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A Study of Intermediate Frequency Magnetic Pulse Device Applied to Reduce in Residual Stress in Thin-walled Bearing Rings (Jackie (1981) reported)

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Residual stress will be in the thin wall bearing rings after they are machined. The residual stress may change the organizational performance and dimension of the bearing rings, and reduce the rate of qualified products resulting in loss of product quality. It has been proposed recently that magnetic treatment is very promising in reducing the residual stress in workpieces (Benson, R.F. (2000) and. JiříHájek (2015) reported). Thus, in the paper, an intermediate frequency experimental device is designed and built to study the effect of this treatment. By comparing the diameter variation of thin wall bearing rings before and after the magnetic treatment, it is shown that the intermediate frequency magnetic treatment is effective in reducing the residual stress in thin-walled bearing rings. The diameter variation was reduced from 0.005mm to 0.009mm after the treatment. At the same time, based on these experimental studies, the optimal design and operation parameters of the intermediate frequency magnetic experimental device are developed.

1. Introduction

Thin-walled workpieces are widely used in various industries such as automotive, and aerospace industries and generating these areas a high demand of these workpieces including thin-walled bearings, and piston rings. As the wall is thin and easy prone to deform, it is not easy to ensure the geometric precision of the bearing rings. So It is critical to reduce the residual stress to improve the mechanical performance and stability of the bearing rings. Mechanical thermal treatment is commonly used for reducing the residual stress of workpieces. Due to its stringent requirement for accurate temperature control, thermal treatment tends to induce extraneous undesirable heat stress and/or material surface oxidation (Tomáš Kovalčík. et al. (2015) reported).

It is developed in recent years to reduce the residual stress of steel materials by pulsed magnetic treatment (Klamecki, Barney E. (2003) and Kovalev, S.I. (2007) and Marin, Georgiana Rosu et al. (2014) reported). The pulsed magnetic treatment is attractive since the process is carried out at room temperature and magnetic fields are easy to produce and control (Miller, PC. (1990) and Oliker, V.E. (2010) and Stepanov, G.V. et al. (2013) reported and WANG Xin-hua et al. (2015) and Vorob'ev, Dubinskii. (2010) reported). Researchers consider the main reason why the magnetic pulses can reduce the residual stress is the magnetostriction causing plastic deformation of the crystal lattice and dislocations homogenization (Oliker, V.E et al. (2012) and Vorob'Ev, Dubinskii. (2014) and WANG Xin-hua, JIAO Yu-lin. (2015) reported). In this paper, we propose a method to apply magnetic pulse to the thin-walled bearing rings to reduce the residual stress. An intermediate frequency (IF) pulsed magnetic experimental device is designed and developed to implement this approach. The experiment results show that the diameter of each the bearing outer rings were all reduced at each measuring points after the IF magnetic treatment and the degree of the reduction is temperature dependent. The amount of change is larger, the more residual stress is reduced. Detection and tracking data show that intermediate frequency electromagnetic pulse treatment significantly reduced the residual stress in the the thin wall bearing rings, so that the reduction of the residual stress significantly enhanced the geometry precision and stability of the thin wall bearing rings. As the reduction of the residual stress is proportional to that of the ring diameter (after the IF-treatment), we further experimentally optimized the process parameters. Diameter of 20mm to 30mm bearing rings can be treated by this IF pulsed magnetic experimental device. Compared to

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the traditional hot aging treatment, the proposed approach is more efficient and consumes less power, resulting in more than 90% less energy consumption, and over two orders of magnitude of reduction in processing time (from 24-72 hours traditionally to 3-7 minutes process time).

