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Procedural Aspects on the Application of the Risk-Based Maintenance Concept in the Case of Structural Integrity Assessment of Industrial Processes Equipment

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Abstract

The paper presents and discusses the essential aspects specific to the application of the national concept of risk based maintenance (RBM), focused on reliability (RCM) and focused on the performance of equipment and facilities in the process industries. Currently, this type of maintenance is one of the most modern and innovative conceptual models which is based on control, monitoring and risk based inspection (RBI), uses a specific application procedure with great benefits and superior performance on improving the safety, integrity and structural reliability of equipment and industrial installations, reduces costs by eliminating ineffective operations of diagnostics, control, monitoring and inspections, and increases the availability of basic technical equipment.

Key words: *maintenance, risk of failure, matrix of risk, structural integrity, process equipment.*

Preliminary Considerations

Although there are today in common practice from the many national organizations in the field of process industries, the tend of planning and use of preventive oriented state control activities, monitoring, inspection and maintenance and based on prescriptive rules and experience, however, the necessity of and application of existing and conceptual modern maintenance procedures and risk-based inspection (RBI & RBM) and focused on reliability (RCM & RCI) became almost imminent.

The basic premise of reliability centered maintenance and inspection (RCM & RCI) is that all the equipment is damaged and have a limited life, but none of these assumptions is valid. Hypothetically though, if equipment or industrial systems are well designed, installed, operated and maintained, would mean that they will not ever damage and their life would be almost infinite. Some faults, if they exist, will be random and external influences (such as operating errors or improper repair) are the cause of all defects. Except instantaneous failures caused by gross operating errors or total abnormal outside influences, the methodology for analyzing the state dynamics of operation, can detect, isolate and prevent system failure.

However, the real concepts of maintenance and risk based inspection (RBI & RBM) covered by this paper, consider the use of a specific application procedure and evaluation of the reliability and structural integrity of the equipment and industrial installations and namely the exhibited risks [1]. These risk-based conceptual models are overall preventive work based on a large volume of monitoring, knowledge of evolution parameters within major equipment, knowledge and performance characteristics of equipment components, knowledge of replacement cost of the equipment itself and the elements components as well as knowledge the associated costs. Application of this type of maintenance assumes a database on:

- performance of equipment and installations;
- the evolution of working parameters;
- monitoring and diagnostic equipment;
- record the events every basic equipment;
- interruptions cost in supply of utilities.

Selecting conceptual models of risk-based inspection and maintenance or reliability-centered is a dependent feature according to which the facilities and equipments are new, modernized, currently being refurbished or have a normal projected life at the permissible limit of manufacturers or applicable regulations.

Description of the Procedure for Applying the Concepts of Maintenance and Risk Based Inspection and Reliability-Centered Maintenance (RBI / RCM)

Applying the concepts of maintenance and risk based inspection (RBI & RBM) and focused on reliability (RCM & RCI) in equipment and facilities for industrial processes require that all related work of specific activities (inspection / control, maintenance, repairs, etc.) are performed by experienced personnel at all levels. Typically, it is recommended that organizational management to consider putting together a complex multidisciplinary teams with expertise in inspection, maintenance, material study, manufacturing, fracture mechanics engineering (mechanisms of damage / degradation, safety and structural integrity), operation and processing equipment and facilities, reliability and risk assessment. In Figure 1 below, the procedure for application of risk-based maintenance is represented, consisting of five basic technical steps [1]:

a) preliminary analysis;
b) the collection and validation of data;
c) risk analysis;
d) the process of decision / action plan;
e) implementation.

In addition to the five basic technical steps shown above, it will be added a technical-organizational phase, defined by assessing the effectiveness. One of the six specific steps procedure for applying the risk-based maintenance, with the largest size, is the risk analysis on several levels.

Preliminary analysis

This first stage characterize the technological location (equipment, facilities, components, etc.), establishes objectives for analysis and system boundaries considered (components, main degradation mechanisms, possible failure scenarios and the time selected for analysis of risk).

