Safe-money-saving is a highly-efficient policy of leading companies

Within a current market situation the main way to increase profitability of continuous production facilities is to reduce operating costs and losses caused by accidents and downtimes due to unexpected failures of processing equipment.

Operating costs can be minimized by timely and intentional real-time health monitoring of equipment, making maximal use of the equipment capacity and eliminating any off-schedule (i.e. emergency) shutdowns and replacements.

Analyzing reliability of contemporary production facilities, it can be concluded that more than three fourths of the equipment failures refers to machinery, which often causes operating troubles, accidents or emergency shutdowns of processing units and plants.

Per contra, output quality, processing depth and production level depend on basic processing units health, mostly influenced by operation methods.

The main source of problems is lack of the equipment health objective evaluation within operating process.

This prevents personnel from keeping a production facility in a technically sound state. The problem solution has been found in the beginning of 1990s, when automated systems for decision-making support have been implemented, thus providing the equipment health monitoring and repair conditions determination.

The main issues of a company’s departments, responsible for production facilities maintenance, are:

- provision of the production safety;
- maximal increasing of run-to-failure by preventing the equipment from accidents and shutdowns due to failures;
- maximal reducing of the equipment repair time by the personnel focused actions, based on the monitoring systems data;
- reducing of operating costs and losses by eliminating off-schedule repairs and minimizing proactive maintenance.

It is necessary to reveal some of the issues crucial to the building of health monitoring system for hazardous production facilities (HPF) providing safe money-saving operation of the equipment and economic effect:

1. Advanced Process Control System – is the first step to build the system of the technological process control with automatic function of physical parameter analysis, and in the COMPACS® systems have the automatic condition analysis function, which has been developing for more than 25 years. It is important to emphasize, that APC-systems are implemented not by system integrator companies, but by the world leaders in automatization together with technology licensors.

2. Automatic Process Control System (APCS) and HPF Condition Monitoring Systems are the systems with completely different aims, tasks and functions, which means, that their combination would be not just unreasonable, but incompatible with management effectiveness principles. Despite the technical possibility of such a combination, all that could be done is to make an interchange of the measured physical parameters’ values, in order to eliminate the duplication of measurement tools, and only in case when such an interchange will not violate the objective function of the each system.

3. Emergency protection (EP) subsystem is not designed for condition monitoring and diagnostics, although it carries out the monitoring of some physical parameters close in title. EP activation is almost an emergency and not its early prevention, of course, if it is not a fail alarm, which high frequency is the reason why EP is usually turned off during the launch time, and then, remains in that condition in order not to cause the breakdown in process. On the contrary – condition monitoring systems are used in technological complex launch, to be sure that the equipment is safe and to observe its state during the complex launch condition. That increase launch speed rates on 30-50% and guarantee its safety.

4. The automatization of parameters measurement much more simple task than automatization of measured parameters analysis, therefore, it is not reasonable to apply the requirements of simple (although highly automated) systems to more complex ones.

The basis of the Automated Control Systems for Safe-Money-Saving Real-Time Maintenance of equipment (SMSRMTm) COMPACS® is the stationary automatic diagnostics and real-time monitoring system COMPACS®, integrated into the diagnostic network of the enterprise Compacs-Net®, operating in the format of operation room of technogenic safety and risk control of hazardous production facilities (HPF) operation in real time. Except the COMPACS® system, SMSRMT includes the personal system for automatic vibration analysis Compacs®-micro™, which is used for root cause analyses of machinery malfunctions and also, the COMPACS® system is used for machinery health assessment after production and repair.
Configuration of all SMSRTM™ COMPACS® systems for enterprises can be determined during the examination and approved by the Customer during the development of the enterprise program of safe resource-saving operation of equipment, after which we carry out feasibility study of the program realization in the particular company conditions.

Application of the COMPACS® makes asset management process more transparent and controllable, as well as reduces capital capacity of production, increases capital productivity, and, as a result, leads to the improved capitalization of an overall company.

