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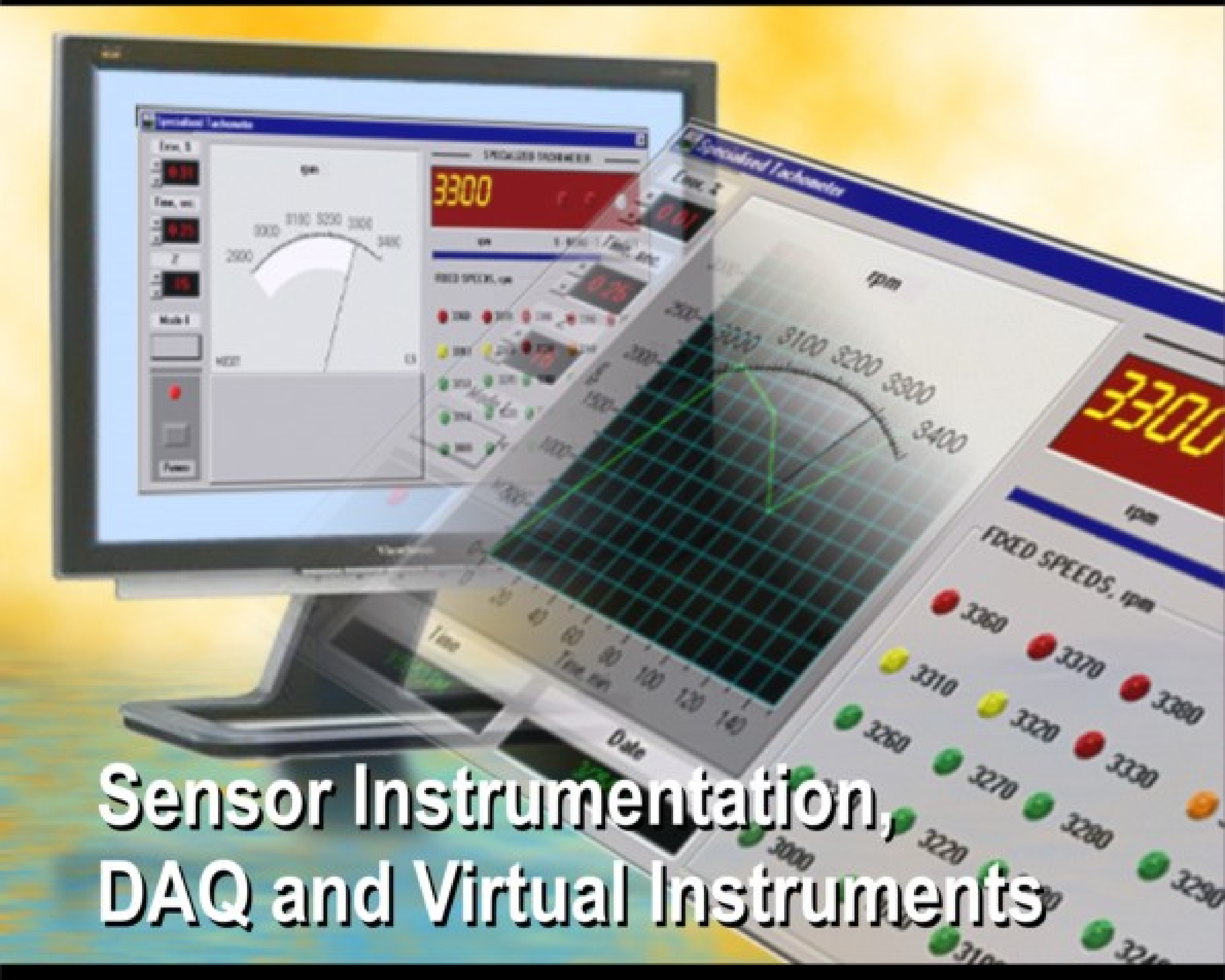

