New Methodology for Monitoring and Prevention of Rotating Parts Failures

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Rotating parts are very widely used as a part of mechanical systems in different industries to perform a large number of functions. Unexpected and instantaneous interruption in performing the main function of rotating part, i.e. transmission of rotating movement very often caused catastrophic failures of particular parts or complete mechanical systems mainly due to inertial forces. Great importance in prevention of rotating parts failures is associated not only with suppressing the injuries, but also with assuring the safety of people. Thus, to establish the adequate methodology for monitoring and prevention of rotating parts failures it is of great importance to define the optimal preventive maintenance and engineering. In this paper the chronological classification of flaws of parts which were built-in mechanical rotation-based systems was presented. New methodology for monitoring and failure prevention of rotating parts was presented through the examples of shaft, as a part which was usually possible to repair, and bearing, as a part which was not possible to repair. In addition, this paper elucidates some possible additional influences which contribute to operating stability of rotation-based systems, and which were not covered by common operating indicators, as well as some measures for prevention of severe failures.

Keywords: *Rotating parts, flaws, failures, preventive maintenance*

1. INTRODUCTION

Operation of rotation-based mechanical systems is a synonym for vibration, reliable operation of a system, efficiency and other technical indices that can provide only an indication of the system functionality during its safe exploitation. However, practice has shown that despite the satisfying technical indices, this type of rotating systems (fans, low-power turbines, different translator of rotating motion etc.) is susceptible to failures and considerable damages.

This work describes chronologically classified flaws of the built-in rotating components and methodology for monitoring and prevention of failures of rotating components exemplified in cases of a shaft which in certain cases can be repaired and a rolling-bearing which cannot be repaired. In addition, the effects of other parameters not covered by the established indices but exerting considerable influence on the operating system stability as well directives for their incorporation into the maintenance procedures aimed at preventing the gross failures were given particular attention.

2. CHRONOLOGICAL CLASSIFICATION OF FLAWS

Failures that can appear at different stages of a component life cycle of rotating systems can be classified in several categories [1], as seen in Fig. 1.

Out of the cited flaws, a certain number, primarily from the design-based group and some from construction-based group, can appear within a relatively short time of operation. However, material-based technological flaws exist as hidden and as such can occur even under the optimal operating conditions. Depending on their magnitude, character and position these flaws are responsible for serious damages and sometimes complete destruction of a component. Operation flaws result from the deviations from the normal operating conditions, whereas the repair-based flaws occur as a result of either inadequate repair technology or the use of unsatisfactory parameters prescribed by the refurbishing technology.

It is therefore of utmost importance to formulate the preventive measures for determining the flaws distribution according to causes and timings of their occurrence during operation. However, analysis of flaw/failure causes, if carried out at all, has many inadequacies, misconceptions and lack of understanding of its purpose and necessity to be carried out whereby the use of preventive maintenance is practically out of any consideration. The objective but not justified reasons for not carrying out such analysis are as follows:

- Cause of flaw/failure is often impossible to determine.
- Due to high probability of simultaneous occurrence of two or more failures in complex systems these flaws remain unnoticed.
- Practically in all flaw/failure analyses the quantitative analysis of the contributions from different damage parameters is absent. This approach and the lack of developed methodology for determining the real causes of failures/damages lead to their subjective assessment.

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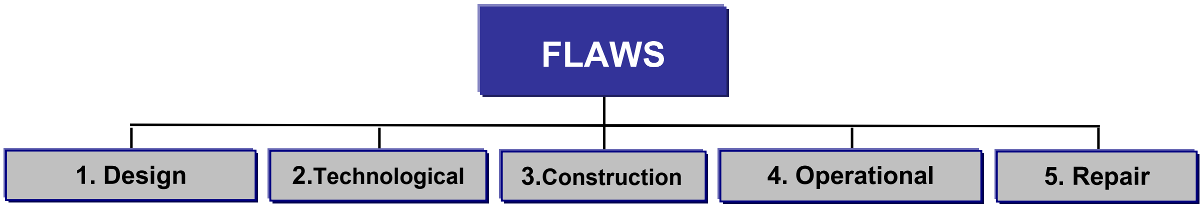

Figure 1. Chronological classification of failures.

- Instead of the real causes of damage mechanisms rather the failure features such as fatigue cracking, stress corrosion etc. are accentuated.

