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Testing Instrument for Internal Stress of Long Seamless Rails

Xin QI, Juan CHEN, Xingye Zheng
Department of Physics and Electronics, Beijing University of Chemical Technology,
15 East Road Beisanhuan Beijing 100029, China
Tel: +86-10-86988003, Fax: +86-10-64434898
E-mail: qixin@mail.buct.edu.cn

Abstract

A new advanced technique in nondestructive testing for residual stresses and surface state of the material is discussed. The testing instrument for internal temperature stresses of seamless rails is developed. The principal, structure of the testing instrument and its application are presented.

Keywords: Barkhausen Noise, seamless rails, Magnetic domain, stress

1. Introduction

Seamless rail is also given the name of long welded steel rail. It is important to carry out high-speed transport. When tens of standard rails are welded together, because of the resistance from the road knots and roadbed, expanding (when heated) and contracting (when cooled) take place only within 100meters at either end. The middle section of the long rail is called fixed section, which doesn't change with the changes of temperature of the rail. Correspondingly, longitudinal temperature stress is accumulated inside the long rail. A simple mathematical formula can give the relation. The temperature stress inside the fixed section changes 2.5Mpa when its temperature changes 1℃. The temperature stress of the long rail changes 75Mpa when rail temperature changes 50℃. In sweltering summer, the temperature of the rail oversteps air temperature about 20℃when air temperature increase to a certain extent. After the long rail fails to undertake tremendous stresses, it releases energy within a short distance. This phenomenon is called expanding rail and off-position. So railroad maintainers hope sometime to know exact longitudinal temperature stresses in order to guide them in maintenance and to estimate the probability of expanding rails.

Long seamless rail longitudinal temperature stress testing instrument is developed by means of Barkhausen Noise technology. The principle, structure, controlling system and its application of this instrument are introduced in this paper. The instrument has following characters: auto-instant testing, easy taking and convenient testing. The testing depth reaches 1mm. The accuracy of a number of tests of spot testing is ±1Mpa.

2. Principle

Ferromagnetic materials are magnetized under an alternating magnetic field. The magnetic domain wall produces jump when the magnetic intensity of the magnetic field exceeds that of the magnetic domain wall to produce irreversible critical field. Dimensions of the domain wall jump increase with the increase of magnetic intensity. Under positive and negative magnetization, the hysteresis loop of the materials is not smooth. A series of sudden, step and shaky irreversible movement are presented under an alternating magnetic field. This phenomenon was first found by German physicist Barkhausen.H, in 1919,called Barkhausen effect. A wide range of voltage pulses and noises caused by the effect in the receiving coil on the surface of the ferromagnetic materials are called Magnetic Barkhausen Noise, briefly written as MBN[1-3].

After years of research, it has generally been accepted that MBN comes from irreversible motion of 180°

and 90° magnetic domain wall and irreversible revolving of magnetic domain vector. The quantity of MBN not only depends on circles of the receiving coil and magnetic variable of each step for irreversible magnetic proceeding, but also intensely depends on microscopic structures and applied-stress state of the ferromagnetic material[4]. Therefore, a testing instrument for longitudinal temperature stresses of long seamless rail is developed by means of MBN effect[5-6].

3. Instrument Outline

Development of the instrument must be based on variation of MBN frequency band with changes of applied applied-stress. It is necessary that Noise's frequency band should be selected, which is sensitive to the changes of the stress.

3.1 Structure of the Sensing Probe

This probe is rectangular, 50mm×40mm×55mm. It mainly consists of three parts.

(1) Magnetizer: a U core, with 0.2mm thick silicon-steel chips pressed together. The area of the magnetic core is 15mm×8mm. Its pulling force is 9.8N. The diameter of the wire is 0.5mm. The ampere circles are 190. Magnetic frequency is 6Hz. And electromotive force is about 3 V.

(2) Receiver: It can be found that the receiving result of MBN depends on the circles. The diameter of the receiving coil and the design of the receiving core. The probe also consists of high-frequency receiving magnetic core and high-sensitive varnished copper wire.

