Device for Precise Measurement of Magnetic Microwire BH Loop at Low Frequency

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Abstract. *In this paper we present a precise and cheap system we developed to measure BH loops of magnetic microwires. We especially focused on low frequency BH loops because we are mostly interested in quasi-static magnetic properties. Due to low frequency, we had to face problems related to low signal to noise ratio. The extremely small cross-section of the microwires turned out in very small flux to be measured. We achieved our goal by realizing a BH tracer based on induction principle, which generates the current necessary to create H field, and it synchronously samples the induced voltage. Digitized voltages are then sent to PC, which performs numerical analysis and returns the BH loop. The system has proved to be cheap and it provided excellent measurement parameters.*

Keywords: BH loops, microwires, low frequency, magnetic properties

1. Introduction

Magnetic microwires have had a rapid development in the last years, due to several applications they can be employed for, and especially because they can be used to build several kind of magnetic field sensors [1]. We can define as magnetic microwires those wires composed by magnetic material, possibly combined with other non-magnetic materials, whose cross-section has diameter in order of tens of μm.

Researchers dealing with this kind of microwires are interested in precise characterization of their magnetic properties. Vibrating Sample Magnetometers (VSMs) can be used for this purpose, but they are extremely expensive, and they require up to several hours to measure a single BH loop. Induction principle can be used instead. The microwire is placed in a solenoid which generates a time-varying H field: a pick-up coil is wound around the microwire to measure the induced voltage V_{ind}, given by the change of magnetic flux in time. Integration of V_{ind} is then performed to obtain magnetic flux, then B field [Fig. 1]. The voltage due to the magnetic flux of the air is subtracted from V_{ind} connecting in anti-series an exact replica of the pick-up coil, without any magnetic wire inside.

This processing is usually performed by analog instruments [2]. The induced voltage is amplified and integrated by an analog integrator. An oscilloscope is used in XY mode to plot the BH loop. The main problem of this method is the noise and drift of the integrator. When the cross-sectional areal of the wire is so small, the signal is very small too. Moreover, any effort to reduce the voltage due to change of air flux, will never lead to perfect compensation. Finally, we will have a very small voltage mixed into some noise signal also due to air flux. When using this method, extremely high number of averaging is required, because of the low quality of the signal (usually thousands of periods).

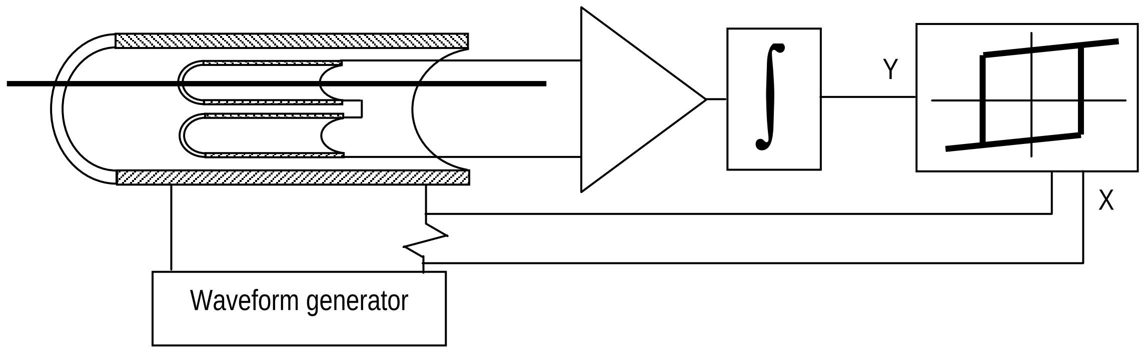

Fig. 1. Simplified scheme of set-up for measurement of BH loop in magnetic microwire.

Moreover, this system requires several instruments: a waveform generator, an amplifier, an integrator and a scope. It is pointless to use all these instruments for this measurement set-up, especially when one needs to constantly have to his disposition a measurement system to measure BH loops, rather than building the set-up once in a while.

Our goal was to develop a card, which performed all these functions, improving in the same time the quality of the measurement.

2. Structure of the developed BH tracer

Fig. 2 shows the simplified scheme of the BH tracer circuit. The core of the system is a PIC18F2550 microcontroller: it provides the connectivity to an host PC by USB bus and it manages all the components of the circuit. The whole circuit is powered by USB bus.

