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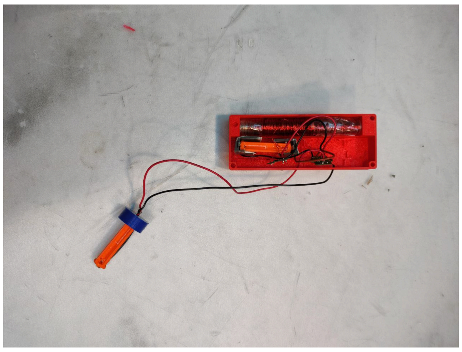
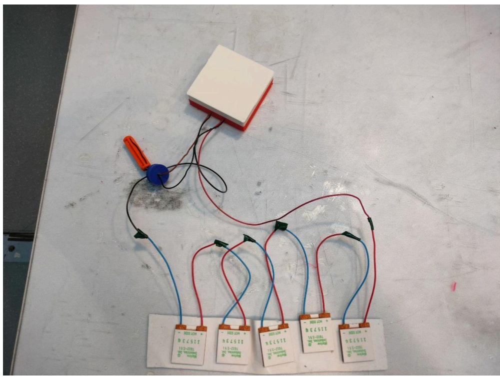
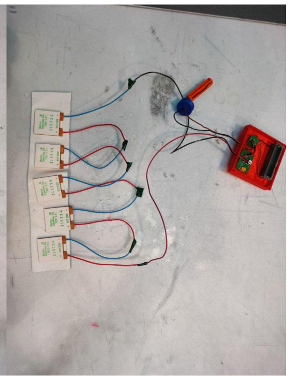
ELEC-D0301 Protopaja
2024

Väliraportti / Loppuraportti

Project
Wearable Battery Booster

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Tiivistelmä

Projekti tehdään yhteistyössä Savoxin kanssa ja tavoitteena on valmistaa akkutehostin heidän melua vaimentaviin kuulosuojaimiin. Järjestelmän tulisi toimia AAA-paristojen kanssa, jotka jo antavat virtaa kuulokkeille, jotta kuulokkeiden akun käyttöikä pitenee. Projektiryhmä otti käyttöön useita erilaisia lähestymistapoja ja alkuperäinen tavoite on vertailla eri kokeissa saatuja tuloksia. Jos lähestymistapa todetaan käyttökelpoiseksi, tiimi jatkaa työskentelyä sen parissa oikean prototyypin kehittämiseksi. Tutkitut ja kehitetyt lähestymistavat ovat olleet tribo sähköinen vaikutus, pietsosähkö, lämpösähkö ja liike-energiasta kerätty sähkö. Tribosähköistä menetelmää pidettiin käyttökelvottomana jo varhain ennen tilausten tekemistä. Pietsosähköinen menetelmä huomattiin nopeasti tehottomaksi moduulien ensimmäisissä testeissä. Sähkön keräämistä liike- ja lämpöenergiasta kehitettiin eteenpäin, sillä molemmilla oli lupaavia tuloksia. Kineettinen lähestymistapa tehtiin sähkömagneettisen induktion avulla. Lähestymistavassa tiimi on ajatellut magneetin asettamista kelaan ja käyttäjän kävelyn aiheuttama tärinä liikuttaisi magneettia kelan sisällä ja tuottaisi sähköä. Toinen kineettinen lähestymistapa oli kiinnittää heiluri tasavirtamoottoriin ja kävely ja päänkäännökset heluttavat heiluria, mikä indusoi virran moottorissa ja antaisi virtaa kuulokkeille. Lämpösähköinen lähestymistapa on kiinnittää lämpösähkö moduuleja käyttäjän iholle ja käyttäjän kehon ja sitä ympäröivän ilman lämpötilaero synnyttäisi virran. Vaikka tavoitteena oli tehdä toimiva prototyyppi, ryhmä on tullut siihen tulokseen, että pelkkä tutkimus olisi erittäin arvokasta, vaikka prototyyppi ei olisi täysin toimiva.

Abstract

The project is being carried out in collaboration with Savox, with the goal of developing a battery booster for their noise-cancelling ear protectors. The system is intended to work with AAA batteries, which already power the headphones, to extend the battery life of the headphones. The project team has implemented several different approaches, with the initial aim of comparing the results obtained from various experiments. If an approach proves to be feasible, the team will continue working on it to develop a functional prototype.The approaches researched and developed include triboelectric effects, piezoelectricity, thermoelectricity, and electricity harvested from kinetic energy. The triboelectric method was deemed impractical early on, before any orders were placed. The piezoelectric method was quickly found to be ineffective in the initial tests of the modules. The harvesting of electricity from kinetic and thermal energy was further developed, as both showed promising results.The kinetic approach was based on electromagnetic induction. In this approach, the team considered placing a magnet inside a coil, where vibrations caused by the user's walking would move the magnet within the coil, generating electricity. Another kinetic approach involved attaching a pendulum to a DC motor where, as the user walks and turns their head, the pendulum would swing, inducing a current in the motor and powering the headphones.The thermoelectric approach involves attaching thermoelectric modules to the user's skin, where the temperature difference between the user's body and the surrounding air would generate electricity. Although the goal was to create a working prototype, the team has concluded that the research itself would be highly valuable, even if the prototype isn't fully functional.

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1. Introduction / Johdanto

In this report the work done so far by the Savox battery team will be documented. The plans on how to move forward will also be listed and reflected on. The report follows the report template found in the courses mycourses page.

The task given to the team was to design a battery booster for a noise canceling hearing protection headset. The topic was given by a company called Savox and the team is using a Savox headset as a reference for the design. The scope and functionality of the project and the prototype was left quite open ended in the beginning. Even a small increase in battery life would be seen as a success and the team has focused on research and making a proof of concept for multiple ways to possibly extend battery life. While the original task was to generate electricity from kinetic energy, other ways of generating electricity like the piezoelectricity, thermoelectric power generators and the triboelectric effect have been considered with some being more promising than others.

The first month was spent mostly researching and brainstorming ideas. Some ideas have been discarded during this phase due to the research showing that the method did not work with our design effectively. The first orders were placed in the beginning of july. Very quickly after getting the first orders the team noticed that some methods would not produce realistically enough power for the headset.

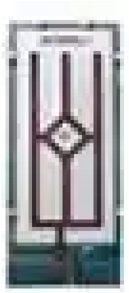
2. Objective / Tavoite

After discussions with Savox and a thorough exploration of available technologies, we defined the objectives of our project as follows:

- **Determine Power Generation Potential:** Assess how much power can realistically be generated using the various methods explored, including kinetic energy, piezoelectricity, thermoelectric generation, and the triboelectric effect.
- **Test Energy Generation Modules:** Integrate each energy generation method into a circuit and test it with the corresponding energy harvesting integrated circuit (IC) to evaluate efficiency and practicality.
- **Evaluate Feasibility for Battery Charging:** Based on the testing results, determine whether the generated power is sufficient to meaningfully charge the battery of the headset, and provide a conclusive recommendation on the viability of this approach.

3. Results Piezoelectric

After the first orders arrived the piezoelectric modules were tested. The tests were done by bending the module and seeing how much current it generated from frequent flicking and bending. It was quickly noticed that, while wearing the headset the module would not bend nearly as much as in tests and during the tests the module did not generate the required amount of electricity to give any significant power boost to the battery. The generated power from normal human head movement is so insignificant that it can’t power the power management IC, the LTC3588, which is an ultra-low power IC for application with small piezoelectric elements.



Picture 1. Piezoelectric module.

4. Results Thermoelectric

Thermoelectric generator

Thermoelectric generators (TEGs) are devices that convert heat energy directly into electrical energy when there is temperature difference between the two sides of the module. In this project, we aim to create a wearable band that generates energy from the small temperature difference between the human body and the environment, therefore our main criteria for choosing the modules are slim design and high sensitivity.

