6th INTERNATIONAL SYMPOSIUM ON INDUSTRIAL ENGINEERING

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&
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PROCEEDINGS

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PREFACE

Since the first symposium in Belgrade, Serbia nearly two decades ago, in 1996, International Symposium on Industrial Engineering - SIE has been held regularly every 3 years. It represents an opportunity for researchers in the Industrial Engineering community to review and evaluate their scientific achievements over the period since the previous SIE, share their most recent results and ideas, and discuss possibilities for new directions in research, joint experiments and observing campaigns.

The aim of the 6th International Symposium on Industrial Engineering – SIE 2015 is to contribute to a better comprehension of the role and importance of Industrial Engineering and to point out to the future trends in the field of Industrial Engineering. The Symposium is also expected to foster networking, collaboration and joint effort among the conference participants to advance the theory and practice as well as to identify major trends in Industrial Engineering today. According to these goals the Symposium addresses itself to all experts in all fields of Industrial Engineering to make their contribution to success and show capabilities achieved in the work that has been done are very welcomed. SIE 2015 provides an international forum for the dissemination and exchange of scientific information in industrial engineering fields through the large number of multidisciplinary topics.

The book brought together 80 papers and more than 220 authors from 19 countries, namely from Serbia, Germany, Portugal, Spain, France, Iran, Finland, Switzerland, Israel, Hungary, Canada, Lybia, China, FR Macedonia, Italy, United Kingdom, Taiwan, Russia and Bosnia and Herzegovina. The submitted full length manuscripts were peer-reviewed, and selected for publication by experts in their respective fields. The authors ranged from senior and renowned scientists to young researchers. Only unpublished papers were accepted and the first author is responsible for the originality of the paper. All papers are classified into seven chapters:

- Plenary Lectures,
- Risk Management,
- Human Factors,
- Production and Quality Management,
- Information Technologies,
- Engineering Management and
- Other Technologies in Industrial Engineering.

We expect that papers and discussions will contribute to better comprehension the role and importance of Industrial Engineering in this and other countries, both in domain of scientific work and everyday practice.

Our efforts in organizing would not succeed without the considerable help of the members of Scientific Program and the financial help of Ministry of Education, Science and Technological Development was greatly supportive for the success of the entire project.

At the end, the editors hope, and would like, that this book to be useful, meeting the expectation of the authors and wider readership and to incentive further scientific development and creation of new papers in the field of Industrial Engineering.

Welcome to the 6th International Symposium on Industrial Engineering – SIE 2015! We wish to all participants a pleasant stay in Belgrade and are looking forward to seeing you all together at the 7th Symposium on Industrial Engineering – SIE 2018.

Belgrade, September 2015

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SIE 2015 6th International Symposium on Industrial Engineering 24th-25th September 2015 FACULTY OF MECHANICAL ENGINEERING STEINBEIS ADVANCED RISK TECHNOLOGIES INNOVATION CENTER FME

RECOMMENDATION FOR A NEW MODEL OF THE MAINTENANCE SYSTEM OF TURBINE AND HYDROMECHANICAL EQUIPMENT AT THE HYDRO POWER PLANT DJERDAP 1

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Abstract. *Turbine and hydro mechanical equipment at hydro power plant 'Djerdap 1' is subjected to service conditions that lead to degradation of material of components and structures. Taking into account the rate of occurrence of failures (damages, accidents) and experience gained through long-term performing of tests it was established that main causes of material degradation are fatigue, corrosion, erosion and cavitation. Results of performed tests and researches carried out in order to identify the causes of material degradation, damaging and fracture of components and structures of turbine and hydro mechanical equipment during the rehabilitation of the hydro power plant 'Djerdap 1' showed that material degradation, damages and fractures occur due to the simultaneous influence of a large number of technological, metallurgical, structural and exploitational factors and that convenient structural solutions which would ensure mechanical reliability of components and structural integrity could be achieved only through absolute knowledge of their behaviour under various regimes of operation. On the basis of those results new system for maintenance of components and structures of turbine and hydro mechanical equipment was recommended.*

Keywords. *Hydro power plant, turbine equipment, hydro mechanical equipment, maintenance system model*

INTRODUCTION

Vertical Kaplan turbines, manufactured in Russia and with nominal power of 200 MW, have been installed in 6 hydroelectric generating units at hydro power plant 'Djerdap 1' [1]. Hydroelectric generating sets are being projected for the service life of 40 years due to structural solutions and limited possibilities of performing periodic inspections and state analyses.

