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USE OF ECONOMETRIC MODELS FOR PREDICTING THE LIFETIME OF STEAM PIPELINES IN THE POWER INDUSTRY

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The object of the research were bends of steam pipelines 10CrMo9-10, in which the highest frequency of failures caused by material cracks occurs. The forecast of pipeline operation time was determined on the basis of results R_m. Applying the principles of statistical inference to forecast the trouble-free operation time of steam pipelines, mathematical models were selected that in a highly statistically significant way most reflect the actual reduction in R_m over time and determine the limit value of material exhaustion to avoid failure.

Keywords: power engineering, 10CrMo9-10 steel, pipeline, tensile strength, econometric models

INTRODUCTION

Steel 10CrMo9-10 is a typical construction material for heating installation. The functioning of the energy and heating sector is a strategy for the economy in many countries. It is an industry sector supplying electricity and heating for industrial and domestic purposes. To ensure safe operation of heating installations (steam pipelines) and the required level of heat energy production, it is necessary to diagnose the installation to determine and assess the degree of degradation of the structure of materials used for pressure elements. The service life of the steam pipeline depends on many usability features of the construction material, and in particular its material durability, which includes [1 - 4]:

- strength reserve, as a difference between the critical stress at which the failure occurs (e.g. yield strength or elasticity, fatigue, loss of stability) and the design stress, typical of a physical phenomenon that may be the cause or one of the causes of a failure,
- permanent deformation or displacement of a pipeline element (elbows, tees),
- amount of looseness on joined elements or degradation of connections e.g. welds,
- total fatigue and other damage typical of working conditions.

Steel used in power engineering is exposed to adverse stress caused by pipeline operation. The usefulness of pipelines is influenced by: material fatigue, creep, friction wear, exceeding of short-term strength, work in critical parameters, inter-crystalline and operational cracking, corrosion, erosion, internal material defects, etc. [5, 6], which worsen the technical condition of the element in the considered its fragment, e.g. cross-section, connection point, narrowing, etc.

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METHODOLOGY

The object of research were secondary superheated steam pipelines made of 10CrMo9-10 steel. The scope of research included knee bends due to the high failure rate of these elements during their operation. Static tensile samples were cut from the knees (according to PN-EN ISO 6892-1 [7] and the tensile strength was determined R_m [MPa] - as an input variable. All samples were cut from pipelines made of the same steel at different periods of operation (from 150 000 to 250 000 hours and longer).

To assess the pipeline operation time, econometric models were used, which by means of equations represent quantitative relationships between the phenomena studied. The research used a model of specific functions, e.g. exponential, power. It was a model of the form: $y = R_m$. Model parameters were estimated using statistical methods based on empirical data [8-9]. Estimation of the tensile strength index (R_m) was determined for a group of samples taken with the known form of the random variable of time distribution of the object's ability and based on the estimation of the reliability value from the random sample representing the examined population. Statistical verification of the models was made on the basis of the degree of matching the model to empirical data (R^2) and establishing the statistical significance of model parameters. The distribution of changes was described using econometric models R_m of 10CrMo9-10 steel in time and time prediction for the failure to occur in a given time horizon [10]. Trends of the studied phenomenon with forecast simulation are presented using a standard graph (one-dimensional time series), in which the object's abscissa (X) is the lifetime of the object (thousands of hours), and on the ordinate (Y) - tensile strength (R_m) [10-11].

HYPOTHESIS OF RESEARCH

The paper hypothesizes that the operating conditions of the examined object from 150 000 to 250 000 hours and longer change as a function of time (chronological time series). This change occurs under the influence of the reheated steam factor and has an impact on the tensile strength of the construction material which is 10CrMo9-10 steel, from which the bend of the steam pipeline is made.

EQUIPMENT AND RESOURCES FOR RESEARCH

The tests were carried out in the conditions of real operation of the facility. The distribution of material properties was determined based on the results of tensile strength R_m measurements. The input database consisted of from 10 to 20 samples taken from pipelines operating in various operating periods. Used empirical data were presented in Table 1. Samples were picked on an Instron 3382 testing machine using a 20: 1 gear ratio and a constant tensile speed of 5mm / min. In accordance with PN-75 / H-84024, the lower tolerance limit Lower Specification Limit (LSL) was determined to assess the change in R_m as a function of operating time, which is 440 MPa for reheated steam. Figure 1 shows the place of sampling for R_m tests from the knee arch (designations: sample 1 and sample 2). The choice of the place of sampling corresponded to the places where the damage occurred, the occurrence of which is shown in Figure 2.