More than 23000 machines of more than 2400 types of various equipment, including centrifugal and piston compressors, console, double-seat, vertical, hermetic and other types of pumps, air-coolers and other rotating equipment are under control of the more than 680 COMPACS® systems on enterprises of Russia, as well as near and far abroad countries, using HPF in 12 industrial and transport branches.

**Safe-Money-Saving Real-Time Maintenance™ (SMSRTM™) - Technology for real-time safe money-saving equipment operation management**

The Automated Control Systems for Safe-Money-Saving Real-Time Maintenance of equipment COMPACS® and created on its basis green technology - SMSRTM™ give the solution for the most significant economic task - the increase of safety and effectiveness of continuous production with minimum expenses for machinery condition support.

All that can be reached without industrial-engineering base reconstruction and big expenses connected with it, due to the fact, that monitoring systems providing safe money-saving operation costs dozens and hundreds times less than diagnostics of processes and equipment, which is especially vital for Russian economy on its current stage and provides green, resource-saving re-equipment of the enterprises.

The COMPACS® systems allow to receive automatically and use a reliable diagnostic information on the equipment health in real time. This information is a set of health diagnoses for constructions, machines, assemblies, mechanisms, received at continuous time intervals, when the equipment health changes insignificantly.
The most important elements of industrial safety and operational efficiency-providing technology are:

- **Automated Control System for Safe-Money-Saving Real-Time Operation and Maintenance of equipment SMSRTM™ COMPACS®** designed and commissioned in accordance to GOST R 53564-2009 "Condition monitoring and diagnostics of machines. Hazardous equipment monitoring. Requirements for monitoring systems".
- **Regulations of safe money-saving condition-monitored operation of technological complexes' rotating equipment in real time**, based on the SMSRTM™ COMPACS® designed on the basis of Russian Monitoring School regulative documents.
- **Reliability monitoring service created on the enterprise in accordance with GOST R 53563-2009 "Condition monitoring and diagnostics of machines. Hazardous equipment monitoring. Organizational procedures"**.

Fulfillment of the above-mentioned requirements allows not only to provide high level of technogenic safety, but to substantially increase their operation effectiveness due to the:

- rotating equipment breakage emergency elimination;
- increase of the rotating equipment and the whole technological complexes' operation life period;
- reduction of technological complexes' shutdown repair periods, due to the awareness of actual condition of rotating equipment;
- reduction of quantity and complexity of rotating equipment repair.

Within the COMPACS® system implementation the complex is equipped with monitoring systems, depending on the risk of accidents occurrence and profit losses associated with it.

**Highly critical equipment** – 1st category (high business risks), which sudden failure may cause 75-90 % reduction of technical and economic production efficiency or negative environmental impact.

**Critical equipment** of a process complex – 2nd category (average business risks), the failure of which may cause 10-25% reduction of technical and economic production efficiency, equipment that transfers hazardous fire and explosive substances, and hardly accessible equipment which condition is impossible or difficult for specialists to control.

**Auxiliary equipment** – 3rd category (low business risks), which failure or shutdown does not cause production losses and does not impact on safety and environment, but leads to unreasonable repair costs, for example, reduces technical and economic production efficiency by 1-2%.

Critical equipment of both 1st and 2nd category are subjected to equipping with the stationary health monitoring systems COMPACS®.

Auxiliary equipment is subjected to diagnostics and periodic monitoring done by portable systems of automatic diagnostics Compacs®-micro. The main advantage of such systems is the built-in automatic expert system that allows even young specialists of minimum experience in diagnostics to diagnose and evaluate the equipment state.

The important components of the COMPACS® are **the stand systems for controlling repair quality**. A company's maintenance departments implement these systems as they provide maximum potential capacity for commissioning of
the equipment which is first pass yield.