Measurements & Evaluation

Two different TEG modules, the TG12-2.5-01LS and the Laird Thermal Systems 387004705, were chosen for this project, and measurements of Voltages and Currents generated from body heat (primarily hand palm) were recorded in this tables:

Measurements of one module with heatsink attached to the cool side: (max value reached), room temperature: 23℃, body temperature around 35℃, hand contact

TG12-2.5-01LS (Voltage - Current)	Laird Thermal Systems 387004705 (Voltage - Current)
130mV - 10mA	78mV - 8mA
165mV - 9.12mA	55mV - 6.1mA
172mV - 9.6mA	60mV - 6.3mA

140mV - 10.5mA	40mV - 5mA
…	…

The TEG module: TG12-2.5-01LS proved to be more well suited to our project, so it will be the main module we use from now on. The plan is to have 5 of these connected in series and then to an harvester module to boost the generated power enough for charging the headset's battery.

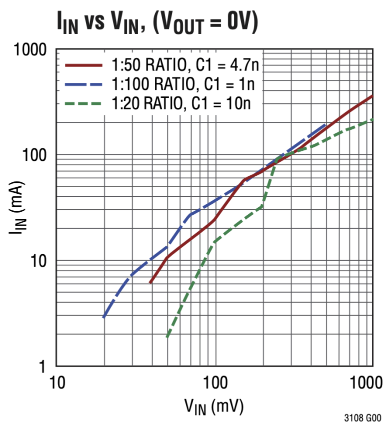
Measurements for a series of 5 TEGs, body temperature around 36℃, neck contact:

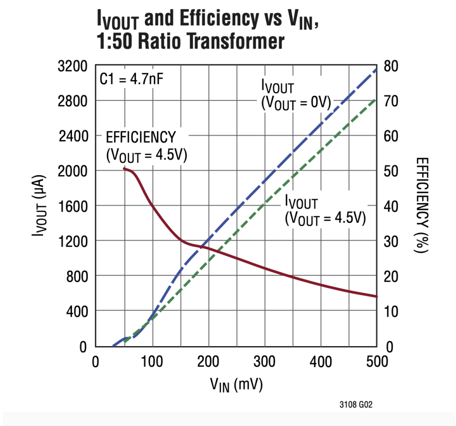
25℃ room temperature	0℃ room temperature
2.5 mA at 310mV	20mA at 1V
2.8 mA at 250 mV	22mA at 1.2V
Other measurements fluctuates very slightly around 2.5mA at 260mV	Other measurements fluctuates very slightly around 20mA at 1V

Table 1.

Results Harvester Module

The Harvester module for harvesting energy from the thermal electric generator has been developed and sent for manufacturing at JLCPCB. The heart of the module is the LTC3108 IC from Analog Devices. When used with a 1:50 transformer, the module can produce a regulated 2.35V output from input voltage ranging from 100mV to 1V. The DC input is labeled J1, while the DC output is labeled J2. The theoretical performance of the module is shown in figures below



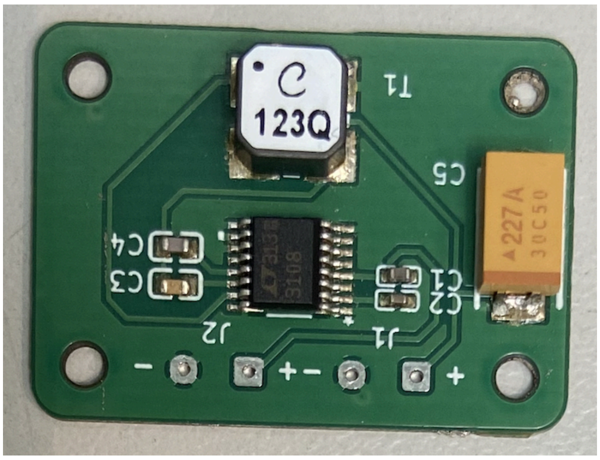


.Figure 1 and 2.

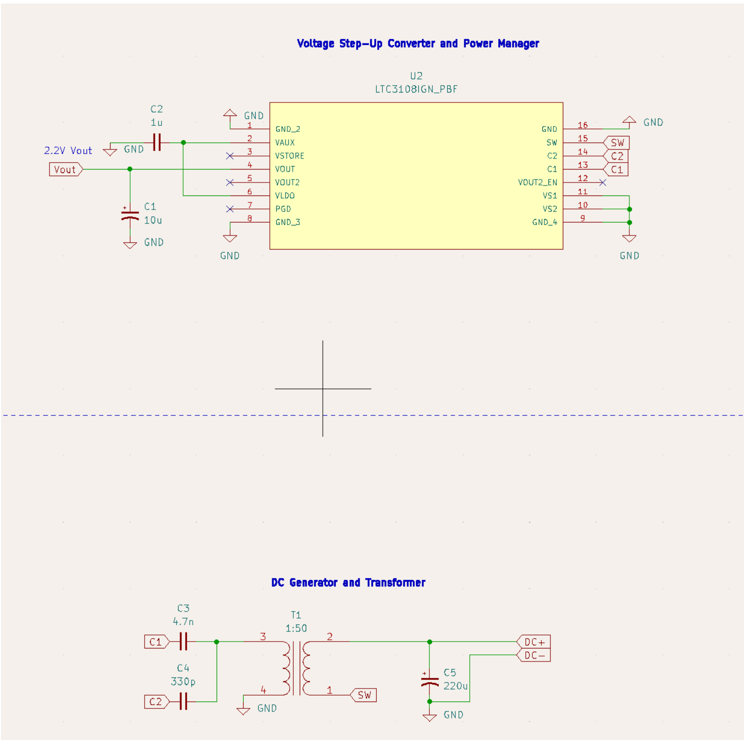
The harvester module was then connected to the band of 5 TEGs and the output was then measured. Two different transformers, the 1:20 and the 1:50, were used in this measurement with the harvester module:

- With LTC3108 Harvester Module and 1:20 transformer - 0℃ room temperature, 36℃ body heat, neck contact : < 0.01 mA closed circuit and 1V open circuit (Not normal operation)
- With LTC3108 Harvester Module and 1:50 transformer - 24℃ room temperature, 36℃ body heat, neck contact: 0.78 mA at 2.35V maximum

A few more measurements were made but the results vary very slightly. Overall, this is a promising approach. The solution could power low power microprocessors like the STM32L0 series and the PIC12F508.

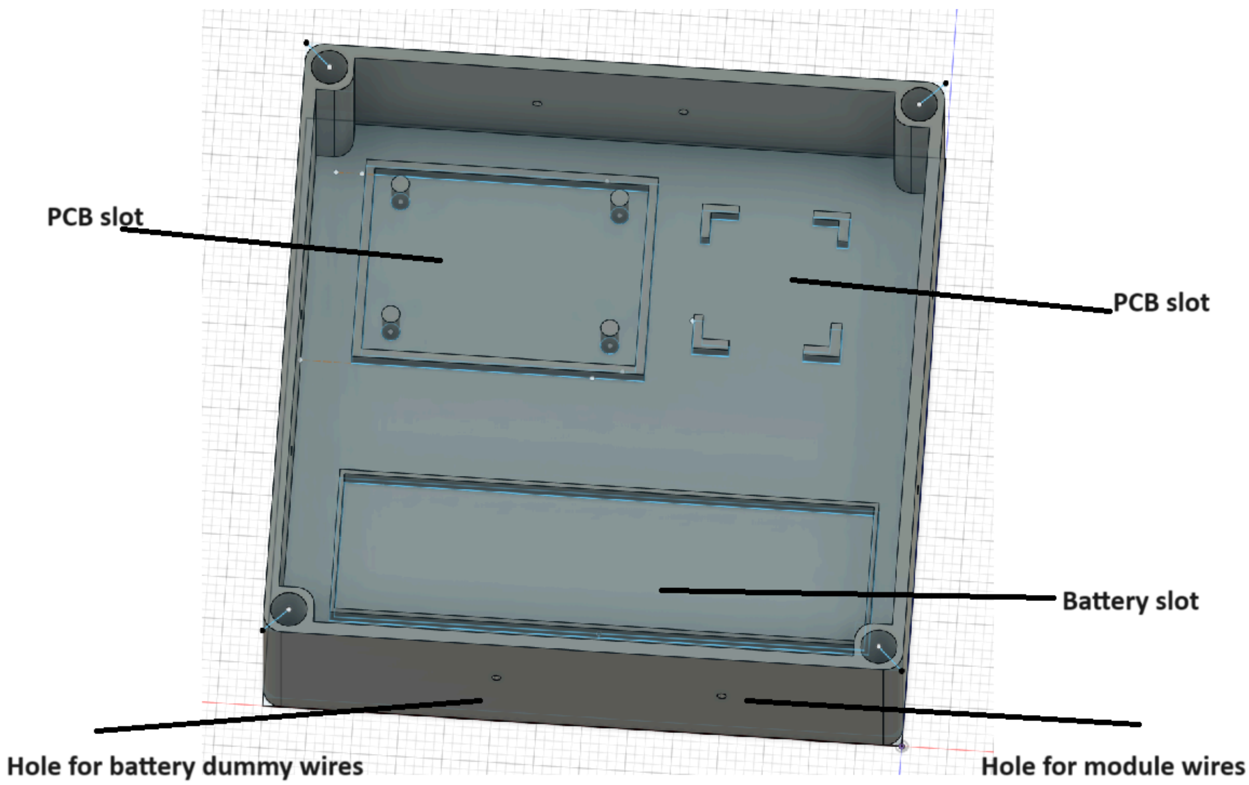


Picture 2.