2. Design and fabrication of the intermediate electromagnetic pulse experimental device

2.1 Preliminary design of the intermediate frequency electromagnetic pulse test device

Magnetic treatment device needs to be small size, lightly weighted, and easy to carry and use. In order to obtain the main factors that adjust the residual stress of the specimen accurately when generating and applying the IF magnetic pulses constantly, pulse magnetic experimental device needs to control the temperature of the specimen when it produces a stable intermediate frequency pulse. The IF pulsed magnetic power is the core component of the device. This is because the IF pulsed magnetic power generates the alternating current, which in turn, produces through the magnetic coil a stable IF pulse magnetic field to process the bearing rings. Preservative solution is employed to cool down the thin-walled bearing rings, and a heater is used to control the ambient temperature to adjust the temperature of preservative solution. The temperature of preservative solution is measured by a digital thermometer. The schematic diagram of the IF pulsed magnetic experimental device is shown in Figure 2.1. The preservative solution containing an antiseptic function for cooling is applied to cool down the rings to avoid the influence of the heat treatment on the bearing rings; the digital thermometer shows the temperature of the preservative solution temperature; the heater is utilized to heat up to increase the temperature of corrosion solution. To prevent the magnetic field spread outward while improving the energy efficiency field, a soft magnetic plate is used to surround and form a barrel on the outside of the magnetizing coils.

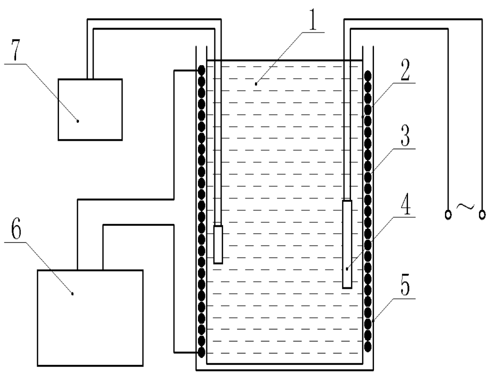

Figure 2.1: The schematic diagram of intermediate frequency pulsed magnetic experimental device.

1- the preservative solution 2- the magnetic treatment drum 3- the magnetizing coils

4- the heater 5-the soft plate 6- the IF pulse magnetic power supply 7- the digital thermometer

2.2 Design Methodology of the IF pulsed magnetic power supply

The IF pulsed magnetic field power supply circuit consists of a filter and rectifier circuit, a resonant circuit, a control drive circuit and a protection circuit, as schematically depicted in Fig. 2.2. The alternative current (220VAC, 50Hz) from the power source is converted to a high-voltage direct current after being filtered through the filter and rectifier circuit along with the bridge rectifier. The high-voltage direct current produces a resonant current (the IF pulse current) in the magnetizing coils after being flown through the resonant circuit. The resonant circuit comprises two coils, namely, the inductance coil and the magnetizing coil; the control drive circuit is used to adjust the excitation pulse, the current frequency and power of the magnetization coils, and a protection circuit is used to protect the filter and rectifier circuit, the resonant circuit, the control driving circuit to avoid the electrical components from being damaged by excessive large voltage. Figure 2.2 is the design diagram of the intermediate frequency pulsed magnetic field power supply.

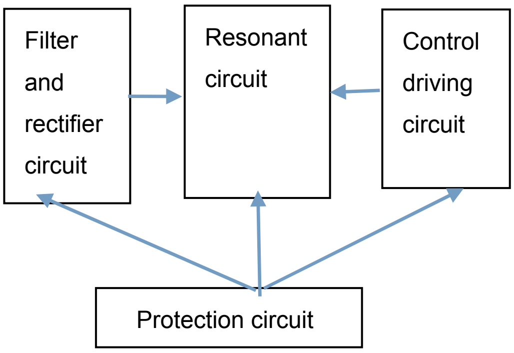

Figure 2.2: the design diagram of the IF pulsed

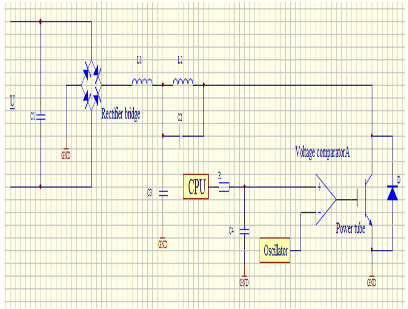

Figure 2.3: The schematic of the IF pulsed magnetic field power supply magnetic field power supply

L1 - the inductance coil   L2 - the magnetizing coil

The resonant circuit and control driving circuit can be explained by the schematic diagram of the IF pulsed magnetic field power supply given in Fig. 2.3. The 220 V, 50 Hz AC power supply is converted into a high-voltage direct current through the capacitor C1 and the rectifier bridge, and then passed through the inductance coils L1, the magnetizing coils L2, the resonant capacitor C2 and C3, the power tube and other components of the resonant circuit, resulting in an alternating magnetic field in the magnetization coil L2.