The COMPACS® system is based on distributed hardware architecture and automatic expert system, which is invariant to the unit's structure and determines the SMCD™ - strategy of minimum cost diagnostics. The systems implementation allows automatic and continuous receiving and using objective information about equipment technical condition, detecting and liquidating fundamental causes of equipment failures (technology LiFCE™), improving labour discipline through objective control and on-time correction of personnel actions.

SMSRTM™ technology provides technogenic safety and increase an operational efficiency of technological complexes by means of:

- real-time condition monitoring of rotating equipment - automatic diagnostics and prediction of the main defects (>95-98%), allowing an early detection, a complete use of capacity and providing maintainability;
- timely and purposeful informing the personnel on the nearest actions to be taken for the equipment health control;
- management of every enterprise control level, quality and efficiency of personnel's actions taken due to the monitoring system's prescriptions in real time;
- creation of purposeful repair plan in real time on the basis of equipment actual condition awareness;
- commissioning of the equipment with maximum potential resource;
- detection and elimination of fundamental causes of equipment failures due to the design and assembly errors, with process flowsheet optimization and equipment configuration (when needed);
- diagnoses, repairworks, replacements and resources data base management, with operation report issuing to the all levels of the enterprise management.

DYNAMICS SPC has developed standards GOST R 53563-2009, GOST R 53564-2009, GOST R 53565-2009 and STO 03-007-11. The standards give classification of monitoring systems and their implication in condition monitoring of equipment with different hazard degree. The standards are based on considerable experience in creation and implementation of systems for real-time condition monitoring of mechanical and process equipment used in hazardous industries such as chemical, oil-producing, petrochemical, oil and gas-processing, mining and metallurgical, rail-way transport, and community services. These standards are recommended by the Russian Federal Service for Technical Supervision (Rostechnadzor) to industrial companies, expert and designer organizations as a guideline document for choosing and implementing the systems of anthropogenic accidents prevention and providing a safe resource-saving operation of the equipment based on its actual state.

Considerable experience in implementation and operation of the COMPACS® systems for vibration analysis, computer monitoring and automatic diagnostics of equipment condition, which controls a few thousands items of equipment in dozens of enterprises, shows that the overall approach to asset management based on the system of schedule-based preventive maintenance and repairs (SPM) does not guarantee necessary performance (Curves 1 and 2 on the picture).

![Risk decreasing tools](image)

1) risk curve when using programs of the repair approved by existing regulative documents (PM method);
2) risk curve increasing from excess inspection activity, when using programs of repair according to normative documents;
3) risk curve during the usage of programs on the basis of RBI and RCM;
4) risk curve during the real-time monitoring of malfunctions and condition of the equipment.

Due to wide application of computer technology allowing the large data arrays processing and the automation of PM planning with regard to the information received on diagnostics, maintenance, repair of equipment, data about actual failures of equipment, the new products such as CMMS (computerized maintenance management software) and EAM (Enterprise Asset Management) have come on the market. These products aim at planning the diagnostics maintenance and repair work of equipment, warehouse stock of spare parts, etc., by using the information about equipment range and configuration, periodicity of the reglamented PM, and the parameters of ambient conditions. However, the major difficulty in using these systems is the manual input of information in situation of the equipment ambient and operating conditions instability (curve 3).

The implementation of a new SMSRTM™ technology at industrial enterprises with uninterrupted cycle, i.e. the technology of equipment operation with real-time focused maintenance carried out on time, which is based on equipment technical condition awareness, leads to significant increase of a company's output per time unit, reduces the time needed...
for scheduled shutdown repairs of process equipment by 30-50% as well as critical process equipment maintenance costs by 4-6 times (curve 4). These prominent results can be achieved without a repair of the process units helping to avoid considerable costs associated with the repair. The cost of the SMSRTM COMPACS® system, which apply the SMSRTM technology of equipment operation, is ten and sometimes hundred times cheaper than the cost of the processes and equipment diagnosed, which is important in the modern economic situation.

