CONDITION MONITORING OF THE EQUIPMENT IN REAL-TIME – TECHNOLOGY OF SAFE-SAVE MAINTENANCE OF THE XXI CENTURY

Kostyukov Vladimir Nikolayevich

SPC «Dynamics»
Rabinovicha st., 108
644099, Omsk, Russia
post@dynamics.ru; http://www.dynamics.ru

ABSTRACT

Operation of the complex manufactures containing hundreds and thousand of units machine and the process equipment, is impossible without representation of the information on its technical condition to administration. Repair and modernization of the equipment, reconstruction of sites, shops and manufactures demand acceptance of the proved decisions which should base on a trustworthy information about the reasons of insufficient productivity, frequent repairs, idle times, industrial malfunctions and emergencies. Reliability of the information is essentially determined by its objectivity, that is independence, of will, desires and reasons of the concrete people who are responsible for operation, repair, modernization of the equipment and reconstruction of manufacture. Only on the basis of the appropriate quality information, (authentic, received in due time and in necessary amount) it is possible to make the correct decisions determining success and profitableness of the enterprises.

KEYWORDS

Condition monitoring, reliability, vibration, vibrodiagnostics, safe and recourse saving maintenance technology.

FULL PAPER

Maintenance of complex productions containing hundreds and thousands units of machine and technological equipment is impossible without providing of management with information concerning its technical state. It is necessary to have reasoned decisions based on reliable information regarding the reasons of insufficient productivity, frequent repairs, downtimes, production failures and breakdown situations, for repair and modernization of the equipment, reconstruction of sections, workshops and facilities. Reliability of information is significantly determined by its objectivity; it means independence of will, desires and understandings of concrete people responsible for maintenance, repair, modernization of the equipment and reconstruction of plant. Only on the base of proper information (reliable, received opportunely and in required quantity) it is possible to make the right decisions which determine success and profitability of plant.

Information concerning the equipment state (diagnosis) is obtained using technical diagnostics means, the reliability of which is defined by the diagnostics methods, measurement accuracy, diagnostician skills and quality of devices adjustment on informative features of signals of the object being diagnosed.

Diagnostics process consists of 7 steps:

1. Preparation of equipment for diagnostics;
2. Measurement of informative (diagnostic) features of the object;

3. Formulation and documentation of diagnosis directly;
4. Registration of diagnostics direction;
5. Delivery of diagnostics direction containing information regarding the object state and actions of its improvement to responsible maintenance personnel;
6. Control for personnel actions concerning the repair of object efficiency and prevention of undesirable consequences;
7. Correction of personnel actions in case of need.

These steps with the use of common methods of diagnostics when diagnosis is made by people with the help of portable devices and/or Internet, in spite of negative influence of «human factor» causes subjective faults, are broken in time and sometimes these time intervals are very long. This fact put obstacles in the way of duly decision making and leads to missing of equipment failures. In this case even prediction takes into account only previous maintenance conditions and is not able to allow for their subsequent deterioration which was caused by influence of human factor, personnel mistakes and irregularity of units operation.

Especially it's actual for dangerous facilities with continuous production cycle: chemical, petrochemical, refinery and oil-and-gas branch as a whole: metallurgy, energy, transport and other main fields. In these branches the impartial, reliable, duly information concerning the equipment state is vitally important not only for enterprise profitability but also for safety of production personnel and citizens of surrounded the enterprises territories with the aim of their protection from man-caused breakdowns and failures.

Increase of individual capacities of the equipment and correspondingly the energy required for its destruction results in growth of degradation speeds of its components which being multiplied on hundreds and thousands of equipment units which are in operation at the same time determine high latent danger of these enterprises.

Reliability analysis of technological settings of modern refinery and petrochemical complexes shows that more than three quarters of equipment failures make machine units failures high concentration of which quite often is the reason of breakdowns and production causing downtimes and reducing rate of their technical use and availability. Often at domestic enterprises it makes 80% and lower that results in high maintenance expenses and loss of profits. Results of assessment of reliability and failures demonstrate that probability of petrochemical complex failure can reach 50% per day for major production with planned production capacity of refining more than 6 million tons of oil per year. High concentration of machine units – pumps, compressors, air-cooling, smoke suckers, etc. with individual capacities from dozens of kW up to unities of MW quite often was the reason of appearance of production faults and breakdown situations.