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Characterization of High Voltage Single Disk-Type Piezoelectric Transducers as a Function of Load Resistance

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Abstract: Two designs of disk-type piezoelectric transducers have been characterized as a function of load resistance, at around their center frequencies. The first transducer was fabricated using BM400 material while the second transducer was fabricated using APCI-880 material. These transducers were mounted inside Teflon insulation using special screws indicated by a and *b*. The input voltage was then applied between ring and bottom electrode using special screws noted as 1 and 3. The output voltages from dot and bottom electrodes of these transducers were terminated with load resistance, and measured from screw 2 and 3. The voltage transformations observed from the second transducer was higher as compared to that obtained in the first transducer, because, the mechanical quality factor of APC-880 is higher than that of BM400 material. The final results of this investigation gave the optimal load resistance of each transducer when operated below and above resonant frequency.

Keywords: Load Resistance, Piezoelectric Transducers, Piezoelectric Transformers, BM 400, APC-880, Single Disk-Type, Resonance, Center Frequency, etc.

1. Introduction

A high voltage piezoelectric transducer, or piezoelectric transformer, is a passive electrical energy transfer device that acts like a transducer employing piezoelectric properties to achieve the transformation of voltage, or current, in the form of impedance or admittance. This device is usually a three terminal solid-state based on piezoelectric material. The design of any high voltage piezoelectric transducer may vary due to the mode of vibration accounting to the poling effects of the piezoelectric material. Thus, the poling of piezoelectric material is an important factor in achieving the voltage transformation. The fundamental principle of characterizing a single disk-type high voltage piezoelectric transducer involves an applied electrical signal at resonance, to the ring electrode, and full-face bottom electrode [1], such that a strong mechanical vibration is generated due to the converse piezoelectric effect, and these vibrations are imparted to the other side of the same single disk, causing attenuated or amplified signal voltage measured from dot electrode and full-face bottom electrode.

Due to some business issues no more emphasis discussed on elemental constituents, doping concentration, and composition of materials used in fabrication of these single disk-type piezoelectric transducers. In this study, the first transducer was designed and ordered from Sensor Technology, a piezoelectric manufacturer in Canada; the device was then made from BM400 material [2]. The second transducer or disk 2 had the same dimensional parameters same as the first transducer or disk1, the difference is that the second transducer was made from APC-880 material, and fabricated from American Piezoelectric Ceramic International (APCI) as per customized design [3]. These disk-type piezoelectric transducers were then mounted inside Teflon insulation and characterized as a function of load resistance. The usefulness of this approach has helped in predicting the performance of piezoelectric transducers as a function of load resistance, of the same devices, having different elemental constituents as well as different mechanical quality factors, and coupling coefficients.

2. Theory

The invention pertaining to the generation of electrical currents or voltage in the form of impedance or admittance from a piezoelectric crystal was noted by Nicolson in early nineteen thirties [4]. Thereafter, Rosen [5-7] illustrated the first device having the highest voltage transformation using two pieces of piezoelectric materials by forming a single junction device. In nineteen fifty nine, Broadhead *et al* proposed the first type of piezoelectric device from a single-element crystal which had varied input and output electrode areas [8]. However; it was difficult to use single element of piezoelectric crystal as high voltage generators due to some limitations such as low mechanical quality factor and low dielectric stability. Because of the recent progress and developments of advanced electronic PZT ceramics, with improved physical, chemical, and piezoelectric properties, it is possible to be tailored to specific applications for high voltage generation [9, 10]. In nineteen seventy-three, Berlincourt proposed a single disk-type high voltage piezoelectric device using PZT ceramics; his design had one poling directions in the same single disk, he called his device a unipoled disk-type piezoelectric transformer [11-13].

