RELIABILITY CENTRED MAINTENANCE

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Reliability centred maintenance (RCM) is the method which is used for the selection of maintenance programme that can effectively achieves the required safety, standby and economy of operation. This contribution is focused on this sophisticated method and is aimed at the description steps of RCM. Moreover, the RCM project is described on an example of the production machine. The objective is to propose the most suitable maintenance system for this production machine. In this project, the specialized software AMST is used.

KEYWORDS
reliability centred maintenance, failure mode and effect analysis, maintenance, criticality matrix, decision tree

1 INTRODUCTION INTO MAINTENANCE

The standard CSN EN 13306 defines the maintenance as a combination of technical, administrative and managerial actions during the life cycle of the object aimed at maintaining it in the current state or returning it to the state in which it can perform the required function. [CSN EN 13306]

Basically, maintenance can be divided into two basic kinds, maintenance after failure and scheduled maintenance. The object, which is at maintenance after failure, is operated uncontrolled over its whole life, and maintenance is done at a moment when a failure has occurred. On the other hand for the scheduled maintenance, we can distinguish between two basic forms. The former is a preventive maintenance, the latter is a predictive and pro-active maintenance. A common sign of both forms of scheduled maintenance is the introduction of such a system according to which the maintenance can be done successively. [Ben-Daya 2009], [Opocenska 2015]

The principle of the preventive maintenance is to prevent any failure. Based on the predicted life of significant parts of the object, the intervals for repairs and part replacement should be specified beforehand. The disadvantage of such method is often a redundant replacement of fully operated parts. The predictive maintenance is done at the moment when the technical life of a part is fully exploited, but before unexpected failure. This kind of maintenance can be called as the maintenance depending on the real conditions. To specify a suitable time interval for such maintenance, it is necessary to monitor the object continuously or at least periodically, and depending on the operating parameters observed this time interval can be specified. For such maintenance, the diagnostic systems are very often applied.

The pro-active maintenance originated from the predictive maintenance and it uses, as well as the predictive maintenance, technical diagnostics as a source of information, but usually more complex. Relatively independent branches of diagnostics are combined for the purpose of pro-active maintenance to monitor optimally the whole object. The pro-activity is also manifested with respect to a possible connection of different diagnostic systems. [Vdolecek 2008]

A selection of suitable maintenance strategy for a specific device is very important task in the field of maintenance management, especially during the programme planning and the maintenance intervention planning. Safety of operation is also important in the maintenance system planning. [Blecha 2014]

At present days, the methods are used to simplify the selection of such suitable maintenance systems. One of such method is the reliability centred maintenance mode (RCM).

2 PRINCIPLE OF RCM

The reliability centred maintenance was developed at the end of the sixties in the last century. It was originally designed for the aircraft industry, however today, it is used in other industrial branches. The objective of this method is to provide as most as possible failure-free operation, usually for complex machinery and equipment.

The basis of RCM is to find such maintenance by which the effective standby, safety and economy of operation will be achieved, and, additionally, the maintenance will be advantageous for the society from the economic point of view. [CSN EN 60300-3-11]

The RCM mode has four basic signs by which it differs from other processes of the preventive maintenance. These are the following signs:

1. Keeping the system functions.
2. Identification of failure mode for the components which can cause undesired functional failures.
3. Categorization of failure mode based on logical decision tree.
4. Searching for usable and effective preventive activities. [Legat 2013]

The instructions for the application of such mode are given in the standard CSN EN 60300-3-11 Dependability management, Part 3-11: Application guide – Reliability centred maintenance. In compliance with the standard, the complete RCM process is divided into five steps which are described in Fig. 1.

