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PREDICTION OF SERVICE LIFE OF COMPONENTS AND STRUCTURES OF HYDRO POWER PLANTS DURING THE DESIGN, PROTOTYPING AND SERVICE PERIOD

Miodrag Arsić[1], Srđan Bošnjak[2], Vencislav Grabulov[3], Dušan Arsić[4], Zoran Savić[5]

Summary: *During the rehabilitation of turbine and hydromechanical equipment at hydro power plant 'Djerdap 1' results of tests and researches carried out in order to analyze the condition of vital components and structures during service led to the conclusion that the components and structures could be made only if parameters of fracture mechanics were applied during the design and prototyping phase, because by doing so the occurrence of fatigue fracture and/or degradation of parent material and welded joints due to variable loading, corrosion, erosion and cavitation would be prevented, therefore the integrity of material would be maintained. Experimental determination of the fatigue crack propagation rate as an important property of development of the fatigue process during the action of the variable load, from the initial to the critical length, enables the prediction of the stable crack propagation period, or in other words of the service life of vital components and structures of turbine and hydromechanical equipment. Taking into account the fact that cracks are most severe of all defects, the results obtained for cracks could safely be applied for other types of defects which often occur in welded joints. This paper contains the methodological approaches for the assessment of integrity and evaluation of service life of components and structures of turbine and hydromechanical equipment during the design, prototyping and service period based on history of fatigue loading and application of fracture mechanics parameters.*

Key words: *hydro power plant, fracture mechanics parameters, service life prediction*

1. INTRODUCTION

Vertical Kaplan turbines, manufactured in Russia and with nominal power of 200 MW, were installed in 6 hydroelectric generating sets at hydro power plant 'Djerdap1', Fig. 1. Their projected service life is 40 years long due to the structural solution which disabled execution of periodic inspections and condition analyses [1].

Fracture mechanics is a scientific discipline which deals with cracks and their influence on the behaviour of materials and structures. Fracture mechanics (originally

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called crack mechanics) started to develop at the beginning of the 20th century through scientific papers created by Inglis and Griffith regarding stress concentration [2] and energy release rate [3], respectively. Irwin has set the foundation of linear elastic fracture mechanics by introducing the stress intensity factor and its critical values [4-5] in the 1950s. During that period fracture mechanics achieves initial significant successes by explaining the fractures that occurred at Liberty ship and Commet airplanes. Development of fracture mechanics in other important areas such as fatigue, creep and corrosion followed soon.

Practical application of fracture mechanics was based on ambiguous interpretation of its parameters from the very beginning. On one side they represent the load and geometry of the structure, while on the other they represent the property of material, or in other words its resistance to crack growth. Thereby the classic triangle of fracture mechanics was established (Fig. 2), while fracture mechanics became one of the foundations of the new scientific discipline – structural integrity. In other words, instead of dealing solely with fracture analysis, fracture mechanics became a significant tool in hands of engineers who need to prevent fractures from happening.

Methods of design of components and structures with limited service lives based on the concept of operating strength and principles of fracture mechanics have been applied more often recently instead of classic idealized calculations that predict endless service lives.

Structural integrity is a recent scientific and engineering discipline which in a broader sense comprises state analysis and behaviour diagnostics, service life assessment and rehabilitation of structures, meaning that beside the usual situation in which it is required to assess the integrity of structures when flaws are detected by non-destructive tests this discipline also includes structural stress state analysis.

2. PREDICTION OF SERVICE LIFE DURING THE DESIGN PHASE AND PROTOTYPE PRODUCTION OF COMPONENTS AND STRUCTURES OF TURBINE AND HYDROMECHANICAL EQUIPMENT

When it comes to components and structures of turbine and hydromechanical equipment it is necessary to perform the test simulation on the prototype and follow its behaviour in realistic operating conditions during the design phase. The goal of test simulations is to obtain data on strains in order to calculate the stress distribution, as well as data on stress concentration factors for welded joints in order to determine critical stresses. On the basis of data obtained in such manner predictions of service life of components and structures of turbine and hydromechanical equipment during the design phase could be carried out, Fig. 3.

In Fig. 4 it can be seen that the loading history, or in other words cyclic curves of dependance between strains and stresses, as well as stress concentration factors are input data for the calculation of damages that occur due to fatigue and prediction of service life of the prototype. The approach is based on the relation between the fatigue fracture and energy gathered during the cyclic strain process. Dispersed energy is being determined from the closed hysteresis loop, taking into account the residual stresses that occur during welding.

