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Teaching magnetic particle spectroscopy to undergraduates – a practical session

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Abstract

Magnetic Particle Spectroscopy (MPS) is a valuable technique for SPIOs analysis. MPI and MPS are beginning to secure their place in university curricular with some universities delivering post-graduate content. To the best of our knowledge it is however yet to be routinely taught at an undergraduate level. Here we present a lab using a low cost MPS system suitable for a final year undergraduate physics or chemistry student. A third year undergraduate physics student tested the lab in which transmit signals are canceled using a gradiometric receive coil, the frequency spectrum of synomag-D 70nm SPIOs obtained and used to produce a calibration of particle concentration which is used to determine the concentration of two unknown samples. The student obtained a calibration graph with an R2 value of 0.99 and low residual error. The student then went on to successfully find the values of the unknown samples with an error of less than 17 %.

I Introduction

Magnetic Particle Spectroscopy (MPS) is a valuable technique for both analysis of SPIOs for Magnetic Particle Imaging (MPI) and as a measurement tool in its own right. Magnetic Particle Imaging (MPI) has many important medical applications such as cardiovascular, angiography and stroke imaging, as well as applications in targeted drug delivery, cancer screening and hyperthermia. MPI and MPS are also sensitive to temperature and viscosity allowing for these parameters to be determined non-invasively on a nanometric scale. Despite the clear and emerging benefits of the technique, it is not universally taught at undergraduate level.

In this abstract, we present a laboratory script that is suitable for a final year undergraduate physics or chemistry student to undertake. This is accompanied by an Instructable (“A Low-Cost Bench-Top Magnetic Particle Spectrometer (MPS)”[1]) detailing the construction of such a system to allow any institutions with access to a 3D printer and SPIO samples to produce their own. The whole system costs less than £1000, which makes it ideal for an undergraduate laboratory and is based on the design presented at IWMPI 2019[2] where an intrinsic 3D printed thread was used to perform the cancellation of the transmit signal.

Standard laboratory equipment is used throughout the experimental protocols to maximize accessibility. We engaged a third-year undergraduate physics student to aid in the development of the script to ensure that each of the exercises is achievable and brings an enhanced understanding and appreciation of this exciting technique.

II Material and methods

II.I MPS design and system components

The design for the spectrometer can be found in the instructable “A low cost Low Cost Bench Top Magnetic Par-

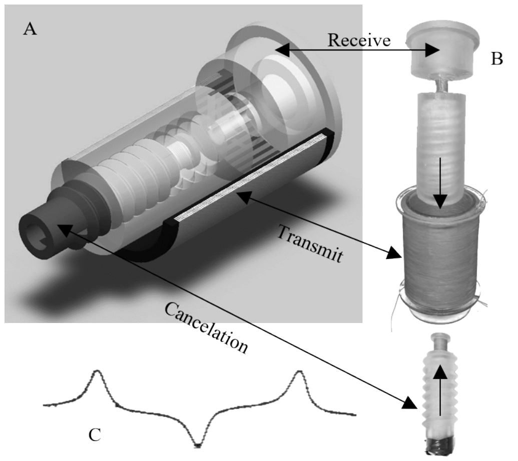

Figure 1: A - Cross sectional model of the coil setup, B – Photographs of component parts, C – Resulting signal from Synomag-D 70nm SPIOs.

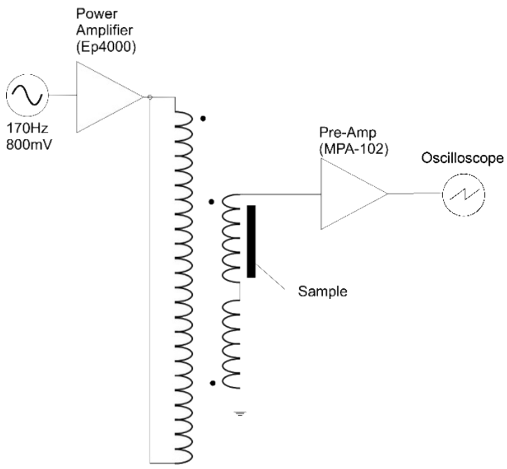

Figure 2: Schematic of the setup for the undergraduate lab.

ticle Spectrometer (MPS)"[1]. A cross sectional view of the design of the MPS system can be seen in Fig. 1.

