1.0 Introduction

The existence of BH time based responses are reasonably well known. By BH time response we mean the time taken for a magnetic material to reach its magnetization value (B) after the application of a magnetizing force (H), or the time based drift of a material from its magnetization value.

Sometimes referred to as ‘magnetic viscosity’, there are in fact several effects that are covered under the term ‘magnetic viscosity’. Two such effects are demonstrated experimentally in this document (medium to long and short term BH responses) with a particular emphasis on the short term BH time response.

2.0 Medium to Long Term Variation

A simple experiment demonstrates the medium to long term effect. The experiment consists of two hall probes, connected to the same power supply, a data acquisition system and a ferrite sample, as indicated in Figure 1.0. The control hall probe is placed so that it is beyond the influence of the ferrite sample (i.e. the magnetic field from the ferrite sample cannot be measured by the control hall probe). The purpose of the control probe is to verify that there is no hall probe drift.

During the experiment the ferrite sample has its magnetization reversed by the application of a strong external magnetic field. The source of this strong magnetic field is then removed from the experiment and the magnetization of the ferrite sample is recorded over a sixteen hour period.

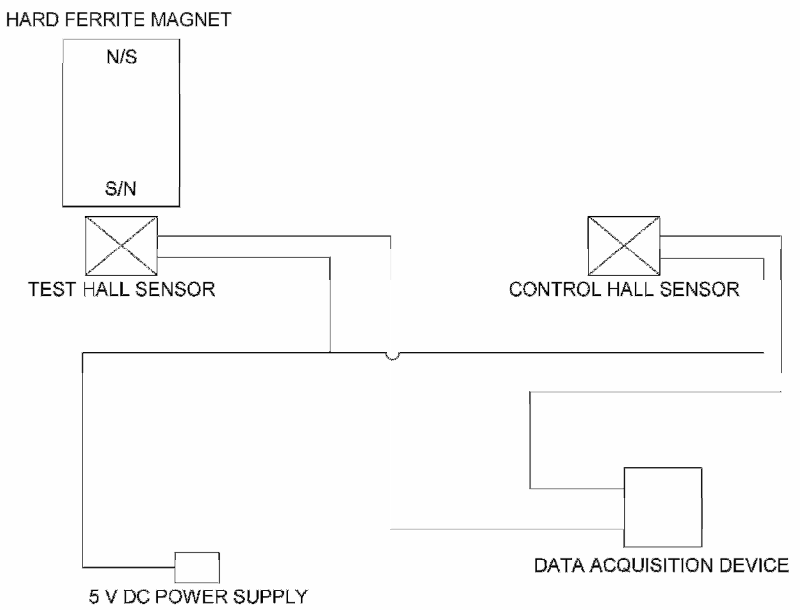

Figure 1.0 – Experiment Setup

Figure 2.0 shows the time during which the ferrite sample had its magnetization direction reversed. Prior to the introduction of the external field, the test hall probe was measuring a magnetic flux density with a value of *plus* 0.072 Tesla. The external magnetic field was applied for several seconds. Following the removal of this field the test hall probe measures a magnetic flux density of *minus* 0.064 Tesla. Hence we can see that the external magnetic field has caused the poles of the ferrite magnetic to 'flip'.

