Concept Design and Analysis of Self Sustainable Triboelectric Pacemaker

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Abstract. The heart is one of the most crucial organs for the functioning of the human body. Due to aging and various other ailments like cardiomyopathy and congestive heart failure, the functioning of the heart tends to drop or stop in serious conditions. In such conditions, a bio-medical device called the cardiac pacemaker is used. The pacemaker is a small device that will be placed in the dysfunctional heart that sends electrical impulses to the heart muscles whenever the functioning decreases or ceases. But the pacemaker existing in the market has a low battery life and has to be replaced every few years which is a painful process for the people using it. Therefore, to overcome this predicament in this study we have designed and developed a self-sustaining pacemaker that can generate its electricity from the pacing of the heart itself thereby increasing its battery life generously. This pacemaker works on the principle of tribe-electricity. The model of this pacemaker is designed using SolidWorks and the electrical circuit for the same is simulated using Simulink.

1. Introduction

Over the past decade, there have been tremendous improvements in the field of medical devices. The growth of micro technologies and low power consumption circuits made it possible for making efficient implantable devices that can be used for diagnosis and treatment purposes for several diseases. Implantable medical electronic devices (IMEDs) are one of the crucial medical technology that is majorly being used for the treatment purposes of various diseases. These are devices that will be implanted inside the human body will help in the proper functioning of the affected system. Cardiac pacemakers, ventricular assist systems are some of the commonly used IMEDs [1]. Cardiac Pacemaker is one such implantable medical device being used widely by many heart patients. It helps in treating a variety of heart-related disorders and conditions which include bradycardia and cardiomyopathy. In such diseases, the muscular membrane of the heart is affected hence the cardiac conduction system gets affected. Due to which the electrical signals that travel from top to bottom of the heart take place irregularly or stops in critical cases. These signals are responsible for the pumping of blood. In such conditions using a cardiac pacemaker low energy electrical pulses can be sent to the heart by implanting it in the patient's body. They help in regulating the pumping of the heart under such conditions [2] [3]. The pacemaker is used by millions of patients and every year the number keeps increasing at a phenomenal rate. However, these IMEDs help to solve and treat such conditions they still seem to have certain drawbacks and cause complications under several conditions. These are generally bulky and cause discomfort due to the bulkiness of the batteries yet they have a short lifespan and low energy density. Apart from these batteries tend to self-discharge and other defects as...
they are implanted inside the human body [4]. An average pacemaker battery generally lasts for five to six years depending on the usage and recent improvements in battery technology have improved this life to ten years. But still, after that, the patients have to undergo another surgical procedure to replace the battery. This causes extreme discomfort in old and diabetic people who are the major users of the pacemakers [5]. Self-sustaining systems with help of an energy harvester can be a good solution to overcome this drawback and help to improve the working of the pacemaker. Various energy harvesters can help harvesting energy from the stretching of muscles to the beating of the heart, and this energy can be used for powering the device. In this study, triboelectric energy is harvested from the pacing of the heart using a triboelectric nanogenerator (TENG). This energy is then used to power the pacemaker so that the longevity of the pacemaker can be extended to the maximum [6].

2. Methodology

A pacemaker is a small implantable medical device mainly used for treating cardiac conditions related to the pacing of the heart. They are implanted near the chest or abdomen region. A pacemaker body consists of three main parts which include the battery, leads, and the outer covering. The battery is used for storing the energy required by the pacemaker for regulating the pacing of the heart. The outer covering also called the casing is made up of biocompatible materials such as titanium or titanium alloys. Its main function is to enclose the microelectronics and other active sensors which are responsible for the working of the pacemaker. Finally, the leads are long wires that run through a large vein from the heart and directly lead to the heart [7]. These leads help in transmitting the electrical signals from the pacemaker to the walls of the heart. The functioning of a pacemaker depends on the patient cardiac condition, as for different conditions different kinds of pacing will be required. Hence the sensors present in the pacemaker help monitoring the condition the heart is undergoing and if it senses any kind of disturbance such as the pacing of the heart slows down then electrical signals are sent to the heart with the help of the leads which stimulates the heart and makes it function properly. These electrical signals are produced by the battery present in the pacemaker [8]. Since the battery can’t be changed often this battery usage has to be optimized or a different and more sustainable source of energy needs to be used for the pacing of the heart. Therefore, in this study for powering the pacemaker triboelectricity is used. Tribo-electricity is a kind of charge that is generated by a process called contact electrification that is certain materials when separated from one another become electrically charged. In this pacemaker to bring out such an effect, a nanodevice called a triboelectric nanogenerator (TENG) is used which harnesses electricity from the pacing or the up and down movement of the cardiac muscles using the same effect. This energy is then stored in a rechargeable battery subsequently used for working the pacemaker [9] [10].

![Figure 1 – Energy flowchart of triboelectric pacemaker](image-url)
As shown in figure 1 the TENG implanted in the walls of the heart converts the mechanical energy of the cardiac muscles during the pacing of the heart into electricity. This energy is then sent to the rechargeable lithium-ion battery for storage of the energy since the amount of energy that is generated in a single cycle is slightly more than the energy required for the pacing of the heart some amount of energy is used directly for pacing and the rest is stored in the battery for back up in case of functional failure. In this study, the pacemaker was designed using the SolidWorks 2020 software [11].