Main reasons of this situation are the lack of appropriate observability and estimation of units' technical state, determined by their internal structure during the production and acceptance at customer-plants, during the repair process in repair departments of refineries, during the units assembling and in the process of their operation at technological settings.

For **achievement of stability** of technological system to different kind of problems including pumping unit it is necessary **to provide observability** of influenced on system external and internal factors describing its technical state and **control of its state** by means of **duly** acceptance of technical and organizational measures. Principal direction of providing of safe maintenance of dynamic equipment at petrochemical complexes as shows long-term experience is **implementation of stationary systems of continuous monitoring, diagnostics and prediction** of its technical state. Operating speed of condition monitoring system for making diagnostic orders to personal must be more quickly then speed of passing process of production system **in circle "observation – execute – stability"**.

Continuous monitoring is necessary for observation of failures development. It means diagnostics with a period which is significantly shorter than interval of failure development with automatic delivery of impartial results irrespective of performers will to responsible for equipment maintenance personnel. Condition monitoring system has to detect these failures, provide the observation of their development and warn personnel in proper time about the necessity of debugging, start of its repair or stoppage. Implementation of monitoring equipment at all stages of petrochemical complex units' life cycle provides significant increase of petrochemical complex reliability without change and reconstruction of the equipment. Condition monitoring in real-time allows to transfer the majority of sudden category failures to the gradual category due to its early detection and warning of personnel about developing failure which is already exists but not yet dangerous and don't affect the reliability of petrochemical complex.

It is established that there is some time (usually not less than 3-5 minutes) [1,3] from the moment of failure up to breakdown as explosion or conflagration. In most cases it is enough time to take measures for elimination of dangerous state. Thus while petrochemical complex is controlled by condition monitoring system which warn personnel about limiting state of petrochemical complex with the help of corresponding personnel actions, breakdowns can be prevented and risk of their occurrence is reduced in ten times. This explains the urgency of this problem for national economy. Significant preservation of resources appears because of the increase of run-to-failure, decrease of petrochemical complex downtime rate and growth of production output. Another important factor is increase of culture of maintenance and operation and abrupt reduction of necessity of spare part and new equipment.

Implementation of computerized monitoring systems at new and reconstructed facilities is actual. New equipment of these petrochemical complexes as a result of uncontrolled, careless and unskilled personnel actions quickly wears out, reaches a limiting condition and always requires rising costs for repair. Achievement of freedom from repair and safety of petrochemical complex is possible due to monitoring systems which have a number of corresponding features first of all functionally undefined structure not dependant on type of equipment being diagnosed, invariant on-line expert system, high performance and reliability of diagnostics – it is not worse (95-98%) [1].

Use of stationary systems of diagnostics and monitoring allow to transfer failures of technological systems of sudden category to gradual category, i.e. observable. Since any recognition system has nonzero mistake $\boldsymbol{\eta}$ there is a task of estimation of required mistake of diagnostics and monitoring system $\boldsymbol{\eta}$; if for technological system which has in existing maintenance situation probability of sudden failures $\mathbf{Q}$ and mean operating time between failures $\mathbf{T_Q}$ it is necessary to provide operating time no less than $\mathbf{T_r}$ and failure admission no more than $\mathbf{r}$ (Fig.1). Use of diagnostic and monitoring systems produce temporary redundancy for personnel actions in situation of oncoming failure which provides observability of its appearance, this significantly increases safety of petrochemical complex operation [1]. Probability of state recognition mistake $\boldsymbol{\eta}$ is determined by ratio:

$$\boldsymbol{\eta} = \mathbf{T_Q / (T_r + T_Q)}, \qquad \boldsymbol{\eta} = \mathbf{[Ln(1-r)] / [Ln(1-r)+Ln(1-Q)]}. \qquad (1)$$