This high voltage piezoelectric transducer has both the input and output terminals on the same face of a single disk, the input and output terminals were separated by non-coated electrode gap on the surface of the disk [14]. After Berlincourt has proposed single element high voltage piezoelectric transducer, Laoratanakul *et al*, and Prya, designed and characterized a single disk-type, which showed high voltage transformation as a function of load resistance [15, 16]. Initially, piezoelectric transducer technology has suffered from serious instabilities and device failures related to immature materials fabrication, and transducer designs. These problems are highly influenced by different techniques of PZT preparation and fabrication process. Since the technology of processing and fabricating piezoelectric single disk-type transducer is available from different manufactures, therefore, it is cheaper and easier to characterize the commercially available piezoelectric material, in order to understand the role of different piezoelectric materials used to fabricate the same device.

3. Design of Single Disk-Type Piezoelectric Transducers

Two types of single disk-type piezoelectric transducers, having the same parameters, were designed and ordered from the manufacturer as per customized design as shown in Figure 1 (a) and Figure 1 (b). Disk 1 was fabricated using BM400 material and disk 2 was fabricated using APC-880 material. The parameters of these disk-type transducers are depicted in Table 1. The k33 in the table represents the coupling coefficient along the thickness, and Qm represents the mechanical quality factor. Y is the diameter of dot electrode of each disk and Z is the diameter that represents the full-face bottom electrode. The first disk was procured from Sensor Tech. (Canada), and the second disk was ordered from APCI, a piezoelectric manufacturer from USA.

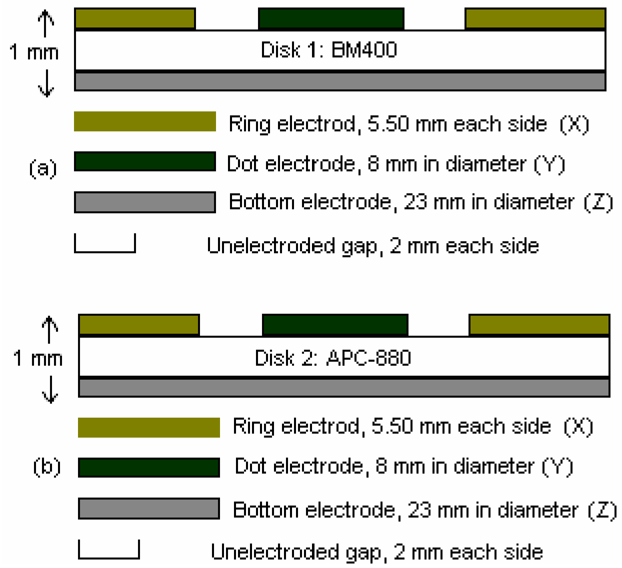

Fig. 1. The side view showing geometry of the single disk-type piezoelectric transducers. Gold electrode was placed to the bottom and upper faces of each disk having either BM 400 material for Disk 1, or APC-880 material for disk 2.

Table 1. Parameters of single disk-type piezoelectric transducers showing the mechanical quality factors (Qm) and coupling coefficients of each disk.

Disk	**Material**	**Dimensions (mm)**			**K33**	**Qm**	**Tc °C**
		Y	Z	Thickness			
1	BM400	8	23	1.0	0.68	500	350
2	APC-880	8	23	1.0	0.63	1000	310

4. Mounting of Disk-Type Piezoelectric Transducers

The disks were inserted in between Teflon insulation using two screws labeled as *a*, and *b*. These screws were used to support the top and bottom Teflon insulations as shown in Figure 2. The screw number 1 shows an input electrode terminal attached to the ringside of the disk, this screw passes through the upper Teflon insulation, to make a contact with ringside of gold electrode coated on the surface of the disk. Screw number 2 was used as output terminal and connected to the dot side gold electrode through the center of the upper Teflon insulation. The third screw was inserted to the center of the bottom full-face electrode or screw number 3 via bottom Teflon insulation; this screw was used as ground electrode for both input and output screw terminals.