The substantial wearing of process equipment, low level of reliability, off-scheduled and emergency shutdowns, high-cost and low-performance organization of equipment preventive maintenance (PM) according to the PM, subjective quality control in equipment manufacturing and repair, lack of equipment condition control during its operation, negative impact of human factor on equipment condition during the process control are the major problems, which cannot be solved by the traditional approach to planning and organization of equipment maintenance and repair.

The PM method based on statistically distributed data provided by manufacturers about the maintenance frequency calculated for different operating conditions for various equipment. Such data does not allow an adequate determination of either the scope of work, or the best moment for maintenance works as in reality the operating conditions for equipment of the same type differ substantially so as personnel qualification and labour discipline in different companies, even those of the same industry. Everything mentioned above leads to a conclusion that more than 2/3 of all repairs, which have been proven to be unreasonable, are done within the PM method, and 30% of all repairs even counter-productive, i.e. deteriorating the repaired equipment condition. Moreover, such PM organization involves a large share of emergency and off-schedule repairs resulting in a high costs (up to 30% of the prime cost PM) and considerable losses due to shutdowns and incidents reaching up to 20% marginal income.

The actual cost of such total management substantially exceeds the calculated value and creates an illusion of efficiency. In this case, the equipment passportization, which is done by commissioning consultants and the company’s specialists, is possible; however, keeping such data base up-to-date at an enterprise that has tens of thousands units of various equipment is impossible. This is proven by the numerous articles, published in the press, and by customers’ feedback. The implementation of the PM method on such software products is possible only in small enterprises with simple configuration of process equipment. These software makes data input to the system labour-consuming and subjective that becomes the reason for the situation when more than 70% of the companies consider the results of the products’ implementation as unsuccessful, because this approach to PM does not solve their major problems: the unpredictability of equipment faults, low level of reliability of the process, and considerable losses due to shutdowns while its working condition is being restored, high maintenance and repair costs due to inefficient use of the equipment’s existing resources, high administrative costs of data input and processing.

**Technical and economic performance of new technology**

The economic effect occurred due to transition to the production management system which is based on the automated control systems of safe resource-saving operation of equipment COMPACS® is ensured by real-time condition monitoring of the main production factors such as:

- equipment efficiency and reliability;
- careful operation of process resulting in minimum possible destructive equipment loads;
- timeliness and focused personnel actions to maintain the equipment in operable condition (maintaining equipment and correcting the process if it is necessary);
- efficiency and quality of repairs;
- labour discipline of the personnel.

The economic effect is achieved through:

- elimination of technogenic accidents and losses of equipment due to increased safety;
- increased run-to-failure period of process units operation due to elimination of downtimes (temporary reduction of capacity) resulted by unexpected equipment failure;
- reduction of time needed to perform scheduled preventive maintenance due to timely and focused preparation to the preventive maintenance;
- reduction of operation costs and losses by elimination of non-efficient off-schedule, planned preventive maintenance and transition to real-time actual condition-based equipment operation.

The expected economic effect is calculated on the basis of accumulated experimental experience, basic methods, and the data gathered during the on-site survey. It has been noted that it is a common practice for oil-refineries to skip gathering and analyzing the information from the surveys, thus they lack the necessary data. This is the reason for wide use of the expert evaluation method when analyzing the collected information as well as of the computational method of determining the expenses, costs and losses according to actual standards. Other methods are damage parameter after an accident, emergency repairs and a number of other indicators that represent an averaged expert evaluation reflected in the reports on technical and economic parameters of process equipment operation. Apart from the above-mentioned methods of performance evaluation, the principle of comprehensive information (the n-principle) is recommended as it allows determination of efficiency of the implemented condition monitoring systems (hereinafter - CMS) through assessment of the interval between failures of the equipment depending on a risk level of their omission by the monitoring system.

