Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 12, Issue, 07, pp.12256-12260, July, 2020

DOI: https://doi.org/10.24941/ijcr.39019.07.2020

ISSN: 0975-833X

RESEARCH ARTICLE

STUDY ON EVALUATION METHOD OF MASS REDUCTION FAILURE OF HEAT TRANSFER PIPE BASED ON MULTI-FACTOR INFLUENCE

***Jun-ge WEN, Shang-kun REN**

Key Laboratory of Nondestructive Testing of Ministry of Education, Nanchang Hangkong University, Nanchang 330063, Jiangxi, China

ARTICLE INFO

Article History:
Received 20th April, 2020
Received in revised form
29th May, 2020
Accepted 27th June, 2020
Published online 25th July, 2020

Key Words:
Nondestructive Testing, Probability Theory, Steam Heat Transfer Tube. Evaluation

ABSTRACT

The development of nuclear power is an important part of the national energy security strategy. Nuclear power safety is the most basic requirement for the development of nuclear power. Based on the testing historical data and expert data of nuclear power heat transfer tubes, the integrity of heat transfer tube degradation is evaluated by using the theory of total probability and Bayes formula. By analyzing the influencing factors such as stress corrosion and fatigue damage, the probability calculation of the degradation distribution of the heat transfer tube under different stress corrosion and fatigue damage conditions is realized. The evaluation method can simplify the complex problem of multiple influencing factors into the correction of a single influencing factor one by one, which simplifies the calculation and processing method. This method can be used for evaluating the degradation probability of heat transfer tubes in nuclear power steam generator.

Citation: ***Jun-ge WEN, Shang-kun REN.*** **2020.** "Study on evaluation method of mass reduction failure of heat transfer pipe based on multi-factor influence", *International Journal of Current Research*, 12, (xxx), xxx-xx.

INTRODUCTION

The research and development of clean energy and the development of nuclear energy are major strategies for national energy security. Nuclear safety is the prerequisite for the sustainable development of nuclear power and the basic requirement of the general public for the development of nuclear power technology. The heat transfer tube of nuclear power is a weak link of nuclear power safety. The safety evaluation of heat transfer tube directly affects the safety of the entire nuclear power plant. Most major accidents in nuclear power plants are related to leakage and rupture of heat transfer tubes (Lu Huaxing, 2011). Liu Yun et al. (2018) Carried out research on ultrasonic non-destructive testing technology of the transition section of the heat transfer tube expansion, and explored the detection problems of the conventional eddy current inspection technology in the expansion section of the heat transfer tube (Zhu Jizhou, 2008). Using the standard GB/T 15260-1994 method, Lin Zhenxia et al. (2017) conducted an intergranular corrosion test on the steam generator 690 alloy heat transfer tube, using boiling nitric acid solution and boiling sulfuric acid-ferric sulfate solution as the corrosion medium, obtained important data for intergranular corrosion rate.

Corresponding author: **Jun-ge WEN,**
Key Laboratory of Nondestructive Testing of Ministry of Education, Nanchang Hangkong University, Nanchang 330063, Jiangxi, China.

At present, most steam generators of the second generation Pressure Water Reactor nuclear power generating units are equipped with anti-vibration strip components in the elbow area to support the heat transfer tubes in the SG elbow area. Suppress the flow-induced vibration of the tube bundle during operation to ensure the integrity of the heat transfer tube during its lifetime. However, the anti-vibration strip also has a certain effect on the integrity of the heat transfer tube. Cui Suwen (2016) and others studied the effect of vibration of the anti-vibration strip on the damage of the heat transfer tube. The study found that the problems of the anti-vibration strip itself have a greater impact on the safety of the heat transfer tube. On the secondary side of the heat transfer tube of the steam generator, there is obvious excitation and vibration of the fluid flowing laterally, with inherent frequency and vibration mode, which seriously affects the safety of the heat transfer tube and is also a key factor for analysis and evaluation (Gao Lixia, 2015; Gao Lixia, 2015) . Shi Shaobo et al. used ANSYS finite element method to simulate and evaluate the rolling plug of the heat transfer tube, and obtained some meaningful results (Shi Shaobo, 2015). At present, there is very little research on the evaluation of the degradation of heat transfer tubes. Based on the concept of probability theory, this paper carries out a probabilistic evaluation study on the safety of the heat transfer tubes of steam generators, hoping to provide reference for the efficient operation and safe production of nuclear power systems.

