In-Time monitoring of the Fatigue Safety in Operation of the Pipelines Parts

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Abstract

The continual monitoring of the fatigue damage cumulation in operation of structures with a high requirement on safety is required when they are cyclically loaded. There are some sections or junctions along the pipelines in which the operating conditions could sometimes vary from the expected designed conditions. It is really impossible to predict such unexpected changes in operation therefore they are usually not considered in the stage of the structure's design. So the continual monitoring of those unexpected loadings in a real operation is the only way how to include them in a calculation of the total stress to be able to properly consider the safety of the pipeline system. In this paper are presented the theoretical fundamentals of a real time fatigue damage monitoring for a pipeline system. The calculation of the total stress is based on measuring the real loadings in the form of time-varying strains in critical places of a pipeline system in its real operation. The presented monitoring system gives the information about real state of the structure and also the information about continuous fatigue damage cumulation in time directly for an operator of service.

Keywords: monitoring, fatigue, pipe

As was already mentioned, in a real operation of the pipeline systems as well as pressure vessels, there are some sections or junctions in which the operation conditions are different to those were considered during the design stage. These places of structure are usually booster pump stations or compressor stations where there are different combinations of active compressors or a lot of technological interventions like (changing of supports, hall rebuilding, changing of the pipeline parts, etc.). There are so called nonstandard situations in operation of those pressure vessels or pressured pipeline systems whose including in calculation of the total stress and the following considering of real material loading is possible only in limited volume because as we already mentioned those changes is practically impossible to predict in operation. Today's state of computational and measuring techniques allowed to set up the system of continual monitoring for monitoring the important physical magnitudes and considering the safety of the service.

1. *Principle of Fatigue Damage Monitoring*

The monitoring of the fatigue damage in a real operation is a complex problem. It is based on continual and non-stop monitoring of the time-varying progress of the strains in spotted critical places with installed sensors of deformation and considering their influence on fatigue life in watched place of structure. If we want to perform exact consideration of the fatigue damage we need to know cyclic material properties for every critical node. Indeed the monitoring of fatigue damage is more exacting for monitoring in-time than monitoring of quality of air and other processes.

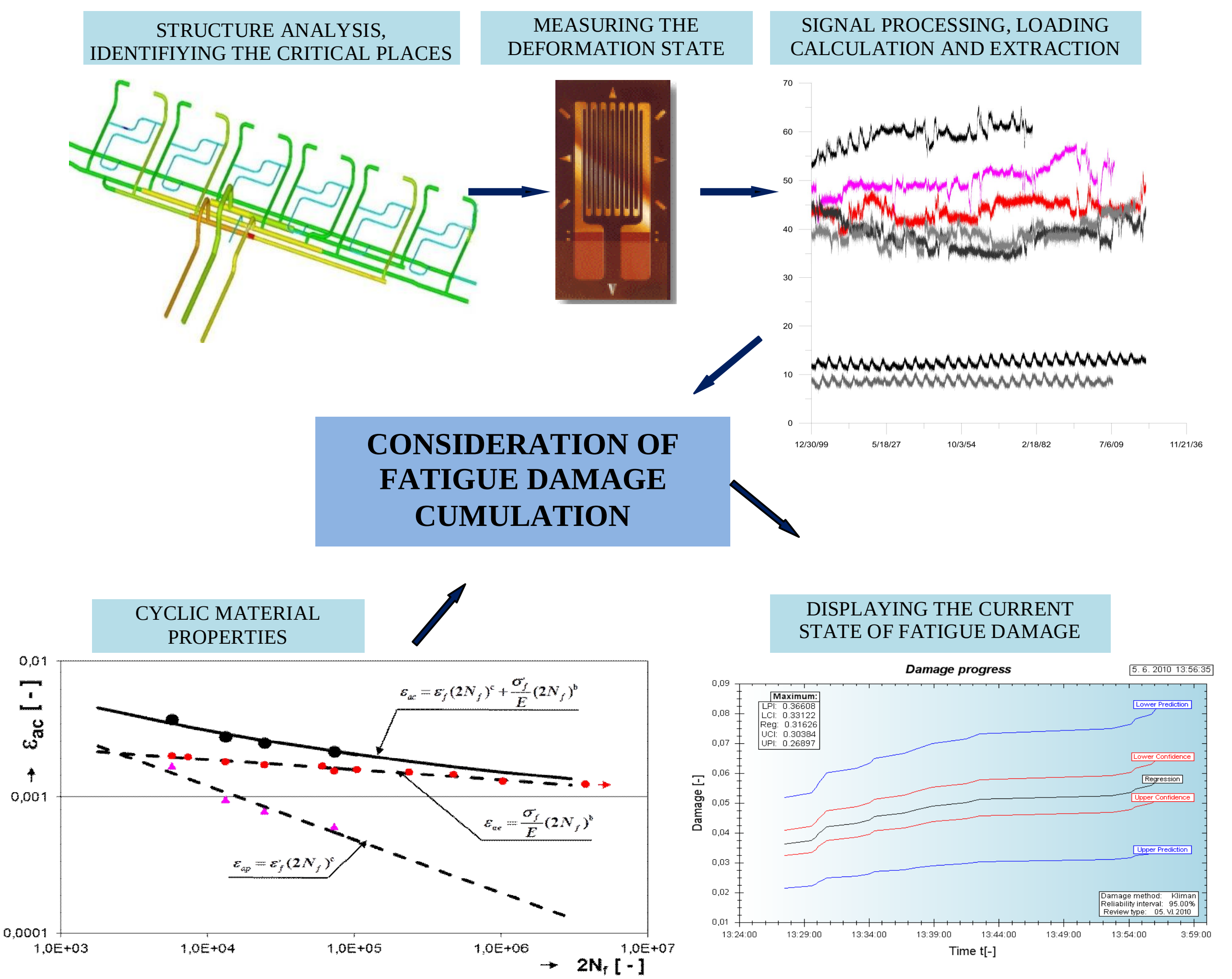
It is because the measuring magnitude and its progress of strain is not the final magnitude itself that is comparing with the limit values but is the only one of input magnitudes that are used for calculation and consideration of the fatigue damage cumulation.