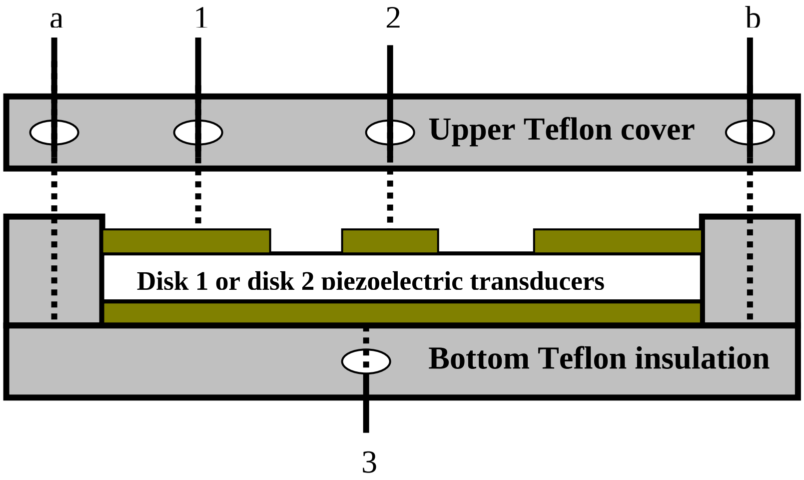

Fig. 2. The side view showing the mounting of single disk-type piezoelectric transducers inside the Teflon insulations with screw terminals for input and output voltages through upper and bottom Teflon insulations.

The picture of the disk-type piezoelectric transducers is depicted in Figure 3. The input voltage is applied across ring and bottom full-face electrode that is not seen in the picture, the output voltage is measured from the dot or center electrode with the bottom full-face electrode. The two screws shown on the right hand side on the Teflon insulation are used as input or output terminals when connected with common screw terminal.

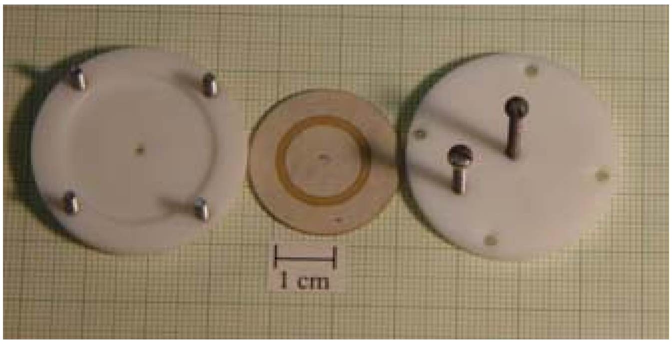

Fig. 3. A picture showing the mounting and geometry of single disk-type piezoelectric transducers as viewed from topside, showing the ring and the dot electrode and screw terminals. The bottom full-face electrode is not seen from the picture.

The left screw on the right Teflon insulation (see Figure 3) is attached to the ringside of the disk, this screw passes through the upper Teflon insulation, to make a contact with ringside of gold electrode coated on the surface of the disk. The center screw is used as output terminal and connected to the dot side gold electrode through the center of the upper Teflon insulation. The third screw was inserted to the center of the bottom full-face electrode via bottom Teflon insulation; this screw was used as ground electrode for both input and output screw terminals.

5. Experimental Set-up

The experimental set-up in Figures 4 is showing the method of measuring the input signal voltage and frequencies applied from signal generator to the ring electrode of the disks, the output voltages from the disks are measured directly from the dot electrode using Pico scope; a computer based oscilloscope. The changes of the output voltage and frequencies from the signal generator were monitored simultaneously as the load resistance is changed to the output terminals of the disk-type transducers. The results of the output voltage as a function of load resistance and frequencies are recorded simultaneously using digital multimeter (DMM) and Pico scope.

