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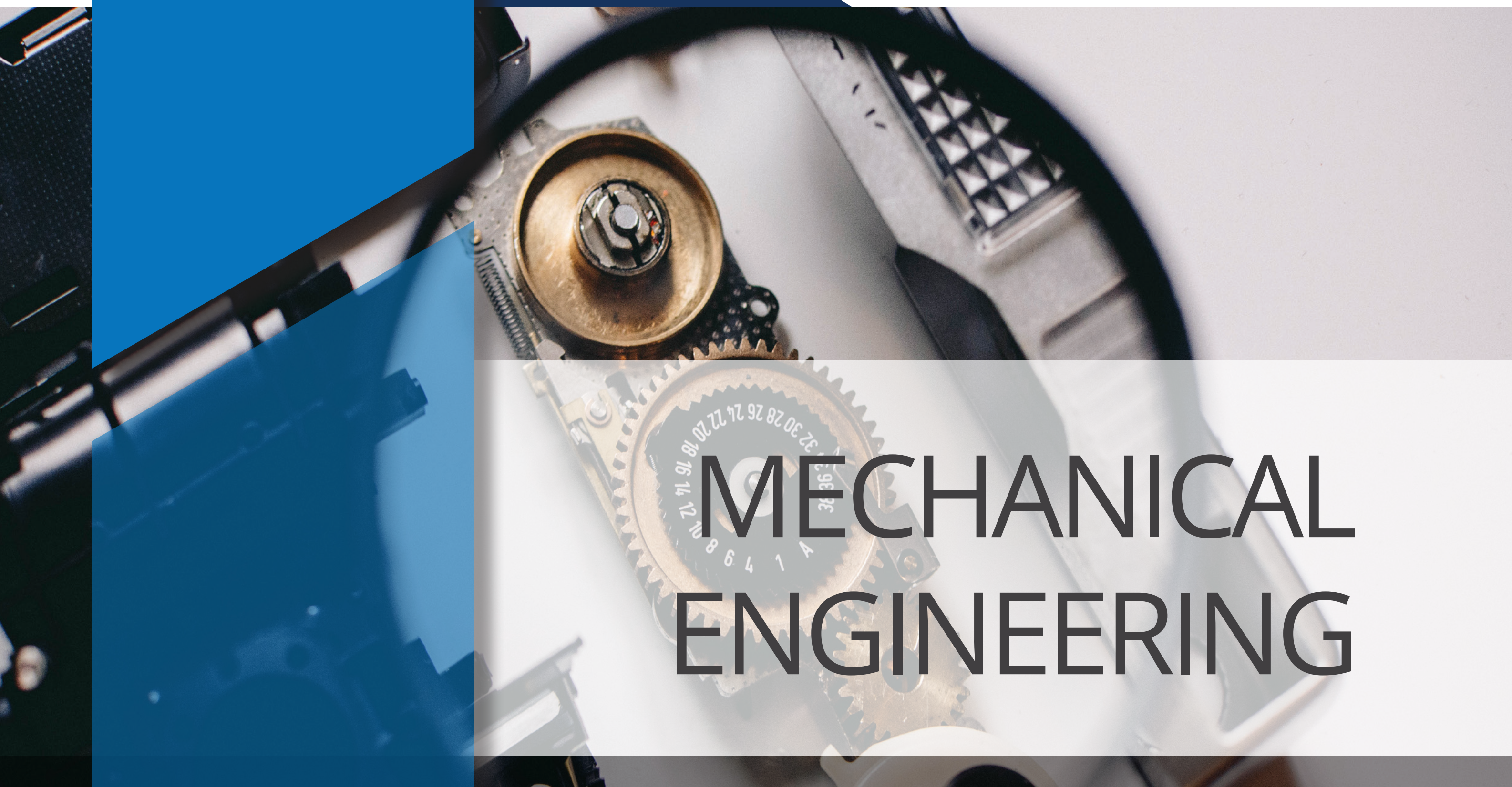

MECHANICAL ENGINEERING

Machine operation and maintenance

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1. BASIC TERMS

Maintenance – combination of all technical, administrative and management activities during the lifecycle of a subject, aimed at keeping it or restoring it in the state where it is capable of performing the required function.

Maintenance strategy – management method used to achieve the goals of maintenance.

Maintenance goals – ensure such a regime of tangible assets care that would provide a realistic objective overview and helps to improve an overall effectiveness of the machines, solves the machines and equipment maintenance problems including their impact on the productivity.

Maintenance philosophy and strategy – system and principle of organizing and performing maintenance. It is based on seeing maintenance as a corporate problem that under optimal conditions ensures the operation of machines and facilities by means of a set of activities.

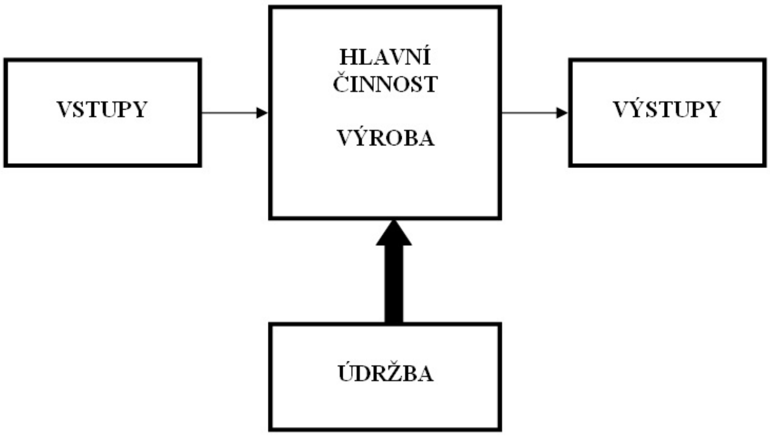
Maintenance concept – description of relations between the place where maintenance is performed, the degree of division of the object and the degree of maintenance that shall be used for the object maintenance.

Sustainability – the ability of the object to remain in the state in which the required function could be carried out if maintenance is performed in the given conditions and given procedures and sources are used.

Maintenance provision – the ability of maintenance team to ensure maintenance at required time or within required time period at a place where the maintenance work is required.

Ensuring maintenance – this includes sources, service and management necessary for operating maintenance system.

Function of maintenance in production process



Legend: vstupy – input, hlavní činnost – main activity, výroba – production, výstupy – output, údržba – maintenance

Basic general maintenance requirements:

Procedural approach – functionality and competence at optimal costs is more efficient when managing maintenance as a process.

System approach – efficiency and effectiveness of maintenance is improved by managing interrelated processes.

Maintenance management – maintenance top management needs to promote and create the environment in line with the overall production management strategy and concept.

Involvement of all workers – maintenance is an issue for the whole staff, not only for the maintenance workers.

Change in thinking and attitudes – in understanding and perceiving maintenance as an approach to increase qualification from the maintenance work perspective.

Decision-making based on facts – data analysis with a pre-defined certainty and their application in information systems operating in real time necessary for making a decision.

Continuous improvement – improvement of maintenance processes in terms of technology and organization.

Promoting good supplier relationships – to solve maintenance by means of centralisation and integration into production (autonomous maintenance) and separation (external maintenance).