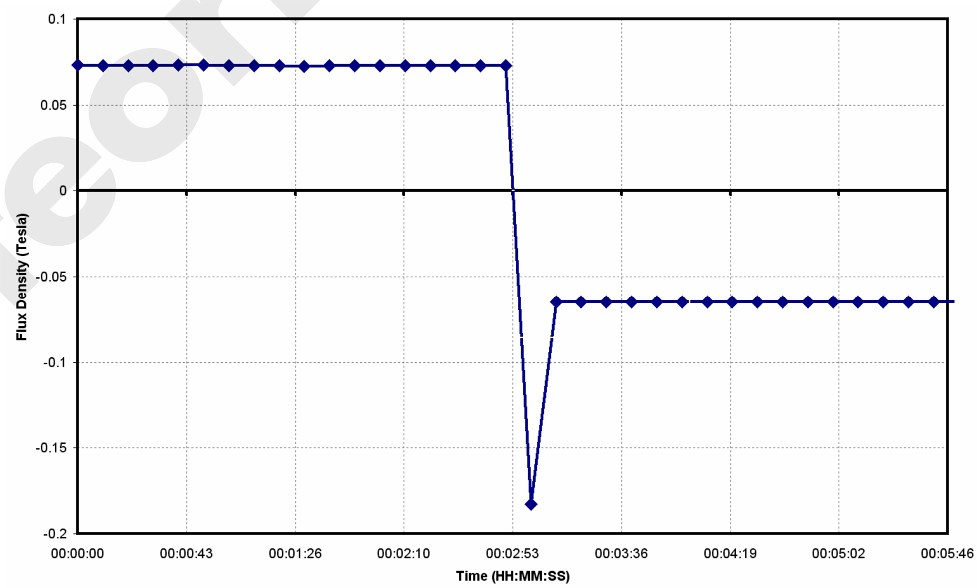

Figure 2.0 – Reversing of the ferrite sample's magnetization direction

Figure 3.0 shows a chart of the magnetic flux density measured by the test hall probe for a 16 hour period after its magnetization direction has been reversed. As can be seen from this graph the magnetization of the ferrite sample is recovering in a linear fashion over an extended period of time.

Such medium to long term changes in magnetization have been previously well document and many white papers are available that discuss this effect in some detail. (See attached Magnetic Viscosity Study in FePt/C granular films).

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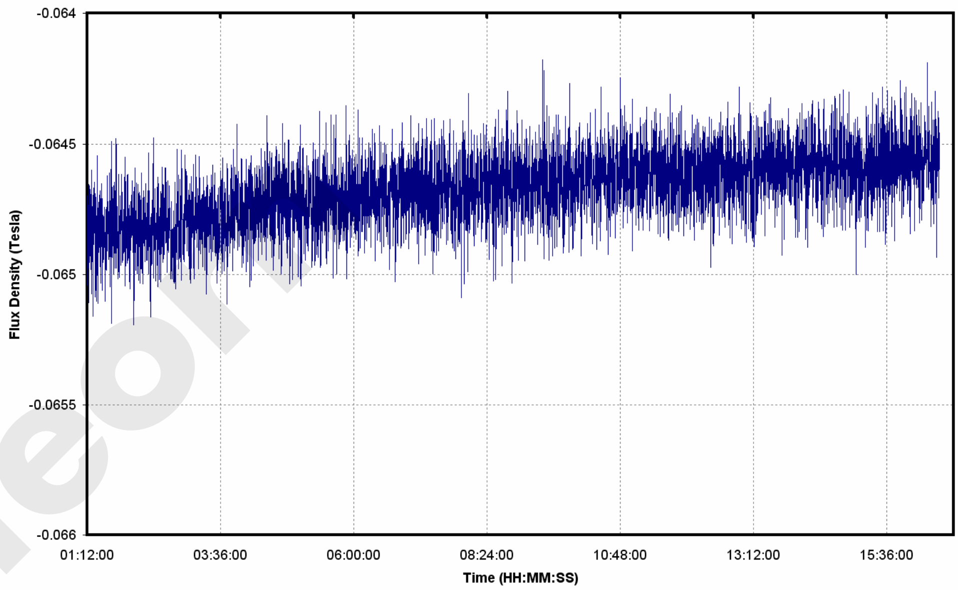

Figure 3.0 – Recovery of the ferrite sample over an extended time period

3.0 Short term BH variation

As demonstrated above there are medium to long term BH time responses, by which we mean responses that happen in time frames of many hours or days.

By short term BH time responses we mean responses that occur in microsecond or millisecond time frames. The effect on the kinetic energy of rotary systems of these short term BH time responses has previously been demonstrated and documented by Steorn.

