Numerical And Analytical Modeling Of The Piezoelectric Transformer And Experimental Verification

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ABSTRACT

In this paper, to approach the modeling aspect, we have selected a Rosen-type structure of piezo-electric transformer which, for us, seems very interesting from an educational point of view. Two approaches will be presented ; (i) The first one consist of performing the analysis with an electric equivalent circuit. The set of hypotheses used in the equivalent circuit method prove to be somewhat restrictive inasmuch as only one type of vibration is being considered, which neglects the coupling phenomena existing in the other directions. (ii) We have therefore added to our modeling approach a more general numerical finite element method using ANSYS software. Because piezoelectric problems are solved as an extension to the total elastic-electric coupling, we have simulated all the 3D structure of the piezoelectric transformer and appreciated the validity of the hypotheses done in the equivalent circuit method. Finally, the results are compared with experimental data in different condition of behavior.

Keywords : Transformers, Modeling, Equivalent circuit, Finite element, Piezoelectric, Longitudinal piezoelectric effect.

INTRODUCTION

Electrical power applications using field are continually advancing and reaching out to new domains. Recent progress achieved, particularly in the domain of the miniaturization of both electrical and electromechanical devices, has enabled envisaging the development of very compact systems (microcomputers, microsystems, cellular telephones, etc.). The supply, storage and transformation of electrical power in these systems must respect this trend. However, the miniaturization of classical electromagnetic transformers raises certain problems pertaining to: manufacturing of both the coils and the magnetic core, increase in magnetic leak, degradation of performances, and electromagnetic pollution of the environment. One interesting solution consists of using a piezoelectric transformer. This would insure an electrical-mechanical and mechanical-electrical double conversion of energy with a transformation ratio that allows adapting the output voltage being used. This kind of transformer, which is more compact, lends itself better to miniaturization, in addition to displaying the attractive characteristics of immunity to the magnetic field and a high galvanic insulation.

In this paper, to approach the modeling aspect, we have selected a Rosen-type structure of piezo-electric transformer which, for us, seems very interesting from an educational point of view. Two modeling approaches, by electric equivalent circuit and by finite element method, are presented. Calculated and experimental results are compared and discussed.

PIEZOELECTRIC TRANSFORMER

The piezo-electric transformer that we are studying here (fig.1) is a classical Rosen type structure [1] builded in the Philips-PXE-43 hard piezo-electric material, witch is more suitable for this type of application. The left part, polarized in thickness, represent the primary whereas the right part, polarized in length, represent the secondary. All external faces are free. As a consequence, we have performed the transformer behavior in full wavelength longitudinal vibration mode, as presented in figure 2.

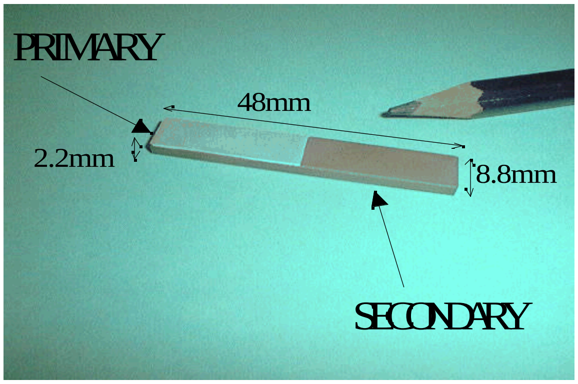


Figure 1 : Piezoelectric transformer (Rosen type structure)

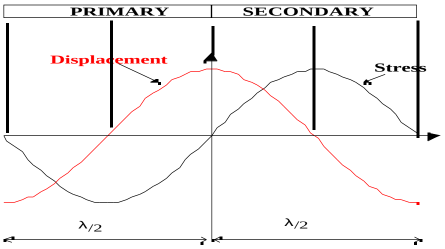


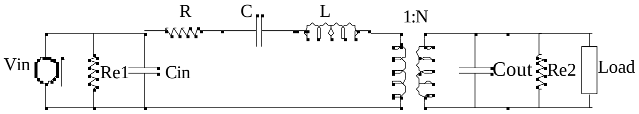
Figure 2 : Stress and displacement distribution along length

MODELING

For approach the aspect of the modeling, two methods are presented in this article. The first one is the analysis with electric equivalent circuit and the second one is the using of a numerical finite element method.

Electric equivalent circuit modeling

This approach is inspired by the technique used in electroacoustic [2][3] and permit to build an electric equivalent circuit (EEC) of a vibrating structure, with piezoelectric element. In our Rosen type structure, this brings us round to a circuit shown in figure 3. This lumped-constant equivalent circuit is made with considering a single longitudinal mode of vibration, neglecting coupling phenomena along the other axes. The element values are approximated near the resonant frequency. The resistance Re1, Re2 and R permits to take into account respectively the primary and secondary dielectric losses and mechanical losses [5][6]. The capacitances C_{in} and C_{out} point out the capacitive nature of the device. The inductance L and the capacitance C traduce inertial and potential mechanical energy.