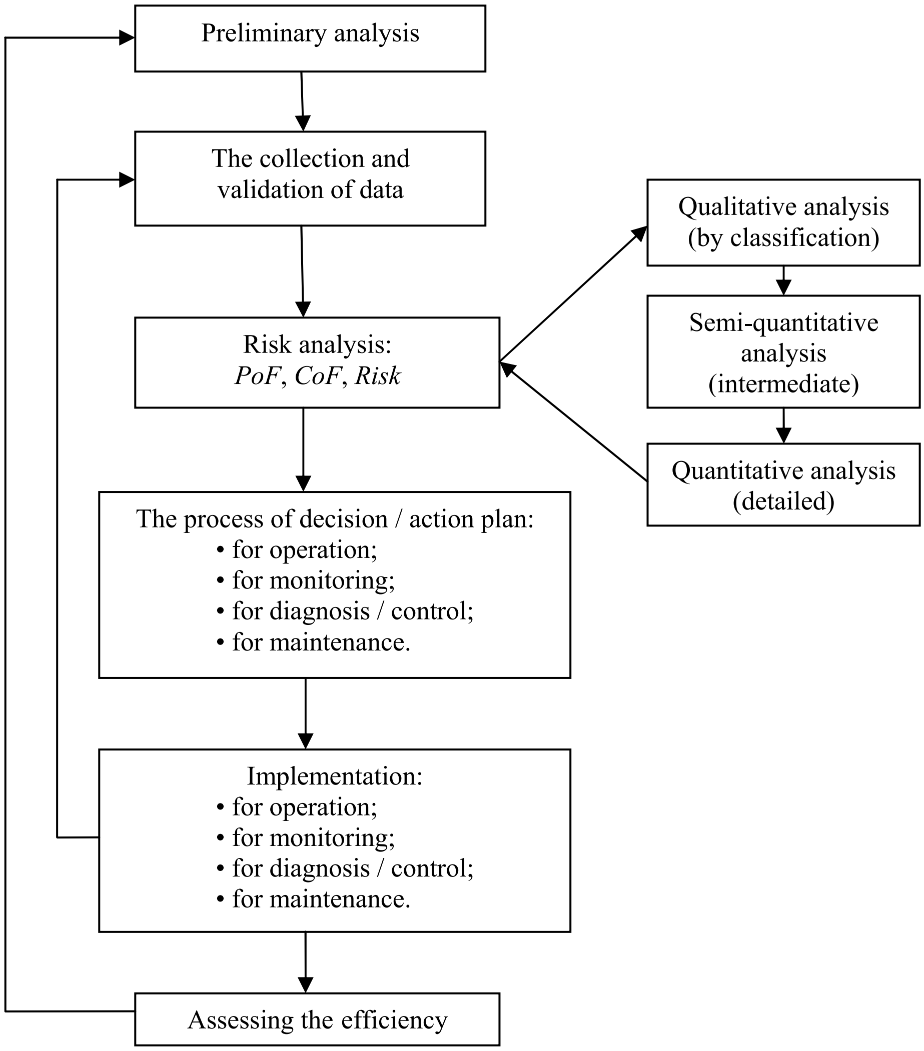

Fig. 1. Procedure representation for applying the risk based maintenance [1]

For example, if a piping system technological within the facilities and equipment for industrial processes, defining the limits of the technical system is analyzed considering the following:

- system components: main pipelines for technological steam (material / steel 12H1MF; pressure P = 150 bar; the working temperature t = 550 ºC; the number of operating hours 141.000; the number of start-stop 142; dimensions of pipe Ø 325 x 38; without incident in operation);
- the main deterioration mechanisms, primarily for simple mechanical stress of creep and mixed - fatigue-creep;
- the main failure scenario possible: breaking of creep; the secondary, cracking creep-fatigue at due to vibration;
- selected time for risk analysis for the piping system is considered 100.000 operating hours, established by the at projection (7,5 years) and 200.000 operating hours, the target-objective established for the analysis (15 years).

