Innovative Air Bubble and Blood Leak Detection for Hemodialysis by Micro Intelligent Transducer

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Abstract- The development of current intelligent systems, which mainly depend on certain intelligent materials, such as: polymer, thermoelectric and piezoelectric can be given solutions to critical problems especially at the level of human health. These systems are based on electronics materials and needs energy for the communications and the data processing. The electronics sensors require the autonomous power where this condition imposed a limitation application, for example, the use of the sensors in the detection of the air bubbles in the haemodialysis machine was generally limited to certain arrangements due partly to cumbersome sources of energy and in more the absence of power and data acquisition system. The entry of air into the organs of the dialysis patient is among the most important problems that may occur while connecting the dialysis machine manually or while it is working, and it is announced rigorously that the presence of bubbles of air in blood circulation constitutes a mortal danger to the patient. Since this fault with which case, it occurs in the haemodialysis must be quickly and strictly detected with high precision devices in order to envisage the strict stopping of the haemodialysis and consequently to protect the patient in danger from death. In this paper, we presented the simulation results of a multilayer piezoelectric system with the associated electronic circuit; permitting to provide the necessary autonomy power supply, to monitor, detect air bubbles and control arterial pressure.

Keywords Hemodialysis, piezoelectric, generation of energy, system of storage, micro intelligent transducer.

1. Introduction

In a dialysis machine, there are two circuits: the blood circuit is intended to make the patient's blood circulate through the extracorporeal circulation lines; the hydraulic circuit is intended to manage the dialysis fluid.

Kidney is a very important organ of the human organism [1]. It is enough that they stop functioning to see our body poisoning itself slowly by its own waste coming from the metabolism of all our cells. The people reached of such a disease are subjected periodically to a dialysis. Indeed, one of the risks, of purification, by hemodialysis is the presence of bubbles of air suitable for infiltrate in blood.

The problem of air bubbles in human blood can be dangerous and even fatal [2]. This problem can lead to blockage of narrowed blood vessels, causing a lack of oxygen transfer from the lungs to the patient's organs and cell death [3], where it is particularly important in the case of a dialysis machine, which is characterized by a low flow rate, and can significantly disrupt the functioning of the patient's organs [2].

Therefore, the World Health Organization has imposed standards specifying the permissible percentage of injected air and the maximum volume of a single bubble in the injected fluid [4].

It is necessary to find means or devices to detect the presence of air bubbles in medical equipment such as the dialysis machine, where is used for the hemodialysis. This machine is used for the patients with end stage renal disease.

In the literature, there are several techniques for detecting air bubbles in the blood. The ultrasound methods based on ultrasonic system proposed by the researchers, Susono Pratondo [5] and S. Ozeri et all [6] are mainly used on the detection of envelope amplitude which is sensitive to noise. The capacitive sensors technique is proposed by Nguyen D.H et all [7] where is structured by electrodes on PCB and vertical side clamp the pipe of blood stream.

We propose, in this work, therefore a piezoelectric system allowing to generate the power necessary to the monitoring [8-9], the detection of the bubbles of air and the control of the blood pressure. The results of simulation of the voltage and the power generated by the piezoelectric system (Fig.1) are given. As for the control of the flow of blood, blood pressure and bubbles of air, it is enough to place piezoelectric sensors (PZT) on the level of the "pump housing ", a pressure sensor piezoelectric on the level of the circuit blood for the control of the blood pressure and the bubbles of air. These sensors convert the mechanical constraint, due to the pressure, in a voltage making it possible to control the pumps.

2. Hemodialysis Generator

The monitor of dialysis makes it possible to ensure an effective treatment thanks to a certain number of parameters. It prepares, control dialysate, ensures the extra corporeal circulation of blood, puts in contact the two fluids by means of a dialyser, and ensures the best course of the meeting of dialysis Hemodialysis being technique of the extra purification renal most widespread; about 80% to 85% of the patients are treated by this technique [10].

2.1. Blood Circuit

During the process of blood transfer from the human body to the dialysis machine and back, as well as during membrane diffusion itself, there are numerous critical parameters to be monitored and controlled. For patient safety reasons, blood circulation is continuously observed with regard to the presence of air bubbles as they may result in life-threatening air embolisms. Membrane defects in the dialyzer, in turn, can accidentally cause blood loss through the separated dialysate. For this reason, the dialysate discharge tube is constantly monitored for blood leaks.

Respiration induces variations in the blood pressure that propagates to the extracorporeal circuit of the dialysis machine. However, the magnitude of these variations is very small compared to pressure variations induced by the dialysis machine. Using Sensors of pressure an estimate of the respiration rate is obtained every 5th second provided that the signal quality is sufficient.

