USE OF BARKHAUSEN NOISE IN FATIGUE

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EFFECT OF ELASTIC AND PLASTIC STRAIN/STRESS

Barkhausen noise is generated by abrupt changes in the magnetization of materials under applied AC magnetizing field /1/. These changes are known to be affected by residual and/or applied stresses /2, 3/. Monitoring the Barkhausen noise under controlled conditions then provides a means of evaluating the stress state of the material /4/. The relation between stress and Barkhausen noise level is illustrated in Figure 1: the lower the compressive stress or the higher the tensile stress, the higher the Barkhausen noise level.

Uniaxial calibration curves have been most commonly used in the magnetoelastic Barkhausen noise stress measurements. Such curves are obtained by measuring the level of Barkhausen noise while stressing the test piece in compression and tension in one direction only and assuming that the stresses in other directions are zero. Recent experiments have, however, indicated that by applying biaxial calibration, the accuracy of stress measurement by this method can greatly be improved /5/.

It is also known that the intensity of the Barkhausen noise is sensitive to the density and distribution of dislocations /6, 7/. An abrupt increase of 20% in noise level has been observed under tensile loading just at the yield strength /8/. This abrupt increase corresponds entirely to the effect of new dislocations since the external stress remains constant at the yield strength during Luder's straining.

The effect of applied unidirectional tensile stress on Barkhausen noise level is illustrated in Figure 2 /9/. The test piece was strained up to a certain stress level and unloaded. The Barkhausen noise was measured on the unloaded sample both parallel (B_p) and transverse (B_t) to the axis of loading. The sample was then reloaded to a higher stress level, unloaded and measured once again. When the loading was below the macroscropic yield strength (282 N/mm^2), a slight change in Barkhausen noise was observed indicating local micro-yielding. A drastic change of Barkhausen noise level takes place just at the yield stress. B_p decreased 40% at the yield and B_p-B_t decreased 200%, whereas hardness increase was only 12%.

The conclusion is that in addition to being sensitive to elastic stress/strain, Barkhausen noise is also sensitive to plastic stress/strain whether it is caused by micro- or macro-yielding.

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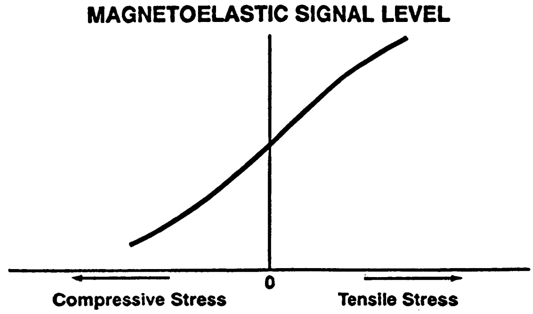


Figure 1. Barkhausen noise response to compressive and tensile stress.

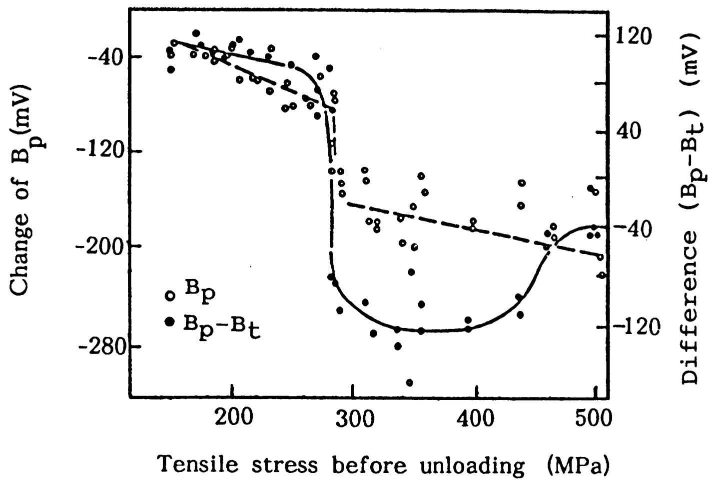


Figure 2. Effect of applied unidirectional tensile stress on B_p and B_p-B_t. The stress is measured before and Barkhausen noise after unloading. Karjalainen et al. /9/.

