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[2]Condition monitoring and maintenance of industrial processes, plants and complex systems: measurements and methods

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Abstract **– Maintenance of industrial processes, plants and complex systems is, of course, extremely important to ensure the quality of work performed, ensure employee safety, timely prediction of the necessary downtime, which of course affects business efficiency. The service life of the plant is extended by regular maintenance inspections and monitoring of malfunctions to eliminate the onset of failure even in the event of complete deviations to avoid a major system failure. Recently, the system has been monitored using automatic BMS / SCADA systems, in addition to which additional regular visual inspections of the system are performed, and the system is preventively maintained in working cycles. With the help of various probes we monitor input and output data parameters in critical places, such as temperatures at heating and cooling stations, pressures in pipelines and liquids and gases, percentages of oxygen in plants with various technical gases, pressure drops on critical filters, pump speed, percentage of fan load, percentage of valve openness. In addition, the positions of doors, fire dampers, flue windows and more are monitored by position. As we can see there are a number of essential parameters that need to be monitored in the synergy of reflection with the automated system.**

Keywords – efficiency; critical parameters; maintenance; life cycle

I. INTRODUCTION

Condition monitoring (colloquial, CM) is a process of monitoring the condition parameters in machines (vibrations, temperature, pressure, etc.), in order to identify a significant change that indicates a malfunction. It is a major component of predictive maintenance. The use of condition monitoring allows maintenance planning or other actions to be taken to prevent consequential damage and avoid its consequences. Condition monitoring has the unique advantage of being able to address conditions that would shorten normal lifespan before they develop into a major failure. Condition monitoring techniques are commonly used on rotating equipment, auxiliary systems and other machinery (compressors, pumps, electric motors, internal combustion engines, presses), while periodic inspection uses non-destructive testing (NDT) and serviceability (FFS) techniques [1] estimates are used for static plant equipment.

Performance monitoring is a less well-known condition monitoring technique. It can be applied to rotating machinery such as pumps and turbines, as well as stationary items such as boilers and heat exchangers. Measurements are required of physical quantities: temperature, pressure, flow, speed, displacement, according to the plant item. Absolute accuracy is rarely necessary, but repeatable data is needed. Calibrated test instruments are usually needed, but some success has been achieved in plant with DCS (Distributed Control Systems). Performance analysis is often closely related to energy efficiency, and therefore has long been applied in steam power generation plants. In some cases, it is possible to calculate the optimum time for overhaul to restore degraded performance.

At the same time, it is important to note that the same tools are used to prove the condition of space or equipment, when it is important for the production process and protection of products or operators to continuously monitor conditions and the environment. Trends of selected parameters are constantly saved and the operating parameters in all stages of the production cycle are easily proven with the help of diagrams. Of particular importance is the audit of trail trends in the pharmaceutical, microprocessor, hospital and nuclear industries.

II. RELATED RESULTS IN THE LITERATURE

System health monitoring is a set of activities performed on a system to maintain it in operable condition. Monitoring may be limited to the observation of current system states, with maintenance and repair actions prompted by these observations. Alternatively, monitoring of current system states is being augmented with prediction of future operating states and predictive diagnosis of future failure states.

Such predictive diagnosis or prognosis is motivated by the need for manufacturers and other operators of complex systems to optimize equipment performance and reduce costs and unscheduled downtime. Prognosis is a difficult task requiting precise, adaptive and intuitive models to predict future machine health states. Numerous modeling techniques have been proposed in the literature and implemented in practice. This paper reviews the philosophies and techniques that focus on improving reliability and reducing unscheduled downtime by monitoring and predicting machine health.

The oldest and most common maintenance and repair strategy is "fix it when it breaks." The appeal of this approach is that no analysis or planning is required. The problems with this approach include the occurrence of unscheduled downtime at times that may be inconvenient, perhaps preventing accomplishment of committed production schedules. Unscheduled downtime has more serious consequences in applications such as aircraft engines.