The above cited omissions are directly responsible for the absence of appropriate maintenance measures

3. EXAMPLES OF FAILURE DAMAGES OF ROTATING COMPONENTS AND THE BASE FOR MAINTENANCE METHODOLOGY

From the techno-economical points of view, the type of component and the flaw present determine the extent and consequences of damage. Few failures that occurred during the last two years on the rotating components of domestic thermal power plants were the result of a joint action of many types of failures. Hence, these failures and all other steps preceding the operation of a system can be used as an essential requirement for modifying the maintenance process and its qualitative implementation [2-5]. Microphotography images (Fig. 2) of damaged fresh air fans taken on two thermal power plants clearly show the damaged bearing, shaft sleeve and fan working wheel.

Basically, for the damaged rotating systems, as the first step in defining the maintenance measures for the repair and replacement of system components, the following distinctions have to be made:

- Replacement of irreparable parts/components following malfunction
- Reparation of reparable parts/components as determined by the extent of damage.

Hence, it is the classification of the components that defines the parameters to be monitored during exploitation.

Due to complex manufacturing process, bearings are generally classified as replaceable elements since their reparation is practically impossible or very expensive. Monitoring of these elements during their exploitation is achieved using vibro-diagnostic methods [6] since these enable to detect clearly and reliably disturbances preceding the more serious malfunctions – failures.

For the components such as shaft whose manufacturing is less complex and therefore selected for reparation (providing that during malfunctioning are not completely destroyed), the question of quality of built-in material, manufacturing and construction is of utmost importance for their safe and reliable functioning. Consequently, damage monitoring and prevention methodologies have to be defined separately.

Also, to maintain the functional operation of the rotating system as a whole, it is very important to know the type and method of manufacturing, that is,

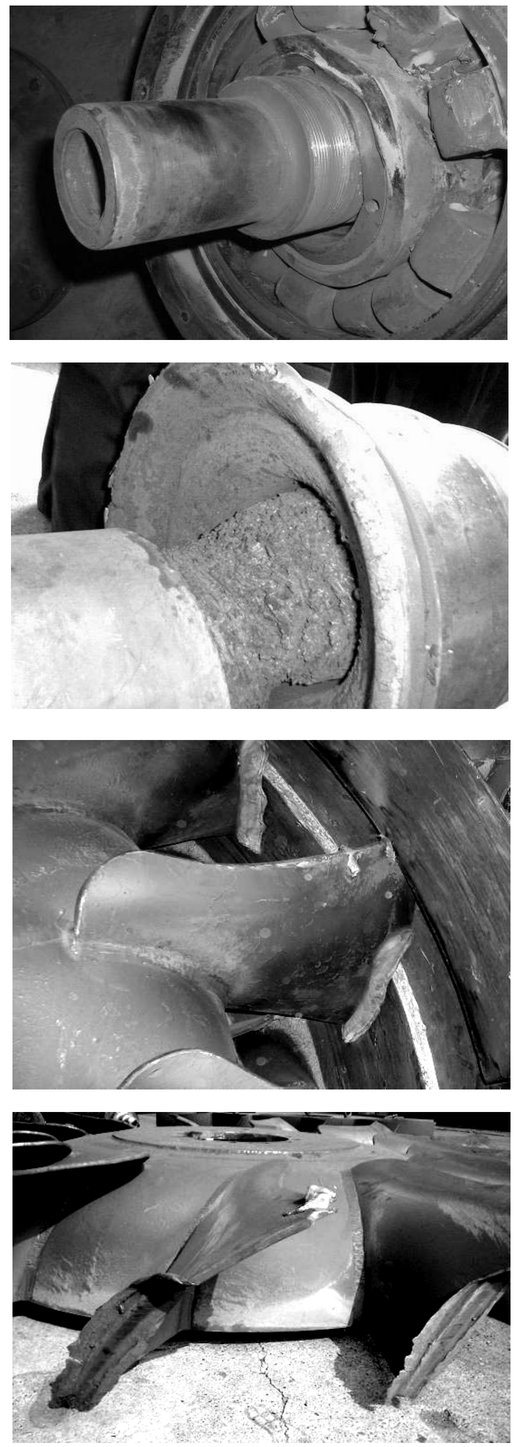

Figure 2. Different types of damages of rotating system components.

interaction of parts/components which can be monitored as well. The efficiency indices of built-in component functionality are often reliable indices of the system main functions as a whole.

