Magneto-acoustic emission in wide ribbons of Metglas 2605SC and in steel bars

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Abstract. Magneto-acoustic emission (MAE) from wide ribbons of an amorphous ferromagnetic glass (Metglas 2605SC) and from a steel have been studied. The anisotropy of the ribbon is highlighted by applying the magnetic field along the axis of the plate or in a direction perpendicular to it. Two independent experimental set-ups with piezoelectric and inductive detectors coupled to synchronous amplifiers have been employed to simultaneously determine resonances of acoustic waves produced by the alternating magnetic field in the range of tens of KHz and with a spectrum analyzer in the range of hundreds of KHz.. These magnetoelastic resonances in the steel are compared with the results obtained when it is excited with more intense magnetic fields at the frequency of the AC line voltage.

INTRODUCTION

The response of ferromagnetic materials to external magnetic fields (Happl) is characterized by the discontinuous dynamics of the magnetic domains. Moreover, when the material presents magnetostriction, the changes in orientation of the magnetic momentum of the domains implies a modification in the volume of these domains. These discontinuities lead to a sharp release of energy in the form of mechanical waves which constitute the base of the so-called magneto-acoustic emission (MAE).

The classic works [1-7] have been carried out on bars of Fe, Ni and different alloys obtaining MAE waveforms by means of piezoelectric transducers with a Happl which varies sinusoidally at line frequencies.

In the early 1980s, amorphous ferromagnetic materials, which offer some interesting magnetoelastic properties, began to be widely used. The most common form was that of narrow ribbons (in the order of 1mm). S.Tyagi et al. [8] studied the r.m.s. values of the MAE signals detected when these specimens were subjected to alternating fields at 60 Hz and their dependence on the applied stress and heat treatments. The coupling of the sensor and the ribbon was carried out using a waveguide.

One of the techniques most widely used [9-12] in the study of these magnetic glasses with high magnetoelastic coupling values consists in determining the resonances by means of induction sensors when the material is subjected to an alternating Happl. of variable frequency. For narrow ribbons of several centimeters of length and propagation speeds in the order of 10^3 m/s, the frequencies for which resonances-antiresonances appear are around the tens of KHz.

The more recent availability of amorphous ribbons with widths of several centimeters has made it possible to use AE sensors in studies of the MAE of these materials [13]. This work will continue examining in-depth the use of piezoelectric AE sensors to search for resonance frequencies, comparing the results with those obtained using coils.

This procedure will also be used for steel bars. The ideas obtained from these analyses will help us to interpret MAE results when the materials are taken to magnetic saturation point at line frequencies.

EXPERIMENTAL

In order to detect the magnetoelastic resonances, two independent set-ups have been used, as shown in Figure 1. One of them detects the electromagnetic signal induced in some coils and the other measures the magnetoelastic waves using a piezoelectric sensor.

The materials used are a magnetic glass, Metglas 2605SC from Allied Signal, which presents a high magnetomechanical coupling factor, in the form of a ribbon 2 in. wide, 0.6 thousandths of an inch thick and cut at 15 cm. in length. The industrial steels used (Ni-Cr-Mo alloy steel type A543) were in the form of bars of 1cm x 1cm x 15 cm .

The experiments were carried out at room temperature and with the specimen in the cast form, with no further heat treatment. The alternating magnetic field was generated either by using Helmholtz coils of 30 cm. radius, or by means of a magnetic yoke system with a coil wound around a bracket and with the magnetic material tested closing the magnetic circuit. An HP-3325B synthesizer in sine waveform and with currents in the order of mA was used as a generator.