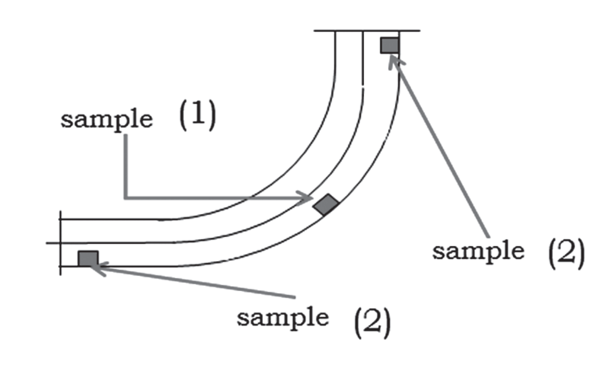

Figure 1 Diagram of the knee and places where strength samples are taken [10]

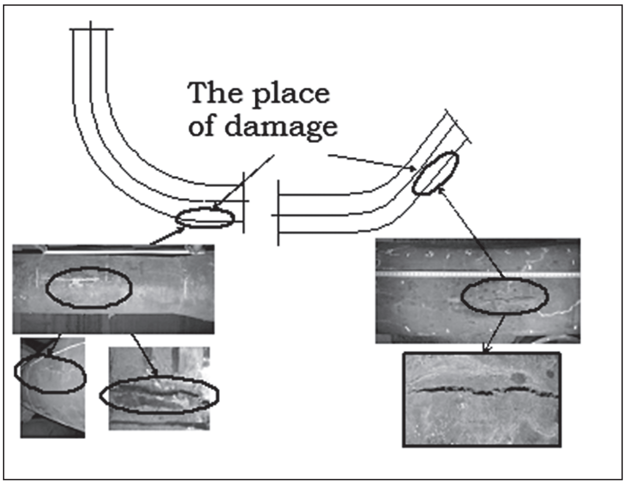

Figure 2 Examples of steam pipeline arc cracks [10]

Table 1 **Empirical data – an example [10]**

a) for Sample 1

Exploration work time/thousand hours	*R*m/MPa
0	551,5
0	551,5
174	496,3
174	496,3
174	496,3
174	496,3
189	488,1
189	488,1
189	488,1
190	487,5
190	487,5
190	487,5
214	472,5
214	472,5
214	472,5
215	471,8
215	471,8
215	471,8
260	436,4
260	436,4
260	436,4
280	417,2
280	417,2
280	417,2

b) for Sample 2

Exploration work time /thousand hours	*R*m/MPa
0	548,1
0	548,1
174	489,0
174	489,0
174	489,0
174	489,0
174	489,0
174	489,0
190	478,1
190	478,1
214	458,9
214	458,9
214	458,9
214	458,9
214	458,9
214	458,9
214	458,9
215	458,1
215	458,1
215	458,1
260	409,8
260	409,8
260	409,8
280	382,0

RESULTS OF RESEARCH

The graphical course of the function of changes R_m during the use of a knee arch made of tested steel is shown in Figure 3. By analyzing the distribution of points on the graph as a function of time, the following econometric models were tested based on their time series: model based on exponential function, model based on quadratic function and hyperbolic model. Using econometric tests to assess the significance of models, the hyperbolic model was rejected. The correct models are shown below:

- model based on exponential function:

$$y = 579 - e^{0,00633x+3,313} \quad (1)$$
$$R^2 = 0,7923$$

- model based on quadratic function:

$$y = -0,0016\,x^2 + 0,0013\,x + 541,07 \quad (2)$$
$$R^2 = 0,8910$$

Both models describe in a statistically significant way the course of the R_m change depending on the operating time of the steam pipe knee arc. The course of functions of the quadratic and exponential models for samples (1) is shown in Figure 3. Based on the econometric models obtained, it was found that the operation of the tested knee arch above 256 000 - 258 000 hours may lead to a decrease in the R_m value below 440 MPa. The same models were used to assess knee arch strength for samples (2). In this case, the hyperbolic model turned out to be the largest degree of matching empirical data to functions. The results are shown in Figure 4.

Capability analysis, ($c_p > 1$), confirmed that the variation limits have a smaller range from Upper to Lower Specification Limit (ULS÷LSL). The improved index of c_{pk} capacity is equal to the index c_{pl}, which indicates a significant decrease in R_m as the steam pipeline's operating time increases, going far beyond the Lower Specification Limit (LSL) tolerance on the left. The values of all prognostic models for the change in R_m as a function of operating time are presented in Table 2.

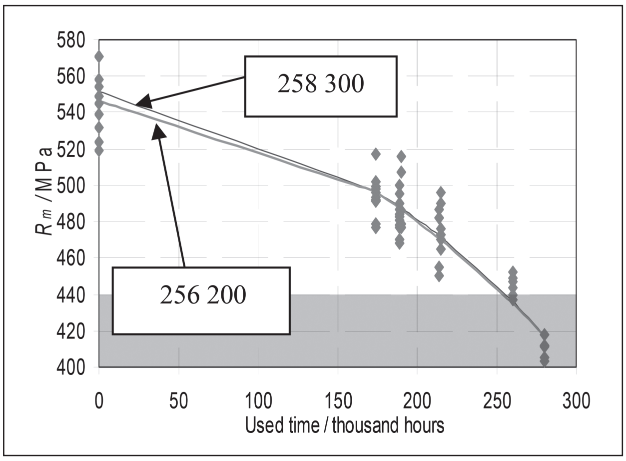

Figure 3 Examples of models describing the course of the R_m change as a function of operating time for the knee arch for samples (1) (place 1) [10]