4. PROPOSED NEW METHODOLOGY FOR MONITORING REPLACEABLE COMPONENTS OF ROTATING SYSTEMS

Rolling-bearings, as the essential elements of mechanical systems, exert significant influence on the system lifetime since the premature failure of the rolling-bearings provokes the malfunctioning of the system as a whole. Furthermore, rolling-bearings can be used as indicators of some errors and irregularities on other mechanical components (rotating elements, shaft and others) and thus to monitor the condition of mechanical systems and prevent the failures, it is essential to monitor the condition of the built-in rolling-bearings. Hence, one phase in defining the maintenance measures and systematic application of the proposed methodology is the knowledge and the use of all relevant data in setting-up the "identity card" for a specific rolling-bearing. In Fig. 3 are shown the main factors defining the lifetime of rolling-bearing and its reliability during exploitation

Condition of rolling-bearing before installation. Rolling-bearings made by the same and particularly by different manufactures differ in quality and thus the same rolling-bearing (same type and series, with the same built-in dimensions and carrying capacity) can have different lifetime under the same operating conditions. Quality of rolling-bearings depends on 1. - Construction determined by the internal geometry complying with contradictory criteria (minimal dimensions and mass but maximal carrying capacity, speed limit and others). 2. - Materials, 3. - Production and assembly technologies (accuracy of dimension, shape and position of rolling-bearing components). In additions, the quality that is shortening of rolling-bearing lifetime reduction is affected by the damages caused by improper transportation and storage.

Incorporation of rolling-bearing. The most important incorporation factors impacting the rolling-bearing lifetime are as follows:

- Positioning in respect to other parts of rolling-bearing within the position tolerances. In case of improper assembling of bearing, relative angular misalignment of rings and cage can occur thus provoking excessive friction in the bearing, jamming of rolling bodies, cage damages etc.
- Proper fitting of the inner bearing ring and shaft sleeve, as well as cage openings and outer bearing should be firm. Appearance of clearance between inner bearing ring and shaft sleeve can cause slip of rings, increased friction and heating of contact surfaces. Bearing arrangements are often designed to allow insertion of an adapter sleeve which in turn lowers the system reliability due to the presence of an additional fit thus increasing the probability of assembling errors and operating irregularities.
- *Requirements:* 1.- Complete fixing of the rolling-bearing in immovable shaft support in the axial direction to avoid vibrations (occurring due to clearance presence) and possible damages of the bearing components, 2. – Assuring the optimal axial clearance in the movable shaft support which, if it is not properly dimensioned, can be lost with increasing operating temperature thus leading to additional, unforeseen axial loading and its premature failure.
- Sealing is important for two reasons: preventing leaking of lubricant essential for proper operating of a bearing and preventing the ingress of dirt particles (can cause severe damages of the working surfaces even sudden outage), vapor, water or other liquids (can change the lubricant quality and oxidation of bearing parts) into the bearing.

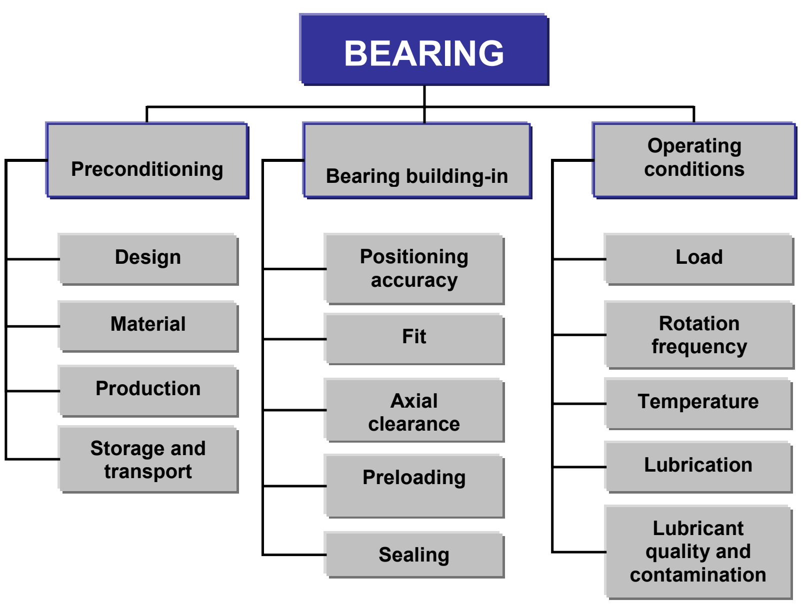

Figure 3. Main influencing factors defining the lifetime and operational reliability of rolling-bearings.