The purpose of the tests documented here is to demonstrate that such short term time based BH responses are in fact due to the slowing down of a magnetic field as it propagates magnetic materials.

The paper sets out to experimentally demonstrate this point by measurement of a magnetic field as it moves through a specific material (Netic, a nickel alloy). Further papers will address the change in propagation speed for various materials and at different points on the BH curve for those materials.

3.1 Experimental Set-up

The experiment comprises an alternating current source, an electrical conductor, sample material, four hall probes and an oscilloscope.

The AC current is allowed to flow through the electrical conductor (copper bar), thus creating a circulating magnetic field around the electrical conductor as per Amperes law, as indicated in Figure 4.0.

The magnetic field produced by the current flowing through the conductor can then be measured at different physical positions using the hall probes (for example as indicated in Figure 6.0).

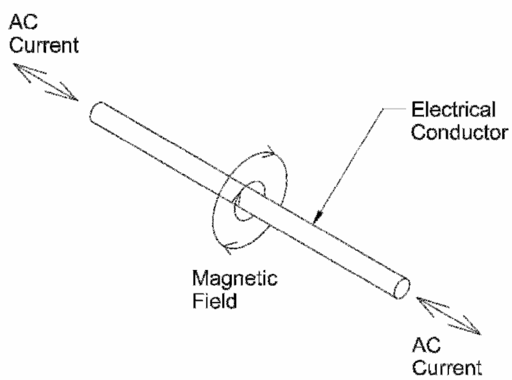

Figure 4.0 - Magnetic field in electrical conductor

The hall probes produce a voltage output that is linearly proportional to the magnetic flux density perpendicular to the face of the probe. The oscilloscope records the voltage output from the hall probes with respect to time, as shown in Figure 5.0. Since the AC source used is a 50 Hz source, we can see from Figure 5.0 that the magnetic field produced is a sine wave also with a frequency of 50 Hz, as expected.

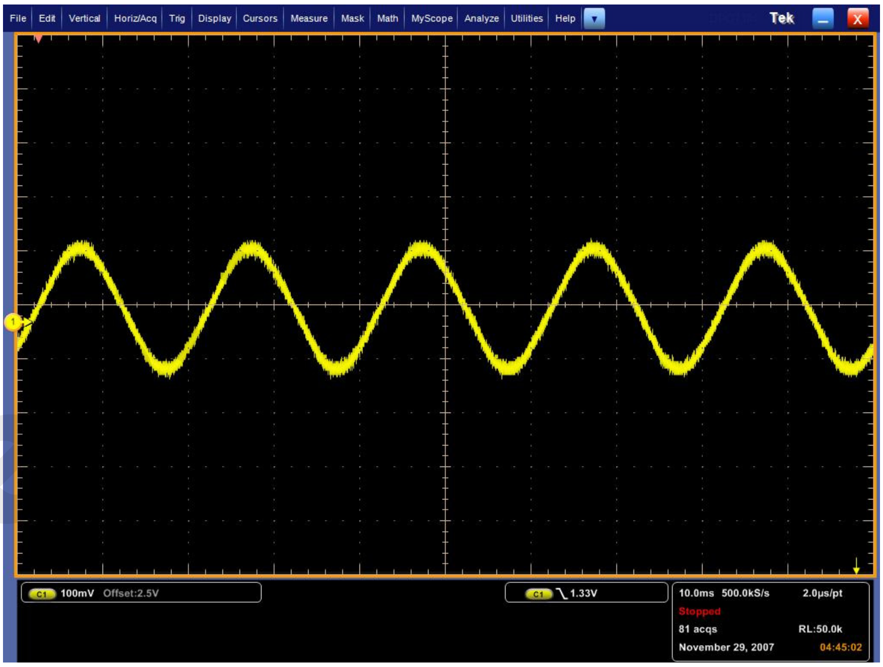

Figure 5.0 – Oscilloscope recording hall probe output with respect to time

3.2 Baseline test

As with any measurement system, there will be a degree of measurement uncertainty. The tests described in this paper rely on the time stamping accuracy of the oscilloscope, the linearity of the voltage output of the hall probes and the response time of the hall probes themselves. In particular the test method is based around the analysis of phases shifts measured by the hall probes.

