Residual Life Prediction of Power Plant Components

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ABSTRACT

A procedure of a diagnostic system DIALIFE results utilisation for nuclear power plant equipment managed ageing is shown. The diagnostic system assesses a continual damage of power plant equipment material damage from a force load, pressure, thermal fields and an environment. The ON-LINE and OFF-LINE assessment results by the DIALIFE system are utilised for a management of a maintenance, repair and a power plant unit service management. The aim is to minimise a trend of a material damage and a equipment function.

INTRODUCTION

A material of nuclear power plant components is permanently damaged during service. At the same time there is a permanent effort to utilise their working parameters more, what multiplies their risk of a failure. That is why it is necessary to introduce a life-time management system into a routine use with the aim to optimise a management of their servicing and repairs and to optimise a management of their operation and so to minimise a process of a material damage during a service.

A life-time management system enables to determine the range of a material degradation and an equipment function by an influence of service conditions and so to optimise a maintenance and repairs. It means to change equipment parts according to a reach of a material characteristics limit degradation or an equipment function and not for the sake it is prescribed in the project. A project cannot fully affects real service conditions, their history, etc. The scheme of chosen components life-time management system is shown in Fig. 1.

Real service conditions and an equipment material response can be ON-LINE recorded by help of suitable sensors, so by the Instrument and Control system (I and C), by the Monitoring and Diagnostic system (MDS) and by the temporary Special measurement (SM).

A life-time management system of a power plant components can be based namely on following factors:

1) a knowledge database creation;
2) a determination of an objective procedure for an assessment;
3) an assessment of a gradual equipment material degradation and rotation machines in a common power plant components service;
4) an acceptance of a provision to reach to longest time of a reliable and safety power plant component service with acceptable financial costs for its maintenance and modernisation.

A COMPONENTS CLASSIFICATION

All equipment, engineering parts, communication systems and civil engineering structures of the whole power plant unit have to be liable to a life-time management system. Individual power plant parts take part in a different rate on a safety and reliability of the whole power plant. A significant factor is a severity of a damaged component exchange for a new one. That is why it is necessary to divide the whole equipment into groups and it these groups to define usually four categories according to influence factors significance, which are an exchange difficulty, a safety and reliability part of a power plant unit, etc.

KNOWLEDGE DATABASE

A knowledge database presents a summary and sorting of all substantial information about an equipment production, its service, maintenance and possibly an exchange.

Information about a response of component material on a load belongs also here, the same way as information about rotation machines function and information about provide research/development works. Namely there are:

1) Production details handed over by a component producer
   * Standards and procedures used at a design and technological procedures elaboration;
   * technological procedures used at a manufacturing;
   * specification of materials and strength and life-time calculations.