Analysis of the factors affecting the degradation of nuclear power heat transfer tubes: There are many factors that cause the degradation of the heat transfer tubes of nuclear power plants, including: stress corrosion, high cycle fatigue, fretting, intergranular corrosion, chemical corrosion. Different degradation mechanisms produce complex and diverse forms of damage. Some degradation mechanisms have independent effects on the heat transfer tubes, and some have effects on the heat transfer tubes that are interconnected and superimposed.

- Stress corrosion. Stress, corrosive substances and corrosive environment work together to cause stress corrosion, which is more destructive than pure stress corrosion. Corrosion is mainly related to high temperature corrosive environment, high residual stress and working stress, and material microstructure. Stress corrosion is an important degradation factor in the primary and secondary regions. Stress corrosion is most likely to occur at the elbows, tube expansions, and dents of pipes. When the stress reaches or approaches the yield strength, the corrosion of the material will deteriorate rapidly, and the pipe is in a dangerous situation.
- High cycle fatigue. High cycle fatigue is a degradation process under the action of long-term periodic changing loads. The U-shaped elbow area and the upper surface of the tube plate are the areas most prone to high-cycle fatigue damage.
- (3)Fretting mechanical wear. During the operation of the nuclear power unit, the heat transfer tube will inevitably vibrate. The collision or tangential sliding of the anti-vibration strip and the support plate is the main reason for the micro-vibration mechanical wear.
- Intergranular corrosion. Intergranular corrosion is a relatively uniform corrosion that occurs at the grain boundaries of the tube material surface. Corrosion will inevitably accumulate on the surface of the pipe, resulting in uniform thinning of the pipe wall, resulting in increased stress and accelerated generation of cracks, resulting in tube explosion.
- (5)Chemical corrosion. In the secondary side water chemical treatment, there are some corrosive compounds. The manifestation of chemical corrosion is that the outer wall of the heat transfer tube is evenly thinned, resulting in accelerated crack generation and eventually tube explosion.

Research on Probability Evaluation Method of Degradation and Failure of Heat Transfer Tube Based on Bayes Analysis Evaluation model of failure probability of heat transfer tube degradation Determination of prior distribution and sample information: Let A3 represent the failure pipe plugging event, P(A3) represents the probability of failure pipe plugging event; A2 represents the event that the degradation reaches the warning threshold, P(A2) represents the probability of the warning pipe event; A1 represents the pipe is in a normal event, P (A1) indicates the probability that the tube is in a normal event. According to probability theory, a complete sample space is composed of basic events A1, A2, A3, Ω={(A1), (A2), (A3)}, P(A1)+P(A2)+P(A3)=1 . In the failure probability assessment, there are usually two ways to determine the prior distribution of P(A3), P(A2), P(A1): ① Historical detection data method. P(A3), P(A2), P(A1) The prior distribution can be obtained through analysis based on historical data; ② Expert subjective probability method. The subjective probability is not an unfounded random setting, but a realistic judgment made by experts on the event. Although it is subjective, it integrates all aspects of knowledge accumulation and practical experience to make reasoning and comprehensive judgment on the development law of objective things .Sometimes it is more reliable than objective data and can be used as a prior distribution of subjective probability. In practice, there are many factors that cause degradation of the heat transfer tube. The prior distribution, whether from subjective data or objective data, can not be used as the reliable probability of tube plugging due to degradation failure in the future, and must be re-evaluated under new conditions. The actual situation of various influencing factors will change frequently, and its internal composition and distribution have uncertain changes, and the probability distribution of various events will also change accordingly. For example, the internal composition of degrading factors is different for full-load operation, half-full-load operation or shutdown of a nuclear power plant.

Assuming that the factor that degrades the test piece Ai is B, B can be divided into j categories, denoted as Bj.The weight ratio of the influence factors of category j is P(Bj). After the occurrence of event Ai, the weight distribution of Bj influencing factors is P(Bj/Ai). Because the conditional probability P(Bj/Ai) obtained by mathematical analysis is easier than the conditional probability P(Aj/Bi). Therefore, first obtain the conditional probability P(Bj/Ai) through mathematical statistics, and then obtain P(Aj/Bi) through the Bayes formula.