3. PREDICTION OF SERVICE LIFE OF COMPONENTS AND STRUCTURES OF TURBINE AND HYDROMECHANICAL EQUIPMENT BASED ON TESTS PERFORMED DURING EXPLOITATION

Procedure for the assessment of service life of components and structures of turbine and hydromechanical equipment at hydro power plants based on results of experimental tests is presented in Fig. 5. Significance of tested fracture mechanics parameters should be analized taking into account the possibility of occurrence of brittle failure. Such parameters are critical stress intensity factor K_{Ic}, initial fatigue crack growth rate da/dN and fatigue threshold ΔK_{th}, Fig. 5.

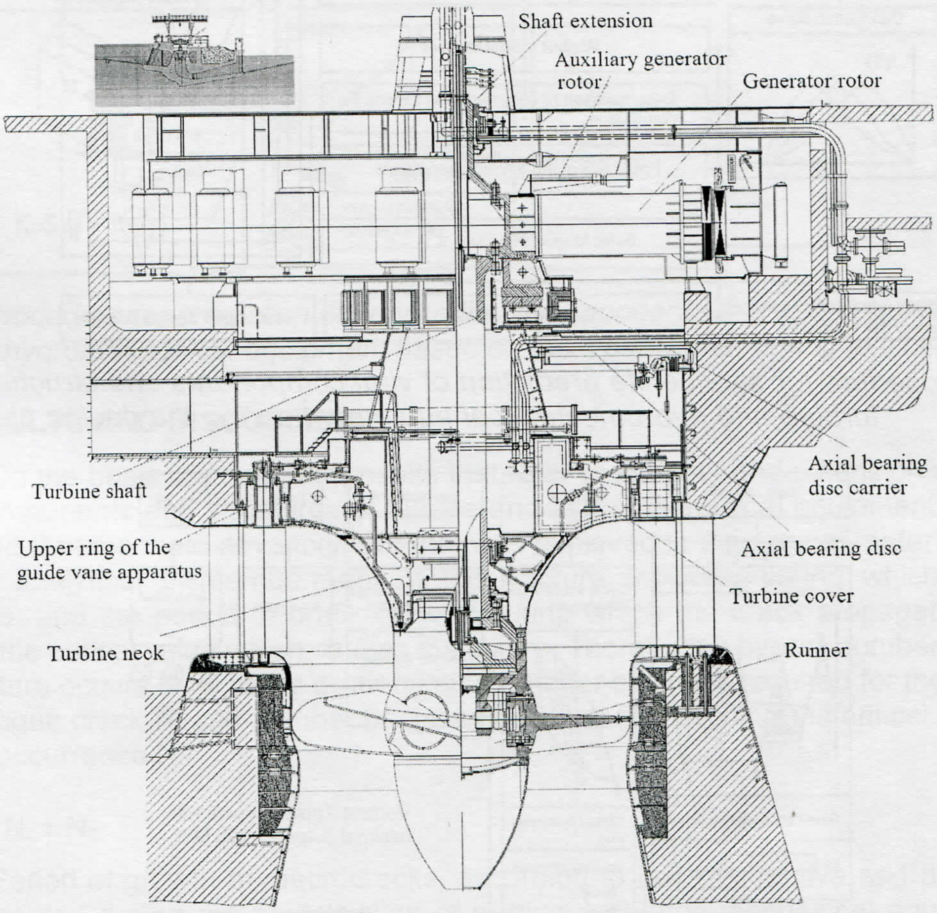

Fig. 1 *Appearance of the vertical Kaplan turbine, nominal power 176 MW*

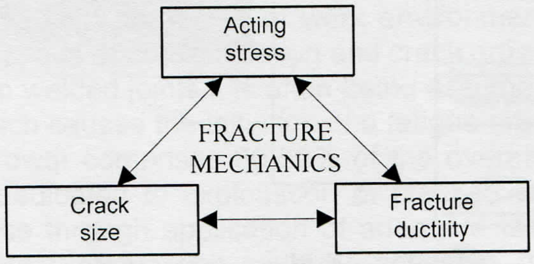

Fig. 2 *Fracture mechanics triangle*

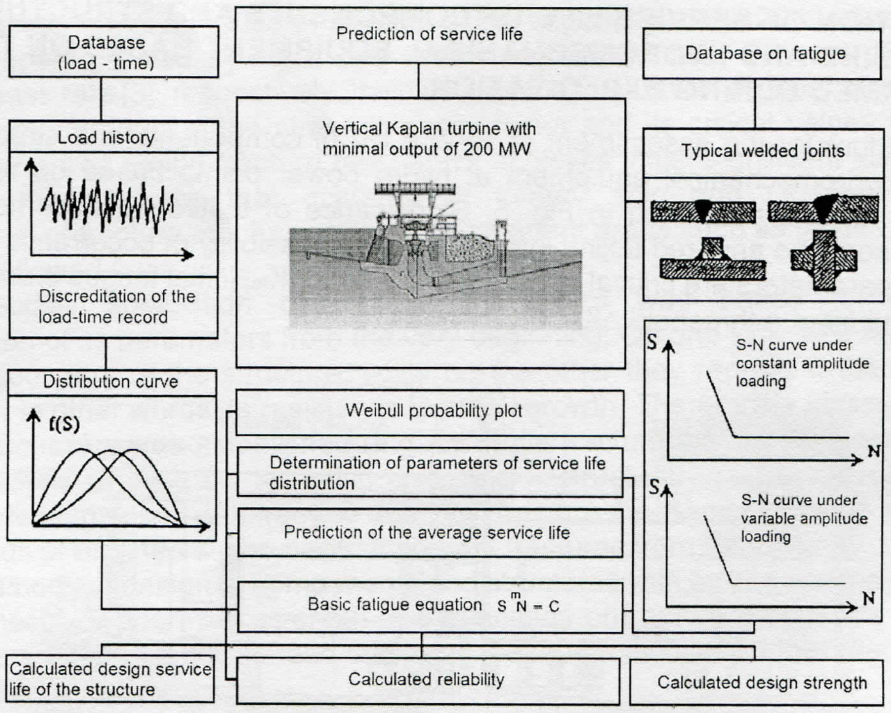

Fig. 3 *Procedure for service life prediction of vital components and structures of turbine and hydromechanical equipment during the design phase*

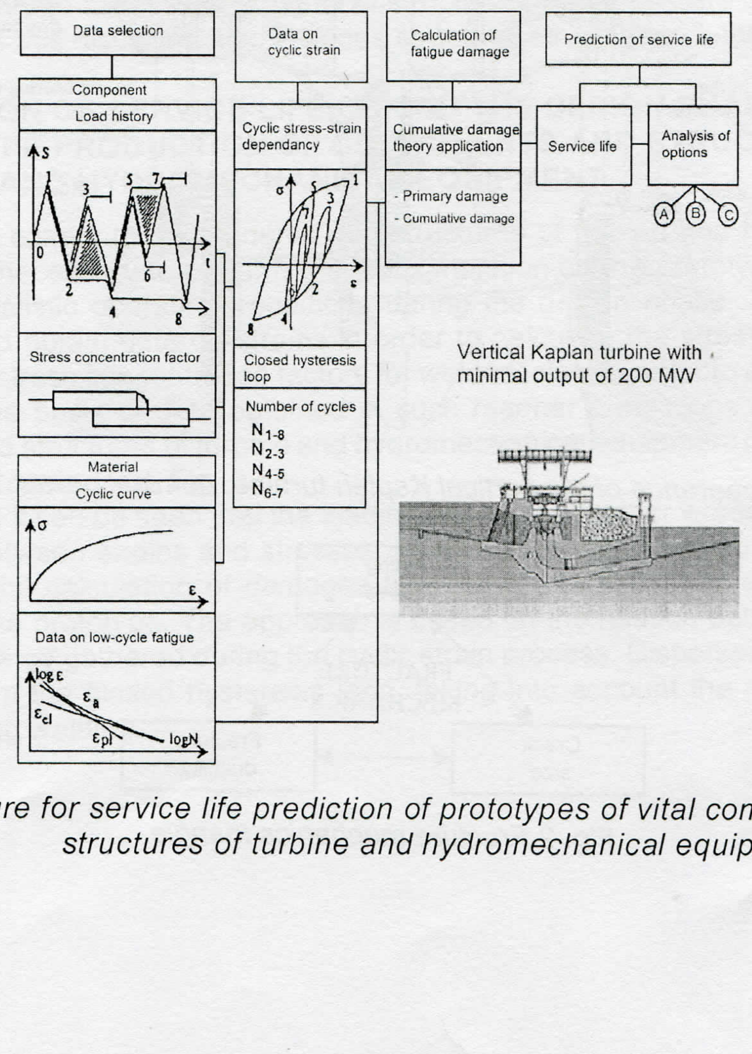

Fig. 4 *Procedure for service life prediction of prototypes of vital components and structures of turbine and hydromechanical equipment*

