

MEASUREMENT OF RESIDUAL STRESSES AROUND A CIRCULAR PATCH WELD USING
BARKHAUSEN NOISE

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INTRODUCTION

Welding is a common means of joining and repairing steel structures. In the case of steel tanks, circular patch welds are often used for repairing the structure after removal of a defective area. Unfortunately, the welding process also produces residual stresses which, if not relieved, can impair the integrity of the structure. Measurement of residual stresses produced by welding is needed, for example, to verify the effectiveness of a stress relief heat treatment which is typically used to remove weld-induced stresses.

Although numerous nondestructive methods such as X-ray diffraction [1], ultrasonic birefringence [2], and magnetically-induced velocity change [3] are available for residual stress measurement, these methods all have shortcomings; none is a rapid, easy to use approach that can be implemented under field conditions. The Barkhausen noise (BN) method meets these criteria, however, and therefore was investigated as a means for measuring welding stresses around circular patch welds. Principles of the BN method and results of an experimental investigation using steel plates with circular patch welds are described below.

PRINCIPLES OF THE BARKHAUSEN NOISE METHOD

Application of a time-varying external magnetic field (H) to a ferromagnetic material produces a value of flux density (B) in the material which does not increase in a strictly continuous way, but rather by small, abrupt, discontinuous increments called Barkhausen jumps [4]. The jumps are due principally to discontinuous movements of boundaries between small magnetically saturated regions called magnetic domains in the material [5,6]. An unmagnetized macroscopic specimen comprises a great number of domains, the direction of whose magnetization is random so that the average bulk magnetization is zero. The specimen becomes magnetized under an external magnetic field mainly by the growth in volume of domains oriented to the direction of an applied magnetic field, at the expense of domains unfavorably oriented. The principal mechanism of growth is the movement of the "walls" between adjacent domains. The direction and magnitude of the mechanical stress to which a region of a

macroscopic ferromagnetic specimen is subjected strongly influence the distribution of domains and the dynamics of the domain wall motion in that region, and correspondingly influence the Barkhausen effect [7,8].

The BN method is implemented in practice using the arrangement shown schematically in Figure 1. A small C-shaped electromagnet is used to apply a controlled, time-varying magnetic field to the specimen. The resulting movement of the magnetic domain walls induces voltage pulses into the detection coil. The solid line in the magnetic hysteresis loop at the top of Figure 2 shows the magnetic flux density, B , as a function of the applied magnetic field, H , (or time). The corresponding burst of Barkhausen noise pulses induced in the sensing coil is shown at the bottom of the figure. Because the pulses can be roughly described as "noise," the term Barkhausen noise is often used. The BN pulses can be processed to obtain a voltage signal proportional to the envelope of the burst of pulses, as shown by the solid line outlining the upper half of the BN burst shown in Figure 2. The peak amplitude of this signal is measured as an indicator of the level of Barkhausen noise.

The BN signal amplitude is dependent on the stress, as well as the angle between the stress direction and the direction of the applied fields, as shown in Figure 3. The BN signal is plotted vs. stress for angles from 0 degrees (vertical axis) to 90 degrees (horizontal axis). For a 0 degree angle, the BN signal increases with tension and, for a 90 degree angle, the opposite result is obtained. The dependence of the BN amplitude on the angle for a given stress is proportional to the strain produced by that stress, indicating that the BN is actually sensing the strain [9]. Therefore, BN measurements can be used to measure stress in a manner similar to strain gages.

EXPERIMENTAL SETUP AND SPECIMENS

Experimental data were taken with an SwRI Series 200 Barkhausen Noise Stress Measurement System using a hand-held probe. The BN data were transferred to a computer for analysis.

The specimen used in the experimental evaluation was a 4-foot square by 0.5-inch thick plate of A516 grade 70 steel. The plate contained a circular patch weld (approximately 6 inches in diameter) which had been cut from the plate and then welded back into place. The BN measurement locations were along each of four lines (designated A, B, C, D) extending radially from the center of the circular patch, as shown in Figure 4. Nine locations were used, starting at the center and extending out to 21.5 inches from the center. At each location, BN measurements were made with the probe oriented with the magnetic field direction both radially (B_r) and tangentially (B_t).

