A PIEZOELECTRIC ACTUATOR, BASED ON A LANGEVIN-TYPE TRANSDUCER, FOR DERMATOLOGICAL AESTHETIC APPLICATIONS

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Abstract: In dermatological aesthetic piezoelectric actuators are widely used: the skin treatment is obtained by the bending vibration, along the length, of a steel foil with a thickness of about 0.5 mm; the vibration frequency is in the ultrasonic range, to avoid annoying noise. In this paper a piezoelectric actuator able to excite a bending motion in the steel foil is described; the active part of the actuator is a piezoelectric Langevin–type transducer soliciting the foil at one edge. The actuator was designed by using ANSYS with the objective to obtain a system with high efficiency, low losses, high mechanical stiffness and low encumbrance. Best results were obtained by means of a Langevin actuator with a stepped horn displacement amplifier, whose total length is $\lambda/2$ at the resonance frequency; the Langevin is connected to the foil by an ad hoc support. The ANSYS results computed in operating conditions show a well sustained bending vibration of the foil with stress values, in all the actuator components, far from the limit value in the material.

1 INTRODUCTION

In dermatological aesthetic piezoelectric actuators are widely used: the skin treatment is obtained by the bending vibration, along the length, of a steel foil with a thickness of about 0.5 mm; the vibration frequency is in the ultrasonic range, to avoid annoying noise. In this paper a piezoelectric actuator able to excite a bending motion in the steel foil is described; the active part of the actuator is a piezoelectric Langevin–type transducer soliciting the foil at one edge. First of all we analyzed by ANSYS the resonance modes of the foil, in order to identify bending modes at an ultrasonic resonance frequency. The second step was the design of a Langevin transducer with the same resonance frequency. By means of analytical models we computed the thickness of the front and back masses of a transducer composed by 4 piezoceramic rings, electrically connected in parallel; in order to amplify the displacements, on the Langevin front face we inserted a displacement amplifier realized by using a classical stepped horn ultrasonic concentrator with both sections one-quarter wavelength long; finally, the connection between the foil and the displacement amplifier is realized by means of an ad hoc prismatic steel "support". In order to optimize the design we analyzed the actuator behaviour by ANSYS, with the purpose to maximize the bending displacement at the free edge of the foil, to minimize the stresses in all the device and to reduce its encumbrance.

2 FOIL RESONANCE MODES

The foil resonance modes were analyzed by using ANSYS, in order to find a bending mode at an ultrasonic frequency; the use of the FEM is justified by the geometry of the foil and by the choice to use this tool for the actuator design. Due to the foil length (45 mm) and material (steel AISI 304), its first bending mode has a resonance frequency of 1283 Hz; obviously this vibration mode cannot be used for the treatment because it lies in the audible range. On the other hand, from the ANSYS modal analysis we obtained that the first bending mode with an ultrasonic resonance frequency is approximately located at 25 kHz; in Fig. 1 is reported the ANSYS simulation of the foil displacement field computed at this frequency.

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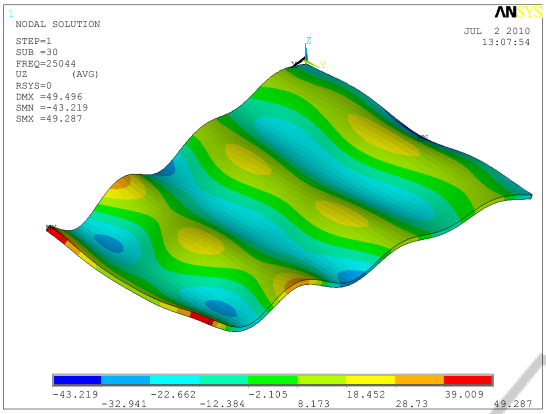

Figure 1: Foil displacement field (arbitrary units) at its first ultrasonic bending mode (25044 Hz).

3 THE DESIGN OF THE LANGEVIN TRANSDUCER

The Langevin transducer is basically composed of two, or more, piezoceramic disks electrically connected in parallel, sandwiched between two metal masses (Langevin, 1924). It can be excited to resonate in length–extensional mode at low frequency, avoiding the need of high driving voltages. The structure is usually pre stressed in order to increase the mechanical strength of piezoceramic elements and is suitable to absorb high electrical power. In our case the transducer is composed by 4 piezoceramic rings (Pz 26, by Ferroperm Piezoceramics A/S, Kvistgaard, Denmark) with a thickness of 1 mm, an outer diameter of 20 mm and an inner diameter of 3.8 mm; imposing a resonance of 25 kHz, by classical 1–D analytical models (Zelenka, 1986) we computed that the thickness of both the front and back steel masses is 44.6 mm.