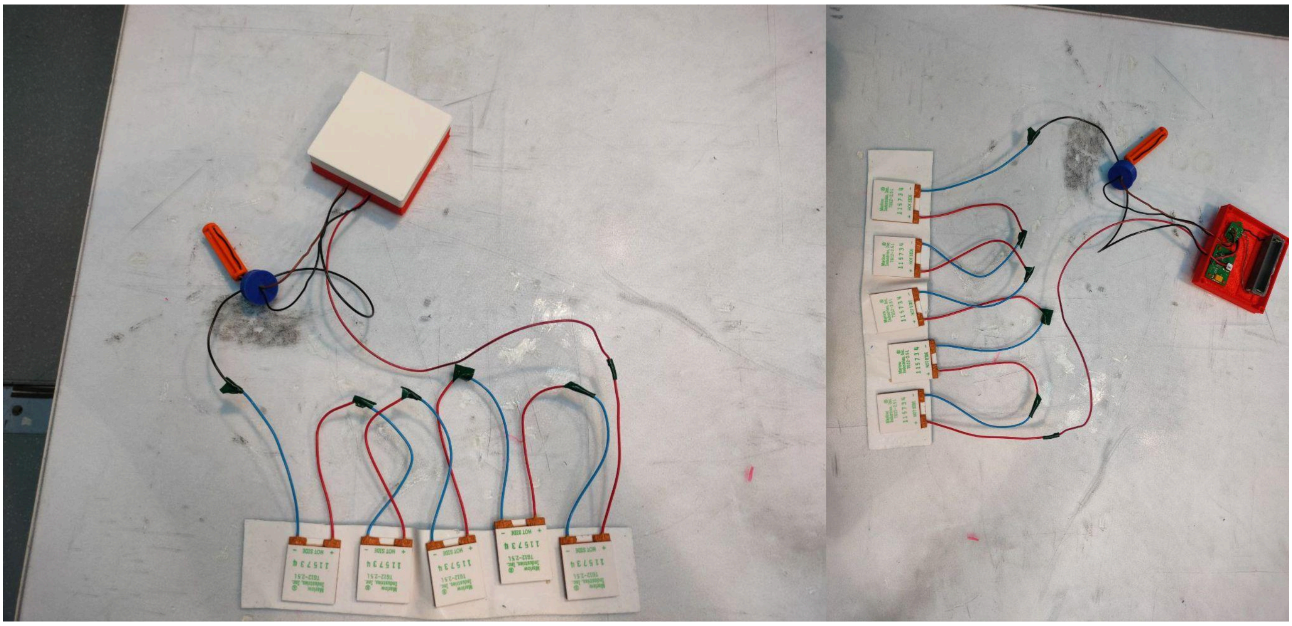


Picture 3. The harvester module

The thermal electric modules and the corresponding pcb were placed in a 3D-printed case. The case was designed to be easy to mount and have slots for the battery and the pcbs.



Picture 4. Labeled thermal case



Pictures 5 and 6. Band of 5 TEGs connected to the harvester module

5. Results induction

There are two distinct designs for the induction-based approach to energy generation. The first design involves a magnet oscillating within a tube, moving back and forth between two coils. This movement induces an electrical current in the coils, which has been thoroughly simulated to predict its performance, as shown in the figure below. The second design is based on a pendulum mechanism, where a weighted disc swings back and forth, driving a DC motor to generate electricity. This pendulum system harnesses the kinetic energy of the swinging motion, converting it into electrical power (see Appendix for more details).

The linear generator, with its straightforward design of a magnet moving between coils, can be seen as a baseline for the project because it is completely custom-made and easier to scale quickly during prototyping. This simplicity allows for rapid adjustments and iterations, making it an efficient choice for ensuring that the project would yield tangible results. Due to the challenging nature of the pendulum approach, which required precise mechanical dynamics and more complex components, the linear option was developed alongside it to guarantee some level of success and a viable final product.

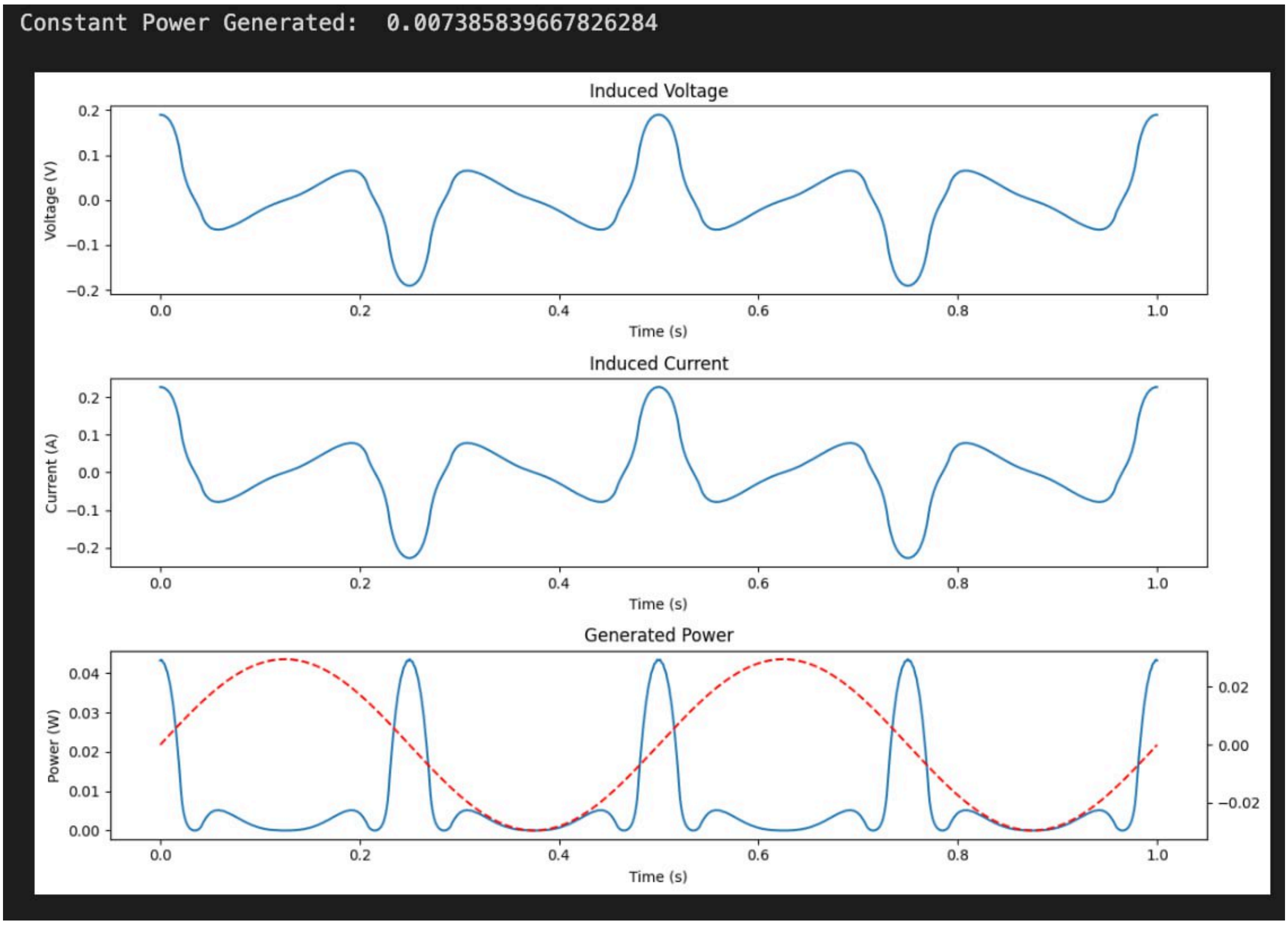


Figure 3. Simulation results for the generated voltage, current and power

Simulation and Analysis

Before developing the induction generator, it was essential to understand the dynamics of head movements during typical activities like walking and running. These movements directly influence the design and effectiveness of the generator, as the kinetic energy generated from these motions will be converted into electrical energy. To gather relevant data, we conducted a series of measurements using the Phyphox app (Staacks et al., 2018) on a smartphone, which was positioned at the right ear. This setup allowed us to capture the acceleration patterns in three directions: front and back, up and down and side to side, while walking and running.