The acceptability criteria are established by the holder of activity through the regulatory requirements (ISCIR, TRD etc).

The collection and validation of data

The target goal of this stage is to gather and organize all relevant data and information necessary for the analysis. These data are used to assess both the probability and the consequence of a failure scenario to the methods of analysis that satisfy the basic requirements of the procedure. For example, for a technological industrial piping system analysis, it will collect the following data:

- geometrical characteristics (inside diameter, projection thickness of the wall etc);
- operating parameters (temperature and pressure of design);
- the characteristics of material (the average creep rupture strength, fatigue strength at a given temperature);
- operating time, in hours;
- monitored parameters (temperature and pressure);
- results of previous test (nil ductility temperature, *NDT*; transition temperature at break with generalized plastic deformation, *FTP*), including the records previous inspection;
- preliminary data calculating (for example, the code ASME, the code TRD/EN 14952).

Risk analysis

This phase has as main objective to identify the relevant risks for each system within the limits of the scope of work and determine the probability and consequences of failure on several levels (in depth, in detail) of risk analysis. The purpose of risk analysis is to reduce work effort for objects at low risk and enhance the effort at high risk.

The result of this stage is to determine a category for the probability of failure (PoF) and other categories for consequence of failure (CoF) corresponding to each part of the equipment examined. Based on PoF and CoF, the results of the risk assessment can be drawn graphically in separate matrices for each type of risk (technical, health and safety, environmental, economico-financial etc.). Since creep and fatigue are the main degradation mechanisms, specific of installations and equipment in process industries, determining the probability of failure (PoF) in the example considered, is based on creep and fatigue exhaustion.

According to the representation of the application procedure of risk based maintenance in Figure 1, presented above, the risk analysis is carried out on following levels:

- qualitative analysis (by classification);
- semi-quantitative analysis (intermediate);
- quantitative analysis (detailed).

In this paper is approached the first level for qualitative risk analysis (by classification) using the available data design technical component of analyzed and as additional data, the actual number of hours of operation. Using German technical rules TRD (EN 14952), it is calculated the service stress and depletion factors (exhaustion creep, e_z, exhaustion fatigue, e_w). Definition of classes corresponding the probability of failure (PoF) and consequence failure (CoF) are used to create failure scenarios using the "bow tie" chart type, whose application example for the analyzed industrial technological pipe system is shown in Figure 2. Thus, for the definition of class *PoF* following are used notation: *PoF Ez* – failure probability based on creep exhaustion; *PoF Ew* - failure probability based on fatigue exhaustion; *PoF E* - failure probability combined for *PoF Ez* and *PoF Ew*.

It is proceeded similarly to define the CoF classes by using the following effects and economic consequences of failure: additional cost of replacement, the typical cost of repair, loss of production due to failure, the overall cost of replacement, combined repair cost / loss of production ; costs due to additional degradation of the equipment ; costs due to replacement / combined degradation; replacement value, cost of breaking by overall degradation.

