

### **MACHINERY CONDITIONS MONITORING FOR PRODUCT AND PROCESS QUALITY ASSURANCE**

**Abstract:** The technical conditions of production machinery play a significant role in attaining high quality of manufactured parts. A formation and a development of machinery comprehensive care system including machinery monitoring is anchored as one of customers' requirement in ISO 9001:2009 and ISO/TS 16949:2009. Contrary to expectations the contemporary prevailing maintenance system in a wide range of organizations follows a model of subsequent maintenance (breakdown maintenance) missing any features of prediction. In order to avert any unexpected manufacturing machinery failures, it is necessary to implement methods and means of industrial (technical) diagnostics. The article provides an experience with maintenance organization within manufacturing organization, describes the most common problems and their root causes, and explains possible countermeasures. The fundamental orientation to problem prevention is a competitive advantage of the most advanced companies and prerequisite for reaching top quality of products and services.

**Key words:** quality assurance, maintenance, industrial diagnostics, problem solving

#### **1.1. Introduction**

The product quality is a relation of many factors acting together. For a final product user the quality is the only one half of expectations in terms of customer satisfaction and the other half is the product quality assurance in defined period of time. Basically, this feature is called the reliability and it is connected to product performance. The final product quality depends on design and development stages realized within APQP process, stable and capable manufacturing process, and finally the company processes performance including the process interfaces. In order the manufacture products would satisfy both the customer and the

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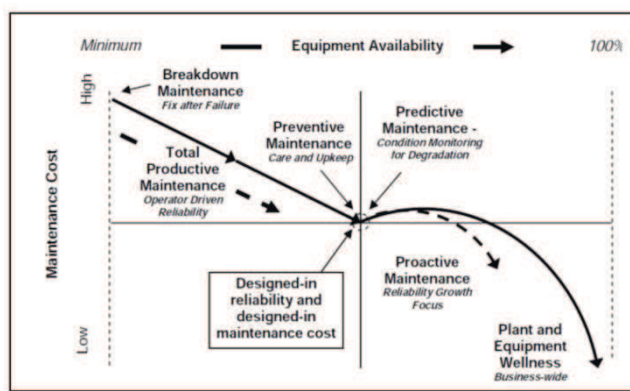
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manufacturer in terms of quality, reliability, dependability, reasonable costs, and all together as just in time process, it is crucial to implement a complex system of machine care based on prediction philosophy including means of technical diagnostics. There might be seen an analogy between human medicine and technical maintenance. A workshop can be considered as hospital for machinery and the maintenance operators the doctors. There has also been a different level between abilities, instrumentation, approach, device, methods, and purposes through the enterprises around the globe. Contemporary approach can be divided into two areas relating to a size of the company. With small companies the means of technical diagnostics are missing or the diagnosis is based on subjective decisions. Contrary to that fact with large companies albeit the means of technical diagnostics are sometimes used the results of measurement are often incorrectly interpreted or raw data are provided without any conclusions or recommendation. The data from outsourced companies are not coordinated and there is no correlation between failure root causes and consequences. Such a situation leads to the most common pattern of maintenance the analysis of machinery after unexpected failure occurrence thus maintenance without of any signs of prediction. Moreover, it certainly may bring the high probability of risk in terms of achieving QCD (Quality, Cost, and Delivery) goal.

## **1.2. The role of technical diagnostics in complex machine care**

With the recent rapid development of technical systems complexity and requirements for their reliable, dependable, safety, and economical operation a necessity for their condition monitoring arises. Knowing the product design and development is not able to assure reliable operation without of established and optimized complex machine care system. There has been historically as well as practically and conditionally known a few approaches to machine care in a form of maintenance. The current trend in assurance of dependability of machinery is depicted in figure 1. Basically there have been two basic maintenance types according to CSN

EN13306. The first type is known as “Preventive Maintenance” in a form of planned and in advance determined intervals of maintenance interventions. The second form can be described as based on current conditions that can be continuous, planned or on request. The second type is known as “Breakdown Maintenance” and in other words after a failure occurrence. This type is also performed in two forms as immediate or postponed. Thus far described maintenance segmentation has been strictly oriented to technical performance. An extensive view of maintenance significance, comparison of particular types and forms in context of costs of diagnostics equipment is depicted in Figure 1.1. The fundamental purpose of technical diagnostics is to uncover hidden failures and nonconformities, identify their locations, determine the extent and causes, and eventually determine their economic, ecological, and safety consequences of further operation without a repair. In other words the technical diagnostics determines statement about current conditions of technical object and prescribes possible evolution of technical conditions. Based on diagnosis and prognosis the management can decide whether there is a necessity of repair, probable development of failure, or withdraw the machine, device etc. from operation.



