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Hybrid System for Magnetic and Acoustic Measurement

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Abstract— **In order to improve the spatial resolution of Biosusceptometry of Alternate Current (BAC), we are suggesting the coupling of a Doppler ultrasonic transducer with the BAC system. The Doppler transducer obtains information from the vibration of ferromagnetic particles immersed in a visco-elastic medium when it is excited by an alternating magnetic field. In this case, the same magnetic particles used as contrast for susceptometric measurement also will work as contrast for the Doppler measurement.**

In this work, we present the characterization of the hybrid system for susceptometric and acoustic measurements simultaneously. It was observed that the susceptometric and Doppler ultrasound signal have the same profile and maximum amplitude for frequency of magnetizing field about 200 Hz. When using ferrite particles as magnetic contrast mixed with yogurt as based material, the susceptometric and Doppler measurement have sensitivity for concentration of particles as low as 1%. The sensitivity of the Doppler is dependent of the gradient of magnetic field over the sample. In this work, the magnetic field 5 cm far from the face of the transducer was 70 µT/volts.

Keywords: *Magnetic field, Magnetic particles, Ultrasound Doppler, susceptometer*

I. INTRODUCTION

In the modern medicine, diagnostic methods are less invasive and less dangerous with purpose of greater comfort and security to the patients. For such purpose, researchers of all part of the world are looking for new technique to be used in the control of health human. For that, new methodologies making use of ultrasound, magnetic field and optics techniques are strongly explored for the clinical diagnosis and therapy.

In this work, we present a new non invasive transducer involving magnetic and ultrasound technique with potential for clinical application.

The use of biomagnetic technique in the clinical practice is new and is increasing. The first valid measurement *in vivo* was made in 1963 [1], but this field started to expand later in 1970 with the development of high sensitive magnetic transducer based on superconducting Quantum Interference Device (SQUID) and with advent of the low noise environment dedicated to perform biomagnetic measurement and more advanced systems of pickup coils [2]. The magnetic field of the human body come from biologic currents or by magnetic materials deposited into the tissues [3].

The ingestion of a food-test marked with magnetic material as contrast of biomagnetic measurement has been a practice used to study the gastrointestinal motility [4-8]. With the improvement of the sensitivity of the non superconducting biomagnetic transducer as Fluxgate, magnetoresistive and BAC system, the concentration of magnetic tracers used to prepare the magnetic meal in the gastric study has been decrease [5].

A very common configuration of BAC consists of a set of sensors that have two pairs of induction coils separated by a base line fixed; each pair of coils is used for excitation of the sample and detection of magnetization. In the gastric study, this magnetic transducer should be used to monitor magnetic tracer in the gastrointestinal tract, to determine the transit time [6], [7], [9], to evaluate gastric emptying time [8] and dynamic activity of gastric contractions in humans [10] and dogs [11].

Although the BAC has been potentially used as tool for study mechanical motion and flow of gastric tract, it has low spatial resolution [12]. With objective of improving the potential of susceptometric measurement, mainly the spatial localization of magnetized source, we developed a hybrid transducer connecting a Doppler ultrasound transducer with a BAC system.

Doppler ultrasound is sensitive for detecting vibration of particles [13]. In this case, the vibrations of ferromagnetic particles (tracers) caused by the action of the magnetic field from the excitation coils of the BAC. A major feature of vibrometer by Doppler ultrasound is that it is non-contact, so that the vibration field of the target is not disturbed. This vibrometer system is able to detect various frequencies emanating and real time measurement of dynamic displacements of target. In addition, ultrasound Doppler vibrometer offer a quantitative displacement resolution down to at least 2 µm and directional monitoring that permits discrimination against background acoustic noise[14].

II. INSTRUMENTAL APPARATUS

A. Acoustic transducer

The working principle of ultrasound is the issue of high-frequency mechanical waves in the kHz and MHz range into the region of interest of the sample and detecting the echoes generated by scattering of waves in the internal structures. In general, the intensity of diagnostic ultrasound beam is lower than 50 mW/cm². Deferments modality of imaging can be generated from mathematical processing of the echoes. For example, imaging of the displacement (M-Mode), of the

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impedance (B-Mode), of the deformation (Elastographic mode) and the velocity (Doppler Mode) of the internal structure of the tissue. The ultrasound modality used to detect the vibration of magnetic particle in this work was the Doppler. When in the presence of an alternating magnetic field, the magnetic particles vibrate and the wavelength and phase of the ultrasound echo changing.