These problems provide motivation to perform maintenance and repair before the problem arises. The simplest approach is to perform maintenance and repair at pre-established intervals, defined in terms of elapsed or operating hours. This strategy can provide relatively high equipment reliability, but it tends to do so at excessive cost (higher scheduled downtimes). A further problem with time-based approaches is that failures are assumed to occur at specific intervals.

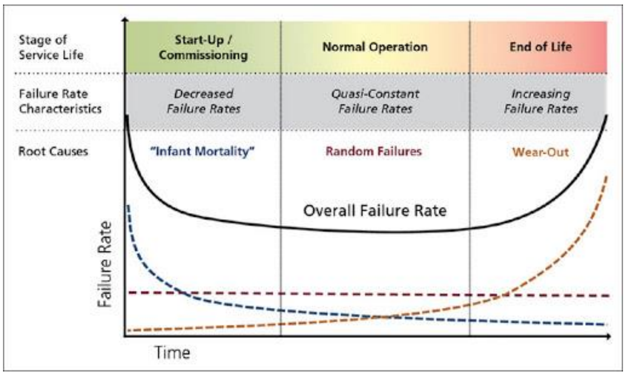

Figure 1 illustrates the typical incidence of failure over the life of equipment

Bathtub curve (see Figure 1) is a composite of several failure distributions and has three fairly distinct periods: decreasing failure rate for infant mortality; constant failure rate for useful life; and increasing failure rate for wear-out period. At the left, so-called "infant mortality" failures are plotted. Failure rates are low throughout the useful life of a piece of equipment, and rise toward the end of life.

This curve however doesn't capture the complex interactions between the components of a system and is loosely based on the assumption that the system progresses (or deteriorates) deterministically through a well-defined sequence of states (however, the curve might in some cases be valid even if the sequence is not well defined). This assumption is not true especially in the case of discrete manufacturing systems and other complex environments where seemingly random failure behavior is a function of the changes in the work content, schedule and environment effects, as well as unknowable variations between nominally identical components or systems.

The only way to minimize both maintenance and repair costs and probability of failure is to perform ongoing assessment of machine health and ongoing prediction of future failures based on current health and operating and maintenance history. This is the motivation for prognostics: minimize repair and maintenance costs and associated operational disruptions, while also minimizing the risk of unscheduled downtime.

The connection between effective maintenance management techniques and significant improvements in efficiency and profitability has been well documented [2]. Though the return on investment is highly dependent on the specific industry and the equipment involved, a survey states that an investment in monitoring of between $10, 000 and $ 20, 000 dollars results in savings of $ 5 00, 000 a year.

Across many industries, 15%-40% of manufacturing costs are typically attributable to maintenance activities. In the current competitive marketplace, maintenance management and machine health monitoring play an increasingly important role in combating competition by reducing equipment downtime and associated costs and scheduling disruptions.

III. DESCRIPTION OF THE METHOD

A. *Use of BMS / SCADA system in maintaining set parameters*

Automation tools have been used in the management of various systems for many years. For smaller drives they are just being introduced, and for more complex systems they are imperative. In all cleanrooms, in any branch of industry, there is always an additional requirement to monitor the parameters of some units that make that space suitable for the activity for which it is intended. As a rule, these are pressure, temperature and relative humidity of the room. An example of a system that controls the operation of the air conditioning chamber and the maintenance of parameters in the rooms supplied by the air of the above air conditioning chamber can be seen in the following figures.

Here we have seen the principle of display of one manufacturer (SCADA system), but all of them are in recent times simple enough, readable and easy to use. The display mode and the number of parameters that are constantly monitored are always agreed directly with the client. Apart from the fact that these systems are indispensable for fine-tuning the work, which is necessary for certain jobs to be done in the premises, they also serve as proof of the achieved parameters, a tool to justify certain production batches, to detect system failures or detection slippage of some values in order to prevent the violation of certain parameters in time. In this article, we will mostly deal with the last thesis, i.e. the analysis for the purpose of maintaining the HVAC system.