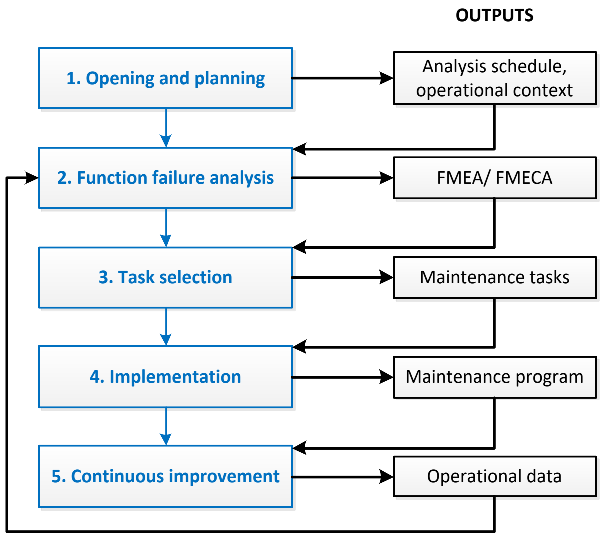

Figure 1. RCM process [CSN EN 60300-3-11]

The first step of the RCM analysis is to determine the needs and the range of the study. According to the available data in the maintenance management system, the system/subsystem area is defined, i.e. machine parts or equipment. The subject of analysis is usually a system and/or a subsystem, at which, for example, the operational context has been changed, and which has manifested insufficient standby, at which the safety affecting events have occurred, which has called for inadequate high scheduled maintenance or maintenance after failure, and which has required excessive costs for maintenance, etc. Additionally, the available knowledge and the skills of the specialized experts with the object and its operational context are identified. To make the analysis, the knowledge and skills about the RCM process, knowledge about details and object conditions, knowledge about the operational context, knowledge of safety and environmental legislation, and finally, the knowledge about maintenance and about total costs are necessary. To make the analysis, the information about the object operation and its previous history is necessary. The analyses of failure-free operation, the producer's user guides, manuals, design documentation, the existing maintenance tasks, reports on failures, operational procedures, expert's opinions, etc. are used. The output of the first step is the analysis schedule and the operational context of the object. The operational context must involve the object operation including the details about the technical system parameters.

In the second step, the failure analysis is discussed, the operational data and the available test data are acquired and analysed, and moreover, the object function is learnt. If the analysis of a complex object is done, the complete functionality can be divided into the following simple parts. Consequently, possible failures are defined for each function. Besides this, the failures involve a complete loss of functionality, insufficient performance, interrupted function or the function performance in the time, when not requested. Moreover, the failure modes, the consequences, and/or the criticality of failures are specified. When the list of failure modes is processed, it is important that only such failures with real possible occurrence are involved. For each failure mode, the consequences of failure are successively identified, i.e., what will happen if an occurrence of the given failure mode happened. The FMEA/FMECA analysis is as an output in this step.

In general, it is not effective to involve all identified failure modes into RCM analysis. Hence, a mode of criticality assessment is very often used, i.e. the analysis of criticality at which the severity and the intensity of failure occurrences are combined. The criticality should involve all aspects of the failure occurrence, including operational performance and costs effectiveness. The criticality assessment is used to determine the priorities and the identification of such failure modes which must be incorporated into the analysis.

In the next RCM step, individual tasks are selected. The maintenance tasks are as an output. For example, the consequences of failures are assessed, the most suitable management failure policy is chosen, and moreover, the time intervals among individual tasks are selected. The objective of RCM task selection is to choose such failure management policy by which you can prevent or mitigate the consequences of the identified failure modes. The choice of such policy is governed in compliance with the decision-making chart which is shown in Fig. 2. For each failure mode, it is classified that the failure of function is for the operator evident or hidden under normal conditions, and if this failure mode leads to the safety/environmental or economic/operational consequences. Additionally, for each failure mode, the most suitable failure management policy will be specified. The condition monitoring, scheduled replacement, scheduled recovery, searching of failures, no preventive maintenance or alternative interventions belong among the selectable and possible analyses. [CSN EN 60300-3-11]

The last step but one is the implementation, and its output is the maintenance programme creation. The details about the maintenance tasks will be expanded, for example, about the information which involves the processes and the performance time, the number of workers needed for maintenance, safety and health instructions, spare parts at each maintenance place, etc. The analysis output can be a huge number of tasks with different frequencies. For creating a suitable maintenance plan, the tasks should be rationalized so that the time intervals are in compliance and the redundancy is removed. The effect of ageing will be investigated for the purpose of the systemic assessment of the interval of maintenance tasks in the object based on the knowledge from operation specifying the optimum maintenance interval.

