Use Case Analysis of Wiegand-based Energy Harvester in Mechanical Sensing Devices

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Abstract— Conventional energy harvester approaches using magnetic-inductive technologies are often realized as mass-spring systems. Due to the small resonance-bandwidth of such systems, bistable magnetic wires can be a sound solution for slow and sporadic movements. On this issue, a pressure sensor system is adapted with a so-called Wiegand-harvester to implement self-sufficient electrical feature functionalities. The Wiegand-harvester consists of an inductor coil mounted on an amorphous Vicalloy-Core (CoFeV). The large characteristic Barkhausen jump of the alloy is used to generate voltage peaks in the pickup coil in a slow changing magnetic field. Contrary to mass-spring systems or periodical induction, only the value of the coercivity field (ΔH_{ce}) is relevant for generating an energetic voltage pulse to power an electrical circuit. This technology can be used in high transients as well as in nearly static environments. A use case analysis for a pressure gauge shows the benefit of Wiegand-based systems. The power supply source is realized by placing eight harvesters circular on a PCB. Thereby a single rotation of a spindle (360°) is quantized in eight steps. A second disk equipped with eight neodymium permanent magnets is mounted parallel to the PCB. So a twist of 45° delivers a multiplied pulse in each of the eight inductor coils. An electrical energy output of approx. 13.5 μWs and the twist-hysteresis of $0°2'$ could be achieved and verified using a magnetic FEM simulation.

1. INTRODUCTION

Motion based energy-harvesting systems using direct piezoelectric or inductive effect are often carried out as mass-spring systems. Therefore, the amount of harvested energy depends on the resonance frequency. However, systems based on large Barkhausen jumps (Wiegand effect [1, 2]) can be a sustainable solution to get voltage pulses in nearly zero speed applications. On this issue the longitudinal movement of a pressure sensor was translated to an angle of 0 to 360°. As a benefit, decentralized and battery-free sensor applications (mechanical sensing devices) can get additional electrical features by attaching a Harvesting-System based on those large Barkhausen jumps.

2. SENSOR ELEMENT

In this case a Vicalloy wire (FeCoV) with a diameter of 0.25 mm and a length of 12.5 mm was used as an energy harvesting system. Thermal and mechanical stress (tension, torsion) during the production leads to a low coercivity core and higher coercivity shell-layer (cold-worked process) [3]. Thus, the magnetization (orientation of the magnetic moment) of the layers is parallel. The exposure to an external magnetic field shows a large Hystersis B-H-Loop plot with a characteristic jump. A high external field leads to a parallel orientation of both layers (saturation case). Initially, a saturation field applied to the sensor ensures that both layers are polarized in the same direction. As a negative field is applied the outer hard core prevent the switching of the soft layer until a sudden shift in the soft layer appears. As the strength of the external field increases, also the hard layer switches its polarity. Especially the switching of the soft layer is quite rapidly (large Barkhausen jump cf. [4–6]). This phenomenon is commonly known as the Wiegand effect.

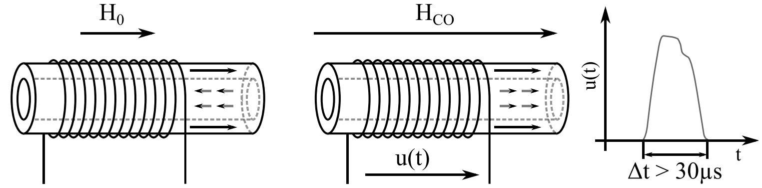


Figure 1: Domain change during increasing external magnetic field.

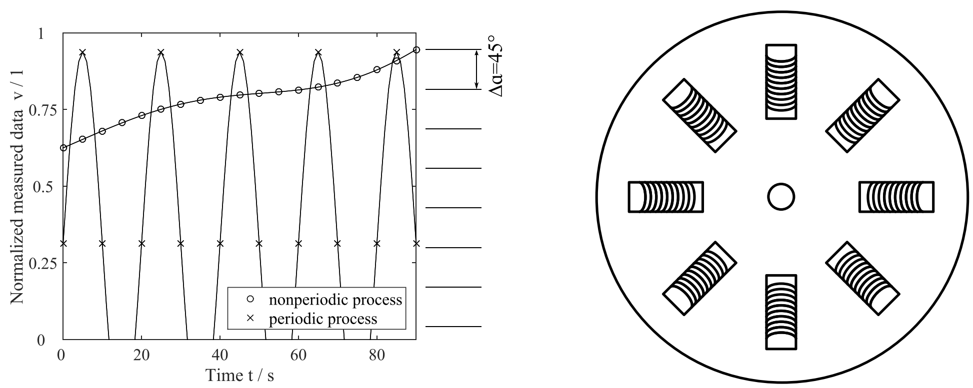
If a sensing coil is applied onto the wire, two different voltage pulses can be seen in one B-H loop. The voltage pulse only occurs at significant coercity values. In contrast to classic inductive harvester technologies with ferromagnetic cores, systems based on large Barkhausen jumps are nearly independent from the changing speed of the external magnetic flux $\frac{d\phi}{dt}$. (Equation (1)) shows the simplified output energy E_w of a harmonic induction circuit with a resistive load R_L, coil inductance L_C and windings N.