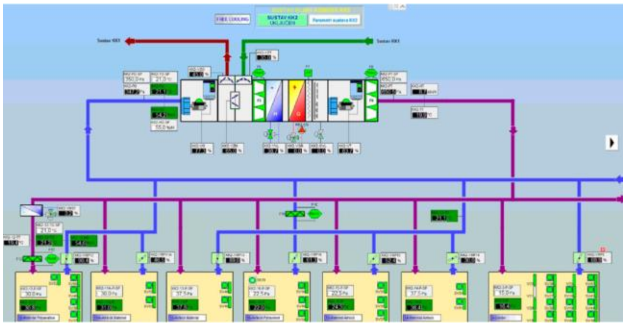

Figure 2. Overview of air conditioning chamber and cleanrooms with monitoring of important parameters

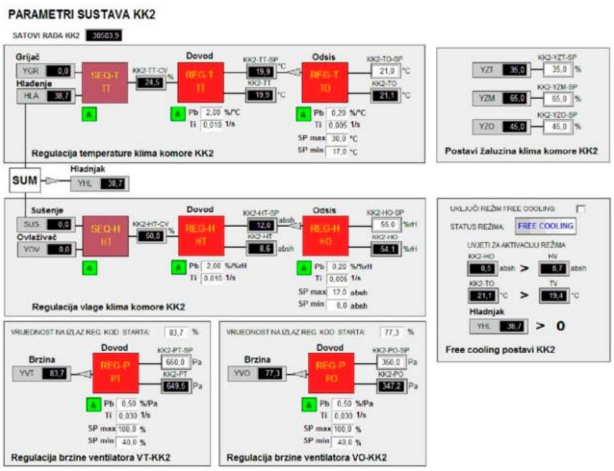

Figure 3. Overview of setting parameters of the air handling unit

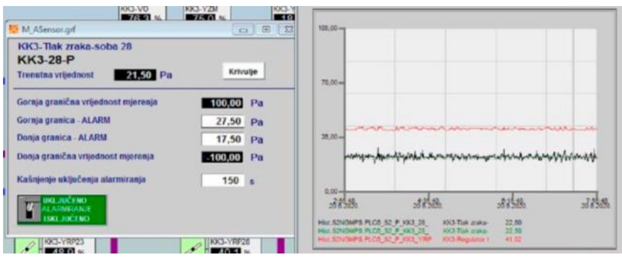

Figure 4. Display of pressure sensor and control valve for one room

B. Use of BMS / SCADA system for malfunction analysis

Alarm: The room pressure is outside the alarm limits

Possible operating errors:

a) insufficient air on the supply side of the system - dirty filters

b) insufficient air on the supply side of the system - malfunction on the regulator (RKP, RVP)

c) failure of the exhaust part of the system

d) door or other opening disturbs the value due to inadequate operation (we will exclude this as it is mentioned that this is the first thing that the user has to check before reporting the malfunction).

Possible solution when analyzing a malfunction:

a) insufficient air on the supply side of the system - dirty filters:

I. The differential pressure switch has activated an alarm at 200 or 400 Pa, it is necessary to replace the filters (this should also be seen in the trend of the exhaust valve, which would have to close more than the starting position, due to less supply air in the room).

II. The supply fan operates at an increased frequency / percentage of operation (due to the higher resistance on the filters, more power is required to overcome the resistance; see Figure 5).

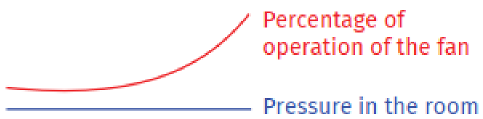

Figure 5. Display of the supply fan trend on the BMS system when the filter gets dirty

III. The valve on the exhaust went to 0% (same as in I. - the trend shows a decrease in openness over time; see Figure 6).

