Abstract

Variations in electric impedance curves of piezoelectric transducers occur under influence of mechanical load, temperature, electric excitation, among others. Electronic circuits for driving these transducers should correct the tune to maintain the performance of the transducer. Considering the changes at resonance, we have developed a circuit for a laboratory bench that performs two functions. The first, working on low power, by swapping frequencies around resonance, allows to the user define electric impedance and frequency operation that intend to apply in the experiment. The operation of this circuit is based on detection of magnitude of current in the transducer. A microcontroller and Labview are used to obtain the results. In the second, while under high power operation, deviations from original impedance are corrected by using a feedback network that evaluates amplitude of impedance. In this circuit, a class D MOSFET amplifier is used for exciting the transducer. Also, a microcontroller system controls the feedback network. Experiments with variation of mechanical loads have shown the effectiveness of the system.

Keywords: microcontroller, Labview, acoustic load

1. Introduction

Piezoelectric transducers that work under high power are largely used in medical instruments for cutting, ablation and dissection of biological tissues. Also, these transducers are used in industrial applications, such as cleaning, cutting, soldering, among others. These transducers are excited by electronic circuits that provide voltages at or near their resonances. However, variations in the resonance can occur when the transducer is in operation. Several reasons are responsible for these variations, such as increasing of temperature and altering of the acoustical loads. The consequence of the deviation of resonance is the loss of performance of the transducer. Therefore, the
electronic system driving the transducer should track the resonance automatically aiming to keep the stable the conditions of operation.

The classic principle of the operation of the most systems for tracking the resonance is based on a phase-locked loop (PLL). Usually the transducers are tuned at resonance which the phase is zero. Electronic circuits are able to detect a phase difference and control the frequency of operation with a voltage-controlled oscillator (VCO). The electronics used in these systems are complex and sensible due to fast variations of frequency that the transducers can show. In general, this complexity becomes the systems limited for the operation in restricted ranges. Ishikawa (Ishekawa et al. 1997) presents a system for excitation and frequency control for ultrasonics at 3 MHz. Ramos-Fernandez (Ramos-Fernandez et al. 1985) shows this technique using analog circuits for tracking the resonance of high power piezoelectric transducers. Mortimer (Mortimer et al. 2011) have based on maximum admittance as reference to search the resonance. Kuang (Kuang et al. 2014) have developed a sophisticated system based on LabView graphical programming software that allows control of the resonance in a large range of frequencies.

In this work, we present a simple system that performs measurements of impedance on low power and automatic correction of operation frequency on high power in piezoelectric transducer usually employed in high power applications. The whole system is built with discreet components guaranteeing a low cost for the implementation. The frequency range achieved by the system is from 4 to 43 kHz. The system is based on voltage and current peak detection. Levels of current are acquired using a current sensor performed on the frequency range of interest. Frequency range is determined by a digital potentiometer that tunes a monolithic function generator. The system is controlled by a microcontroller. The microcontroller communicates with a personal computer where results are stored and showed in LabView interface.

The whole system consists of two circuits. The first circuit is for impedance selection. This circuit is typically a simple impedometer that determines the amplitude of the impedance based on measures of voltage and current in the transducer working on low power. Some techniques for the impedance determination have been reported in the literature (Baptista et al. 2009, Doerner et al. 2007, Schmid et al. 1990). Section 2 describes the system for impedance selection.

The second circuit has a similar operation principle of the first one. However, the current is sampled and compared with a reference value early chosen during the impedance selection process. A microcontroller system evaluates the comparison and feedbacks an oscillator that supplies the transducer promoting the frequency correction. Details for the operation of this circuit are found in Section 3. The variations of the operation frequency used to test this system are produced by insertion of different acoustic loads.

2. Impedance selection

The principle for the determination of impedance of the transducers is based on measures of voltage and current in the transducer. A monolithic function generator (XR2206 – Exar Co.) works as a source of sinusoidal voltage. The voltage is amplified (Amp1) and applied to the transducer ($Z_L$). The frequency of this voltage is controlled by a digital potentiometer inserted in the tune network of the function generator IC. The current in the transducer is captured by a current sensor (LA25NP-SP14 – LEM Co.). The current is transformed in a proportional voltage in the sensor output. Both voltages, from XR2206 and current sensor (amplified by Amp2), have their maximum value detected in two peak detectors circuits and sent to the analog digital converter of a microcontroller (PIC18F4550 - Microchip). Software, stored in the microcontroller, controls the digital potentiometer with Serial Peripheral Interface (SPI) communication using 10 bit-length words. Acquisitions of maxima values of voltage and current are made for each frequency defined by electric resistance of the potentiometer. In addition, the users can define the frequency sweeping range.

The microcontroller manages the process and transfer results to LabView (National). This software makes a set of operations for calculation of impedance, calibration and display using a interface with the users. The calibration of the system is necessary due two reasons: the conversion of values from the sensing process when current is converted into voltage and, the compensation of the effects produced by inductive reactance present in the sensor coil.