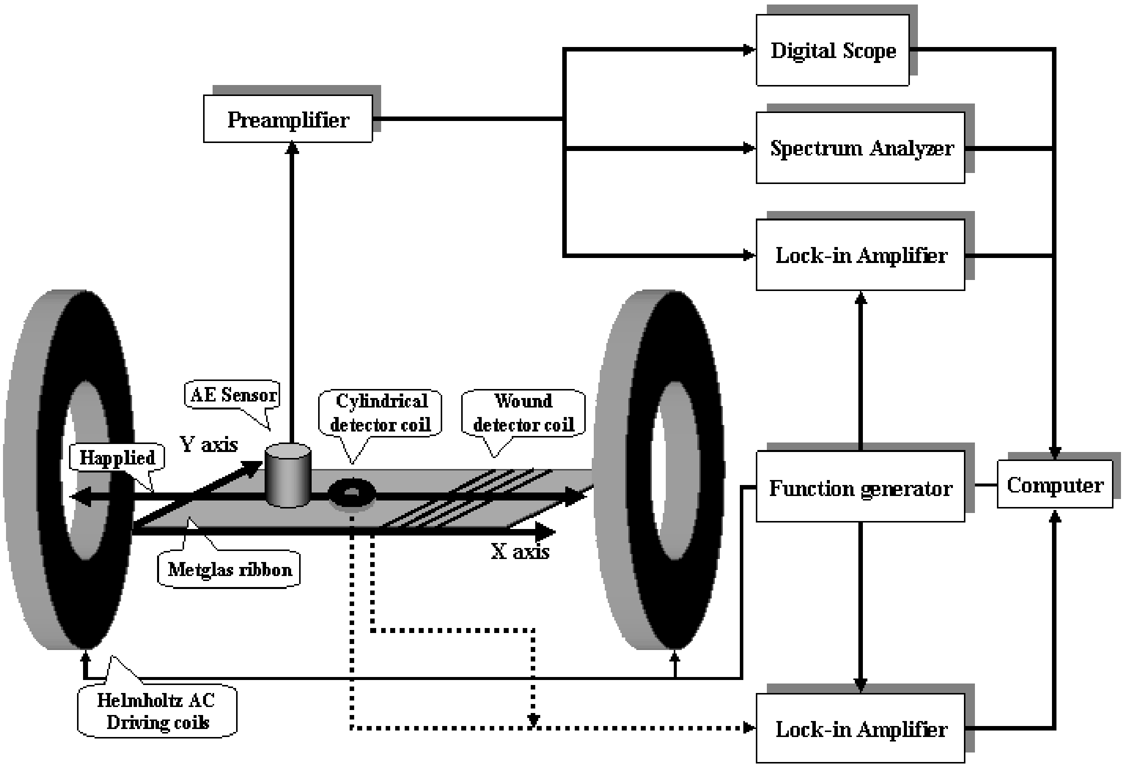

Figure 1. Experimental device for the simultaneous measurement of magnetoelastic resonances using AE and induction sensors.

The detection of the induced electromagnetic signal was carried out using a 200 turn coil wound around the specimen and another identical one wound in the opposite direction below the ribbon. Another test set-up was one of a coil of 100 turns, with a diameter of 20 mm and a thickness of 6 mm placed as a disk parallel to the specimen surface. This latter geometry has the advantage of remaining symmetrical if the orientation of the specimen situated between the two Helmholtz coils is changed in order to study the effects of the axial anisotropy of the ribbons, with different responses according to the orientation of the Happl with respect to the specimen axis.

The AE signal is detected using a Vallen VS30-V sensor and is sent to a P.A.C. 1220 Preamplifier with a gain of 60 dB with filters in the range of 20-100 KHz. . The induction signals and the MAE signals are sent to synchronous detector amplifiers, lock-ins, a 7220 Model from E.G.&G. and an SR-850 from Standford Research.

As these lock-ins have a higher range of around 100 KHz, the analyses at higher frequencies were performed using an HP-8591E spectrum analyzer. At this range of 100 KHz – 1 MHz, Vallen VS375-M sensor and R15 and R6 sensors from P.A.C. have been used, changing the filter in the preamplifier.