2.1.1. Pump with Blood

The pump with blood is always necessary to carry out extra-body circulation. There are several varieties of pumps with blood. The majority function by crushing of a segment of the pipe of the arterial line by means of rollers or of a wheel offset. So that the blood flow is satisfactory, it imports that the adjustment of these pumps is correct, that the rollers or the wheel are tight with precision on the part of the arterial pipe which one calls " pump housing ". If not, this flow remains low, even no one, and blood is badly purified

2.1.2. *Detectors of Air Bubbles*

If the circuit located between the arterial needle and the pump at blood is not tight, the air is aspired and pushed in the dialysis machine by the pump. That can occur in the event of bad connection between the arterial needle and the pipe where the air is aspired. If they are only some bubbles, they are stopped by the trap with bubbles, but they can be very numerous, and the trap with bubbles fills of foam, letting pass in the circulation of the micro bubbles. The danger is more important if a great quantity of air is injected, it is the gas embolism that can be mortal.

2.1.3. *Sensors of Pressure*

A pressure in the circuit blood, too weak or too strong, causes the stopping of the pumps. They are actuated in the event of defect on the body extra circuit.

The piezoelectric pressure sensor is a sensor that uses the piezoelectric effect of piezoelectric materials to convert the measured pressure into an electrical signal. Use electrical components and other machinery to convert the pressure to be measured into electricity. Measuring precision instrument for related measurement work. Such as pressure transmitters and pressure sensors [9-16].

2.1.4. *Pump Anti-Coagulation*

To avoid coagulation, a constant flow of anticoagulant is injected permanently into the arterial circuit.

3. Smart Materials

The smart material (piezoelectric) used in this study is sensitive, adaptive and evolutionary and has functions which enable him this to comprise like a sensor [11] (to detect signals), an actuator [12-13] (to carry out an action on its environment) or sometimes like a processor (to process, compare, store data). This piezoelectric is able to modify its physical properties spontaneously, for example its form, its connectivity, its viscoelasticity [14] or its color in answer, with natural or caused excitations coming from the outside or the interior of material. In a general way a piezoelectric micro generator [15 -16] consists of a mechanical device able to transmit a mechanical request to a piezoelectric element connected to an electric circuit constituting the receiver of energy. The potential difference between the final electrodes of the piezoelectric element depends primarily on the mechanical solicitation and the behavior of the charge electric [9].

4. Piezoelectric System

4.1. *Description of the Piezoelectric System*

Concerning the system, a long piezoelectric bar, of cylindrical form, is incorporated at an end and vibrates in the other side in mode 33. F1 and V1 are respectively the force and speed at the loose lead R_L . The two ends are connected to a load with a piezoelectric bar made up of N thin layers (Fig.1).

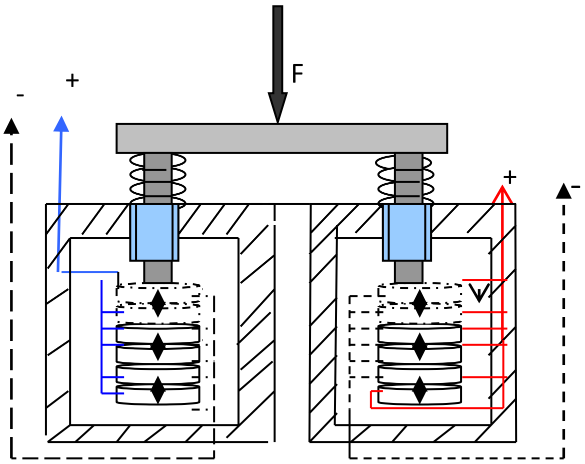

Fig. 1. Piezoelectric system deformed according to mode 33 with N layers.

The established model is unidimensional, thus only the components along the axis x3 are taken into account. Eq. (1) represents piezoelectricity with the variables.

$$\begin{cases} S_3 = s_{33}^D.T_3 + g_{33}.D_3 \\ E_3 = -g_{33}.T_3 + \beta_{33}^T.D_3 \end{cases} \quad (1)$$

With D_3 represents the electric flux density, E_3 electric field, β_{33}^T the reverse of the dielectric permittivity for a constraint constant or null, S_3 the deformation, T_3 the constraint, s_{33}^D mechanical compliance, g_{33} coefficient it piezoelectric equal to ($\frac{S_3}{D_3}$ with T constant or $\frac{E_3}{T_3}$ with D constant). The combination of the law of newton in Eq. (2) with the relation Eq. (1) enables us to deduce the voltage U, current I and displacement V in Eq. 3.