In order to determine the uncertainty of the experiment with respect to phase shifts, a simple baseline test is conducted. The four hall probes, are placed on the copper bar as shown in Figure 6.0.

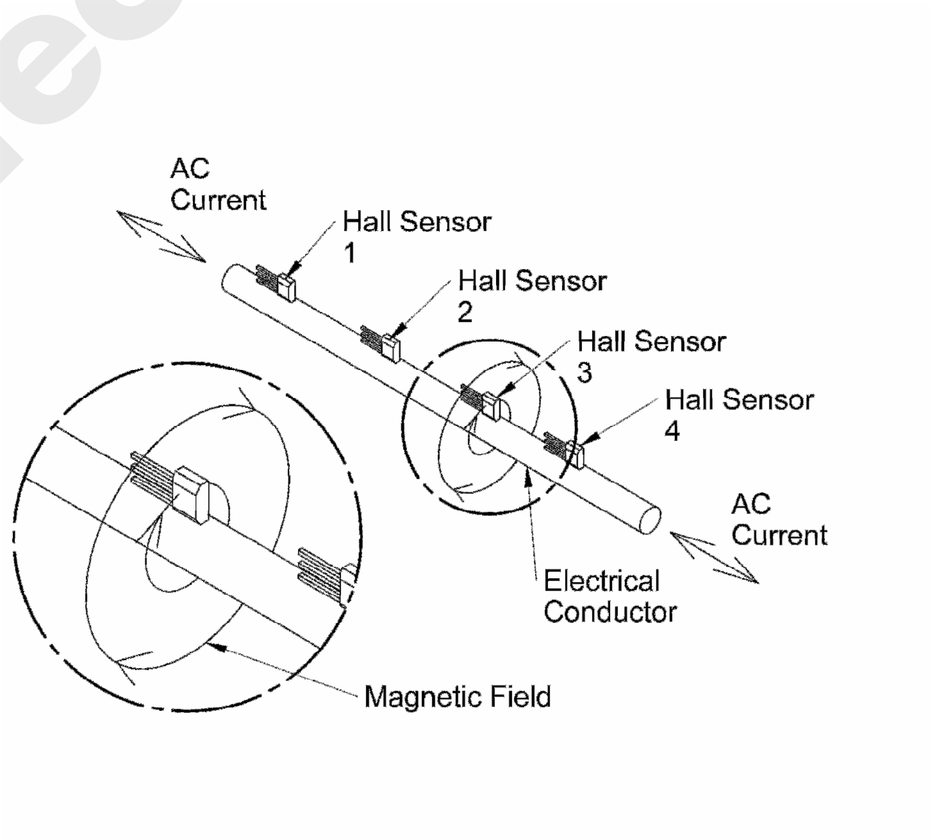

Figure 6.0 – Baseline hall probe set-up

Per Amperes law all four hall probes will experience the same magnetic phase and any phase shift recorded between the four measurements highlights the measurement uncertainty of the experiment.

Figure 7.0 shows the flux readings captured during a baseline test. The maximum phase shift is found to be less than 100 microseconds (note that this test is conducted multiple times in order that any repeatability issues are included in the measurement uncertainty). The minor variation in amplitude of the four signals shown in Figure 7.0 is as a result of the probes not being exactly at the same distance from the copper bar.

