MAGNETO-ACOUSTIC STRESS RESPONSES OF VARIOUS RAIL METALLURGIES

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INTRODUCTION

The magneto-acoustic stress measurement technique has been evaluated by the authors as a means of revealing information on residual and applied stresses in ferromagnetic materials. Past work has included: documentation of the response of carbon steels to various test configurations [1], the effect of grain size and cooling rates in medium carbon alloy steels [2], test results obtained with a railroad rail sample [3], and investigations performed with a prototype device for examining full railroad wheels [4]. Other published papers have sought to provide detailed reviews of the test theory and model behind this technique in light of the accumulated test data [5,6].

The specific purpose of the present study was to determine the applicability of this methodology to various railroad rail samples. While sharing a common geometric configuration, randomly selected rails may represent a range of alloying additions, experience localized or full-section heat treatment, or be straightened by various techniques. While various "premium" rails may be selected for service with a particular emphasis on mechanical strength or wear resistance, the full gamut of rails are all subject to an increasing concern for measuring and understanding the effects of fabrication (residual) and service (applied) stresses on total performance.

TEST PROCEDURE

As stated above, complete descriptions of the magneto-acoustic test technique and model are available in the literature. By way of a very truncated summary, this approach exploits the stress-dependent behavior of magnetic domains, and their influence on the velocity of ultrasonic waves. In the test methodology, an ultrasonic signal is established in a test sample. A device developed by NASA-LaRC, known as the pulsed-phase locked-loop (P2L2) interferometer, generates this reference signal by inducing a voltage to a piezoelectric transducer, and

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monitors the phase of the outgoing ultrasound. The P2L2 then compares the phase of the incoming pulse/echo signal to the reference signal's phase, and drives a voltage-controlled oscillator to adjust the operating frequency of the transducer until the phase difference is nulled. The velocity of the ultrasonic wave will be affected in inverse proportion to the amount of 90° magnetic domain walls it encounters while travelling through the sample. An increasing amount of such barriers to the ultrasonic propagation will result in a decrease in the natural velocity of the wave. The initial magnetic domain alignments are directly affected by the stress state in the sample, and an externally applied magnetic field may be used to induce movement and realignment of these domains. Therefore, a record of the frequency shift in the ultrasonic signal, as an external magnetic field is swept through the specimen, affords an observation of the stresses in the sample.

In this study, flat specimens were machined from the webs of selected rails. These samples represented rails with various compositions and processing histories. Samples were tested from: chromium/vanadium and chromium/molybdenum alloyed steel rails, rails with intermediate strength and intermediate hardness levels, a head hardened and a fully heat treated rail, and a rail that had been straightened by a stretching operation, as opposed to the more conventional method of roller straightening.

Controlled loads were then applied axially to the samples, while a pair of electromagnets were used to induce a magnetic field parallel to the stress axis. A ½-inch diameter, 5 MHz transducer was used to propagate ultrasonic waves through the specimen thickness, perpendicular to both the field and stress axes. The fractional frequency shift was monitored, and plotted as a function of induction in the test samples.

RESULTS

The stress response curves of the intermediate strength and intermediate hardness rails are shown in Figures 1 and 2, respectively. These rails were produced by two different domestic steel mills, and would represent their "standard" rail product. It may be observed that the responses to applied stresses for both samples are well-behaved, compared to previous results for medium carbon steels [6] and randomly selected rail samples [3]. That is, the increments of applied load produced distinctly separate response curves, and under applied compression, the negative initial slope of the curve was present. This is a trait characteristic of medium carbon steels in the magneto-acoustic technique.

The results of tests performed on the chrome/vanadium and chrome/moly rails are shown in Figures 3 and 4, respectively. These rails, produced by a foreign and a domestic steel mill, were alloyed for enhanced mechanical properties. It may be seen that the alloying additions of chromium and vanadium dramatically reduced the distinction between different levels of apllied tension and the unloaded condition. Further, the level of magnetic induction produced in this sample was lower than the other samples examined, presumably due to a lower permeability. While the sample of rail alloyed with chromium and molybdenum also exhibited somewhat of a suppressed distinction between low