An additional plate measuring approximately 3.5 feet x 6 inches x 0.5 inch thick, with no weld, was used in obtaining BN calibration measurements as a function of applied strain. Strain gages were mounted on this specimen and load was applied in a four-point bending fixture.

EXPERIMENTAL APPROACH AND RESULTS

The residual stresses around a circular patch weld are known to be biaxial, with the principal stresses existing in both the radial and tangential directions [10] as shown in Figure 5, which is a theoretical plot of both components as a function of radial position from the center of the patch. As shown in Figure 5, both the tangential and radial components are tensile and have the same value at the center of the patch (radial position 0). As the radial position increases, both components increase and peak in the region of the weld with the tangential component

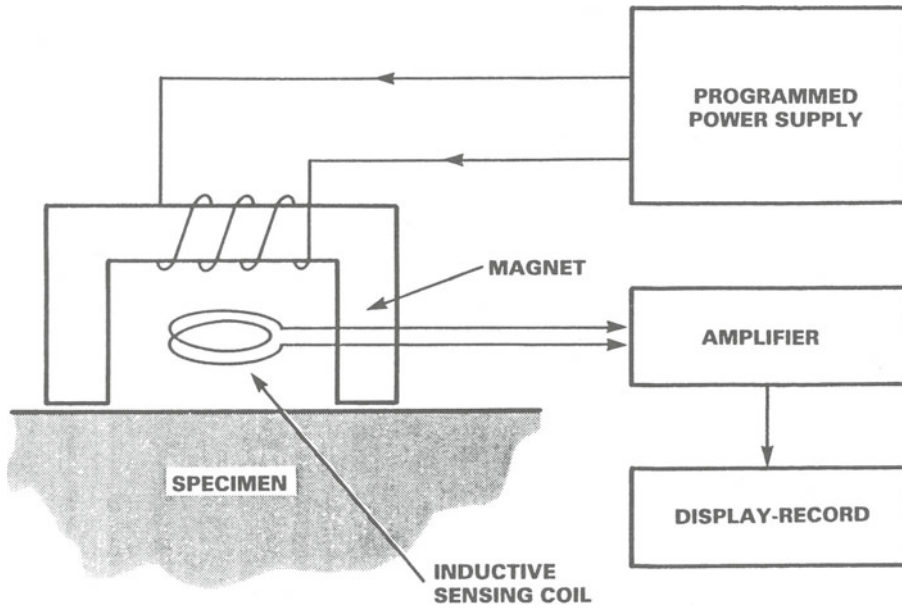


Fig. 1. Schematic diagram of Barkhausen instrument

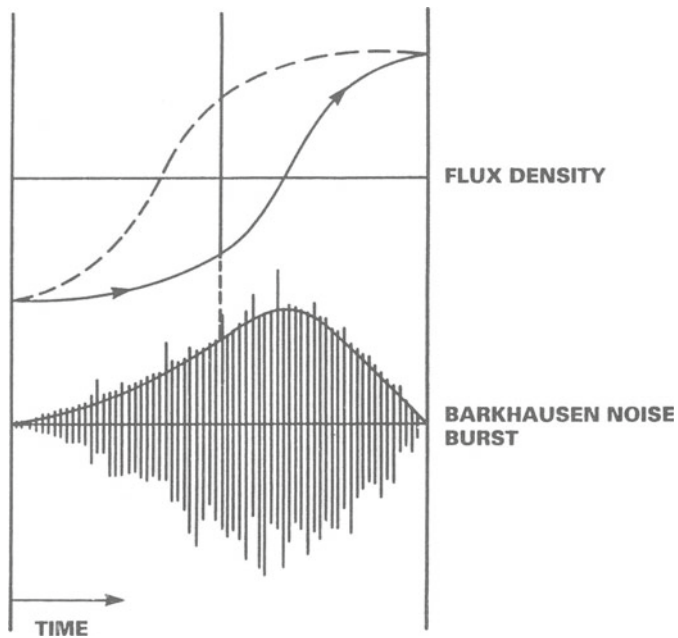


Fig. 2. Flux density produced by applied magnetic field (top) and corresponding burst of Barkhausen noise (bottom)