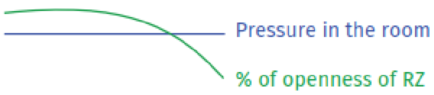

Figure 6. Display of the RZ trend on the BMS system during filter contamination

IV. Evidence of a smaller quantity on the supply is measured by a balometer in clean space or a Pitot-tube on the supply channel.

V. If we do not have a differential pressure switch on each filter, it is necessary to periodically measure the pressure drop on the filters. This can also serve as final proof of contamination before replacement.

b) insufficient air on the supply side of the system - malfunction on the regulator (RKP, RVP)

I. If the pressure in the room drops or rises linearly on the trend display, and the fan is running at approximately the same value at the same time, it is possible that there is a physical blockage in the duct, drive failure, or someone disconnected the tube on the RVP drive. In any case, it is necessary to go out on the field and perform a control measurement and inspection before replacing the part.

c) failure of the exhaust part of the system (see Figure 7):

I. If the pressure in the room drops or rises linearly on the trend overview, the fan runs at approximately the same value at the same time, while the RZ on the exhaust shows proper operation, it is possible that there is a physical blockage in the duct, drive failure or drive failure so the drive spins idle and everything looks good on the system. It is also possible that everything is working properly, but someone has disconnected the pressure tube from the space and the measurement shows the pressure of the reference space. In any case, it is necessary to go out on the field and perform a control measurement and inspection prior to replacing the part.

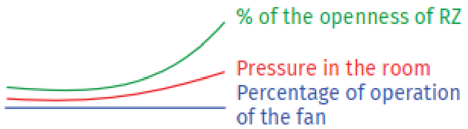

Figure 7. Trend display on the BMS system in case of failure on the exhaust part of the system

Alarm: Temperature / relative humidity of the room is outside the alarm limits

Possible operating errors:

a) not enough air changes in the room

b) improper operation of the valve on the heat exchanger line

c) additional possibilities

d) no cooling or heating medium (we will exclude this as it is mentioned that this is the first thing that the user has to check before reporting the malfunction).

Possible solution when analyzing a malfunction:

a) not enough air changes in the room:

I. Static pressure trend on the supply duct and the percentage of fan operation should be reviewed. This can quickly confirm whether the basic parameters have been violated, and after that it is necessary to perform confirmatory measurements in the field.

b) improper operation of the valve on the heat exchanger line (see Figure 8):

I. The valve drive does the job, but the valve body is stuck. Although the automatic operation is correct, the valve is in the same position at all times. It is necessary to determine the real situation by going out on the field.

II. It is possible that a fault has occurred in the heating or cooling station, so we do not have media that can transfer or take over the heat. This can be checked by reviewing the trend, reading on thermometers or reviewing with a thermal camera. If there is no other way, it can be checked by feeling the heat (using hand is often the fastest way to see results).

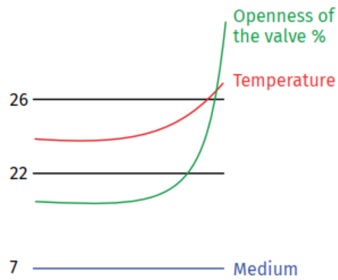

Figure 8. Trend display on the BMS system during valve failure

c) Additional possibilities:

I. It is possible that seemingly everything is fine; the drive and valve body work as well as the pump, the medium is present but the flow is impaired. This often cannot be seen on trend, but it is possible to see if the temperature difference at the flow and return lines is too small. Another way is to examine the barometer to see what the pressure is in the pipeline on the supply and return line. Often the above can be compared to a nearby heat exchanger. If the values deviate greatly, a conclusion can easily be drawn. The problem can occur due to clogging of the slats on the outside (less air flow over the surface of the slats) or clogging on the dirt trap (often occurs after commissioning because all debris in the pipes is found in the dirt trap after a while).