2.1. Model Design

Unlike a conventional pacemaker instead of three main parts that is the outer casing, leads, and the battery in this design there will be an additional unit called the TENG which will also be running through the veins along with the leads to the cardiac walls. The TENG is a nano energy harvester which is a feasible solution for converting a small amount of mechanical energy into electrical energy [12]. For this purpose, the small amount of electricity generated is will be enough for the proper functioning of the pacemaker. Figure 2 and Figure 3 represent the model of the pacemaker designed.

![Figure 2: Modelling of the triboelectric pacemaker](image1)

![Figure 3: Outer casing and internal view of the triboelectric pacemaker](image2)

| Part            | Material / specification                  |
|-----------------|------------------------------------------|
| Outer casing    | Titanium                                 |
| Teng            | Composite of Polymers, Metals, and Inorganic materials |
| Leads           | Silicone rubber                          |
| Teng connector  | Polyurethane                             |
| Battery         | Lithium                                  |
| Electrode       | Titanium                                 |
| Circuit board   | Lithium-Carbon, Lithium-Iodine, Mercury  |
Table 1 contains the list of parts and materials used while designing the pacemaker. The main body or the outer casing of the pacemaker is made up of Titanium. The mechanical properties and chemical composition of the same are given in tables 2 and 3. The used material is biocompatible, when implanted inside the human body it will not cause any adverse chemical reactions [13].

**Table 2: Mechanical properties of Titanium used**

| Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (% min) |
|------------------------|----------------------|-------------------|
| 220                    | 240                  | 54                |

**Table 3: Chemical Composition properties of Titanium used**

| Element | O  | Ti  | Fe  | C  | N  | H  |
|---------|----|-----|-----|----|----|----|
| %       | 0.25 Remainder | 0.30 | 0.08 | 0.03 | 0.015 |

2.2 Circuit Design

For this study, a circuit diagram has been designed using Simulink and the circuit diagram is the pacemaker is shown in figure 4. In the initial section of the simulation setup, a DC voltage is included in the circuit. This DC voltage acts as the power source for the circuit setup. The current is passed through the triboelectric nanogenerator unit. Followed by it, it is passed through the converter, through which the data is fed to the battery. After this, the circuit branches to become 2 sections. One section will be going to the battery and the other one to the inverter. The battery measures the voltage and also keeps a track of charging data. Hence, through the inverter, the ac supply can be powered and the load current can be measured [14] [15].

**Figure 4: Circuit diagram of the pacemaker**

The working mechanism of the triboelectric nanogenerator is mainly based on contact charging and electrostatic induction. When an external force is applied to the TENG, the two triboelectric materials come in contact and the charge will transfer between the two materials. In this condition, one of the material surfaces that possesses a strong electron-attracting ability will produce negative charges. Positive charges will appear on another surface. When the external force is released, an electric potential difference is established because of a separation of the two materials [16].
3. Result and Discussion

The results can be discussed in two aspects. The structural and the electrical aspect. By performing the structural analysis, the strength and capacity of the pacemaker casting and the overall structure are analysed. Along with it, the results of the electrical simulation performed are discussed to know the nature of the circuit present.

3.1. Structural Analysis

As a part of structural analysis, 3 major tests were performed. Figure 4 depicts the Von Mises analysis; Figure 5 indicates equivalent displacement analysis and Figure 6 represents strain analysis done on the pacemaker. These tests were performed to analyse the structural behaviour of the pacemaker and to see its capacity and thus to make sure that the user is not operated with an unsafe device that might affect his or her health physically. These tests were performed applying the human muscle force on the surface of the pacemaker to find the deformation. It can be seen that there is a very minute impact of the strain and von mises stress on the pacemaker. The equivalent displacement analysis depicts that the deformation is evenly distributed and does not affect the circuit region of the pacemaker. This indicates that the pacemaker is safe to be implanted inside a human body and it will not create any sort of physical disturbance or injury.

Figure 5: Von Mises analysis of the pacemaker

Figure 6: equivalent displacement analysis of the pacemaker
4. Electrical Simulation

The electrical aspect of the pacemaker has to be carefully tested to analyse the capacity of the TENG. The rechargeable battery is to be powered by the TENG and therefore, the battery is tested for its rechargeability. 4 output plots were obtained by running the simulation. Figure 8 depicts the DC output voltage plot, Figure 9 indicates the battery charging and battery voltage graph, Figure 10 represents the load vs voltage plot and Figure 11 depicts the load vs current graph. It can be observed that the output of the DC voltage is high (spikes in the graph denote the same) and thus this highlights that this setup can be used to generate energy to charge the battery. The difference in the voltage of the battery (spikes are formed due to the voltage difference) indicates that the battery can charge from the TENG energy source. A typical feature of the TENG is a high voltage and a low current. Through this process, the energy generated is 0.496 µJ. The required amount of energy for pacing is 0.377 µJ. In this way, the heart can be paced using the energy obtained through TENG.
5. Conclusion

Cardiac pacemakers and other implantable medical devices are currently among the most crucial devices for treating various diseases. Technological development to improve the functioning and reliability of these devices are a must in the current scenario. In this study, it has been observed that triboelectricity can be a viable option for a self-sustaining source of energy rather than a battery. With the basic simulation and analysis were done in this study, it has been observed that energy can be harvested with the help of cardiac pacing and can be used for the working of the pacemaker. Employment of such a technology can be of great advantage to those patients who need to use pacemakers but cannot afford to undergo subsequent surgeries for battery change due to economic or medical conditions. Being a sustainable alternative, it also helps in reducing the battery waste seen in a conventional pacemaker. With further studies and experimenting on this concept and design, such a concept can soon be a reality.

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