With the law of newton

$$\frac{\partial T_3}{\partial x_3} = -\rho.\frac{\partial^2 .u}{\partial t^2} \quad (2)$$

$$\begin{cases} U = \dfrac{R_L.N.\dfrac{1}{jC_0\omega}.F}{(R_L + \dfrac{1}{j.C_0})Z(j\omega) + \dfrac{h_{33}^2}{\omega^2}} \\ I = \dfrac{N.\dfrac{1}{jC_0\omega}.F}{R_L + (\dfrac{1}{jC_0\omega})Z(j\omega) + \dfrac{h_{33}^2}{\omega^2}} \\ V_1 = \dfrac{R_L + \dfrac{1}{JC_0\omega}}{(R_L + \dfrac{1}{jC_0\omega})Z(j\omega) + \dfrac{h_{33}^2}{\omega^2}} \end{cases} \quad (3)$$

One deduces finally the electric average power (P_{elec}) converted and the provided mechanical power (P_{meca}) in Eq. 4.

$$\begin{cases} P_{elec} = \dfrac{R_L.\dfrac{h_{33}^2}{\omega^2}.F^2}{2\left|(R_L + \dfrac{1}{jC_0\omega}).Z(j\omega) + \dfrac{h_{33}^2}{\omega^2}\right|^2} \\ P_{meca} = \dfrac{((R_L^2 + \dfrac{1}{jC_0^2\omega^2}).R_e(Z(\omega)) + R_L.\dfrac{h_{33}^2}{\omega^2}).F^2}{2.\left|(R_L + \dfrac{1}{jC_0\omega})Z(j\omega) + \dfrac{h_{33}^2}{\omega^2}\right|^2} \\ \eta = \dfrac{R_L.N^2}{(1 + R_L^2C_0^2.\omega^2)R_e(Z(j\omega)) + R_L.N^2} \end{cases} \quad (4)$$

5. Sensor of Air Bubbles

5.1. *Diagram synoptic*

The diagram above given by the Fig.2, shows the steps to be followed to detect air bubbles in the dialysis machine.

The electronic diagram of our proposed system is given in the Fig.3. A Regulator 7805 is used to stabilize the reference voltage standard U to 5V, a the 16F84 microcontroller manages the pump control signals according to the amplitude and the frequency received through the piezoelectric sensor.

The piezoelectric sensor (PZT) generates a signal proportional to the pressure applied on the "pump housing". After rectification and filtering, the signal is transmitted towards an analogical-digital converter of eight bits (ADC 0831). The voltage Vin measured, and corresponding to the pressure of air bubbles, is compared with the reference voltage V_{ref}. The difference between the two voltage V_{in} and V_{ref} makes it possible to the microcontroller to actuate the engines of the pumps after comparison of the measured V_{in} value with the stored values in the micro-controller memory corresponding to the normal operation of the kidney.

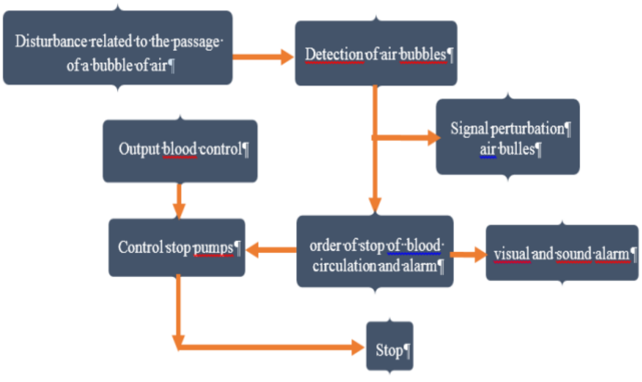

Fig. 2. Synoptic diagram.

