ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering

Tome XII [2014] – Fascicule 1 [February]
ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]
a free-access multidisciplinary publication of the Faculty of Engineering Hunedoara

[1.] Istvan KUCORA, [2.]Ljiljana RADOVANOVIC, [3.]Eleonora DESNICA, [4.]Jasmina PEKEZ

APPLICATION OF FUZZY FUNCTION ON PYROLYSIS FURNACE TUBES REMAINING LIFE ASSESSMENT

[1.] Stock Company for Production of Petrochemicals, Raw Materials and Chemicals „HIP-Petrohemija" Pancevo - under Restructuring, Pancevo, SERBIA
[2-4.] University in Novi Sad, Technical faculty Mihajlo Pupin, Zrenjanin, SERBIA

Abstract: Pyrolysis furnace is taken as a typical example for studying the questions of remaining life prediction based on data measured from the furnace tubes, such as wall reduction, outside diameter enlargement, hardness and metallographic examination, etc. and the experimental results obtained by specimens which are made from dissecting the furnace tubes. Metal loss causes tube wall thinning and outside diameter swelling. Wall reduction and wall outside diameter enlargement are two important attributes of the tube metal, indicating the grade of metal damage. Thickness dependency vs. time has been investigated. The maximum wall reduction rates have been calculated by Fuzzy function. Results have been compared with the existing relevant data from the literature and measured data of the plant in order to determine the accuracy and verify the validity of the methods. The goal is to obtain simple intuitive models for interpretation and prediction.
Keywords: fuzzy function, pyrolysis, furnace tubes, remaining life

1. INTRODUCTION

The residual life of tubes is related to the redundant thickness of wall and the thickness reduction rate or metal loss rate. However, both these parameters have double uncertainties: randomness and fuzziness. Due to the conditions of inspection at the site having uncertainties (such as the locations of measurement being difficult to select at the same point every time of inspections in the different shut-down maintenance period, the quality of cleaning the oxide on the outer wall surface, the skill level of technician for wall thickness or outside diameter examinations, etc.) and due to so many factors influencing the remaining life of tubes, the values of wall reductions or wall outside diameter enlargement cannot cover the overall attributes of a metal for use at elevated temperature. Thus, the remaining life of a furnace tube to be found by using measured data of wall reduction or wall outside diameter enlargement is merely a possible value.

Moller et al. [7] have modeled damage by means of a Fuzzy damage indicator for the plane type reinforced concrete framework structure. This method has been applied to metal loss in tubes by calculating the rate of wall reduction as well [3]. Dai suggested that the wall thickness measuring has a Fuzzy meaning because of the lack of precision, dependency of operator's skill in using ultrasonic unit and difficulties to find exactly the location of previous measuring point. Therefore, Fuzzy set theory is proposed to determine the maximum wall thickness reduction rate.

2. RANDOMNESS AND STOCHASTIC PROCESSES

There are various types of uncertainties in practical problems. Some of these are statistical uncertainties, such as in basic material behavior (e.g. the scatter of mechanical properties, fatigue crack growth) or in the state environment (e.g. load, temperature, corrosion, etc.). Some of these are nonstatistical uncertainties, such as in the theoretical models used to describe to estimate stresses and temperature; the procedures used to calculate the critical limits; and in scaling of models for size effects, processing, and machining or assembly operations. Although the statistical uncertainties and the nonstatistical uncertainties are different in nature, they are often handled similarly by probability theory and statistics, and are called "random uncertainty".

Randomness uncertainty in the engineering parameter is associated with certain probability distributions and is characterized by the expectation values, variance, and moments. For failure probability analysis and life prediction purposes, physical models of failure used must be accurate and apply over a wide range of conditions. Furthermore, the uncertainty in the model parameters must be accounted for [2]. However, in practice, the probability computation is an approximation.

The term 'possible life' has only a vague meaning, which can be solved by fuzzy set theory, so the method of extreme of fuzzy functions is proposed [1]. It includes the following steps.

2.1.To find the minimum wall thickness

The following stress criterion must be satisfied

$$\sigma = \frac{p}{2}\left(\frac{D_0}{h_{min}} - 1\right) \le [\sigma] \quad (1)$$

where: p - is the internal pressure, D_0 - is the outside diameter, h_{min} - is the minimum wall thickness, σ - is stress, and [σ] - is allowance stress.

If p, D_0 , and [σ] are random variables and if their distributions and the parameters of these distributions are given, the limit state function is

$$g(s,r) = [\sigma] - \frac{p}{2}\left(\frac{D_0}{h_{min}} - 1\right) = 0 \quad (2)$$

where g is the limit state function. The minimum wall thickness, h_{min} can be solved at a given value of reliability or probability of failure by using the method of first-order second moment or of Rackwitz-Fisselar or Palohemo-Hanus [1]:

$$h_{\min} = D \cdot p \big/ \left((2\sigma_{all} - p) V_n + 2p \right) \quad (3)$$

Also, eqn (1) can be solved by using the deterministic method when the distributions and parameters of distributions of variables p, D_0 , and [σ] are unknown. In the present project, dimensions of the furnace tube are 79.5 mm outside diameter x 8 mm wall thickness, p =1.1 MPa.

