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Off-line system for determination of the residual life of vessels by experts

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ABSTRACT: The OFF-LINE and ON-LINE systems for determination of the damage of the pressure vessels materials during operation of nuclear power plants are created. Procedures of the OFF-LINE system performed by the experts are discussed in this paper.

1 INTRODUCTION

The material of nuclear power plant pressure vessels is mostly damaged by fatigue and influence of corrosive environment. Secondary side of steam generators is especially damaged. The ON-LINE system is determined for the continuous evaluation of the material damage by the exchanges of the pressure and temperature fields during operation. ON-LINE system has to know relations (influence function) between the measured temperature and damage of the material in the most loaded pressure vessel parts. The mostly damaged places are usually on the inner side of the vessel wall, but thermocouples are located on the outside surface of the wall, Figure 1. An accuracy of ON-LINE system depends on the precision of influence functions.

The OFF-LINE system on two levels has been developed in our Institute. First level presents our program CEZZAR, developed by Vincour (1993). This program has to know values of cumulative damage factors (usage factors) for all design or experimentally measured transient events. User of the CEZZAR inputs number of the occurred transient events during one campaign to this program. The CEZZAR calculates the cumulative damage factors for all service life of the unit and for every campaign. The trends of fatigue damaging of a material are then known. The accuracy of the CEZZAR depends on the determination accuracy of cumulative damage factors.

System ON-LINE and system CEZZAR (OFF-LINE) offer only informations about the fatigue damage, but in an arbitrary moment during service condition. The conservatism of the informations is a necessary condition for both systems.

Figure 1: Location of thermocouples on the surface of the steam generator feed water nozzle

Figure 2: Stresses in the bolt section of the steam generator primary collector during one year campaign

2 OFF-LINE SYSTEM DIALIFE

OFF-LINE system DIALIFE for determination of the residual life of pressure vessels performed by experts is developed in our Institute. This system is based on the data acquisition (pressures, materials and medium temperatures, quantity and flowing speed of the medium, etc.) during operation of the unit, ageing of materials, quantity of corrosion additives in the water and real defects in materials. This OFF-LINE system offers more accurate results than both, systems discussed before.

Figure 3: Temperatures on the outside surface of the steam generator during start-up of the unit. TNV - feed water, TNV1, TNV2 - feed water nozzle, TK1 - primary collector in the area of the water level, TT1,2,3,4 - upper and lower surface line of the steam generator

Figure 4: Temperatures on the outside surface of the steam generator during shutdown of the unit. TNV - feed water, TNV1, TNV2 - feed water nozzle, TK1 - primary collector in the area of the water level, TT1,2,3,4 - upper and lower surface line of the steam generator

Figure 5: Scheme of the System DIALIFE

Usability of DIALIFE program is based on small numbers of transient events during the evaluation period, for example during one campaign, Figure 2. More exchanges of temperatures of the medium and materials are measured only during start-up and shutdown of the unit, Figure 3 and 4 from Vejvoda (1993) and Vincour (1994). Input data for calculation of temperature fields, deformations and stresses are modified by the measured data. Heat-transfer coefficients are chosen for achievement of the conformity between calculated temperatures and measured ones by sensors. Deformations and stresses are calculated after then. Usage factors are calculated by program STATES (assessment of limit states) developed by Vejvoda (1989), which is based on the eastern standard (NTD A.S.I., Section III - Association of Mechanical Engineers of the Czech Republic) and on the ASME Code, Section III. This system DIALIFE has been developed for steam generators and pressurizers of the WWER nuclear power plants. The procedure of the system DIALIFE are fol-

lowing (Figure 5):

(1) Data acquisition (pressures, temperatures, quantity and flowing speed of the medium, atc.) during operation of the unit.

(2) Collected data protection.

(3) Creation of the load block (Figure 2, 3 and 4) from saved and attended data.

(4) Calculation of temperature fields (a choice of heat-transfer coefficients for achievement of the conformity between calculated and measured temperatures).

(5) Calculation of deformations and stresses in elasto-plastic state (Neuber's rule as approximate procedure is possible to use).

(6) Assessment of limit states (fatigue, static, growth of defects), for example calculation of allowed numbers of cycles $[N_O]$ using of the design fatigue curve of the Manson Coffin type, modified by Vejvoda (1989):

$$(1) \quad \frac{\epsilon_{at}}{\varphi_W} = \frac{\epsilon_f' - 0,35 \epsilon_{p,max}}{n_{\sigma} (2 [N_O])^{-c}} + \frac{\sigma_f' - \sigma_m}{n_{\sigma} E (2 [N_O])^{-b}}$$

$$(2) \quad \frac{\epsilon_{at}}{\varphi_W} = \frac{\epsilon_f' - 0,35 \epsilon_{p,max}}{(2 n_N [N_O])^{-c}} + \frac{\sigma_f' - \sigma_m}{E (2 n_N [N_O])^{-b}}$$

where:

ϵ_{at} - an amplitude of the total deformation in the elasto-plastic state,

σ_m - a middle stress of the cycle,

$\epsilon_{p,max}$ - a maximum of the plastic deformation for all service time,

n_{σ}, n_N - safety factors, usually $n_{\sigma} = 2$, $n_N = 10$,

φ_W - reduction coefficient of the fatigue resistance by welding joints,

E - Young's modulus,

ϵ_f' - fatigue ductility coefficient,

σ_f' - fatigue strength coefficient,

b - fatigue ductility exponent,

c - fatigue strength exponent.

Characteristics of degraded materials are used (ageing, influence of medium).

(7) Calculation of usage factor and of the residual life of vessels.

(8) Evaluation of results and desing of measures.

3 SUMMARY AND CONCLUSIONS

OFF-LINE system for determination of the residual life of vessels by experts offers sufficiently accurate results, then:

- (1) loading block is based on measured data during the evaluated period of the unit (pressure, temperature, quantity and flowing speed of medium, temperature of materials),
- (2) material characteristics are considered for ageing material,
- (3) quantity of corrosion additives are considered,
- (4) calculated temperature fields are in conformity with measured temperatures,
- (5) finite elements method for calculation of strains and stresses in elasto-plastic state is used,
- (6) real material with defects is considered,
- (7) assessments of fatigue, growth of defects and damage by corrosion influence of the medium are based on measured material characteristics,
- (8) evaluation is done by experts.

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