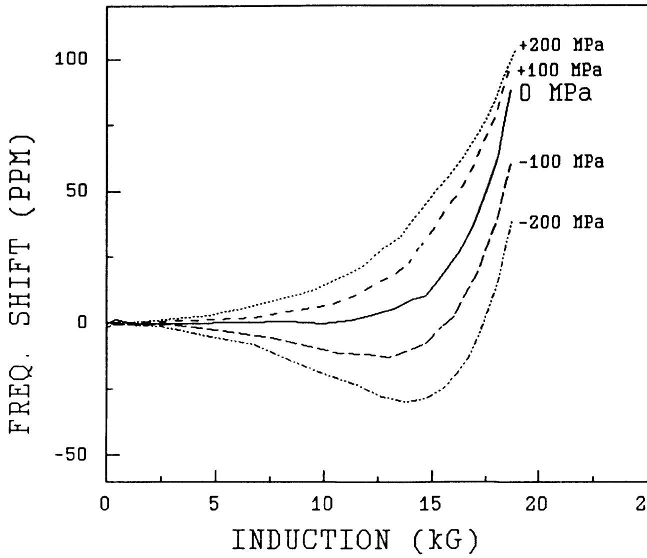

Figure 1. Stress Response Curves for Intermediate Strength Rail Sample.

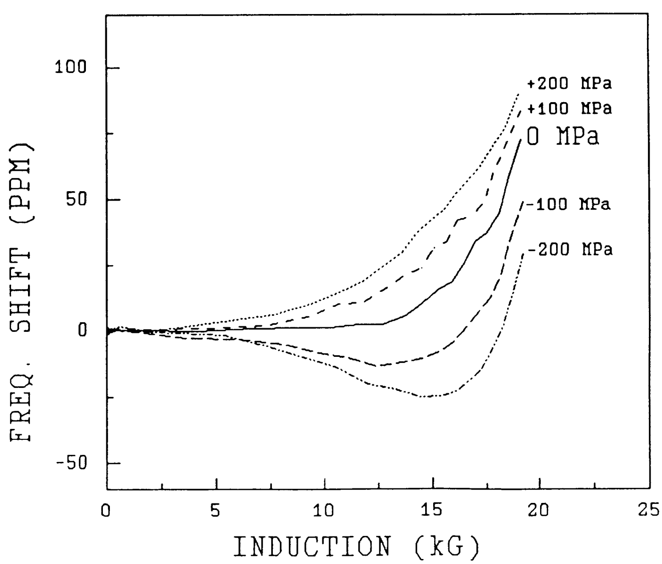

Figure 2. Stress Response Curves for Intermediate Hardness Rail Sample.

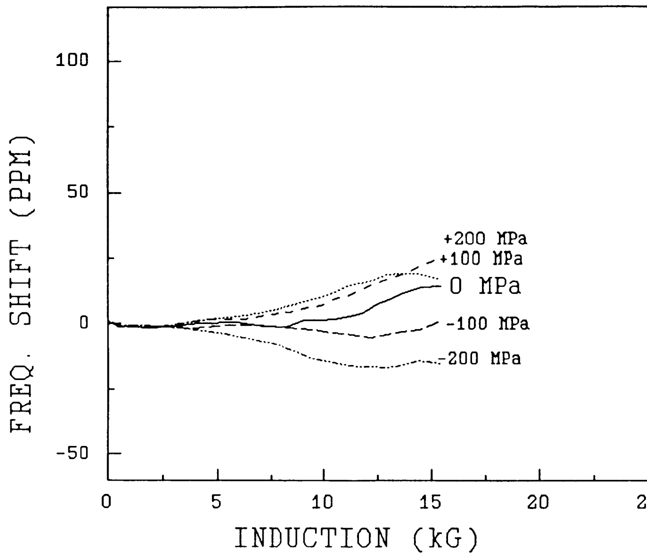

Figure 3. Stress Response Curves for Chromium/Vanadium Alloy Rail Sample.

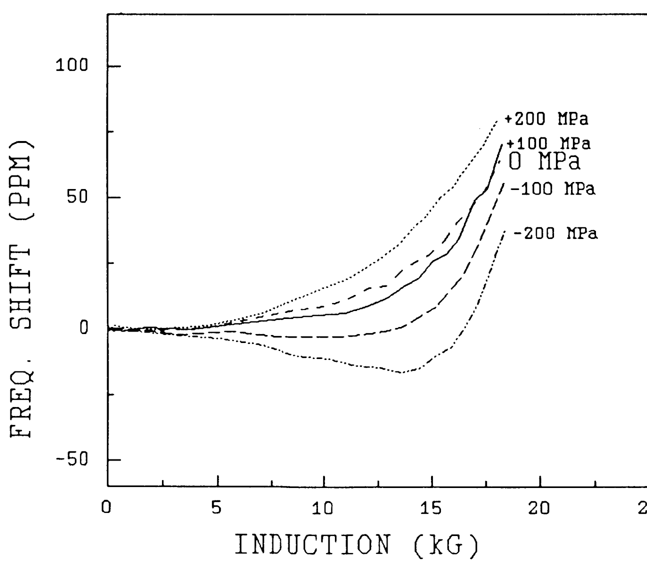

Figure 4. Stress Response Curves for Chromium/Molybdenum Alloy Rail Sample.

levels of applied tension and the unloaded state, the results were not as dramatic as for the chrome/vanadium rail.