When calculating the expected economic effect, the probability of timely execution of diagnostic instructions by personnel must be assumed as equal to 1 as it reflects the planned level of labour discipline and personnel motivation. Furthermore, in case of partial inclusion of critical equipment of the 1st and 2nd categories, it is not reasonable to talk about accident prevention probability of 100% since the difficulty lies in the human factor valency. Calculating the expected economic effect, the share of controlled units in relation to all other units must be taken into consideration as it is a potential source of accidents, downtimes and high operation costs.

The planned annual economic result is defined as the difference between overall savings from CMS introduction and the total investment into it.
Table 1. Equipment operation according to its actual health of the Catalytic cracking unit on the basis of the COMPACS® system

<table>
<thead>
<tr>
<th>Best Practice Maintenance Benchmarks*</th>
<th>Best World Rates*</th>
<th>Average rates of technological complexes, equipped with the COMPACS® systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Maintenance</td>
<td>&gt;85%</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>Reactive Maintenance</td>
<td>&lt;15%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Run to Fail (Emergency + Non-Emergency)</td>
<td>&lt;10%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Reactive Emergency: Total REM/Total Maintenance Hours Available</td>
<td>~2%</td>
<td>~0%</td>
</tr>
<tr>
<td>Reactive Non-Emergency: Total RNEM/Total Maintenance Hour Available</td>
<td>~8%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Plant Availability: Available Time Maximum Available Time</td>
<td>&gt;97%</td>
<td>~99%</td>
</tr>
</tbody>
</table>

*according to the data from Reliabilityweb.com

According to the information published by the Company’s customers, the economic effect achieved by the implementation of the COMPACS® system makes on the average 10 rubles per each invested ruble; the payback period does not exceed several months, and sometimes even several days. The Internal Rate of Return (IRR) or the return rate of discounted cash flows defined as a discount rate if the NPV=0 exceeds 95%, in the Company’s projects. The net profit ratio defined as the ratio of the cash flow present value to the total sum of investment, makes approximately 40.

The organization of the interrelations between the departments within the enterprise based on real-time condition monitoring ensures industrial safety, expansion of process units run-to-failure, reduction of operation costs, and elimination of situational losses, and hence an increase of labour efficiency and production profitability.

The results of actual condition-based equipment operation on the basis of the COMPACS® system are provided below:
1. During the Catalytic Cracking unit operation controlled by the system, no occurrence of sudden failure of machines was detected. The production safety increased considerably. The equipment technical readiness coefficient grew from 50% to 90%.

2. During the period under review the unit run was 350 days and nights, which is \( \sim 96\% \) of the maximum possible annual run.

3. The total number of repairs was reduced by nearly 2.5 times.

4. The number of "beneficial" repairs was reduced by more than 4 times.

5. The average monthly number of repairs was reduced by 17 times.

6. The scope of maintenance became stable and was about an average of 55 works per month. The personnel learned how to work with the system and perform condition-based equipment operation in real time doing timely and focused maintenance which aims at full unit's capacity use and prevention of any extra repairs.

7. The annual economic effect of unit operation under the control of the system amounted to more than $1 bln. USD, allowing DYNAMICS SPC to guarantee a full return of investment into the COMPACS\textsuperscript{R} within a year.

The Automated Control System for Safe-Money-Saving Real-Time Maintenance of equipment (SMCSRTM\textsuperscript{R} COMPACS\textsuperscript{R}) are awarded with the Russian Federation Government Award in the field of science and technology, have high quality standards – ISO 9001, are pioneer and breakthrough technology of Russian Science and supported by Russian Federal Service for Ecological, Technical and Atomic Supervision and RF Ministry of Energy.