Opeating conditions. For reliable monitoring and lasting operation of a mechanical system the input data should incorporate the real operating conditions when selecting a particular roling-bearing, load, rotation frequency, operating temperature, characteristics of lubricating and filtration systems, lubricant properties, and the degree of contamination of the working medium. In case of unplanned and unforeseen disturbances in working conditions, such as changes in load direction, tendency and intensity, shocks, vibrations, sudden and high temperature changes of the contacting parts fit changes – tight fit transforms into loose and vice verse) poor quality, purity and quantity of lubricant can cause premature outage of rolling-bearings.

5. Proposed new methodology for monitoring the operation of irreplaceable components of rotating systems

Shafts as the carriers of rotating mechanical components are used to transfer the momentum along the rotating axis and have two supports, one of which is fixed and the other movable (enables translation in the axial direction). The load on the shaft comes from the rotating parts (main load), weight of shaft and its parts and no equilibrated masses on the shaft, whereby the first are covered by design/construction, whereas the second are not because these are production- or assembly-related. Important shaft "identity card" data is manifested through the effects defining the shaft lifetime and also tendency towards sudden and severe forms of outages, Figure 4.

Design/Construction. The role and main operating loads of a shaft are determined by the design, whereas its construction should ensure reliable functioning under required conditions. Shaft reliability is often misinterpreted as safety. However, reliability can only be considered after the shaft is built-in and used under real operating conditions and therefore thus subjected to the effects of a number of direct and indirect factors. On the other hand, since the safety factor should ensure sufficient thickness of a given material for specified operating conditions – requirements of statistical nature, its main role is therefore to compensate for differences in strength of materials and operating load [7], although often under extreme operating condition this cannot be realized. Hence, from the points of view of applied load charges, technology and maintenance, the validity of design, that is, construction of a component is necessary but not satisfactory condition for a reliable operation.