Generation of H field

In order to generate H field we must inject a time-varying current into the main solenoid. We use a programmable waveform generator based on DDS technology (AD9833) to generate both sine and triangular waveform. The frequency of the waveform is an exact fraction of the input Master Clock, provided by the PIC microcontroller. The microcontroller generates the Master Clock using a PWM module, based dedicated registers incremented by the microcontroller clock. In this way we have exact synchronization between the microcontroller and the generated waveform. Frequency range of the resulting H field is between 20 and 100 Hz.

Microcontroller communicates to the waveform generator on SPI bus, instructions such as the choice between sine and triangular waveform. Then, we amplify the waveform and we use a current source circuit (based on feedback operational amplifier and transistors) to feed the main solenoid.

Acquisition of induced voltage

The voltage induced into the pick-up coil is amplified by an AD620 instrumentation amplifier. The gain is set by a resistor, selectable by means of a multiplexer (controlled by the microcontroller as well). Then the amplified voltage is digitized by AD7685 ADC (16-bit, 250 kHz) and the result is sent to microcontroller by SPI bus. The acquired data is stored in internal flash memory of microcontroller and finally sent to PC by USB.

According to the composition of the magnetic material of the microwire, the induced voltage will include sharp peaks, due to sudden change of magnetic flux around coercivity field. Such peaks determine high frequencies into voltage’s spectrum and require sampling frequency much higher than H's frequency. Despite the ADC has 250 kHz maximum sampling frequency, we found out that 80-90 kHz were more than enough for our application.

We had to use a 16-bit ADC because the signal could be so small that high resolution is necessary.

Acquisition of H field

In order to measure the H field we acquired the voltage on a shunt resistor. In this case the measured voltage is either sine or triangular waveform at 20÷100 Hz, therefore we used the internal 10-bit ADC of the PIC microcontroller, whose resolution was sufficient. Due to short spectrum we used much lower sampling frequency (2.2 kHz).

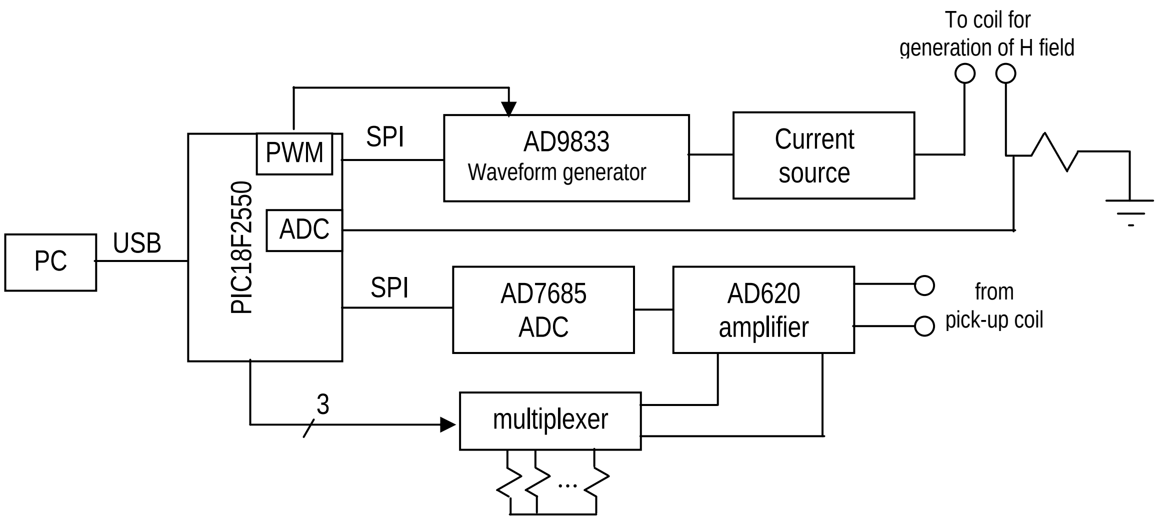

Fig. 2. Simplified scheme of the developed board. The core is a PIC18F2550 which manages all component of the circuit and provides connectivity to PC by USB.

3. Results

We have developed the firmware for the PIC microcontroller and a software in Labview which allows the user to set all the parameters of the circuit (such as frequency and shape of H field, gain of amplifier, sampling rate…); moreover this software acquires the data stored into the PIC and performs numerical integration of induced voltage to derive B field. The software includes the possibility to perform averaging, as well as numerical compensation of air flux.