R_{E1}=1.53 MΩ	R=154.82 Ω
Cin=701.96 pF	C=14.556 pF
L= 0.2193 H	Cout=3.9174 pF
N= 81.8509	R_{E2}=253.99 MΩ

Figure 3 : Electric equivalent circuit at the resonance.

So, this electric equivalent circuit is easily enough exploitable with an electric circuit simulator. Figure 4 shows the frequency dependence of the calculated input impedance looking from the primary side, where output terminal on the secondary side is open. One even can see that the resonance frequency witch correspond to the minimum value of the module is near 70.65 kHz. This frequency correspond to the maximum transformation ratio as we can see in figure 5, when different resistive loads are connected to the secondary.

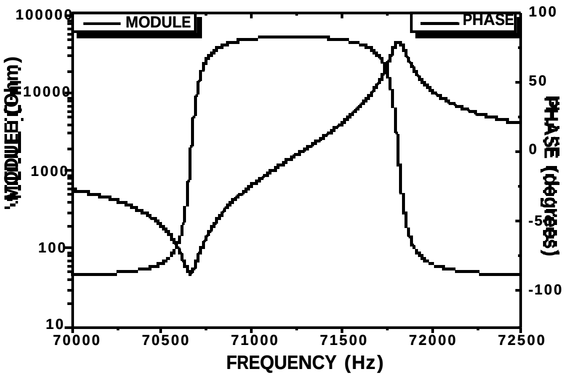


Figure 4 : Calculated input impedance versus frequency. (EEC)

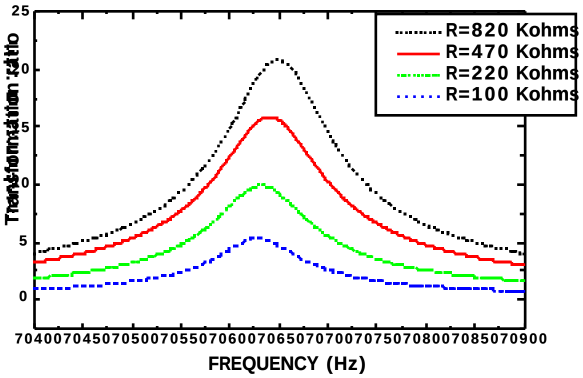


Figure 5 : Global transformation ratio versus frequency. (EEC)

Hence, the characteristics for output voltage, output power and efficiency are calculated, as shown in fig.6, versus value of the load resistance, for an input tension of 10 volts. We can see that maximums occurs for different value of the load resistance.

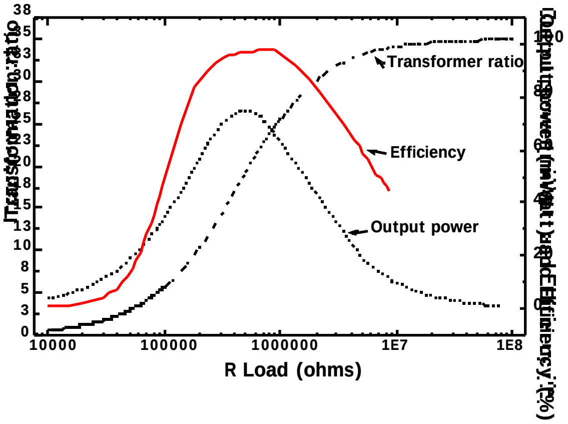


Figure 6 : Calculated efficiency, output power and transformation ratio versus load resistance. (EEC)

Finite element

Hypothesis used in the equivalent circuit method are a little restrictive insular as we are considering only one type of vibration, neglecting coupling phenomena in other directions. So, we have added to our study an other modeling approach by finite element. For that, we have used the commercial ANSYS software. Piezoelectric problems are solved as an extend elastic-electric coupling. The problem consist on calculate displacement and electric potential on nodes of the mesh of the structure.

On figure 7, we can see module and phase of the input impedance versus frequency. Results are in a good adequation with them calculated in the previous method. Absolute values of the module are very important because we don't taking into account losses. We can noticed a gap of 1% on the resonant frequency that occurs now at 74,2 kHZ.

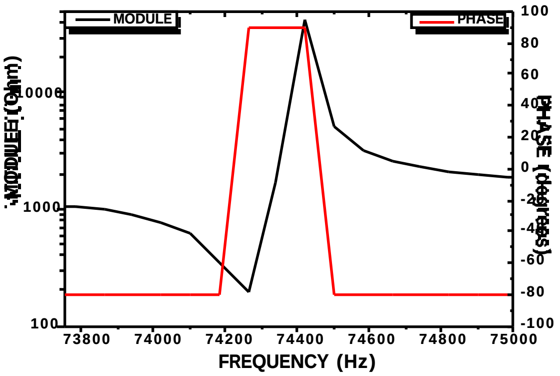


Figure 7 : Frequency dependence of the calculated input impedance. (FEM)

Figure 8 show us the 3D deformed mesh of the studied Rosen transformer in a longitudinal mode of vibration. We can also see spurious vibrations on other axes dues to coupling phenomena. On figure 8 one visualizes also the stress of the structure 3D. One can notice that one obtains the same result that in figure 2.