The 4 piezoceramic rings are electrically connect in parallel by means of 4 copper rings (0.35 mm thick and with the same diameters of piezoceramic disks) placed between them. In order to verify if the presence of the copper rings can be neglected in the actuator design, we computed by ANSYS the electrical input impedance Z_i of the Langevin with and without these rings; in Fig. 2 is shown the Z_i amplitude computed in the two cases in a frequency range around the foil resonance. As it can be seen, the presence of the copper rings is not negligible: the resonance and antiresonace frequencies both shift of about 600 Hz (the 2.4 % of the resonance frequency); in the next steps of the transducer design the presence of copper contact rings must be accounted.

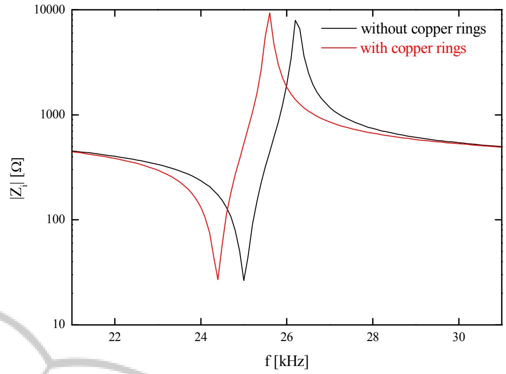

Figure 2: Electrical input impedance of the Langevin transducer computed by ANSYS taking (in red), or not (in black) the copper contact rings into account.

In order to amplify the displacement on the actuator front face various solutions can be used; among these, sectional ultrasonic concentrators, made from rods of variable and constant cross section, are those that have been mainly exploited in applications. Basically, sectional concentrators are designed to resonate in length–extensional mode at the same frequency of the Langevin transducer and the displacement amplification depends on the ratio between the back and the front sections. Sectional concentrators have been widely analyzed by Merkulov (Merkulov, 1957) and Kharitonov (Merkulov, Kharitonov, 1959) for several shapes (conical, exponential and catenoidal). These authors concluded that the maximum displacement amplification is achieved for a stepped horn, when the two sections are both one-quarter wavelength (λ/4) long; in this case, the amplification factor is equal to the ratio between the areas of the two end sections. By using this design criterion, the actuator total length is therefore λ: λ/2 of the Langevin transducer plus λ/2 of the stepped horn displacement amplifier. For the design of the displacement amplifier we just decided to use a stepped horn device (the whole actuator is shown in Fig. 3); the sections of the amplifier are both 48.6 mm long, the thinner section has a diameter of 10 mm while the other has the same diameter of the other Langevin components.

The main problem of this kind of actuator is its total encumbrance: in the present case the whole length is 194.4 mm. In order to reduce the encumbrance we designed a device whose total length is λ/2 at the operating frequency (≈ 25 kHz): it is composed by the same 4 Pz 26 piezoceramic

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rings and the same copper contacts of the λ actuator, while the length of the two masses is 26.3 mm, and the two sections of the displacement amplifier are 29 mm long; with this choice the actuator total encumbrance is 116 mm, more than 40 % smaller.

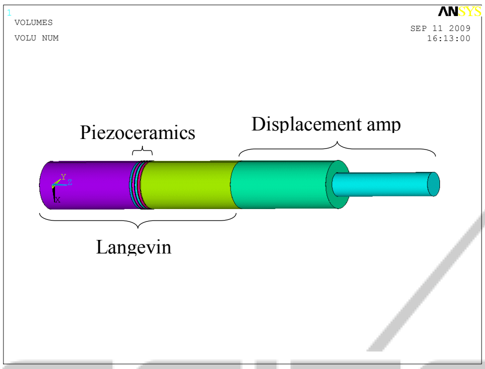

Figure 3: Schematic view of the Langevin actuator with the classical stepped horn displacement amplifier.

In order to compare the performances of the two solutions we computed by ANSYS the vertical component of the displacement, u_z in the center of the front face for both transducers; in Fig. 4 the $|u_z|$ amplitudes computed in the two cases are compared with $|u_z|$ computed for the Langevin without displacement amplifier.