1 Analysis of Monitoring Chain

The individual steps and processes that are performed during the monitoring process of the fatigue damage for concrete construction node is schematically ordered into monitoring string and displayed in Fig. 1.

1.1 Analysis of the Structure

It is not possible and also not advisable to monitor and also consider all sections of structure. The first step before developing the monitoring system for concrete structure is necessary to perform the stress-strain analysis of this structure. It rests in developing the most realistic mathematical model of the structure on which it is possible to consider the influence of different operation states. In the case of pipeline courtyards there are mainly the nonstandard states of natural vibration type in blind detours, opening the valves (specially the antipumping ones) or pumping of the compressor. The accurate model has to include the effects of supporting elements including their truepreloads and nonlinear characteristics as well. The real geometry of pipelines which is not the same in all details with documentation needs to be also considered. The influence of technological progress, the assembly and the influence of soil for subterranean parts of pipelines also need to be considered if we want to create an exact model. As the result of the structure analysis using the FEM methods we get the areas with the extreme values of stresses and strains. This complex model needs to be created with methods of sub modeling if we want to get more precise results (Il'kaev,Seleznev, Aleshin, Klishin 2005). At the end of analysis we should identify the concrete sections with highest level of loading including the real notch effect as well.



1.2 Loading Measuring

There is necessary to install sensors for sensing the strain without influence of the pipeline surface in the critical sections or in their nearness. For installation is suitable to use mainly the resistance strain gauges for which it is possible to ensure the long lifetime. Sensors is necessary to install about the circumference of the identified sections in the form of three-axial sensors with regular separation about 120^{o} in order to evaluate the internal forces of all loading effects (deformation because of internal pressure, additional bending and torsion Fig. 2) in monitoring place using the methodology presented in work Poděbradský (1992).