Figure 8 : 3D deformed structure. (FEM)

EXPERIMENTAL RESULTS

In order to compare calculated and experimental data and validate our modeling, we have done few experiments on the piezo-electric transformer presented in the beginning of this paper. First, we have recorded the input impedance using a HP-4195A impedance analyzer. As we can see on figure 9 and 10, experimental and calculated are in good adequation despite normal few differences discussed in conclusion. Practical frequency resonance occurs at 75.5 kHz.

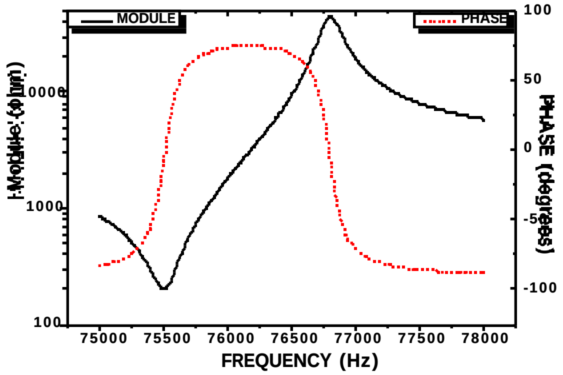


Figure 9 : Frequency dependence of the input impedance.(HP - 4195A)

Secondly, we have measured (fig.10) the global transformation ratio versus frequency, under different values of the load resistance. As expected, the maximum output voltage occurs for resonant frequency.

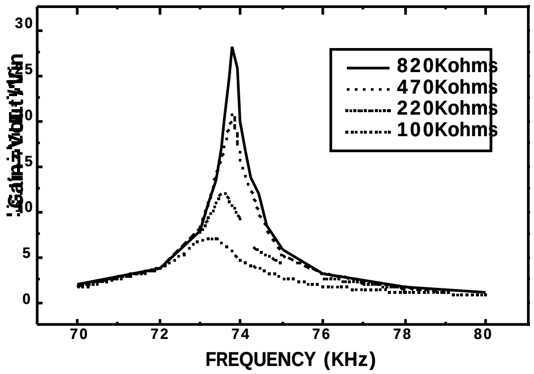


Figure 10 : Frequency dependence of the measured transformation ratio.

Finally, for an input voltage of 10 volts and resonant frequency, we have recorded the output voltage and power versus load resistance. Peak occurs for different values of the load.

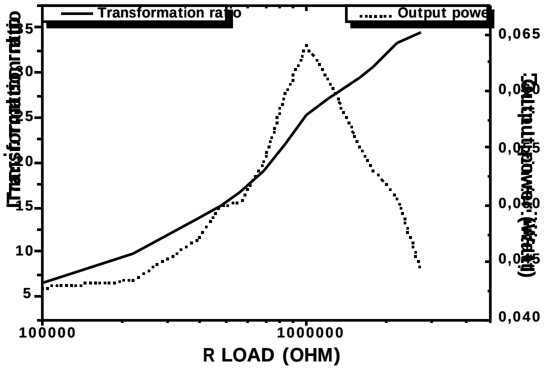


Figure 11 : Measured output power and transformation ratio versus load resistance.

CONCLUSION

In this paper, we have presented calculated and experimental results of the behavior of a piezo-electric transformer. Two approach of modeling have been selected, one with electrical equivalent circuit (EEC), the second with finite element method (FEM). Finally, a sample of transformer have been tested under low level of excitation.

As we can see, all results are in good adequation, despite few differences in resonant frequency, transformation ratio and power. This differences are quite normal because insofar as starting assumption are different. The EEC method is the more restrictive one because only longitudinal vibration along the length is taking into account. But, results obtained are not so bad and this method allows us to used an electric simulator and to take into account the electronic environment.

The FEM is interesting to appreciate local values in terms of internal stress, electric field and coupling phenomena in a 3D structure. But, for instance, dielectric and mechanical losses are not taking into account.

To resume the behavior of this piezo-electric transformer, one can retain that maximum efficiency, output voltage and power occurs at the resonant frequency. These characteristics indicate the possibility for gain controlling by frequency modulation. In practice, there is a shift of the resonant frequency caused by the load resistance change. And one can choice operation of the transformer at maximum output voltage or power, or efficiency by changing value of the load resistance.

The author wish to continue their study by requesting the transformer has levels of power superior and by introducing it into converter circuitry.

ACKNOLEDGMENT

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