Due to limited amount of flash memory available on the PIC we had to sample the waveforms in consecutive sections and transfer the data to PC every time. Thanks to already mentioned synchronization between H field and microcontroller we could sample the waveforms every time starting from the exact time when we ended sampling the previous time: no missing points at all. Assuming the signal to be stable, this technique was completely satisfactory.

Quality of the measurement

Thanks to the developed board, we were able to measure the BH loop of magnetic microwire with very high quality, compared with similar analog system. This is clear when we notice that averaging over 10 periods returns excellent BH loops for 40 μm diameter microwire. Previously mentioned analog system require thousands of periods for averaging. Moreover, we do not have problems related to drift of integrator: any average value is subtracted from digitized data before numerical integration.

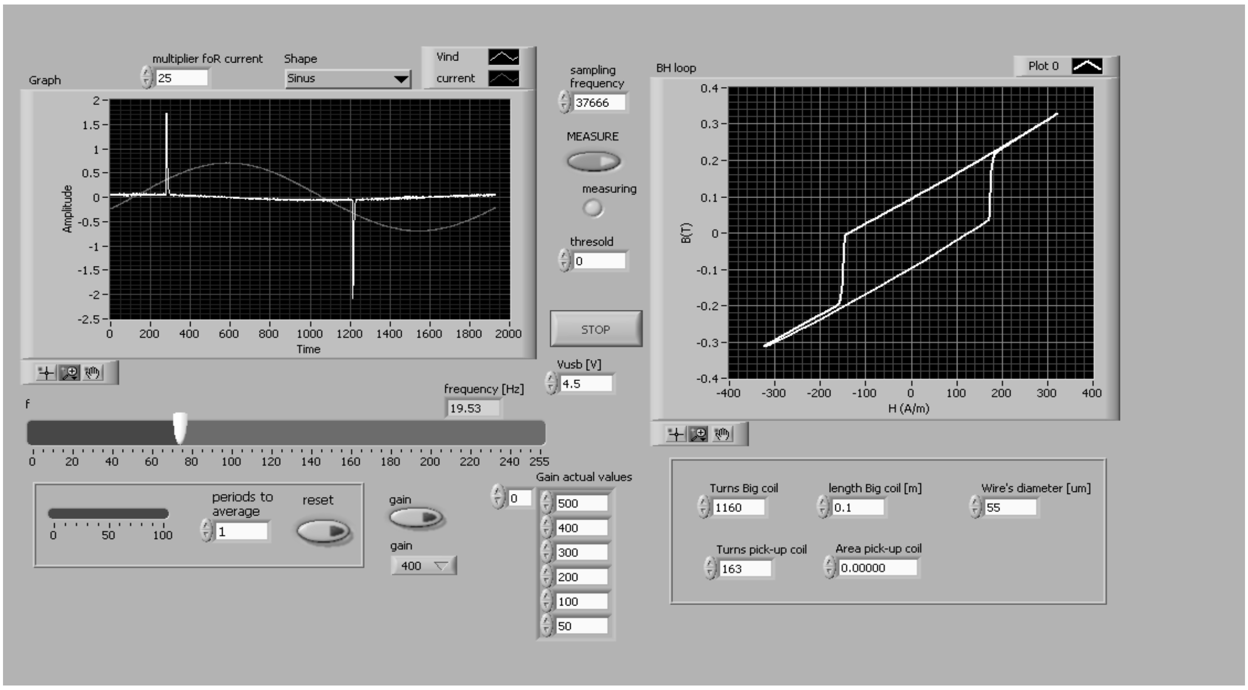

Fig. 3. Screenshot of the software used to acquire the data from the board and compute the BH loop.

4. Discussion

We have presented a board which can simplify the characterization of magnetic microwires. The user can just connect the board to the PC by USB and does not have to care about anything else. The implementation of digitalization of signals and numerical integration proved to improve the quality of the measured BH loop to a level never reached by analogue techniques. Thus, due to low number of averaging the measurement is much faster and reliable. Finally we should mention that all electronic components used to build this card can be bought for less than 50 EUR, that is orders of magnitude less than instruments traditionally used to measure a microwire BH loop by analogue techniques.

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