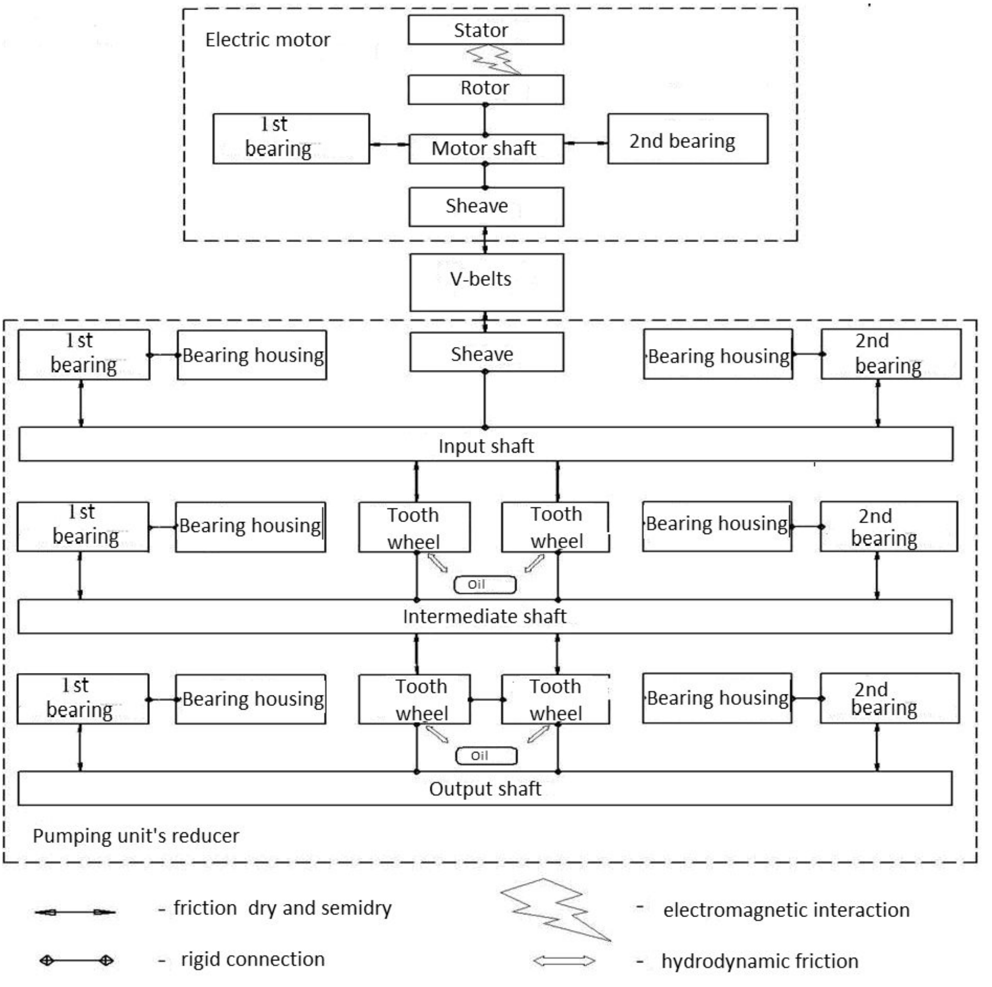

Fig. 2. Functional diagram of the pumping unit reducer

For a more detailed study of processes occurring in the gearbox of pumping unit, and facilitate the development of its diagnostic model, we build a functional diagram of reducing gear given in Figure 2. Analyzing the structure of the gear, we will select its three major functional parts: driving motor, v-belt transmission and gearbox. Through the constructive complexity and considerable operating charging the reducer is more vibroactive part of the drive compared to the driving motor. All major components and parts are linked between them by following types of interconnections: rigid connection, dry and semidry friction, electromagnetic forces, hydrodynamic friction. Rigid connections do not play a significant role and, if we do not take into account that over time the quality of such connections get worse (such as backlash in V-belt pulley and transmission gears relatively to shafts due to jam of spline and spline grooves), the influence of this type of connection can be neglected.

The transfer of momentum from the electric motor to the gearbox via v-belt transmission makes relatively little impact in the process of drive performance. Very important types of relationships are dry, semidry and hydrodynamic friction and to overcome them in the process of work the much of the energy is spent, which consequently is transformed into noise and vibration or into heat. Since the torque and hence loading, which is perceived by toothed gear shafts are different, respectively, and will be different for them the work performed by friction. It is very important in constructing a model of pumping unit gear.