3 P principle

- **PREVENTION** – performing maintenance at the right time – in advance
- **PROACTIVITY** – looking for causes of breakdowns
- **PRODUCTIVITY** – set up maintenance work so that the production is not affected

2. REQUIREMENTS AND ENSURING OPERATIONAL RELIABILITY, MAINTENANCE THEORY

Operational reliability

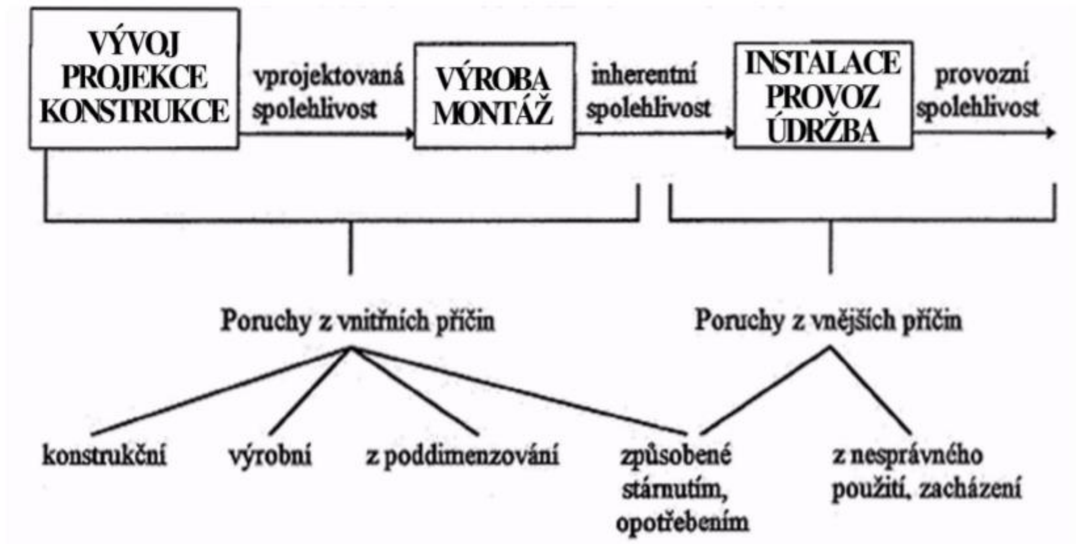
"A product (machine) characteristic property that enables to perform specified functions within the allowable tolerance under given operational conditions and required operation time." Its main properties include: functionality, safety, reliability, maintainability, preparedness.

Ensuring operational reliability has to be seen as a system problem of solving all interlinked processes and activities in context.

Operational reliability and technical life of object

It can be said that ensuring operational reliability is a part of technical life of each object. Operational unreliability can start at the very beginning of the technical life of the object.

The course of technical life: it refers to assigning reliability and failures to the basic division of the object life cycle:

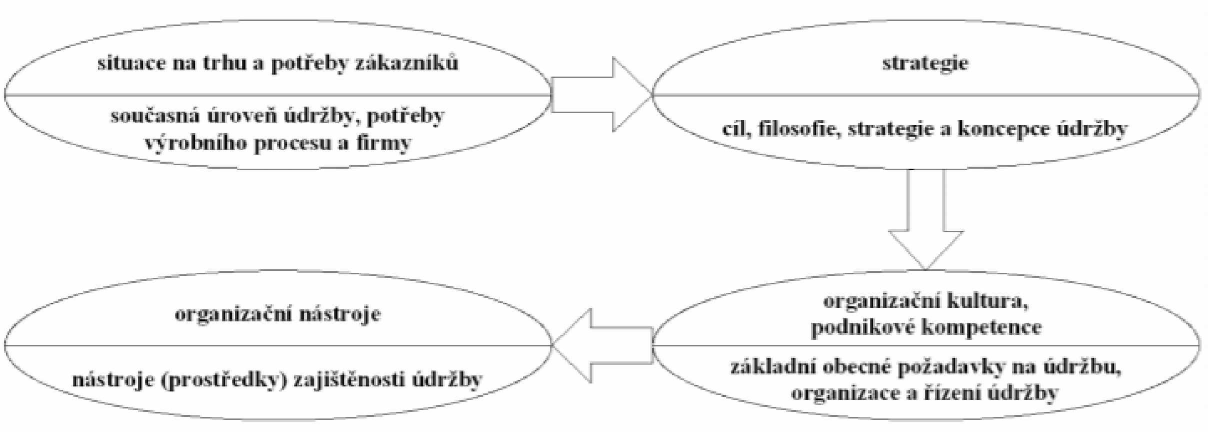


Legend: vprojektovaná spolehlivost - designed reliability, výroba/montáž - production/assembly, inherentní spolehlivost - inherent reliability, instalace/provoz/údržba - installation/operation/maintenance, provozní spolehlivost - operational reliability, poruchy z vnitřních příčin internally caused failures, poruchy z vnějších příčin - externally caused failures, konstrukční - construction, výrobní - production, z poddimenzování - undersize, způsobené stárnutím / opotřebením - caused by aging / wear, z nesprávného použití/zacházení - improper use / handling

The picture clearly indicates what the term operational reliability means. It is the most important stage of a machine technical life, since the machine becomes a means of production = it creates a value. Obviously, there is an operational reliability monitoring feedback, which leads to an innovative reconstruction of unreliable construction hub or its parts.

Operational reliability requirements

If we want to meet the need for a system approach to maintenance as a means of ensuring operational reliability, such procedures and processes must be used that enable to achieve the objectives, strategies and concepts (see the following figure).



3.EVALUATION OF MAINTENANCE EFFECTIVENESS

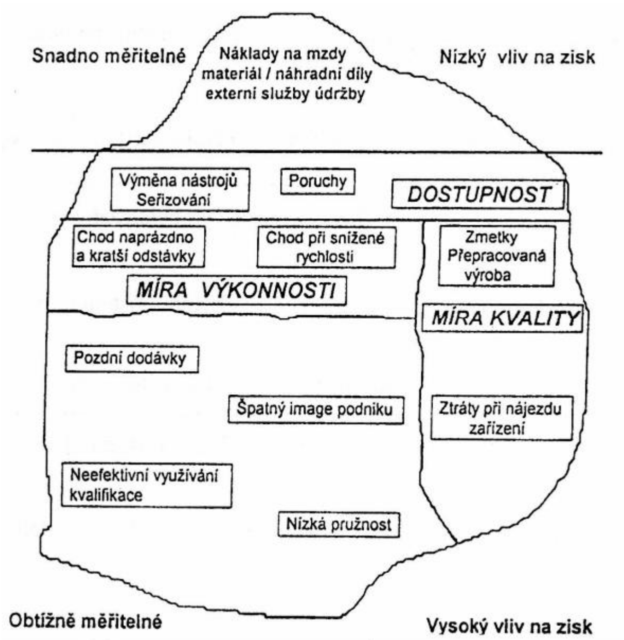
Maintenance costs are necessary for restoration of the production facility original function; therefore it is necessary to deal with the maintenances economic efficiency and evaluation.

- Problems that has to be solved:
  - Maintenance costs x minimizing the downtime (machine inactivity)
- The ratio between costs and expenses is not clear
  - direct (easy to calculate – spare parts, lubricants, ...)
  - difficult to evaluate the influence the maintenance has on failures, deterioration of quality, losses, ...

Effective and productive operation means:

1. benefits for the facility / machine
2. benefits for people (service staff)
3. benefits for machine operation

For the actual costs, it holds true that 7/8 of the costs are hidden or hard to identify. This is clearly shown in the DIAGRAM (so-called iceberg cost model).



Legend: Snadno měřitelné – easy to measure, nízký vliv na zisk – small impact on profit. Obtížně měřitelné – hard to measure, vysoký vliv na zisk – high impact on profit, náklady na mzdy, material, náhradní díly, externí služby údržby – wage, material, spare parts, external maintenance service costs, výměna nástrojů, seřizování – replacement of tools, adjustments, poruchy – failures, dostupnost – availability, chod naprázdno a kratší odstávky –

idling and short downtime, chod při snížené rychlosti – operation at lower speed, míra výkonnosti – level of performance, zmetky, přepracovaná výroba – rejects, reworked products, ztráty při nájezdu zařízení – losses at commencement of operation, míra kvality – level of quality, pozdní dodávky – late deliveries, špatný image podniku – bad image of company, neefektivní využívání kvalifikace – inefficient use of qualified staff, nízká pružnost – low flexibility

Overall effectiveness of equipment

OEE – level of utilisation x level of performance x level of quality

OEE – „Overall Equipment Effectiveness“

Level of availability utilisation – losses due to failures, reconstructions, settings and adjustment

Level of utilisation = $\frac{\text{(Possible operation time - downtime)}}{\text{Possible operation time}}$

Level of performance – losses due to unused downtime, reduced speed and short closures.

