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Power characterization of ultrasonic piezoelectric transducers

Enrique Riera, Juan A. Gallego-Juárez, Alfonso Blanco[1], V.M. Acosta

Power Ultrasonics Group, Instituto de Acústica, CSIC, Serrano 144, E-28006 Madrid, Spain, eriera@ia.cetef.csic.es
Instituto de Física Aplicada, CSIC, Spain

Abstract: The development and application of power ultrasonic transducers implies a proper characterization of their behaviour under power operation. As well known, problems such as heating, nonlinear interactions of vibrating modes, fatigue, etc., are specifically produced at high excitation levels. To study the different transducer behaviour at low and high-power conditions a specific system has been developed and tested. Such a system is based on a combination of the electrical excitation with electrical, vibrational and acoustical measurements. Special hardware and software has been developed for the excitation, control and signal recording and processing in real time.

The characterization system allows the control and monitoring of the main parameters of the transducer: a) voltage and current sampled on the out-port-side of the impedance matching unit; b) vibration amplitude and phase sampled by a laser scanning vibrometer; c) temperature sampled by thermocouple and infrared probe and, d) acoustic pressure sampled by microphone or hydrophone.

Results clearly show the benefits of the developed tool in the re-design and optimization of power ultrasonic transducers for industrial processing.

Key words: Power ultrasound, characterization of transducers, ultrasonic transducers

A. Introduction

High-power ultrasonic transducers are used in a great variety of devices for cutting [1], [2], welding [3], drilling [4], drying [5], [6], washing [5], defoaming [7], extraction [8], atomization [9], comminution processes [10] and agglomeration [7] among others. Driving piezoelectrics at high power levels introduces nonlinear interactions of vibrating modes and thermal effects that may produce instabilities in the system. Therefore, the performance of the transducer may be strongly limited by nonlinearities [11], [12], fatigue [13], etc. At low power regime, piezoelectrics are typically linear. Nevertheless, when the same materials are driven at high power levels the conditions can change considerably. Consequently, the development and application of power ultrasonic transducers implies a proper characterization of their behaviour under power operation.

To study the different transducer behaviour at low and high-power conditions, an experimental system has been developed and tested. Such a system is based on a combination of the electrical excitation with electrical, vibrational, acoustical and thermal measurements. Specific hardware and software has been developed and applied for the excitation, control and signal recording and processing in real time. In this paper we present the characterization system that allows the main parameters of the transducer to be controlled and monitored as well as the identification of its resonance frequency. Results clearly show the benefits of the developed tool in the design and optimization of power ultrasonic transducers for industrial processing.

B. High-power characterization of ultrasonic transducers

B.1. Experimental set-up

A block diagram and a picture of the driving and characterization system are shown in Fig.1a and Fig.1b, respectively. The system consists of the following parts: power ultrasonic transducer, impedance matching unit, power generator, data acquisition unit, computer, and a set of different probes. The system allows the simultaneous determination of: a) voltage (V) and current (I) sampled on the output of the impedance matching unit; b) vibration amplitude (ξ) and phase (θ) sampled by a laser scanning vibrometer; c) temperature (T) sampled by a thermocouple or/and an infrared probe and, d) acoustic pressure (Pa) measured by a microphone (M) or a hydrophone (H) depending on the fluid media.

The ultrasonic devices to be tested are basically power piezoelectric transducers for use in fluids (air or water). They are generally driven by a power generator and an impedance matching unit. The impedance matching unit allows the maximum energy transfer between the electronics and the transducer. This unit is prepared to provide a sample of voltage and current of the driving signal of the transducer. Such sampled signals are used to control frequency and to elaborate different calculations.

The power generator consists of two main parts: a broad-band power amplifier and a signal generator. The signal generator has three different basic configurations:

a) Function/Arbitrary waveform generator

b) Digital/Analog output from the data acquisition unit

c) Resonance Frequency Control Unit

First configuration is used to generate a signal according to the parameters provided by the computer. It allows frequency swept with different waveforms, high stability, accuracy and frequency resolution at different amplitudes. The signal distortion may be controlled. Second configuration is used to compute and generate an arbitrary noise band. In this way it will be possible to find the frequency response of the different modes of the transducer. Finally, the third configuration is used to drive the transducer always at resonance by keeping in phase the voltage (V) and the current (I) signals, according to the principle that piezoelectric transducers provide purely resistive electric impedance at resonance, once the interelectrode capacitance is compensated. The unit is also able to keep constant the power or the driving voltage applied to the transducer.