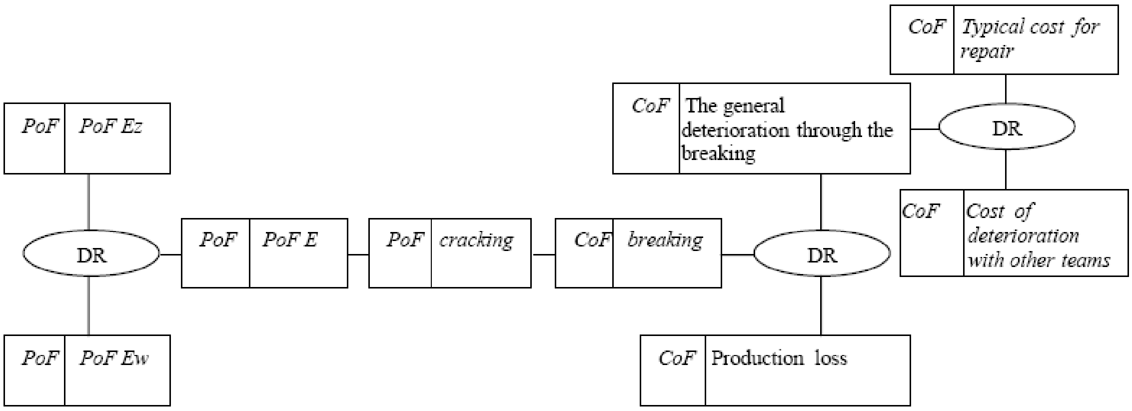

Fig. 2. „Bow-tie" diagram type for the technical analysis system

The definition phase of the classes aforementioned is succeeded by calculation of the values, respectively for PoF and CoF. In the qualitative analysis from the classification stage it have been defined 5 classes for POF (Class 1 - virtually impossible, Class 2 - highly unlikely, Class 3 - unlikely, Class 4 - somewhat likely, class 5 - very likely) and 5 classes for CoF (Class A - Repair / waste of time, class B - repair or replace the pipe with financial consequences, class C - the burst and the financial and environmental consequences, class D - breaking and shutdown / financial and environmental consequences / loss of reputation , class E - additional to the previous class - casualties / deaths, injuries).

The consequence of failure (CoF) was assessed by expertise / diagnostics combined with existing information from service and maintenance history [2, 3]. Aspects of potential consequence have included engineering and technical consequences including: degradation, cracking, potential / catastrophic burst by failure and financial consequences (cost of repair / replacement and lost production, the consequences of environmental pollution and impacts on the safety of personnel, by dead, injuries and loss of business reputation, etc.).

Given the PoF and CoF values and following previously defined scenario diagram, by "bow tie" diagram of each component, it is proceeded to determine the risk through risk matrix corresponding to this first level of qualitative analysis through the use of classes corresponding to these values. In the considered case of the example, the risk matrix is shown in Figure 3.

As the duration of the projected life of 100,000 hours was exceeded at this level of risk analysis, it is considered that there is a maximum failure probability and a maximum consequence of failure as well the failure probability PoF is on class 5 and failure consequences CoF is in the class E. In this case of major risk is necessary on the one hand, the risk analysis at higher levels (intermediate and detailed) and on the other hand, organizing the maintenance activities (diagnostic / control, planning / programming execution, monitoring / inspection).

PoF	***5***					
	4					
	3					
	2					
	1					
		A	***B***	***C***	***D***	***E***
	CoF					

Fig. 3. Risk matrix for the qualitative analysis

Structural Integrity Assessment of the Technical System Analyzed

The evaluation of the damage (degradation, destruction) of the analyzed pipe material in the present paper, in the case of creep-fatigue mixed load, in the absence of national regulations is done according code ASME, Case N - 47- 29, Annex T [4]. Thus, according to [4-6], cumulating of damage in creep-fatigue mixed load must satisfy the relation:

$$\sum\left(\frac{n}{N_d}\right)_j + \sum\left(\frac{\Delta t}{T_d}\right)_k \leq D \tag{1}$$

where, $D = 1$ is total deterioration creep-fatigue; $(n)_j$ – number of repetitions applied to the type of cycle „j”; $(N_d)_j$ – admissible number of cycles at the design stage for type of cycle „j”, determined from the curve of fatigue (thermal) corresponding to the maximum temperature in the cycle; q – the unique number of time intervals necessary for time of service at the request of creep load; $(T_d)_k$ – duration of admissible time determined by extrapolating the curve for time dependent stress creep; should be used maximum strength in pipe by the factor K', according Table T 1411-1 [4]. For the deformation ε_t = 0,2% from the curve of thermical fatigue [7], resulting value of $(N_d)_j = N_{fmedp=50\%}$ = 37520 cycles.