Results of performed state analyses and researches that referred to determination of the cause of material degradation, damaging and fracture of components and structures of turbine and hydro mechanical equipment during the rehabilitation of hydroelectric generating sets A4, A5 and A6 at hydro power plant 'Djerdap 1' [2-6] showed that material degradation, damaging and fractures occurred due to the simultaneous influence of a large number of technological, metallurgical, structural and exploitational factors and that convenient structural solutions, which would ensure mechanical safety of components and integrity of structures, could be achieved only through absolute knowledge regarding their behaviour in various operating regimes. Basic components of the vertical Kaplan turbine are shown in figure 1.

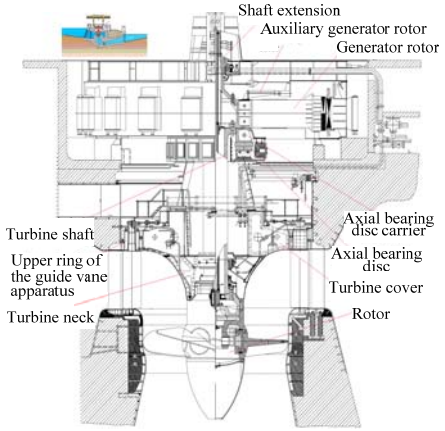

Figure 1. Appearance of the vertical Kaplan turbine

TECHNICAL DIAGNOSTICS USED DURING THE REHABILITATION OF HYDRO POWER PLANTS

Gradual degradation of parent material and/or deformation of components and structures of turbine and hydro mechanical equipment occurs during the service life of hydro power plants, therefore the diagnostic measurements and tests are being carried out only when the accelerated failure of components and structures due to flaws that occur during the manufacturing, assembly and service, as well as during the planned rehabilitation of hydro power plants [2-6], happens. Technical diagnostics during the rehabilitation of hydro power plants has to be based on 3 principles:

– Scope of testing and measurements have to be based on the history of use of turbine and hydro mechanical equipment,

– tests and measurements have to be carried out in compliance with specified procedures, through the use of adequate equipment and qualified personnel,

– results of tests and measurements need to be shown in such a way that the conclusions comprise the exploitation of manufacturing technical systems and a team of experts with suitable experience and knowledge from various professional and scientific areas. Properly executed technical diagnostics prevents sudden failure of components and structures of turbine and hydro mechanical equipment from happening, as well as rational technical and economical exploitation and safe working conditions for employees. It is very hard to analyse large production systems, such as hydroelectric generating sets at HPP 'Djerdap 1', due to the complexity of their structure, operating conditions and a large number of components and structures of turbine and hydro mechanical equipment. In such cases it is suitable to use FTA (Fault Tree Analysis), figure 2 [5]. For the analysis of modes and effects of failures, a method of qualitative and quantitative reliability analysis of components and structures of turbine and hydro mechanical equipment in all phases of service life and preventive analysis for all potential modes of failure of hydro mechanical generating set elements and their influences, FMEA (Failure Mode and Effect Analysis) is being used, figure 3. On the basis of performed researches regarding the failure and cause of malfunction of components and structures of turbine and hydro mechanical equipment at hydro power plant 'Djerdap 1' through the use of Fault Tree Analysis and Failure Mode and Effect Analysis [5], as well as indicators of reliability obtained on the basis of analysis of collected data for realistic conditions of service, optimum setting of the system for continual diagnostification of turbine and hydromechanical equipment based on the application of PLC-PC coupling could be carried out accurately.