Modification of influencing factors: First discuss the revision of the single impact factor. After obtaining the P(Ai) prior distribution and sample information P(Bj/Ai) according to the test records and expert data, the data is corrected according to Bayes' theorem to obtain the posterior distribution. The posterior probability of influencing factor B's evaluation of the plugging event $P(A_i / B_j)$ can be obtained from Bayes formula.

$$P(A_i / B_j) = \frac{P(B_j / A_i) P(A_i)}{\sum_{i=1}^{n} P(B_j / A_i) P(A_i)} \quad (1)$$

According to the revised posterior probability and combined with the weight ratio of each category of influencing factors,the occurrence probability after taking the internal changes of the influencing factors into account can be obtained by using the total probability formula.

$$P(A_i)_B = \sum_{j=1} P(B_j) P(A_i / B_j) \quad (2)$$

For the correction of multiple impact factors, similar operations can be performed on each factor in turn, and each impact factor can be revised one by one. When there are multiple influencing factors that need to be corrected for the probability, it is assumed that each influencing factor is independent. The probability calculation steps are as follows.

Step 1: Determine the prior distribution P(Ai) based on historical inspection data or expert data. The weight values of P(A1), P(A2) and P(A3) are determined according to the degree of deterioration and damage.

Table 1. Distribution status, weight values and meanings of factors affecting heat transfer tube degradation and failure

Stress corrosion B			Fatigue vibration damage C		
expression	implication	Weight	expression	implication	Weight
B_1	Severe	$P(B_1)=0.4$	C_1	Severe	$P(C_1)=0.4$
B_2	General	$P(B_2)=0.3$	C_2	General	$P(C_2)=0.3$
B_3	Slight	$P(B_3)=0.3$	C_3	Slight	$P(C_3)=0.3$

Table 2. Sample information under the influence factors of stress corrosion

$P(B/A_1)$		$P(B/A_2)$		$P(B/A_3)$	
$P(B_1/A_1)$	0.3	$P(B_1/A_2)$	0.6	$P(B_1/A_3)$	0.7
$P(B_2/A_1)$	0.3	$P(B_2/A_2)$	0.3	$P(B_2/A_3)$	0.2
$P(B_3/A_1)$	0.4	$P(B_3/A_2)$	0.1	$P(B_3/A_3)$	0.1

Table 3. Sample information under the influence factors of fatigue vibration damage (C)

$P(C/A_1)$		$P(C/A_2)$		$P(C/A_3)$	
$P(C_1/A_1)$	0.3	$P(C_1/A_2)$	0.7	$P(C_1/A_3)$	0.8
$P(C_2/A_1)$	0.4	$P(C_2/A_2)$	0.2	$P(C_2/A_3)$	0.1
$P(C_3/A_1)$	0.4	$P(C_3/A_2)$	0.1	$P(C_3/A_3)$	0.1

Table 4. Posterior probability distribution of influencing factors of stress corrosion (B)

$P(A_1/B)$		$P(A_2/B)$		$P(A_3/B)$	
$P(A_1/B_1)$	0.998767	$P(A_2/B_1)$	0.000999	$P(A_3/B_1)$	0.000233
$P(A_1/B_2)$	0.999433	$P(A_2/B_2)$	0.0005	$P(A_3/B_2)$	0.000067
$P(A_1/B_3)$	0.999877	$P(A_2/B_3)$	0.000125	$P(A_3/B_3)$	0.000025

Table 5. The posterior probability distribution of influencing factors of fatigue vibration damage (C)

$P(A_1/C)$		$P(A_2/C)$		$P(A_3/C)$	
$P(A_1/C_1)$	0.9983097	$P(A_2/C_1)$	0.001369	$P(A_3/C_1)$	0.000322
$P(A_1/C_2)$	0.999568	$P(A_2/C_2)$	0.0003918	$P(A_3/C_2)$	0.0000403
$P(A_1/C_3)$	0.9998259	$P(A_2/C_3)$	0.000147	$P(A_3/C_3)$	0.0000302

Step 2: Classify the determined influencing factors, such as influencing factors B, C, D, etc.

Step 3: Determine the level of the influencing factor according to the characteristics of the influencing factor, and the weight proportion of different levels. If the influencing factor B can be divided into B1, B2, B3, that is, three levels of serious impact, medium impact, and slight impact.The weight ratio can be set as P(B1)=0.4, P(B2)=0.3, P(B3)=0.3, etc. P (B1)+P(B2)+P(B3)=1

Step 4: Perform mathematical analysis based on previously recorded test data to obtain sample information P(Bj/Ai) under an influencing factor (eg B)

Step 5: Use Bayes formula to calculate the posterior probability P(Ai/Bj) of the influencing factor B.

Step 6: Use the full probability formula to calculate the revised probability of influencing factor B.

$$P(A_i)_B = \sum_{j=1}^{3} P(A_i / B_j) P(B_j)$$

Step 7: Based on the revised probability value of the influencing factor B, calculate the revised probability of other influencing factors in turn.