The analysis of the measurements (Figure 4) revealed that the frequency of head movement in both the up-down and front-back directions was around 2 Hz during both walking and running, reflecting regular and rhythmic motion. In contrast, the side-to-side motion was more irregular, with no dominant frequency as pronounced as those observed in the other directions.

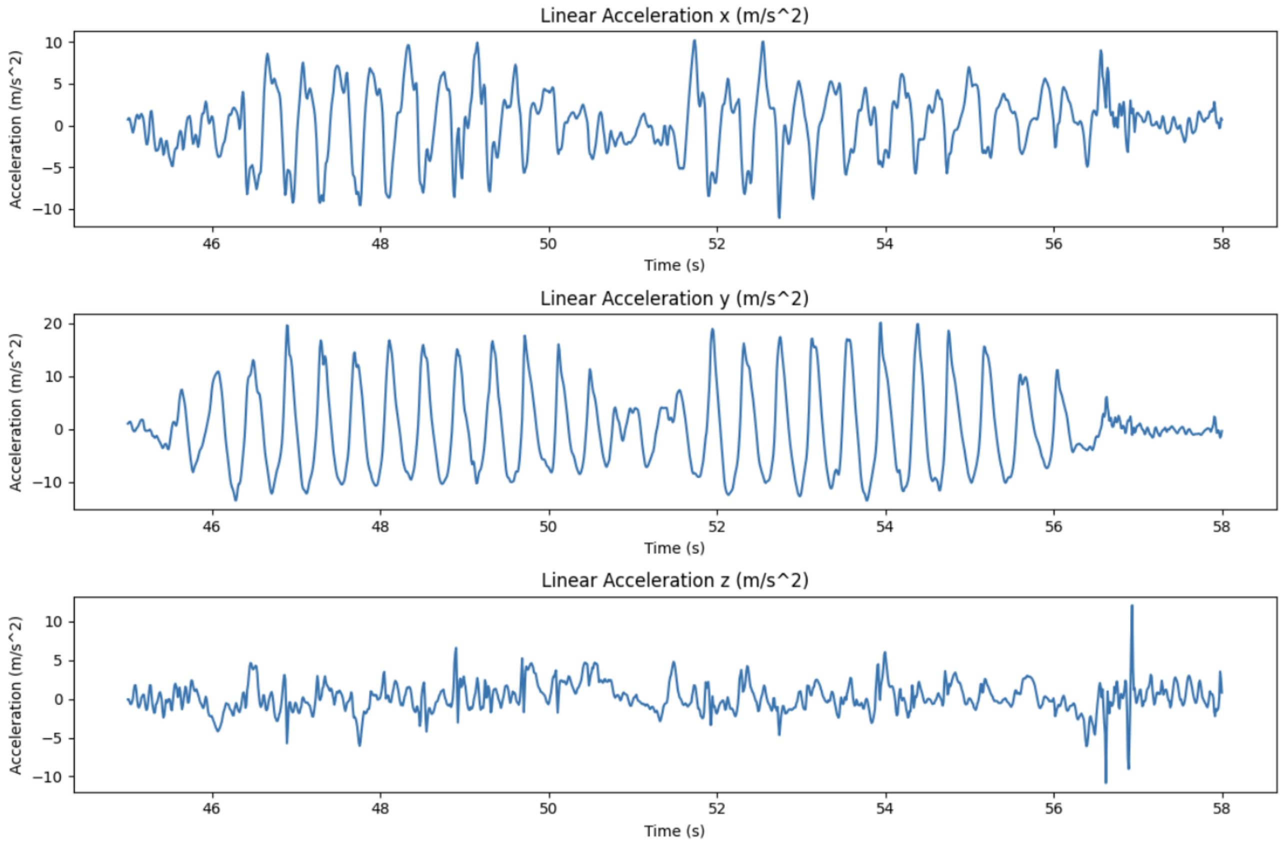


Figure 4. Linear acceleration in the front-back (x), up-down (y), and side-side (z) directions, from the wearer's perspective, measured during running, showing dynamic head movement patterns.

With a clear understanding of head movement dynamics, we transitioned to simulating the performance of the induction generator using Python and the Magpylib library (Ortner & Coliado Bandeira, 2020). The objective was to assess the potential power output of a system designed to fit within the size constraints of an AAA battery and to refine the design for practical applications.

In our simulation, we modeled the magnet oscillating inside a coil, using a sinusoidal motion at a frequency of 2 Hz, which reflected the measured head movement patterns. The system's design parameters, including the coil's number of turns, radius, and length, were carefully selected to fit within the compact battery dimensions. Resistance was calculated based on the conductivity of copper, and inductive resistance was considered negligible due to the low frequency.

Our simulation process involved calculating the voltage difference along discrete segments of the coil using Faraday's Law, specifically by considering the rate of change of magnetic flux through each segment over time. By summing the contributions from all segments, we determined the total voltage generated across the entire coil. Initially, the simulation results were promising, with output figures approaching our target of 10mW. However, after discovering an error in the simulation parameters, the corrected figures revealed significantly lower output, yielding sub-mW power levels. This correction helped us adjust our expectations.

To optimize the power generation, we explored using multiple smaller magnets aligned in different orientations, rather than a single uniform magnet. This approach was intended to maximize the gradient of the magnetic flux through the coil, enhancing the induced voltage. By carefully aligning the magnets with alternating polarities and spacing them better, we aimed to create a more optimal magnetic field, leading to higher induced voltage and greater power output. The simulation results, visualized through plots of induced voltage, current, and power over time, provided valuable insights into how different magnet configurations and motion parameters impacted system performance. The optimization process demonstrated that a well-designed magnet assembly could improve the efficiency of energy generation.

Overall, the simulation and analysis revealed both the potential and the limitations of using a magnet-coil system to generate electricity in compact spaces. The simulations showed that, within the size constraints of an AAA battery, any configuration for the linear induction generator would be physically unable to achieve the desired power output. This realization led us to scale up the design in later physical experiments. One of the key factors influencing power generation is the motion of the magnet. While we initially assumed a sinusoidal movement for simplicity, this was far from optimal. More effective magnet motions involve flipping velocity as quickly as possible at the edges of the oscillation, which increases the rate of change in magnetic flux and thus enhances the induced voltage.