Since the consideration of all listed in Figure 2 the relationships are too complex scientific problems, so the construction of the diagnostic model should ask some simplification and limitation. To build a diagnostic model of reducer we take for background information to the simplified scheme (Fig. 3), taking into account all the basic relationships of its parts and assemblies.

The main structural units are grouped in the gear drive blocks and marked P_2 ... P_n. The input of block P_i, which are external inputs, have been indicated by X_1 ... X_m, input of block P_i, which are the outputs of other blocks – $Y_{i,1}$ ... $Y_{i,\,n}$, and outputs of block Pi – $Z_{i,1}$ ... $Z_{i,n}$, where i = (1, n). Each block has a number of inputs (outputs), equal to the number of its input (output) parameters. The simplified block diagram is presented in Figure 3.

The structure of the pumping unit reducer includes such working parts as motor (shaft P_1, stator winding (stator) P_6, cage rotor P_7, the first bearing P_8, the second bearing P_9, motor pulley P_2), V-belts P_3 and reducer gear (gear pulley P_4, driving shaft P_5, the first bearing of drive shaft P_{16}, the second bearing of drive shaft P_{17}, the bearing housings of drive shaft P_{22}, and P_{23}, intermediate shaft P_{10}, the first bearing of intermediate shaft P_{18}, the second bearing of intermediate shaft P_{19}, intermediate shaft bearing housings P_{24}, and P_{25}, gear wheels of intermediate shaft P_{12} and P_{13}, output shaft P_{11}, the first bearing of output shaft P_{20}, the second bearing of output shaft P_{21}, bearing housings of output shaft P_{26}, and P_{27}, gears wheels of output shaft P_{14} and P_{15}).

Next forces act on the elements:

X_1 – force of reaction of bearings;
X_2 – friction force of lubricant;
X_3 – strength of electromagnetic interactions;
X_4 – force of torque.

Gear drive blocks are combined together by following links:

output $Z_{7,6}$ and input $Y_{6,\,7}$ strength of electromagnetic interactions of electric motor stator-rotor;

output $Z_{6,1}$ and input $Y_{1,6}$ tension forces on the rotor shaft of the electric motor;

output $Z_{1,2}$ and input $Y_{2,1}$ force of tension of pulley on the shaft of the electric motor;

output $Z_{2,3}$ and input $Y_{3,2}$ power torque of motor shaft;

output $Z_{4,3}$ and input $Y_{3,4}$ complex forces of reaction (friction, force torque, hydrodynamic effects);

output $Z_{5,4}$ and input $Y_{4,5}$ tension pulley force on drive shaft;

output $Z_{12,10}$ and $Z_{13,10}$ and input $Y_{10,12}$ $Y_{10,13}$ forces of tension of gears on the intermediate shaft;

output $Z_{12,5}$ and $Z_{13,5}$ and input $Y_{5,12}$, and $Y_{5,13}$ frictional forces between the surfaces of teeth, hydrodynamic effects, force torque of drive shaft and intermediate shaft gears;

output $Z_{14,11}$ and $Z_{15,11}$ and input $Y_{11,14}$ and $Y_{11,15}$ forces of tension of gears on the output shaft;

output $Z_{14,10}$ and $Z_{15,10}$ and input $Y_{10,14}$ and $Y_{10,15}$ frictional forces between the surfaces of teeth, hydrodynamic effects, force torque of intermediate shaft and output shaft gears.