2.3 Manufacturing of IF pulsed magnetic field device

To generate a sufficient magnetic field to achieve the desired effect of magnetic treatment, we should consider the following factors including the power of the current or voltage value being passed through the magnetizing coil, the turns of the magnetization coil, and the diameter of the solenoid wounded by the solenoid coils, etc. In practice, the magnetic induction of a solenoid can be expressed as(Jia qiming et al. (2010) reported):

$$B = \mu_0 \frac{N}{l} I \tag{2-1}$$

In Formula 2-1, where B is the magnetic induction of the solenoid, N denotes the number of turns of the coil, I denotes the current through the coil and l is the length of the coil in the solenoid, μ_0 is the vacuum permeability. According to the design principle of magnetizing coils, a magnetization coil of 27 turns with the cross-sectional diameter of 18 cm was chosen, which produced a current through the magnetizing coil of 5 A through the magnetizing coil. In order to reduce the amount of heat generated by
the magnetizing coils, the cross-sectional area of 1.5 mm^2 soft copper or multi-strand soft copper wire in parallel was used. The experiment measurements showed that the heat of multi-strand parallel copper wire was significantly reduced, and the temperature of the magnetization coil does not exceed 60 ℃ over 6 hours of operation. The magnetic treatment drum is made of non-ferromagnetic material and wounded by the multi-strand soft copper wire in parallel. Treating the magnetic solenoid coil as a slender, the induced magnetic induction coil within the theoretical strength field is about $4.5\mu_0$.

$$B = \mu_0 \frac{N}{l} I = \frac{27}{30} \times 5 \times \mu_0 = 4.5\mu_0$$

The IF pulsed magnetic field power supply and the experimental device are shown in Figure 2.4 and Figure 2.5, respectively. As depicted in Fig. 2.4, the magnetizing coil is wound around the plastic drum by three wires in parallel and the number of turns of the magnetizing coil is 27. The outer diameter of the upper and the lower ends of the drum are at 20 cm and 16 cm, respectively. The cross-sectional area of the copper wire used is 1 mm^2. An alternating current passes through the magnetizing coils, and the maximum effective current and voltage are at 5.5 A and 300 V, respectively. The heater of the device is relatively independent, using frequency current to manually control the temperature of the preservative solution.

Figure 2.4: IF pulsed magnetic

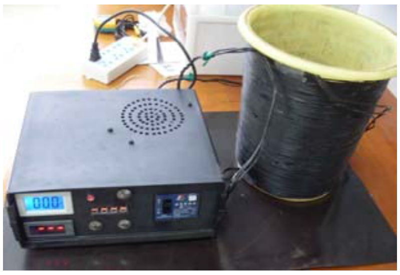

Figure 2.5: IF Experimental magnetic treatment field power supply device

3. Experimental Test of the thin wall bearing outer rings

The outer diameter of 30 mm thin-walled bearing outer rings were selected for the test. The experimental specimen and distribution of four measurement points are shown in Fig.3.1 and Fig.3.2, respectively.

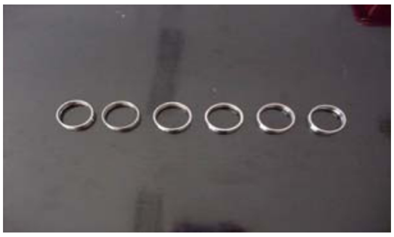

Figure 3.1: Thin wall bearing outer rings

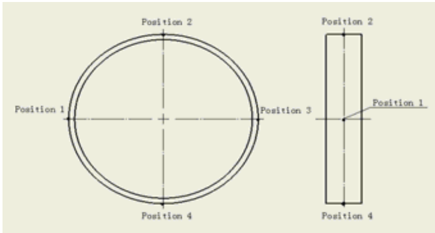

Figure 3.2: Distribution of four measurement points

Before the IF pulsed magnetic field treatment, the diameter of the four measurement points of the thin wall bearing outer rings had been measured. Then the outer rings were placed in the center position of the magnetic field, and the axial direction of the outer rings were positioned in parallel to the magnetic field direction. After the IF pulsed magnetic field treatment, the diameter of the same four points were measured again. The diameter changes before and after the IF pulsed magnetic field treatment were compared---the amount of change is larger, the more residual stress is reduced, so the effect of magnetic treatment is more ideal. The frequency of magnetic treatment was 2000 Hz; the processing time was 455 s, and the temperature of the outer rings was 30 □. The testing results are shown in Table 3.1.