Level of performance = $\frac{\text{number of products produced x TAKT (ideal cycle)}}{\text{Possible operation time - downtime}}$

Level of quality – losses due to rejects, commencement of production, reworks.

Level of quality = $\frac{\text{number of products produced – rejects – more work}}{\text{Number of products produced}}$

OEE = $\frac{\text{number of quality products x ideal cycle}}{\text{Possible operation time}}$

OEE improvement by 1 % corresponds to 5-20 % of maintenance costs!

Comprehensive methods of maintenance evaluation:

- Overall maintenance efficiency
    - Maintenance efficiency index
    - Maintenance indicators curve
    - Maintenance audit
- Maintenance risks (assessment methods)
    - FME/FMECA –failure mode analysis / failure mode, effects and criticality
    - FTA – fault tree analysis
    - ETA – event tree analysis

4. MAINTENANCE RISKS

Danger – ability of the object to cause a negative phenomenon / situation

Threat – possible activation of danger

Risk – acceptable form of given activity (awareness of potential danger and its scope)

Fault tree analysis FTA – process

- Defining of fault analysed, identification of possible causes and type
- Development of top level into low level phenomena (causes of superior event are sought)
- Description of faults causes (what, where, how, why)
- Carrying out analyses in order to:
    - Make list of combination of possible types and causes of faults
    - Probability with which the situation may occur

Event tree analysis ETA – process

- Reverse process to FTA: the effects of components state on the whole system are sought
- Often used as a FTA complement

Risk factors in maintenance

- Maintenance risk is a product of fault occurrence probability and effect
- Fault occurrence probability value:

$$P_i = \frac{n_i}{H \cdot N - \mathrm{Pr}}$$

- P_i – hodnota pravděpodobnosti vzniku poruchy
- n_i – počet oprav i-té kategorie důležitosti daného uzlu
- H – počet hodin práce za den
- N – počet dní v roce
- Pr – prostoj daného uzlu v dané kategorii důležitosti

Legend: hodnota pravděpodobnosti vzniku poruchy – failure occurrence probability value, počet oprav i-té kategorie důležitosti daného uzlu – number of repairs for i-th level of the given hub importance, počet hodin práce za den – number of work hours per day, počet dní v roce – number of days per year, prostoj daného uzlu v dané kategorii důležitosti – downtime of the given hub in the given importance level

- Consequence of failure

$$D_i = \frac{m \cdot c + U_i}{H \cdot N}$$

- D_i – důsledek vzniku poruchy
- m – množství výrobků za rok na daném uzlu
- c – cena výrobku
- H – počet hodin práce za den
- N – počet dní v roce
- U_i – celkové roční náklady na údržbu daného uzlu

Legend: důsledek vzniku poruchy – consequence of failure, množství výrobků za rok na daném uzlu – number of products per year for the given hub, cena výrobku – product price, počet hodin práce za den – number of work hours per day, počet dní v roce – number of days per year, celkové roční náklady na údržbu daného uzlu – total annual costs of the given hub maintenance

- Maintenance risk is a product of failure occurrence probability and its consequence

$$R_i = D_i \cdot P_i$$

- R_i – hodnota rizika údržby
- D_i – důsledek vzniku poruchy
- P_i – hodnota pravděpodobnosti vzniku poruchy

Legend: hodnota rizika údržby – risk maintenance value, důsledek vzniku poruchy – failure occurrence consequence, hodnota pravděpodobnosti vzniku poruchy – failure occurrence probability value

5. MAINTENANCE AUDIT

It refers to checking of the implemented organizational unit management system and identification of possible non-compliance with the relevant standards, documentation, etc.

Classification:

- System audit
- Process audit
- Operation audit

Maintenance audit includes:

- Maintenance benchmarking
- Maintenance outsourcing
- Locators study of maintenance
- Management maintenance quality
- Risk analysis
- Quantification of operational reliability

Benchmarking

It is a continuous and systematic process of comparing and measuring products, processes and methods of the organization with those of the organizations that have been chosen as suitable for the purposes of defining the objective to improve own activities.

General procedure of benchmarking

- Determining of items for comparison
- Determining of who to compare with
- Gathering of data on process performance and customer needs
- Comparing of processes and identification of possible quality improvements

Benchmarking objectives:

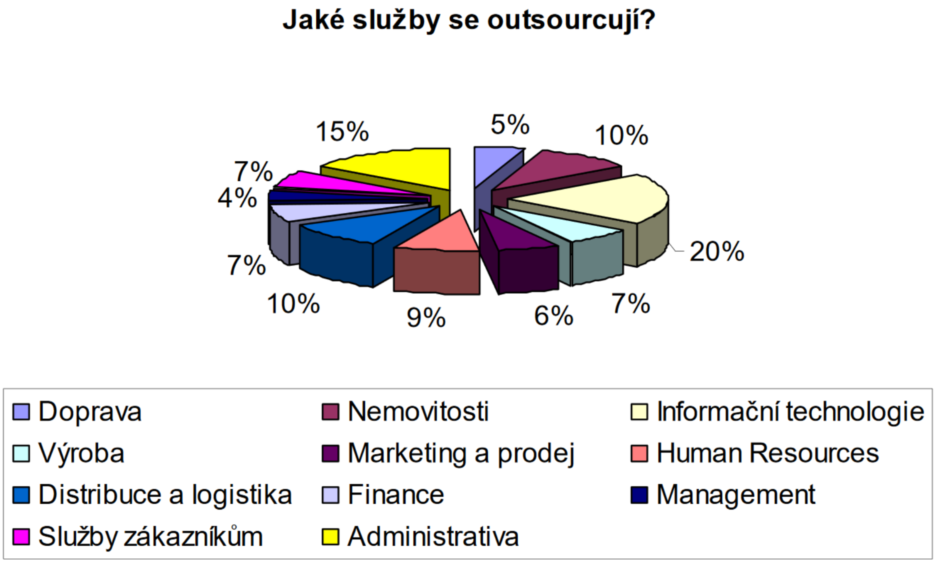
- Saving costs
- Increasing customers satisfaction
- Understanding world-class performance
- Better decision-making
- Setting more demanding objectives
- Speeding up the process of change

Outsourcing - outside re**sour**ce us**ing**

- Using outside resources
- Ensuring operations that are not key competences of the company audited

Outsourcing objectives:

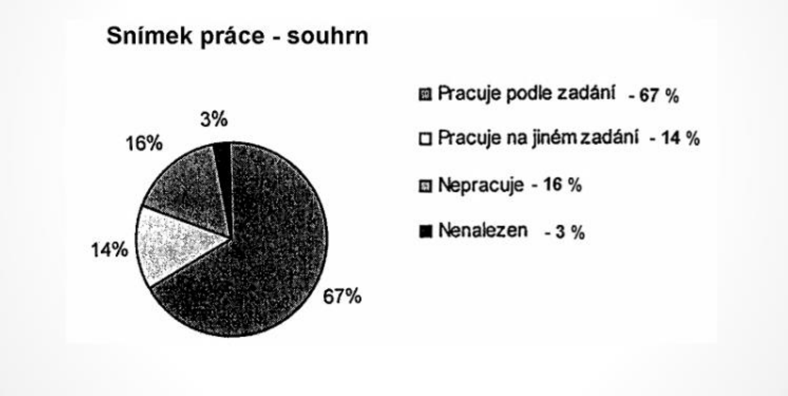
- Performing selected activities and tasks faster, more safely and more economically
- Reducing the number of own workers
- Concentration of own sources on key competences



