Early Inspection of Wet Steam Generator Tubes Based on Metal Magnetic Memory Method

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Abstract

Fatigue tests on wet steam generator 20G tubes were carried out and the metal magnetic memory (MMM) signals were detected. Though the analysis of MMM signals from different fatigue cycles, the variation characteristic of the MMM signals was obtained and a novel quantitative evaluation method of the early failure by MMM technology was proposed and applied in oilfield on-site test finally. The test results showed that MMM method can effectively locate the stress concentration zone (SCZ). The magnetic gradient indicates the damage severity of the investigated zone of the tube. If the magnetic gradient is above 12A/(m·mm), this zone is damaged seriously.

Keywords: metal magnetic memory; 20G tube; stress concentration

1. Instruction

The wet steam generator is one of the major equipments used in steam process technology in the current world. In China, it has been widely used in Shengli and Liaohe oilfield. The water from high-pressure injection pump is heated to high-temperature and high-pressure coexistent steam, and then is transported into subsurface deposit through specific pipe lines. Thus, the viscosity of oil is reduced and the oil is pumped more easily. Tubes which include convection section and radiation section are one of the important parts used in heat exchange in wet steam generator, and they are the single straight tube, arranged in horizontal reciprocating [1]. Because radiation section of tubes bears high temperature (about 350°C), high pressure (about 18Mpa) and pressure fluctuation from reciprocating pump, stress concentration occurs in this area commonly, resulting in failure and even severe accident. According to statistical data, economic losses caused by the wet steam generator tube failure amount up to millions of Yuan every year [2-4]. At present, failure detection methods for wet steam generator tubes include ultrasonic flaw detection, ultrasonic thickness test, magnetic particle inspection, etc [5]. These methods can detect existing faults, but cannot examine potential faults and early stress concentration zones (SCZ).

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Metal magnetic memory method based on magnetostrictive effect and magnetoelasticity effect is a new detecting method, which can be used to detect potential faults and SCZ. This method has many advantages such as pre-processing free, rapid detection and easy operation, etc.\cite{6-7}, so it can be applied to detect the early faults of wet stream generator tubes so as to prevent accidents and ensure the safety in production.

2. Metal magnetic memory method

Metal magnetic memory (MMM) was firstly proposed at 50th International Welding Conference in 1997. The fundamental principle of MMM testing is to detect the self-magnetic leakage field, which generates in stable gliding dislocation zones with stress concentration in ferromagnetic materials. In stress concentrated parts of ferromagnetic structures, tangential component of magnetic leakage $H_p(x)$ shows the maximum value, while normal component of the magnetic leakage $H_p(y)$ shows to be zero. The irreversible changes of this kind of magnetic status can retain after the working load is removed. This phenomenon is the basis of MMM inspecting method that only involves measuring normal component of magnetic leakage to locate the stress concentrated areas in a tested object.\cite{8} Thus, the early prediction of boiler tube faults is feasible.

The reason for most of tubes failure is that pressure fluctuation causes stress concentration in the weak areas where fatigue failure occurs more easily. The quantitative evaluation of MMM is to determine the value of $K$ which is the gradient of magnetic field $H_p(y)$ in the stress concentration zone ($K=\frac{\Delta H_p(y)}{\Delta l}$). The value of $K$ is proportional to internal stress in the work piece.\cite{9-10} In this paper, the magnetic memory signals are detected by fatigue tests and field tests in order to obtain characteristics of $K$, which represents the deformability of intensive stage of metal before damage.

3. Fatigue test

3.1 Experimental material and operational mode

Experimental object is 20G pipe. Its yield strength is 320MPa, intensity degree is 470Mpa. The Pipe length is 400mm, the outside diameter $\Phi16$mm and the thickness 3mm. Force was loaded by universal testing machine, and MMM signals were detected by TSC-1M-4 signal detector. The effective length of detection is 200mm, and there are four tube samples for test.

A gap with stress concentration was processed manually in the center of the first three samples to shorten the fatigue test cycle. The original MMM signals of processed samples’ were stationary. Stress controls with the maximum of 22kN, 20kN and 18kN were adopted in the fatigue tests, respectively. Loading force was sinusoidal, stress ratio was 0, and loading frequency was 10Hz. The MMM signals were detected by TSC-1M-4 stress concentration detector every 1000 cycles. The sample was placed on the level platform after unloading. MMM signals were detected uniformly in the same direction by detection probe.

3.2 Characteristics of magnetic memory signals

Fig.1, Fig.2 and Fig.3 are the variation of processed sample MMM signals with maximum fatigue stress 22, 20 and 18kN respectively. Fig.4 shows the variation of intact sample MMM signals with maximum fatigue stress 20kN.
The abscissa is the effective length for measuring, the ordinate is the magnetic field intensity, and different colors represent different cycles. It can be seen from the figures that the $K$ value of SCZ increases slowly with the cycle increasing. When the sample is close to damage, the $K$ value of SCZ increases fast. The sample cracks after about 3,000 fatigue cycles, then the positive and negative magnetic
poles forms around the faulted zone. Compared Fig.2 with Fig.4, the variation of MMM signals of intact sample are the same as processed sample. It can be seen from Fig.1, Fig.2, Fig.3 that the smaller the fatigue stress is, the more fatigue cycles are and the greater the K value of SCZ is.

Table 1 Magnetic gradient K of SCZ in the process of fatigue test

| Fatigue testing | $K_s$ (A/(m·mm)) | $K_b$ (A/(m·mm)) | $m = K_b/K_s$ |
|-----------------|-----------------|-----------------|----------------|
| Fatigue 1(22KN) | 7.5             | 15.5            | 2.1            |
| Fatigue 2(20KN) | 8.5             | 23.5            | 2.7            |
| Fatigue 3(18KN) | 14.5            | 34.0            | 2.3            |
| Fatigue 4(20KN) | 17.5            | 22.5            | 1.3            |
| Average value   | 12.0            | 23.9            | 2.0            |

4. Field test

The variation of MMM signals of wet steam generator tube is shown in Fig.5. From the figure 5 it can be seen there are three positions(100mm, 500mm, 1000mm) where the value of K is greater than or equal to 12A/(m·mm). The value of K at these points are 12A/(m·mm), 12A/(m·mm) and 15A/(m·mm) respectively. In the field test, there were no apparent changes in the ultrasonic signals by ultrasonic flaw detection in these three positions, while the wall thickness was found less than the standard value by ultrasonic thickness test. As is shown in Fig.6, large corrosion pits inside the tube can be found. It indicates that this tube section had greater stress concentration and damaged seriously. 20G tubes which was chosen randomly had no obvious damage when the value of K was below 12A/(m·mm).

From above analysis, it can be concluded that metal magnetic memory technology with application to wet steam generator tube is feasible by laboratory test and field test.
5. Conclusions

(1) MMM method can effectively locate the stress concentration zone, and the zone which $H_p(y)$ is a peak zone is SCZ.

(2) The $K$ value of SCZ increases slowly with the cycle increasing in the initial stage of fatigue test. When the sample is closing to damage, the $K$ value of SCZ increases to 12A/(m·mm). Faulted zone forms positive and negative magnetic poles.

(3) Through laboratory tests and field tests, when the $K$ value is larger than 12A/(m·mm) wet stream generator 20G tubes are almost damaged.

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