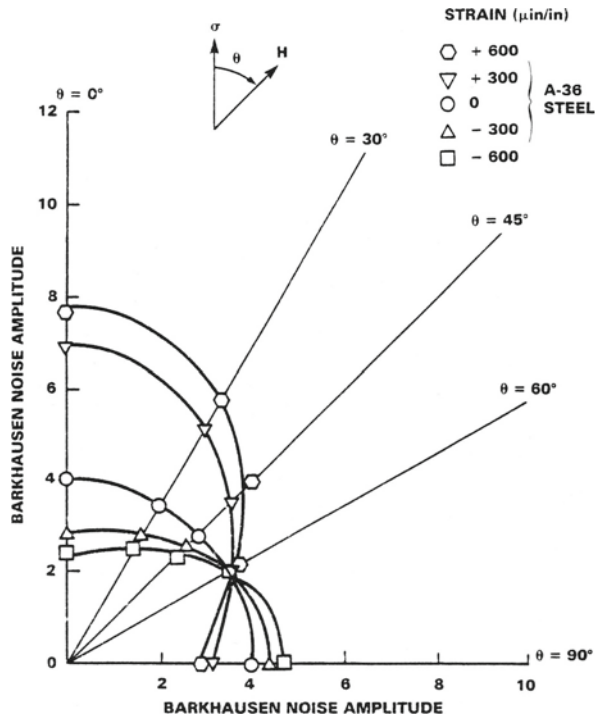


Fig. 3. Dependence of Barkhausen noise amplitude on stress and on the angle between the stress and magnetization direction in ASTM A-36 steel. (100 $\mu\text{inches/inch}$ strain is equivalent to approximately 3 ksi stress. Barkhausen noise amplitude is in arbitrary units. From Reference 9.)

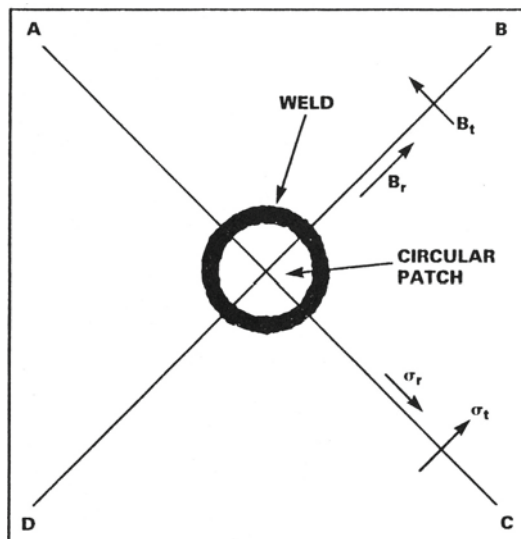


Fig. 4. Sketch of 4-foot square steel plate with circular patch weld showing BN measurement locations. Barkhausen noise measurements were made along radial lines A, B, C, D with probe oriented radially (B_r) and tangentially (B_t). The stresses in the radial and tangential directions are designated by σ_r and σ_t , respectively.

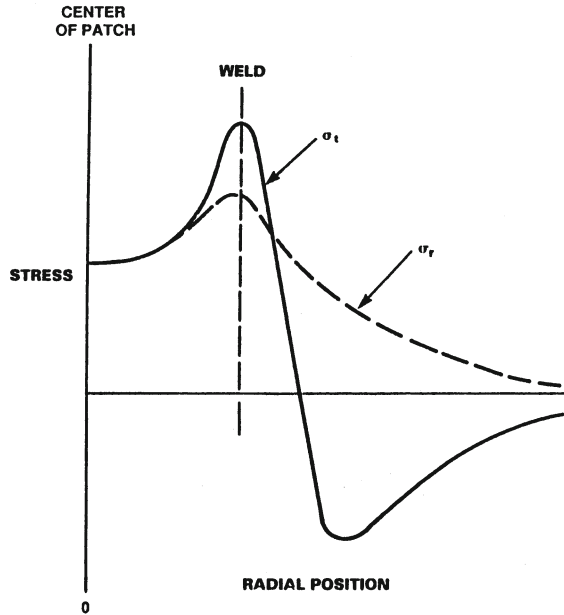


Fig. 5. Theoretical distribution of residual stress vs. radial position from center of welded circular patch from Ref. 10.

becoming larger than the radial component. The radial component then decreases monotonically toward zero stress with increasing radial distance. The tangential component decreases, becomes compressive, and then approaches zero with increasing radial distance.