Legend: Jaké služby se outsourcují? – Services outsourced. Doprava – transport, výroba – production, distribuce a logistika – distribution and logistics, služby zákazníkům – customers service, nemovitosti – real estates, marketing a prodej – marketing and sales, finance – finance. Administrativa – administration, informační technologie – information technologies, human resources, management

Locators study of maintenance

- Study of maintenance staff utilisation
- The study shows the actual work load and utilisation during work hours



Legend: snímek práce – souhrn – overview of work load, pracuje podle zadání – work corresponding to assignment, pracuje na jiném zadání – work not corresponding to assignment, nepracuje – not working, nenalezen – not found

Risk analysis

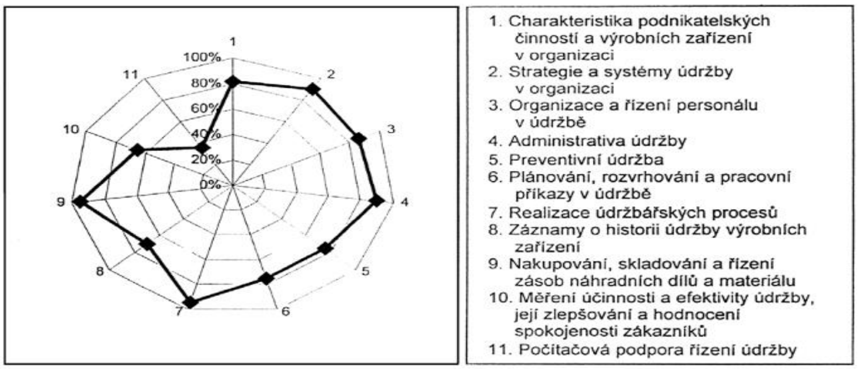
Identifies the probability of accident and its consequences by means of the following methods: FMEA, FMECA, FTA, ETA, HAZOP, etc.

Quantification of operational reliability

Mathematical base of reliability quantification is the number of probabilities and mathematical statistics. These tools are necessary for the description and analysis of random phenomena and processes corresponding to the failure and renewal processes.

Maintenance management quality

It is basically the quantification of a response to 11 types of issues, which are entered in so-called radial diagram.



Legend: Charakteristika podnikatelských činností a výrobních zařízení v organizaci – characteristics of entrepreneurship activities and production equipment in organization. 2. Strategie a systémy údržby v organizaci – strategies and systems of maintenance in organization, 3. Organizace a řízení personálu v údržbě – organization and management of maintenance staff, 4. Administrativa údržby – maintenance administration, 5. Preventivní údržba – preventive maintenance, 6. Plánování, rozvrhování a pracovní příkazy v údržbě – Planning, scheduling and work orders in maintenance, 7. Realizace údržbářských procesů – Realization of maintenance processes, 8. Záznamy o historii údržby výrobních zařízení – records on history of production equipment maintenance, 9. Nakupování, skladování a řízení zásob náhradních dílů a materiálu – Purchasing, storage and management of spare parts and material, 10. Měření účinnosti a efektivity údržby, její zlepšování a hodnocení spokojenosti zákazníků – measuring efficiency and effectivity of maintenance, its improvement and assessment of customer satisfaction, 11. Počítačová podpora řízení údržby – IT support of maintenance management

6.RELIABILITY MANAGEMENT

Reliability – According to ČSN 010102, reliability is defined as: "*general property of the object consisting in the ability to fulfil the functions required while preserving the values of established indicators within given limits and time in accordance with the established technical conditions*. "

This definition is completed by several explanatory notes:

- Reliability is a complex property which may include e.g. trouble-free operation, lifespan, sustainability and storability, either separately or combined.

- Technical conditions refer to the specifications of technical properties required for the specific function of the object, types of operation, storage, transport, maintenance and repairs.

- Operational parameters are indicators of productivity, speed, electrical energy and fuel consumption, etc.

Reliability management tools

- Reliability plan
- Reliability program
- Reliability methods
- Reliability tests
- Reliability standards
- Training and qualifications improvement in the area of reliability

Need for reliability management

- All company departments are involved in ensuring reliability, by performing activities that must be in specified order and at specified time and extent. For this reason, these activities must be coordinated so that the customer required reliability is achieved from the initial reliability level.

- Reliability management is performed in accordance with the system applicable for individual company departments through different tasks (number, difficulty), power and responsibilites

- Reliability management refers mainly to coordination of all activities and operations related to create and ensuring reliability in accordance with standards and other legislation related to reliability.

- It refers mainly to ensuring reliability in the longest operational stage.

- Reliability need to be paid great attention to.

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- The more complicated the equipment is, the less favourable conditions and the more serious consequences resulting from unreliability there are, the higher is the need or even necessity to manage the operation of the equipment, that is, to purposefully act upon ensuring the reliability.

Reliability in individual stages of product life cycle

- Reliability disciplines are applied in all product life cycles; life cycle can be defined in accordance with the standard CSN EN 13306 Maintenance – Maintenance terminology

- Specifically, it refers to:

- Concept (specification) of requirements for equipment, its performance, reliability and life span – so called specified reliability

- Design and development of the equipment parameters, conditions of trouble-free operation and maintainability, so-called reliability "design".

- Implementation (production) – demand, choice and installation of the equipment – we work with so called inherent reliability.

- Operation and maintenance – testing equipment and its installation into operation; due to various conditions at various customers it is referred to as "operational reliability"

- Disposal – disposing of a non-functioning or disused machine

Bathtub curve

There are more ways to divide the life cycle of equipment, one of them being the bathtub curve, which divides the life cycle into three stages.

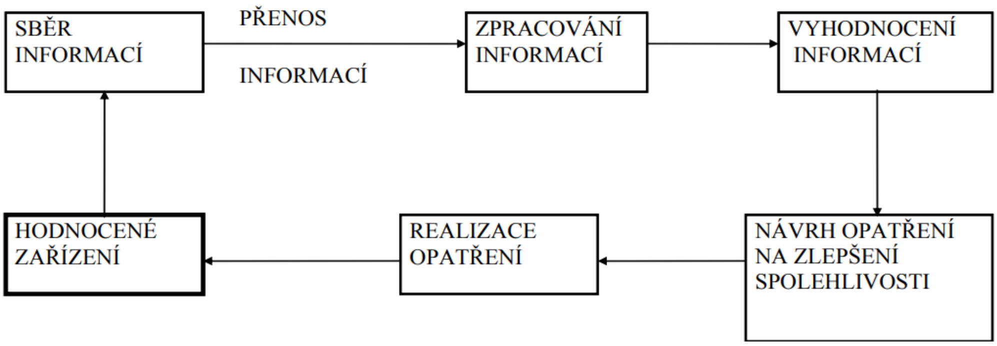
- Stage I – a period of frequent failures. It is characteristics with a sharp decrease in failure rate. High failure rate at the beginning is caused by the machine running-in, during which malfunctions due to manufacturing, assembling or design errors.

- Stage II – a period of normal operation. It refers to a long period called a period of normal utilisation. The equipment is used for its original purpose with more or less constant occurrence of about 26 failures. These are mostly due to external causes, there is no wear affecting the properties of the equipment.

- Stage III – a period of wear-out. The failure rate increases due to material ageing and wear. After exceeding the acceptable failure rate the equipment is put out of operation and disposed of.