Table 3.1: The change of diameter of bearing rings before and after IF pulsed magnetic field treatment (Unit: cm)

Bearingss ring		Position 1	Position 2	Position 3	Position 4
1	Before treatment	30.032	30.035	30.028	30.038
	After treatment	30.025	30.027	30.022	30.030
	The amount of change	0.007	0.008	0.006	0.008
2	Before treatment	30.042	30.036	30.026	30.036
	After treatment	30.034	30.031	30.018	30.029
	The amount of change	0.008	0.005	0.008	0.007
3	Before treatment	30.036	30.028	30.034	30.040
	After treatment	30.030	30.019	30.026	30.034
	The amount of change	0.006	0.009	0.008	0.006
4	Before treatment	30.030	30.025	30.027	30.034
	After treatment	30.025	30.018	30.019	30.026
	The amount of change	0.005	0.007	0.008	0.008
5	Before treatment	30.036	30.032	30.028	30.030
	After treatment	30.030	30.024	30.023	30.024
	The amount of change	0.006	0.008	0.005	0.006

4. Testing results

As shown in Table 3.1, the averaged amount of diameter change of the five specimens are 0.00725mm, 0.007mm, 0.00725, 0.007mm, 0.00625mm, respectively, and the total average change is 0.00695mm. The experimental data shows the diameter of each bearing outer ring has a different degree reduction at each measuring points after the magnetic treatment. This reduction is shown in Fig.3.7.

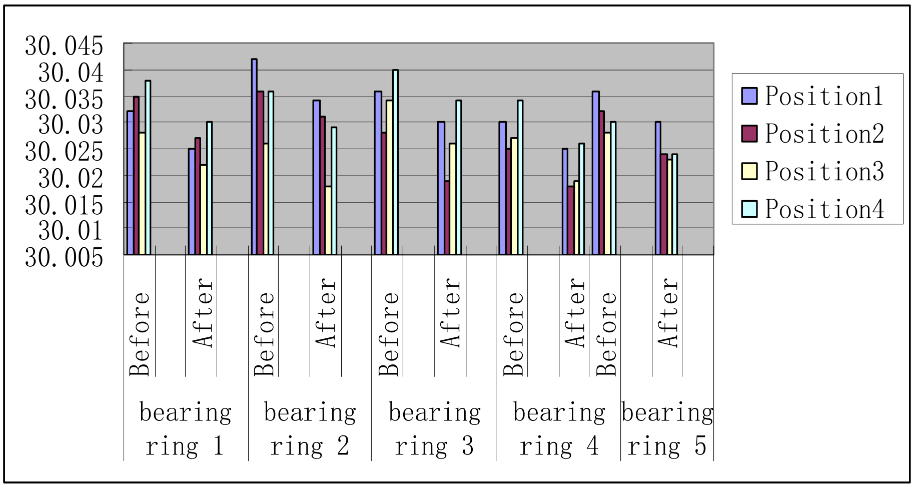

Figure 3.7: the diameter reduction of each bearing rings after IF magnetic treatment

5. Conclusions

In this paper, the IF pulsed magnetic field treatment of bearing rings was proposed and an IF pulsed magnetic field treatment device was designed, constructed, and tested through experiments. The largest diameter variation of the bearing rings is 0.008mm after the magnetic treatment. The optimal process parameters obtained via the experiment were at the IF pulsed magnetic field treatment. The frequency is of 2000 Hz; the processing time is of 455 s, and the temperature of the outer rings is 30 ☐. The experimental results demonstrated that comparing to the traditional hot aging treatment, the intermediate frequency magnetic field treatment is more effective in reducing the residual stress in thin-walled bearing rings and consumes less power, resulting in more than 90% less energy consumption, and over two orders of magnitude of reduction in processing time. Therefore, the proposed IF pulsed magnetic field treatment shows great promise for widely applied in reduction the stress of other ferromagnetic materials parts and dimension process stabilization.

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