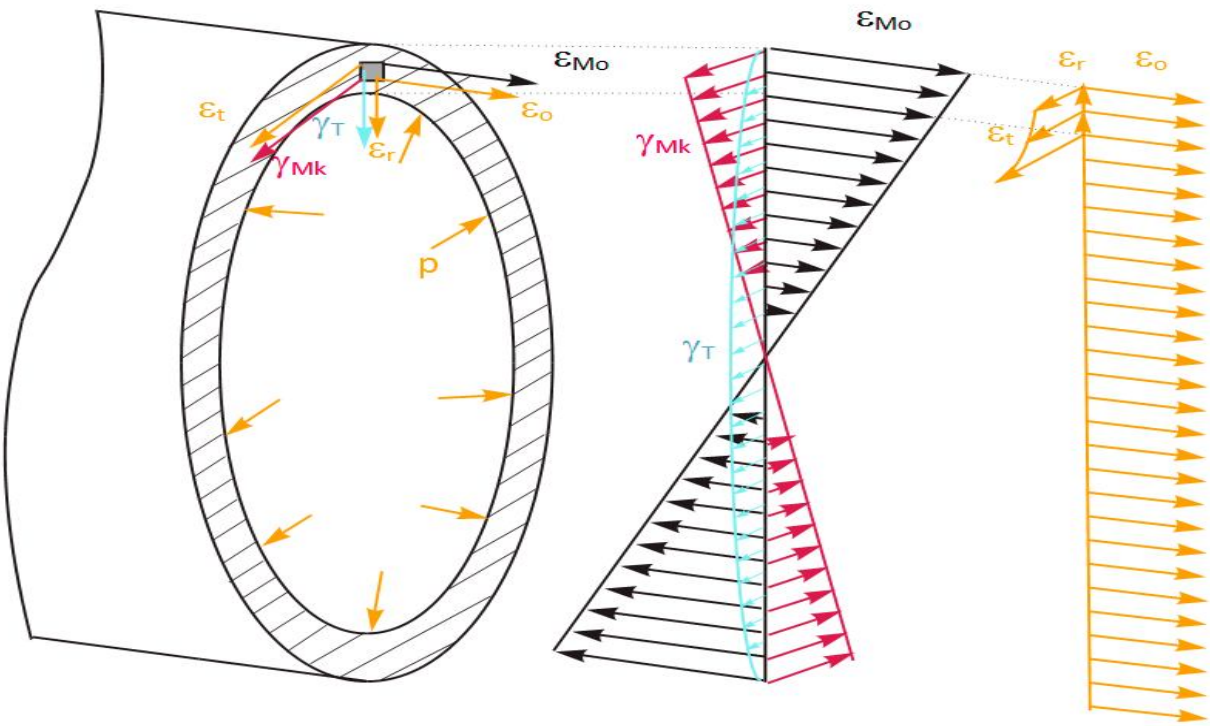


Fig.2 The Deformation State of Pipeline Loaded with Internal Pressure (ε_T, ε_R, ε_O), Additional Bending (ε_{Mo}, γ_T) and Torsion (γ_{Mk})

1.3 Processing of Measured Signals

Measured diagrams of strains do not enter directly into calculations, but in the first step, it is necessary to separate the individual components of loading in order to get the total process of strain at the highest loaded fiber of a cross-section. This process of total strain is calculated from the three-axial state of deformation and its value needs to be watched in a vector sense. In the next step, it is necessary to perform selection of extreme values of the process from the total strain and process it for needs of fatigue life consideration e.g. a macroblock of harmonic cycles using the standardized method of rain-flow (Amzallag, Gerey,Robert,Bahuaudt 1994). In the last step, it is necessary this macroblock to be centered and if there are some undamaged amplitudes this macroblock is reduced because the harmonic cycles with these amplitudes are eliminated (Bílý, Kliman, Füleky 1993). These all steps are necessary to perform to be able to get relevant parameters of loading process for the following calculation of the fatigue damage. Reducing of the process and macroblock also helps saving the storage capacitance because of huge volumes. The data of load processes after preliminary processing is convenient to archive for needs of downward analysis of the operation. In respect of the problem of recalculation the strain which is directly measured by strain-gauges into stress (Fig. 3), the authors work with the signal of strain (Garan 2010, Šulko & Garan 2013).