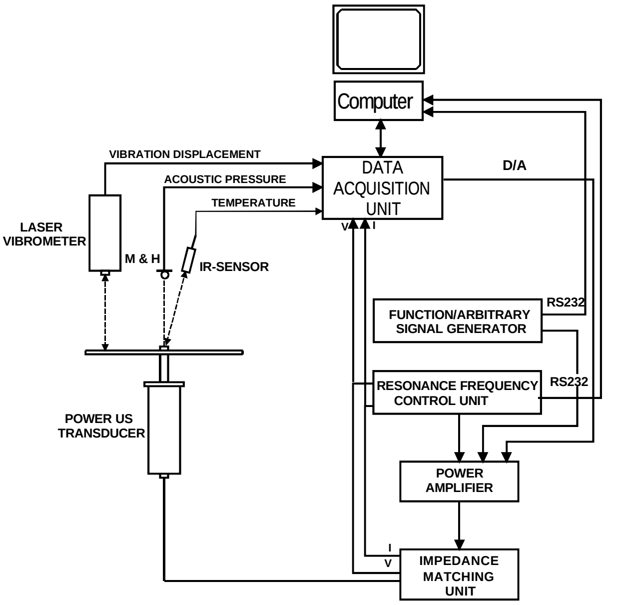

Fig.1a. Scheme of the experimental set-up for power characterization of ultrasonic transducers

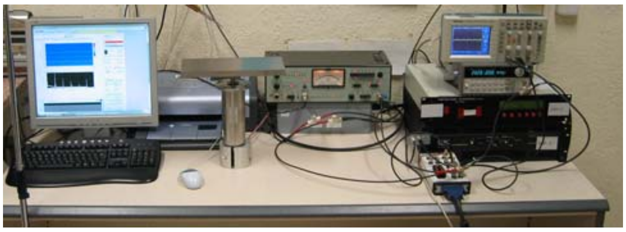

Fig.1b. Experimental set-up for power characterization of ultrasonic transducers

The data acquisition unit receives the signals from the set of different probes and digitizes them for processing. The signals are captured with their corresponding phases. This unit is able to produce signals as previously mentioned. This unit is complemented by a PCI-card A/D/A located inside the computer. The computer is in charge of signal processing, data storage and post-processing of the data generated during the different tests. It also controls the function/arbitrary signal generator and the resonance frequency control unit.

Specific software based on LabView code has been developed for driving and characterizing the transducer behaviour at high-power operation.

B.2. Characterization procedure

During the tests, a collection of signals is generated. Such signals are taken from excitation (V, I) and from the probes (ξ, θ, Pa, T). Signals are processed in both time and frequency domains. Different kind of analysis can be applied and in all cases the result data are stored. The first general analysis for the transducer characterization consists of a frequency swept and in measuring the RMS values of the V and I signals. In such a way the impedance or the admittance for any frequency may be obtained. To reach a whole knowledge of the transducer behaviour different tools may be used to get the impedance or admittance values under different conditions: i) single point, both frequency and voltage are fixed; ii) linear-swept, constant voltage in a certain frequency range, and iii) multiple-swept, both frequency and voltage are alternatively varied. In addition, the frequency swept may be done in two directions, following increasing or decreasing frequencies to study the transducer hysteretic (nonlinear) behaviour. The results may be shown as a single value, as a line graphic and as a surface envelop. In all cases the excitation signals are applied at different amplitude levels.

In the time-domain analysis, two different configurations can be applied: function/arbitrary signal generator or resonance frequency control. Both are used to see the transducer performance and its time evolution. A waveform graphic page displays the signals (V, I, ξ, Pa or T) in the time domain together with their RMS-values. A set of displays shows the ratio of the RMS-values of the different signals to evaluate the nonlinearity of the ultrasonic transducer. Another set of tools have been developed to analyze the actual power, phase, impedance and total harmonic distortion of the signals. The power applied to the transducer is always calculated by averaging a certain number of sampled values along the total acquisition time.

For the analysis in the frequency domain, three main forms of spectrum are used: FFT-amplitude and phase; power spectrum (or power spectrum density) and the time spectrum evolution. The number of samples, sampling frequency and spectral resolution is established. Actual, averaged and cumulative spectra may be visualized. Last option is useful for the detection of transient events.