The last step monitors the maintenance effectiveness, and the performance of safety, operational and economic objectives. The RCM analysis will reach its objective during the next development, and hence the operational context and all documents related should be kept over the whole life of the object and checked in the regular intervals as soon as the configuration or the operational requirements are changed. [CSN EN 60300-3-11]

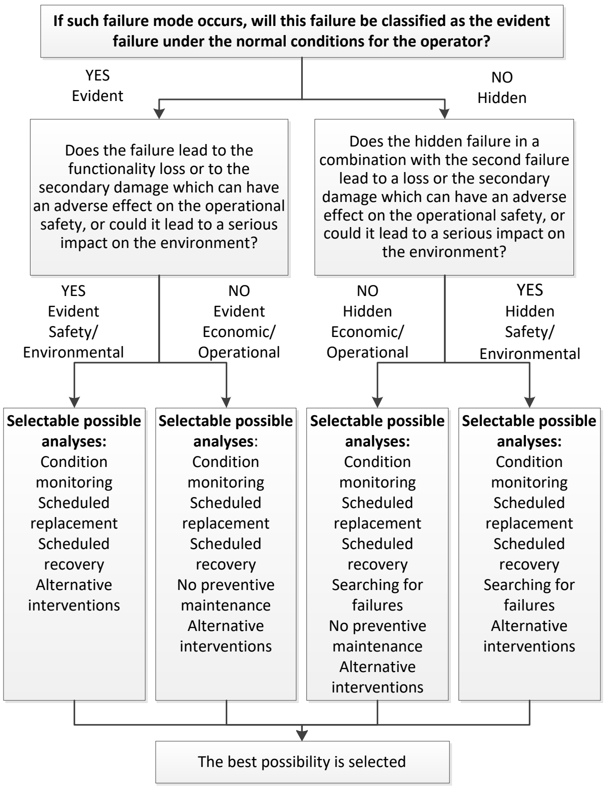

Figure 2. Decision-making chart in RCM [CSN EN 60300-3-11]

From the above mentioned steps, it is evident that RCM provides the complex programme aimed not only at the preliminary but also at the consecutive activities needed for achieving the demanded results of the analysis.

3 RCM APPLICATION WITH PC SUPPORT

If we come back to Fig. 2, it is evident from the chart that the choice of the most suitable management policy depends mainly on the expert who performs the RCM analysis. Whether the maintenance was designed properly, the time will show.

To make easier the decision for selecting the maintenance system, the specialized software packages are used. One is the AMST (Asset Management Support Tool) program which is intended directly for the RCM analysis support.

In the following text, the RCM project is described in details. As mentioned earlier, the analysis schedule and the operational context of the object were created. An automatic lathe was chosen for the analysis due to its insufficient scheduled maintenance. The objective was to propose the most suitable maintenance system for the lathe.

The existing maintenance system is shown in Fig. 3.

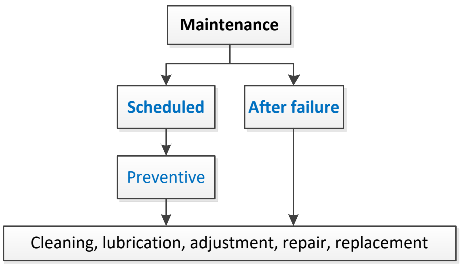

Figure 3. Existing maintenance system of the lathe

The individual systems and subsystems to which the RCM mode should be applied must be defined for the analysis area specification. For the analysis purpose, the equipment was divided into the individual parts, that is, the kinds of servo units, spindle motors, pumps, amplifiers, lubrication units and pneumatic unit, spindles, battery, chucks, etc. After specifying the analysis area, 95 parts were defined for the lathe. Into the operational context, all important information about the equipment was involved, for example, technical parameters, production programme, percentage utilization (production, downtimes, number of cycles), consumption, etc. In the framework of the analysis, the information and the data about all possible failures of the lathe have been collected since its putting into operation in March 2011.

In the next step, all possible failure modes, their possible causes and consequences were identified and entered into the software package. The AMST software environment is shown in Fig. 4, where is an example of the main spindle and assigning its failure modes and cause of failure mode to the individual analyzed parts.