Results linear induction

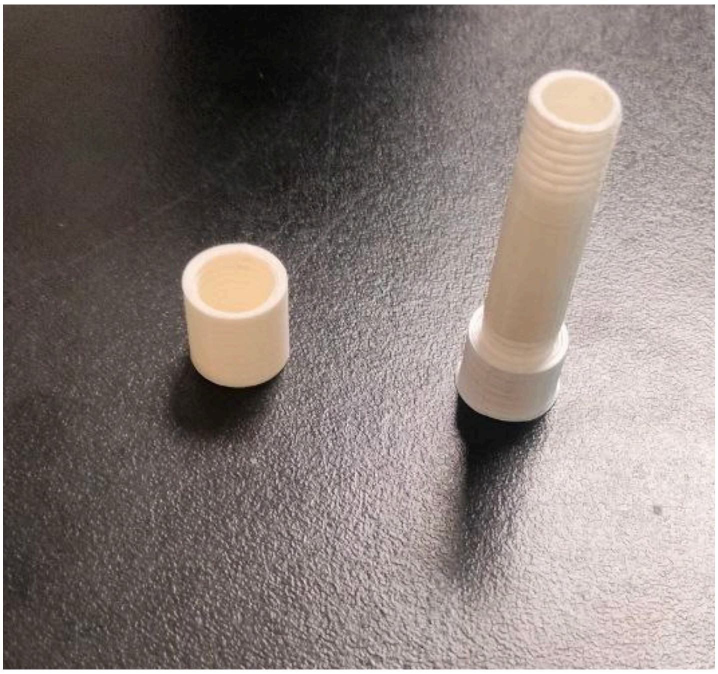
The linear induction generator was the approach the team first expected the system to work with when hearing about the topic. It would apply a concept that is familiar to even many high school students. The idea was to put a magnet inside an induction coil to generate electricity. The approach was thought to be simple enough that the team members could even make simulations before ordering parts or making a final decision to continue with the approach. One of the simulations was detailed in the chapter above. There was a second simulation made by a different team member on simulink with simpler values found from the datasheets of initially proposed parts. This simulation was however found to be inefficient and it did not provide usable results.

After the simulations showed that the induction method is plausible to use, development of the physical device began. Since the minimum requirements for generating electricity from induction is to have wire and magnets, those were the first components ordered. In total 5 different kinds of magnets were ordered, but the most significant magnets for the final products were a rod magnet with a 8 mm diameter and a height of 30 mm and 10 disc magnets with a 8 mm diameter and a height 4 mm. Also a few kinds of wire were considered, but in the final product a 26 AWG Magnet Wire Kit was used. This specific wire was used in the simulation detailed in the previous chapter. The wire has a cross section area of 0.14 mm^2.

Picture 7. Rod magnet

Picture 8. Disc magnet

When the orders for the linear induction generator were placed the mechanical design started. Development began with having a coil that fits in the volume of a AAA battery. The idea was to 3D-print a cylindrical shell, placing a magnet inside and closing the hollow shel with caps on both sides. The coil would then be wrapped around the shell. Then the magnet would move freely inside the shell and would induce a current in the coil. The idea was to have the generator fit inside the battery slot of the headset, however the idea was quickly scrapped since a generator that size would not produce enough voltage with the frequency given by the movement of the head.

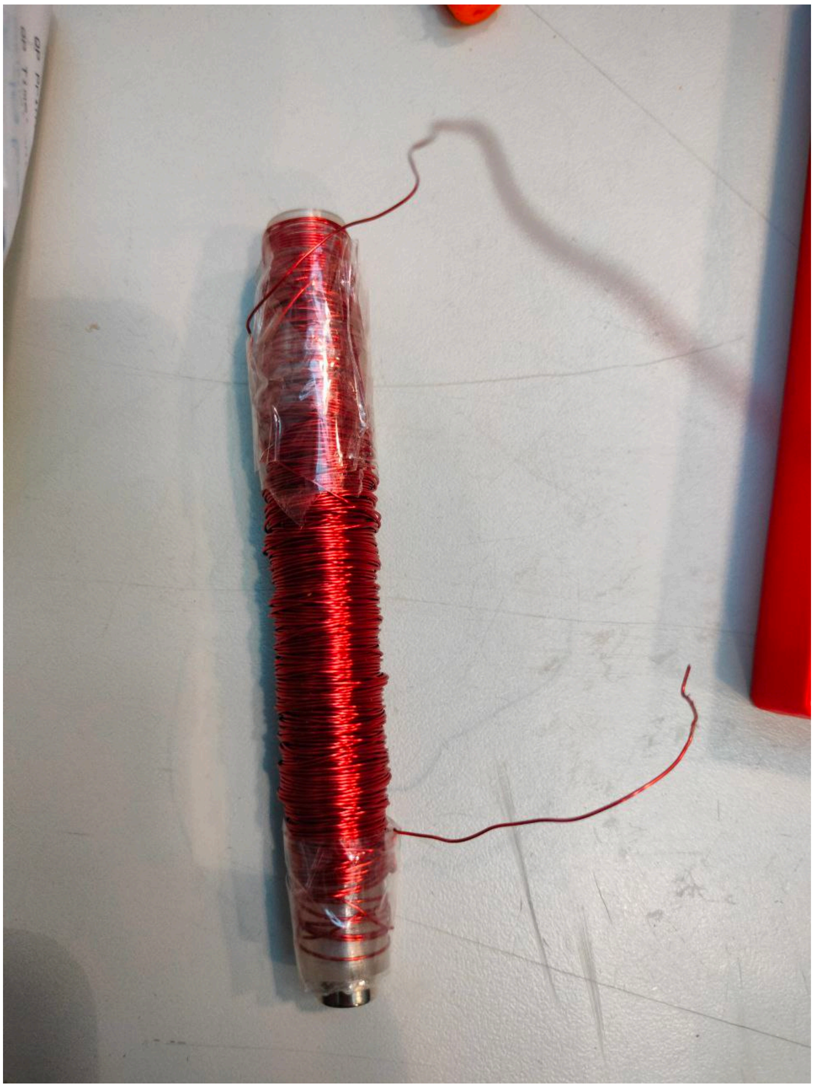


Picture 9. One of the first iterations of the 3D printed shell and caps

This realization started an iterative process where new shells would be modeled and printed, slowly increasing the diameter, thread size and length of the shell. The idea of magnetic levitation was introduced to help the magnet inside to oscillate more and therefore inducing more current. In the end after testing a shell with a height of 100 mm was deemed sufficient, maximizing the space for the rod magnet to move, while keeping the prototype size still manageable for its use purpose.

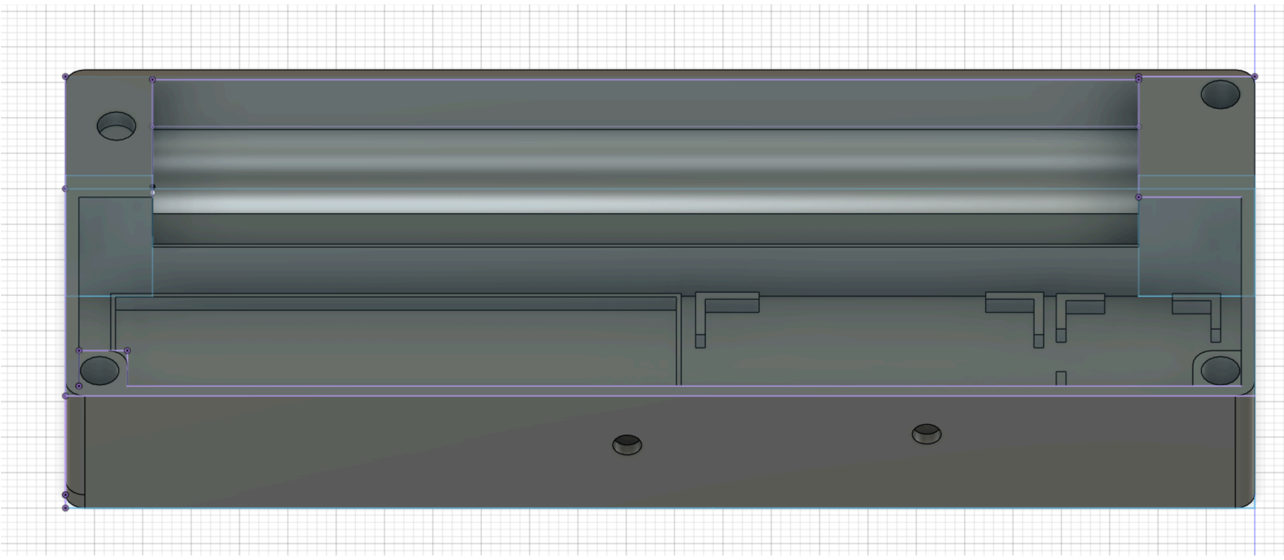
The magnets available were able to be used for the so-called magnetic springs, to realize the magnetic levitation idea. First the idea was to put magnets with repelling polarities on both tops of the cylinder, but the magnets available were too powerful and they held the rod magnet in place and decreased the displacement of the rod. In the end one magnet on the bottom was deemed to be sufficient to bounce the rod magnet, increasing the oscillation and current induced. However energy is still lost when the rod hits the opposing side of the cylinder. This energy loss was a catalyst to start looking into the rotational induction approach, where less energy would be lost from changing directions. Using only one magnet meant that the prototype would have to be held in a certain orientation during use. The direction of gravity would have to match where the bottom of the cylinder was pointing

The mechanical design and the implementation of the magnetic springs were designed simultaneously. When it came time to design the case for the generator and the electronics, the case ended up being designed in a way where the caps would not be needed and the magnetic springs were placed in the case design instead as seen in Picture 10.



