Abstract— The major drawbacks of current pacemaker are the battery replacement. Patient will need additional surgery to replace the pacemaker unit with the new one. It has been suggested to use rechargeable battery to solve this issue. Recharging a battery within the body, however, is not viable owing to the lifetime of tissue heating and battery charging. For these purposes, the use of piezo-polymer is appropriate as a power harvester for a self-powered pacemaker. Piezo-polymer was commonly used for energy harvesting, but none for implantable cardiothoracic devices. This study focuses on identifying the optimum location on the heart to put the piezo-polymer. This research is conducted by simulation of left ventricle of heart via ANSYS. Heart stress-strain Finite Element Analysis (FEA) are employed to obtain the maximum harvested power. The result shows the location of myocardial contraction that produces sufficient kinetic energy for the placement of the pacemaker. The heart 3-dimensional images are taken from cardiac-CT or cardiac-MRI to search the optimum location on the heart for energy harvesting and minimize pacing energy. Left ventricle electronics model is created to represent the movement of the left ventricle and how piezo-polymer works. In conclusion, the left ventricular wall movement and deformation induced by the movement of the cardiac wall were analyzed in the simulation using the left ventricular model to obtain the place of the peak kinetic energy.

Keywords— Left Ventricle Simulation, Heart Three Dimension Mechanical Simulation, Simulation, Kinetic, Energy.

I. INTRODUCTION

Pacemaker is used to regulate an abnormal heart rhythm by offering electrical stimulation to the heart and causing core contractions [1]. Pacemaker is required when a malfunction occurs in the heart electrical system. Approximately 560,000 pacemaker implantations in North America and 680,000 in Europe were estimated in 2007 [2]. From 2011 to 2016, the Pan-African Cardiology Society (PASCAR) gathered information from 31 African nations on invasive management of cardiac arrhythmia. The result shows that eight of the 31 nations surveyed (26%) did not carry out implantations for pacemakers. The average implantation frequency for pacemakers was 2.66 per million people per nation (range: 0.14–233 per million people) [3]. This proof has shown that pacemaker is an important thing for patients with heart failure. A leadless pacemaker has been launched by a latest sophisticated technology to replace the traditional pacemaker. The significant disadvantages of the present pacemaker after a couple of years are battery substitution. To replace the pacemaker unit with the fresh one, patient will need extra surgery. Use of rechargeable battery was suggested to solve this issue. Recharging a battery within the body, however, is not viable owing to the lifetime of tissue heating and battery charging. For these purposes, the use of piezo-polymer is appropriate as a power harvester for a self-powered pacemaker.

Piezo-polymer has been widely used as energy harvesting but none for cardiothoracic implantable device. This study focuses on specific location of heart. The proposed fundamental research aims to identify the optimum location on the heart epicardium that able to generate energy for any sensors. Conventional and leadless pacemaker used non-rechargeable, long-life, and high-density battery to supply the power that lasting less than 10 years. A new method of energy harvesting is introduced by harnessing physiology
sources of human body. Energy harvesting by using piezoelectric material is theoretically feasible to provide energy for implantable device.

However, there is not enough study to optimize the piezoelectric material to provide sufficient energy for epicardial pacemaker. The force from myocardial contraction and relaxation could provide the sensor such as the piezoelectric sufficient power to supply epicardial pacemaker with small dimension. This needs identification of the best harvesting placement.

Existing conventional and leadless pacemaker prototypes use non-rechargeable, long-life, and high-density battery to supply the power. One of the drawbacks is, for example in paediatrics, the battery still needs to be replaced after couple of years, which means additional surgery to take out the pacemaker unit. To overcome this problem, utilization of rechargeable battery has been proposed.

Recharging method is one of the problems of using rechargeable batteries for pacemaker. Unlike the lead-based pacemaker battery, which is situated just below the patient's skin inside the generator, leadless pacemaker battery is situated inside the heart chamber; therefore, wireless charging is hard. A technique has been proposed by using radio frequency (RF) [4]. RF requires room for power transmission antenna, however, it is not feasible for leadless pacemaker of tiny size.