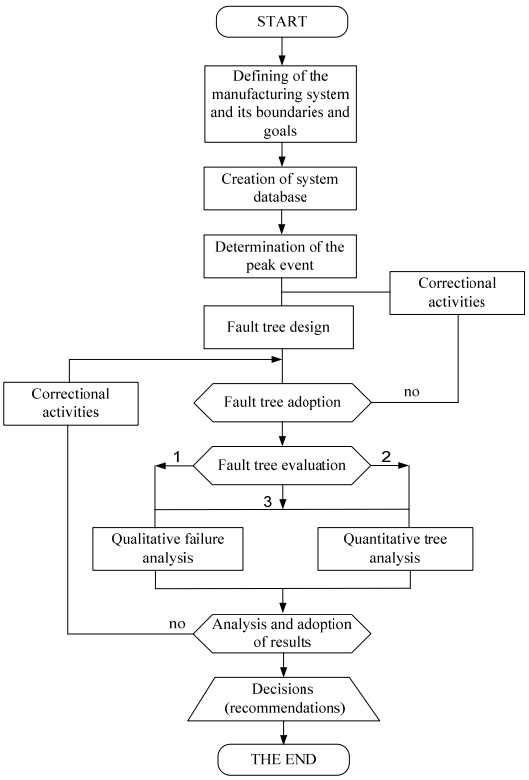

Figure 2. Fault Tree Analysis, block diagram

Figure 4 shows the schematical appearance of the configuration of the system for continual management, monitoring and diagnostification of the vertical Kaplan turbine through all system levels. It can be seen that it is possible to directly connect operational interface and hand-held programmer to the PLC [7]. Hand-held programmer has a numerical keyboard with light indicators for status marking and operator terminal which, with better models, can define up to 200 numerical and variable messages. Operator interface has the alphanumeric display with the functional keyboard and displays values of process variables, statuses, alarms and messages, logs that refer to system flaws and those defined by the user's program with the moment of creation and parameters predetermined by name or address.

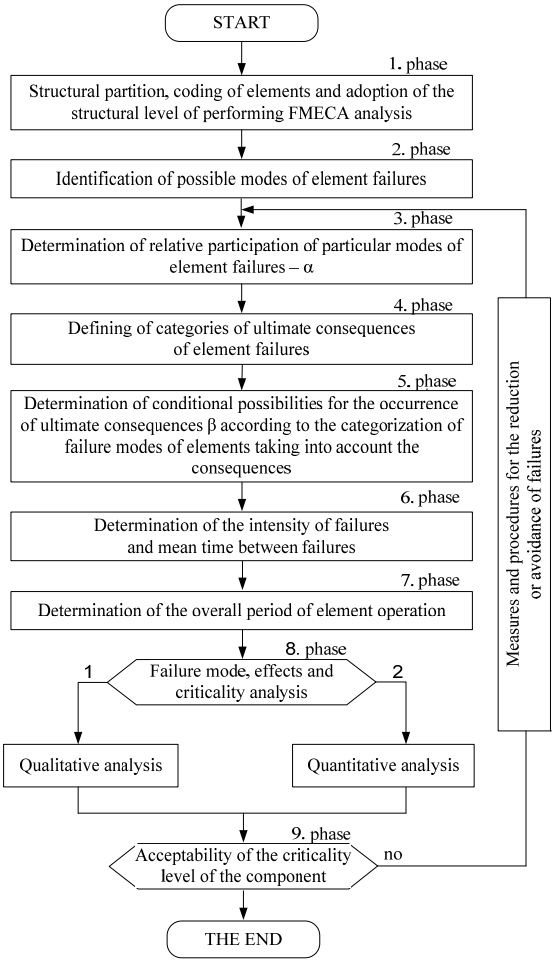

Figure 3. Failure Mode, Effects and Criticality Analysis, block diagram

DATABASES

Data on loads, properties of parent material and welded joints, technology of their creation, technical and physical characteristics of recorded fractures and prescribed measures of damage and failure prevention are being imported into suitable databases. Organization of the maintenance system of turbine and hydromechanical equipment at hydro power plant 'Djerdap 1' depends primarily on the nominal power, type and structure of the turbine, number of employees, experience of experts and suitable databases that refer to maintenance and previous inspections.

On the basis of realized researches [2] and many years' experience of authors regarding the maintenance of complex systems, the proposition of a new model of maintenance system for hydro power plant 'Djerdap 1' was made, figure 5.

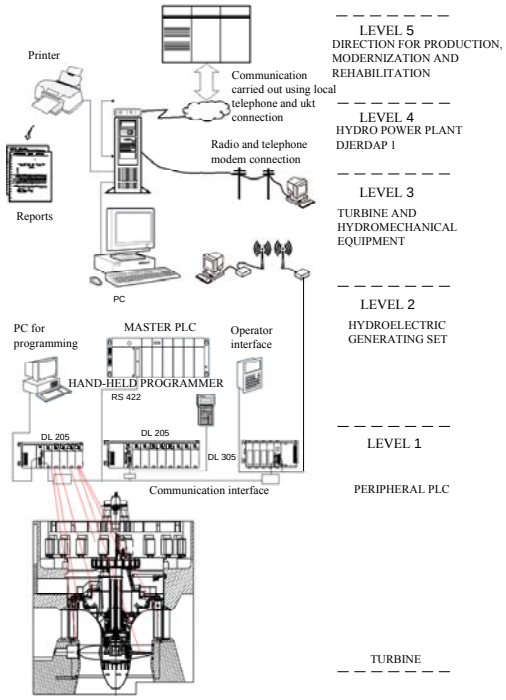

Figure 4. Appearance of the configuration of the system for management, monitoring and diagnostification of a turbine

