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PROGRESS OF THE MAGNETIC MEASUREMENT BENCH FOR PULSED MAGNETS BASED ON A MODIFIED VIBRATING WIRE TECHNIQUE

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Abstract

A measurement bench, dedicated to the characterization of pulsed magnets such as injection kickers, is under development at ALBA. The bench employs a modified vibrating wire technique allowing to measure high frequency magnetic fields in the range of hundreds of kHz. In the traditional vibrating wire technique an AC current carrying wire is stretched through the bore of the magnet and the force acting on the wire is proportional to the product of the wire current and the magnet field. A vibration of the wire is observed when the frequency of the wire current happens to be equal to the natural resonant frequency of the wire, typically a few hundreds of Hz. To characterize the high frequency behavior of the magnet, the measurement is modified by offsetting the frequency of the wire current by an amount equal to the magnet excitation frequency. This condition results in a resonant excitation of the wire vibration independently of the magnet field frequency. A feedback system based on the continuous excitation of multiple frequencies allows to track the resonant frequency of the wire, drastically increasing the measurement accuracy.

INTRODUCTION

An attempt at pulsed magnetic measurements by means of a vibrating wire setup was previously presented in [1] In a first experiment the traditional vibrating wire technique was applied to sample the field of a small bore kicker magnet powered with a constant current source. A thin metallic wire under tension was stretched through the bore and an alternating current tuned to the mechanical resonant frequency of the wire was applied to the wire. The wire vibration resulting from the interaction between the magnetic field and the current was sampled using an optical pickup allowing to determine the vibration amplitude and from this the magnetic field strength. Furthermore it was shown how the same technique could be modified in order to measure a field oscillating in the range of hundreds of kHz, well above the mechanical resonant frequency of the wire. For this purpose the wire was excited with a high frequency current tuned to the frequency of the magnetic field plus the mechanical resonant frequency of the wire, this condition allows in fact to produce a resonant excitation of the wire similarly to what was obtained in the constant field case. While the experimental test shown how the proposed technique can indeed be applied to sample an alternating field at high frequency, the overall results had a limited precision, and therefore were not suitable for an accurate characterization of a magnet.

In the following sections we proceed to illustrate further optimizations to the already described technique along with the experimental results.

FREQUENCIES COMB EXCITATION AND FEEDBACK

As shown in [2–4] the magnetic field strength is determined by fitting the wire frequency response. In the previous work a total of 25 frequencies were used to sample the wire response resulting in an overall acquisition time of roughly 20 minutes. This long acquisition time makes the measurement sensitive to any drift in the wire parameters. For instance a temperature drift during the measurement can easily change the wire resonance enough to result in a distortion of the measured resonant curve.

In the new setup to cut off the measurement time, the single frequency excitation of the magnet is changed changed in favor of multiple frequencies, allowing to measure several points of the response curve at the same time (Fig. 1). For simplicity only 3 frequencies were used, a central frequency that is tuned to the resonant frequency of the wire and two equally spaced side frequencies. The signal is generated by applying an amplitude modulation to the magnet current with frequency equal to the required frequency spacing. The frequency spacing was set to 100 mHz such that the two side frequencies result in an excitation amplitude of roughly half the peak amplitude. To be able to resolve the contribution of each spectral line the acquisition time is set to a multiple of the period of the frequency spacing. It was found that

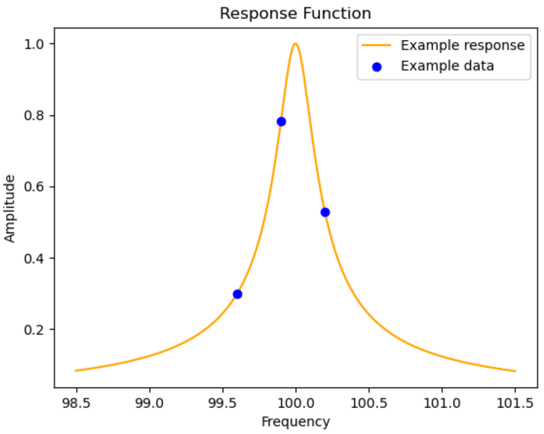

Figure 1: The simultaneous excitation of 3 frequencies provides the minimum required information to carry out the fit of the wire frequency response (solid line).