CYCLIC STRAINING

Karjalainen et al. /8/ have conducted extensive cyclic bending tests on a normalized low-carbon steel with yield strength of 280 N/mm², tensile strength of 460 N/mm² and fatigue limit of 200 N/mm² to determine the effect of cyclic loading with stress amplitudes below and above the fatigue limit on Barkhausen noise level. Variation of B_p with bending stress during single cycles was recorded at several stages of fatigue life. Examples are given in Figure 3. Note the difference on the stress scales between Figure 3 a and b. There are distinct changes in the stress loops as a function of the stress amplitude as well as the number of cycles. The higher the stress amplitude, the larger the area of the loop.

It is interesting to note the changes in Barkhausen noise upon unloading. Although the stress amplitude in Figure b is below fatigue limit of 200 N/mm², the Barkhausen noise level in unloaded condition is changing when the number of cycles is changing, indicating plastic deformation. It is evident that Barkhausen noise will detect plastic

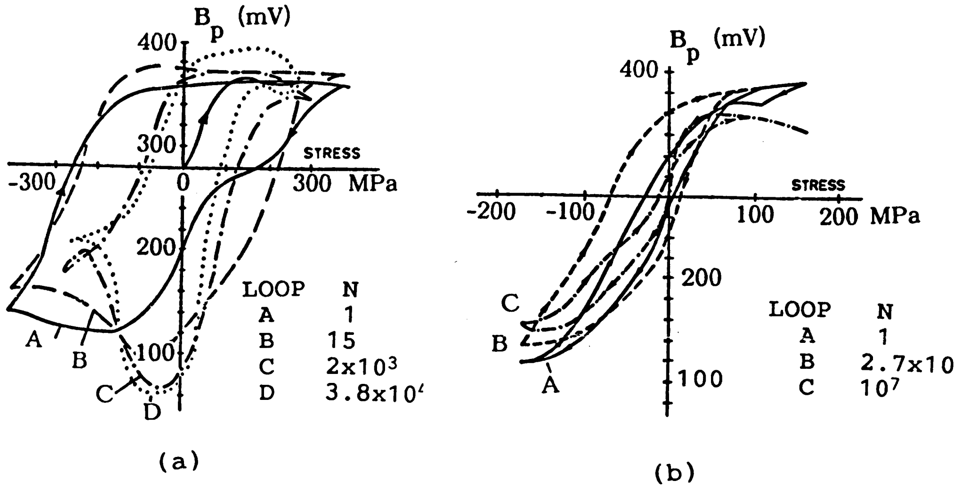


Figure 3. **Variation of Barkhausen noise (B_p) with bending stress during single cycles after certain number of cycles (N) at a strain amplitude of (a) 0.00250 (above fatigue limit), and (b) 0.00085 (below fatigue limit). Karjalainen et al. /8/.**

deformation below fatigue limit which demonstrates the high sensitivity of the technique. Figure 4 is a more systematic presentation of these changes for the same steel as a function of number of cycles for five different strain (stress) amplitudes. The changes observable in Figure 4 correspond to the variation in residual stress due to fatigue softening and hardening. It is suggested in Reference 8 that the measurement of Barkhausen noise offers an efficient method for detecting softening-hardening phenomena in the surface layer of a ferromagnetic material even during bending fatigue.

It is interesting to observe in Figure 4 the difference between Curve 1 (obtained with stress amplitude below fatigue limit) and Curves 2-5 (obtained above this limit). There are also distinct, although minor, changes with number of cycles in Curve 1 indicating that the method is capable of detecting deformation even below the fatigue limit /10/, as discussed above.

From practical point of view, the curves of Figure 4 could be used to monitor the accumulation of fatigue damage on components exposed to cyclic loading. Once the Barkhausen noise vs. number of cycles curves are available for a particular material, the Barkhausen noise can then be evaluated nondestructively on the component itself to determine how much change has taken place during use of the component in order to predict the remaining service life.