(3) Preamplifier: According to the data from the spectrum analysis, after matching main amplifier, choosing the amplifier and many times of filtering different frequencies, the amplifier with high-flux filter contains capacitance and electric resistance, which is used to prevent interference from the power pack.

The probe makes magnetic lines concentrate and can receive 10KHz-200KHz uV level signals with high signal to noise ratio. The probe is fixed on the structure shelf. The pulling force of the spring is 3.5N, which is used to test in field. See fig.1.

Fig.1 testing structure shelf in the field

3.2 **Structure of Main Frame**

The block diagram of the circuit is show in figure 2.The circuits are supplied with power by storage battery. This circuit system includes three parts: main-amplifier, select-amplifier and detector. The figure of merit of the select-amplifier is 25.6. This circuit system uses the high-pass filter, band-pass filter and frequency-selective amplifier. The band is depressed step by step in order to prevent interference of the noises.

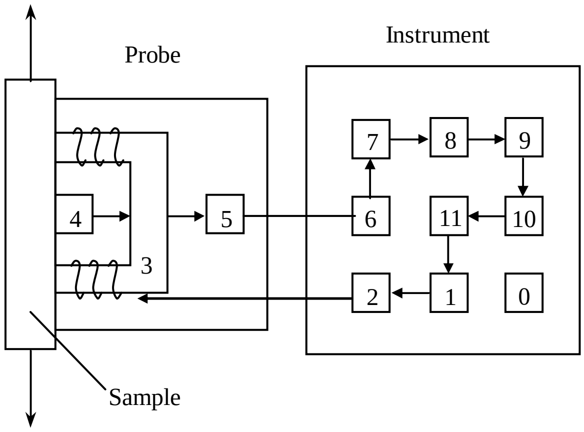


Fig.2. The block diagram of the circuit
0.battery 1.signal generator 2.power amplifier 3.magnetizer 4.receiver 5.preamplifier 6.band-pass filter 7.main-amplifier 8.select-amplifier 9.transrectification 10.data compilation 11.data processing

Positive half cycle signals for MBN are detected. Envelopes of 20 cycles for outputting MBN are collected by a path A/D(analogue-to-digital) of single-chip microcomputer 8098. Collected data are processed by data base utility, temperature signals are collected by another path A/D of 8098. A centigrade degree of testing is given by means of specimen temperature curve. Temperatures and stresses in in-field testing can be shown on the panel of the instrument. The main program which processes the relationship between the MBN signal and the stresses is shown in figure 3.

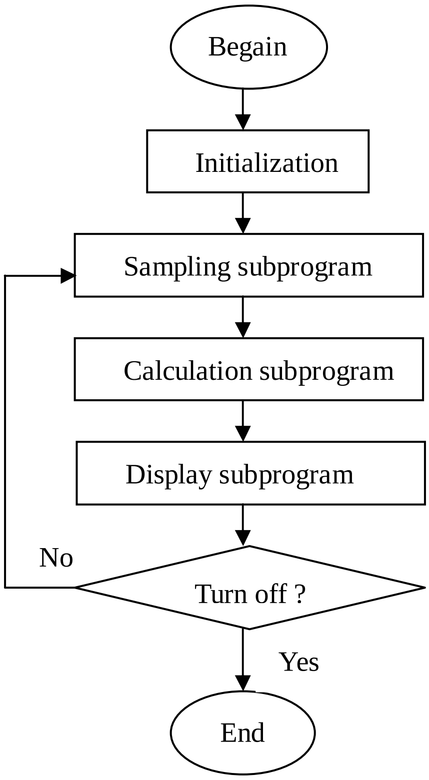


Figure 3. The main program

3.3 **Making if Specimen Stress Curve**

Testing of temperature stresses of the long seamless rail is based on the standard curve obtained form experiment in material test machine. The sample is cut off from the waist of the formal rail, which just leaves the factory and is free from rust on the surface. The probe is fixed on one side of the sample. 6Hz sine wave is used to magnetize the sample. The peak-peak value of the contour of the MBN signal is taken. Figure 4 gives the relationship between the MBN and stresses.