CONCLUSION

Realized researches offer great possibilities in wide-ranging analyses performed in order to define behaviour of components and structures of turbine and hydromechanical equipment at hydro power plant 'Djerdap 1'. The goal of these analyses is to determine the cause of material degradation and failures of components and structures due to variations of a large number of influential factors, in order to get safer components and structures or to reduce undesirable effects to acceptable values, or in other words to realize suitable structural solutions.

A fast and reliable solution for the realization of convenient structural solutions regarding the components and structures could be achieved solely through the creation of databases and bases for the development of computer programs. The accompanying software packages would enable more efficient use of databases, analyses of particular influential factors, improvement of techniques, possibilities for fracture prevention and considering alternative solutions in all phases of design and development of components and structures of turbine and hydromechanical equipment. The above-mentioned would enable the development of the expert system for prevention of failure of turbine and hydromechanical equipment at hydro power plant 'Djerdap 1'.

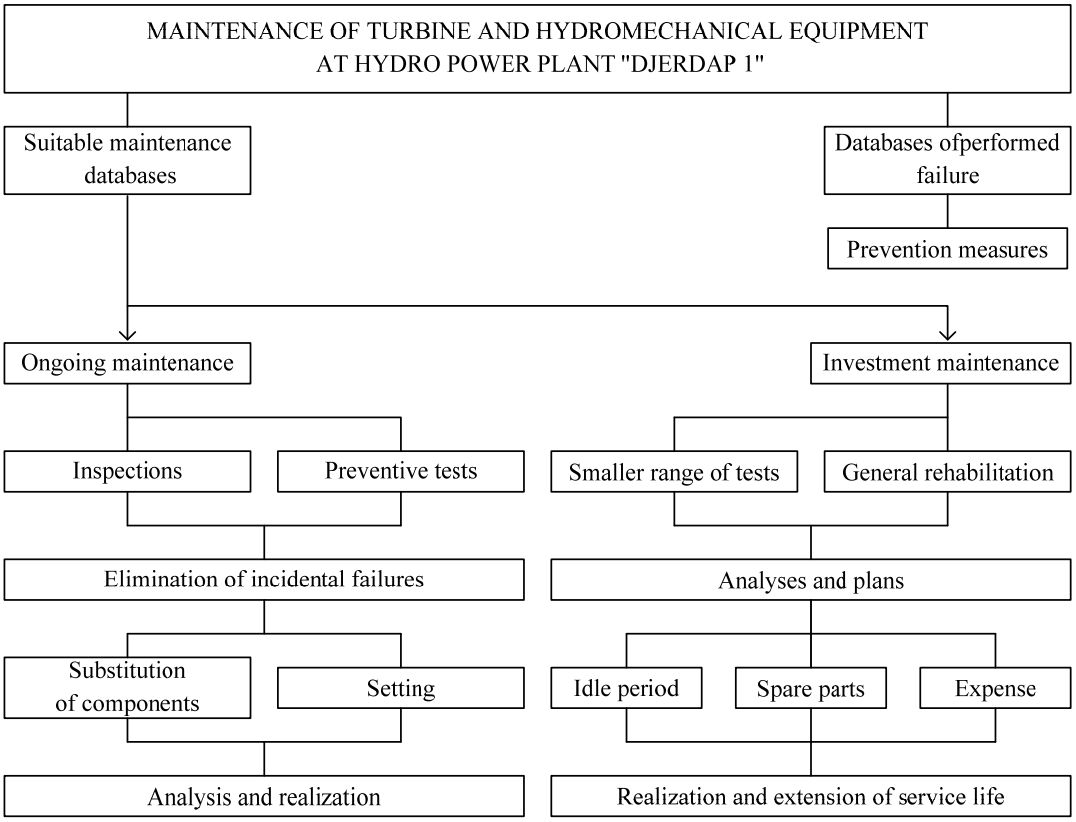

Figure 5. New model of the maintenance system for turbine and hydromechanical equipment at HPP 'Djerdap1'

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