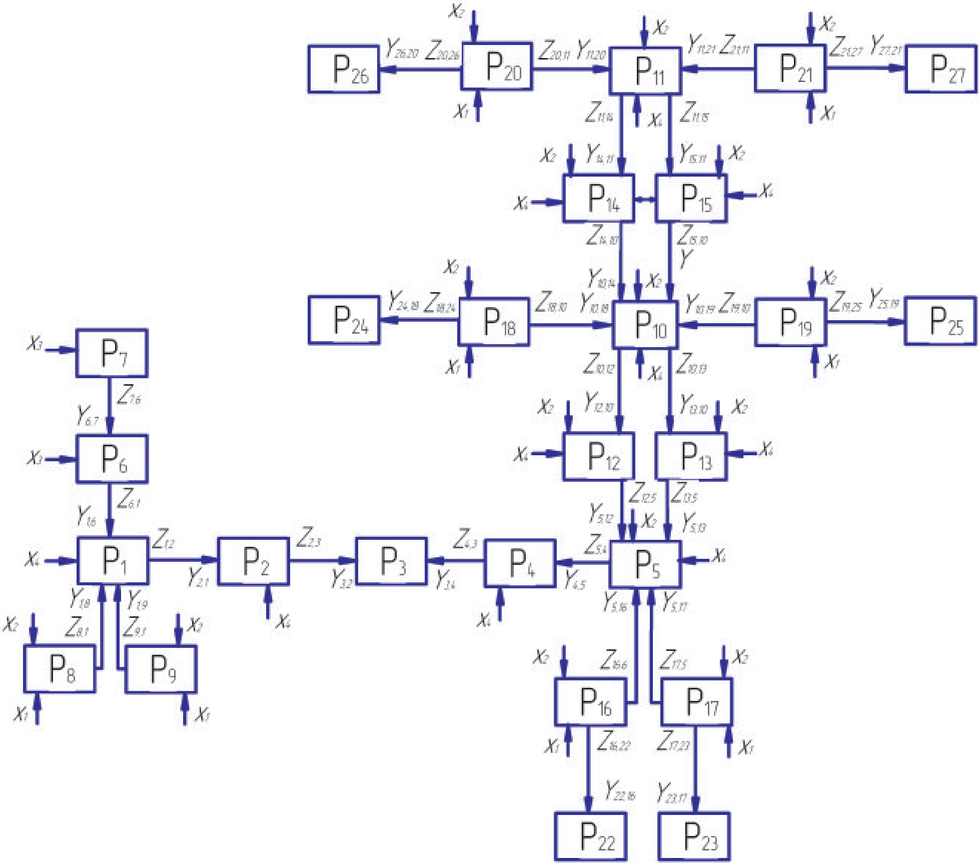

Fig. 3. Simplified block diagram of the pumping unit reducer

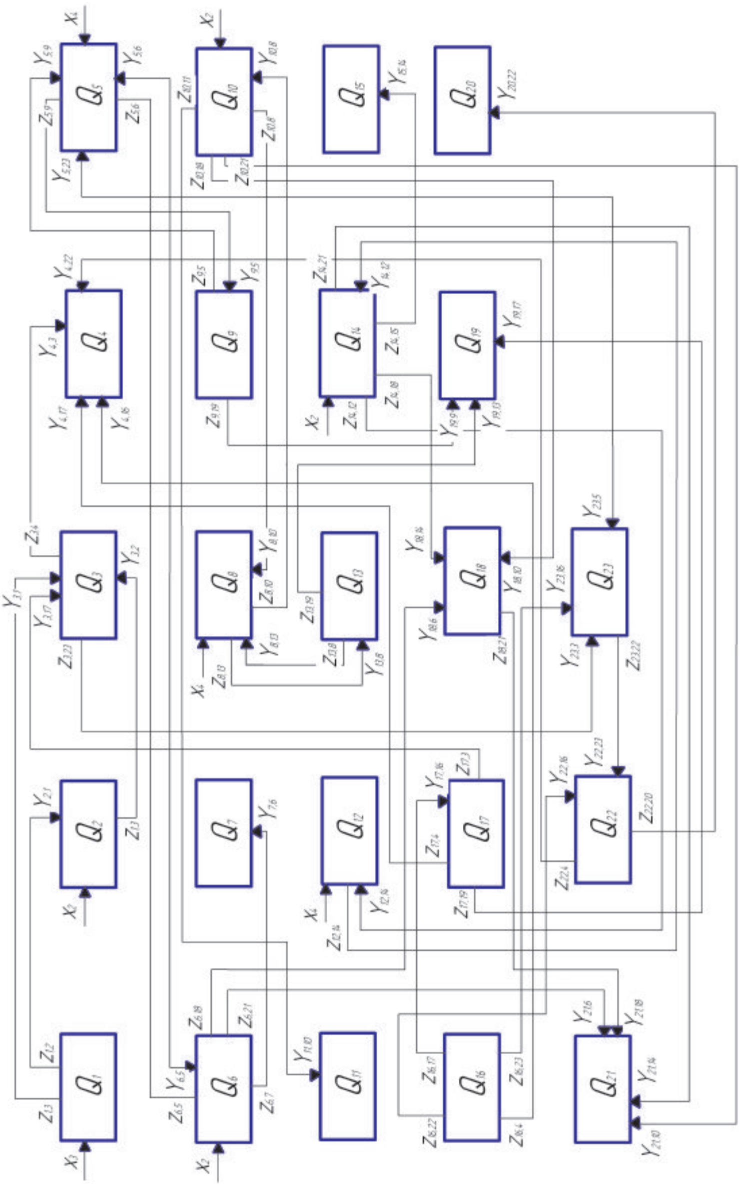

Fig. 4. The logical diagnostic model of the pumping unit reducer

After analyzing a simplified block diagram of gear reducer diagnostic logic model has been built (Fig. 4). As the drive of gear reducer is designed to perform a work function algorithm, in the implementation of which all the elements are involved, and all links of the functional diagram, for the entire diagnostic workflow is built only one functional circuit. For the logical model each block is changed by simplified block diagram of the unit with the appropriate links. In this case the functional block diagram corresponds to a subset of the logical model of the set of Q_1 ... Q_n, where $n = \Sigma n_i = 23$.

Denote the blocks of logic model as: Q_1 – electromagnetic motor defects; Q_2 – increasing of gap in the motor bearings, Q_3 – curvature of the shaft of the electric motor, Q_4 – wear of V-belts, Q_5 – wear of drive shaft, Q_6 – increasing of gap in the shaft bearings of drive shaft, Q_7 – wear of housing of bearing of drive shaft, Q_8 – wear the intermediate shaft, Q_9 – wear of gears of intermediate shaft, Q_{10} – increasing of gap in the intermediate shaft bearings, Q_{11} – wear of the intermediate shaft bearing housings, Q_{12} – wear of the output shaft, Q_{13} – wear of gears of output shaft, Q_{14} – increasing of gap in the output shaft bearings, Q_{15} – wear of the output shaft bearing housings, Q_{16} – weakening of the foundation fastenings, Q_{17} – wear of pulleys, Q_{18} – violation of the parallel axis of gear shafts, Q_{19} – imbalance, Q_{20} – mechanical losses, Q_{21} –change between axis distance , Q_{22} – inappropriate tension of v-belts transmission, Q_{23} – buckling of pulley.