**Fig 1.1. The types of maintenance and the journey to plant and equipment wellness.**

Source: SONDALINI M. 2009

In order to be able to determine actual technical conditions, avoid machinery downtimes, effectively find and determined a failure, and finally predict available equipment life it is essential to use means of technical diagnostics. The utilization of means of technical diagnostics is linked to consideration whether the cost of diagnostics will be less than savings generated by diagnostics. Basically the main savings concerning diagnostics implementation are connected to 1. Revelation of incorrect adjusted or regulated parameters and their prompt correction which brings direct reduction of operation costs, reduction of wear propagation, and a number of manufactured non-conformities decrease. 2. Revelation of processes leading to breakdown that can save the costs in terms of elimination of loss from dependent failures, reduction of downtimes, reduction spare parts amount, and overtime. 3. Machinery operation in safe and regulation compliant mode assuring emission elimination and safety increasing. The expected results of diagnostics implementation are permanently good machinery conditions, high level of dependability, reliability, significant cost reduction, and increase of the level of product and process quality (LEGAT V. 2007).

### **1.3. The means of technical diagnostics**

Prevalent contemporary diagnostics instruments use various physical principles. There have been six fundamental groups of interest in terms of utilization. These are the NDT (non-destructive methods), measurement of operational parameters, subjective methods, vibrodiagnostics, termodiagnostics, and tribodiagnostics. The NDT methods are focused on determination of existence, location, and extent of either inners or surface material failures. Into the group of these methods belong the eddy current techniques, ultrasound, radiography, capillary techniques, and acoustics emission (POSTA J. 2012). The machinery operational parameters measurement and monitoring contributes to process regulation. The CTQ characteristics are monitored via miscellaneous sensors with immediate feedback and operation in on-line mode. The supporting software is able to calculate statistical outputs

in a form of  $C_p$  and  $C_{pk}$  and providing immediately regulation diagrams. Conversely there have been techniques monitoring parameters in order to get an insight to deterioration like wear processes inside of machinery helping predict technical conditions of rotational machines e.g. compressors, pumps, fans, transmissions, electric motors, and engines, particularly their bearings conditions, unbalances, wrong transmission assembly etc. based on monitoring parameters of vibrations in either audible spectrum, ultrasound or their combination. The regular on line or off line measurement accompanying with trend analysis may visualize current technical conditions, avoiding machine or system unexpected failures and prescribing an available technical life for further operation. For detection of electrical discharges, air and liquids leakages the ultrasound is valuable detection technique. Techniques using oil as information source belong to tribology and provide an analysis of wear particles in terms of concentration, size, morphology, and wear mechanisms submitting valuable information about current machine conditions. Furthermore, provides also information relating to oxide, sulfites contamination accompanying with additives degradation, and finally water, air, and fuel contamination. The measurement technique using temperature distribution field is designated as termodiagnosics. Observing the temperature distribution the increasing friction conditions caused by wrong assembly, lubricant deterioration or loss, short circuit etc. can be detected.

#### **1.4. Experience with current wide spread maintenance approach and its influence on product quality**

Most of the current quality problems in a serial production are linked to manufacturing process but in detailed view rather the supporting processes as maintenance and engineering. There is number of factors having the influence to the production process. To uncover the basic factors and relations the 6M (Measurement, Material, Method, Man, Milieu, and Machine) technique, FTA, 5 Why, and Ishikawa chart may be