The test results for the head hardened and fully heat treated rails are shown in Figures 5 and 6, respectively. The head hardened rail was produced by a foreign mill, and an induction hardening technique was employed in production. The logic behind head hardening is to produce a rail with enhanced wear resistance. Although only the head of this rail had been heat treated, it was of interest to determine if possible stress effects manifested themselves in the adjacent web region. The fully heat treated rail was produced by a domestic steel mill, and represents an attempt to provide higher strength levels overall. Results indicate good distinction between load levels for both rails. The fully heat treated rail was unique in that a slight negative response was detected in the unloaded state, suggesting that an amount of residual compressive stress remained in the sample after machining from the parent rail section. Also, the permeability of this material seems to be higher than that of the other samples examined, based on the higher level of induction achieved in this sample.

The stress response curves for the stretch straightened rail are shown in Figure 7. As mentioned previously, the conventional practice in North America for straightening rail is to pass the rail between a series of rollers. This foreign rail is gripped at the ends of the rail length and an axial stretching force is employed to straighten the rail. The results of the magneto-acoustic testing suggest that a pronounced residual compression was present in the sample taken from the web of such a rail. this is inferred from the negative slope in the unloaded condition. This deduction does not coincide with the anticipated behavior for such a rail; the manufacturer's research has indicated that a residual tension in the web would have been expected. This apparent discrepancy remains to be resolved.

The relative responses of the various rails studied in this experiment are evidenced by comparing the response curve for each of the samples when evaluated in the unloaded condition. This comparison is shown in Figure 8. It is immediately suggested by this plot that the fully heat treated rail sample and the stretch straightened rail sample are distinct from the somewhat clustered response of the other rails evaluated. This may be accounted for by markedly different microstructural properties in the fully heat treated rail web, and by a unique fabrication process in the case of the stretched rail.

DISCUSSION

The magneto-acoustic test had been shown to be applicable in a fairly generic sense as a potential stress measurement tool for evaluating railroad rail. Based on the results of this inquiry, it would appear that this methodology is capable of being extended to a range of modern rail steels. Difficulties would be expected in this extrapolation for the case of alloy steel rails, such as the chrome/vanadium rail studied here.

The results of this investigation also raise other questions. The interpretations presented here are predicated on the assumption that the stress state in the samples studied

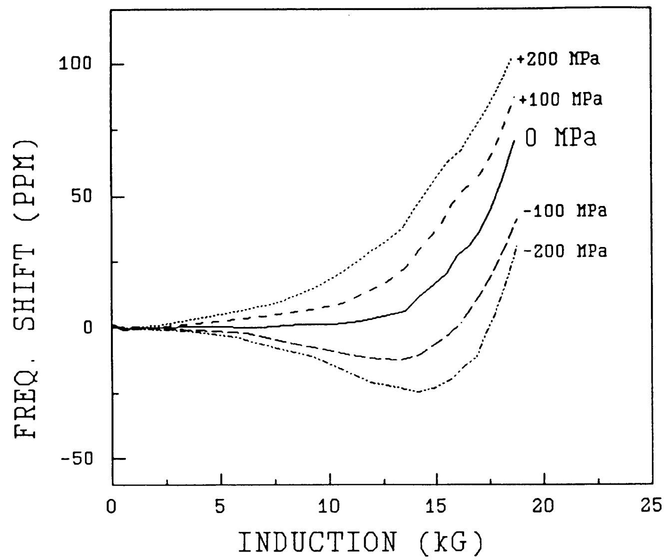

Figure 5. Stress Response Curves for Head Hardened Rail Sample.