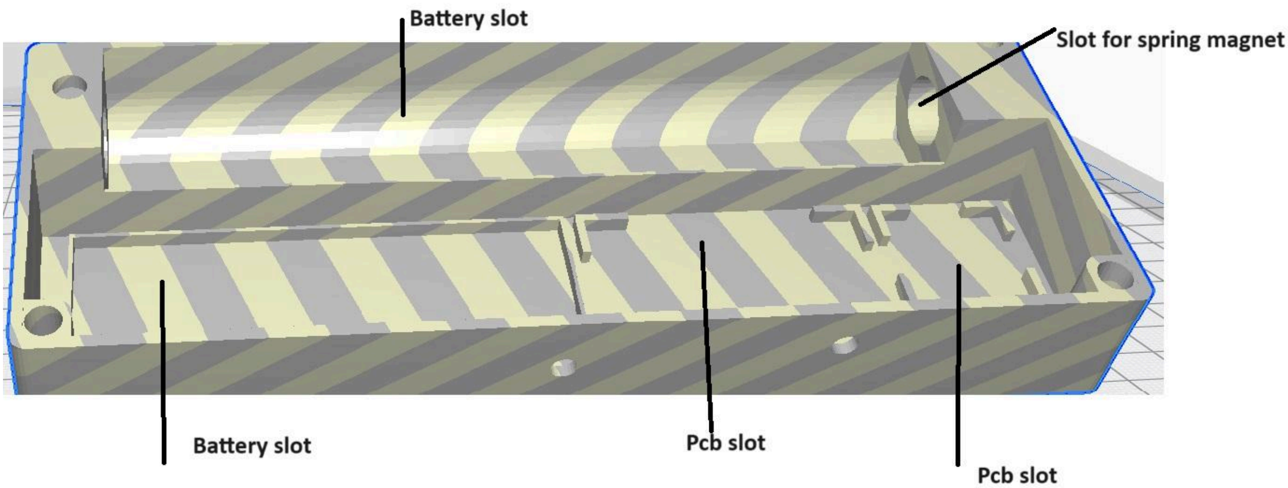
Picture 10. Final Linear induction generator design

The final linear generator was a 100 mm hollow cylinder with 2 mm walls and the bottom end sealed shut. The magnetic spring is placed in the bottom, by dropping a disc magnet inside and securing it by placing a second disc magnet on the outside (Seen in picture 8.). The shell was wrapped in 95 m of wire to produce the coil. Since the wire is insulated there was no worry in having the wires touch and it could be wrapped on top of itself. 95 m was the amount in the coil ordered and the whole coil was used. This made around 500 revolutions (builder stopped counting after 250 revolutions). The coil was secured with tape to keep it from unraveling.



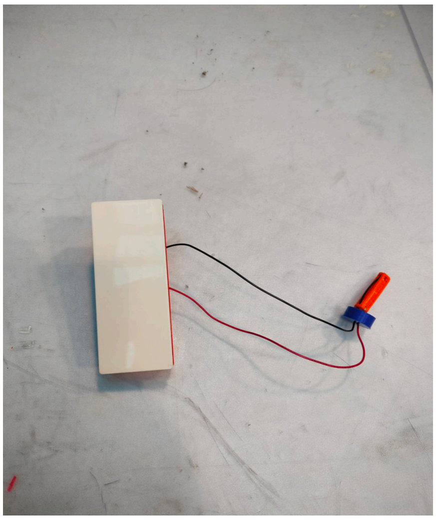
Picture 11. 3D design of the casing for the linear generator

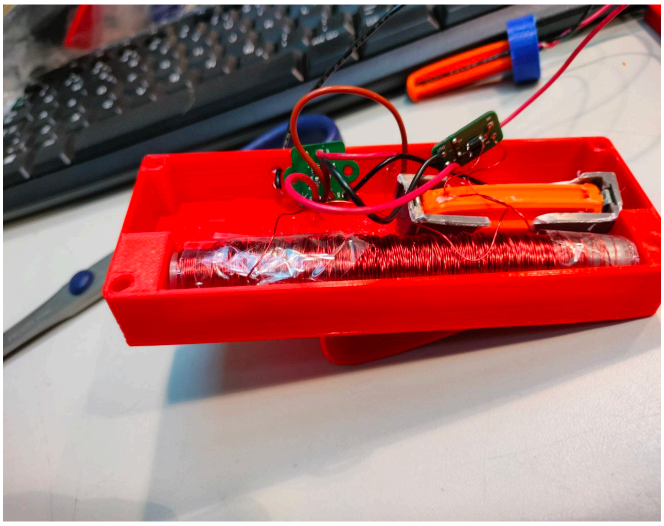
The generator is then placed in a case that also houses a AAA battery and the pcbs. The case was 3D printed and has a lid to close the electronics inside.



Picture 12. Labeled case

In the end, measuring with an oscilloscope the voltage generated with the generator, the generator was able to generate a RMS of 500 mV with moderate shaking of the generator and with intensive shaking the RMS would go up to 1.2V. These tests were done by shaking the generator up and down by hand. These numbers might not be realistic with the shaking produced by walking and head movements.



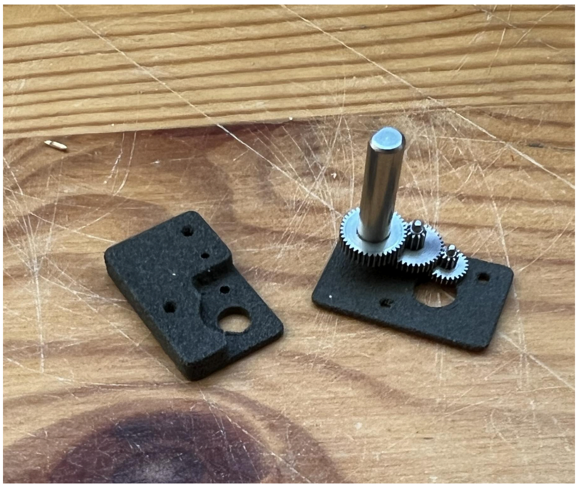


Picture 13. and Picture 14. Final linear induction prototypes

Results rotational Induction

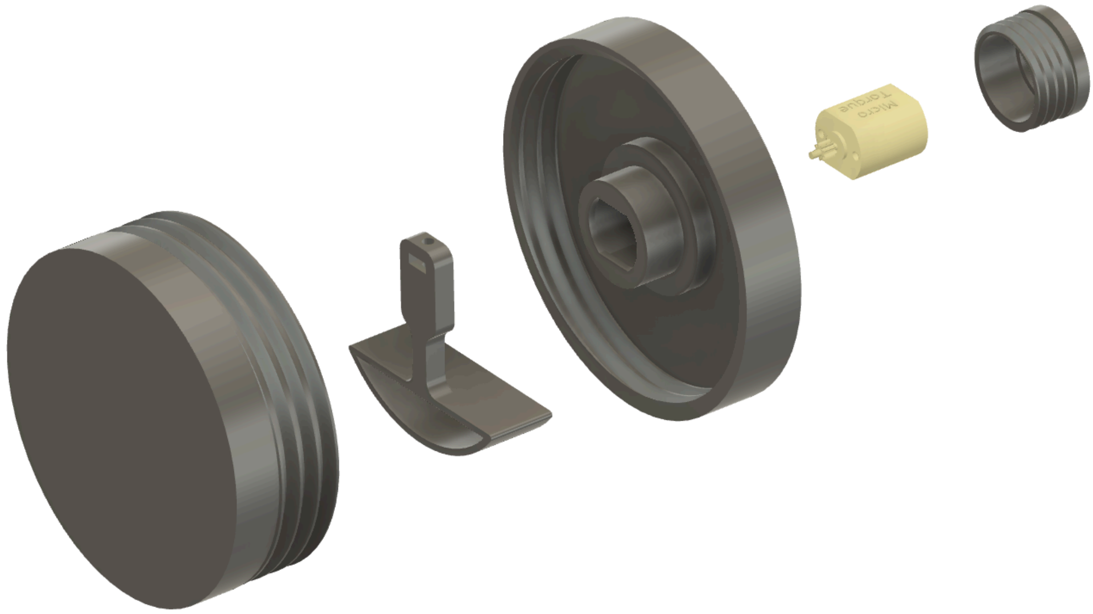
As we began to suspect that the linear induction generator might not, in practice, produce sufficient power to meet our objectives, we initiated the design of an alternative system in parallel: a rotational induction generator. This design leverages a DC motor driven by a weighted disc. The disc, acting as a rod pendulum, rotates and in doing so drives the motor. As the motor turns, it generates an electromotive force (EMF) that can be harnessed for power generation.

