Welding residual stress reduction assessment in steel rings via the spectral harmonic vibration aging test

X D Liang¹, G L Shi¹², G Z Wang¹, X Z Zhou¹ and B S Shang¹

¹College of Mechanical and Traffic Engineering, Guangxi University of Science and Technology, Liuzhou, 545006, China

E-mail: sgl8913@163.com

Abstract. The generation of welding residual stress easily causes fatigue cracks in the interior of the structure where the welding residual stress is high. It finally causes the fatigue fracture under the combined action of external load and internal stress, resulting in failure of welded structural parts. It has the fatigue crack and fracture failure during the use of the radial engineering steel ring. In view of this phenomenon, this paper proposes a spectrum aging test analysis of steel rings using spectral harmonic vibration stress relief system. Through the statistical analysis of the test data, the results show that after the vibration aging treatment, the transverse and longitudinal welding residual stresses in the steel ring’s weld seam have a large downward trend as a whole, and the residual stress reduction rate of each test point is about 25%. This study provides a reference for the application of vibration aging technology to steel ring weldments.

1. Introduction

As the most important safety component of engineering vehicles such as loaders, the engineering steel ring is subjected to the pressure of parts and the weight of the load, including bearings and stressed parts. In the actual production, the engineering steel ring is mainly welded by rims, spokes, retaining rings and other parts. So the welding process is the most important process in the entire steel ring. With the welding process, the welding residual stress will be formed in welded parts, and the stress generated during the stamping process will cause cracks, fracture, and other failures during the product operation. It is very important to carry out proper aging treatment of the steel ring with welding residual stresses. The traditional aging method has the disadvantages of long time, high energy consumption, large heat treatment furnace, and pollution when removing the welding residual stress of the steel ring, and also decrease the mechanical properties of the matrix material [1]. The natural aging method has the disadvantages of longer processing time (more than a few months), large occupied space, and poor stress removal effect [2]. The vibratory stress relief (VSR) technology overcomes the shortcomings of thermal failure and natural aging, and has the advantages of short production cycle, low investment, energy saving, and no pollution [3]. In addition, the steel structure size, shape and weight do not affect the welding process during the application of vibratory stress relief technique [4]. At present, the VSR technique has been applied in many industrial fields, but there are few reports on vibration aging analysis of steel ring welded parts. To this end, the authors of this study selected the Q235B steel ring as the research object, carried out the experimental research on the influence of vibration aging treatment on...
the residual stress of steel ring welding, and provided reference for the application of VSR technique on steel ring welding parts.

2. Test methods and surface treatment of steel ring

2.1. Test method
Using the X350A stress tester as shown in figure 1, the welding residual stress before and after the vibration of the engineering steel ring is detected. In the X-ray stress detection experiment of this paper, the measurement method adopts the roll fixation method, with $\Psi$ values of 0 and 45°. Other parameters are listed in table 1. The welding part of the engineering steel ring includes the midpiece’s butt-welding, the midpiece and hypomere’s butt-welding, the spoke and midpiece’s T butt-welding, and the rim epimere and midpiece’s butt-welding. In this paper, the harmonic spectrum vibration test is carried out on the butt welding parts of the middle of the three steel rings, and then separately detects the residual stress before and after the vibration aging treatment. Due to the large size of the steel ring, it is necessary to test the residual stress after welding of the steel ring in the open air, so the X-350A stress measuring instrument head is clamped on the vertical measuring frame, as shown in figure 2. The measured positions of the three steel rings are A1, A2, B1, B2, C1, C2 and the distribution of each weld test point are shown in figures 3 and 4, wherein the stress parallel to the weld is longitudinal stress, vertical the stress on the weld is transverse stress.

2.2. Test steel ring surface treatment
Due to the production of the steel ring, the surface of the steel ring will be oxidized by air. So the surface of the steel ring needs to be treated before the X-ray residual stress test. First, use a sander to polish the weld near the weld to remove harmful substances such as rust layer and oxide layer, then smooth the surface with fine sandpaper, and then the measuring point is electropolishing, among them the electrolyte is saturated with NaCl. Finally, the welding residual stress detection before and after the vibration aging treatment of the steel ring is completed.
Table 1. The set parameters of X-ray test equipment

| Specimen name | Engineering steel ring | Line target | Crkα |
|---------------|-------------------------|-------------|------|
| Material      | Q235B                   | Diffraction crystal face | (211) |
| X-ray tube current | 5.0mA                | Ψ angle (°) | 0.0°, 45.0° |
| 20 scan start angle | 161.00°              | Stress analysis constant | -318 MPa/ degree |
| 20 Scan end angle  | 152.00°               | 20 Scanning step | 0.10° |
| Counting time | 1.0s                   | X-ray tube high voltage | 25.0KV |

