Collapse of Magnetic Hyperfine Splitting in a Soft Magnet Studied by Multiple Spectrum Mössbauer Data Acquisition

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The time scales for establishment and collapse of the magnetic hyperfine splitting and FM sidebands of a magnetic foil subject to a strong RF field were investigated using a newly developed, multiple spectrum, Mössbauer spectrometer. The sideband response was of order milliseconds, while the magnetisation response was approximately one second due to magnetic viscosity.

1. Introduction

We have recently developed a unique, multiple spectrum Mössbauer data acquisition system which is capable of taking a series of spectra, such that they are equally spaced in time following some initial triggering event [Cashion et al., to be published]. The triggering event may be regular or random. The system has many potential uses for studying the time evolution of systems which are subjected to a magnetic, electric or laser pulse or for delayed coincidence studies. In this first application of the system we are using it to study the effect of RF pulses on magnetically soft, metallic glasses. The use of continuous RF radiation with Mössbauer spectroscopy has been developed by Kopcewicz and coworkers over 20 years [see e.g. 1-3] as an important technique in the study and development of glassy metal systems such as the METGLASS, FINEMET and NANOPERM systems.

2. Experimental

In conventional ^{57}Fe Mössbauer RF collapse systems [1], the absorber is placed in an RF tank coil and subjected to intense RF radiation. This radiation has the effect of collapsing the magnetic hyperfine splitting if (a) the RF field is stronger than the anisotropy field, (b) the RF frequency is greater than the nuclear Larmor precession frequency and (c) the switching time of the magnetisation is shorter than the RF period. Furthermore, it also produces magnetostrictively induced sidebands separated by multiples of the RF frequency. Turning off the RF causes the magnetic hyperfine field to be re-established and the sidebands disappear. However, until now there has been no way of measuring how quickly these transitions occur.

In the present application, the soft magnetic material is subjected to RF radiation which is amplitude modulated by a square wave. The arrival of the trailing edge of the square wave resets the spectrum counter, so that counting always starts in spectrum 1 when the RF is switched off. The system then steps through the spectra being accumulated, with uniform dwell times, until reset to spectrum 1 by the arrival of the next square wave trailing edge. The maximum number of spectra to be acquired is a trade-off between the desired resolution and reasonable total counting time and typically 6-12 spectra are fitted into the square wave period. The sequence continues over several days until sufficient statistics have been accumulated, so the physical phenomena must be perfectly reproducible. In the present configuration, the minimum dwell time per spectrum is 50 ns and the maximum is 3.5 min.

In this first application of the system, we have studied the collapse phenomenon in a 30 μm glassy metal sample of $Fe_{40}Ni_{35}Si_{10}B_{15}$ using an RF frequency of 37.5 MHz. The

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square wave frequencies varied from 300 Hz to 0.28 Hz and the corresponding dwell time per spectrum ranged from 0.5 ms to 600 ms.

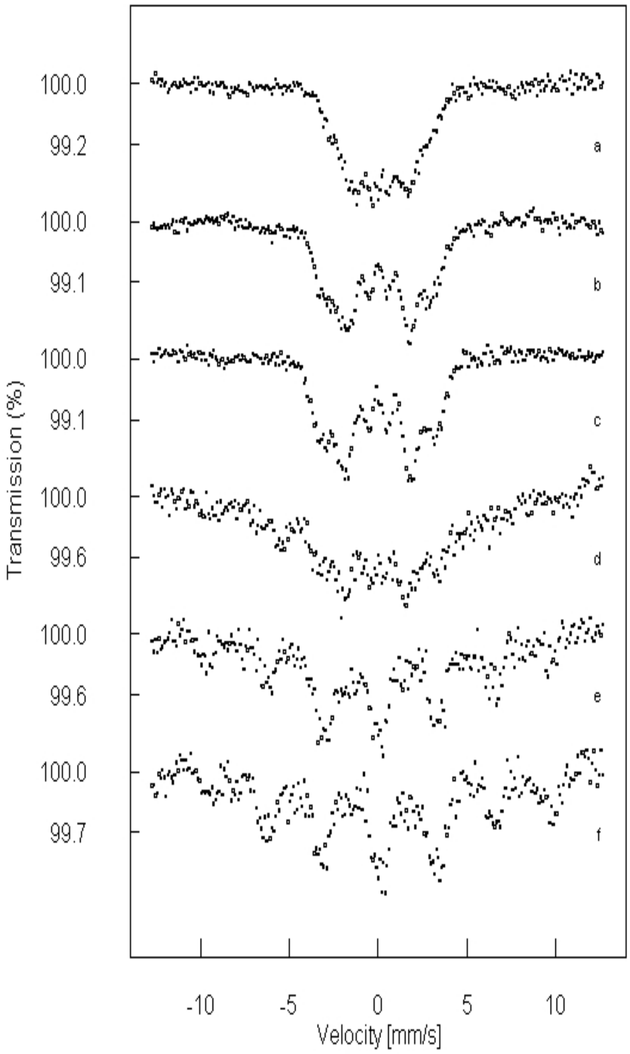

Fig. 1. A series of spectra taken on a sample of $Fe_{40}Ni_{35}Si_{10}B_{15}$ with an RF frequency of 37.5 MHz, square wave modulation of 0.28 Hz and spectrum dwell time of 600 ms.