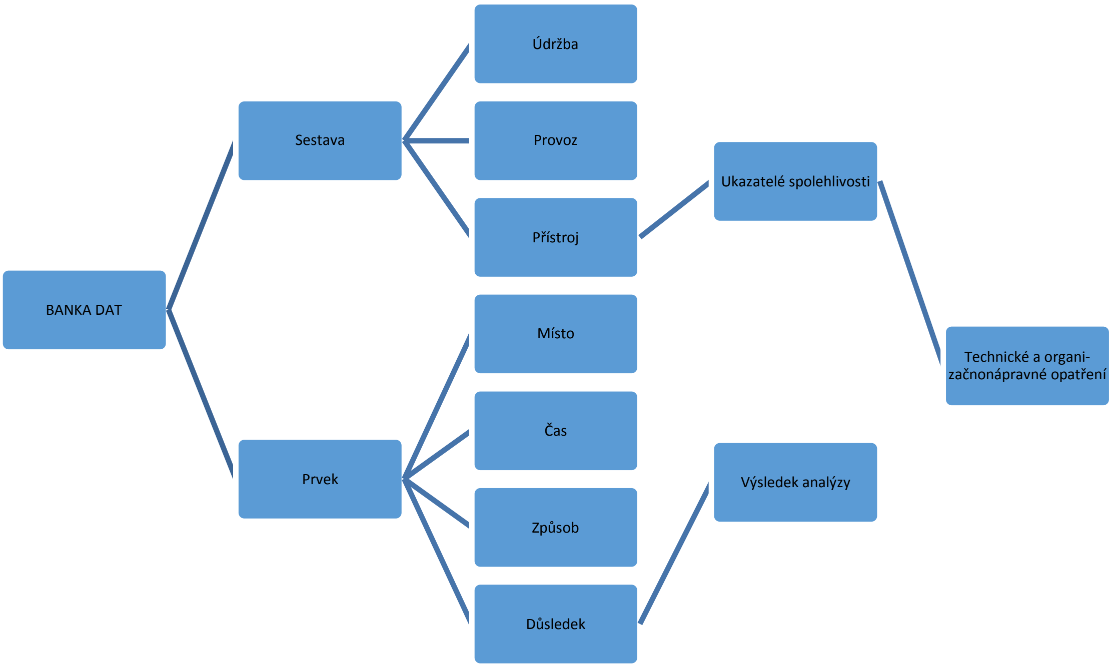
Feedback

- An important part of reliability management is feedback
- Feedback enables the departments ensuring the operation to be aware of:
    - The difference between the required and actual reliability
    - Reasons for such a difference



Legend: sběr informací - collecting information, přenos informací - transmission of information, zpracování informací - processing information, vyhodnocení informací - evaluation, návrh opatření na zlepšení spolehlivosti - proposing measures to improve reliability, realizace opatření - implementation of measures, hodnocené zařízení - equipment / device assessed
Background information for reliability management

- Important part:
    - Analysis of reliability
    - Reliability data bank



Legend: banka dat - data bank, sestava - assembly, prvek - element, údržba - maintenance, provoz - operation, přístroj - device, místo - location, čas - time, způsob - method, důsledek - consequence, ukazatelé spolehlivosti - indicators of reliability, výsledek analýzy - result of analysis, technické a organizačně správné opatření - technical and organizationally proper measures

7. RELIABILITY MANAGEMENT METHODS

Important methods of reliability analysis and deficiencies diagnosis within the reliability management include the following:

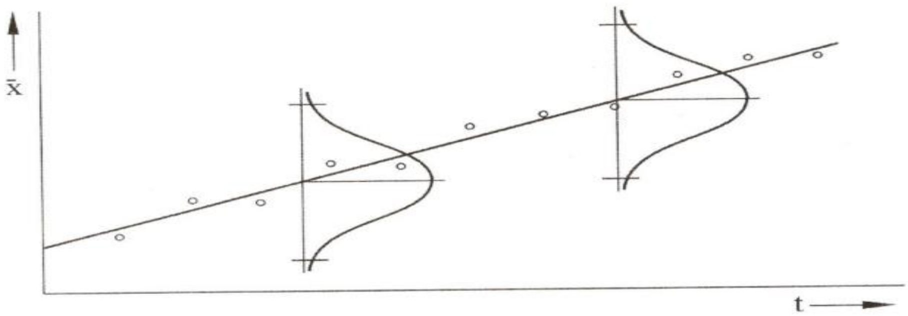
- Histogram
- Trend
- Pareto chart
- Ishikawa diagram

Histogram

Histogram is a graph illustration of data distribution by means of a bar chart with the bins of the same width expressing the intervals (classes), while their height represents the frequency of the variable monitored in the given interval.

Trend

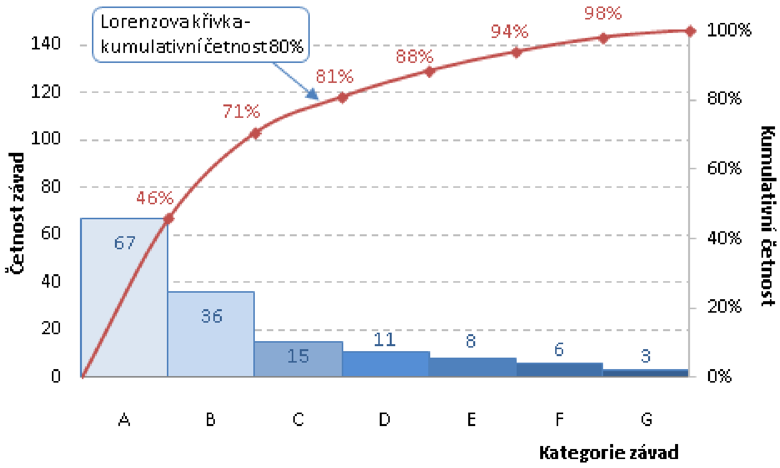
Shows the development of reliability indicators over time



Pareto chart

- Pareto chart, named after Vilfredo Pareto, is a combination of a bar and line graph, where the bins representing the rate for individual categories are ordered by size (the highest bin being on the left, the lowest one on the right) and the line represents the cumulative rate percentage. Pareto chart is used for showing the importance of the individual categories.

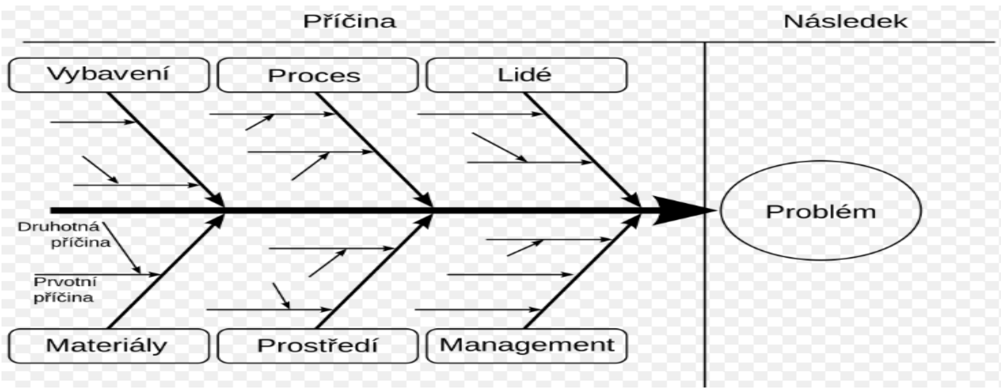
- Pareto chart shall be used when analysing the process failure rate, where the failures can be caused by many factors and it is important to identify the most significant ones. When creating Pareto chart it is necessary to determine the categories to be shown, the variables to measure and the period to be monitored.



Legend: kumulativní četnost - cumulative frequency, kategorie závad - category of defects

Ishikawa diagram

- It is the Cause and Effect diagram
- It solves the issue of identifying the probable cause of a problem
- Ishikawa diagram is one of the seven basic tools of quality improvement



Legend: příčina - cause, vybavení - equipment, proces - process, lidé - people, následek - consequence, problém - problem, druhotná příčina - secondary cause, prvotní příčina - primary cause, materiály - materials, prostředí - environment

8.RELIABILITY TESTING AND TEST PLANS

Reliability testing aims to obtain the information from which the reliability indicators are derived based on examining the equipment during the reliability test.

