Proc. Estonian Acad. Sci. Engng., 1999, 5, 1, 64–70
https://doi.org/10.3176/eng.1999.1.05

LIFE ASSESSMENT OF POWER PLANT COMPONENTS

Harri TALLERMO and Ivan KLEVTSOV

Institute of Thermal Engineering, Tallinn Technical University, Kopli 116, 11712 Tallinn, Estonia; klevtsov@sti.ttu.ee

Received 24 March 1998, in revised form 17 June 1998

Abstract. If the manufacturing defects of power equipment are not taken into account, the condition of the metal operating under creep may be reliably characterized only by structural changes. To guarantee reliable operation of a power plant component, it is important to locate critical areas and monitor and conduct metal testing at a proper time. The system presented here, allows us to estimate stress distribution in a component, to find computational assessment of the cumulated damage, to determine when and where it is necessary to cut off microsamples or take replicas. Finally, the real condition of the metal may be assessed on the basis of metallographic research and a reasonable 3-R (run, repair, replacement) decision can be made on further use of the component.

Key words: power plant, creep damage, life consumption estimation, microstructure testing.

1. INTRODUCTION

The power equipment developed and operated in 1960–1970 was designed for the term of about 100 000 hours. Wall thickness of power plant components and the permitted operational pressure were designed for the same lifetime. In spite of the fact that many power plant components have already operated for 200 000–250 000 hours and their design life has expired, they may still be in a satisfactory condition [1]. The reasons lie in their exploitation at lowered steam temperature, timely inspection of the metal condition, repairs, and partial replacements. Today such power plant components require continuous inspection.

If the defects of manufacturing and repair are not taken into account, the reliability of a component is defined by the changes in the structure of the metal which are mainly caused by creep. Ultrasonic testing and superficial defectoscopy as well as monitoring of the creep rate by measuring the deflection of the component cannot reveal structural damages before cracks occur. In practice, structural damages can only be detected by metallographic research. We consider the condition of the metal structure, mainly the level of cumulated changes in the microstructure, the most authentic criterion for the estimation of metal serviceability in the given circumstances. Knowing the relationship between the level of cumulated changes and life consumption, it is possible to take decisions on more extensive inspection, repair or replacement of a component at a particular time.

2. COMPUTATION OF LIFE CONSUMPTION

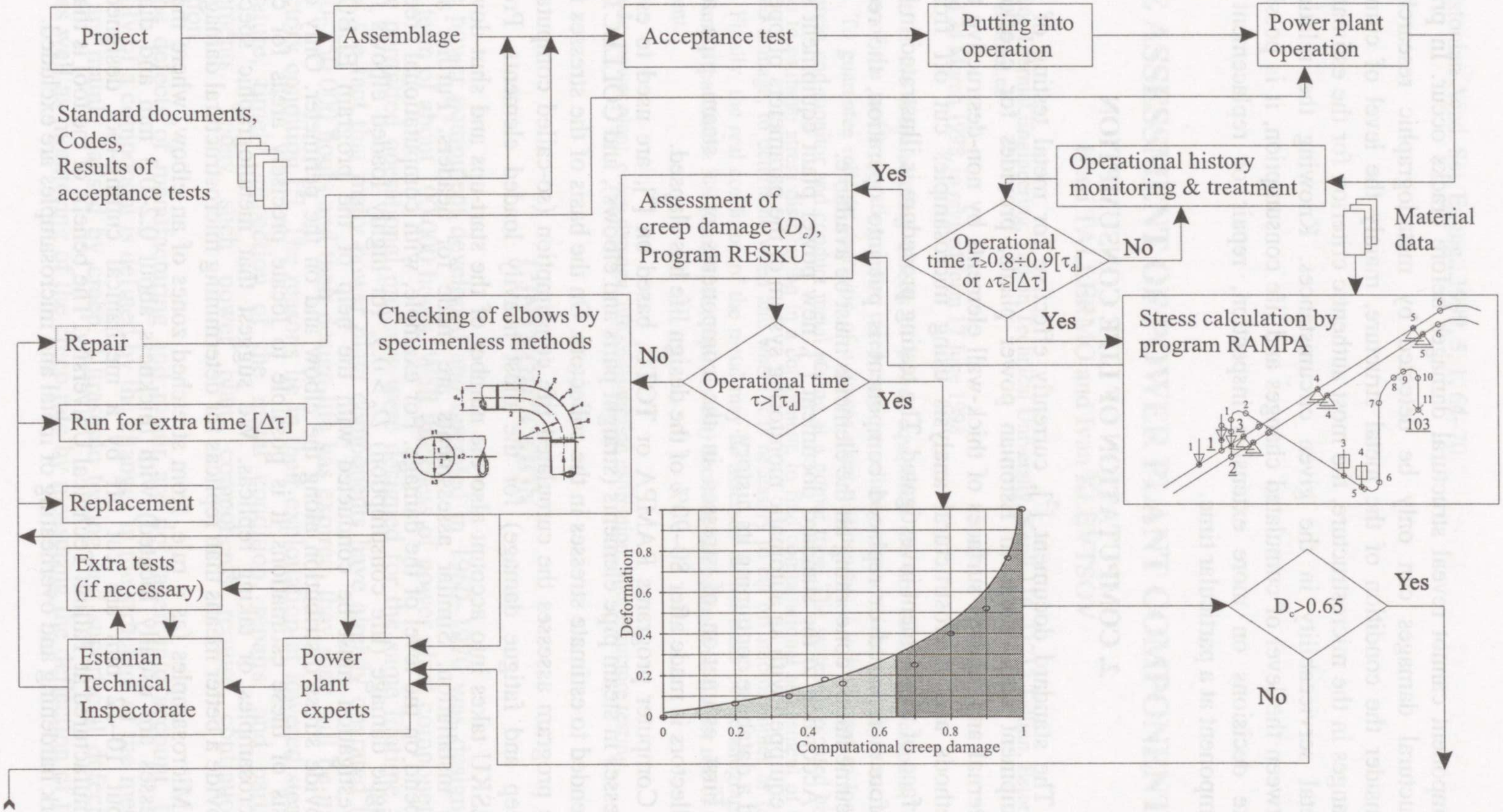
The standard document [2], currently effective for metal testing of power equipment components in Estonian power plants, provides for checking of external and internal surfaces of thick-wall elements by non-destructive testing methods and microstructural analysis using microsamples cut off from the surface of the element investigated. The testing procedure is illustrated in Fig. 1. Before a repaired or replaced component is put into operation, the required documentation concerning all the elements must be available.