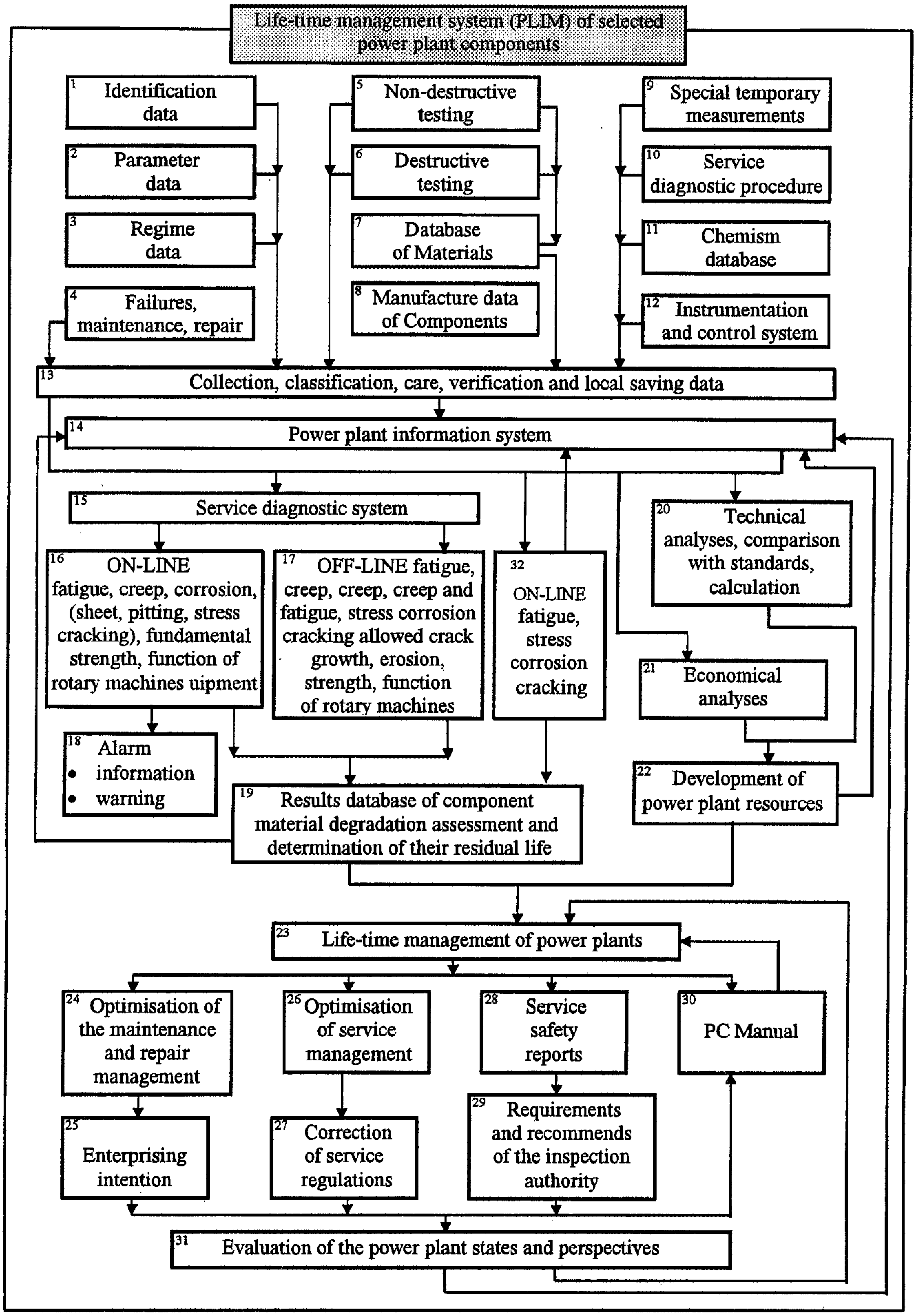

Fig. 1 Scheme of the life-time management system of selected components of the power plants

2) Information about a component function, service conditions and juridical documents
   * a scheme of component location and lay-out;
   * service parameters and loading;
   * maintenance and service history;
   * repairs and reconstruction of component parts;
   * juridical demands, regulations;
3) A component state at a life-time management system setting
   * a component details gained from operator:
     - service conditions,
     - forces from pipe systems,
     - results from provided non-destructive testing,
     - parts exchange for their damage,
     - reconstruction during scheduled shut down,
     - assessment of a material degradation cased by a service loading and by an environment within time of an actual power plant service.
4) Results of research/development works
   * a life-time and strength calculations,
   * a choice of extremely stressed component regions,
   * experimental determination of mechanical and physical material parameters.

OBJECTIVE PROCEDURES DETERMINATION FOR AN ASSESSMENT

A life-time equipment management means to manage a service and maintenance with the aim to slow down a degradation of a component material against a project assumptions. An assessment of a gradual material degradation requires a sufficient mathematical description of it degradation during a service. Those mathematical descriptions are parts of an objective procedures for an assessment of material degradation trends and a determination of a residual life-time.