The Doppler signal, in this case, is related with the vibration of magnetic particles (tracers), embedded in a visco-elastic means, by action of an alternating magnetic field. In this work, it was used a fetal continuous Doppler ultrasound.

The magnetic field used to exciting the magnetic particles is the same used in the measurements with the BAC.

B. Magnetic Transducer

The careful design of the coil set is very important for the correct operation of the whole susceptometer. The dimension and profile of the BAC transducer was evaluated by numerical simulations to guarantee a magnetic field intensity of 10 mT at 5 cm from the excitation coils. The simulation was done using Matlab®. The BAC consists of two identical excitation coils (1800 turn/each) and two identical sensor coils (800 turn/each) turned symmetrically in a cylindrical substrate. Details of these coils are shown in Fig. 1 and 2. The sensor coils was turned in the opposite direction to guarantee a balance transducer, i.e. the susceptometric output signal is null when no sample is present. This configuration of BAC is denominated of first order gradiometric biosusceptometer. All coils were made with copper wires on a cylindrical of PVC substrate. The sensors coils (Fig. 1) is placed inside the excitation coils (Fig. 2), so that they are symmetrically aligned. Electrical characteristics of the probe are described in table I.

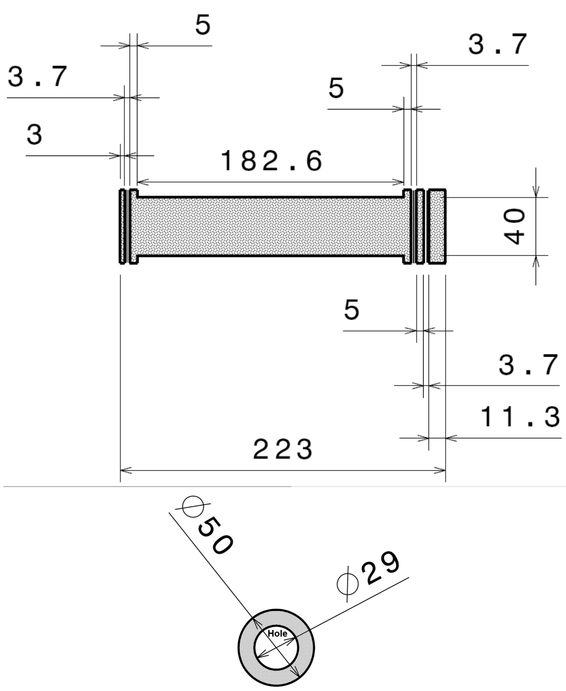

Fig. 2: Details of dimension and profile of the BAC transducer sensor coils. The metric value in this figure is in mm.

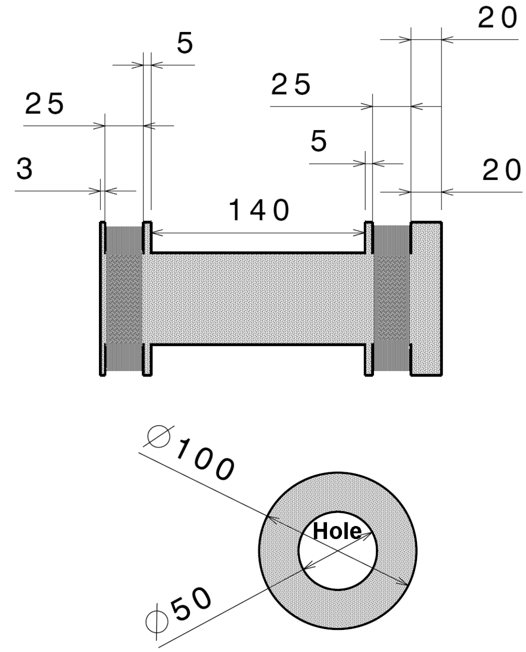

Fig. 1: Details of dimension and profile of the BAC transducer excitation coils. The metric value in this figure is in mm.