OVERLOADING

Overloading causes instant plastic deformation and can drastically reduce the service life of a component. The capability of Barkhausen noise to detect overload is demonstrated by Palmer /11/ and King /12/ by load and strain controlled experiments on shot peened 300M material

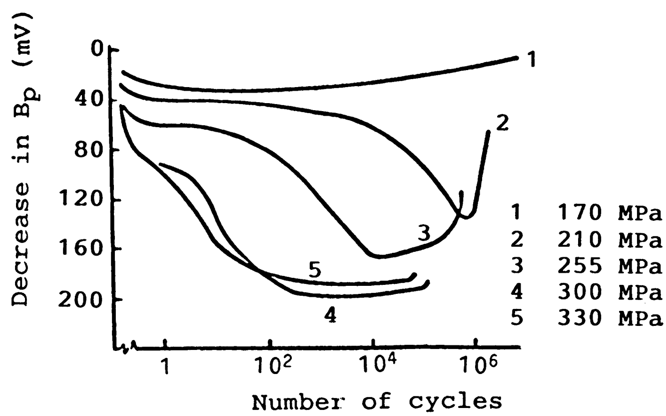


Figure 4. **Variation of Barkhausen noise (B_p) in unloaded fatigued samples of low-carbon steel as a function of number of cycles. Stress amplitude of curve 1 is below fatigue limit, curves 2–5 above fatigue limit. Karjalainen et al. /8/.**

having nominal yield of -1450 N/mm² and surface residual stress of -650 N/mm². Due to the high surface residual stress generated by shot peening, the components may exceed the compressive yield in field applications, leading to plastic deformation and residual tension after unloading. Figure 5 illustrates the Barkhausen noise response (MPU) as a function of strain. It is immediately clear that the higher the strain overload, the higher the MPU in unloaded condition. Figure 6a shows the horizontal strain displacement from Figure 5a and Figure 6b the vertical displacement or increase of MPU obtained from Figure 5b as a function of compressive strain overload. These figures demonstrate the systematic and reliable response of Barkhausen noise to overloading.

Results from cyclic overloading of shot peened 300M are given in Figure 7 /12/. Due to the high residual stress on the surface of the shot peened 300M, the Barkhausen noise value from the uncycled sample

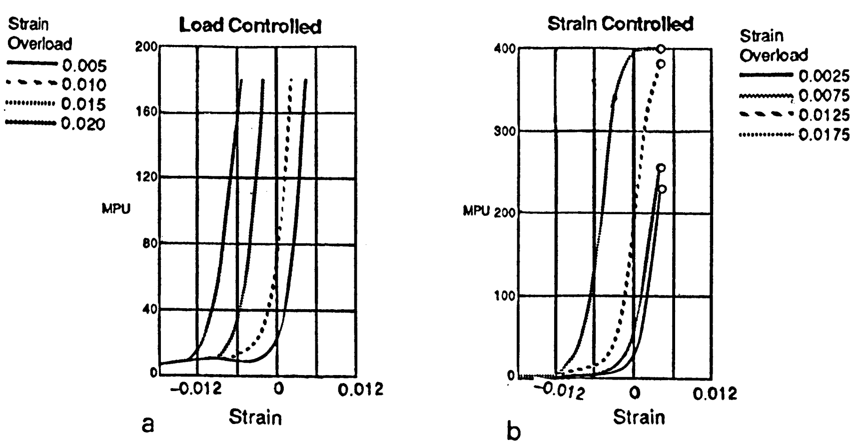


Figure 5. Barkhausen noise as a function of compressive overload.
a) Load controlled test
b) Strain controlled test
Palmer et al. /11/.

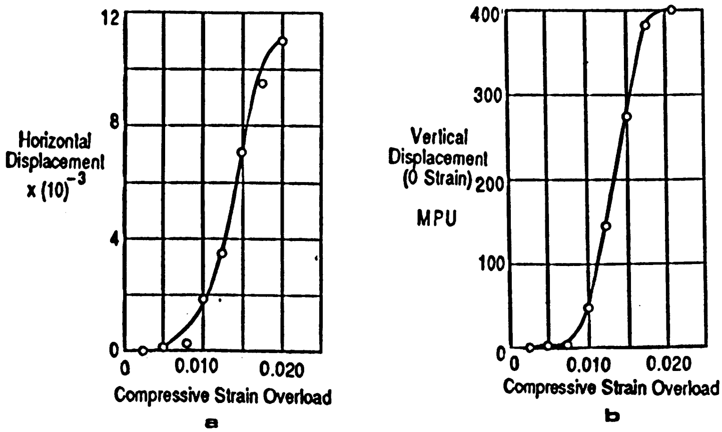


Figure 6. **Horizontal strain displacement from Figure 5a and vertical displacement from Figure 5b as a function of compressive strain overload. Palmer et al. /11/.**