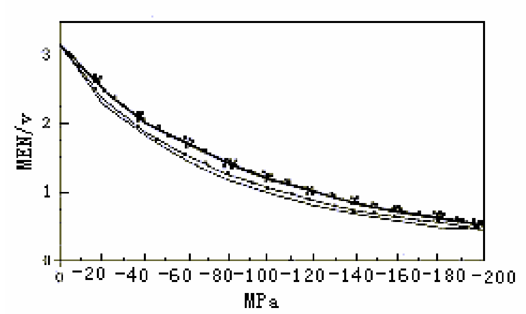


Figure 4 Calibration curve for the relationship between MBN voltage and the stress

The applied forces change from zero to -200Mpa and then return back to zero. It can be seen that the relationship between the MBN and stresses is a little different at different times. The final Calibration curve is their average.

4 Testing in the field

4.1 The scheme of the test

Stress difference between temperature stresses in the field and residual stresses before locking the seamless railroad are used in the test of the longitudinal stresses of the railroad[7-8]. Experiment has proved that longitudinal temperature stress is equally distributed in the cross section of the rails. We can calculate the rail's longitudinal stress caused by temperature changes by testing the waist of the rails. Because the instrument for testing internal stress of the long seamless rails can't distinguish between applied stresses and residual stresses the "practical" longitudinal stresses can't be worked out without measuring the initial value of the residual stresses when no longitudinal stresses exists[9-10].

In the rail producing progress ,though different factories have strict and similar technique requirement, the rail's initial stress value are different because the metallurgical furnaces and the service time of rails used in the field are different. Different sections and different surface states of the railroad bring much difficulty in the measure of stresses. 20 standard rails that just leave the factory are welded together to form a 500 meters long rail. On its surface 1500 spots are polished with a grinder. The surface roughness Ra is less than 2.5(Ra＞2.5). Ten days later the MBN value is tested on these spots. The results show that it is almost impossible to get a uniform measurement background even if the surface states of these spots are about the same.

The only acceptable test plan is pinpoint test at regular intervals. Square frames of the same size (60mm×50mm) are polished with grinders on the surface of the waist of the railroad that just leaves factories. The surface rough degree Ra is kept between 1.6 and 2.5. Then these square frames are calibrated with calibration meter and painted with rustproof oil. After these rails are locked up on the line, pinpoint testing will be carried out.

4.2 Testing in the field

The longitudinal rail stress instrument consists of the portable main circuit and the probe mounted on the waist part of the rail. The power of the instrument is supplied by a storage battery.

A 721 meters long free rail that is off the line is tested at XuJia railway station, Harbin district of Heilongjiang province in china. The changes of the temperature of the rail with that of the environment are shown in figure 5.

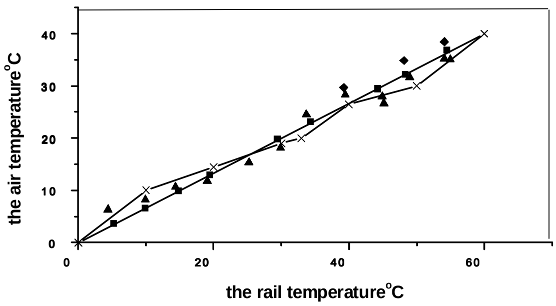


Figure 5. Variation of the rail temperature with the air Temperature

The tests are made every two days. The results of the five tests are different from each other. In sum, when the temperature of the environment is between 10-25°C, the temperature of the rails is 10°C higher than that of the environment. When the temperature of the environment is between 25 -35°C, the temperature of the rails is about 20°C higher than that of the environment. The changes of the stresses with that of the temperature of the rails are shown in figure 6. Five different spots are tested. Usually the stress increases 2.2-2.5MPa as the temperature of the rail increases 1℃. But due to the influence of the degree of how fast the rails are fixed, in some section of an area, the stresses increase only 1.8-2.0MPa as the temperature of the rails increases 1℃.