2.3. Process diagram and test of VSR

The vibration aging device places an exciter with an eccentric mass on the workpiece to be processed. The motor is started by the controller and the rotation speed is adjusted to make the workpiece in a resonance state as shown in Figure 5. The vibration treatment can be adjusted after 20~30 min to achieve the purpose of adjusting the residual stress. [5] After the steel ring is finished, it is treated by vibration aging without heat treatment. After many experiments, a process that meets the effects of vibration aging is
obtained. The vibration aging process is: three-point support with a rubber damping pad, the vibration exciter is fixed on one side of the spoke surface of the steel ring, and the vibrator is fixed on the other side of the spoke surface of the steel ring, and the exciter is deviated 40 degrees, as shown in figure 6. The model of the vibration exciter is HY3008, the maximum excitation force is 20KG, the rated speed is 8000rpm, the stability accuracy is ±1, the rated voltage of the motor is 180V, the rated current of the motor is 13.8A, the output power of the motor is 2200W, and the power frequency is 50Hz.

![Figure 6. The spectrum harmonic vibration aging test.](image)

3. Analysis and discussion of test results

3.1 Residual stress test results

After the spectrum harmonic vibration aging test, then we make the stress test of the midpiece’s butt welding of the rim, and the results for three steel rings before and after vibratory stress relief are shown in figure 7.
Figure 7. Residual stress distribution of steel rings in different directions before and after VSR in: (a) No.1 steel ring at A1 position; (b) No.1 steel ring at A2 position; (c) No.2 steel ring at B1 position; (d) No.2 steel ring at B1 position; (e) No.3 steel ring at C1 position; (f) No.3 steel ring at C2 position.

3.2. Experimental analysis and discussion
It can be seen from the test results that there are lateral and longitudinal residual stresses in the steel ring before the vibration aging treatment, which is due to the action of the welding heat source and the welding heat cycle and the internal stress caused by the uneven heating of the workpiece during the welding process. The general welding residual stress is based on the internal stress occurring in the workpiece after the nonuniform temperature field generated by the welding operation completely disappears. Meanwhile, longitudinal and lateral residual stresses in the steel ring are obviously relaxed after the vibration aging treatment. It can be calculated that the elimination rate of the residual stress of most test points (the residual stress difference before and after vibration aging divided by the residual stress before vibration aging) is about 25%, and larger residual stress values will be reduced by the
vibration aging test. However, some of the smaller residual stress values did not change after the vibration aging test, and a small portion of the smaller residual stress value will become larger. This indicates that the vibration aging test does not completely eliminate the welding residual stresses in the workpiece but makes their distribution more uniform and diminishes their stress concentration.

4. Conclusion
This paper discusses three common methods used for reducing welding-induced residual stresses and compares the characteristics of vibration aging with those of natural and thermal ones. From the experimental results, the welding residual stresses in the engineering steel ring before and after the vibration aging exhibit a significant downward trend. Due to energy conservation and structural stress balance, larger stress values decrease with vibration aging, while smaller ones may slightly drop or even rise. The vibration aging does not completely eliminate the residual stresses but makes their distribution more uniform and diminishes their stress concentration.

Acknowledgements
These researches were supported by the Reform Subject of Guangxi Department of Education Degree and Graduate Education”(Grant No. JGY2018109), Guangxi University of Science and Technology Graduate Innovation Project (GKYC201903, GKYC201807). We gratefully acknowledge the support agency.

References
[1] Shalvandi M et al 2013 Influence of ultrasonic stress relief on stainless steel 316 specimens A Compos. Mater. Design 46 713-23
[2] Sun Y S et al 2016 Residual stress relief in Al-Zn-Mg-Cu alloy by a new multistage interrupted artificial aging treatment Materials & Design 92 281-7
[3] Ma Y B et al 2019 Effect of vibration aging treatment on fatigue properties of 7055-T775 aluminum alloy Mech. Eng. Mater. 43 35-40
[4] Hou B 2019 Analysis of welding residual stress and welding deformation control technology of steel structure China Metal Bulletin (02) 139-40
[5] Li J M et al 2018 Analysis of 3 times superharmonic resonance characteristics of linear spring combined vibration aging device Vibration and shock 37(20) 173-8