Considering a safety coefficient for the range of deformation n_e = 2 [2, 3] and a safety coefficient for the number of cycles n_N = 10 [7] for $\Delta\varepsilon_a$ = 0,2/2 = 0,1%, resulting the durability $N_{fmedp=50\%}$ = 26000 cycles. Applying the safety coefficient n_N = 10, resulting the admissible number of cycles $(N_d)_j$ = 26000 cycles. By doing the report between the number of expected starting-stopping cycles (142), resulting the rate of fatigue damage (thermal):

$$\sum\left(\frac{n}{N_d}\right)_j = 0{,}00546.$$

The values for technical time dependent resistance/stress determined by extrapolation through Larson-Miller method for 20.000 operating hours, according Table 1, are represented in Fig. 4, below:

Table 1

Method	$R_{rmed.}$			$R_{r\,\min}$		
	10.000	20.000	30.000	10.000	20.000	30.000
Larson-Miller	99.00	93.9	91.1	79.2	75.12	72.88
Scherby-Dorn	97.3	91.7	88.7	77.84	73.36	70.96

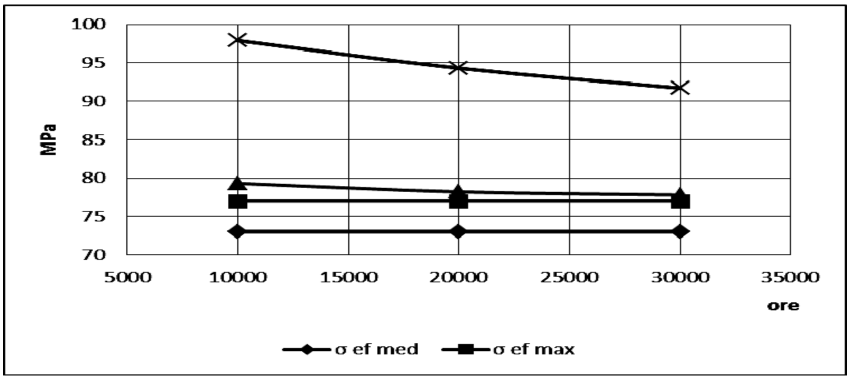

Fig. 4. Variation of technical time dependent resistance/stress through Larson-Miller extrapolation method

The rate of damage by creep is determined with the relation:

$$\sum\left(\frac{\Delta t}{T_d}\right)_k = \frac{20000}{50000} = 0.4\ \cdot$$

Taking account of the common action creep-fatigue, the sum for rate of damage calculated with the relation (1) is 0,40546, lesser than 1 (the corresponding for linear summation of deterioration). With the aid of values for the rate of fatigue damage (thermal) and creep it is represented *the cumulation diagram of creep-fatigue damage* from Fig. 5 (for austenitic stainless steels type 304 and 316, low alloy steel 2.25Cr1Mo and alloy 800H tip NiFeCr) [4].

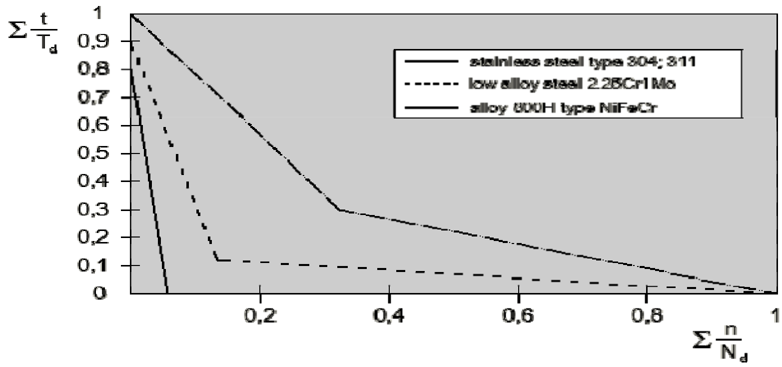

Fig. 5. Cumulating diagram of creep-fatigue damage

At the end, it has been found that besides the consumed lifetime for 141.000 operating hours, the pipe – main line can also operate in safe conditions for approximately 20.000 hours, according Fig. 6.