With minor $\mathbf{r \ll Q \ll 1}$ the maximum possible mistake of diagnostic and monitoring system is estimated from correlation $\boldsymbol{\eta} = \mathbf{r / Q}$. Nomogram for determination of allowable mistake of diagnostics and monitoring system is shown in **Fig.1**. For example, for typical values per day $\mathbf{Q}$ = 20 %; $\mathbf{r}$ = 1 %, the mistake of diagnostic system $\boldsymbol{\eta}$ must not allow 4%. For estimation of economic efficiency of diagnostics and monitoring systems implementation the dependence of time increase ratio between failures $\mathbf{k_T}$ from mistake of recognition of dangerous states of petrochemical complex by means of monitoring system **η:**

$$k_T = 1 / \eta - 1. \qquad (2)$$

Nomogram for ratio determination of time interval increase $k_T = T_r/T_Q$ between sudden undetected units' failures during the diagnostics and monitoring systems implementation is shown in Fig.5. For the same example interval between production faults and breakdown situations increases in 24 times. This fact explains significant technical and economic profit due to monitoring systems implementation.

On the other hand risk **r** can be used as criterion of petrochemical complex control efficiency by minimum of empirical risk (probability) of failure admission and appearance of breakdown situation or failure for comparison of different systems and control technologies which are characterized by vector of parameters **{Z}** [1]:

$$r = \text{Min } Q\{Zi\}. \qquad (3)$$

The information above explains the necessity of diagnostics of units' state at all stages of life cycle: for estimation of production quality, repair and assembling at setting, assessment of technical state during the maintenance because of the wear, mistakes of service personnel and violation of operating mode of the unit.

Great volume of diagnostic data which is necessary to collect process and present to personnel in appropriate form even at the equipment diagnostics of one technological setting during small period of time equal 3-5 minutes which is determined by maximum failure development speed on the one hand and by the necessity of duly mistakes detection and carelessness of service personnel on the other hand and violation of technological operating mode resulting in its failure requires the use of stationary systems of continuous condition monitoring exceptionally.

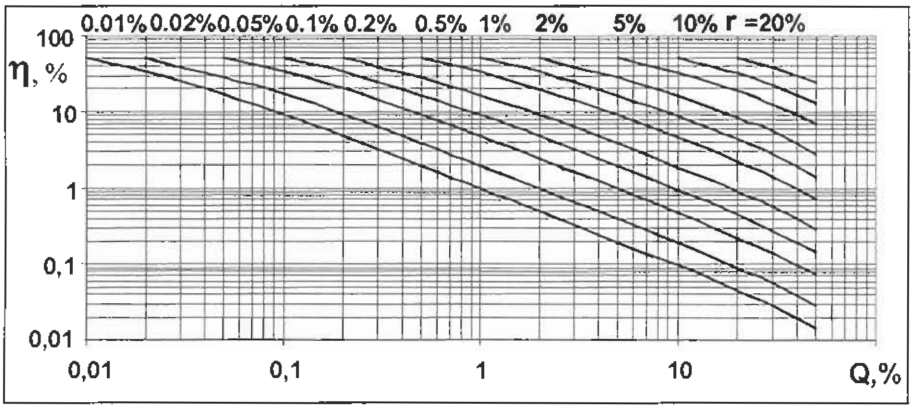


*Fig.1 Admissible mistake of diagnostics **η** by actual probability of equipment failure Q and required risk of failure admission **r***

Other reason of stationary systems use is the necessity of presentation to personnel of different kinds of reliable impartial diagnostics results and targeted directions concerning the critical equipment at the moment which must not depend on discipline, skills and health of diagnostician, operable condition of his device, susceptibility of the mentioned personnel and his direction storage method.

The third reason is the necessity of full use of resource of the equipment under the storage of its maintainability and production safety. In case of personnel mistakes and equipment operating mode violations it's possible to do it by means of fast acting stationary computerized systems of diagnostics and monitoring of the equipment's state in real time.

With the object of breakdowns elimination the parameters monitoring systems of responsible objects (compressors, reactors, etc.) which combine in time stages 1, 2, and 5 have appeared. In 70-s the first diagnostics systems have appeared, at the beginning of 90-s – computerized condition monitoring systems of responsible equipment at petrochemical complexes combining stages from 1 to 5 in real time. Condition monitoring systems significantly differ from parameters monitoring systems.

First of all the presence of wideband sensors which cover frequency band from portion of hertz up to hundreds kilohertz using vibroacoustic methods of diagnostics.