Reliability tests classification

- By the specific property the reliability test is aimed
- By decision how the equipment showing failures during the reliability test will be dealt with
- By the reliability tests results
- By a specific test purpose
- By the place where the reliability test is carried out
- By the stage of product creation

By the specific property the reliability test is aimed, the test are further divided into tests of:

- Trouble free operation
- life span
- maintainability
- reparability
- storage life
- standby

By decision how the equipment showing failures during the reliability test will be dealt with:

- without renewal – when a failure appears, operational capability of the equipment is not restored and the test continues with a lower number of elements tested

- with renewal – operational capability of the equipment is renewed by means of repair or replacement

By the reliability tests results:

- shortened tests – they are finished before a failure of all tested equipment occurs

- accelerated – those are carried out in tightened functional and external conditions, that it under conditions that normal do not occur in normal operation

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By a specific test purpose:

- determining – identifies the value of reliability indicators for the given equipment
- verifying – the reliability indicators value is compared with the prescribed or required value

By the place where the reliability test is carried out:

- laboratory tests – they are carried out under specified laboratory conditions
- simulation tests – these are carried out in laboratories if such conditions imitate operational conditions
- field tests – they are carried out in determined operational conditions
- test operation – these are carried out in conditions that correspond to real operation

By the stage of the product creation:

- development tests
- production tests

A reliability tests planning describes a set of main activities performed in the chronological order. It includes:

- Description of the required function the equipment has to fulfill
- Determining measurement method which will be used during the testing in order to detect possible failures occurrence
- Specification and ensuring suitable measuring and registration procedures for continuous monitoring and recording the operation conditions in which the equipment has to operate during the test
- Determining a critical failure, that is, the limits of individual measured parameters or other features characterizing the function of the equipment tested and when exceeded, the equipment is considered faulty
- Determining the testing plan

Testing plans

Testing plan is a set of rules that have to be followed when obtaining data for estimating reliability indicators.

Testing plan is marked by a combination of three symbols: n – number of pieces equipment tested, U/R/M – replacement or renewal of faulty components / elements, r- – if the test is finished at occurrence of the r-th failure or t- – if the test is finished after the period t.

Example:
[n, U, n] – n objects are monitored. Faulty objects are not renewed or replaced. Monitoring is finished when the number of failures is n.

[n, U, t] – n objects are monitored. Faulty objects are not renewed or replaced. Monitoring is finished after the period t.

Testing methodology

It contains mainly expert information and technical documentation for the test:

- Type of test, name
- Purpose of test, binding, validity
- List of tested and assessed parameters
- Qualitative parameters values
- Test procedure
- List of testing equipment, devices and tools
- A diagram of testing equipment connecting
- Specification of products and their components for which the methodology is suitable
- Algorithms, mathematical methods and relations for testing evaluation
- Software for testing evaluation and test report printing
- Accuracy of testing method and corresponding veracity of the test result
- Heading for the table for test data collection
- Test conditions
- Specification of test conditions
- Load of working environment parameters
- Number of pieces tested
- Duration of the test
- Testing cycle
- Results evaluation criteria
- Limiting conditions
- Name of the organization and the author of the methodology, responsible employee and signature
- List of standards, regulations and documents based on which the testing methodology has been prepared

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9. MODELLING AND QUANTIFICATION OF SYSTEM RELIABILITY

Systems reliability

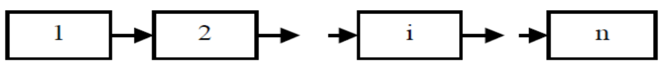
Reliability can be seen as the ability of the system (a product, component, machine, software, etc.) to perform the required function. High system reliability is required especially for the systems that run critical applications or even human life. System reliability is influenced by its components and their connection into the system. System reliability also changes according to the operational conditions in which the system works. An example is aviation equipment, which is repeatedly subjected to dynamic changes in its ambient during the flight. From mathematical point of view, reliability is defined as probability that the system operation during the given time and under given operational conditions will be adequate to the system purpose.

Reliability models

- Serial model of reliability
- Parallel model of reliability
- Combined serial-parallel system

Serial model of reliability

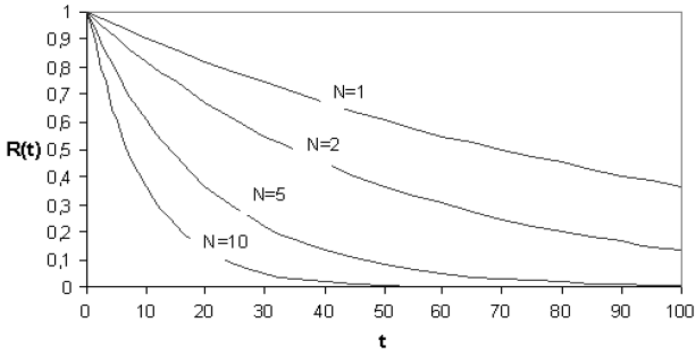
Serial system refers to connecting elements in a series (consecutively), where a failure of any element causes the whole system failure. The block diagram is shown in Figure 4.1. The blocks in connection correspond to individual elements. Between the input and output, there is only one connection passing through all blocks. This system can be also displayed by the graph in the picture.



Obr.4.1 Blokové schéma sériového systému.

Figure 4.1 - Block diagram of serial system

Průběhy *R*(*t*) pro sériové spojení jsou pro různý počet prvků uvedeny na obr. 15.



Obr. 15 Průběh *R*(*t*) pro sériově spojené prvky

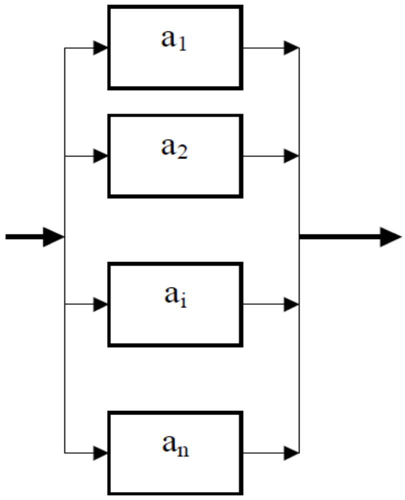
Courses R(t) for serial connection for different number of elements - see Figure 15

Figure 15: course R(t) for serial connection

Parallel model of reliability

Parallel system is the connection of n-number elements in parallels (next to each other). A system failure occurs if there is a failure of all elements. The block diagram and oriented graph of a parallel system are shown in the figure.

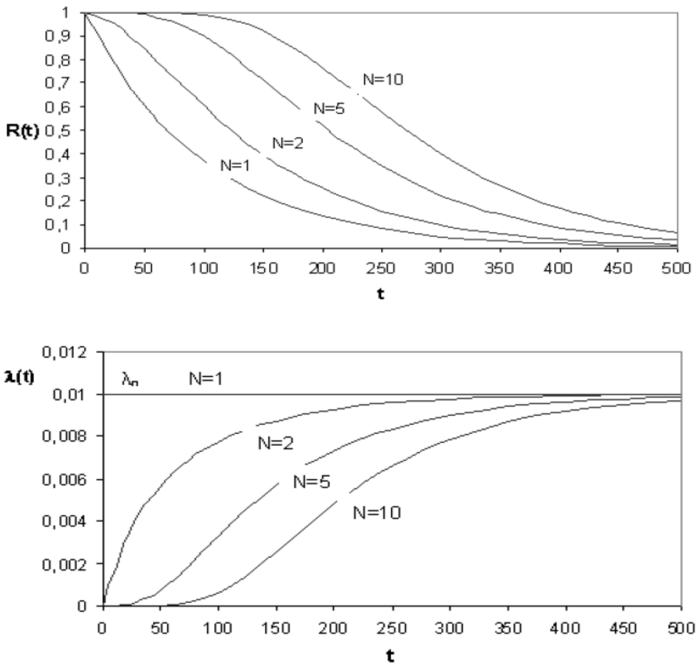
To ensure a trouble-free operation, one fully operational element is sufficient. Such a connection can be called redundant or backup, and i tis also very often used just for the purpose of backup.