Mathematical descriptions of a degradation are built so for ON-LINE also for OFF-LINE assessment [1] and [2]. Namely for ON-LINE assessment it is necessary to create sufficiently fast, but accurate procedures [3].

Damage Processes

A power plant components can lose a safety, reliability and function namely:

a) Suddenly:
   * by a reach of a limit state of a plastic carrying capacity at an overload (brittle, tough);
   * by a stability loss;
   * by a resonance.
b) By a gradual material damage :
   * fatigue (high-cycle, low-cycle, two frequency loading), Fig. 2;
   * creep, Fig. 3;
   * corrosion - mechanical damage, Fig. 4;
   * erosion;
   * thermal and deformation ageing.

Material of nuclear power components is especially damaged by fatigue and stress corrosion cracking. Every from damage processes can be dominant in the different part of the component. Mathematical description of the fatigue process is discussed in the [2].

Stress Corrosion Cracking

Mathematical description of the gradual damage by corrosive process is based on the following stages [4], Fig.4.

Stage 1 represents the origin of a surface microdefect defect such as a crack or pitting. Time of the 1st stage duration is indicated as t_{i1}. At this time, the micro crack will reach value $a_o \sim 0,05$ mm.

Stage 2 represents a defect growth caused by forces in corrosion environment but excluding stress corrosion cracking conditions. The crack growth in comparison with the previous stage accelerated due to the cyclic loading.