The voltage differential probe was added to the experimental set-up in order to be able to measure higher output voltage from the device under test; disk 1 or disk 2, because the Pico scope has limitations, and it cannot measure more than 100 V. The differential probe (ADF25A (MI053) X10 / X100) has two channels, in which channel 1 is used to record the input signal voltage to the device while channel 2 is used for measuring the output signal voltage from the device. The columns displaying input voltage, frequencies, and output voltages can be seen automatically from the computer screen; showing both the spectrum of input and output voltages. For calibration purpose, the DMM was used to measure voltage transformation when the device was terminated with different load resistance.

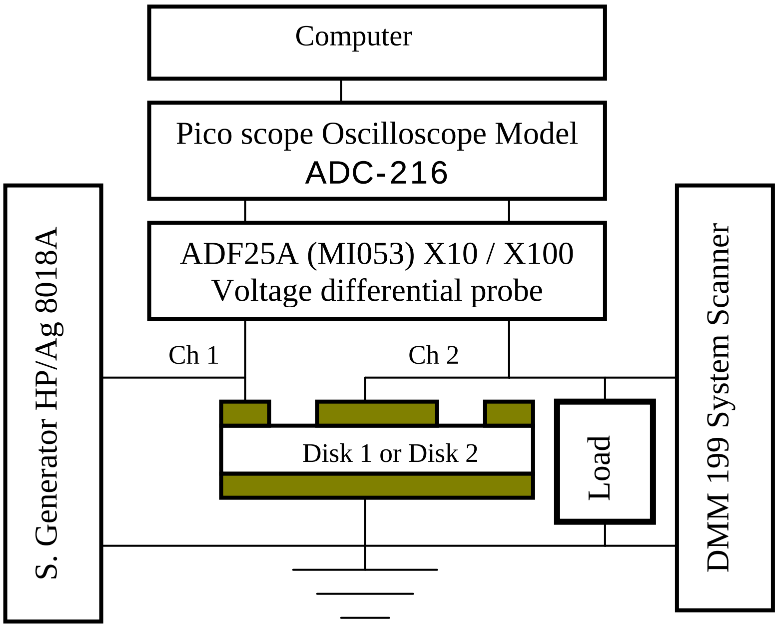

Fig. 4. The experimental set-up for measuring the input and output voltages of disk-type Piezoelectric Transducers as a function of load resistance and drift frequencies.

6. Results and Discussions

The voltage transformations of each disk-type piezoelectric transducer has been presented in two parts; the first part is showing the spectrum of input and output voltages when the disks were excited at resonance only, the second part is showing the voltage transformation at around resonance when the disks were terminated with load resistance. For the case of disk 2, it was excited at resonance frequency (106 kHz) with input signal, non-RMS voltage of 11.0 V. The curve showing the input and output voltages of disk 1 at resonance is shown in Figure 4 (a). The green line is showing the non-RMS output voltage as 120 V.

This disk was then terminated with different individual load resistance, the results showing the output voltages as a function of load resistance is in Figure 4 (b). The output voltage parameters were displayed directly from the DMM while the drift frequencies data were collected using computer through the Pico scope oscilloscope. The collected data were then plotted as output voltages as a function of load resistance at around its center frequency, from 115 kHz to 99 kHz; 106 kHz being the center frequency.