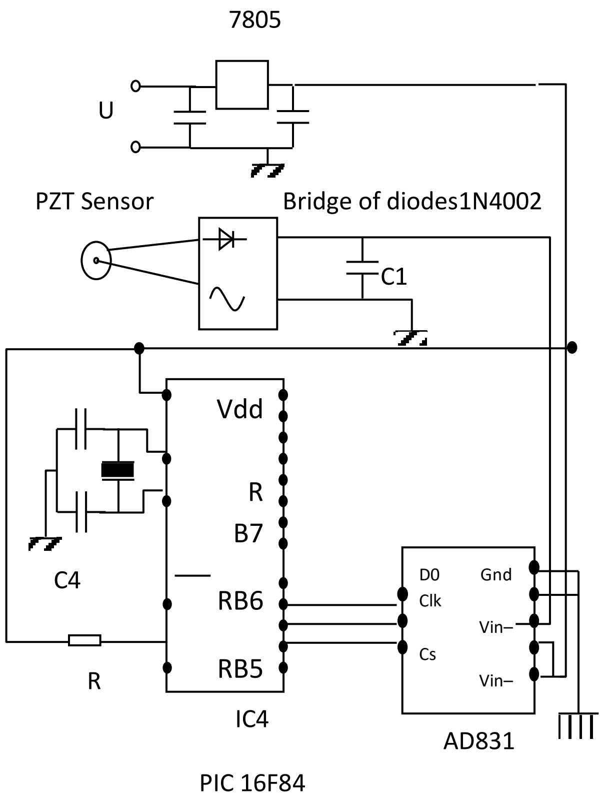

Fig. 3. Electronic diagram associated with the sensor of air bubbles.

6. Simulation

The data of the tableau.1 [9], permits us to simulate the influence of piezoelectric thin layers numbers (Fig. 4) on the efficiency, of surface and the thickness on the tension generated (Figs. 5 and 6), of surface and the electromagnetic coefficient on the power generated (Figs.7 and 8) and finally the cyclic ratio on the output power (Fig. 9).

The piezoelectric pressure sensor is a sensor that uses the piezoelectric effect of piezoelectric materials to convert the measured pressure into an electrical signal. Use electrical components and other machinery to convert the pressure to be measured into electricity. Measuring precision instrument for related measurement work. Such as pressure transmitters and pressure sensors.

7. Results and Discussion

The results of the piezoelectric system suggested shows that the generated power depends primarily on geometrical sizes of the bar and the number of thin layers which composes it. The maximum of generated power can be reached by using a massive piezoelectric sample having a great thickness and a minimal surface. However, the maximum of power can be to improve in substituting the massive sample by a sample of the same volume but composed of several piezoelectric thin layers. In this work, the power of 2,2 mW was obtained by parallel connection of ten piezoelectric layers of 1mm each one. The optimal transfer of this energy towards the load was reached for a cyclic ratio, of the converter, of 2;4%

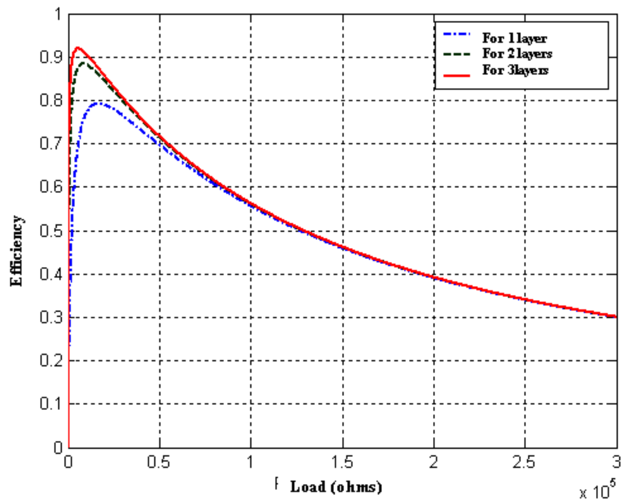

Fig 4. The influence of the layers numbers on the efficiency.

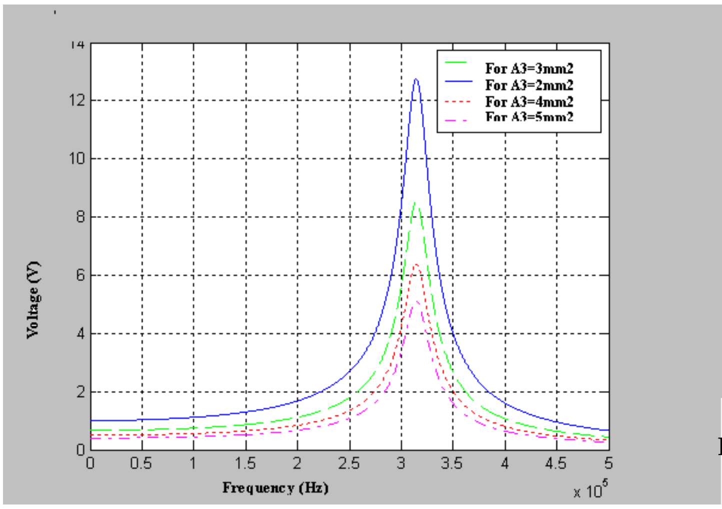

Fig. 5. Voltage generated according to the frequency for different surfaces piezoelectric bar for a L3=0.3cm thickness.