Power spectrum is useful for the evaluation of the energy content of the different frequency modes. There is also the possibility of making a zoom of a zone of the spectrum by means of a special algorithm. The time spectrum evolution shows a reduced set of power spectra to observe the temporal evolution of the spectral content of the signals in a chart-graphic form with pseudo-colours. This analysis can also be shown with “water-falls”. This tool is adequate to see the interaction of modes in the transducer.

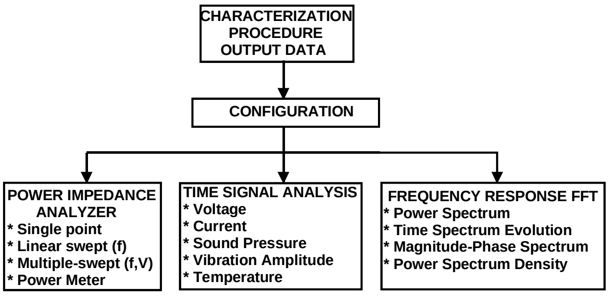

Fig.2. Developed tools for the power characterization procedure

Fig.2 shows the block diagram of the characterization procedure that summarizes the three sets of developed tools used in this work.

C. Results and discussion

An example of the application of the developed procedure is presented below. A rectangular-plate transducer made of titanium was chosen. The transducer was constructed to be used for ultrasonic drying of porous materials in direct contact. The rectangular plate radiator is driven at its centre by a piezoelectric vibrator and its profile is grooved in the back side to get as much as possible uniform vibration amplitude.

At low power, a HP-4194A Impedance Analyzer was used to analyze the admittance response of the transducer in a frequency range (20 – 22 kHz) around the operating frequency (20281Hz). Two vibration modes were detected, one at 20281 Hz and other at 21431 Hz. First frequency corresponds to a vibration mode with eight nodal lines parallel to the shorter side of the plate (operating frequency), and the second one to a mode with four nodal lines mode parallel to the longer side. The same modes were detected at high excitation (See Fig. 3).

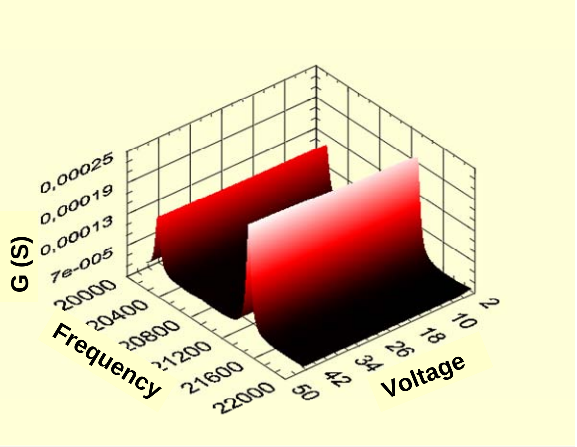

Fig.3. Conductance of the transducer versus frequency (20-22 kHz) and excitation voltage (1-50V)

The difference in frequency between both modes at low and high-excitation was almost constant and of about 1150 Hz. The transducer has an estimated power capacity of 200W. Table I summarises the electrical characteristics of the transducer measured with the commercial impedance analyzer.

Table 1. Characteristics of the transducer

	F (Hz)	Bw(Hz)	Z (Ω)
In air	20281	4,2	342
In contact with porous materials	20277	6,8	565

Fig. 4 shows the resonance curve obtained at high-power operation (300V-100W) when its surface is in direct contact with porous materials. In this case a waveform generator in accordance with previously mentioned configuration a) was used. During drying process the transducer response was stable and almost constant. In Figure 5 a multiple-swept carried-out in the 20 -20,5 kHz frequency range at voltages from 1 up to 300V is presented. It is apparent from the 2D-surface envelop that the transducer resonance frequency does not suffer a relevant shift to lower frequencies when the excitation voltage increases.