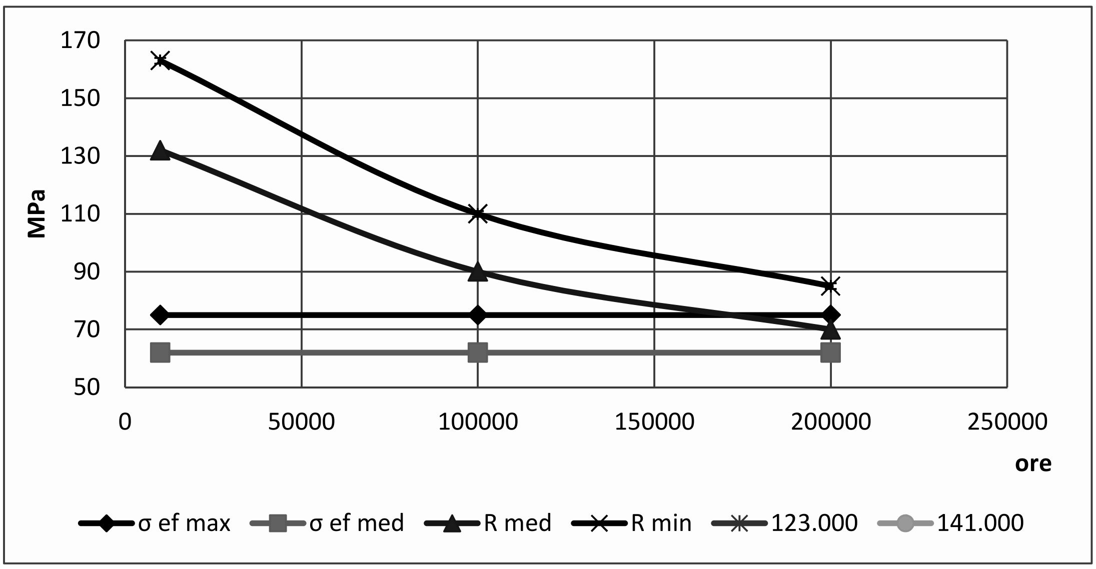

Fig. 6. The life-time diagram

Thus, the probability of failure *PoF* can be fitted in class 2 and the consequence of failure *CoF,* in class E. That is why, it is also recommended a non-destructive examination after about 10.000 hours after the consummation 141.000 operating hours, for the detection of possible type crack faults, which are very dangerous for such application. Therefore, risk matrix is almost identical to with that of Figure 3, above.

Results and Conclusions

Considering that this paper represents an approach for procedural implementation of the maintenance concepts and risk based inspection of equipment and installations in process industries, it is highlighting the applicability of them in order to assess the risk and consequences of on safety and integrity of installations, people, the environment and financial costs.

From the qualitative risk analysis it results that the examined technical system presents a high risk, which places it in the critical area of major risk matrix and the evaluation of the damage to the pipe material analysis confirms on one hand, the possibility of safe operation during the remaining service life and on the other hand, the need to implement specific procedures for planning operations / work monitoring, diagnostics / control as well as of the maintenance and inspection based on risk related to the probability of failure during the remaining life.

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Aspecte procedurale referitoare la aplicarea conceptului de mentenanță bazată pe risc în cazul evaluării integrității structurale a echipamentelor pentru procese industriale

Rezumat

Articolul prezintă şi abordează aspectele esențiale specifice aplicării conceptului de mentenanță bazată pe risc (RBM), centrată pe fiabilitate (RCM) şi focalizată spre performanță asupra echipamentelor şi instalațiilor din industriile de proces. Actualmente, acest tip de mentenanță reprezintă unul dintre cele mai moderne şi inovative modele conceptuale care se bazează pe controlul, monitorizarea şi inspecția bazate pe risc (RBI), utilizează o procedură de aplicare specifică cu beneficii însemnate şi performanțe superioare asupra îmbunătățirii siguranței, integrității şi fiabilității structurale a echipamentelor şi instalațiilor industriale, reduce costurile, prin eliminarea operațiilor de diagnoză, control, monitorizare şi inspecție ineficiente, şi creşte disponibilitatea echipamentelor tehnice de bază.