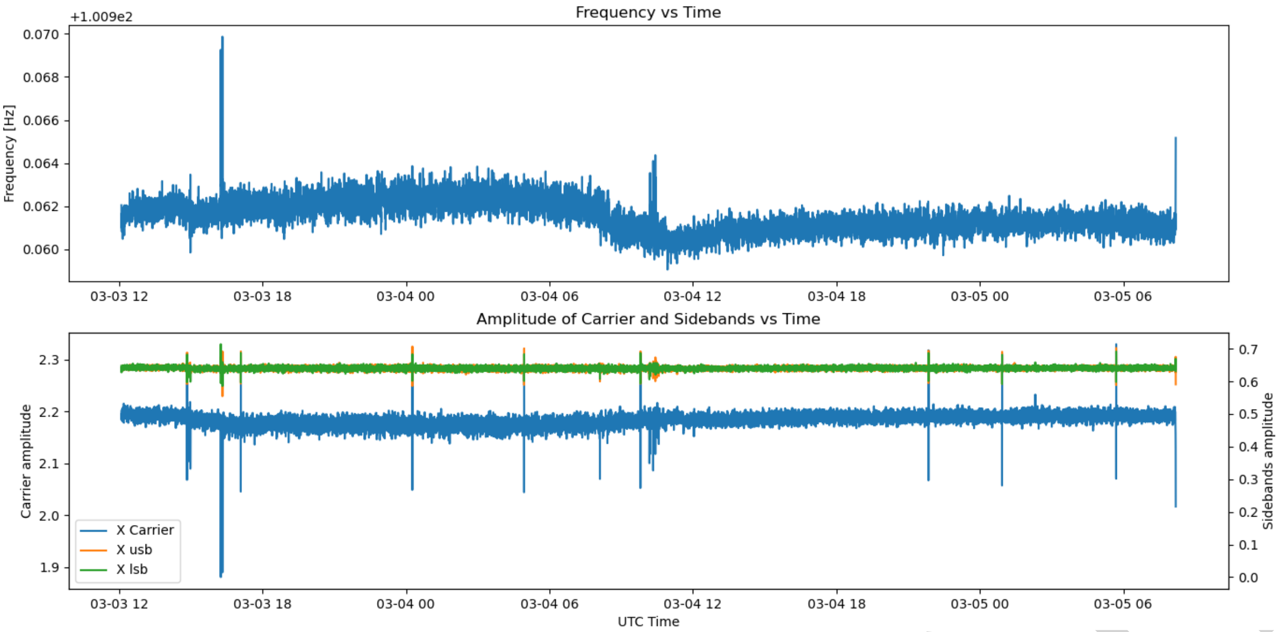

Figure 2: A two days continuous measurement shows the frequency tracking capabilities of the feedback system. In the top picture a slow drift of the frequency due to night and day temperature variation is visible. The bottom picture instead shows the amplitudes of the central and side spectral lines. The amplitude of the two side spectral lines is kept to the same value by the action of the feedback.

an acquisition time of 20 s provided the best compromise between the acquisition time and accuracy.

A feedback algorithm was implemented to keep the system on resonance. At every iteration (every 20 s) the feedback measure the amplitude of the two lateral spectral lines and from the difference compute a frequency correction. As shown in Fig. 2 this allowed to track effectively the slow frequency drift due to temperature change in the laboratory.

A simple power amplifier visible in Fig. 3, was built to drive the magnet with high current. The amplifier uses a complementary transistor pair in a push-pull configuration, polarized in order to operate in the linear regime. With this setup it was possible to drive the magnet at the frequency of 100 kHz and with a current up to 2 A resulting in an harmonic distortion inferior to 1 %

EXPERIMENTAL RESULTS

Several acquisitions were carried out using the power amplifier and the feedback system running. A fit of the wire frequency response was carried out individually for each acquisition. The result of the resonant frequency, quality factor and amplitude obtained from the fit are shown in Fig. 4. The plots show the distribution of the 3 parameters along with a Gaussian fit that provides an estimate of the spread of each parameter. The fourth plot instead shows the value of k, which is proportional to the magnetic field and is defined as:

$$k = \frac{A f_0^2}{Q} \tag{1}$$

Where the parameters A, f_0 and Q are obtained from the previous fit and represent respectively the maximum vibration amplitude, the resonant frequency and the quality factor. Because of the proportionality relation between k and the magnetic field, the relative error on k can be assumed as an estimate of the relative error on the field. Is worth noting that this error is smaller respect to the sum of the individual errors on the 3 fit parameters, this is to be attributed to a correlation between quality factor and amplitude, that results in a partial cancellation of the overall error.

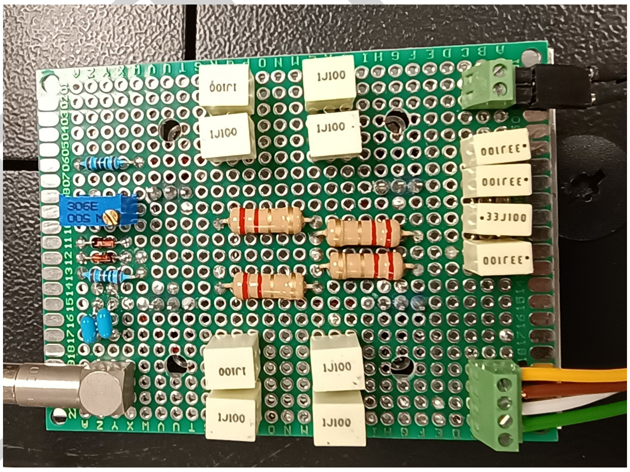

Figure 3: Picture of a prototype of the power amplifier build on purpose to drive the magnet at 100 kHz with up to 2 A.