Electromagnetic motor defects Q_1 causing excessive load on the rotor and it leads to increased clearance in the bearings of the electric motor Q_2 (communications output $Z_{1,\ 2}$ – input $Y_{2,\ 1}$) and distortion of the electric motor shaft Q_3 (communications output $Z_{1,\ 3}$ – input $Y_{3,\ 1}$). Q_3 results the effects of pulley wear and of v-belt transmission Q_{17} (communication output $Z_{17,\ 3}$ – input $Y_{3,\ 17}$) and clearance in the bearings of the electric motor Q_2 (communications output $Z_{2,\ 3}$ – input $Y_{3,\ 2}$).

Quite common defect in Q_4 – wear V-belts – can be caused by a number of reasons: due to distortion of the motor shaft Q_3 (communications output $Z_{3,\ 4}$ – input $Y_{4,\ 3}$), wear of pulley Q_{17} (communication output $Z_{17,\ 4}$ – input $Y_{4\ ,\ 17}$), weakening of the foundation attachment Q_{16} (communication output $Z_{16,\ 4}$ – input $Y_{4,\ 16}$), and through the inappropriate tension of belts Q_{22} (communication output $Z_{22,\ 4}$ – input $Y_{4,\ 22}$).

Main reasons that cause the failure of reducers are gear drive shaft wear Q_5 due to bearings wear of drive shaft Q_6 (communications output $Z_{6,\ 5}$ – input $Y_{5,\ 6}$), wear of gear of intermediate shaft Q_9 (communications output $Z_{9,\ 5}$ – input $Y_{5,\ 9}$) and buckling of pulley Q_{23} (communication output $Z_{23,\ 5}$ – input $Y_{5,\ 23}$). In turn, drive shaft bearings Q_6 are worn through the wear drive shaft Q_5 (communications output $Z_{5,\ 6}$ – input $Y_{6,\ 5}$). The housing of drive shaft bearing Q_7 wears due to damage of the bearing of drive shaft Q_6 (communications output $Z_{6,\ 7}$ – input $Y_{7,\ 6}$).