Finally, after the process, the operation frequency can be chosen using either a data file generated by LabView or observing the graphic of impedance modulus as function of frequency.
3. Impedance controller

The system for the frequency control is starts to work using the frequency previously determined and chosen in the early step. The values of frequency and current are reference for the impedance control block operation. In this step the transducer is supplied by a full bridge of MOSFETs, such as suggested by Agbossou (Agbossou et al. 2000). The central branch of this bridge is constituted by two 2nd order Butterworth filters, the transducer and the current sensor (LA25NP-SP14 – LEM Co.). The filters attenuate the superior harmonics of square signal obtained from the switching of MOSFETs. The voltage supplied by high voltage source is constant. The current that flows by the transducer is converted in a proportional voltage in the current sensor. This voltage is sent to an analog digital converter (ADC) in a microcontroller PIC18F4550. Software stored in the microcontroller reads 200 values of voltage from the ADC and selects the maximum one. When the physical characteristics of the transducer change, the current is altered and the software stored in this microcontroller runs an algorithm for searching a new frequency. This new frequency is successfully generated through of resistance variations of the tune network of the oscillator (IRS2453D - International Rectifier) of the MOSFETs bridge. The behavior of the voltage between the terminals of the digital potentiometer presents noises that cause interferences in IRS2453D. For this reason, an optical coupling has been used to guarantee the perfect operation of the oscillator and better sensitivity in the control. The block diagram of the impedance controller is shown in Figure 2.
4. Methodology

Both circuits were tested. The procedure used for testing of the circuit for impedance selection consists of the comparison of the curve obtained from the data file generated in Labview with curves got with a phasorial impedometer HP4294A (Agilent).

A piezoelectric transducer used for high power applications has been selected to test the system and shown in Figure 3. It has the following characteristics: resonance frequency is 28.48 kHz, anti-resonance frequency is 30.77 kHz, electromechanical coupling factor is 0.38 and capacitance at 800 Hz is 3.60 nF.

![Piezoelectric transducer](image)

**Fig. 3.** Piezoelectric transducer (Eleceram Co., Taiwan) used in the tests.

A frequency of 29.35 kHz has chosen to be the initial operation of this transducer from its impedance curve. Thus, the operation frequency is between the resonance and the anti-resonance. A cylinder of light plastic material has been fixed in the larger ending (inferior ending in Fig. 3) of the transducer to be used as storing of water. Water is used as acoustic load. For different heights of water the curve of impedance is determined. This procedure has repeated for 5 volumes of water: 0 ml, 30 ml, 60 ml, 90 ml and 120 ml.

The high voltage source is set with a voltage of 30 V. The microcontroller is set to make the oscillator works at chosen frequency. Firstly, the plastic cylinder is empty. The operation frequency of the signal generated by impedance controller is monitored. The current supplied by power source is measured. A volume of 30 ml of water is poured in the cylinder after 1 min and the new frequency is observed to evaluate if the system has the correct frequency and to maintain the values of current supplied by power source.

5. Results and Discussions

Fig. 4 shows a comparison of two typical impedance curves of a piezoelectric transducer obtained with our system and HP4294A.

![Impedance graph](image)

**Fig. 4.** Impedance as a function of frequency of a piezoelectric transducer. Results obtained with HP4294A (black line) and our system (blue line).
Fig. 4 shows a good fitting of the curves. However, our system is limited to determine impedance values from 100Ω to 10 kΩ. Devices with impedances that exceed these limits cause saturation in the system. The maximum range of frequencies for operation of the system is restricted between 4 and 43 kHz.

The results obtained are shown in Figures 5 and 6. Fig. 5 shows a set of curves of impedance of the transducer obtained using HP4294A. Each line trace corresponds to a water volume according to the legend.

![Fig. 5. Impedance as function of frequency for different water volumes.](image)

Fig. 5. Impedance as function of frequency for different water volumes.

Fig. 6 shows a zoom containing the interest range of frequency from Fig. 5 and the indications of the frequency changing. In the path 1 (blue line), we can see the first frequency variation from 29.35 kHz to 28.44 kHz caused by addition of 30 ml of water as acoustical load. The next paths, denoted by 2 (red line), 3 (green line) and 4 (black line), represents the other variations due to more addition of 30 ml of water each one.

The resolution of the control of the steps of frequency is of 30 Hz/bit. The range of frequency achieved by the system is limited in 1024 values.

6. Conclusion

The system developed in this work represents the first experimental prototype of a driver with control of frequency. Other improvements are still necessary for a better and reliable operation. The improvements concentrate
on the upgrading of the software that controls the system aiming a quicker and smarter searching of operation frequency. The system has a low cost and can be used in applications out of the laboratories. The electronics of the system should be improved to get measurements of larger ranges of impedance and frequency and, as consequence, diversify the types of transducer that can be measured and controlled.

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**References**


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