RESULTS AND DISCUSSION

Figure 2 shows a comparison of the results obtained with the coil wound around the Metglas ribbon and using the AE sensor The alternating magnetic field was applied with the Helmholtz coils in the lengthwise direction of the ribbon. The frequency was varied at 50Hz intervals and after a period of stabilization the detected signal was stored simultaneously with the two lock-ins. This was done in order to take into consideration the possible modification in the resonance frequencies caused by the use of the AE sensor with a mass of 43.9 grams supported by gravity on the ribbon of 0.945 grams. The aim of this work was not to determine exactly the resonance frequencies, which would have required a different positioning of the sensor.

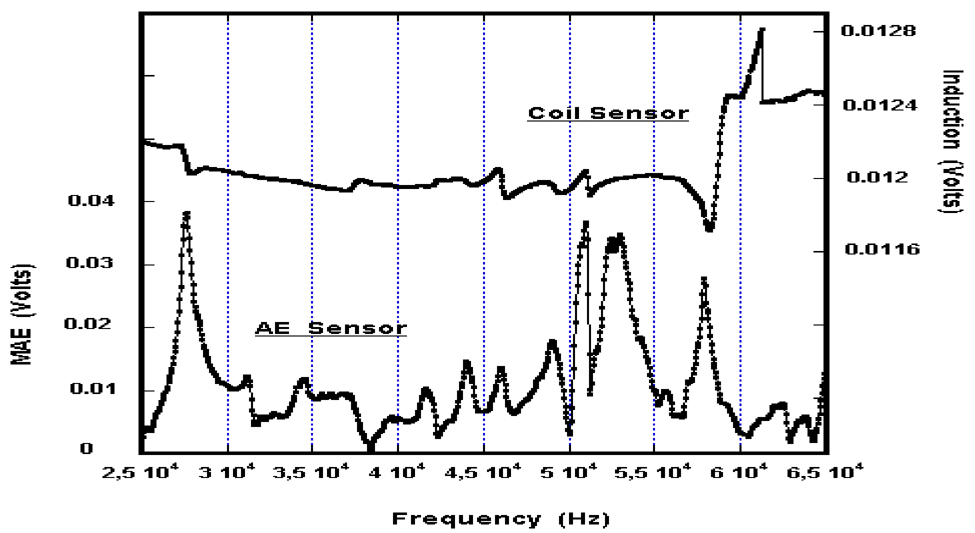

Figure 2. Magnetoelastic resonances in a Metglas ribbon obtained from a coil and AE sensors using Lock-in amplifiers.

The induction signal is shown corrected from its tendency to vary according to the frequency ω. This dependence arises from the fact that the coil wound around the specimen and the one located in the air and wound in the opposite direction are not strictly identical, so that there exists an inductive term proportional to ω. Moreover, the skin effect predicts a penetration proportional to $(\omega)^{-1/2}$ for the magnetic field. For the purpose of comparison, Figure 4 shows a signal with no correction.

It can be observed that the AE signal has well-defined peaks in relation to the base line. The induction signal requires the lock-in capacity to extract the low-voltage signals from the background noise. Certain AE peaks present a clear correlation with the resonance-anti-resonance forms of the induction curves.

Figure 3 compares the AE graphs for the case where the axis of the ribbon is oriented according to the magnetic field applied (Hx) or angled 90º with respect to that direction (Hy). Differences in the relative amplitudes of certain peaks are observed. A previous work [13] analyzed the differences between the individual induction pulses (Barkhausen signals) for the two orientations.