The rotational induction generator was designed with specific parameters to optimize its performance while maintaining a compact form factor. The disc was given a radius of 2 cm and a weight of 10 grams. These values were determined through careful calculations, considering the torque required to turn the motor and analyzing the forces that would be present in practical applications when the generator is worn on the head.



Picture 15. and Picture 16. SLS printer gearbox designs.

To enhance the efficiency of the system, we began developing a gearbox intended to be attached to the motor. The gearbox was designed and 3D printed using selective laser sintering (SLS) technology, which allowed us to achieve the sub millimeter accuracy necessary for the intricate design. The gearbox was meant to enable the disc to drive the motor more effectively by increasing the torque through gear reduction. This approach offers the advantage of allowing the motor to generate more power from the same magnitude of rotation by converting a small rotation of the pendulum into a large rotation of the motor shaft. However, the first prototype of the gearbox encountered issues due to the nylon material used in the SLS printing process. We did not do any post processing of the nylon, leaving the surface rough. As a consequence, the gearbox to gear shaft interface caused excessive friction, which significantly reduced the efficiency of the gearbox. Due to time constraints, we were unable to resolve this issue and complete the development of the gearbox.



Picture 17. Exploded view of the rotational induction generator design.

In addition to the gearbox, we developed a physical prototype of the rotational induction generator that included several features to facilitate testing and optimization. The design (Picture 17) features a chamber that houses a pendulum, which moves within it. The chamber is composed of two main parts: a base and a lid. The lid is designed to screw onto the base, closing the chamber. A motor is mounted on the lid, and the pendulum is attached to this motor. The exploded view (Picture 17) of the design shows the separate components: the base, lid, pendulum, and motor, illustrating how they fit together to form the complete assembly. The generator was designed to be modular from the ground up. As we faced uncertainty about the final generator configuration it was important to design the generator so that parts of it can be swapped out for different parts without having to redesign the whole assembly. The pendulum, which drives the motor, was equipped with a compartment to hold different weights, allowing us to experiment with various weight configurations to determine which provided the best performance. We also constructed a test rig designed to facilitate the experimental evaluation of different gearing ratios. The rig features swappable gears, enabling quick changes in gear size to observe their impact on the pendulum's swing and the overall efficiency of power generation. These developments provided practical testing opportunities and highlighted the potential for further refinement in selecting the optimal weight and gearing configurations to maximize the system's performance.

Picture 18. The test Rig. The lower gantry is movable to facilitate different gears.

The experimental results for the generator showed varying levels of AC power output depending on the setup. With a 2 Hz movement of around 5 degrees amplified by a 50:1 gearbox, the motor shaft achieved an effective rotation of 250 degrees, resulting in an output of 1.5V peak-to-peak with an RMS voltage of 250mV when unloaded. Without the gearbox, lighter movements produced an output of only 150mV. Despite these outputs, we faced significant challenges in efficiently harnessing the generated energy. The primary IC (LTC3109) that was intended for this approach failed to work for unclear reasons, which are discussed later in this report. The backup method using a voltage doubler to rectify the AC output and feed it into the LTC3108 IC, similar to the thermoelectric approach, also proved unsuccessful. The low output voltage, often below 0.5V, caused significant voltage drops across the Schottky diodes in the voltage doubler, making energy recovery using this circuit infeasible. Consequently, the measurements had to be conducted without a load.

Comparing the output of this generator to the linear generator reveals several differences. The linear generator, with its larger size and heavier components, generated higher power levels, but this required much stronger and less realistic movements—specifically, vigorous shaking by hand. These more intense motions are unlikely to be replicated by typical head movements. In contrast, the generator discussed here was tested under more realistic conditions, simulating gentler, more natural motions. While this approach produced lower power levels, it aligns better with the expected use case of harnessing energy from everyday head movements.

The experimental results were as follows:

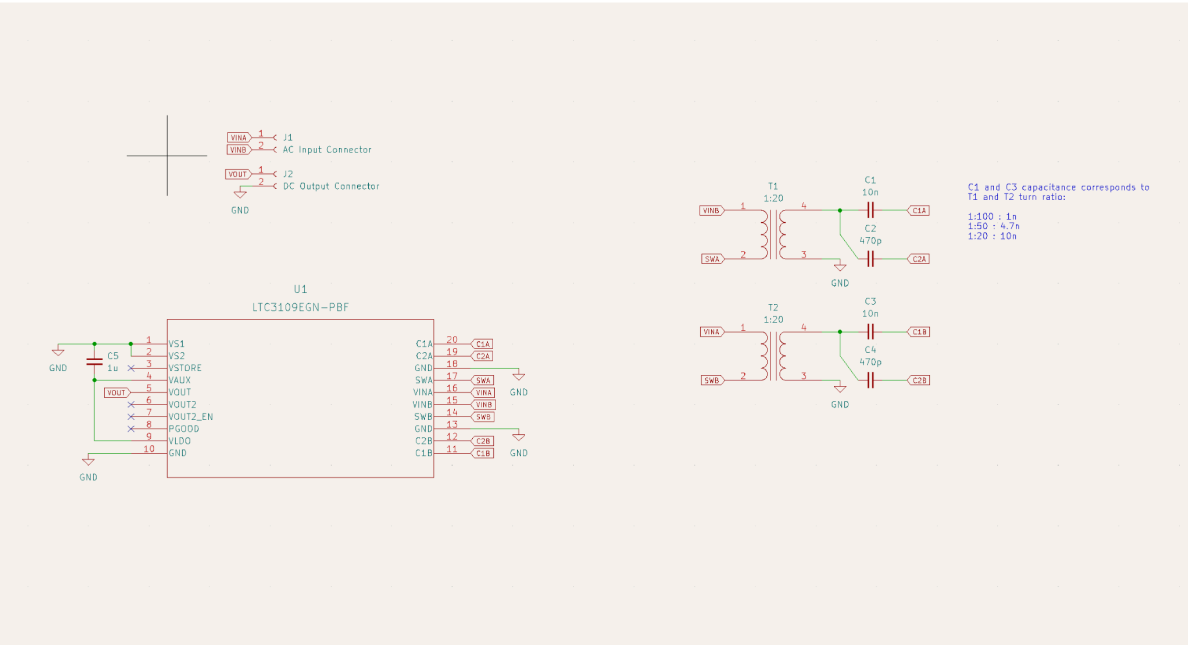
- AC power without load:
    - 2 hertz movement of around 5 degrees through a 50:1 gearbox.
      The effective movement of the motor shaft: 5 degrees * 50 = 250 degrees
        - 1.5V peak to peak and a rms of 250mV
- AC power without load and no gears:
    - Light movement: 150mV

Results Harvester Module

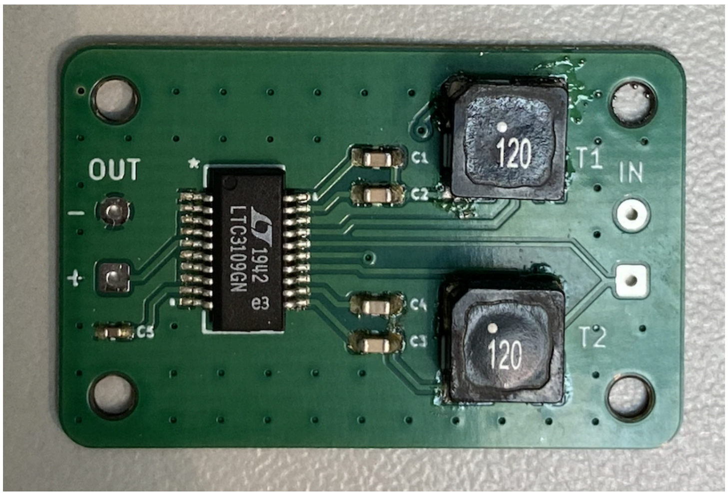
For the induction generators, two harvester module solutions have been developed: A more complex module based on the LTC3109, and a backup alternative module based on the Delon Voltage Doubler.