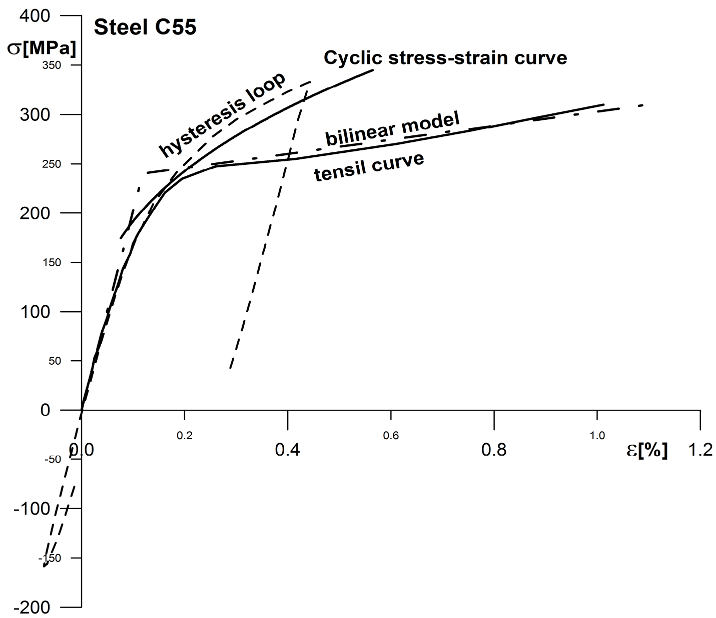


Fig.3 Comparison of the Different Stress-Strain Curves and Their Models for Steel C55, Measured on a Value of Strain Corresponding to a Value of a Stress with Respect of Chosen Model of a Material Characteristic

1.4 Cyclic Properties of Material

The calculation of the fatigue damage needs to merge the parameters of loading in the concrete volume of the material (critical place of the structure) with its cyclic properties. It needs to realize the total Manson-Coffin curve in the following shape

$$\varepsilon_a = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \quad , \qquad (1)$$

where σ_f' (ε_f')is the fatigue strength (ductility) coefficient of materials

b (c) is the fatigue strength (ductility) exponent

N_f is the number of cycle to crack

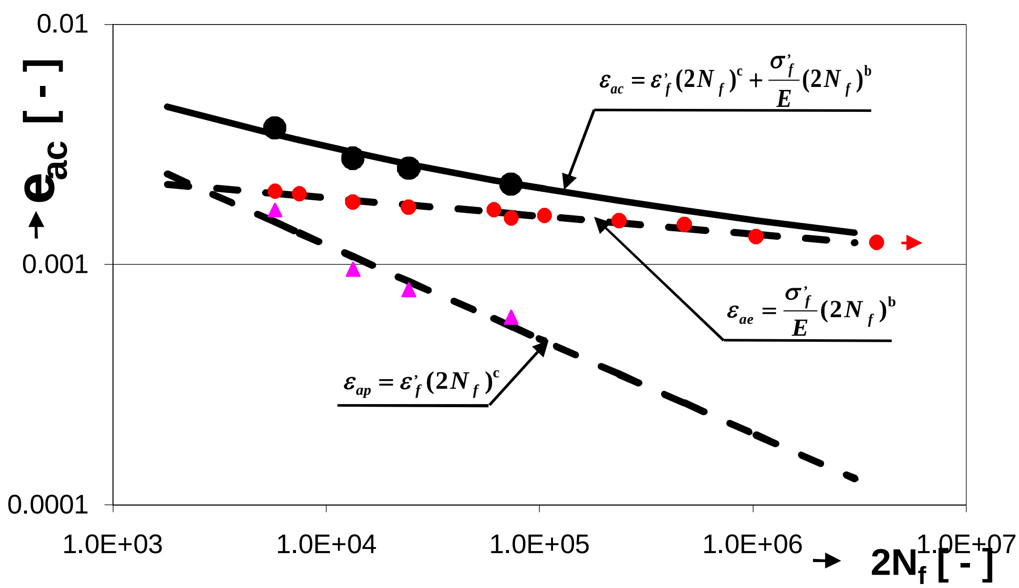


Fig.4 TheTotal Manson-Coffin Curve Acquired by Direct Measuring

This dependence is possible to get e.g. using electro-hydraulic pulsation system on specimens of material representing critical place of the structure in the mode of controlled force and controlled strain (Fig. 4). The direct measuring of this dependence in addition enables to get the review about the dispersion of cyclic material properties which can be used in the calculation and evaluation of the fatigue damage (Kliman 1999, Garan2008).