Then the presence of advanced analyzers of spectral-correlative and other statistical parameters of signals for selection and estimation of informative diagnostics features.

And the presence of computerized on-line diagnostic expert system interpreting values of diagnostic features in terms of structural parameters which determine and describe equipment's condition. Diagnostic conclusions of expert system were formulated on language clear for technicians including speech output of corresponding warnings.

Necessary diagnostic frequency is determined by degradation process velocity in equipment in consequence of deterioration and human impact. The danger of equipment's condition is determined by peak of degradation process velocity in plants equipment. Our experience of condition monitoring several thousands machine of petrochemical plants and refinery allow me to confirm in evaluation of condition period mast be not more than a few minutes. On-line condition monitoring provide well-timed stop to repair machine in spite of different degradation process velocity in equipment and human factor which is guilty of 90% breakdowns and faults.

Completely on-line automated machinery's faultiness diagnostics is realized by built-in on-line expert system which is invariant to both machine's design philosophy and forms relatives between both diagnostic indications and equipment's structural characteristics. The on-line expert system provide fast, full and reliable non-folding diagnostics machinery's condition monitoring by revelation next failures:

- weakening of fastening of unit with substructure;
- violation of alignment and disbalance of revolving details;
- fastening and pipeline's vibration;
- cavitation shock into pumps and hydroblow into compressors;
- bearing blemish;
- deterioration of coupling sleeve;
- seal leakage;
- inadmissible temperature;
- inadmissible pulsation, frequency and amplitude of electric motor's current;

On-line system continuously measure, diagnose, accrue and save data into database up to 9 years. It allow to both observe machinery's history and restore in detail what was machine's condition and what did personal when breakdown happened.

12 hours trend show unexpected fast bearing destruction with crank outer racer in pump casing which be accompanied by fast increase of vibroacceleration from allowable to dangerous zone (Fig.2). Machine was stopped because of well-timed spoken message from system. Only stationary continuous condition monitoring systems can prevent the same breakdowns. Obviously that only same system can find out similar defects and help to stop machine with safe its resources and maintainability. Only same system can provide high-performance safety of operation.

On figure 3 we can see trends which showing how personal allowed hydroblow in machine because of disturbing operating practices. Hydroblows 1 and 2 generated bearing blemish of vertical pump which began intensive develop after five week after that. Final bearing destruction was happened after hydroblow 5 and pump was stopped by personal because of well-timed spoken message from system was realized. Maintainability and safety of operation was provided. Evidently that diagnostician can't provide maintainability and safety in this case. Nobody say around the clock "who was guilty and what to do?" Only stationary continuous condition monitoring systems with built-in on-line expert system can provide impartial root cause failure analysis.

These systems was designed for unit's technicians as a result of this personal ignore system's order every so often. Thereof was designed **CCS SM (computerized control systems for Safe and resource Saving maintenance –SM-maintenance)** which these combined diagnostic station (main computer of same systems) from units into one plant's diagnostic net.

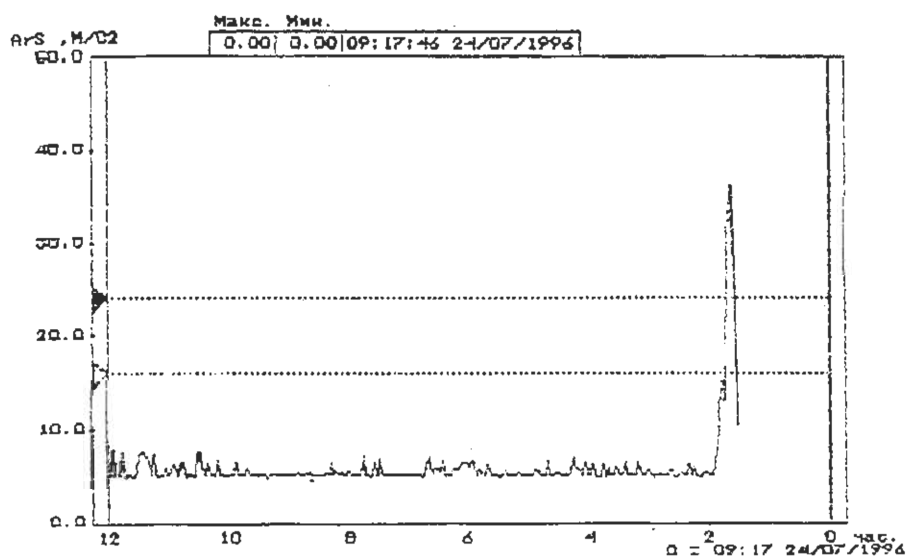


Fig.2 Fast destruction of bearings with crank of inner ring in the crankcase. Due to speech warning the unit was stopped.