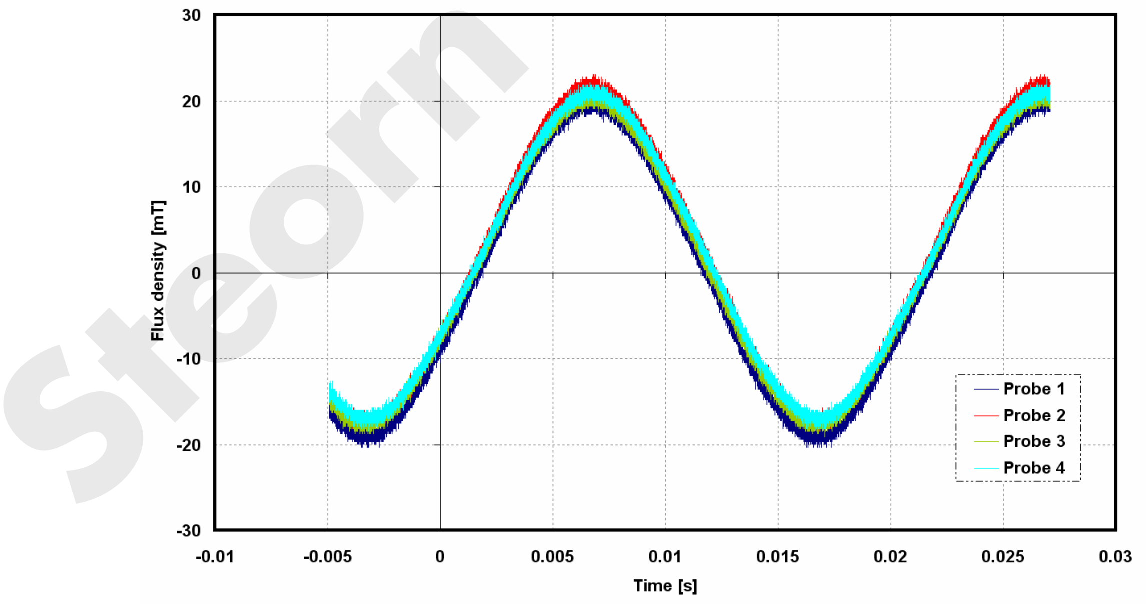

Figure 7.0 – Baseline waveforms

3.3 Propagation Experiment One

The test system is set-up as shown in Figure 8.0. The sample shown in the set-up diagram is Netic, a nickel alloy.

The hall probes are placed to measure any delay in the propagation of the magnetic field from the copper bar through the sample. One of the hall probes is placed on the copper bar to measure the magnetic field generated by the passing of the AC current through the copper bar, and the other three hall probes are placed at known distances along the sample material, in a direction perpendicular to the copper bar.

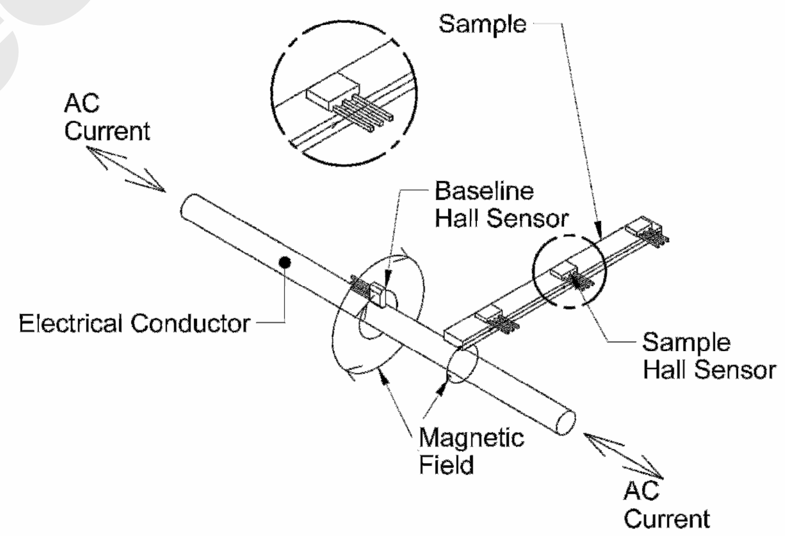

Figure 8.0 – Static Propagation Test One Set-Up

AC current is passed through the copper bar and the magnetic fields measured by the four hall probes are recorded with respect to time. A phase shift analysis is performed so that the phase shift between the three hall probes on the sample material can be calculated. The phase shifts are found to be linear with respect to distance from the copper bar and are shown in Figure 9.0.