II. In addition to the above possibilities, at the beginning of operation it is possible to find that the heat exchanger, in the coldest or warmest days of the year, cannot meet the needs even at 100% operation. It is a lack of heat or cooling capacity. There are no problems with temperature (unless there is a consumer in the room with a large dissipation of heat that is not taken into account), but with the maintenance of relative humidity. On the warmest days of the year, it is necessary to cool the external air extremely, in order to maintain the relative humidity within narrower limits.

IV. RESULTS AND DISCUSSIONS

By using analyses, we were able to detect the cause of the problem faster, and thus the reaction is always faster. no time is wasted on field detection, the possibility of necessary spare parts is narrowed. Service customers value proactivity and reduce the frequency and duration of possible downtimes, and transfer the lessons learned to the requirements for new processes, equipment, and entire plants.

It is important to state that when creating URS (User requirements specification), operatives who have experience with typical machines and drives must be included, because at the beginning the critical parameters that need to be monitored the most are recognized. after that, in the design phase, all the necessary sensors are turned on and detected, which will be in the critical base, and which will serve only as an indication. All critical parameters should be constantly monitored and upper and lower warning and alarm limits must be set around the set points, so that maintenance personnel can be alerted to the condition of the equipment in a timely manner.

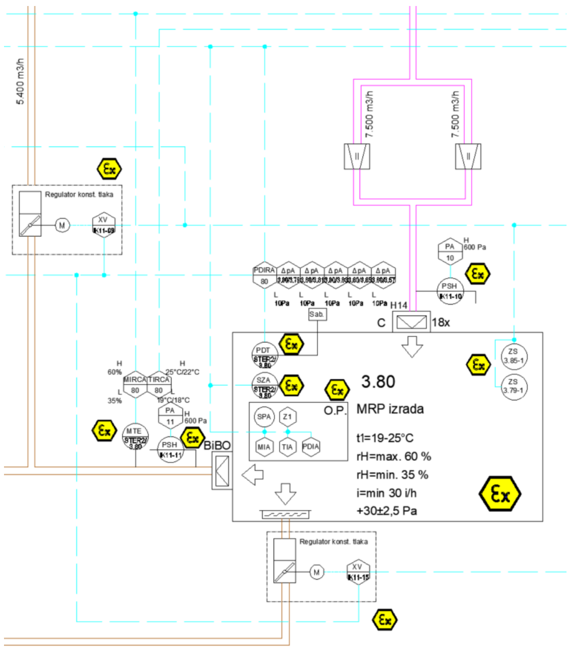

Figure 9. An example of a well-planned request and listing of all required monitoring sensors

On a simple example of an engine, it is easy to conclude that regular oil changes and temperature monitoring can extend service life, while without sensor assistance there could be fatal consequences that sometimes end in total damage, and then all production processes depend on the rapid availability of new parts. nowadays less and less companies are kept in stock, so delivery times are counted in weeks, not days.

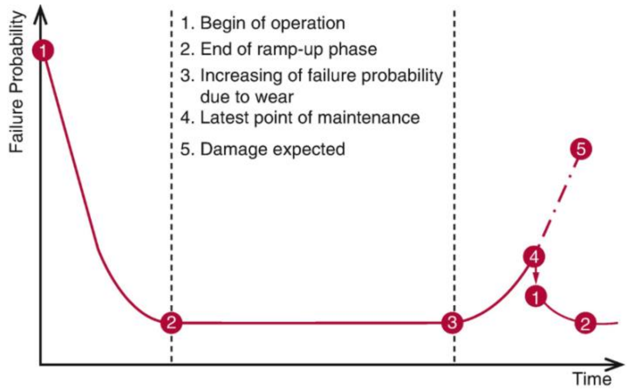

Figure 10. The bathtub curve, a model of failure rate vs. operating time elapsed

The appropriateness of a specific maintenance system for a given technical system is heavily dependent on the system's failure rate over operating time elapsed. The bathtub curve (Figs. 2 and 3 top left) is often referred to as an idealistic template of this function. It features three characteristics regions: in the early operating phase, an elevated failure rate due to production flaws is considered; in the main operating phase, stochastic failures cause a constant, low failure rate; in the late operating phase, wear and deterioration increase and cause elevated failure rates again.