Diagnostic net introduce all condition monitoring databases in real time to managements thereby 7 steps of diagnostics process was tied together.

CCS SM is a new form of management systems at the heart of which is self-acting receiving and practical utilization diagnostic information about equipment's condition in real time. **CCS SM** based on three components:

1) stationary continuous condition monitoring systems;
2) diagnostic systems for repair and equipment's production quality control;
3) diagnostic net of the plant.

CCS SM is providing safe and recourse saving maintenance technology (**SM**-technology) for condition monitoring managing which is providing observability of equipment's condition during production, operation and repair, quality controllability of all life-circle stages, stability, safety and effectiveness operation.

CCS SM is between SCADA (operation systems) and ERP (management systems) and its relate to MES (manufacturing execution systems).

The analysis of 18-years experience of **CCS SM** which protect more than 10000 machines and units at 20 great petrochemical and oil and gas refining enterprises shows that this is reliable method of protection from man-caused breakdowns the majority of which happens because of the production personnel mistakes. Also this is indispensable tool for prompting of rational decision during the planning of volumes and terms of repairs, replacement of the equipment and estimation of such replacement results.

CCS SM is perfect control tool of personnel discipline and quality of their work (this circumstance sometimes hinder from systems implementation at some plants). Use of **CCS SM** allows greatly increase production efficiency due to removal of waste, breakdown situations, profit losses and economy of all kinds of resources without reconstruction of production-technological base and connected with it huge expenses due to the fact that cost of monitoring system lower than cost of processes and equipment being diagnosed in tens and hundreds times.