2.2. Allowance for wall outside diameter enlargement

The limiting value for the enlargement of wall outside diameter is

$$[\delta] = \frac{D_0 - D_f}{D_0} \quad (4)$$

where [δ] is allowance of outside diameter enlargement. The subscripts 0 and f represent beginning of life and end of life, respectively. Considering only one unit length of tube, the metal loss at the time interval of t_1 and t_2 is:

$$\text{metal loss} = \pi\rho\left[(D_1 - h_1)h_1 - (D_2 - h_2)h_2\right] = L$$
$$\text{metal loss rate} = \frac{\text{metal loss}}{t_2 - t_1} \quad (5)$$

where ρ is density.

3. FUZZY METHOD

The emergence of a Fuzzy theory is a revolution in the development of classical algebra and a upgrade to a higher level so that it is now possible to take the information and data that was not specified in the mathematical modeling process. Posing the possibility of absorbing information and more data in a mathematical model to a problem. The theory is based on the idea of removing the Fuzzy boundaries on the logic of reparation classical groups, which says that the group contains a specified number of elements each element that does not belong to this group cannot be attributed by any link, which often contradicts with nature and human behavior.

Classical time series analysis requires many assumptions such as the normality of data, linearity in the autocorrelation coefficient and statistical parameter estimations. It is almost impossible to find all these assumptions applicable in stochastic time series generation or simulation.

Fuzzy systems have numeric interpolation capabilities and are therefore suited for function approximation and prediction. The advantage of fuzzy systems is that they can provide simple intuitive models for interpretation and prediction. Fuzzy systems conveniently allow us to model a partially known dependency between independent and dependent variables.

The architecture of Fuzzy method is given in Fig.1[6]. As it is shown its manipulation involves three primary processes, namely fuzzification, Fuzzy inference and defuzzification. Fuzzification operations combine a real input value with stored membership function information to produce Fuzzy input values. Fuzzy inference matches fuzzified input facts based on Fuzzy rules. Defuzzification combines all Fuzzy outputs to find out a possible life.

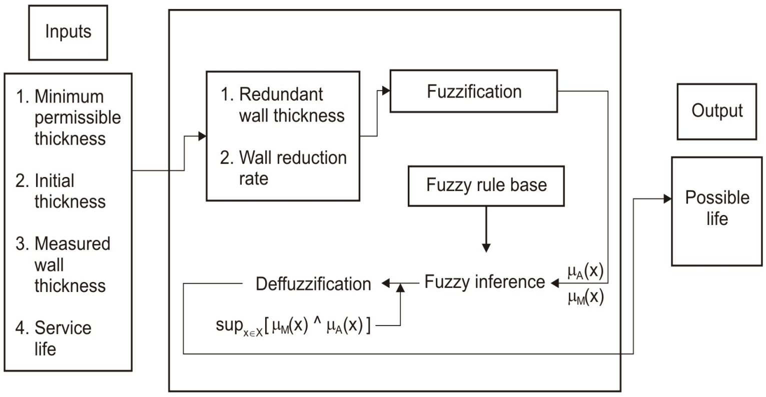

Fig. 1. Architecture of Fuzzy model for life prediction

4. REMAINING LIFE

The residual life of tubes is related to the redundant thickness of wall and the thickness reduction rate or metal loss rate. However, both these parameters have double uncertainties: randomness and fuzziness. Due to the conditions of inspection at the site having uncertainties (such as the locations of measurement being difficult to select at the same point every time of inspections in the different shut-down maintenance period, the quality of cleaning the oxide on the outer wall surface, the skill level of technician for wall thickness or outside diameter examinations, etc.) and due to so many factors influencing the remaining life of tubes, the values of wall reductions or wall outside diameter enlargement cannot cover the overall attributes of a metal for use at elevated temperature. Thus, the remaining life of a furnace tube to be found by using measured data of wall reduction or wall outside diameter enlargement is merely a possible value. The term "possible life" has only a vague meaning, which can be solved by fuzzy set theory, so the method of extreme of Fuzzy functions is proposed.

Let X be a set of locations on the outside surface of furnace tubes at which the wall thickness or outside diameter of tubes is measured, such that: $X = \{x_1, x_2, ...x_n\}$

For an industrial furnace in general one must take the possible residual life of tubes seriously rather than consider the maximum residual life based on the weakest-link mode. [2]

The possible minimum residual life is related to the minimum redundant wall thickness or wall active mass, and the maximum wall thickness reduction rate of maximum mass loss rate, respectively.