Case study: Probability theory calculationmodel is used to study the case of heat transfer tube degradation failure probability. The factors that affect the degradation of the heat transfer tube are analyzed and classified into two categories. One is stress corrosion factor B including intergranular corrosion and chemical corrosion, and the other is fatigue vibration damage factor C. It is assumed that stress corrosion and fatigue vibration damage are two independent damage events. The following first analyzes the failure distribution of the pipe caused by stress corrosion.

Step 1: Determine the probability prior distribution based on historical data statistics or subjective data given by experts. For example, among the 100,000 recorded heat transfer tubes, there are 10 failed tubes, 50 early warning tubes, and the rest are normal tubes. $P(A_1)=0.9994$, $P(A_2)=0.0005$, $P(A_3)=0.0001$.

Step 2: According to historical statistics or subjective data given by experts, determine the weight value P(B) of the influencing factor B. The values, meanings and composition ratio of the influencing factors stress corrosion B and fatigue vibration damage C are shown in Table 1. According to the degree of stress corrosion and fatigue vibration damage, the weight of the state of the influencing factors is assigned. P(B1)=0.4, (B2)=0.3, P(B3)=0.3 shows that among the pipes inspected in history, 40% of the pipes are in a severe corrosion state, 30% of the pipes are in a general corrosion state, and 30% of the pipes are in a slightly corroded state. If the operating status and environment of nuclear power have changed, the weight distribution in Table 1 should be adjusted.

Step 3: Perform mathematical statistics on the sampling historical test data and expert data to obtain the weight information P(Bj/Ai) of the distribution of influencing factors when the three status events of the tube occur, as shown in Table 2 and Table 3. Table 2 shows the distribution of sample information P(Bj/Ai) produced by stress corrosion, and Table 3 shows the distribution of sample information P(Cj/Ai) produced by vibration fatigue wear.

Step 4: Use Bayes formula (1) to calculate the posterior probabilities P(A/B) and P(A/C) of the influencing factors B and C as shown in Table 4 and Table 5. Let P(A1)=0.9994, P (A2)=0.0005, P(A3)=0.0001.

Step 5: Use the total probability formula (2) to calculate the modified probability of influencing factor B. $P(A_i)_B = \sum_{j=1}^{3} P(A_i / B_j) P(B_j)$

Available:

$P(A_1)_B$=0.9993, $P(A_2)_B$=0.0005875, $P(A_3)_B$=0.0001208

That is, the probability after correction by the influencing factor B. If the stress corrosion is serious, the weight value is modified to P(B1)=1, P(B1)=0, P(B1)=0, and the probability after correction by the influencing factor B is, $P(A_1)_B = 0.998767$, $P(A_2)_B = 0.000999$, $P(A_3)_B = 0.000233$ .It can be seen that the probability of failure pipe which need to be blocked (0.000233/0.0001208=1.93) increases to 1.93 times, and the warning rate increases to 1.7 times. If the stress corrosion is slight, the weight value can be modified to P(B1)=0, P(B1)=0, P(B1)=1, and the probability after correction by the influencing factor B becomes: $P(A_1)_B = 0.999877$, $P(A_2)_B = 0.000125$, $P(A3)_B = 0.000025$.

The probability of failure pipe needing to blocked is reduced to 0.2 times (0.000025/0.0001208=0.2), and the early warning rate is reduced to 0.2 times. It can be seen that when the corrosion state and fatigue damage status change, the blocking rate required for failure pipe will obviously change. Due to the influence of stress corrosion factors, compared with severe corrosion and mild corrosion, the change probability of failure probability of corroded pipes will reach 1.93/0.2=9.6 times. That is, if the last inspection cycle system was operated in a slightly corroded state, the failure probability of the tube during inspection was η; if the current inspection cycle system was operated in a severely corroded state, the failure probability of the tube would reach 9.6η.