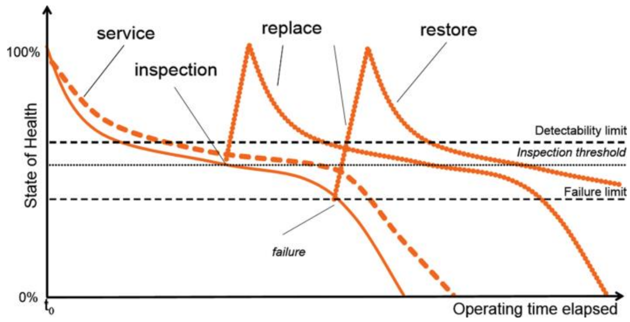

Figure 11. Depicts the effect of various maintenance activities

"Replacement" and "Restoration" mean literally that the curve is set (back) to a higher level. In the ideal case, this reset returns the state of health back to the initial value of 100%. "Service" reduces the effects of wear, so that degradation becomes slower and operating time longer. "Inspection" evaluates the actual state of wear, so that violation of a predefined maintenance threshold can trigger appropriate preventive maintenance activities [5].

V. CONCLUSIONS AND OUTLOOK

Benefits of trend analysis on the BMS system

It is unquestionable whether we benefit from trend analysis on the BMS interface. Although sometimes it is not enough for a complete conclusion, after the analysis it is possible to advise the user how to check more details before leaving the service centre. If we are not sure about the problem, an additional check can narrow it down to two, three possibilities. For large systems, it helps to know that after checking, a service technician with two possible spare parts must be sent to the field. After some time, users themselves recognize the advantages of working with this tool and some order periodic inspections in maintenance in order to be prepared in time to quickly rectify the malfunction or replace the part until the problem has not yet occurred. All of us who deal with maintenance find it useful to have preventive inspections and periodic replacement of spare parts. This reduces unplanned and urgent corrective actions that are much more expensive due to unplanned downtime and lack of reserved resources. Of course, they also cause stress at work which we are not in lack of in these times.

Performance monitoring is a less well-known condition monitoring technique. It can be applied to rotating machinery such as pumps and turbines, as well as stationary items such as boilers and heat exchangers. Measurements are required of physical quantities: temperature, pressure, flow, speed, displacement, according to the plant item. Absolute accuracy is rarely necessary, but repeatable data is needed. Calibrated test instruments are usually needed, but some success has been achieved in plant with DCS (Distributed Control Systems). Performance analysis is often closely related to energy efficiency, and therefore has long been applied in steam power generation plants. In some cases, it is possible to calculate the optimum time for overhaul to restore degraded performance.

The selection of critical parameters is usually determined in advance in the design phase with technologists from different professions involved, but of course they can also be added to the system after the operation phase shows that a parameter needs to be monitored for various reasons. We divide maintenance into preventive and corrective. In preventive maintenance, we change known consumable parts, lubricate moving parts, change transmissions, all in order to avoid corrective maintenance, because the same brings unplanned longer downtime and consequently much larger and more expensive failures. For these reasons, it becomes clear that the planned maintenance extends the life cycle of the plant and its efficiency, and becomes an indispensable part of a business. It is no longer questionable whether the maintenance is carried out but only how often and whether it is done by someone within the company or by an external service.

VI. ACKNOWLEDGMENTS

We have acquired the acquired knowledge that we apply today for many years, and I would like to thank the company that guided me for the last 12 years, all colleagues and mentors who recognized commitment and dedication to work, influenced by example to become better engineers, help when needed , and to all clients because we spread knowledge at their plants and processes. It is necessary to thank the partner companies for joint projects and of course the competition because it made us better. Nowadays when everything becomes online, the ability to connect remotely and analyze gives us an advantage in times when movement has become a burden and working from home an advantage. The new tools have enabled us to continue to carry out our activities in a timely and consistent manner.

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