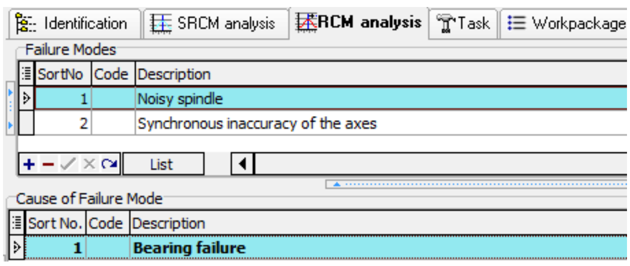

Figure 4. Failure modes and cause of failure mode assignment in AMST software

Then, the corresponding criticality matrix was created in the software. The criticality matrix can have different forms and different criteria for the assessment, for example, safety criterion, loss of production, financial impact, environmental impact, etc. [SKF 2015]. In the framework of the RCM analysis, a one-parameter criticality matrix was used while the criterion of the financial impact was applied for the assessment based on the failure modes. The criticality matrix used including the amount of the financial impact are shown in Table 1.

Financial impact	Low	Middle	High	Extremely high
Criticality value	Financial impact up to 5 000 CZK	Financial impact from 5 000 CZK to 50 000 CZK	Financial impact from 50 000 CZK to 100 000 CZK	Financial impact above 100 000 CZK

Table 1. Criticality matrix used

The next step of the analysis selects the maintenance strategy of the given equipment, i.e. making decision about the maintenance mode.

The AMST software package assists the user in selecting the most suitable maintenance strategy and even in selecting its individual components by means of the decision tree which is shown in Fig. 5.

Follow from up to down in the decision tree and select the answers (YES, NO) for the questions given in boxes.

Meaning of individual questions:

- Hidden? – Is the occurrence of failure hidden for the operator under the normal operating condition?
- Critical? – Is the occurrence of the failure consequences unacceptable?
- FAR? – Is the failure age related?
- Cond. Ind? – Is there any indicator by means of which you can identify a possible failure?
- CFI? – Has the failure a constant and known failure interval? [SKF 2015]

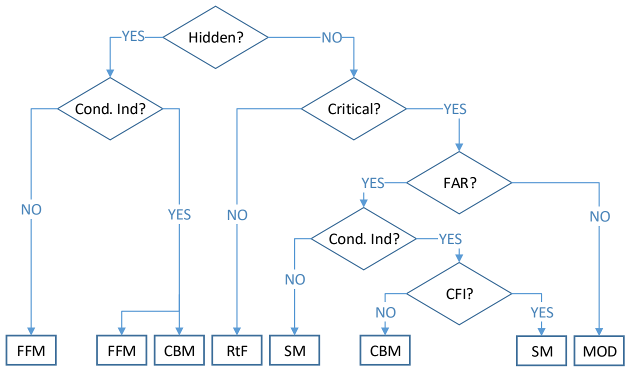

Figure. 5 RCM Decision Tree

After selecting the answers in the decision tree, the software will propose a suitable maintenance system. The meanings of individual maintenance systems are as follows:

- RtF – Run to Failure. Maintenance is done after failure.
- FFM – Failure Finding Maintenance or Functional testing. For this maintenance mode, the regular tests are done to find out whether a component operates properly. This maintenance does not prevent failures, only detects and provides some indicators for the future.
- SM – Scheduled Maintenance. Maintenance of parts is done in the intervals defined beforehand and independently on the real condition of the part.
- CBM – Condition Based Maintenance. The real conditions of individual parts are observed during this maintenance. Based on the results of measurement, it is decided if maintenance is needed.
- MOD – Modification. This means that a change should be done at the equipment. The changes can be done in the design, process, material, safety provisions, monitoring of conditions, etc. [SKF 2015]

For the failure mode of the main spindle already mentioned above as the example for its extremely high financial impact, the CBM maintenance mode was selected based on the decision tree. The decision tree for the main spindle in the AMST environment is shown in Fig. 6.