A second optical pickup was then included in order to measure the 2 transverse magnetic field components. While the first tests shown promising results a more detailed analysis revealed some unexpected behavior. Figure 5 shows the wire normalized amplitude in the two transverse directions as a function of frequency. In this case the magnetic field

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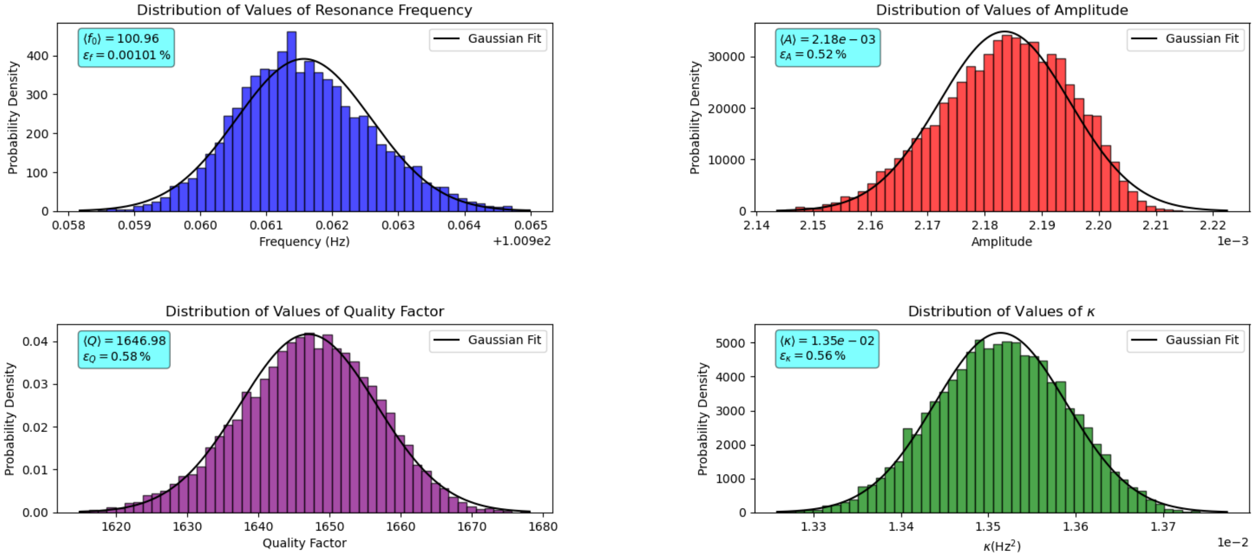

Figure 4: Distribution of the parameters A, f_0 and Q obtained from the fit. The bottom right plot instead shows the distribution of the resulting k.

was oriented in such a way that the oscillation was aligned with one of the two pickups. A strange peak, with a non Lorentzian profile appears also in the orthogonal direction.

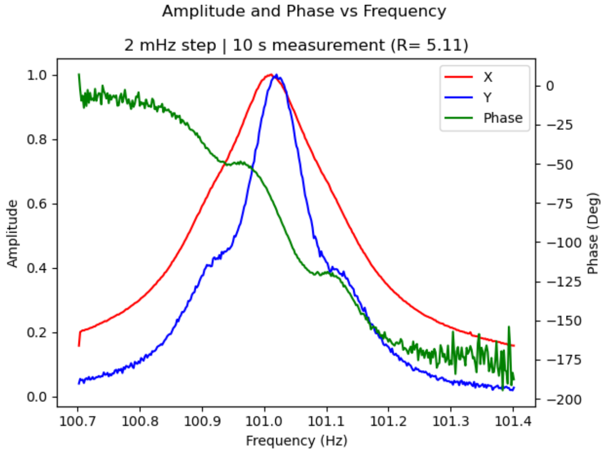

Figure 5: Normalized wire vibration amplitude measured in the two orthogonal directions while scanning the frequency. The magnetic field was aligned in order to produce an oscillation only in the direction ‘x’. The oscillation in the direction ‘y’ shows a non Lorentzian profile.

CONCLUSIONS

Improvements to the previously presented work on the measurement of a fast oscillating magnetic field with the vibrating wire technique were presented. A substantial measurement speed improvement was obtained by employing a multiple frequency excitation scheme, allowing to acquire 3 experimental points at the same time. Furthermore a feedback system was implemented allowing to keep the system on resonance. These two changes resulted in a measurement substantially more immune to drifts. A first experimental test shown how a single 20 seconds long acquisition allows to sample the magnetic field with a statistic error of roughly 0.5 %. Later the experimental setup was extended to include a second optical pickup in order to measure both transverse components of the magnetic field. Unfortunately a first test shows an unexpected result, an non Lorentzian response is observed in the direction orthogonal to the wire vibration. This could be the result of wire imperfections that induce a coupling of the two transverse vibration modes of the wire. A convincing interpretation of the measurement is still to be identified.

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