According to the standard document [3], new power plant equipment should be equipped with an automatic monitoring system of the parameters of operation and a database containing its history.

First estimation of stresses in the components of a steam pipe and in collectors is made after 80–90% of the design life has elapsed.

Computer programs RAMPA or TOTU, based on [4], are used to estimate stresses in steam pipe elements (straight parts and elbows), and COLLECTOR is intended to estimate stresses in the collectors. On the basis of the stresses found, the program assesses the cumulated life consumption (so-called computational creep and fatigue damage) for the most heavily loaded elements. Program RESKU takes into account also the number of the start-ups and shut-downs of the installation. Similar assessments are made for headers. Further actions depend on the level of the damage. For example, with computational creep and fatigue damage (life consumption) $D_c > 0.9$, for highly loaded elbows further investigation must be conducted with the help of the program ELBOW to provide stress distribution along the elbow and on the perimeter. Only on the basis of these estimations it is possible to locate precisely areas for cutting microsamples or taking replicas. We suggest that metallographic specimens provide a better means than replicas for determining microstructural damage.

Microsamples (as a rule, from stretched zones of an elbow, where maximal stresses are usually located) with thickness about 0.2–0.3 mm and diameter about 10–12 mm are cut off by a mechanical cutting-tool designed and manufactured at Tallinn Technical University. The benefit of the tool is that cold work hardening and overheating of metal and microsamples are excluded.


Project
Assemblage
Acceptance test
Putting into operation
Power plant operation
Standard documents,
Codes,
Results of acceptance tests
Operational history monitoring & treatment
Material data
Assessment of creep damage (D_c), Program RESKU
Yes
No
Operational time $\tau \geq 0.8 \div 0.9[\tau_d]$ or $\Delta\tau \geq [\Delta\tau]$
Yes
Stress calculation by program RAMPA
Checking of elbows by specimenless methods
No
Operational time $\tau > [\tau_d]$
Yes
Repair
Run for extra time [$\Delta\tau$]
Replacement
Extra tests (if necessary)
Estonian Technical Inspectorate
Power plant experts
Deformation
Computational creep damage
$D_c > 0.65$
Yes
No