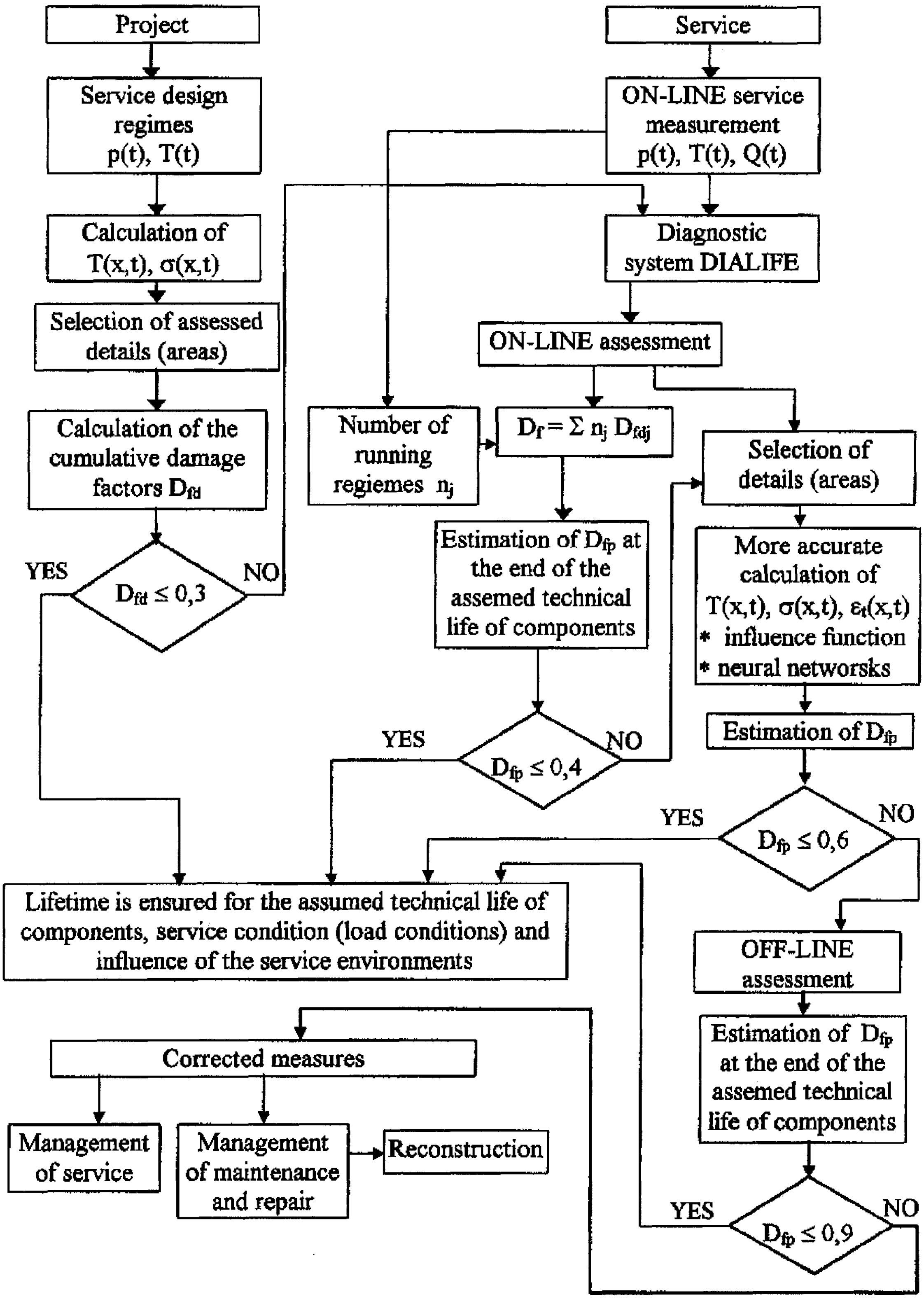

Fig. 2 Assessment procedure of the component material damage by fatigue
D_{fd} – cumulative damage factor for design conditions (D_{fdj} - for project regime),
D_{fp} – estimation of the cumulative damage factor at the end of the assumed technical life of components