An arbitrary waveform generator (AFG-2225) is used to generate a 170Hz sinusoidal signal which is amplified using an off the shelf audio amplifier (EP4000). The signal from the gradiometric coil is amplified using a microphone pre-amp (MPA-102) run on batteries to reduce the noise levels. Unlike the Instructable[1] which utilizes a sound card for capture, the students will collect the data using a digital oscilloscope to make it more suitable to an undergraduate laboratory. The schematic for the setup is shown in Fig. 2.

II.II Labscript

The laboratory script introduced MPS through a brief background section including the mechanisms of functionality. There are 5 exercises for the students to com-

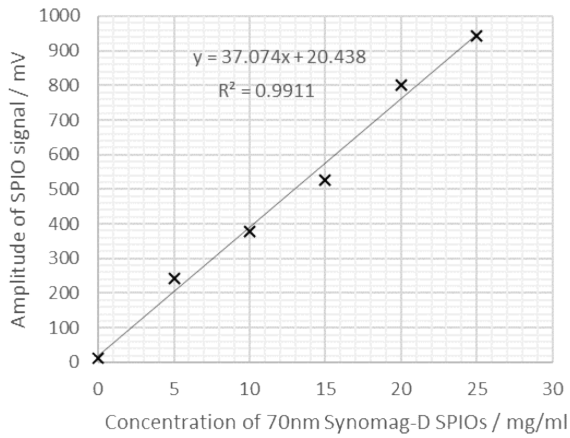

Figure 3: Calibration curve produced during exercise 4 of the laboratory script.

plete which is expected to take less than 3 hours. The activities are summarized below.

Exercise 1 - Optimising the position of the cancellation coil

The student adjusts the cancellation coil using the intrinsic thread system to get the best possible cancellation of the transmit signal, observing the signal using the oscilloscope.

Exercise 2 - Testing the MPS

The students look at the signal produced by a high concentration (25mg/ml) of synomag-D 70nm SPIOs and check this against their expectations and understanding

Exercise 3 - Understanding the MPS signal

The students look at the signal produced by iron filings and explain why this is different to that produced by the SPIOs. The frequency spectra are compared by saving the waveforms on a memory stick and processing in MATLAB (Mathworks, MA).

Exercise 4 – Calibration Graph

The students will collect data to produce a calibration graph of peak amplitude as a function of concentration using (0,5,10,15,20 and 25) mg/ml Synomag-D 70nm SPIOs in water.

Exercise 5 - Find the concentrations of the unknown samples

Finally, the students will measure the peak to peak amplitudes of two unknown samples (A=12.5mg/ml and B=7.5mg/ml) and use their calibration graph from exercise 4 to determine their concentrations of A & B.

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III Results and discussion

The undergraduate student undertook the experiments as detailed above. They found "[each stage to be] simple to follow" and stated that the "equipment worked without problems".

They went on to produce the calibration curve in Fig. 3 which showed a clear linear correlation between the concentration of SPIOs and the peak amplitude of the resulting signal.

By outputting the line of best fit from the data in Fig. 3, the student went on to obtain values for the concentrations of the unknown samples of 11.8±1.4 mg/ml and 6.8±1.1 mg/ml for the 12.5 mg/ml and 7.5 mg/ml respectively. These values match well with the actual values.

IV Conclusions

The laboratory script was tested and the values of A & B found were very close to actual concentrations of 12.5mg/ml and 7.5mg/ml which shows that the students can find the concentrations of unknown samples after producing a calibration graph. The frequency spectra of the SPIOs could be found by exporting the waveforms from a digital oscilloscope and showed the odd harmonics in the SPIO signal and just the fundamental for the iron filings (not shown). The final laboratory script will be provided with the MATLAB (Mathworks, MA) code so the students can obtain the frequency spectrum and compare this with just iron filings without prerequisite knowledge of the software. The student who undertook this experiment enjoyed the experiments, finding MPS (of which they were not previously familiar) "a very interesting concept". This laboratory script will be further tested by undergraduate students and when ready will be implemented in the Medical Imaging module of the undergraduate integrated MSci course at Nottingham Trent University.

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Author's Statement

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