1.5 Evaluation of the Fatigue Damage Cumulation

The selection of suitable hypothesis of fatigue damage cumulation is very wide. The authors work with the signal of deformation and therefore they prefer the expression for evaluation of the fatigue damage in the form of hysteresis energy created on the base of plastic strain component in the following form

$$D_{ak} = \sum_i \frac{n_i \cdot \Delta W_i}{\Delta W_{Li}} = \sum_{i=1}^{r} 2 \cdot n_i \cdot \left[\frac{\varepsilon'_f}{\varepsilon_{api}} \right]^{\frac{1}{c}} \quad (2)$$

where

ΔW_i is hysteresis energy of loading strain amplitude on the i-th level

ΔW_{Li} is the hysteresis energy to crack for the i-th level of loading amplitude

n_i is the number of loading amplitudes on the same i-th level

ε_{api} is the amplitude of plastic strain on the i-th level of macroblock of loading cycles

The value of damage at the time t = ti is possible to define according the following expression:

$$D^i = D^{i-1} + D^i_{act}, \ \mathrm{i} = \overline{0,n}, \quad (3)$$

where D^{i-1} is the previous level of the fatigue damage in the previous state and D^i_{act} is the actual value of damage in the current time t = t_i, calculated by the expression (2). For the initial state where i = 0, the initial damage of structure can be considered as D_0 = 0. The description of using expression based on the Palmgren-Miner formula in detail can be found in works (Kliman 1984, Bílý 1993).

1.6 Displaing the Actual Fatigue Damage

The primary sense of monitoring system is to give the instant information about the state of exhaustion of the fatigue life for the critical places of the pipeline system. Because there is some dispersion in the values of cyclic material properties it is usual to represent the material properties using the statistical methods. In this way the fatigue damage can be displayed in the bandwidth in which the value of damage can be expected with the required probability of occurrence of material properties (Fig. 5).

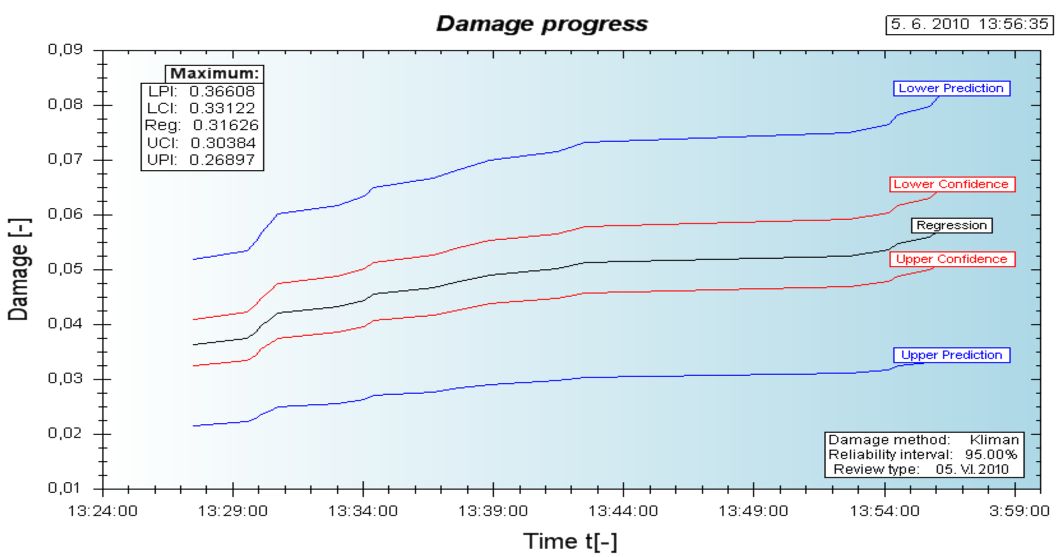


Fig.5 Display of the Current State of Fatigue Damage in the Individual Critical Place of the Structure Dispersion Bandwidth Represents the Inhomogeneity of the Cyclic Material Properties

The progress of the current state of the fatigue damage in the individual critical places of the pipeline system is possible using the internal network, or by internet and mobile networks provide to a responsible or interested person through the entry policy.

2 Conclusion

This brief review of the on-line monitoring system of the fatigue damage for monitoring the critical places of the pipeline system provided the complexity, deepness and the range of the problem. Requirement of the monitoring the fatigue damage cumulation in critical places incidental of occurrence possibility of so called non-standard operational situations and needs to consider the influence of these situations on the next operation (directive EU 37/1998). The real operational loading of the structure can be different against the projected one e.g. (lower than expected), there out by monitoring of real a progress of the fatigue damage the will be result the extension of the serviceability of the structure. On the other hand, the monitoring system can warn about needs to change the critical place of the structure respectively reduction of the safe serviceability for inaccessible risk of the crack.

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