Obr. 4.3. Blokové schéma paralelního systému

Figure 4.3 Block diagram of parallel system

Průběhy pravděpodobnosti bezporuchového provozu $R(t)$ pro různý počet paralelně zapojených prvků s exponenciálním rozdělením dob do poruchy jsou vyneseny na obr. 17.



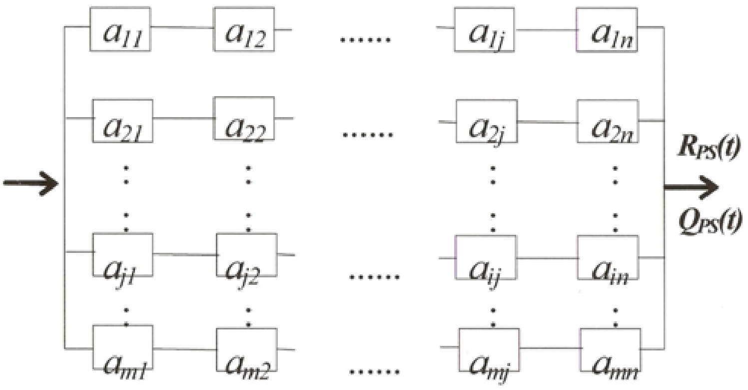
Obr. 17 Průběh $R(t)$ a $\lambda(t)$ pro různé hodnoty počtu paralelně zapojených prvků

Figure 17: Course R(t) and (t) for different values of elements connected in parallel

Combined serial-parallel system

It is a combination of serial and parallel connecting of elements in a reliability block diagram. The calculation of individual reliability indicators is carried out by gradual simplification of individual serial and parallel connections up to complete simplification.

When solving the problem, it is necessary to deal with the individual parallel elements and serial chains gradually, while the procedure of the methodology for multiplication of the failure or reliability probability must not be changed. Conversion from one parameter to another is carried out by subtracting from 1.



Comparing Rps(t) and Rsp(t)

- With the same values of Rij and the same dimensions of the system m, n the value of the Rsp(t) is always higher than the Rps(t) due to the fact that in serial-paralles system there are always more paths from the input to the output.

- Serial-parallel system describes a backup of each elementen separately, while in the parallel-serial system, always the whole sub-system is backed up.

10. MACHINE PERFORMANCE

Machine performance must be monitored regularly. For performance monitoring, there are three possible methods.

The first method consists in a semi-automatic performance monitoring, when the input data are entered automatically if it is possible. The data is collected electronically. However, the data is still partly collected manually by authorised personnel. The collected data are then processed and evaluated by a competent employee. For these purposes, information technology is used in the form of computers, and data is stored on a disc that is shared and to which other workers have access or the data is sent directly.

The input data for calculations can be collected manually, and the calculations are also carried out manually, using paper forms, and evaluated manually as well. The data are usually presented only a few times a year on a selected site in the company. A disadvantage of such a method is a dependence on the human factor, inaccuracy, frequent data failures due to various reasons and the related unreliability.

The method when the machine performance data are collected automatically consists in equipping both the machines and the workplaces with terminals where data are collected automatically after product passing the line. At control workplaces workers enter the date into the computer. The data are then gathered in the information system. In this case, the possibility of human error is negligible and the data show high reliability and accuracy. The results of such processes are appreciated. Certain disadvantage of this data collection method is high purchase price; on the other hand, the costs of daily data collection are almost zero.

Electric power

Machine performance varies but a basis of every machine is a source of power, e.g. a servo motor, electric motor and other sources of power. In terms of mechanical engineering, it can be said that machine performance is determined by electrical sources, especially in the case of machine tools and other machines used in mechanical engineering. This electrical machine performance is called rated power. Rated power must be determined by the producer. When determining rated power, the producer must choose one of the rated power classes. The indication of the class must be given after the rated power. If there is no indication, the rated power for permanent load applies. Rated power can be divided into four classes for four types of power source. For DC generators, it is a rated power measurable on the terminals. Another source is an AC generator, where the apparent power is measured at terminals and is expressed in voltampere, while in the case of DC generator the power is given in watts. One of the most widely used machine power sources are electric motors, where the rated power is mechanical power at the shaft of the motor, expressed in watts. The fourth type, which is not that widely used, but it is worth mentioning, are synchronous compensators, where the rated power is reactive power at the terminals and is given in reactive voltampers.

Rated power classes

Rated power for permanent load

Rated power at which the machine can work for an unlimited period of time while at the same time complying with the requirements.

This rater power class corresponds to the load S1 and is referred to as rated power for load S1.

Rated power for short operation

Rated power at which the machine can work for a limited period of time, starting at ambient temperature, while at the same time complying with the requirements. This rated power class corresponds to the load S2 and is referred to as rated power for load S2.

Rated power for periodical load

Rated power at which the machine can work in work cycles while meeting the requirements.
This rated power class corresponds to one of the periodical load S3 – S8 and is referred to as rated power for the relevant load type. If not specified otherwise, the length of the work cycle must be 10 minutes.

Rated power for discontinuous constant load and revolutions

Rated power at which the machine can work with relevant load and revolutions of the load type S10 for an unlimited period of time while meeting the requirements. When determining the maximum allowable load during one cycle, it is necessary to take into consideration all machine components, e.g. insulation system with regard to the exponential rule for relative expected thermal lifetime, the bearing with regard to temperature, and other components with regard to thermal expansion. If the maximum workload is not specified in other relevant IEC standards, it must not exceed 1.15 times the load resulting from load type S1. Minimum load can be zero, while the machine idles or is disconnected and does not work. This rated power class corresponds to the load S10 and is referred to as rated power for load type S10.

Rated power for equivalent load

Rated power for test purposes at which the machine can work under constant load till reaching a steady state temperature and at which the same warming of the stator winding as the average warming during the work cycle with the specified type of load.

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A machine designed for a general use must have a rated power for permanent load and must be capable of working under load type S1. If the load has not been specified by the customer, the load type S1 is used and the assigned rated power must be the rated power for permanent load.If the machine was designed for a rated power for a short operation, the load type must be S2.If the machine was designed for changing load or for load including idle operation or disconnection, the rated power must be the rated power for periodical load resulting from the selected load type S3 – S8. If the machine is designed for non-periodical changeable load with changing revolutions including over-load, the rated power must be the rated power for non-periodical load resulting from load type S9. If the machine is designed for discontinuous constant load including idle operation or overload, the rated power must be the rated power with discontinuous constant load resulting from load type S10.

Sx are types of load specified in the standards.

11. MACHINE TOOL PERFORMANCE AND OPERATION

Machine tool performance has an increasing decisive influence on production efficiency and product quality. Today customers are looking for machine tool producer who would meet their high performance requirements. Being competitive on the world market means to be able to produce machine tools with high speed and accuracy. Similarly, more reliable and energy efficient machines and components are required. The operators require production wil less demanding maintenance, low impact on the environment and low operating costs, which is what profitability depends on.

Machine work performance

Work performance Q of automated production lines is a performance achieved in actual operation. Is considered a basic one and consists in certain technologic, cycle and actual performance.

Technologic performance – refers to a number of workpieces machined by a given equipment per a time unit, while fully using the possibilities of the technological process.

Cycle performance – describes maximum performance when achieving all designed parameters at trouble-free operation. Determining the cycle performance results from the assumption that the automated line operates continuously without faults and downtime.