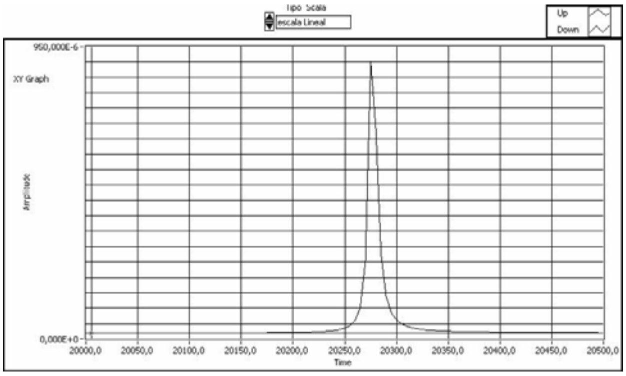

Fig.4. Conductance of the transducer versus frequency at 300V

Fig. 6a and 6b show the acoustic pressure response generated by the transducer driven at 300V. Signals in both time and frequency domains are shown. Distortion appears on the current or vibration velocity and acoustic pressure waveforms due to high voltage.

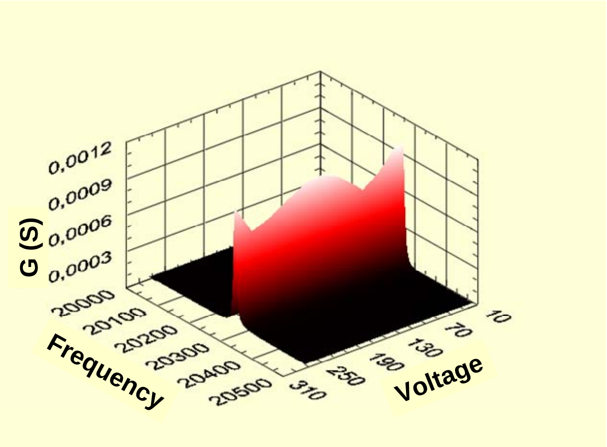

Fig.5. Conductance of the transducer versus frequency and excitation voltage

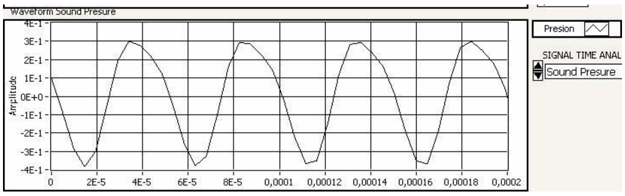

Fig.6a. Time distortion on the experimental pressure (applied voltage 300V)

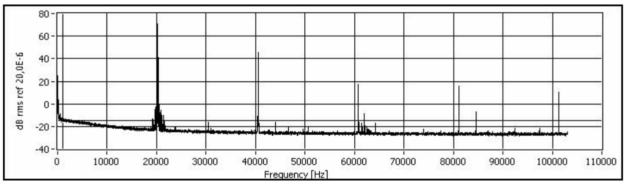

Fig.6b. Power spectrum of the acoustic pressure (applied voltage 300V)

The overtone amplitudes increase with the applied voltage as expected according to the nonlinear behaviour of piezoelectric transducers. The time evolution of the spectral content of the acoustic pressure signal is also shown in Fig. 7 in which overtones are seen as red lines in the frequency-time presentation.

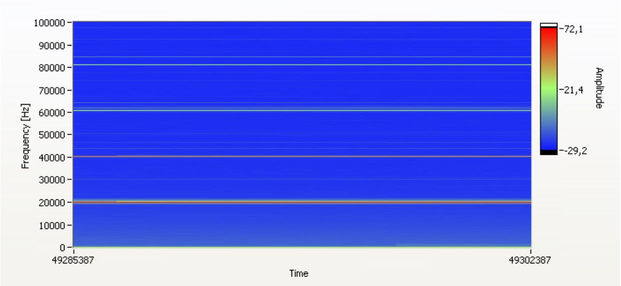

Fig.7. Time spectrum evolution of the acoustic pressure at 300V

No change was detected in the transducer behaviour during several working hours of continuous operation. Therefore, the power characterization of this transducer with the developed hardware and software tools validates its behaviour for industrial application. Finally, no heating was detected with IR probe during the power characterization of the transducer.

D. Conclusions

An experimental procedure is presented to characterize ultrasonic transducers under high-power operation in real time. The procedure allows the full characterization of the transducers by electrical, vibrational and thermal parameters and phase under high drive levels. In addition because of direct access to the waveform of above signals Fourier techniques were applied to determine the transducer response as a function of power applied and operation time.

It is apparent from the tools developed and results presented that the experimental procedure is useful for studying transducer stability and response during long periods of time under high-power operation.

Although not presented here the software also allows the determination of the hysteretic (nonlinear) behaviour of piezoelectric transducers. In summary, a powerful and flexible tool needed for the development of ultrasonic devices for industrial processing.

E. Aknowledgements

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