is low (MPU=30). The heavy overloads in compression will increase this value more than tenfold in the unloaded condition. The beneficial compressive stress induced by shot peening to increase fatigue life can then be removed by a single overloading. The damage generated by the overloads caused the samples to fail after the fifth cycle for both experiments of Figure 7.

The examples presented above will indicate that Barkhausen noise could be used to measure the extent of damage due to overloading on actual components in order to prevent catastrophic failures.

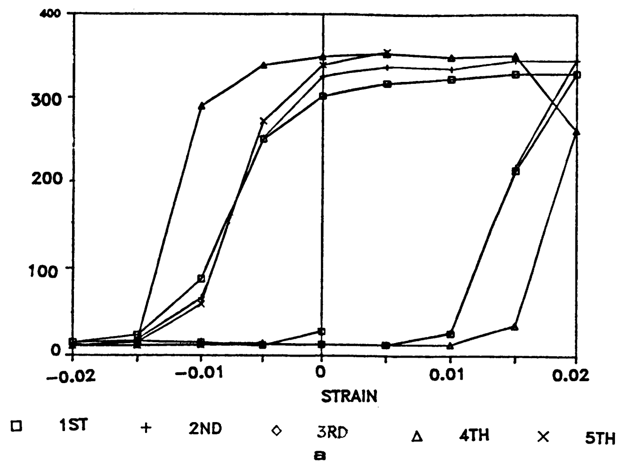
Jiles /13/ has analyzed the Barkhausen noise response of 300M to strain from a theoretical point of view and found a good agreement between theoretical and experimental data as shown in Figure 8.

STRESS RELAXATION

Relaxation of residual stress of surface-hardened components in cyclic loading has been studied e.g. by ENSAM /14/ and CETIM /15/ in France. The initial surface compressive stress is removed by elastic shakedown and stress relaxation processes.

Figure 9 shows the results of Barkhausen noise and X-ray diffraction stress testing on some fatigued samples from ENSAM. The initial residual stress was determined to be approximately -500 MPa. With increasing amount of cycles, the residual stress is relaxed, as indicated by both X-ray data and an increase of Barkhausen noise level. The higher the stress amplitude, the faster the compressive stresses are relieved.

The data would suggest that Barkhausen noise could be used to measure the amount of stress relaxation on surface-hardened components exposed to cyclic loads.



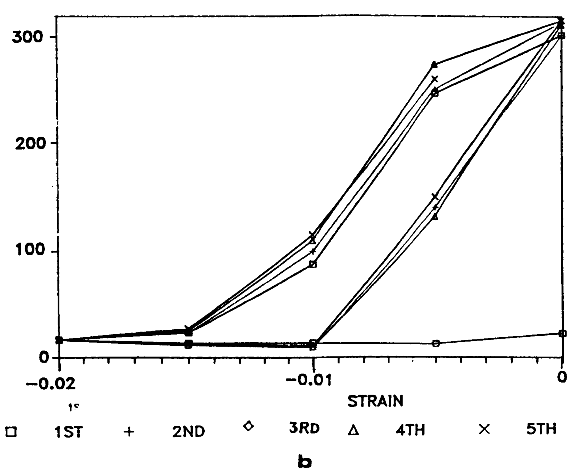


Figure 7. Variation of Barkhausen noise (MPU) with axial strain for five cycles.
a) Strain oscillated between compressive and tensile values.
b) Strain oscillated between compressive and 0 strain.
The sample broke after fifth cycle in both a) and b).
King /12/.

SUMMARY

The examples given above indicate the following:

1) Barkhausen noise is responsive to micro-yielding below yield strength in monotonic tests.