Actual performance – is given by work in real conditions, when it is necessary to consider both continuous operation and operation with downtime caused by tools replacement, adjusting, etc.
Individual interruptions in the operation of automated production lines are referred to as off-cycle losses. They can relate to tools (replacement, adjusting, etc.), to machines and their accessories (mechanism and control failures), technical and organizational, caused by the rejection rate, related to the changes of production programme. Even though all the machines of the production line have the same losses, the performance can be different due to the different structure of the line. The individual machines have downtime not only due to their own losses, but also due to other machines that do not fulfill their functions. Thus, additional losses occur, whose extent depends on the structure of the production line

Off-cycle losses consist of:

Expected own losses – e.g. start of the line operation before reaching the work temperature, change of the shift, planned maintenance, tools replacement, checking machine nodes, etc.

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Random own losses – tool failures (breaking of blade), mechanisms failures of some of the machines in the line, rejects etc. Random own losses can be reduced by dividing the line into individual sections, between which storage reservoirs for workpieces are, so that in the case of accidental failure the whole line is not out of order, but only the part where the failure occurred and in which the individual machines are interconnected. This can reduce downtime, increase the performance and utilization of the line.

Machine performance is influenced by the following three basic areas of work cycle:

Automated work cycle, sequence of functions on the machine, clamping and handling with workpieces, manipulation with tools and measuring workpiece dimensions, position of tool blade.

For users, overall performance of a modular single purpose machine tool is important, determined by:

Required number of work-piece produced on a specified machine per certain period of time, machine shiftability.

Here, the overall performance is calculated as time required pro production of one workpiece using the specific machine:

$tpc = (60 * Sp * H * Dd * \tau) / Nr$

where: tpc – is maximum overall time for production of one workpiece

Sp – number of work shifts per 1 day

H – number of working hours per shift

Dd – number of working days in a year

τ – coefficient of machine utilisation (0.7 – 0.85)

Nr – required annual production (pieces).

Machine operation

Machine operation refers to the time when the machine is capable of full operation and thus produce a product or perform activities for which it is intended. Operational deployment of machines depends on regular and proper maintenance of the machines. Machines as such are designed so that they are ready for work immediately after turning on, including the initial setting of parameters.

Machine maintenance

General definition of maintenance: Maintenance is a combination of all technical, administrative and managerial activities during the life cycle of the object focused on keeping it or returning it to the state in which it is capable of performing the required task or function. The objective of the maintenance is to keep the production equipment in technically good and operational condition at optimal costs. Preparedness is a machine ability to be in the state of performing the required function in given conditions, at a given moment of time or in a given time interval, provided that the necessary external re-

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sources are ensured. All this depends on reliability, maintainability and ensuring maintenance. Reliability or trouble-free operation is the machine ability to perform the required function in given conditions and in a given time interval. Maintainability is the machine ability to remain or to be restored in the state in which it is able to perform the required function under given conditions.

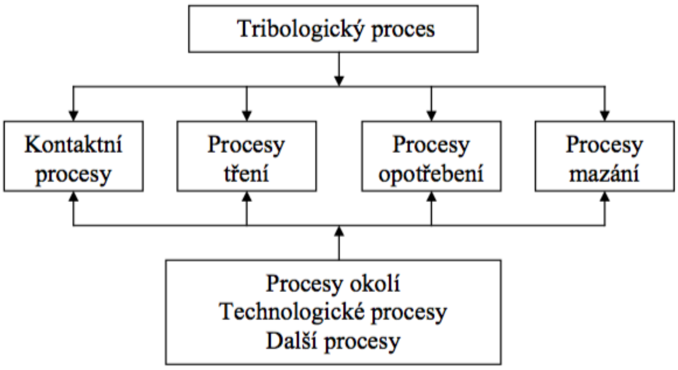
Proper machine maintenance principles

During the installation and handing over the new machine, the supplier should pass also the information and instructions regarding the regular maintenance of the machine, as well as the types and individual activities and functions of the machine, to the service staff or the responsible person.
Like any other performed activity, maintenance of machine tools shall adhere to the set rules and principles which include the following: Regular and efficient maintenance consisting in preparing a maintenance schedule and its strict adherence, keeping operating log for each machine, where every maintenance related activity shall be recorded. There should be also recorded every random or more serious error message. The records are then used by service technicians in order to identify and repair the individual faults, spare parts register kept as wear caused by the machine operation, mark and specify the individual functions of the machine, to provide a complex overview on service interventions being performed to individual machines and costs related to removing the defects, immediate removal of the defect detected, and in the case of necessary expert intervention, to contact service technician. The effectiveness of regular maintenance and control measurements has been demonstrated in several areas: increase in life span of the machine, ensuring machine accuracy in the long term, reducing the rejection rate, saving money, ensuring safety of work. The companies that already have applied regular and quality machine maintenance in their production facilities show considerable savings in costs related to machine repairs compared to the situation when the machine maintenance was not give adequate attention to. Nowadays they are able to prove that the initial investment is actually saving money. Lack of regular maintenance results in low machine operation.

12. TRIBOLOGY AND TRIBOTECHNICS

Tribology is a discipline dealing with processes of friction, wear and lubrication

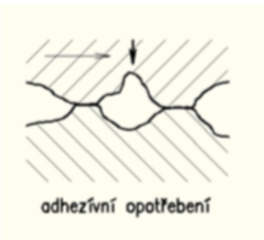
- Sliding, rolling, striking and oscillation
- Mechanical engineering – designing bearings, piston motors and other devices, machines and their components
- Cosmetics – lipsticks, conditioners, powders
- Medicine – joint replacements



Legend: tribologický proces – tribology process, kontaktní procesy – contact processes, procesy tření – friction, procesy opotřebení – wear, procesy mazání – lubrication, procesy okolí – ambient processes, technologické procesy – technologic processes, další procesy – other processes

Wear

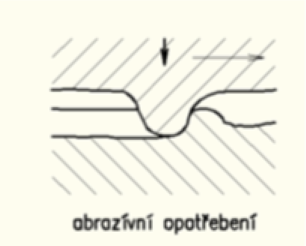
Adhesive wear – is characterized by separating and displacement of metal particles between two contact surfaces



Erosive wear – it takes place when particles contained in the flowing medium fall on the functional surface

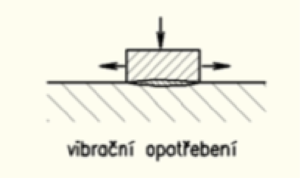
Fatigue wear – is created by gradual accumulation of failures in the surface layer of the functional area

Abrasive wear – separating of material particles due to hard and rough surface



Cavitation wear – separating of material particles due to the cavitation of the flowing medium

Fretting – separating of material particles between two contacting surfaces due to mutual oscillatory movement



Tribotechnics

- One of the tribology disciplines dealing with the application of tribology results in practice
- Significantly contributes to a more efficient use of machines in industry

Tribotechnics deals with:

- Lubricants and lubricants testing
- Materials for friction pairs
- Calculation, construction and optimizing of friction pairs
- Lubrication methods and lubrication systems
- Scientific foundation for friction and wear
- Measuring and control methods for tribotechnic processes
- Special technological processes to increase the wear resistance
- Organizing lubrication technique in the operation

Economic importance

Using the proper application it is possible to achieve significant savings in a number of areas:

- Reducing the consumption of energy necessary to power the machines
- Increase in machines and devices lifespan
- Reduction of downtime caused by failures and necessary repairs
- Reduction of maintenance costs and costs of machine repairs
- Increase of machines accuracy
- Reduction of investment costs
- Reduction of costs necessary to purchase suitable lubricants

Lubricants

The main function of lubricants is:

- To reduce friction at the contact point of two objects
- To ensure heat removal
- To remove dirt from the friction surface
- To protect metal surface against corrosion
- To seal lubricated surfaces

There are various lubricants based on their types, properties and ability to perform the required function:

- Liquid lubricants (lubricating oil, cutting fluids)
- Plastic lubricants (greases)
- solid lubricants (e.g. graphite, MoS_2)
- gas lubricants (e.g. air).