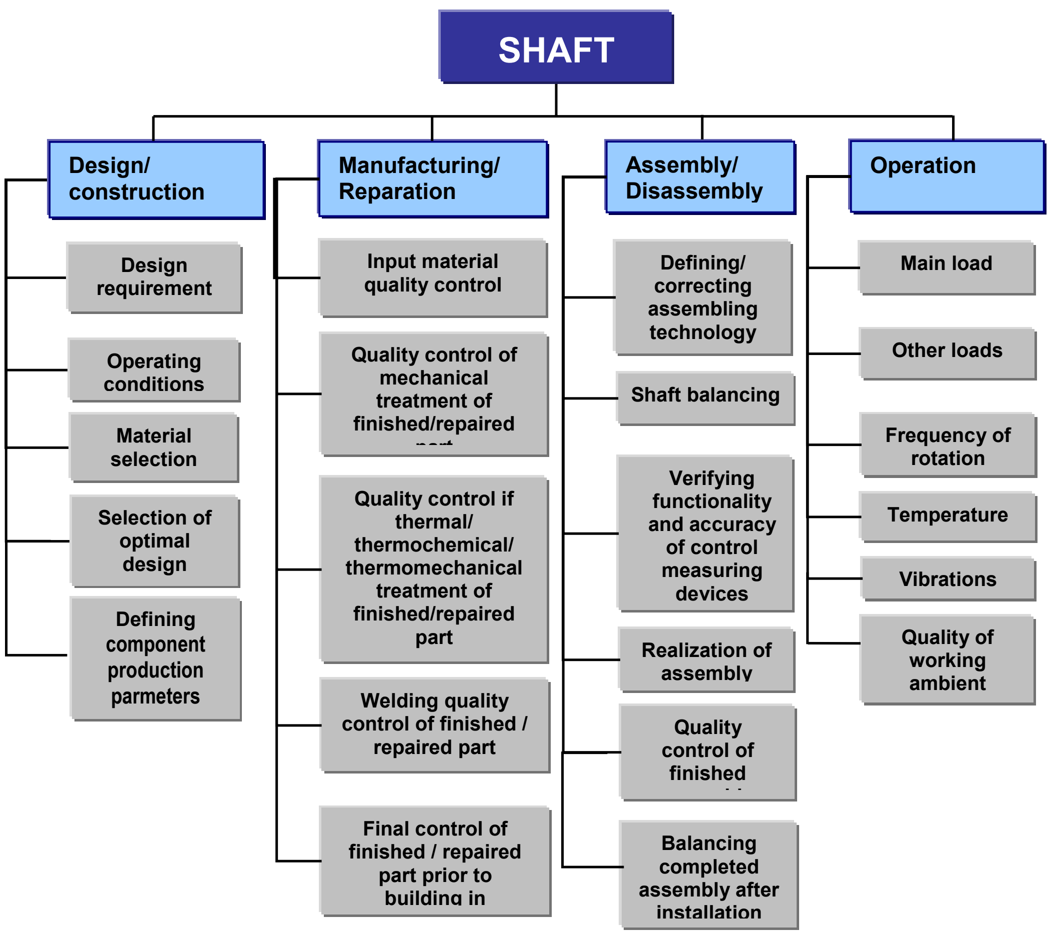

Figure 4. Main factors defining the shaft lifetime and reliability.

Production/Reparation. According to contemporary experiences, construction of a shaft involves a number of phases and is therefore a “weak spot” requiring quality control during its fabrication. Figure 4 depicts clearly the phases for which the quality control (material, fabrication or technology) is essential. This phase in the shaft lifetime is often completely absent and thus the lack of this data in the quality control process is unfavorable as essential for the analysis of the causes of outages. Following outages, shafts that sustained certain damages and required no replacement are often repaired and basically subjected to the same quality control procedure as when these were built. When reparation is required the accompanying documentation (sketches, attests, certificates) is essential. Contemporary experience has shown that most of the reparations are not sufficiently or even not all documented thus ignoring the fact that the repaired sites were the cause of outage and consequently tracing the real causes is impossible. It should also be pointed out that shafts delivered as new have often the sites that were repaired but not reported, so that the user discovers these during detailed examination or after outage.

Assembling. Assembly phase of a rotating system is one of the most delicate phases and from the chronological point of view is a second “weak spot”. Although manufacturer is obliged to provide precise instructions concerning the assembling and disassembling of delivered equipment, this often is not the case with domestic suppliers. Only clearly defined assembly procedure enables consideration of certain corrections bearing in mind the specific features of given equipment and required assembling conditions. The launching process of an assembly should include certification of the working capability of the whole assembly which, in the case of rotation-based systems, should include balancing, that is, checking the radial and axial assembly plays which is strictly specified for a particular type of rotating systems.

Operation. The operation conditions can limit or shorten the lifetime of certain assembly components relative to the assembly lifetime as a whole. It should also be pointed out that the lifetime of an assembly, as determined by the design, is reduced during construction and assembling processes and that it tends to change during exploitation. Therefore, in order to monitor the components conditions and prevent their outages it is required to maintain the operating parameters within their allowed limiting values and ensure simultaneously monitoring of the actual condition of the key parameters. Selection of parameters and their monitoring has decisive role not only to reduce the effect of outages but often as means for their prevention.

5. CONCLUSIONS

From many aspects, complete consideration of outage prevention is rarely treated fully, while the search for the real causes of an outage is even rarer. Based on detailed analysis of the high capacity and high-priced rotating mechanical systems, a new methodology is developed enabling to monitor the operating conditions and prevent outages on two types of components: replaceable – rolling-bearing and irreplaceable – shafts. Correct application of certain monitoring procedures, specific for these two types of components, makes possible to eliminate in advance the caused leading to extensive outages. It was shown that particular attention has to be given to the quality control throughout the entire life cycle of these two types of components. Systematic monitoring and quality control ensures that the reliability of these systems is no longer unknown factor and to certain extent can even be increased. One of the beneficial effects of applying these procedures is reducing the extent of damage when the outage is inevitable.

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ПРЕДЛОГ НОВЕ МЕТОДОЛОГИЈЕ ЗА ПРАЋЕЊЕ ПОНАШАЊА И ПРЕВЕНЦИЈУ ХАВАРИЈА РОТАЦИОНИХ ТЕЛА

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Ротациони делови су врло распрострањени у машинским склоповима и системима и обављају врло широк спектар функција у готово свим индустријским гранама. Непредвиђени и моментални престанак обављања основне функције ротационих делова - преношење ротационог кретања, углавном као резултат великих инерцијалних сила, има за последицу појаву хаваријских оштећења често праћених комплетним разарањем појединих делова или целог машинског склопа. Значај превенције хаварије ротационих делова се не огледа само кроз спречавање великих штета, већ и кроз обезбеђење сигурности особља у погону. Стога је дефинисање адекватне нове методологије за успешно праћење понашања и превенцију хаварије ротационих делова од изузетног значаја са аспекта превентивног инжењеринга.