3. Results

A set of six spectra taken with a 0.28 Hz square wave modulation of the RF is shown in Fig 1. The dwell time per spectrum is 600 ms. The RF field is off for spectra (a) to (c) and comes on approximately one-third of the way through the fourth spectrum. We can see in Fig. 1(a) that there are no sidebands but the magnetic splitting does not recover until (b) and (c). Fig. 1(d) has some time with RF off and then on, but it can be seen that the magnetic splitting has collapsed for part of the spectrum and the sidebands are starting to form. In (e) and (f), the sideband intensity is building up and an expanded scale spectrum (not shown) of the centre peak (zeroth sideband) shows the known quadrupole split spectrum of this sample.

For the spectra in Fig. 2, the dwell time per spectrum has been reduced to 160 ms, with eight spectra taken with the RF off, followed by four spectra with the RF on. In Fig. 2(a-e) we see the gradual re-establishment of the magnetic hyperfine splitting. It is interesting to note that the re-establishment is not symmetrical (Fig. 2(d)) and is almost fully achieved by Fig. 2(e). The first spectrum with the RF on (Fig. 2(f)) is almost featureless, with the sidebands then slowly appearing as seen in Fig. 2(g), which is contiguous with Fig. 2(a).

To determine the effect of the length of time for which the RF was off, a set of spectra was taken with 40ms RF off and then spectra at 50 ms intervals. The spectrum for the first 50 ms RF-on period showed sidebands almost as well-formed as those in Fig. 1(f), in contrast to Fig. 2(f)

A final set was taken with 0.5 ms dwell time, three spectra with RF off, followed by three spectra with RF on. The RF-off spectra showed a single line with some side structure, very similar to the previous set. The RF-on set showed clear evidence of sidebands.

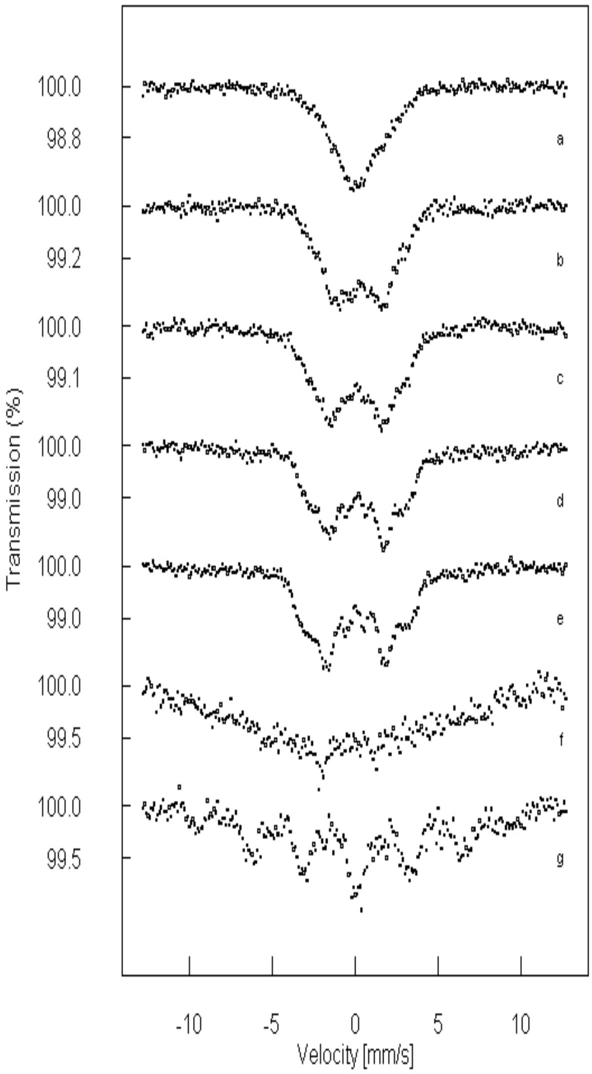

Fig. 2. As for Fig. 1, but with a dwell time of 160 ms. RF off for spectra (a) 0-160 ms, (b) 160-320 ms, (c) 320-480 ms, (d) 480-640 ms and (e) 800-960 ms; RF on for spectra (f) 1280-1440 ms and (g) 1760-1920 ms.

4. Discussion

The results show a surprising variety of effects. Firstly, the FM sidebands stopped almost instantly on removal of the RF. However, the magnetic structure took nearly a second to re-establish as seen in Fig. 1. The speed of establishment of the sidebands depended on the state of the magnetic hfs at the instant that the RF turned on. If the hfs was fully developed, then the sidebands took a second to become clear. However, if the RF-off time was insufficient for the hfs to re-establish, then the sidebands became visible in milliseconds.

In searching for an explanation for the longer time scale, most of the physical phenomena involved, such as the velocity of sound, phonon lifetimes and domain wall speeds all have times of order milliseconds. We believe that the key is the RF skin depth, which is approximately 1 μm at this frequency, so that the information on the state of the RF field is transmitted inwards via the slow Barkhausen mechanisms which account for magnetic viscosity.

Acknowledgments

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