Equally very important is the failure of the intermediate shaft Q_8 due to wear of gear of output shaft Q_{13} (communication output $Z_{13,\ 8}$ – input $Y_{8,\ 13}$) and wear of bearings directly of intermediate shaft Q_{10} (communication output $Z_{8,\ 10}$ – entrance $Y_{10,\ 8}$). Defects of the intermediate shaft gears Q_9 arise through the wear of drive shaft Q_5 (link output $Z_{9,\ 5}$ – input $Y_{5,\ 9}$). Intermediate shaft bearings Q_{10}wear through injuries and defects of teeth of intermediate shaft Q_8 (communication output $Z_{10,\ 8}$ – entrance $Y_{8,\ 10}$). The housing of bearing of the intermediate shaft Q_{11} goes down due to the influence Q_{10} – bearing wear (contact output $Z_{10,\ 11}$ – input $Y_{11,\ 10}$).

Main reasons that cause the failure of output shaft Q_{12} is wear directly of gearbox bearing of output shaft Q_{14} (communication output $Z_{14,\ 12}$ – input $Y_{12,\ 14}$) and from the wear of bearings Q_{14} the output shaft wear Q_{12} depends (links output $Z_{12,\ 14}$ – input $Y_{14,\ 12}$).

Damage of gear of output shaft Q_{13} depends in turn on the failure of the intermediate shaft Q_8 (communication output $Z_{8, 13}$ – input $Y_{13, 8}$). Wear of the housing of bearing of output shaft Q_{15} depends on the wear of bearings Q_{14} (communication output $Z_{14, 15}$ – input $Y_{15, 14}$). Defects of pulley Q_{17} can cause the weakening of the mounting base Q_{16} (communication output $Z_{16, 17}$ – input $Y_{17, 16}$).

There are several reasons that affect the parallel of shafts in gearbox Q_{18}: wear of drive shaft bearing Q_6 (communications output $Z_{6, 18}$ – input $Y_{18, 6}$), intermediate shaft bearings wear Q_{10} (communication output $Z_{10, 18}$ – input $Y_{18, 10}$) , wear of bearing of output shaft Q_{14} (communication output $Z_{14, 18}$ – input $Y_{18, 14}$). Wear of gear of intermediate shaft Q9 causes common defect – an imbalance Q_{19} (communications output $Z_{9, 19}$ – entrance $Y_{19, 9}$), gears of output shaft Q_{13} (communication output $Z_{13, 19}$ – input $Y_{19, 13}$), pulley Q_{17} (communication output $Z_{17, 19}$ – entrance $Y_{19, 17}$.) Significantly affect the mechanical losses Q_{20} the tension of belts Q_{22} (communication output $Z_{22, 20}$ – input $Y_{20, 22}$).

The problem of keeping a distance between axis Q_{21} depends on the wear of bearings of drive shaft Q_6 (communications output $Z_{6, 21}$ – entrance $Y_{21, 6}$), intermediate shaft bearings Q_{10} (communication output $Z_{10, 21}$ – input $Y_{21, 10}$), bearings of output shaft Q_{14} (links output $Z_{14, 21}$ – input $Y_{21, 14}$), parallel shaft Q_{18} (communication output $Z_{18, 21}$ – input $Y_{21, 18}$).

The problem of tension of belts Q_{22} is caused by two reasons: the weakening of the mounting base Q_{16} (communication output $Z_{16, 22}$ – entrance $Y_{22, 16}$) and buckling of pulley Q_{23} (communication output $Z_{23, 22}$ – entrance $Y_{22, 23}$). Pulley buckling Q_{23} occurs for two reasons: distortion of the electric motor shaft Q_3 (communications output $Z_{3, 23}$ – input $Y_{23, 3}$) and weakening of the foundation fastenings Q_{16} (communication output $Z_{16, 23}$ – input $Y_{23, 16}$).

3. CONCLUSION

Thus, the diagnostic logic model provides a visual representation of the most prone to initiation of defects of elements and assemblies in the reducing gear, and also the links of structural and diagnostic parameters that ultimately will choose the diagnostic signs and give the possibility to put them on the basis of methods of control of pumping unit reducing gear, that may be developed. Diagnostic logic model will help to establish and classify defects in development, to determine the direction of their development and cause-effect relationship with other defects.

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