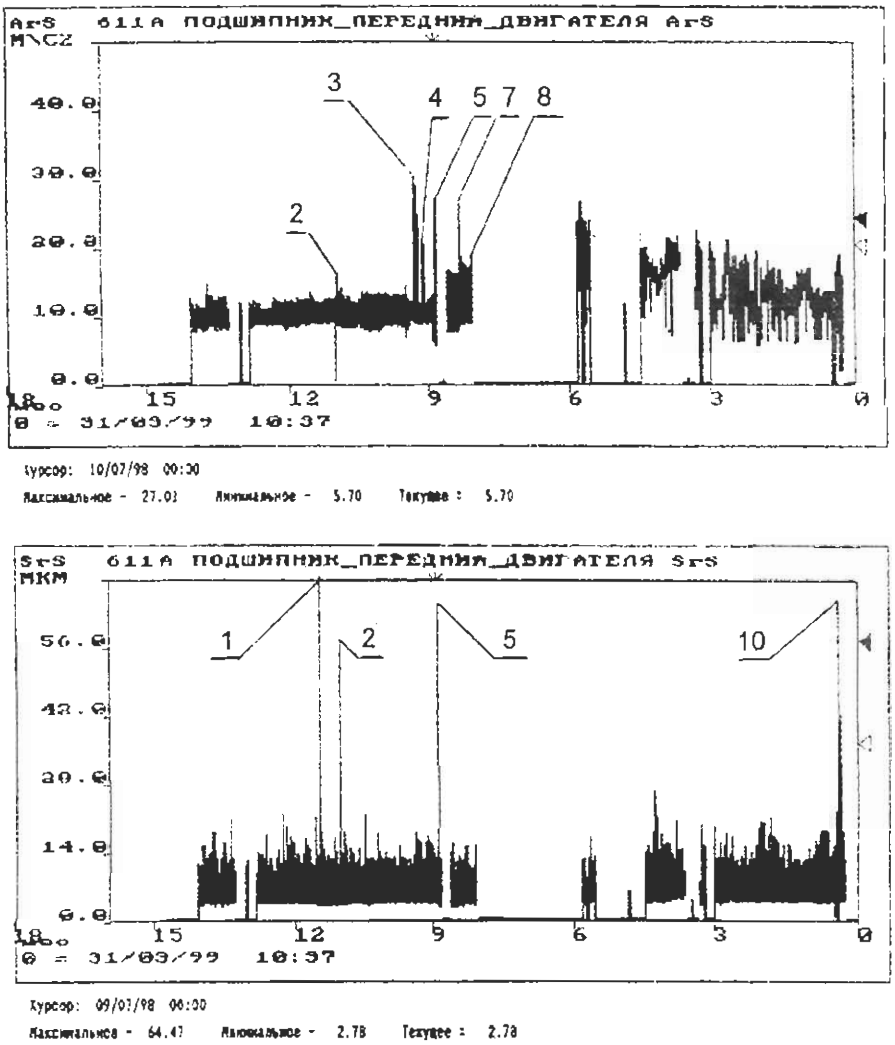


Fig.3 Failure of the pump unit because of the operating mode violation. Hydroblows 1, 2 were the reason of defect appearance in the front bearing of engine, hydroblow 5 resulted in destruction of bearing.

Today this is extremely important for world economy. This is especially actual that scientific and technical and practical results provide production and implementation of **CCS SM** as standard plant's systems ensuring maintenance of the equipment according to real technical state by the full use of planned resource, keeping of its maintainability and production assurance [1-3]. Large-scaled implementation of stationary monitoring systems at enterprises of Russia and abroad provides very important advantage as full use of equipment resource by simultaneous keeping of its maintainability and operation safety what is impossible at use of portable and other «not stationary» systems.

Usually computerized systems of maintenance control (CMMS) include systems of technical-economic planning and management decisions making of the upper level ERP and distributed control systems DCS. Now we add to CMMS the «third layer» of systems – MES-systems of continuous monitoring and diagnostics presenting the state of production equipment in real-time, providing full use of the equipment resource, by simultaneous keeping of its maintainability and production safety, control of units repair quality, representation of quasi-static equipment state (with slow condition change) and presenting of all information on the computers of diagnostic net users within the whole plant - CCS SM (DMSSM – Distributed Management Systems of Safe Maintenance). Only CCS SM allows to realize SM-technology in full. Of cause CCS SM have to diagnose not only machine but also technological equipment by methods of nondestructive testing and also by other methods; first of all by acoustic-emissive, current-vortex, thermal and ultrasonic and there were made certain steps in this direction. Analyzing sources and reasons of immediate effect after implementation of systems we come to conclusion that continuous monitoring of the equipment's condition guaranties profitability on the base of resource-saving safety (Safe-Save Maintenance). Productivity of stationary monitoring systems and CCS SM in whole is higher than ordinary manual devices in many times even in the presence of Internet. This provides the cost of diagnostic order with full control of its performing less than 1 cent. The main source of profitability is reduction of sudden failures, quantity and duration of technological settings downtime in dozens of times. The terms of start operating mode of technological systems decrease significantly. Run to failure of the equipment increases in dozens of times (Fig.4). Operating time between repairs of the equipment increases and cost for repair and spare parts decreases. Due to keeping of maintainability by simultaneous providing of safety the structure of repairs was redistributed from overhaul and middle repairs up to current maintenance.