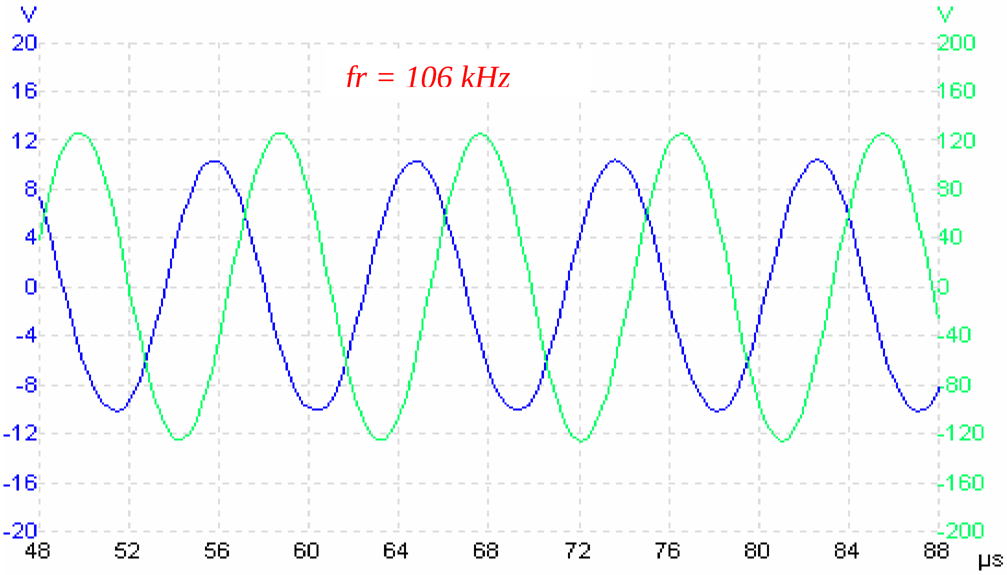

Fig. 5 (a). The voltage transformation of disk 2 at resonance (106 kHz), the green line is showing the non-RMS output voltage as 120 V, while the blue line shows the non-RMS input voltage as 12 V.

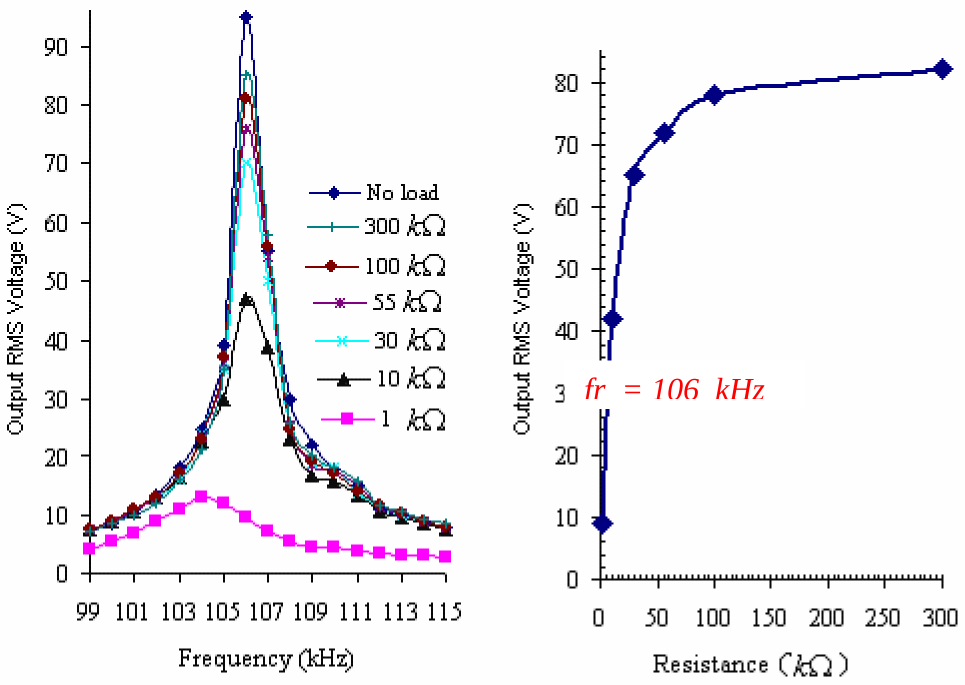

Fig. 5 (b). The voltage transformation (RMS voltage) of disk 2 as a function of load resistance at around center frequency between 99 – 115 kHz. The insert curve is showing the RMS output voltages as a function of its maximum load at resonance.