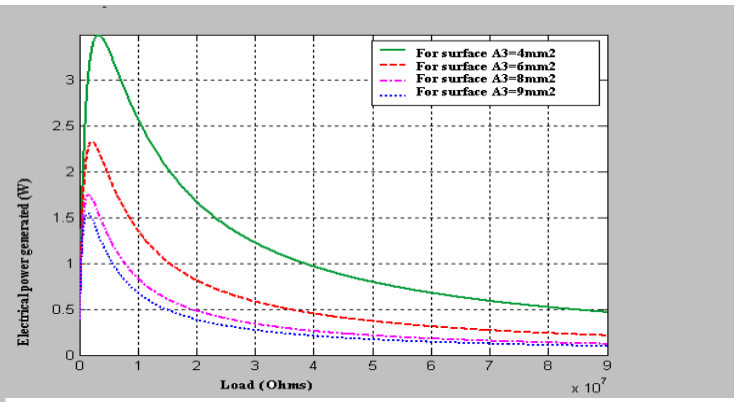

Fig. 7. Electrical output power generated for various values of the surface of the bar with thickness $L_3 = 1cm$.

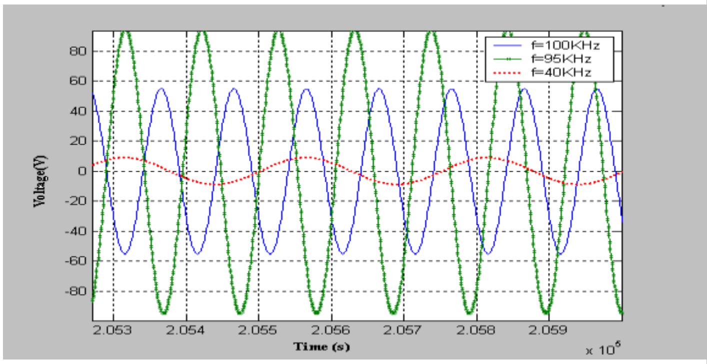

Fig. 6. Voltage generated for various values of the frequencies with *L3=1cm, A3=(9mm)*^{2}.

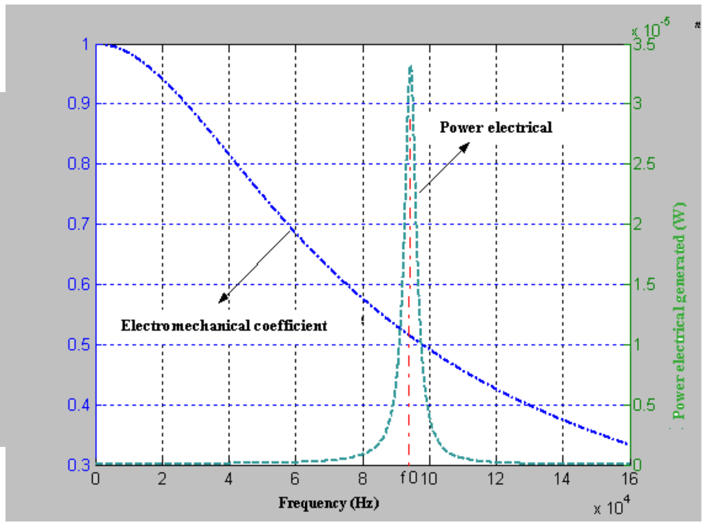

Fig. 8. Power and electromechanical coefficient according to the frequency.

Table 1. Tableau.1 Piezoelectric sensor parameters [8]

ρ =7700kg/ m^3	Z_e =262Ω	u_p =3780m/s	C_0 =6.64× $10^{-12}F$
s_{33}^D =9.09× $10^{-12}m^2/N$	g_{33} =26× $10^{-3}Vm/N$	h_{33} =28.6× $10^8V/m$	R_0 =1.2 ΩG
β_{33}^T =6.11× $10^7V^2/N$	C_m =8.19× $10^{-9}F$	L_m =3.47× $10^{-4}H$	Q_m =80
l_3 =1cm	A_3 = $9mm^2$	R_m =16.2Ω	tan δ =0.02

8. Conclusion

In this work, a piezoelectric system has been presented for to provide the autonomous power necessary to the monitoring and the detection of air bubbles and the control of the blood pressure. In order to optimize the electric power produced by the micro generator, the results of simulation show that it is necessary to have a surface of the piezoelectric transducer in the order of the micrometers, as shown in the Fig. 2, a great thickness in the order of the centimetre and a maximum number of ten thin layers (fig.1) when the ration between thickness and surface has been constant. These values permit to remain in magnitude order of volume lower than 1cm^3 and an optimal value of the cyclic ratio of about 2.4% to reach a maximum of power.

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