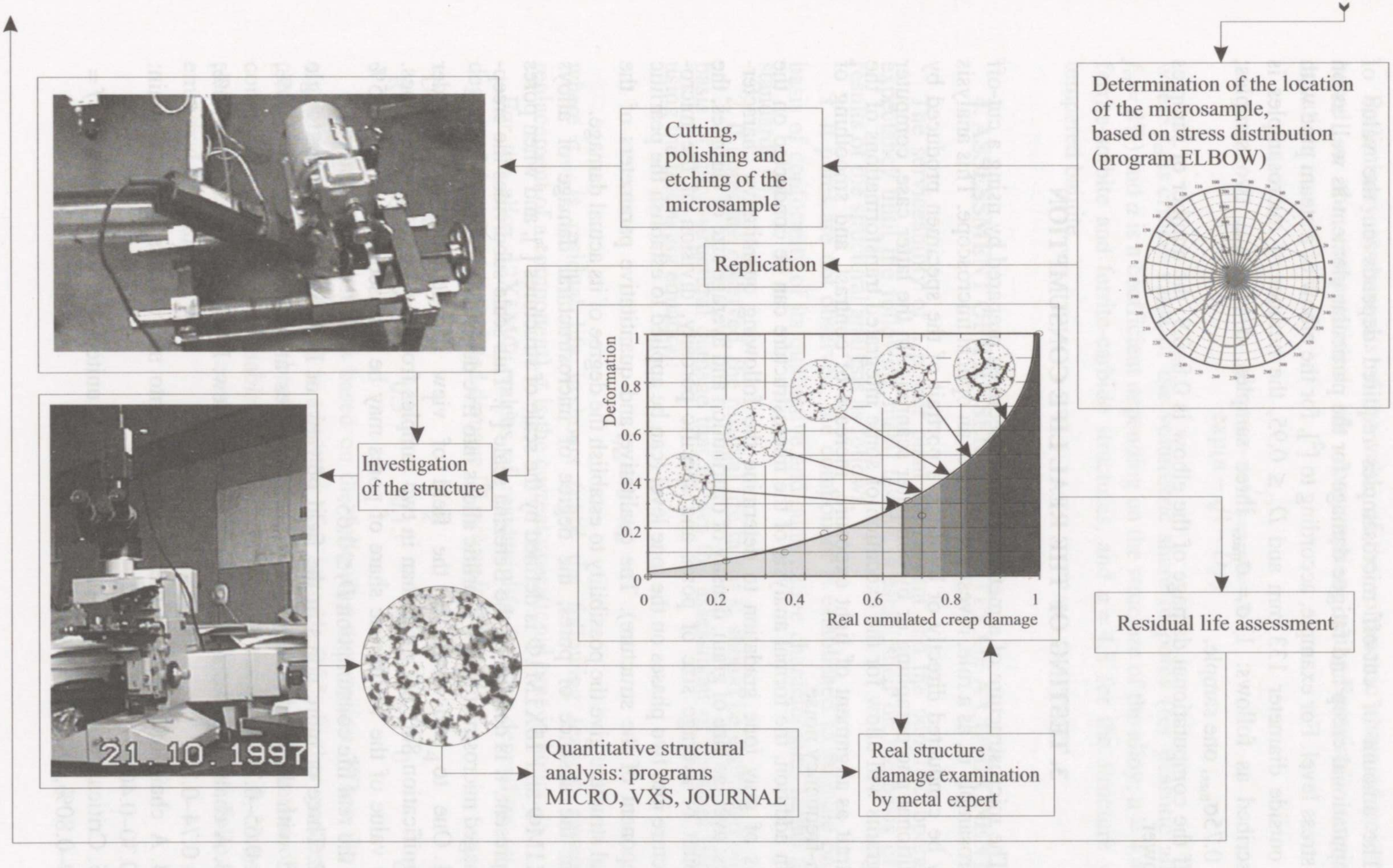


Fig. 1. Schematic presentation of the system for testing of cumulated metal creep damage and for assessment of its residual life.

The amount of cut-off microsamples required depends on the value of computational creep and fatigue damage for the particular element as well as on the stress level. For example, according to [2], for the elbow of a steam pipe with the outside diameter 133 mm and $D_c \le 0.95$, the number of microsamples is prescribed as follows: 1) $\sigma = \sigma_{max}$, three samples; $\sigma = 0.9\sigma_{max}$, two samples; $\sigma = 0.75\sigma_{max}$, one sample.

If the computational damage of the elbow is 0.8–0.9, the number of samples is lower.

3. TESTING OF THE REAL LIFE CONSUMPTION

The microstructure of a metallographic specimen prepared by using a cut-off microsample is, as a rule, investigated under an optical microscope. This analysis may be conducted directly or by using a portrait of the specimen produced by traditional photographing or by computer scanning. In the latter case, computer programs will allow for the execution of some integrated transformations of the portrait as alignment of light exposure, increase of contrast, and smoothing of high-frequency noise.

In addition, the formal analysis of the microstructure can be conducted on the basis of gray tone gradation to determine the following quantitative characteristics: average size of grain, density of distribution and average size of carbides, the amount of average size of pores and specific porosity, division of the microstructure into two phases on the tone level (can be applied to establish the pearlitic component of the structure). The qualitative and quantitative parameters of the metal structure give the possibility to establish the degree of its actual damage.

In the absence of pores, the degree of microstructural damage of alloys 12X1MΦ and 15X1M1Φ is defined by the scale of structures [5], and when pores are present, it is defined by the Berezina scale [6]. This scale subdivides the creep-damaged microstructures of pearlitic alloys into five degrees as follows.

