Design and fabrication of a low-frequency energy harvester for leadless pacemakers

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Abstract

In this paper, we present a solution for leadless pacemakers electrical supply based on inertial piezoelectric micro-generator that would allow the harvesting of a portion of the vibrational energy of the heartbeat. Based on the analysis performed on real cardiac signals, we have proposed the harvester optimal frequency range centered at 16 Hz. Constrained by this low frequency and small device size, we have defined the structure optimal dimensions requiring piezoelectric layers thicknesses in the range of tens of micrometers. The device optimal dimensions mainly resulted from an optimization that highlights the need for a new PZT layers fabrication technology. We present the work that has been done to develop a thick film fabrication technique (typ. 15 to 100 µm) by thinning thick layers of PZT. Finally, we show that the fabricated demonstrator vibrating at 16 Hz converts the electrical power from heartbeats reproduced in a laboratory experiment fulfills the requirements (10 - 15 µW) for the implementation of an energy supply solution for leadless pacemakers.

Introduction to leadless pacemakers (LPM)

The efficiency of the heart beat lies on the correct synchronization of the systole (contraction) and the diastole (relaxation) phases of different cardiac chambers (left/right atrium and ventricle). The sequence of phases is defined by the propagation of the cardiac action potential from the sinoatrial node to the Purkinge fibres.

Electrocardiographic examination is very useful in the analysis of cardiac cycle synchronization and the detection of cardiac rhythm and conduction abnormalities. For instance, the interval PQ corresponds to the time that separates the beginning of the atrial contraction (P wave) from the beginning of the contraction of the ventricular myocardium (beginning of the QRS complex). Thus, this interval indicates the quality of AV (atrioventricular) conduction. The QT interval, on the other hand, indicates the time between the beginning of the depolarization of the ventricular myocardium (beginning of the Q wave) and the end of the repolarization (end of the T wave). It defines the electrical systole of the ventricle. It is a fundamental electrocardiographic marker because of the link between duration and dispersion of QT and the survival of potentially fatal ventricular arrhythmias.

Field of application of cardiac pacemakers

A pacemaker is prescribed for patients who suffer from a failure of the natural electrical conduction of the heart or the sinus node and which no longer makes it possible to obtain spontaneous contractions at a satisfactory frequency. This type of failure usually results in symptoms such as syncope, dizziness, abnormal fatigue during exercise, and so on. It is generally identified precisely when examined by an electrocardiogram with abnormalities.

The pacemaker makes possible to impose a rhythm of beating to the heart by means of weak electrical pulses delivered on the heart muscle. Depending on the type of pathology treated, one or more stimulation sites can be determined.

In its current version, pacemakers are fully implanted. Stimulation pulses are generated by an electronic circuit located in a hermetic case and delivered to the heart muscle by means of special electrical leads. The leads connect the pacemaker to the heart via electrodes, placed at theirs ends positioned in contact with the heart tissue. The electrodes also allow the pacemaker to detect the heartbeat. Current pacemakers are thus able to detect the spontaneous activity of the heart. They trigger the stimulation only when necessary.

Short history of heart pacing

It is difficult to attribute the paternity of heart pacing. The work of L. Galvani and A. Volta on the effects of electricity on the muscles of the frog, and in particular his heart, nevertheless marked the beginning of electrophysiology at the end of the 18th century [Galvani 1791]. A century later, at the end of the 19th century, J.A. Mc Williams undertakes a synthesis of the works available on the subject. We owe him the identification of many cardiac problems, as well as the demonstration of the interest that the electrical pulses have for the treatments of these symptoms. He has thus established concepts that form a basis of current electrostimulation [Ward 2013].

It was not until around 1930, however, that first stimulation devices of a human heart were almost simultaneously presented by M. Lidwell (1928) and A.S. Hyman (1930). Through a transthoracic approach, they allowed a needle through a thorax to a heart, to deliver impulses in order to restart the heart after a failure. In 1950s, first devices for the preservation of the heart rhythm appeared.