used. The reliability and machinery set up is the prerequisite of the quality product and it is certainly connected to complex machinery care. The responsible department for the machinery care is the Production Engineering and the Maintenance department. The widespread current practice in terms of machinery care is the „after failure care” (Breakdown maintenance) without any predictive approach. In such a system the production is only waiting what problems the particular shift will bring. The common problems are high level of non-conformity connected to high cost level, problems with quality of manufacturing tools, insufficient amount of spare parts, and what is very important the insufficient quality assurance level ( $C_{pk}=1,67$ ) associated with the high risks for the customer. The system of machinery care originates in investment policy when design and specifications for production machinery are formulated. Negligence or the lack of knowledge in this stage can create a significant failure in terms of the company having new machinery which is able to reach merely  $C_{pk} \approx 1$  for critical parameters instead of  $C_{pk} \approx 1.67$ . The root cause of this failure is the poor project management, low awareness level of reliability management, dependability of machinery, and the communication across the company departments too. During machinery operation while adjusting the technological parameters there is prevailing opinion when the adjusted or regulated parameter falls in the range of tolerance it is in order. Unfortunately, such an approach is not able guarantee the required quality assurance level and it is necessary to convert attitude towards the Taguchi principle (DIAN M. 2012). From different point of view the breakdown maintenance causes unexpected, unpredictable stoppage of machinery bringing high risk of jeopardy of customer production. The maintenance and repairs management without the sense of prediction and prevention relates to weak maintenance plans, rules and policy. Some of the companies do miss the matrices of responsibility which causes delays in machine maintenance and repairs interventions, the quality of interventions, and the action plans. The records from intervention are not properly stored and analyzed and the feedback is not performed at all. This leads to uncovering the failures root

causes and the reoccurrence of the same mistakes and problems over and over again. One of the reasons having the troubles with uncovering the root causes is the lack of understanding and usage of problem solving techniques and methodologies as 5 Why, ISHIKAWA, FTA (Fault Tree Analysis), FMEA (Failure Mode and Effect Analysis), and TRIZ (Theory of Inventing Problem Solving). Moreover, there is no database of the occurred problems, the methodology of their solving including the countermeasures. Advanced database is necessary for the optimization of maintenance process and planning and can be used also as the training tool for the maintenance operators. Machinery adjustment is performed often when the control measurement register the readings out of the tolerance range, albeit the SPC (Statistical Process Control) is implemented and playing the preventive tool role. The manufacturing production requires also tool management. Current situation in industry uses rather intuition instead of complex management system based on “theory of renovation”, when tool exchange is organized based on wear observation with prognosis for life prediction. The tool management helps the organization to have an appropriate amount of spare parts at the time when needed. The tool management shortage can cause the usage of damaged or worn out tools because the new tool is not available at the moment undoubtedly with awareness of risk to the customer. The last problem influencing the quality of product pertains to maintenance system covering the absence of model procedures, rules and instruction which induces the extend of repairs and maintenance times, escalates the risks of uncovering the failures fast enough or whatsoever, and finally the different approach to maintenance interventions. Within the “after failure” the Breakdown type of maintenance system there are not used any diagnostic techniques and equipment for machinery current technical condition status. Some attempts to implementation i.e. tribodiagnostics methods or vibrodiagnostics via outsourcing are known. On the other hand the outsourced companies often provide only data without any reasonable conclusions. Such diagnostics approach is merely compliant with ISO/TS 16949:2009 requirements but nothing else. Performing any

remedial activities as the consequence of failures there is the absence of PDCA (Plan-Do-Check-Act) technique at all. Summarizing above described observations the most problems and their root causes are related to the company top management, following the procedures and their quality, and established appropriate quality monitoring system with necessary feedback. Further problems are hidden in the level of employees' knowledge, education and training, and motivation as well.

### **1.5. The technical-economic criterion for technical diagnostics utilization**

As well known quality guru Armand V. Feigenbaum explained the savings from quality that are not usually simply visible must be turned to money so the management would be able to see them. The same counts for the maintenance and technical diagnostics. There have been two categories that play a significant role in technical-economic approach to diagnostics utilization. The first is known as cost of purchase and the second the running cost. Using a methodology based on both types of costs an optimum interval for maintenance, diagnostics or intervention linked to technical-economic point of view can be determined. See the equation 1.1 (HAVLICEK, J. 1993).

$$u(t) = \frac{N_{p-z}}{t} + \frac{N_p(t)}{t} \rightarrow \min \quad (1.1)$$

“u(t)” average unitary costs, “Np-z” costs of purchase, “Np(t)” running costs, „t” time of operation

The equation 1.1 expresses the optimization principle for the determination of ideal time for machinery replacement, maintenance intervention or repair from technical-economic point of view.