1. One to two pores in the field of view of the microscope under magnification 800, not more than in two samples from the 20 investigated ones. The value of the volumetric share of pores may be assessed here as $f \le 0.15\%$ and the real life consumption $D_r \le 0.65$.

2. Three or more pores in the field of view, or less than three in the single field with three or more fields, in which pores are located: $f = 0.15$–0.20%, $D_r \cong 0.65$–0.74.

3. A chain of pores at least in one field of view. In this case $f = 0.20$–0.30%, $D_r \cong 0.74$–0.81.

4. A chain of pores and their association into microcracks within a grain: $f = 0.30$–0.40%, $D_r \cong 0.81$–0.87.

5. Critical damage and microcracks are united into macrocracks: $f = 0.40$–0.80%, $D_r \cong 0.87$–0.96.

Preliminary assessments of the value of the volumetric share of pores are based on the computational life consumption, using Berezina's empirical equation:

$$f = \frac{f_{cr}}{\exp(a - \sqrt{1 - D_c})},$$

where f_{cr} is critical value of the volumetric share of pores (for pearlitic alloys $f_{cr} = 2\%$) and a is a coefficient depending on the structure of the alloy; $a = 4.4$ for ferrite-sorbite and ferrite-carbide structures, and $a = 4.8$ for the structure with tempered bainite.

4. ASSESSMENT OF THE SERVICEABILITY OF A COMPONENT

The serviceability of a power plant component and the admitted operation expectancy until the following metal testing is established on the basis of the results of the structural analysis as follows.

1. If pores are not observed, the component is established as suitable on the basis of conformity of its qualitative and quantitative characteristics to the alloy standards [5].

2. If pores are observed, the residual life factor k_τ should be estimated on the basis of microstructural damage that allows the assessment of residual life by using the following equation:

$$\tau_{res} = \tau \cdot k_\tau,$$

where τ_{res} is residual life in hours (until the following testing, repair or replacement of a component), τ is the current operational time in hours.

For the alloy 12X1MΦ, values of residual life factors, depending on the degree of the actual cumulated damage [6], are as follows:

Degree of damage	1	2	3	4	5
Residual life factor, k_τ	0.3	0.15	0.03	0	0

Residual life factor k_τ is based on the following assumption. When the life consumption $D = \tau/[\tau]$, ($[\tau]$ is admitted life) exceeds 0.85, further process of creep damage accumulation becomes unpredictable, and further operation of the component becomes unreliable and inexpedient. It means that k_τ may be estimated on the basis of actual cumulated damage by using the following empirical equation:

$$k_\tau = \frac{0.85}{D} - 1\,.$$

REFERENCES

1. Tallermo, H., Klevtsov, I., Arras, V., and Gorohhov, J. Trends in life management of Eesti Energia power plants. *Proc. 3rd Baltic Internat. Confer. on Plant Condition & Life Management*. Helsinki-Stockholm, 1995, 2, 621–627.
2. Tallermo, H. and Klevtsov, I. The standard for testing of metal condition of power plant components under internal pressure. Tallinn Technical University, Tallinn, 1997.
3. Tallermo, H., Klevtsov, I., Lausmaa, T., Eivak, J., Prikk, A., Pedik, V., and Zaselski, S. Standard document for estimation of life consumption of metal of steam pipes and headers operating under elevated temperature (>450 °C) and pressure (>9.0 MPa). Tallinn Technical University, Tallinn, 1995.
4. Standard Document for Strength Estimation of Energy Equipment's. RTM 24.038.08-72. Ministry of Energetics of USSR, Moscow, 1972 (in Russian).
5. Scales of Microstructure of Boiler Tubes of Alloys 12X1MΦ and 15X1M1Φ. Appendix to MRTU 14-4-21-67. Dnepropetrovsk Tube Institute, Dnepropetrovsk, 1968 (in Russian).
6. Berezina, T., Bugay, N., and Trunin, I. *Diagnosis and Prognosis of Power Equipment's Metal Life*. Tekhnika, Kiev, 1991 (in Russian).

ELEKTRIJAAMA SEADMETE RESSURSIKULU HINDAMINE

Harri TALLERMO ja Ivan KLEVTSOV

Roomavuse tingimustes töötava metalli seisundit iseloomustavad kõige paremini tema struktuuris toimunud muutused. Seadme elemendi töökindluse tagamiseks on oluline kriitiliste kohtade väljaselgitamine ning nende õigeaegne kontroll. Artiklis esitatud süsteem võimaldab hinnata elemendi pingejaotust, määrata kindlaks kuhjunud kahjustust ning leida, millal ja kus on vajalik kontrollimiseks välja lõigata katsekehi või võtta jäljendeid. Struktuuriuuringu baasil saab hinnata metalli tegelikku olukorda ja teha põhjendatud nn. 3-R (*run*, *repair*, *replacement*) otsus elemendi edasise kasutamise kohta.