The highest RMS output voltage was around 105 V when disk 2 was measured without load resistance (no load) at around 106 kHz. The voltage dropped down to 85 V when the PT was terminated with 300 kΩ; this was the optimal load resistance in which the highest output voltage was obtained at resonance. The output voltage continued to degrade and dropped dramatically when the disk was terminated with lower load resistances. The voltage transformations as a function of load resistance at 106 kHz of this disk were recorded as followings: 100 kΩ corresponds to 80 V; 55 kΩ corresponds to 75 V; 30 kΩ corresponds to 70 V; 10 kΩ corresponds to 47 V; and 1 kΩ; corresponds to 10 V. The inserted curve in Figure 4 (b) is showing the output RMS voltage of disk 2 as a function of load resistance at 106 kHz.

The curve showing the input and output voltages of disk 1 at resonance is shown in Figure 6 (a). This disk was excited at 93 kHz with 10 V as input signal voltage (non-RMS). The spectrum showing this signal voltage was displayed on the computer screen as blue line. The green line is showing the non-RMS output voltage as 45 V.

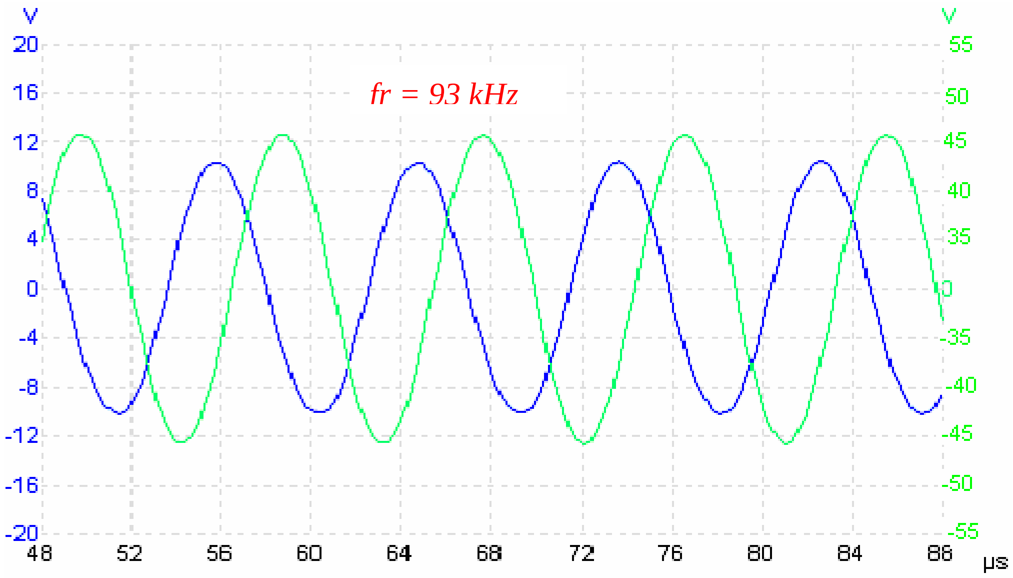

Fig. 6 (a). The voltage transformation of disk 1 at resonance (93 kHz), the green line is showing the non-RMS output voltage as 45 V, the blue line shows non-RMS input voltage as 12 V.

In Figure 6 (b) is the curve, which shows the output voltage, measured across the output terminals of disk 1 when it was excited at resonance and then terminated with different load resistances; the output voltages were then recorded relative to their corresponding drift frequencies. The voltage transformation results of this disk has been reported in two cases, the first case is when the disk output voltage was measured without load resistance and the second case is when the disk was terminated with load resistance. The results observed at non-loading condition of this disk was approximately 40 V, the voltage transformation as a function of load decreased to 34 V when this disk was terminated with 55 kΩ, this was its optimum load resistance. The voltage transformation as a function of different load resistance at resonance, 93 kHz, was as followings: 1 kΩ corresponds to 13 V, 10 kΩ corresponds to 30 V, 30 kΩ corresponds to 32 V, and 55 kΩ corresponds to 34 V. Some degradations of the output voltages were observed when the disk was terminated with 100 kΩ, at this time, the voltage dropped rapidly from 40 V to 25 V as the frequency drifted from 97 kHz to 93 kHz. The insert curve in Figure 5 (b) is showing the output voltage as a function of load resistance at resonance or 93 kHz.

