INTRODUCTION

In the aerospace industry, there is an ever present need to detect fatigue in structural materials. For instance, the ability to detect serious plastic deformation in landing gear materials is highly desirable. Since most landing gear are composed of ferromagnetic materials, the nondestructive methods of testing are limited. The procedure chosen for this investigation is monitoring the Barkhausen effect, with the criteria for instrumentation choice being portable and easy to use. The Rollscan 100-2, designed and manufactured by American Stress Technologies, Inc., met the criteria (Figure 1). Internal stress measurement using this instrument is based on the principle of magnetoelastic interaction between magnetostrictive and elastic lattice strains [1]. The Rollscan 100-2 can monitor another physical phenomenon, which is the Barkhausen effect. This effect can be defined as a series of abrupt changes or jumps in the magnetization of a steel when the magnetizing field is gradually altered [1]. A set of laboratory experiments were designed to measure the Barkhausen effect as a function of compressive overloading in 300M steel using the Rollscan 100-2. This paper describes the experiments performed and the corresponding results.

BACKGROUND

Interest in the Barkhausen effect or Barkhausen "noise" as it is commonly known, arises from its dependence on material properties such as applied stress, residual stress, grain size, carbon content, phase morphology and precipitate size and distribution [2]. Barkhausen noise was discovered by H. Barkhausen in 1919 when he wound a ferromagnetic specimen with wire and connected the wire to an amplifier and loudspeaker. The generally accepted explanation of the origin of the Barkhausen discontinuity is nonuniform motion of magnetic domain walls within the material [3]. Magnetic domains, which are regions of similarly oriented crystals magnetized to saturation in the same direction, make up the bulk of the material. Magnetic domain walls are simply the separation between the magnetic domains. There are two types of domain walls: 90-degree walls and 180-degree walls. The
90-degree walls separate areas that are magnetized at right angles, whereas the 180-degree walls separate areas that are oppositely magnetized [3]. The application of either a magnetic field or an applied stress causes the domain walls to move. In either case, domain wall movement allows domains favorably aligned to grow larger [3]. Favorably aligned domains are those with magnetic polarity parallel to the applied stress or magnetic field.

As stated before, the Rollscan 100-2 combines the phenomena of magnetoelastic interaction between magnetostrictive and elastic lattice strains and the Barkhausen effect. The combination of these phenomena [1] permits a qualitative stress evaluation whereby an increase in tensile stress causes an increase in the magnetic "Barkhausen noise" level, which is generated by jumps. Accordingly, an increase in compressive stress will cause a decrease in the noise level.

Fig. 1. Rollscan 100-2 unit with probe.
EXPERIMENTAL PROCEDURE

Ten 300M steel tensile specimens were fabricated for the purpose of this evaluation. Each specimen was machined to 7.75 inches in length, with 1.5 inch gage sections (Figure 2). These specimens were subsequently heat treated so as to produce hardnesses of R =53-55. Afterwards, each specimen was temper etched and shot peened using standard shot with Almen intensities of 0.008/12 A. Eight of the ten specimens were subjected to compressive overloads, while two were held for standardization purposes.

X-ray diffraction was used to test each specimen for residual surface stresses, which were brought about by the shot peening. These tests were performed using a Rigaku X-ray test rig. Residual stress measurements were made both before and after the overloading to determine how the loading affected the surface stresses.

Prior to loading, the Rollscan probe was attached to the machined portion of each specimen (Figure 3). The frequency range and magnetization chosen for this investigation were 70-200 kHz and 90, respectively. Provisions were made so that load vs. strain, Barkhausen effect vs. load and Barkhausen effect vs. strain could be plotted simultaneously. The compression tests were performed with the use of an Instron mechanical testing machine. Each specimen received different strain overloads, ranging from 0.0025 to 0.02; however, the loading schemes were relatively the same. The loads were applied using two loading modes: load control and strain control. In the load control mode, the specimens were loaded elastically using load control, compressed using strain control and returned to the original elastic load using load control (Figure 4a). In the strain control mode, the specimens were compressed and returned to the original elastic strain using strain control (Figure 4b). The load controlled overloads were 0.005, 0.01, 0.015 and 0.02; whereas the strain controlled overloads were 0.0025, 0.0075, 0.0125 and 0.0175.

Fig. 2. Tensile specimen with gage section
Fig. 3. Experimental configuration.

Fig. 4. Loading schemes for both load control (a) and strain control (b).
RESULTS

The results of the X-ray diffraction tests, both before and after loading, are represented in Figure 5. The difference in residual stress noted before and after overloading was plotted as a function of the compressive overload. The results are somewhat consistent above a strain overload of 0.005, or above the yield point. As the compressive strain overload increases, the change in residual stress decreases due to the surface compression from the shot peening.

Figure 6a shows Barkhausen noise vs. compressive strain overload for load controlled conditions. This plot reveals that the strain required to achieve equivalent Barkhausen readings decreases with increasing overload conditions. This can be explained by the fact that an increase in compression will cause an increase in the overall orientation of the 180-degree domain, thus upon an application of a tensile load, the strain required to achieve an equivalent Barkhausen response will increase in compression. This is also apparent under the strain controlled conditions, shown in Figure 6b. For an equivalent elastic strain, the Barkhausen noise response increases with increasing strain overload conditions, again due to the increased orientation of the 180-degree domain walls.

Figure 7a shows the comprehensive results of the load controlled experiments. A definite trend is evident in relating the strain displacement at equivalent Barkhausen noise readings to the compressive strain overload. As the strain overload increases, the strain displacement required to achieve equivalent Barkhausen responses increases proportionally. This stems from the fact that as the strain overload increases, the strain required to achieve equivalent Barkhausen readings increases compressively, thus increasing the horizontal strain displacement. The same trend is noted in Figure 7b in comparing the Barkhausen noise response with compressive strain overloading. Increasing the strain overload increases the Barkhausen response when reversing from compression to tension. An increase in the strain overload increases the Barkhausen response at equivalent strains, thus increasing the vertical scale displacement.

![Graph showing change in residual stress vs. compressive strain overload.](image)

Fig. 5. Change in residual stress vs. compressive strain overload.
Fig. 6. Barkhausen effect vs. strain for both load control (a) and strain control (b).

Fig. 7. Comprehensive results for both load control (a) and strain control (b).
CONCLUSIONS

In conclusion, monitoring Barkhausen noise was found to be an effective tool for stress evaluation in ferromagnetic materials. Although standardization procedures were needed, excellent correlations were obtained between the Barkhausen effect and compressive strain overloading, which is sometimes evident in landing gear steel. As an extension of this work, investigations in the area of quantifying shot peen depth are underway using the Barkhausen effect as the prime evaluation tool.

REFERENCES