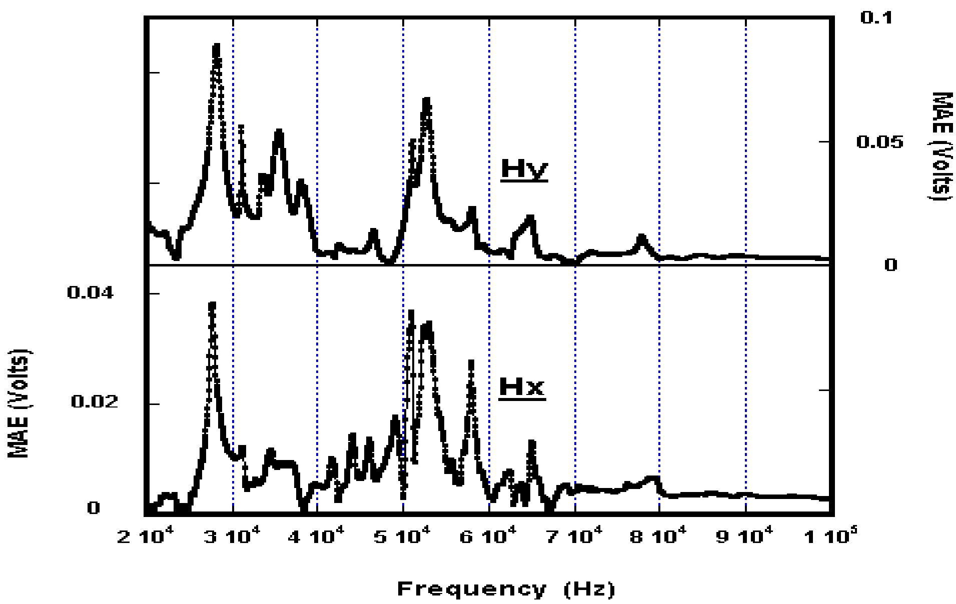

Figure 3. Comparison of MAE signals obtained by applying the magnetic field both along the axis of the Metglas ribbon (**Hx**) and in a perpendicular direction (**Hy**)

The analysis of the steel bar was performed by applying the magnetic field both with the yoke and with the Helmholtz coils. In this latter case, the system of opposed coils was used, placing the bar on one of them. The signal obtained thus, and the one obtained using AE, are shown in Figure 4 at the frequency interval of 40 to 70 KHz. The induction signal module and its quadrature component are shown, this being more appropriate for highlighting small changes in the tendency. As in the case of amorphous glass, the MAE signals show clear peaks, while the inductive module turns out to be a small variation with respect to the base line.

The existence of peaks detected by means of AE which are not present in the induction curve may be due to several causes. One of these may be the existence of resonances intrinsic to the AE sensor itself. The effect of the magnetic field on the piezoelectric sensor was assessed by placing this in the same geometrical arrangement on a non-magnetic material, obtaining noise signals with far lower levels than those of the peaks of Figures 2,3 and 4. However, in this experiment the effect of the magnetic field created by the magnetization of the specimen itself is not taken into account. At short distances, this field may be intense when saturation is reached.

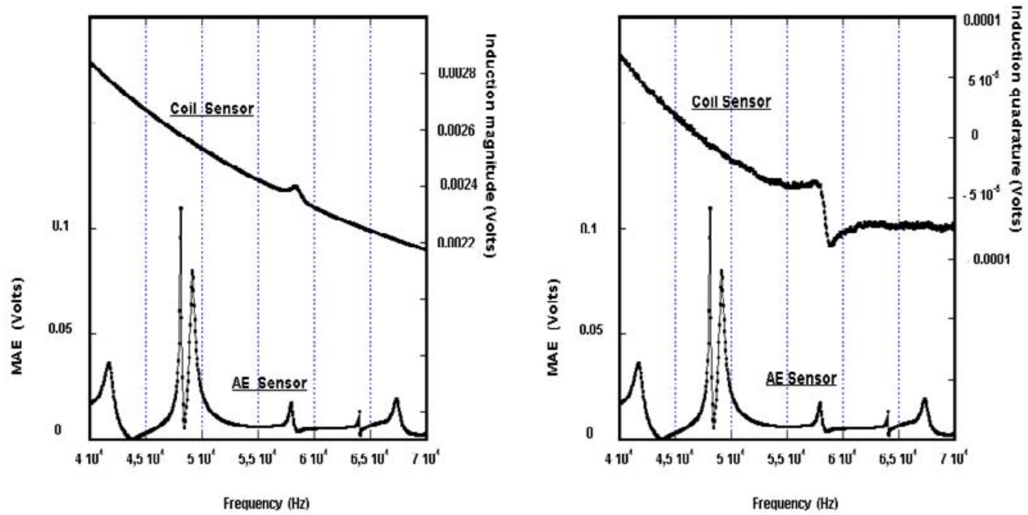

Figure 4. Magnetoelastic resonances in a steel bar. Comparison of MAE signals with the magnitude of the induction signal (left) and with the quadrature component of the signal (right).