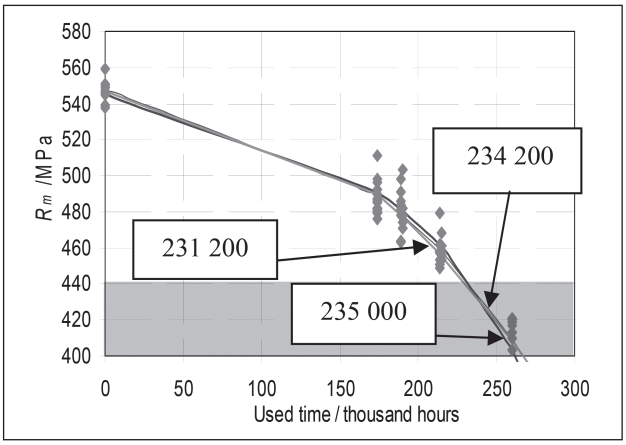

Figure 4 Examples of models describing the course of the R_m change as a function of operating time for the knee arch for samples (2) (place 2) [10]

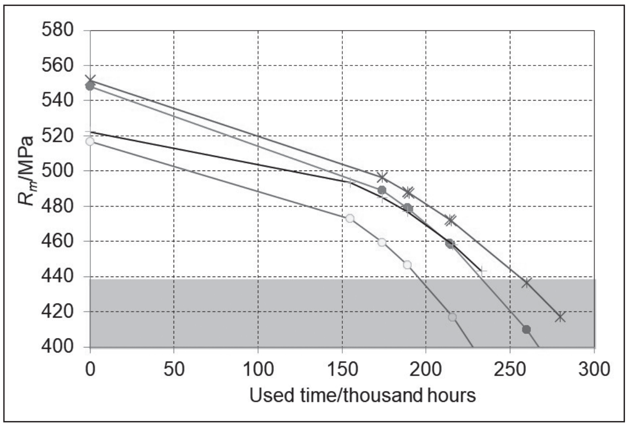

Figure 5 Summary statement of the R_m change forecast as a function of elongation time of the secondary superheated steam pipe [10]

Table 2 **Obtained econometric models [10]**

a) for Sample 1

Model $y = Rm$	R^2	F T/thousand hours
$y = -0,0016x^2 + 0,0013x + 546,01$	0,891	256,2÷258,3
$y = 579 - e^{0,00633x+3,313}$	0,792	
$y = (607,2x - 204319,1)/(x - 375,06)$	0,997	231,2÷235,0
$y = -0,0024x^2 + 0,0921x + 546,62$	0,939	
$y = 567 - e^{0,00815x+2,393}$	0,939	

b) for Sample 2

$y = -0,0022x^2 + 0,1883x + 518,23$	0,817	236
$y = 528 - e^{0,0115x+1,757}$	0,823	
$y = (554,7x - 158158,3)/(x - 307,76)$	0,986	193,4÷198,2
$y = -0,0027x^2 + 0,1334x + 515,13$	0,962	
$y = 525 - e^{0,0119x+2,111}$	0,921	

Where F –Forecast of exploration work time

The trends of obtained prognostic charts R_m for the best model (which was the exponential model) is shown in Figure 5.

CONCLUSION

The motive for undertaking the research was dictated by the need to maintain proper operation of steam pipelines that operate above the critical temperature and ensure their safe use for subsequent years. This problem is very important because it concerns about 90 % of the power units used in Poland.

The obtained models $y = R_m$ (models of the function of the elbow of the steam superheated steam pipeline for 10CrMo9-10 steel) indicate that in all cases exceeding the pipeline's operating time (200 000 hours) increases the risk of structural damage. Based on the results of tensile strength, it can be assumed that the predicted trouble-free operation of steam pipeline components is:

- about 231 200 - 258 300 hours for samples taken from the so-called "curvature" of the knee arch (samples 1),
- about 193 400 - 236 000 hours for samples taken from the so-called "straight" knee bends (samples 2).

From the results it can be concluded that after exceeding the above threshold time, the tensile strength reaches a value below the lower tolerance limit (440 MPa). In such cases, more frequent diagnostic tests should be recommended, as the pipeline "enters" the potentially emergency area, causing the need to replace the elbow in the pipeline installation. The presented methodology of statistical tests can be used to estimate the forecast of material durability, as a derivative of the reliability of operation of pressure installation components, in particular steam pipe elbows, which confirmed the assumed research thesis. The proposed statistical forecasting time operation of the pipeline should be considered as a tool to support decision-making process, which complement traditional studies to assess the degradation of the structure of materials, which are made knee steam pipelines. The analysis of forecasting models should be supplemented by a methodology based on the calculation of the theoretical degree of material depletion for a given pipeline life cycle divided into time intervals required for diagnostic services [12], and development of scenarios of possible events, in this case for operated devices energy industry (e.g. pipelines).

Acknowledge

The Article is part of Disertation [10].

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Note: The responsible for English language J. Jamrozik, Poland.