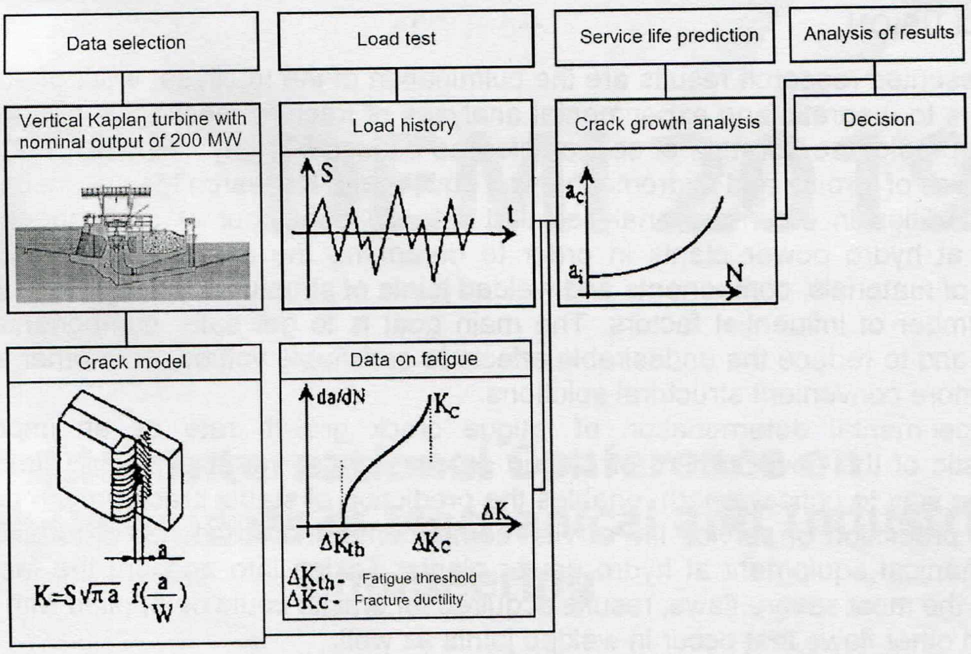

Fig. 5 *Procedure for prediction of service life of components and structures of turbine and hydromechanical equipment based on tests performed during exploitation*

4. RESULTS AND DISCUSSION

On the basis of presented results that refer to integrity and extension of service life of components and structures of turbine and hydromechanical equipment it can be concluded that the main advancement that was achieved in the area of material fatigue was the analytical dismemberment of the fracture process, during which a crack originates, and the period of crack growth, during which the crack propagates until it reaches the critical value which causes the failure. Thereby the overall number of cycles until fracture occurs N_o is being divided into a number of cycles required for the initiation of the fatigue crack N_i and number of cycles required for reaching the critical length for fracture occurrence N_c.

$$N_o = N_i + N_c \qquad (1)$$

Period of growth of macrocracks, according to non-destructive and destructive tests executed during the revitalization of turbine and hydromechanical equipment at hydro power plant 'Djerdap 1', comprises 60-80% of the overall service life, depending on the type of material, dimensions and shape of the component, stress concentrators, type and frequency of loading, properties of work environment, as well as accepted criteria for division into periods of crack initiation and crack growth.

When it comes to welded joints it is often being assumed that an initial crack or a sharp notch exists, which causes the initiation of a fatigue crack and in such case the period of macrocrack growth comprises 30-60% of the overall service life. Therefore extreme care is being dedicated to exploitation of cracked welded structures under complex loading, because through application of adequate tests and by knowing the laws of crack growth timely intervention could be achieved, therefore preventing the failure of vital structures.

5. CONCLUSION

Presented research results are the culmination of the multiyear work of authors which refers to theoretic and experimental analyses of fracture mechanics parameters in order to predict the duration of service life and assess integrity of vital components and structures of turbine and hydromechanical equipment. Research results are offering great possibilities in extensive analyses that refer to behaviour of components and structures at hydro power plants in order to determine the changes of mechanical properties of materials, components and welded joints of structures through variation of a large number of influential factors. The main goal is to get safer components and structures and to reduce the undesirable effects to satisfiable values, or in other words to realize more convenient structural solutions.

Experimental determination of fatigue crack growth rate as an important characteristic of the development of fatigue process under variable loading, from the initial all the way to critical length, enables the prediction of stable crack growth period, as well as prediction of service life of vital components and structures of turbine and hydromechanical equipment at hydro power plants. Taking into account the fact that cracks are the most severe flaws, results acquired for cracks could be applied with great certainty to other flaws that occur in welded joints as well.

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