Another cause could reside in the differences generally accepted [2][14] between the mechanical signal, whose generation is associated with magnetostriction, and the induction signal related to the rotation of the magnetic moment in the domains. The domain wall movements which imply variations in volume with a change in orientation of 180º should not originate elastic wave signals, while the induction signal will be at the maximum. When the changes in orientations are of 90º, mechanical waves will appear in response to the magnetostriction of the material, but the induced signals will be of lower amplitude. Also to be taken into account is the relative geometrical arrangement between the coil and the change in the magnetic moment in the domain.

To continue the analysis of the resonances at higher frequencies, a spectrum analyzer was used. An experiment was repeated in the range studied above (20-100 KHz), verifying that the results obtained with the lock-in and with the analyzer were very similar. Figure 5 shows the results for the iron bar excited between 250 and 350 KHz , a common zone in which the P.A.C. R15 sensor and the VS375-M Vallen sensor show a high sensitivity. It was observed that several peaks coincide for the two detectors. These coincidences in two sensors from different manufacturers might constitute an argument against the possibility of an excessive influence of Happl on them or the existence of peaks due to intrinsic resonances.

A great number of the classic works on magnetoacoustics has been carried out taking the material up to magnetic saturation by applying intense fields generated by currents obtained from the line. Figure 6 shows an MAE signal from steel obtained by using the ac line voltage at 50 Hz and with a current 100 times greater than that of the experiments described above.

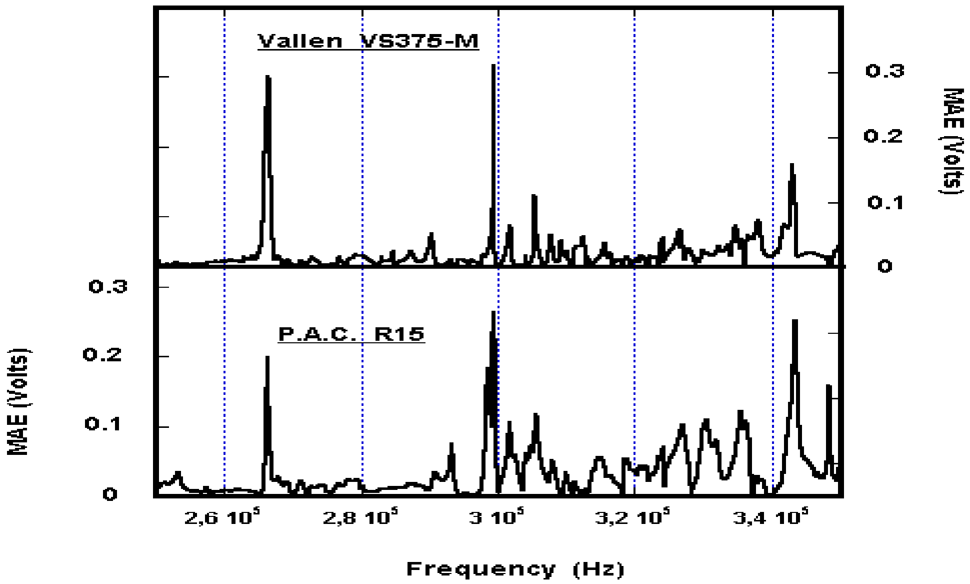

Figure 5. Spectral analyses of the resonances of the steel bar for two different AE sensors, the VS375-M from Vallen and the R 15 from P.A.C.

The magnetoelastic resonances detected were studied in this experimental situation of excitation at 50Hz. The spectral analyses for the 20-100 KHz range and for the 100-300KHz are shown in Figure 7. Comparing this figure with Figure 4, it can be observed how several of the most important peaks have a similar pattern even though the excitation is now performed at a far lower frequency.