Step 6: Based on $P(A)_B$ and adopt Bayes formula (3) to calculate the posterior probability of the influencing factor C. The posterior probability $P(A_i / C)$ is shown in Table 5.

$$P(A_i / C_j) = \frac{P(A_i) P(C_j / A_i)}{\sum_{n=1}^{3} P(A_n) P(C_j / A_n))} \tag{3}$$

Step 7: Use the full probability formula (4) to calculate the modified probability of the influencing factor C

$$P(A_i)_{BC} = \sum_{j=1}^{3} P(A_i / C_j) P(C_j) \tag{4}$$

Available:

$P(A_1)_{BC} = 0.9991421$ $P(A_2)_{BC} = 0.000709$, $P(A_3)_{BC} = 0.00015$

This is the probability after correction by influencing factors B and C. If the fatigue damage is serious, the weight value is modifiedto:

$$P(C_1) = 1, P(C_2) = 0, P(C_3) = 0$$

Available: $P(A_1)_{BC} = 0.99831$, $P(A_2)_{BC} = 0.001369$, $P(A_3)_{BC} = 0.000322$

Therefore, if the fatigue damage is serious, the probability of failure pipe needing to blocked (0.000322/0.00015=2.15) will increase to 2.15 times, and the earlywarning rate will increase to 1.93 times. If the fatigue damage is minor, the weight value is modified to $P(C_1) = 0, P(C_2) = 0, P(C_3) = 1$

Available:

$P(A_1)_{BC} = 0.999826, P(A_2)_{BC} = 0.000147$, $P(A_3)_{BC} = 0.0000302$

Therefore, if the fatigue damage is slight, the probability of failure pipe needing to blocked(0.0000302/0.00015=0.2) will be reduced to 0.2 times, and the early warning rate will be reduced to 0.21 times. Under the influence of fatigue damage factors, severe fatigue and mild fatigue, the failure probability of the pipe would change to 2.15/0.2=10.75 times. At the same time, considering the combined effects of stress corrosion factors and fatigue damage factors, the severe degradation and slight degradation of the environment in which the pipe is located will result in the failure probability difference of the pipe reaching 9.6×10.75=103.2 times.

Conclusion

Based on the concept of total probability and Bayes theory, this paper analyzes and establishes an evaluation method for the probability of degradation and failure of nuclear power heat transfer tubes. Combining the Bayes formula and the concept of total probability can solve the complex problems of multiple influencing factors. The Bayes formula mainly plays the role of calibration. The full probability formula solves the problem of the probability of pipe failure, simplifying the calculation method. The model can be modified one by one for multiple specific degradation factors. For a single influencing factor, the damage is serious and the damage is slight, which will cause the failure probability of the pipe to change by 10 times.

That is, due to the influence of a single factor, the minimum probability of tube failure is η, then the maximum probability of tube failure can reach 10η; if the two influencing factors are considered together, the two influencing factors are severely damaged and mildly damaged. If the minimum probability of pipe failure is η, the maximum probability of pipe failure can reach 100η. It can be seen that the detection sensitivity is very high, and the probability of different levels of degradation can be further calculated. This research method aims at different influencing factors and use mathematical methods , which can obviously eliminate the adverse effects of human subjectivity on the evaluation results, and has a strong operability.

Acknowledgements

This work was financially supported by the Nanchang Aviation University Graduate Innovation Special Fund Project (YC2019052).

REFERENCE

Lu Huaxing. Research on localization of AP1000 steam generator U-tube alloy material (J). Nuclear Power Engineering, 2011, 32(3): 29-32.

Iu Yun, Lu Wei, Ding Song, Yin Peng, Yang Jinli. Ultrasonic Inspection Technology for Water Immersion in the Transitional Section of Heat Transfer Tube Expansion of Steam Generator(J). Nuclear Power Engineering,2018,39(4):75-79

Zhu Jizhou. Operation of PWR Nuclear Power Plant (M). Beijing: Atomic Energy Press,2008.

Lin Zhenxia, Dang Ying, Xu Qi, Chen Yong. Research on Intergranular Corrosion Resistance of Stea,m Generator 690 Alloy Heat Transfer Tube(J). Nuclear Power Engineering2017, 38 (Increase 2): 128-130

Cui Suwen, Zhu Yong, Ren Hongbing. Analysis of the effect of anti-vibration strip on the integrity of the heat transfer tube of the steam generator (J). Nuclear Power Engineering,2016,37(6): 109-112.

Gao Lixia, Yu Daping, Tan Tiancai, Ma Jianzhong, Liu Litao. Dynamic characteristics of heat transfer tubes in steam generators (J). Nuclear power engineering,2015, 36(5): 65-67

Gao Lixia, Tan Tiancai, Yang Jie, Yu Danping, Ma Jianzhong. Study on random turbulence excitation of heat transfer tube in steam generator inlet section (J). Nuclear power engineering,2015, 36(5):87-90

Shi Shaobo, Shen Ping, Tian Xianglu, Gao Luyang. Effectiveness analysis of steam generator heat transfer tube plug (J). Nuclear power engineering,2015,36(5): 72-74

****