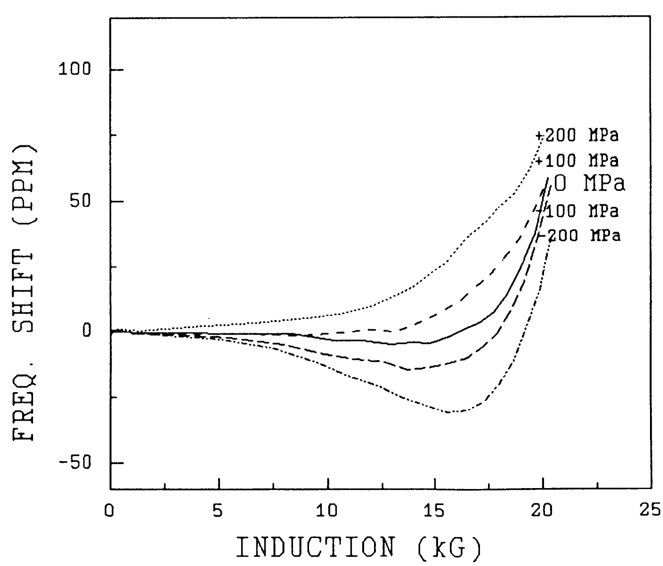

Figure 6. Stress Response Curves for Fully Heat Treated Rail Sample.

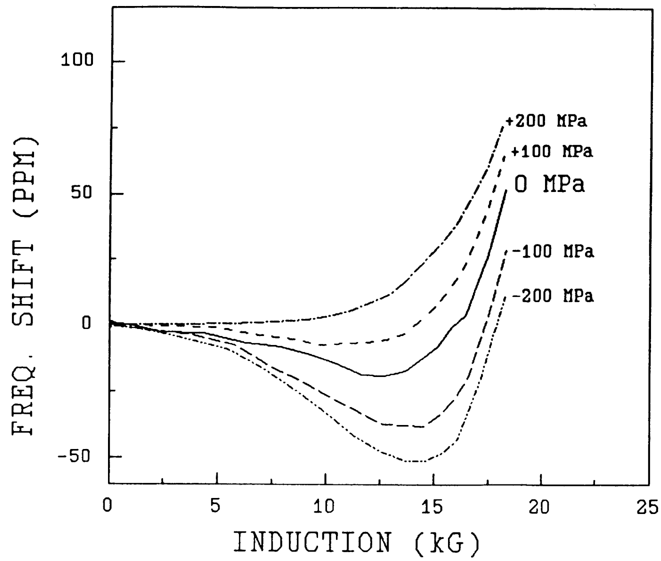

Figure 7. Stress Response Curves for Stretch Straightened Rail Sample.

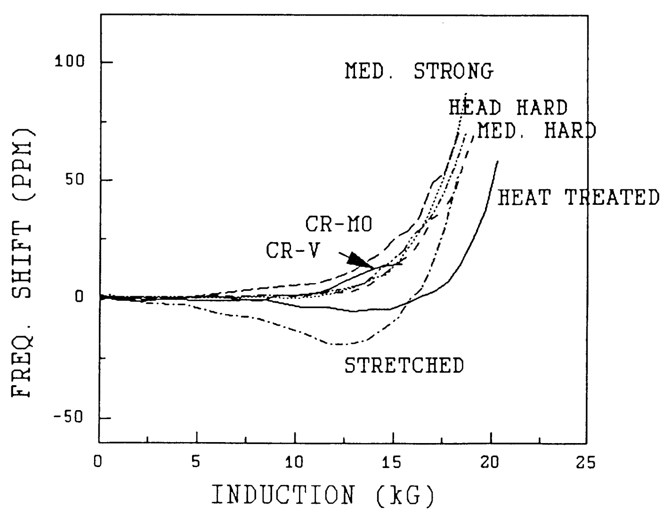

Figure 8. Test Response Curves for the Various Rail Samples When Tested in the Unloaded Condition.

played the major role in determining the test response. Certainly, the microstructure of the sample will contribute to the test response. It remains to be determined to what degree such variability, as encountered with the fully heat treated rail, will affect the test output. Further, the interpretations based on apparent residual stress levels in samples machined from the webs of rails need further corroboration to be validated. therefore, this set of test samples is scheduled to be thermally stress relieved and retested. If, then, the stretch straightened rail sample truly did retain a high level of compression, it would be expected that a significant upward shift of the test curve would be produced in subsequent test trials.

Finally, stress information obtained with such samples must eventually be correlated with the results of tests performed on the actual rail components. Such experiments would be a critical link for taking this laboratory procedure and establishing it as a field-worthy measurement tool.

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