BN measurements made as a function of probe orientation in this work indicated that the stresses were biaxial with principal stresses in the radial and tangential directions with respect to the center of the circular patch, as expected from the theoretical calculations. The principal stresses are the maximum and minimum values of stress and lie along mutually perpendicular directions [11].

The BN data from the welded specimen were converted to strain values using the calibration curve shown in Figure 6 which was obtained as a function of strain from the non-welded specimen. The principal stresses were then calculated using the following equations:

$$\sigma_r = \frac{E}{1 - \mu^2} (\epsilon_r + \mu\epsilon_t)$$

$$\sigma_t = \frac{E}{1 - \mu^2} (\epsilon_t + \mu\epsilon_r)$$

where σ_r and σ_t are the principal stresses in the radial and tangential directions, E is the elastic modulus of steel, μ is Poisson's ratio for steel, and ϵ_r and ϵ_t are the principal strains for the radial and tangential directions respectively (as determined from BN measurements).

The resulting principal stresses as determined from the BN measurements on the welded plate are shown in Figure 7 (a and b for the radial and tangential directions, respectively). It is estimated that the accuracy of the measurements is ± 5 ksi. At the center of the patch, the radial stress is in the range of approximately 13-18 ksi tension. As the distance from the center increases, the stress increases in tension in

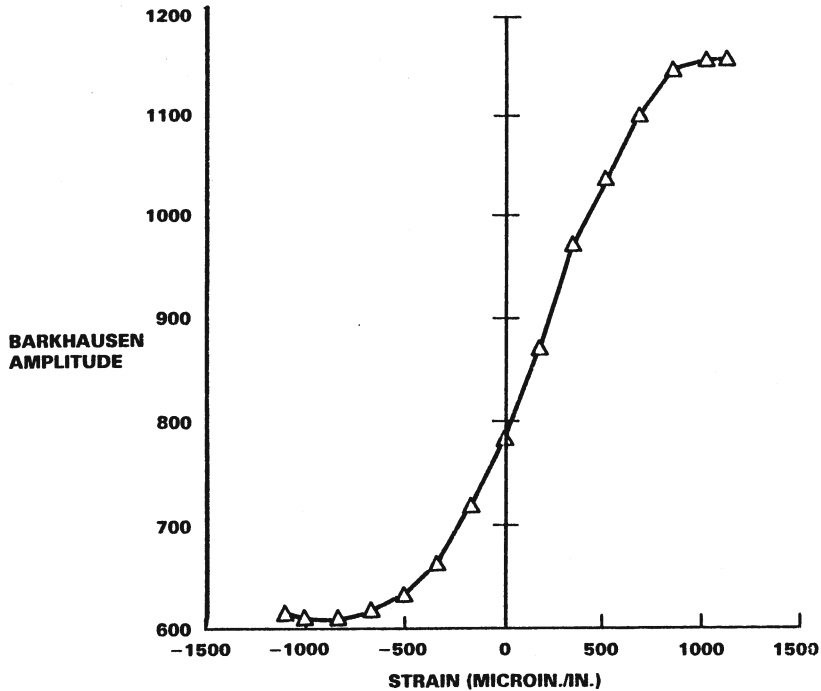


Fig. 6. Barkhausen signal amplitude versus strain for calibration specimen cut from same plate as welded specimen