In addition, power transmission effectiveness via RF is very small, with mostly heat dissipation passing through tissue. The implanted battery charging scheme based on ultrasound has been proved by [5]. Successfully collected 600mW through 10–15 mm of tissue depth through their in-vitro test. The drawback is power transmission using ultrasound can only be limited to a certain time due to heat effect on tissue. Tissue heating is also occurred in RF technique. The other problem comes up with usage of rechargeable battery is the life-time of the battery, which decreases in line with the number of charge-discharge cycles.

By these reasons, in our opinion, both RF and ultrasound techniques are not suitable for long term battery recharging system, and therefore, not suitable for leadless pacemaker.

The ideal concept of leadless pacemaker is “Implant and Forget”. In other words, the pacemaker needs to be self-powered. For this purpose, a continuous electrical power supply from energy harvester is an essential factor. The power may be obtained from several sources, such as: sound, solar, body heat, breathing, movement [6], muscle, joint movement, and glucose-based biofuel cell. Piezoelectric materials are one of the emerging concepts to provide self-energy harvested from human body. There are a number of materials that exhibits piezoelectric properties, either natural or synthetic materials. One of the promising materials for the pacemaker energy harvester is polymer piezoelectric (piezo-polymer). Although its electromechanical coupling factor is not as high as ceramic-based, piezo-polymer is biocompatible and more mechanically flexible, both are very important factors for implanted medical devices.

Energy harvesting by using piezoelectric materials may result in sufficient energy for pacemaker depending on the properties they have. One of the hypotheses provided by [7] has estimated that the power resulted from piezoelectric materials from heart movement could achieve hundreds of µJ.

To obtain maximum output power from a piezo-polymer-based energy harvester, its resonance frequency needs to be set as close as possible with the ambient operating frequency [8]. An approach was performed by [9][10]. They adjusted the piezo-polymer through a corrugation-shaped structure to keep the harvester work optimally in ambient vibration frequency. Another approach was based on topology optimization in order to adjust harvester resonance frequency [11]. However, those researches are based on cantilever-structured piezo-polymer which is not suitable for epicardial pacemaker application due to its low output power as well as its difficulty to be miniaturized [7]. Proper methods for this specific application need to be investigated.

This study will involve 2 types of software which are Solidworks and ANSYS to design and running the simulation. The design of the geometry is a complete structure of heart. But the only part that will undergo the simulation is the left ventricle. The structure of the design is created by using the information according to [12] the heart size is usually described as the size of its individual fist, with typical values of 120 mm in length, 80 mm wide and 60 mm in thickness. The cardiac muscle of the left ventricle is assumed as homogenous tissues with the thickness value of 12 mm [13]. The simulation result is then compared with the images of Cardiac-MRI or Cardiac-CT. On the other hand, the result will be calculated to get the actual values of kinetic energy produced. This research would be the fundamental to create a self-powered pacemaker. The force from myocardial contraction and relaxation could provide the sensor such as the piezo-polymer for sufficient power to supply the pacemaker with small dimension.

II. METHODOLOGY

For this research, there are several steps are carried out in order to achieve its objective. The approaches that have been performed are designing, simulation and calculation. The left ventricle is design in 3 dimension and simulated by using the chosen platform. Based on the simulation result, every single data of the geometry deformation will be calculated to obtain the kinetic energy by using the kinetic energy formula. For the validation, the simulation result has been compared with the cardiac-CT or cardiac-MRI data that has been collected.

A. Data Collection

For the purpose of this research, the data is collected for designing and running the simulation. There are 2 types of data which is the pre-processing data and post-processing data. The pre-processing data is collected in order to design the structure of the heart, according to the real organ. The data includes the dimension of the heart, the density and Young Modulus. The collected data will be inserted as the engineering data inside the simulation software.

The heart is shaped like a cone. The foundation was up and tapering down to the apex. The heart's biggest compartment is generally slightly left side of the chest, although it can rarely be offset to the right. An adult heart usually has a weight of 250-350 grams in anger. Usually the heart size is described as the size of the individual fist, with typical length values of 120 mm, 80mm wide and 60mm in thickness [12]. While this description is controversial, the
heart may be slightly larger [14]. The left heart is bigger and stronger. Pumping and distributing the blood to all areas of the body has a thicker muscle.