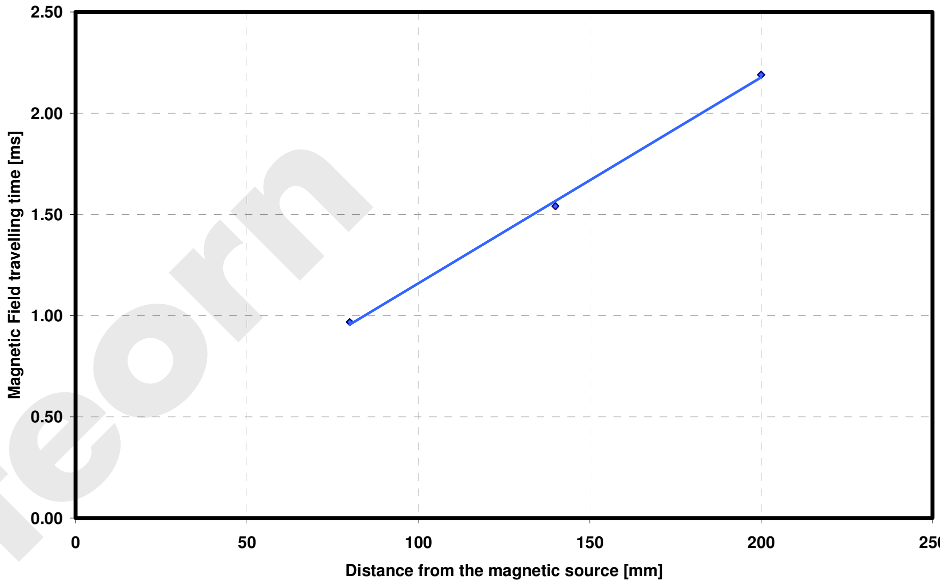

Figure 9.0 – Propagation Test One Results

3.4 Propagation Experiment Two

The test system is set-up as shown in Figure 10.0. The sample shown in the set-up diagram is Netic, a nickel alloy.

This experiment involves measuring the magnetic field at the end of the sample and the field produced by the copper bar (as shown in Figure 10.0). The sample material is moved so that its end (along with the hall probe) is at a different distance from the copper bar while keeping the sample material itself perpendicular to the copper bar. In this way the distance between the end of the material and the copper bar producing the magnetic field can be varied and the phase shift for different distances can be calculated.