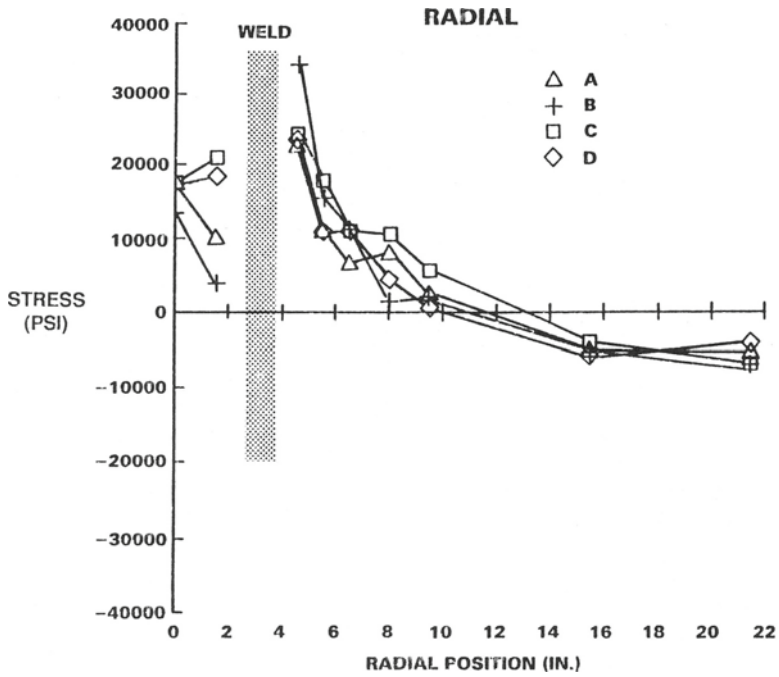
the region of the weld, becomes zero at approximately 8-12 inches from the center, and then becomes somewhat compressive.

The tangential stress (Figure 7b) is approximately the same as the radial stress at the center of the patch. As the distance from the center increases, the stress decreases to zero in the range of 4-6 inches from the center, becomes compressive, and then approaches zero.

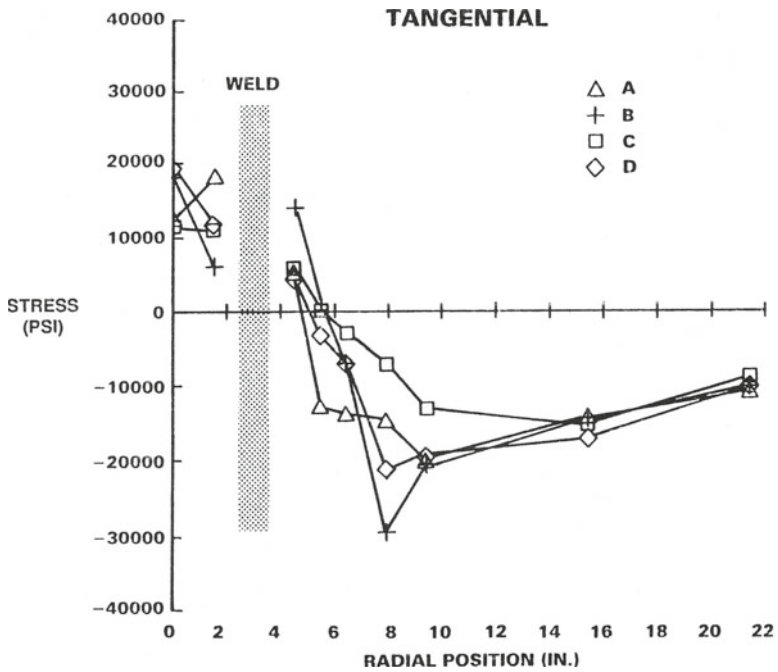
Although the magnitude of the stresses is not known for the theoretical distribution, the trends in the experimental data for both the radial and tangential stress distributions agree well with theoretically calculated distributions as shown in Figure 5. The magnitude of the stress values determined from BN is in general agreement with those reported in Reference 12 which were determined by using a destructive layer-removal method.

CONCLUSION

Barkhausen noise measurements of principal stresses in the radial and tangential directions around a circular patch weld in a steel plate were in general agreement with published theoretical and experimental stress distribution data. The results indicated that the BN method is very promising for residual stress measurements near welds.



(a) Radial



(b) Tangential

Fig. 7. Residual stress (calculated from Barkhausen) in radial direction (a) and tangential direction (b) versus radial position from center of welded circular patch at locations A, B, C, D

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