2) Plastic deformation changes Barkhausen noise drastically.

3) Fatigue damage either increases or decreases the Barkhausen noise in the unloaded condition depending on whether last cycle was in compression or in tension.

4) Overloading in compression can readily be detected by Barkhausen noise.

5) Barkhausen noise shows promise to detect stress relaxation due to fatigue.

The good correlation of Barkhausen noise to fatigue damage can be attributed to its sensitivity to elastic/plastic strain/stress and dislocation density/arrangement. Most of the data reviewed here has been obtained with a commercially available instrumentation that has been designed for easy use and portability. The same instrumentation could be utilized in the field to rapidly and nondestructively assess the condition of the components exposed to fatigue and overloading. The results would readily help in determining maintenance schedules and possible design changes in order to prevent field failures.

Barkhausen count rate versus stress

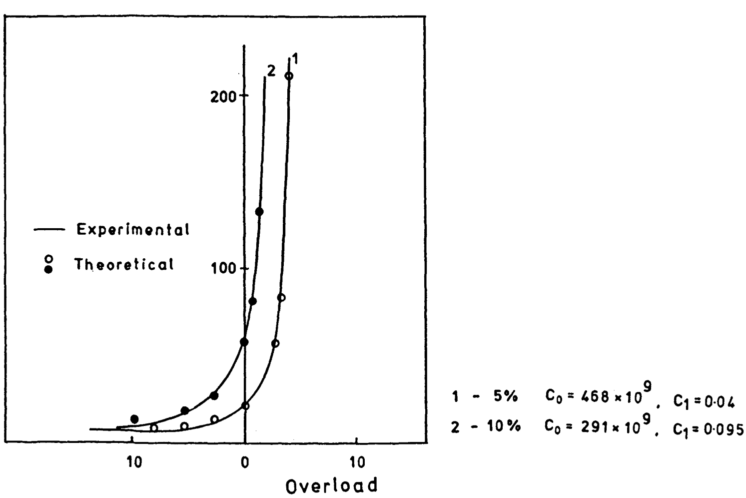
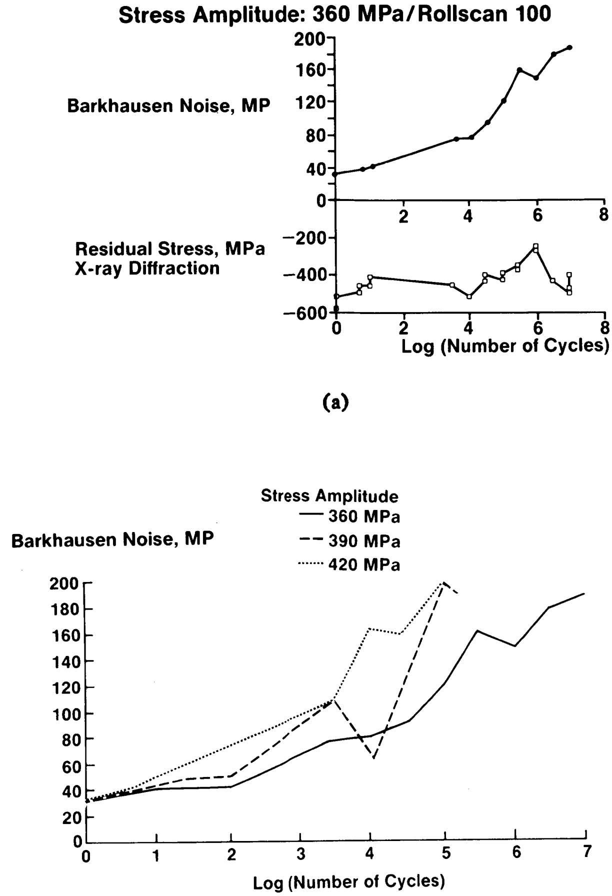


Figure 8. Calculated and experimental values of Barkhausen noise as a function of overload. Jiles /13/.



(b)

Figure 9. Relaxation of stress in fatigued samples with number of cycles as measured by X-ray diffraction (ENSAM) and Barkhausen noise (AST) techniques.

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