A. Hybrid System

The hybrid system consists on the cylindrical ultrasound transducer of 2.8 cm of diameter placed in the center of the BAC. This ultrasound transducer contains two piezoelectric elements (PZT5) of 2 MHz connected to a continuous Doppler ultrasound module (Sigmed® DM200). One element is used to emit the ultrasound field and the second one to pick up the ultrasound echo.

The acquisition of the both output signal from biosusceptometer and from ultrasound transducers were performed based on lock-in amplifier synchronized with the source of excitation. The signal generator and lock-in were connected to a computer by a GPIB interface and controlled with dedicated software developed in a LabView® environment. The performance of this hybrid transducer was characterized using in vitro measurements with samples made with ferrite particles smaller than 38 µm immersed into the viscous-elastic fluid.

III. EXPERIMENTAL RESULTS

The susceptometric and Doppler measurement were performed individually for the same sample and the same magnetizing field.

This sample consists on particles of ferrite mixed with 80 ml of yogurt in a weight concentration of particles raging from 0% to 5%. The magnetizing coil was energized with an amplified sinusoidal current with frequency ranging from 100 Hz to 700 Hz with power of 20 Watts. The hybrid transducer was placed close to the sample keeping the ultrasound transducer in contact with the sample to guarantee the acoustic coupling. The Doppler signal was acquired with the lock-in amplifier configured in the second harmonic frequency because magnetic particles vibrate with double of magnetizing frequency [13]. Figure 3 shows the profile of the signal obtained for 5 different concentrations of magnetic particles.

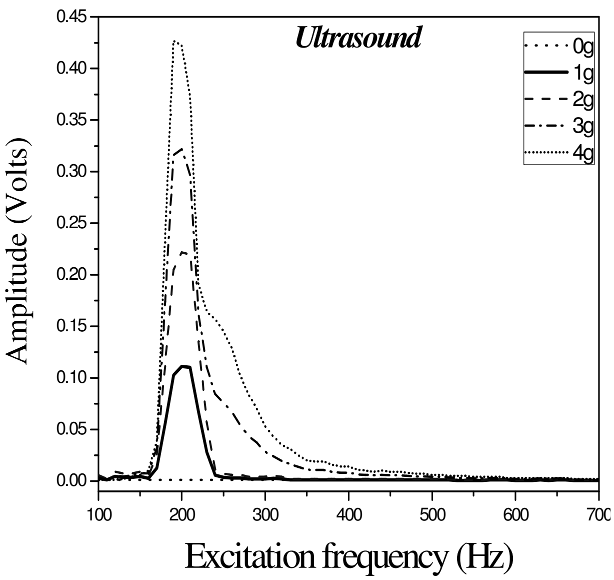

Fig. 3: Doppler signal versus frequency of magnetizing field obtained for 5 samples with different concentration of magnetic particles (ferrite)

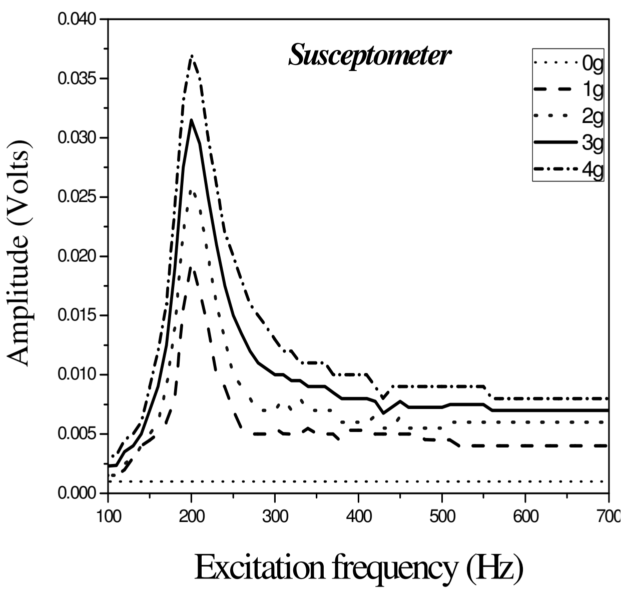

Fig. 5: Susceptometric signal versus frequency of magnetizing field obtained for 5 samples with different concentration of magnetic particles (ferrite).