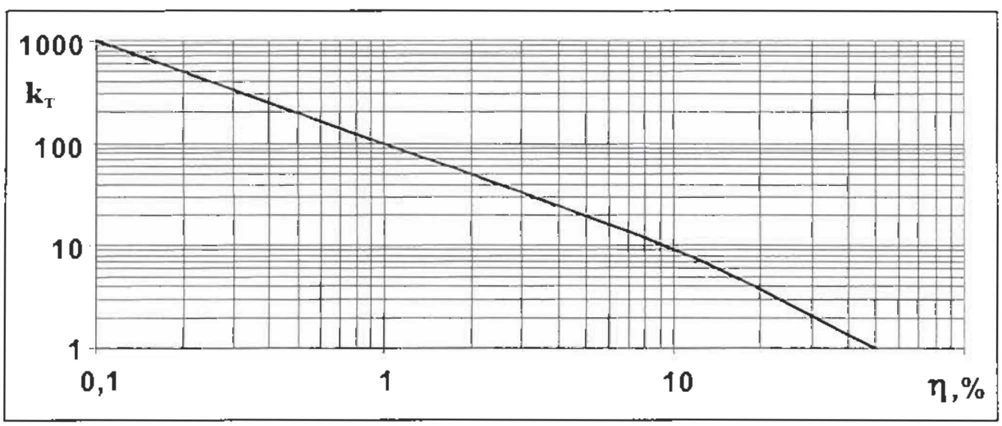
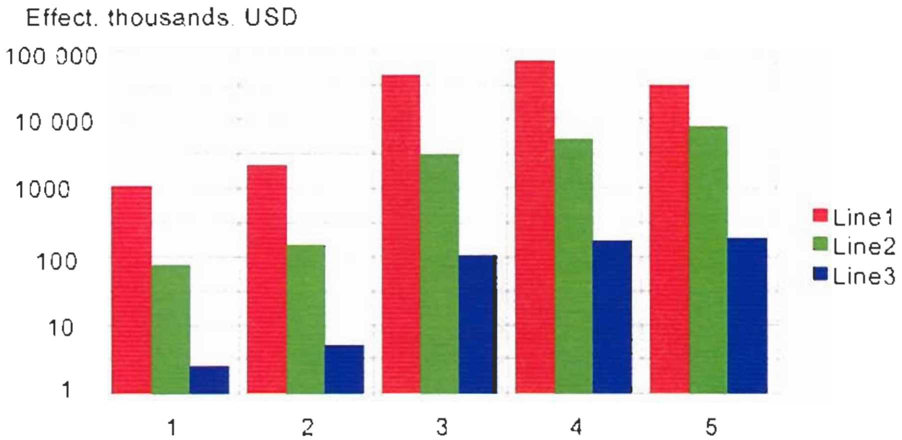


Fig.4. Ratio of operating time increase k_T between sudden failures of the equipment depending on diagnostic mistake η



1 – Increase of productivity of measurements and diagnostics;
2 – Decrease of maintenance cost for equipment repair;
3 – Decrease of losses due to breakdown prevention;
4 – Reduction of volumes and terms of overhaul;
5 – Acceleration of putting into operation of new production

Line1 – General effect; Line2 – Effect on system; Line3 – Effect on unit

Fig.5 Economical effect components due to implementation of CCS SRM and SM-technology of alone refinery

CONCLUSIONS

High level of safety of the equipment during maintenance according to actual technical state was reached. The economy of operating costs and profit losses of plants significantly increase $2 per ton of oil refining a year (Fig.5). All these things provide profitability of the plant for stockholders!

REFERENCES

1. Kostyukov V.N. Monitoring of production safety. Moscow: Mashinostroyenie, 2002.-224p.
2. Kostyukov V.N., Boichenko S.N., Kostyukov A.V. Computerized systems of safe maintenance of the equipment control at refining and petrochemical plants (CCS SRM –COMPACS®). Moscow: Mashinostroyenie, 1999.-163p.
3. Implementation of COMPACS® systems – providing of safe operation at the plants with continuous production cycle/ E.Malov, I.Bronfin, V.Dolgopyatov, V.Kostyukov, S.Boichenko.// Safety of labor in production. – 1994. - №8. – p.19-22. http://www.safety.ru.
4. Compass in the world of safety and effectiveness/Advantages of MES-systems of safe maintenance of the equipment control on the base of CCS SRM – COMPACS® //V.Kostyukov, E.Malov, V.Ryabov, A.Shatalov, An.Kostyukov – Oil of Russia, 2006, №4, p.4-7. http://www.oilru.com.

The Fifth International Conference on Condition Monitoring & Machinery Failure Prevention Technologies

Click here for KEK IVEPE Advertisement

Contents by author

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Contents by paper title

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

- Click on the letter of choice above and you will be taken to the contents page with paper titles or author names beginning with that letter.

13 Number ISBN: 978-1-901892-31-4

THE 5TH INTERNATIONAL CONFERENCE ON CONDITION MONITORING AND MACHINERY FAILURE PREVENTION TECHNOLOGIES

First edition 2008

Published by
Coxmoor Publishing Company
Oxford, UK
Tel: +44 (0) 1451 - 830261
E-mail: mail@coxmoor.com