The first case study depicted in figure 2 was realized on cooling pumps in a power plant. The contemporary approach to bearings exchange is based on different experience of maintenance operators that

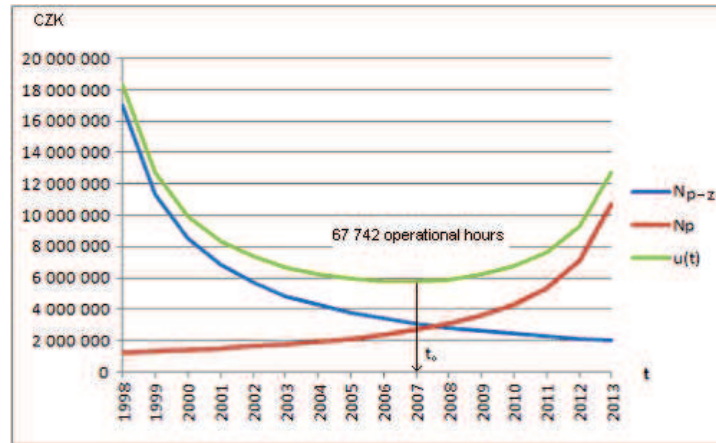


are also forced by management into prolongation of bearings life to their technical limits. The optimum renovation interval was determined based on off line vibrodiagnostics data gathering and analysis. Additionally the running costs and purchased cost were calculated, summed and minimum determined. The exact optimal interval from technical-economic point of view was 67 742 operational hours. Any direction either over this number or below it brings an economical loss.

The second case study shown in figure 3 was undergone in different power plant in the same region, focused on transmissions and particularly their bearings. The contemporary replacement interval relating to bearings is determined based on history and „modus operandi“ approach. Thus the current replacement interval is set up for 4 years. Comparison to figure 3 the organization loses one third of bearing technical life. Taking to consideration nowadays prices for bearing purchase and replacement the total costs would be 245 000 CZK. In the context of wasting one third of technical life the lost represents about 81 666 CZK for one bearing.

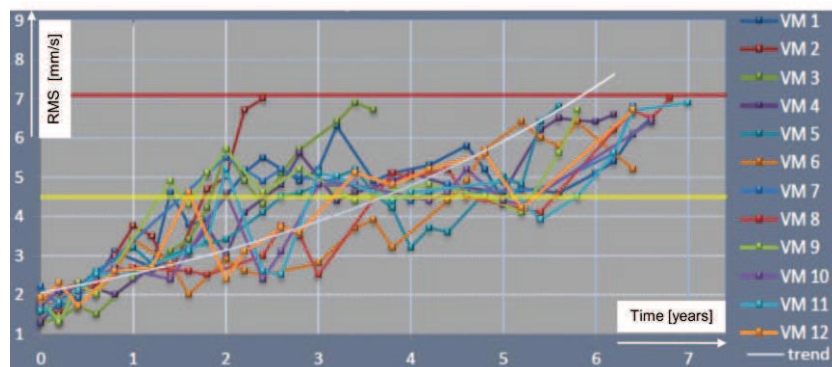
## **1.6. Conclusion**

The machinery complex care process is inseparable from quality assurance process having a significant influence on process and product quality in serial production. The means of technical diagnostics provide an insight into machinery current technical conditions, and based on machinery genesis allow to set up a trend and thus determine further possible utilization. Such an approach can bring an optimum exploitation of machinery parts and systems that enables the required quality assurance level. By diagnostics based critical to customer parameters regulation may be more efficient and operative. The decision whether to use any diagnostics equipment have to be based on reasonable comparison of purchased costs and running costs.



*Figure 1.2. Determination of optimum diagnostics interval of cooling pump bearings from vibration measurement based on equation 1.1.*

*Source: FUKSA J. 2013*



*Figure 1.3. Determination of transmission bearings replacement based on vibration diagnostics.*

*Source: (Tvrznik T. 2012)*

The ideal moment of intervention in terms of repair, renovation, part or system change can be determined based on technical-economic criterion. The introduced case studies provide evidence of attainable cost savings using vibrodiagnostics for bearings lifespan extension and the ideal renovation intervention interval determination.

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