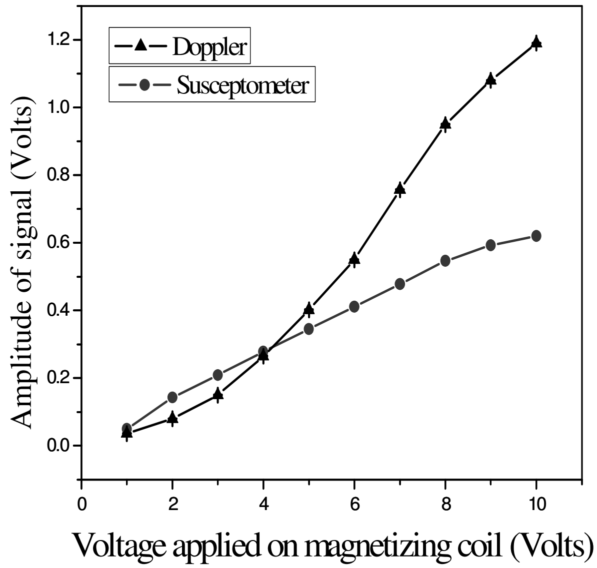

Fig. 4: Response of Susceptometer and of Doppler transducer as function of the level of voltage applied on magnetizing coil of the susceptometer.

The susceptometric signal was acquired with the lock-in synchronized in the same frequency of excitation. Figure 4 shows the profile of the susceptometric measurement.

The intensity of the magnetizing field at 5 cm far from the face of the transducer was about 70 μT/Volts. During these measurements, the magnetizing coil of the susceptometer was energized with 30 Volts.

From figure 5 we observed that both susceptometric and Doppler ultrasound output signal have the same profile of amplitude versus frequency of magnetic field with maximum amplitude about 200 Hz.

Figure 5 shows the profile of the susceptometric and Doppler output signal as function of the voltage applied on the magnetizing coil of the susceptometer.

The output signal from the BAC was amplified in 20 dB to keep in the same level of output signal from the ultrasound transducer.

IV. DISCUSSION

This work describes a new transducer dedicated to taking susceptometric and Doppler ultrasound measurement simultaneously of a sample marked with ferromagnetic particles. Both magnetic and acoustic techniques present high sensitivity and accuracy and have the same profile of response versus the frequencies of magnetization of the sample. The resonance frequency of the output signal for both techniques was the same and about 200 Hz. It was observed that this resonance frequency is dependent of the kind of ferromagnetic particle.

As physical principle of working of the susceptometer is different from the ultrasound, one measurement doesn't interfere in the other when they are work simultaneously.

Another fact observed is the linearity of output signal with concentration of ferromagnetic particles for both techniques.

The maximum amplitude of Doppler ultrasound and susceptometer outputs for were linear with the ferromagnetic particles concentration mixed the viscoelastic fluid.

The relative deviation on reproducibility of the Doppler measurement was large than for the susceptometric measurement because the first one is more dependent with the position of the transducer relative to the distribution of the particles into the viscous-elastic fluid.

V. CONCLUSION

In conclusion, we shown the feasibility of use Doppler ultrasound to detect the vibration of ferromagnetic particles used as magnetic contrast for susceptometric measurement. This ultrasound measurement is an important technique to identifier the localization and distribution of the contrast marked with magnetized particles. For example, in the study of the motility of gastrointestinal tract by susceptometric measurement, the Doppler signal will help to localize the distribution of the magnetic tracers. The BAC is useful to get mechanical information of the gastric system as frequency of peristaltic motion and time of empting and the ultrasound measurement will be useful to localize the distribution of the magnetized contrast into the segment of gastrointestinal tract and help to place the BAC transducer in the external region of interest.

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