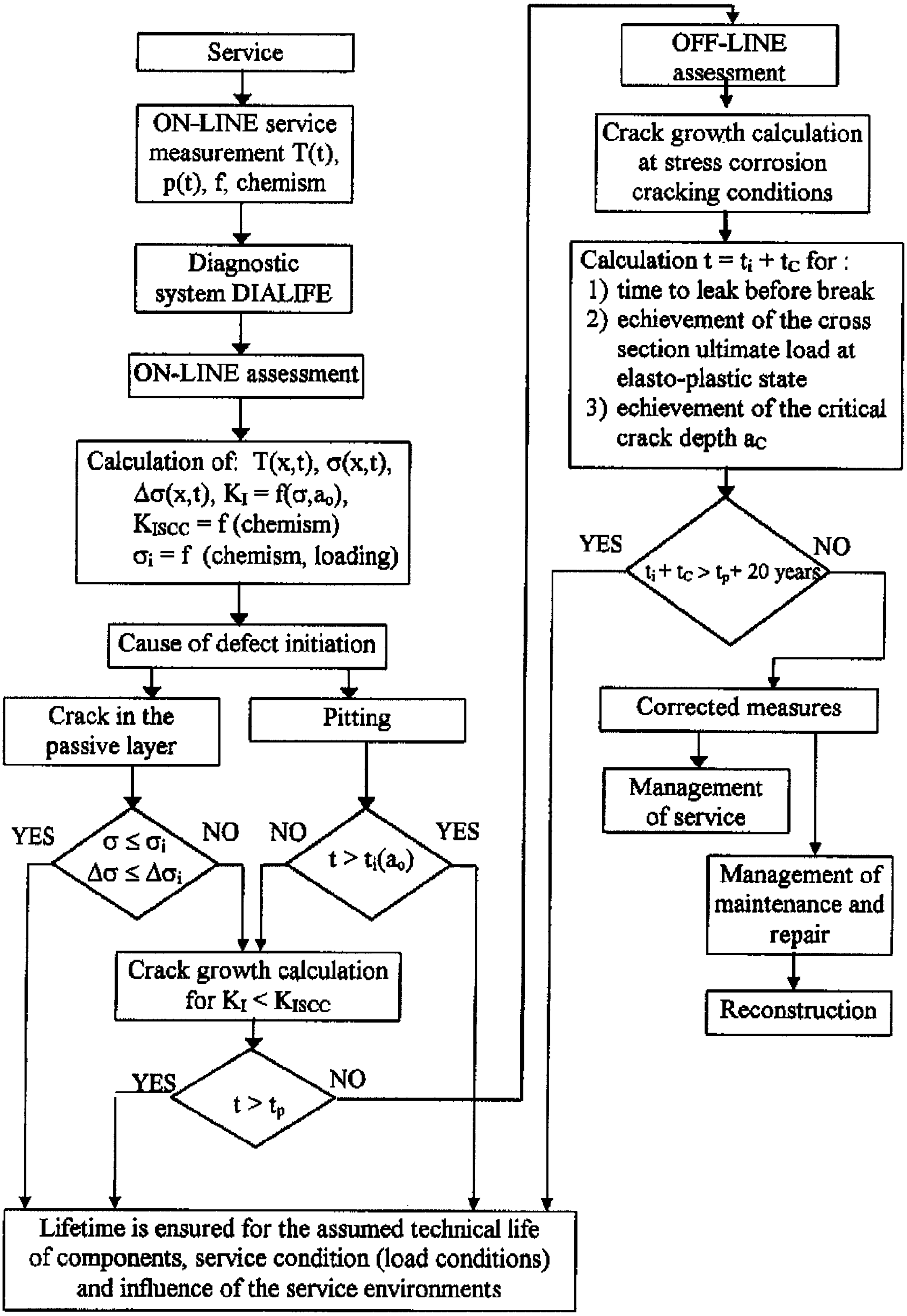

Fig. 3 Assessment procedure of the corrosion-mechanical damage of component materials
$σ_I$ – initiation stress for the passive layer damage; t_i – time of the crack growth for the initiation stage; t_c – time of the crack growth at stress corrosion cracking; a_o ~ 1 to 2 mm; t_p – time of the assumed technical life of components