**Real-time Monitoring of Malfunctions and Risks**

In order to provide efficient asset management to the Customers, DYNAMICS SPC offers absolutely new unique solution Compacs Asset Management\textsuperscript{TM} (CAM\textsuperscript{TM}), which is based on objective, relevant and timely information about the equipment condition provided by the monitoring systems COMPACS\textsuperscript{R}, integrated into the single diagnostic network of the enterprise Compacs-Net\textsuperscript{R}. All the above mentioned systems form the automated control system of safe resource-saving equipment operation SMSRTM\textsuperscript{TM} COMPACS\textsuperscript{R}.

CAM\textsuperscript{TM} includes a number of software products, automatically formed stationary and mobile monitoring systems, published in real time within the diagnostic network of the enterprise. The information enters CAM\textsuperscript{TM} automatically from the following COMPACS\textsuperscript{R} software modules: "Monitor", "Trend", "Mechanic engineer log-book", "Events log-book". CAM\textsuperscript{TM} contains references of possible causes for the unit repair, lists of repairs and replacement that have been performed during the maintenance of dynamic equipment (electric motors, centrifugal and reciprocating piston pumps, air coolers, centrifugal and reciprocating piston compressors, general ventilation fans, etc.) and static equipment (columns, reactors, pipelines, heat exchangers, furnaces etc.). Such organization principle allows the system to automatically generate reports on equipment condition of process units; reports on repair history with the statistics of work and replacement that have been held regarding every single unit of equipment and the overall complex; reports on planning of maintenance works, urgent and potential repairs with indication of specific defects and possible equipment failure causes, to evaluate the level of complexity and labour intensity of the repair-and-renewal operations.

Furthermore, CAM\textsuperscript{TM} automatically generates absolutely objective reports on a single unit equipment reliability, overall complex equipment, and the process complex itself that are based on the information received from the monitoring systems. The reports include statistics of the whole set of indexes, namely, the index of the normative monitoring exceeding period, index of length equipment operation of in faulty condition, the index of PM actions distribution by process positions, critical equipment of the 1st and 2nd categories operating in hazardous condition, which is close to limited condition and many others.
The reports and indexes are generated in five temporary bases from 12 hours to 9 years, thus allowing the management of assets and production to be effected not only in operative mode but also in strategic aspects relying on balanced system of indicators reflecting the functioning of the process complex, generated by the system taking into account the level of process unit load in comparison with its design capacity, which is configured during the introduction of CAM™.

The advantages of CAM™ are:

- objective assessment of production assets condition due to real-time condition monitoring;
- objective assessment of labour discipline and process personnel efficiency due to automatic report generation in the subsystem;
- objective assessment of PM costs which can be of great importance for both the operation personnel, as it becomes unnecessary to prove that equipment needs repairing, and for the managers, as it becomes unnecessary to verify the information received from their subordinates indicating the required costs of equipment repair and maintenance;
- timely and focused reports generated in one diagnostic network at every management level;
- the most comprehensive representation of information of work and replacement done during equipment repairs and maintenance, due to automatic saving and storage of data for a period of up to 9 years;
- substantial facilitation of search and elimination of fundamental causes of equipment failures (faults of design and assembly, need of process flaw diagrams correction and amendment of the Rules regulating the operation of the equipment and personnel), due to objective and timely reports that include all necessary statistics and indicators of process equipment and personnel functioning;
- opportunity to apply the principles of flexible budgeting and building a well-balanced system of process complex performance indicators of the process complex and of the overall enterprise.

CAM™ is the informational basis of the MES-systems COMPACS® integration into modern systems of management of the enterprise in general and the process of production and equipment operation management in particular.

The implementation of the automated control systems for safe resource-saving operation of equipment COMPACS® results in increased reliability of process complexes and ensures the transition from SPM systems to condition-based operation of equipment in real time.

Thus, the economic performance of the enterprise is substantially increased due to the increase of the run-to-failure and run-between-repairs periods of equipment operation, the expansion of the process units uptime to 99% per year, reduction of maintenance costs by 4–6 times, higher level of labour discipline, and objectivity of assessment of specialists contribution in the enterprise’s achievements.