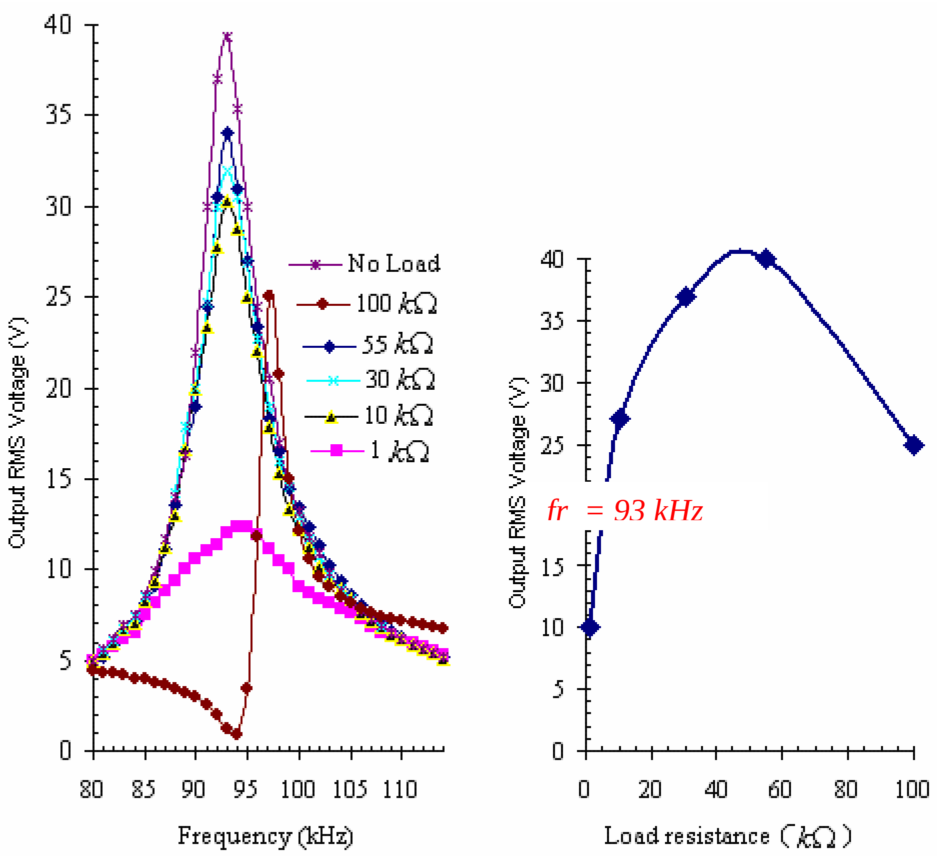

Fig. 6 (b). The voltage transformation of disk 1 as a function of load resistance at around center frequency or resonance (80 -115 kHz). The insert curve is showing the RMS output voltages as a function of its maximum load at resonance.

The results have shown that disk 2 has higher transformation ratio because of having higher mechanical quality factor than disk 1. Due to business issues, no more discussion is presented regarding the doping concentration, elemental constituents and device processing of each disk l.

7. Conclusions

The voltage transformation behaviors of loaded and unloaded single disk-type piezoelectric transducers have been presented as a function of drift frequencies, at around their center frequencies. These devices have shown promising feature applications when terminated with different load resistance. The voltage transformations in disk 2 was found to be higher as compared to voltage transformation in disk 1, because, disk 2 has higher mechanical quality factor (Q_m = 1000) as compared to mechanical quality factor of disk 1 (Q_m = 500). The optimal load resistance was identified as 300 kΩ for disk 2, and 55 kΩ for disk 1.

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