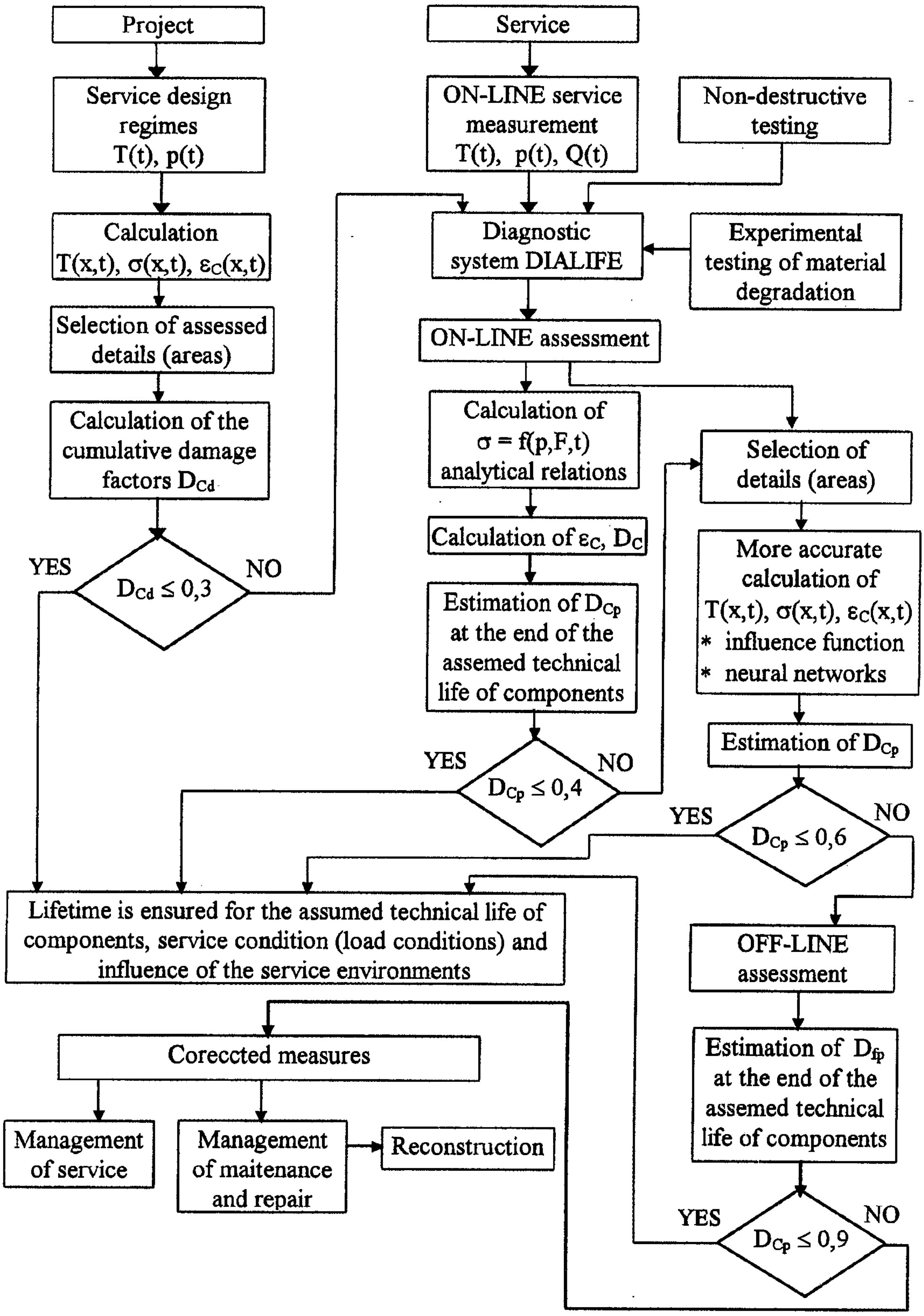

Fig. 4 Assessment procedure of the component material damage by creep
D_{Cp} - cumulative damage factor for design conditions; D_{Cp} - estimation of the cumulative damage factor at the end of the assumed technical life of components

Time of stage 2 duration is indicated as t_{i2}, and at its end a defect depth will reach value a_i. These conditions may be describe by stress intensity factor. A factor K_I can be for given load, shape and position of a defect determined by the finite element method as function of a defect depth a:

$$K_I = \sigma Y \sqrt{\pi a} = f(\sigma, a, Y) = b_o + b_1 a + b_2 a^2 \qquad (1)$$

Stage 3 represents a defect growth under stress corrosion cracking when stress intensity factor K_I reaches value K_{ISCC}, representing threshold value K_I. The crack growth continues by a mechanism of stress corrosion cracking until limit value a_L is reached. The time of duration of stage 3 is indicated as t_c.

Total time of the stud bolt operation its damage:

$$t_t = t_{i1} + t_{i2} + t_c \geq (t_R \text{ or } t_s \text{ or } t_{LBB}) + \Delta t \qquad (2)$$

In the probability analysis, time t_t is related to periods of non-destructive tests being 3, 4, 5, 6, 7 and 8 years. Used symbols: t_p – time to repair of a defect; t_s – time to a end of service; t_{LBB} – time to leak before break; Δt – safety time reserve.

1) Stage 1, the origin of a surface defect

The time of the origin of a surface defect may be determined from relation [5], [6]:

$$t_{i1} = C_{t1}\,[Cl^-]^{-m_1}\,(V_{cor} - V_c)^{-m_2} \qquad [\text{ppm; mV; mm/s}] \qquad (3)$$