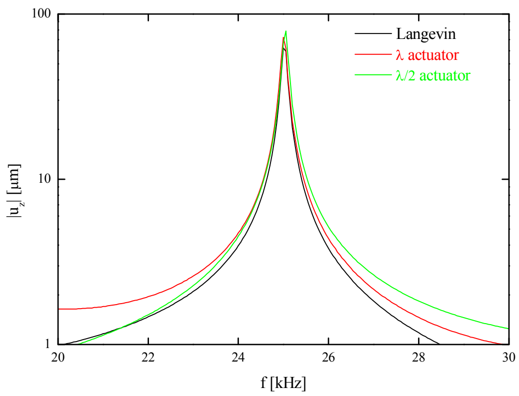

Figure 4: Displacement computed by ANSYS at the center of the front face of the Langevin actuator (in black), of the λ actuator (in red) and of the λ/2 actuator (in green).

As it can be seen the resonance frequencies are practically the same, while the λ/2 transducer shows a displacement amplitude a bit greater than that of the λ one; this result within the device encumbrance let us to prefer the λ/2 device. The only problem of this solution is that in this case the node of u_z is not in the piezoceramic zone; this problem will be accounted in the design of the whole actuator.

4 THE DESIGN OF THE WHOLE ACTUATOR

In order to mechanically connect the front face of the displacement amplifier to the vibrating foil, an ad hoc "support" is needed. This support is a parallelepiped whose length is equal to the radius of the front face of the displacement amplifier, while the width is constrained to be equal to that of the vibrating foil. The only degree of freedom of this element is therefore its thickness: it cannot be too small in order to avoid flexural vibrations in the foil in the width direction; on the other hand it cannot be too large to don't excessively charge the Langevin and therefore to weaken its mechanical excitation. By using ANSYS we designed the thickness of the support in order to maximize the amplitude of the flexural vibration in the foil: the best results were obtained with a support thickness of 3 mm. In Fig. 5 is shown the geometry of the whole transducer: it is composed by the Langevin actuator, the stepped horn displacement amplifier, the mechanical support and the vibrating foil.

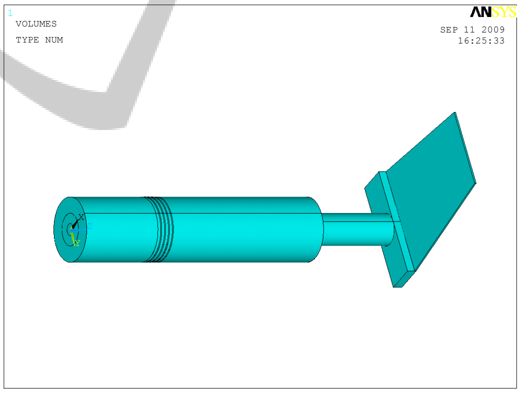

Figure 5: Geometry of the proposed actuator.

For applications in dermatological aesthetic, the actuator must be designed to maximize the amplitude of the vibrations in the foil; we analyzed the proposed actuator by ANSYS first of all to evaluate the resonance frequency, to verify that the displacement field in the foil is flexural and to maximize the foil displacement. In Fig. 6 is shown the amplitude of $|u_z|$ computed by ANSYS at the center of the foil free edge. As it can be seen, the maximum of the displacement is obtained at 26.1 kHz; this shift in respect to the resonance frequencies of both the Langevin (with the displacement amplifier) and the foil, and the ripple in the explored frequency range are due the support and the superposition of many modes that are strongly coupled together.

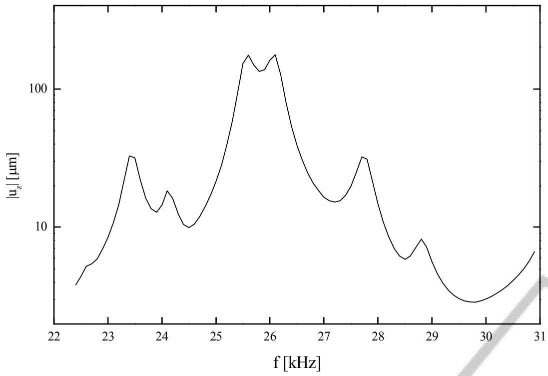

Figure 6: Amplitude of the displacement computed by ANSYS at the centre of the foil free edge.

In order to verify if the foil vibration at the resonance (26.1 kHz) is a flexural vibration we computed the displacement field in the actuator at this frequency; in Fig. 7 is shown the obtained result.