![Heart dimension image](image)

Fig. 1. The dimension of heart.

The heart dimension in Figure 1 is obtained from each atrium and ventricle's cross diameter. The significant female cross diameter of the left ventricle is $45.2 \pm 3.4$ mm diastolic and $30.5 \pm 3.5$ mm systolic for the assessment of ventricular dilation. It's $30.7 \pm 3.8$ mm diastolic and $22.3 \pm 3.8$ mm systolic for the correct ventricle.

The appropriate thickness of the septal wall measured in the brief axis of the left female ventricle is about $8.0 \pm 1.0$ mm diastolic and $10.9 \pm 1.4$ mm systolic to determine a left ventricular hypertrophy. Meanwhile, the measurement is $51.6 \pm 4.6$ mm diastolic and $33.8 \pm 3.6$ mm systolic for the masculine left ventricle cross. It's $37.1 \pm 5.9$ mm diastolic for the correct ventricle and $2.1 \pm 4.4$ mm systolic.

The corresponding septal wall thickness for left ventricular hypertrophy is $9.9 \pm 1.2$ mm diastolic and $13.6 \pm 1.9$ mm systolic [15]. The normal heart size values measured in males are generally greater than the heart size values measured in females. However, owing to practice and extensive training, well-trained athletes can have much bigger hearts and it affects the heart muscle, comparable to the response of skeletal muscle [12].

B. Design

The geometry is constructed in 3-Dimension model of heart using Solidworks software. The shape of heart is created by combining the triangular facet until it is become an enclosed geometry. Figure 2 shows the design of the heart.

![Heart design image](image)

Fig. 2. Heart design.

After the full design of heart is completely built up, it is cut into four sections. The figure 3 shows the design of left ventricle.

![Left ventricle design image](image)

Fig. 3. Left ventricle design.

C. Simulation

The shape has only the outermost layer surface that represents the wall of the core. The geometry is then saved as an IGES file to be imported into the Finite Element Analysis (FEA) software of ANSYS 16.0. The Dynamic Explicit is chosen for simulation due to the time-varying behaviour of the research of the core. In the software, it is compulsory to select the engineering data, select the geometry surface, and set the boundary condition. Table 1 shows the engineering data that has been used in ANSYS.
Table 1: The Engineering Data for the simulation.

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus (MPa)</td>
<td>30</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1037</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.4</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>12</td>
</tr>
</tbody>
</table>

The Post-processing data is the data that is the result provided after the simulation running. The provided data is the information regarding the location and the kinetic energy. The post-processing data is used for the analysis of the left ventricle.

III. RESULTS

A. Simulation

The results of finite element analysis are presented in Fig. 4 where the location of kinetic is formed. The result of the total deformation shows the colour contour that represents the movement of the left ventricle. The force from myocardial contraction and relaxation could provide sufficient power of kinetic energy for the observation.

![Fig. 4. Total deformation of left ventricle](image)

B. Calculation

The kinetic energy is calculated by using the formula.

\[
\text{Kinetic Energy} = \frac{1}{2} m v^2
\]

Where;
\( m \) = mass of the left ventricle.
\( v \) = velocity of the left ventricle.

General equation for velocity:

\[
\text{Velocity} = \frac{\text{Distance}}{\text{Time}}
\]

For equation (1), the mass of left ventricle is approximately 0.147 kg [16]. Since the maximum distance is assumed as 2 cm per beat, the value of velocity, in equation (3), depends the heart rate reading. The heart rate is the speed of the heartbeat measured by the number of contractions of the heart per minute (bpm). The heart rate may differ depending on the physical requirements of the body.

C. Left Ventricle Electronics Model

Figure 5 illustrates the left ventricle electronics model. This electronic model is created based on movement of the left ventricle. The DC motor controls the spring movement. Piezo-polymer experience tension and generate certain value of voltage that can be displayed via oscilloscope.

![Fig. 5. Left ventricle electronics model](image)

IV. CONCLUSION

In conclusion, the myocardial contractility can produce sufficient force for energy harvester to provide sufficient power for epicardial pacemaker pulse generator. It is a huge benefit towards self-powered pacemakers. Plus, the kinetic energy produced by the left ventricle is depends on the value of the heart rate.

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