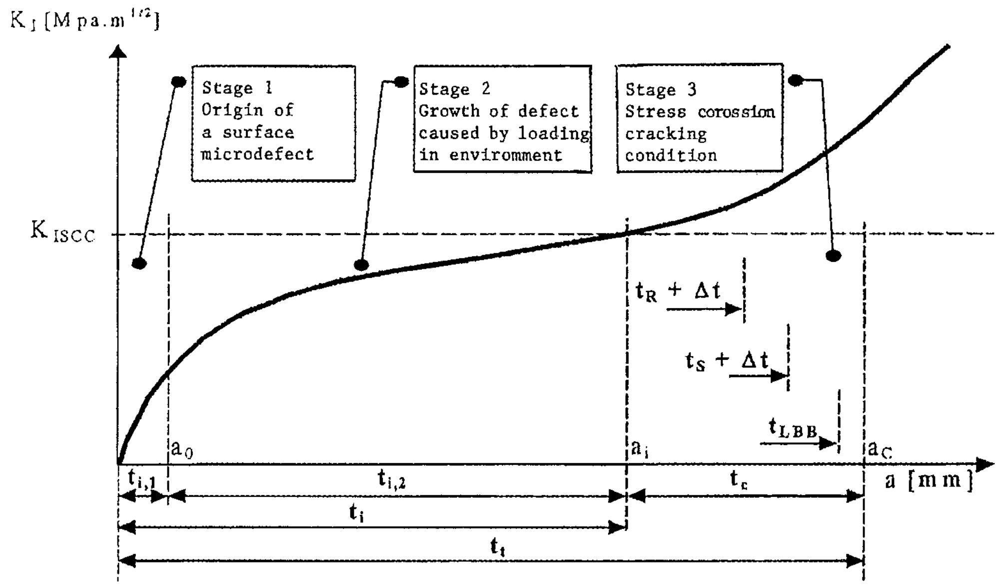

Fig. 5 The process of material degradation under stress corrosion cracking

2) The crack growth during stages 2

The defect will grow from value a_o to value a_i during the time t_{i2}:

$$a_i - a_o = v_i\, t_{i2} + \sum_{j=1}^{k} f_j\, t_j\, C\,(\Delta K_I)_j^m\,, \qquad (4)$$

where:

$$t_{i2} = C_{t2}\,[Cl^-]^{-m_1}\,(V_{cor} - V_c)^{m_2} \qquad [\text{ppm; mV; mm/s}] \qquad (5)$$

The type of the cycle j has frequency f_j. The time $t_{i2} = t_1 + t_2 + \ldots + t_j + \ldots + t_k$, where an index k is equal to number of cycle types.

3) The crack growth during stage 3

a) corrosive cracking conditions when K_I = const
Relation determines this speed of a crack growth:

$$\frac{da}{dt_c} = C_c K_I^{m_c} = C_c[b_0 + b_1 a + b_2 a^2]^{m_c} \qquad [mm/s] \tag{6}$$

The time the crack growth under corrosion cracking is determined from relation:

$$t_c = \int_{a_0}^{a_L} \frac{da}{C_c [b_0 + b_1 a + b_2 a^2]^{m_c}} \qquad [s; mm] \tag{7}$$

b) corrosive fatigue, ΔK_I is changed:

$$t_c = \int_{a_0}^{a_L} \frac{da}{f\, C_c (\Delta K_I)^{m_c}} = \int_{a_0}^{a_L} \frac{da}{f\, C_c \left[\left(b_0 + b_1 a + b_2 a^2\right)_{max} - \left(b_0 + b_1 a + b_2 a^2\right)_{min}\right]^{m_c}} \qquad [s; mm] \tag{8}$$

Characteristics C, C_c, C_{t1}, C_{t2}, m, m_c, m_1, m_2 have to be determined by tests of specimens for a given material and environment; f – frequency of a stress cycle.

CONCLUSION

The life-time component management presents a system, which is managed by a manner in agreement with the power company quality system. It requires a functional information system. A significant part is the diagnostic system for an assessment of continuous material degradation and an equipment function in real operational conditions, determination of assumed degradation trends and a degradation level on the end of assumed technical component life-time. For an achievement of operator intentions and for safe criteria and reliability equipment operation performance, relevant provisions have to be accepted for a management of an operation, maintenance, repair and reconstruction. Invested financial costs at the same time must be acceptable for an operator.

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