$$E_w(t) = \int_0^t \frac{N^2}{R_L + j\omega L_C} \left(\frac{d\phi(t)}{dt}\right)^2 dt \tag{1}$$

Due to the core characteristics, the parameter $\frac{d\phi(t)}{dt}$ can not be substituted by a harmonic forcing function (that depends on the characteristic jump and domain propagation). The energy output of a Wiegand system can be approximated by [7].

3. PROTOTYPE AND EXPERIMENTAL RESULTS

Mostly, non-electronic sensor are used in decentralized environment for visual monitoring or safety functionalities. An example of a use case is mechanic pressure gauge adapted on a tank to supervise the pressure. If the pressure is above a given limit, the sensor should control a safety valve. As the pressure of the tank is almost constant, a frequency optimized energy harvester is infeasible. In this case a Barkhausen sensor can be used as a sound solution to measure and control local tasks.



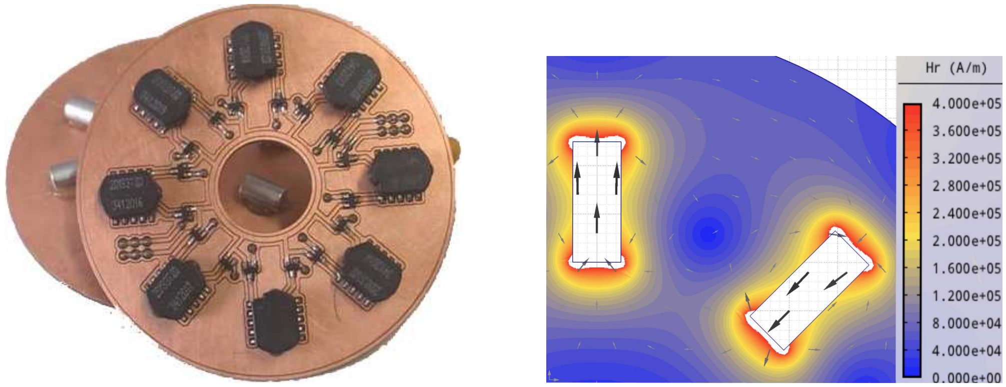
(a) Measure Scenario for slow and periodic processes (b) Wiegand orientation

Figure 2: Measure scenario for slow and periodic processes and quantisation.

Upon the harvesting element (Co. Werap, Ch), a simple measurement application for mechanical sensing devices was developed. A small longitudinal movement (i.e., 3 mm) was translated to an full turn angular motion (Fig. 2). Two congruent disks were manufactured and positioned on top of each other. The stationary disk was assembled with eight neodymium ($Nd_2Fe_{14}B$) magnets-the moveable part is equipped with eight Wiegand-sensors. The developed prototype uses a packaged Wiegand-sensor (Co. Werap), that is not specified in detail. The eight neodymium magnets are in circular position on top of the movable disk and generate external magnetic fields upto ($H_e = 160\frac{kA}{m}$). To minimize jitter and maximize the energy output the magnets are assembled anti-parallel. So the field gradient between the magnets is as high as possible. In this case, the rotation of 45° leads to a induction pulse in the sensing coils, which marginal depends on the rotational speed. The superposition of the eight energy pulses can be utilized to drive a small electrical circuit. In this experiment an energy output of $E_O = 13.5\,\mu\text{Ws}$ by a full turn was stored in capacitors (accumulated). In this case the optimization of the power output and stabilization of the voltage is not investigated.

4. VERIFICATION AND SIMULATION

Due to the reduction of the hysteresis effect and the synchronization of the induced pulses in the sensing coils, a stationary FEM simulation of the neodymium disk (Fig. 3(b)) has been created. A high field gradient (∇H_e) between the magnets improves the synchronized pulse generation significantly. The anti-parallel orientation of the magnets ensures this behavior. As a result, the Wiegand-sensors on the stationary disk toggles between two saturation states (cf. B-H loop) quickly. The prototype shows a hysteresis, by changing the rotational direction, of approx. $0°2'$.



(a) (b)

Figure 3: (a) Magnetic Harvesting PCB. (b) FEM Simulation of the neodymium magnets.

5. CONCLUSION

The experimental behavior meets perfectly the requirements for non-periodic mechanical sensors. All sensing instruments, that are converting a physical parameter (temperature, pressure etc.) into a translational or rotational movement, are suitable to be powered by such an harvesting system. Nevertheless, the energy output is not yet sufficient for powering complex electrical circuits.

ACKNOWLEDGMENT

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