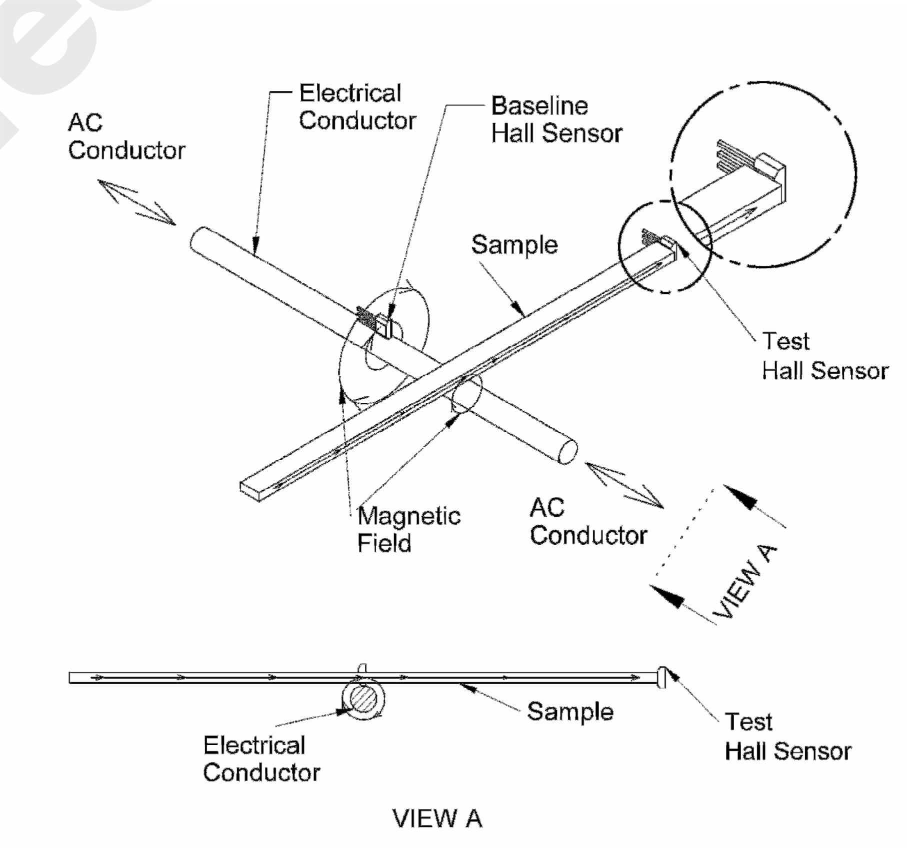

Figure 10.0 – Propagation Test Two Set Up

Figure 11.0 shows the results from this test for various different distances between the copper bar and the end of the sample material (and associated hall probe).

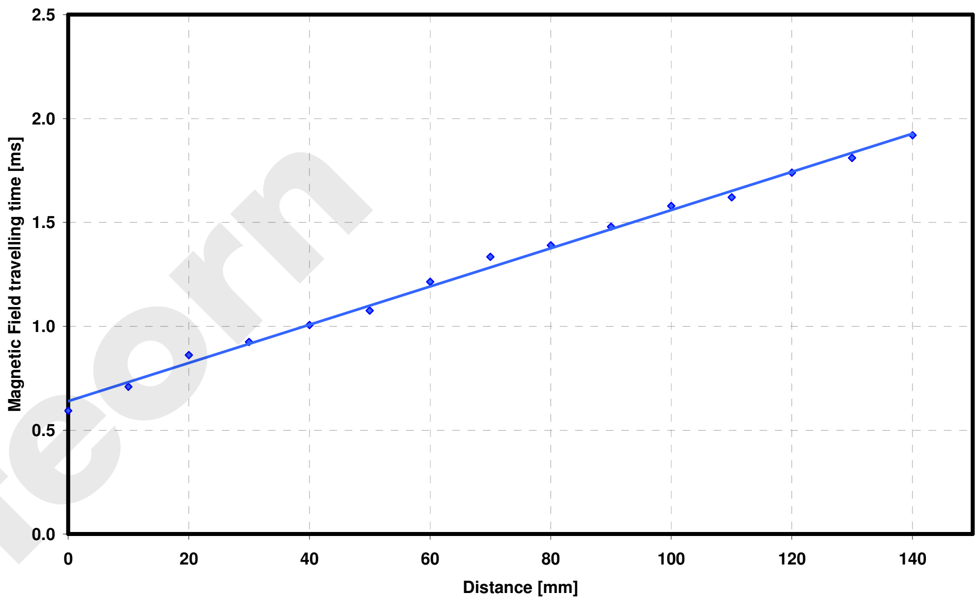

Figure 11 – Propagation Test Two Results

3.5 Conclusions based upon Short Term BH Tests

Both of the short term experiments described in this paper demonstrate that there is a phase shift well beyond the experimental uncertainty between the various hall probe measurements. The phase shifts are shown to be a linear function of distance from the source of the magnetic field. Such phase shifts can only be caused by the propagation of the magnetic field through the sample being relatively slow.

Both tests show that the magnetic field propagates through the sample material at a speed of 100 meters/second and that the speed of propagation through the material is linear.

The pronounced reduction in the speed of propagation of the magnetic field will produce a BH time based response when measured on an magnetic object as a whole, i.e. since it takes a finite time for the field to propagate through the material, the overall magnetization of the material in question will take time to respond to an external magnetic field.

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