Let f(x) be a real-valued function inX, and let inf(f) and sup(f) be its lower bound and upper bound, respectively. The fuzzy set $M = \{(\mu(x)/x)\}, x \in X$ with:

$$\mu_M(x^*) = \frac{f(x) - \inf(f)}{\sup(f) - \inf(f)}, \quad \forall_x \in X \tag{6}$$

is called the maximizing set, where μ is a membership function, ∈ is "an element of" and ∀ is "for all".

Assume that A is the fuzzy subset of X. The solution x*, x*∈X which satisfies the following equation:

$$\mu_M = \sup_{x \in X}\left[\mu_M(x) \wedge \mu_A(x)\right] \tag{7}$$

is referred to as maximum point f(x) on A, and f(x*) is referred to as maximum value of f(x) on A under fuzzy constraints.

Table 1 shows the remaining life predicted from the wall reduction using the method of extreme of fuzzy functions. The thickness was measured by ultrasonic thickness meter with 5 MHz probe. The accuracy of the device is about 0.1 mm

Considering numerical data for HK40 centrifugally casting tubes D= 79.5 mm, p= 1.1 MPa, T_{fluid} = 871°C, T_{tube}= 1066 °C, safety factor = 1.5, V_n (welding factor) = 1 and design strength value at 1066 °C equal to 41 MPa, the numerical value of h_{min} calculated based on Eq.(3) is exactly 1.0. Membership functions $\mu_A(x)$ and $\mu_M(x)$ are calculated based on Eq.(6). Maximum and minimum membership functions $\mu_A(x)$ and $\mu_M(x)$ are determined, then the minimum probable residual life is calculated by dividing redundant wall thickness of element with the maximum of ($\sup_{x\in X}$ [$\mu_A(x) \wedge \mu_M(x)$]) to its corresponding wall reduction rate.

Table 1. Remaining life predicted by the wall reduction

PARAMETERS	SET OF MEASURED LOCATIONS				
	x_1	x_2	x_3	x_4	x_5
Measured outside diameter D_0 [mm]	79.76	79.69	79.93	78.97	79.57
Minimum wall thickness $h_{min}=D_0/(2[\sigma]/p+1)$ [mm]	2.042	2.041	2.047	2.022	2.037
Measured wall thickness h[mm]	6.9	7.3	6.5	7.8	7.5
Redundant wall thickness $h-h_{min}$ [mm]	4.858	5.259	4.453	5.778	5.463
$\mu_A(x)$	0.55	0.5	1	0	0.49
Wall reduction rate $(h_0-h)/5$ [mm/year] (h_0=8 mm)	0.22	0.14	0.3	0.04	0.1
$\mu_M(x)$	0.5	0.5	1	0	0.5
$\mu_M(x) \wedge \mu_A(x)$	0.55	0.5	1	0	0.49
$\sup_{x\in X}[\mu_M(x) \wedge \mu_A(x)]$			1		
Possible life	4.453/0.3= 14 years				

CONLUSIONS

The method of extreme of fuzzy functions provides an easy and simple approach for finding the possible residual life of furnace tubes. The advantage of fuzzy systems is that they can provide simple intuitive models for interpretation and prediction. Fuzzy systems conveniently allow us to model a partially known dependency between independent and dependent variables.

The calculated value of residual life of furnace tubes based on the wall reduction or outside diameter enlargement provides only a possible value for reference. It is desirable that one should consider more attributes of the tube, such as wall hardness and the metallographic condition, etc. to evaluate the grade of deterioration, and so proceed to a multicriteria analysis. Due to the absence of a thorough knowledge and mastering of the art of retardation micromechanisms, it has not really been easy in gauging life on the basis of the very complicated circumstances.

REFERENCES

[1.] Dai, Shu-Ho, Fuzzy assessment for process equipment reliability, J. Chem. Znd. Engng (China), 44 (1993) 103-110.

[2.] Dai, Shu-Ho, Wang Ming-O, Reliability analysis in engineering applications, New York, Van Nostrand Reinhold, 1992.

[3.] Dai Shu-Ho. Methodology for predicting damage to structural material and remaining life of process equipment, Int J Pres Vessel Pip 2001;78:515–20.

[4.] Grant, N. J. & Bucklin, A. G., Deformation and Fracture at Elevated Temperature, M.I.T. Press, Boston, MA, USA, 1965.

[5.] Larson, F. R. & Miller, J. A., A time-temperature relationship for rupture and creep stresses, Trans. ASME, 74 (1952) 765-71.

[6.] Majidian A., Saidi M.H., Comparison of Fuzzy logic and Neural Network in life prediction of boiler tubes, International Journal of Fatigue 29 (2007) 489–498.

[7.] Moller B, Graf W, Beer M. Fuzzy structural analysis using a-level optimization, Comput Mech 2000;265:547–66.

[8.] Simonen, F. A. & Jaske, C. E., A computational model for predicting the life of tubes used in petrochemical heater service, Trans. ASME, J. Pres. Ves. Tech., 107 (1985) 239-46.

[9.] Zhou C., Shandong T., A stochastic computation model for the creep damage of furnace tube, Int J Press Vessel Pip 2001(78):617–25

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering

***