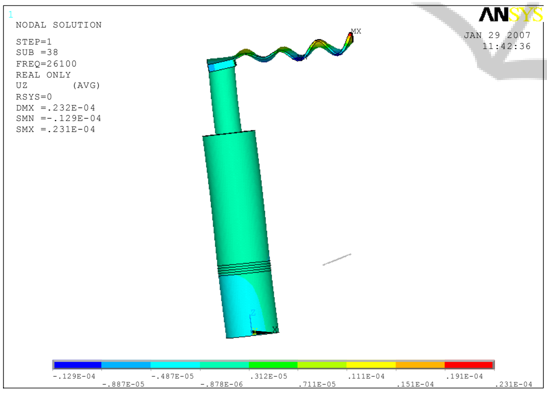

Figure 7: Displacement field (in meters) in the proposed actuator computed at 26.1 kHz.

As it can be seen, an uniform bending vibration is excited in the foil and the displacements have their maximum amplitude at the unconstrained edge. The displacements in the "Langevin" actuator are negligible with respect to those of the foil, and therefore a good stiffness of the whole structure is expected.

Finally, in order to verify the stiffness of the proposed structure, the stresses in the actuator have been computed by supplying it at 26.1 kHz with a sinusoidal voltage signal of 250 V in amplitude. In Fig. 8 the field of stresses along the structure is shown.

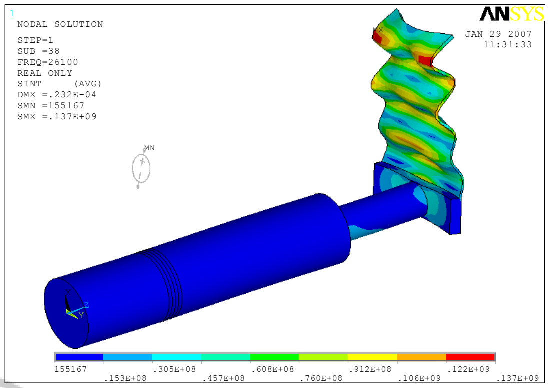

Figure 8: Stress field (in Pascal) computed supplying the proposed actuator at 26.1 kHz with a sinusoidal voltage generator of 250 V.

The weaker actuator part is the zone of contact between foil and support; as it can be seen, only in a small area around the centre the stress reaches a value of about 100 MPa, whilst in the remaining contact areas it is below 76 MPa and even sinks below 13 MPa in the external zones; these values are far from the yield point, of about 500 MPa in the steel of the support and the foil. Even the stress on the piezoelectric ceramics is small: below 15 MPa; this avoids depolarisation problems (the depolarization limit is 30 MPa). Finally, the maximum of the stress on the foil doesn't exceed 140 MPa and therefore also in this zone it is far from the limit value in the steel.

5 CONCLUSIONS

In this paper a piezoelectric actuator able to excite a bending motion in a steel foil is described; the active part of the actuator is a piezoelectric Langevin–type transducer soliciting the foil at one edge. The resonance modes of the foil were analyzed by ANSYS in order to identify bending modes at an ultrasonic resonance frequency. The second step was the design of a Langevin transducer with the same resonance frequency: by means of ANSYS we designed a transducer composed by 4 piezoceramic rings, electrically connected in parallel, a front and a back mass and a displacement amplifier realized by means of a classical stepped horn ultrasonic concentrator. We compared the performance of this actuator with that of a Langevin with the same components but with a total length equal to λ/2 at the resonance frequency; the performance of this device is a bit greater than that of the other, with the advantage of an encumbrance about one half. The

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connection between the foil and the displacement amplifier is realized by means of an ad hoc prismatic steel "support". The design of whole actuator was optimized by means of ANSYS, with the purpose to maximize the bending displacement at the free edge of the foil. Finally, in order to test the actuator stiffness, we computed the stresses in the structure in operating conditions and we verified that their values in any point are far from the material limits.

The next step will be the realization of an actuator prototype in order to experimentally verify its performance and to refine the design.

The actuator design criteria are the basis of an international patent (Lamberti et al., 2008).

REFERENCES

Langevin P., French Patent n. 503913 (29/5/1929), n. 505703 (5/8/1920), n. 575435 (30/7/1924).

Zelenka J., 1986. Piezoeletric resonator and their applications, *Elsevier*, New York.

Merkulov L. G., 1957, Design of ultrasonic concentrators. In Sov. *Phys. Acoust*., 3, pp. 246–255.

Merkulov L. G., Kharitonov A. V., 1959, Theory and analysis of sectional concentrators. *In Sov. Phys. Acoust*., 5, pp. 183–190.

Lamberti N., Casacchia G., Ardia L., Caputo A., 2008, Actuator with interchangeable bending-vibrating foils, based on a langevin-type transducer, *International Patent*, PCT/IT2008/000431.

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