The existing maintenance of the main spindle is based on daily checks (visual and acoustic checks) of abnormalities which can occur during automatic operation of the machine, monthly cleaning of sliding guides and collet, and finally, annual check of spindle run-out. This means that the only preventive maintenance mode is used.

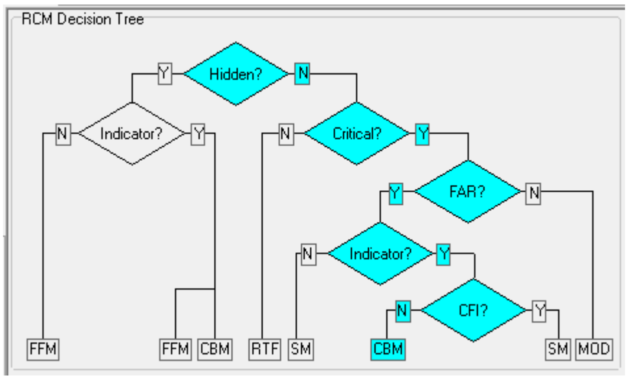

Figure 6. Decision tree in AMST software package for main spindle

Based on the RCM analysis and the AMST results, a new maintenance system was designed for the main lathe spindle which incorporates both the predicative and pro-active maintenance, because the Condition Based Maintenance was selected based on the decision tree in AMST software. The newly designed maintenance system is shown in Fig. 7. In this case, a combination of the methods from different branches of technical diagnostics should be used.
The condition monitoring of the lathe to prevent failure and total saving to the maintenance will benefits of the new maintenance system.

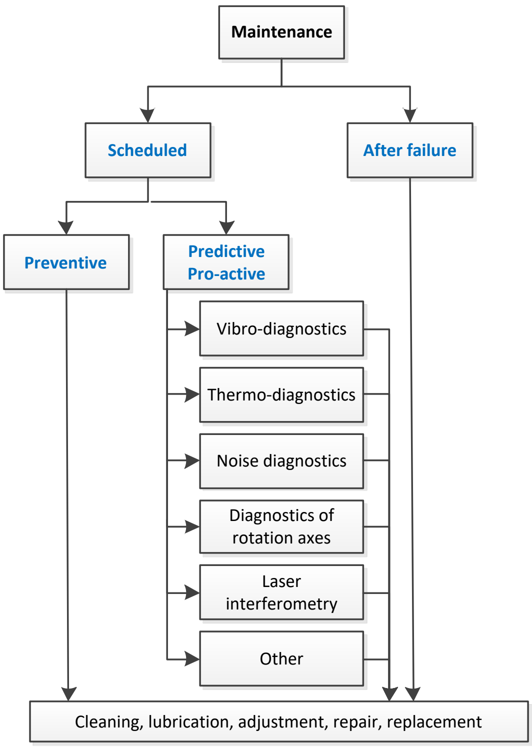

Figure 7. Proposed maintenance system for lathe

4 CONCLUSIONS

The present article is a contribution to the issues of reliability centred maintenance. This modern and sophisticated approach of maintenance is based on the principle of the logical decision tree, in which a suitable maintenance system is chosen based on the answers to the submitted questions.
In this contribution, the individual steps of the RCM analysis and the decision tree for choice of maintenance system according to the standard CSN EN 60300-3-11 were described. The decision tree according to the standard has several outputs, so the final choice of the maintenance system depends, to a large extent, on an expert's subjective assessment.
This contribution was focused on the implementation of the RCM project on the real example of the automatic lathe. The objective was to propose the most suitable maintenance system for this automatic lathe. In this RCM project, the AMST software was used, because this specialized software makes easier the decision for selecting the maintenance system. After answering the questions defined in the decision tree, the AMST software proposed the most suitable maintenance system.
From the analysis performed, it is evident that both the preventive maintenance system and the predicative/pro-active system should be used for this lathe. In this case, a combination of the methods from technical diagnostics should be used for monitoring condition, such as vibro-diagnostics, thermo-diagnostics, noise-diagnostic and other.
Whether the RCM analysis applied according to the standard or using the specialized software package, despite the considerable advantages of the RCM analysis, the drawback is still the subjective assessment of both the failure criticality and the setting of optimum intervals among maintenance interventions.

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