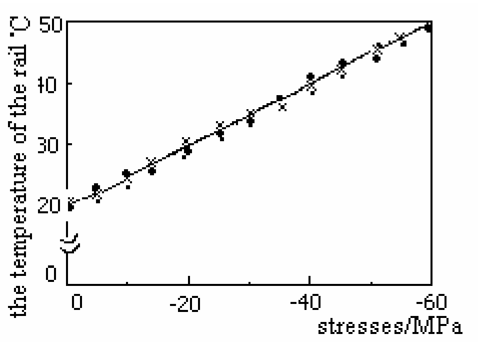
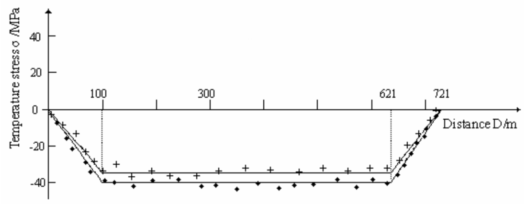


Figure 6. Dependence of temperature against stresses in the sample

In July of the hot summer, the temperatures of the rails vary between 42℃ and 44℃. The initial values of the stresses at various spots are tested. Then the rails are locked up. 20 days later, when the temperatures of the railroad vary between 38℃ and 41℃, the test is made again. The result of the test is shown in figure 7.



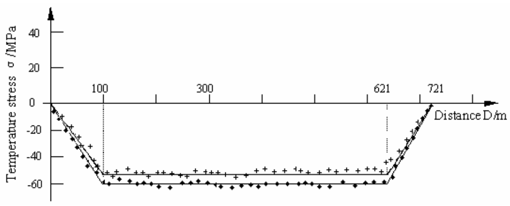
+ the left section

. the right section

Figure 7. Result 1 of the rail stress testing in the field
Average of the right section (-40.1MPa)
Average of the left section (-38.6MPa)

The distribution of the longitudinal stresses in the fixed section of the seamless railroad is basically even. The MBN value decreases as the temperature of the rails increases, As the temperature of the rails is above the locked-up temperature, the stresses in the rails appears to be oppressive. The distribution of the stresses in the free section and the fixed section appears to be ladder-shaped. Near the point of conjunction the difference is zero. At this time, the seam between two rails disappears. The average difference of the left one of the upgoing rail is -38.6MPa. The right one is -40.1MPa. The results are related to the size of the seams and the degree to which the rails are fixed.

In the middle of July of the next year, when the temperatures of the rails vary between 44℃ and 46℃, the test is made again. The results are shown in figure 8.



+ the left section

. the right section

Figure 8. Result 2 of the rail stress testing in the field
Average of the right section (-59.3Mpa)
Average of the left section (-57.6Mpa)

The average difference of the left one of the upgoing rail is -57.6MPa and the right one is -59.3MPa. During the test, it is also found that: (1) after the rails are crushed by trains for a long time, the residual stresses in the railroad appears to distribute evenly when the temperature of the rails returns below the locked-up temperature. (2) The longitudinal temperature stresses on the cross section of the rails is related not only to the resistance of the rails and the magnitude of temperature changes but also to the course of temperature changes in certain section of an area.

5.Conclusion

(1) The instrument for the on-line test of the stresses in seamless rails caused by thermal expansivity and cooling constriction is based on the Barkhausen effect theory, That is, the relationship between the stresses and the MBN signals caused by the irreversible movement of the 180° and 90° magnetic domain walls and the turn of the magnetic vector.

(2) When testing the stresses of the seamless rails, the test point should be selected at the waist part of the rails. The differences between the stresses in locked rails and the stresses in unlocking rails can be used to calculate the stresses in rails caused by the air temperature. The magnitude of the stresses in the lengthways cross section of the rails caused by the air temperature not only have something to do with the resistance of the rail and the change range of the air temperature, but also with the change co urse of the air temperature in certain district. The probability that the rails may distort due to the rail expending can be judged synthetically from the appearance of the peak value of the stresses in the dangerous areas using self-made instrument.

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