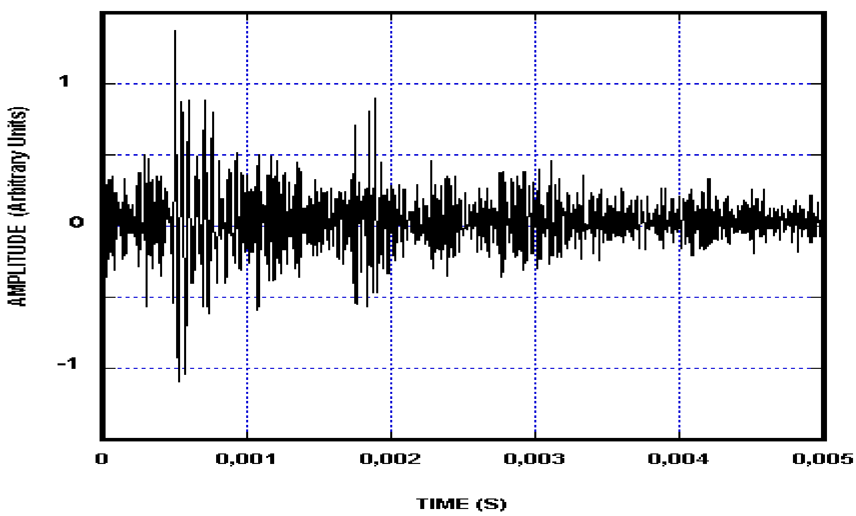

Figure 6. MAE waveform of the steel bar placed on a magnetic yoke and excited by a line signal of 50 Hz.

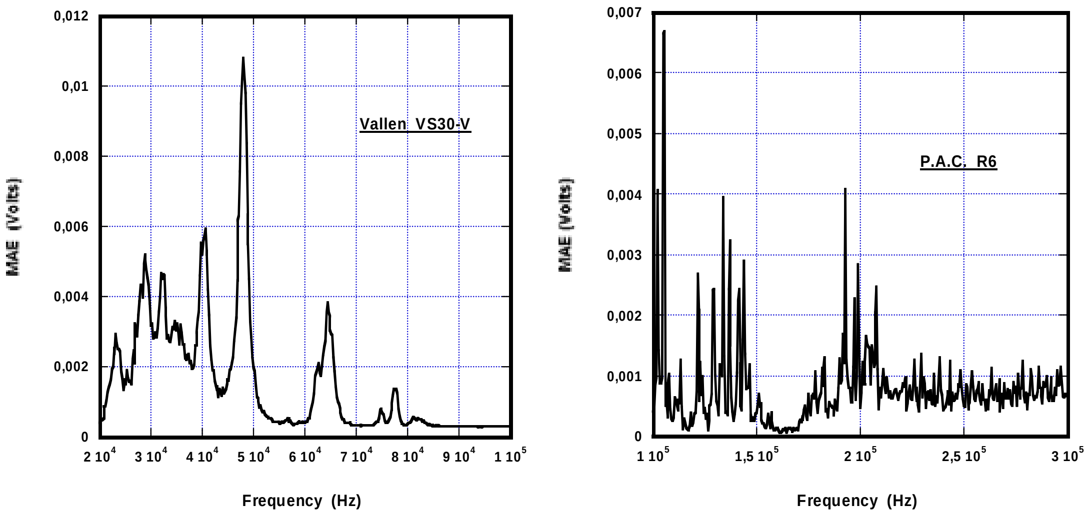

Figure 7. Spectral analyses of the MAE signal of a steel bar excited by the line signal of 50 Hz. Range between 20-100 KHz (left) and between 100-300 KHz (right)

In this situation of more intense magnetic fields, the experiment was repeated to try to assess the Happl effect on the sensor, placing this at barely 1mm from the magnet poles of the yoke. For applied fields in the order of $1.6\ 10^4$ A/m, both for the sensor axis and for the case perpendicular to it, the signal obtained by the analyzer was indistinguishable from the background noise.

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