IC-based solution - Not functional

The primary approach was building a module around the LTC3109 with a pair of 1:50 transformers, which can theoretically work with low frequency AC sources because of the LTC3109's two power inputs and an internal supply switch. However, when tested with our self-designed generators, the module didn't work as expected. The root cause of the issue wasn't discovered, but we suspect it was due to assembly issues instead of the design. We couldn't confirm this because we only ordered two ICs for self-assembly, and we broke one of them during assembly.



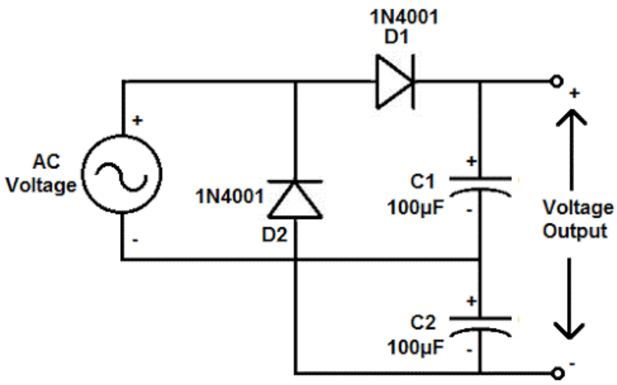
Picture 19.

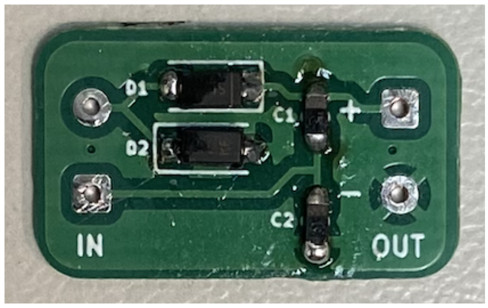


Picture 20.

Alternative backup solution - Functional

Because the primary solution didn't work as expected, we developed a more rudimentary alternative solution based on the Delon Voltage Doubler. This circuit is often referred to as the full wave voltage doubler. It basically takes an AC source as input, and outputs a DC signal with voltage approximately equal to the peak-to-peak voltage of the input. The circuit was constructed according to the schema below, except that we chose the 1N5819 Schottky Diode instead of the 1N4001 to reduce voltage drop.





Pictures 21 and 22.

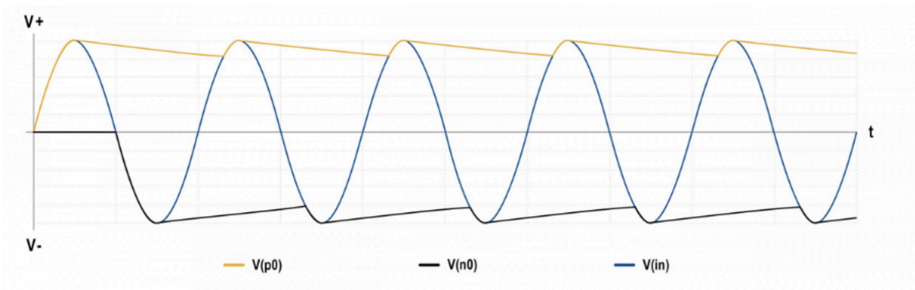


Figure 5.

When tested with the generators, the experimental results were as follows.

Linear Induction Generator

- With Delon Voltage Doubler circuit: 1N5819 Schottky Diodes and 100uF Electrolytic capacitors:

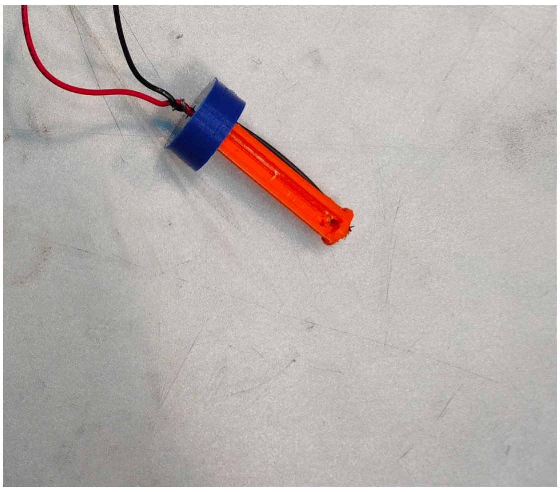
        - Normal movement: 12k ohms load
            - 0.05 mA at 500mV - 1V
        - Intensive movement: 12k ohms load
            - 0.1 mA at 700 mV - 1.2V

Pendulum Generator version

- With Delon Voltage Doubler circuit: 1N5819 Schottky Diodes and 100uF Electrolytic capacitors:
    - Normal movement: 12k ohms load
        - 0.1 mA at 200mV - 300mV
    - Intensive movement: 12k ohms load
        - 0.15 mA at 800 mV - 1.2V

5. Results Integration with AAA Battery - Not Functional

Since the battery of the headset will be attached in the prototype instead of into the headset itself, a way to run current to the headset from the prototype was needed. A dummy AAA battery was developed with wires running through it. A new cap for the battery terminal was also 3D printed to add a hole to the cap that the wires could be run through. The wires were soldered into one of the PCBs to attach them into the rest of the system



Picture 23. The cap and the dummy battery with wires running through

The system architecture for integration with a AAA battery as the primary source involves an additional module based on the LM66200DRLR IC. This module is a dual ideal diode that switches between supply inputs and is ideal for systems where a battery is connected to one of the inputs. These low currents extend the life and operation of the battery when in use. This is a promising approach; however, the design was flawed. It was during the integration phase that we discovered the flaws, thus we couldn't fix them or devise an alternative backup solution.

6. Reflection of the Project / Projektitoiminta

6.1 Reaching objective / Tavoitteet saavuttaminen

The primary objective of developing a working prototype capable of delivering a constant power output of 10mW was not fully achieved. The requirements turned out to be more difficult—perhaps even impossible—to meet within the current scope and constraints.

One of the key challenges we faced during development of the induction generators was the departure from a rigorous analytical approach, which is crucial for well-informed development. Initially, we followed a structured methodology with the linear induction generator, allowing us to gain valuable insights into the system's behavior. However, when it became evident that the output power of the initial design would fall short of our target, we decided to split our efforts and pursue two separate generator designs: the linear induction generator and a rotational generator. This decision stretched our resources and led to a lack of focus, particularly in the theoretical groundwork for the rotational generator. Unlike the linear generator, which benefited from early modeling, the rotational generator was developed with limited theoretical understanding due to the reduced manpower and time constraints. As a result, the development of the rotational generator may have been more of a blind pursuit, lacking the analytical rigor that could have guided it more effectively.

Another factor that affected our progress in the case of the induction based generators was the decision to consider harvesting IC modules only after the generator design was already in place. Ideally, the generator and the power management components should be designed together, as they are intrinsically linked. The load resistance has a significant impact on the output power of the generator. A co-design approach would have allowed for better integration and optimization, potentially leading to a more successful outcome.

Our project was exclusively focused on hardware development, which meant that progress was often closely tied to the availability of physical components. During periods of waiting for ordered parts to arrive, it was sometimes challenging to direct our efforts toward productive pursuits. While we aimed to use this time for planning and refining our designs, the lack of hands-on work occasionally limited our ability to move forward at the desired pace. This dependency on component deliveries highlighted the need for careful scheduling, work planning and delegation.

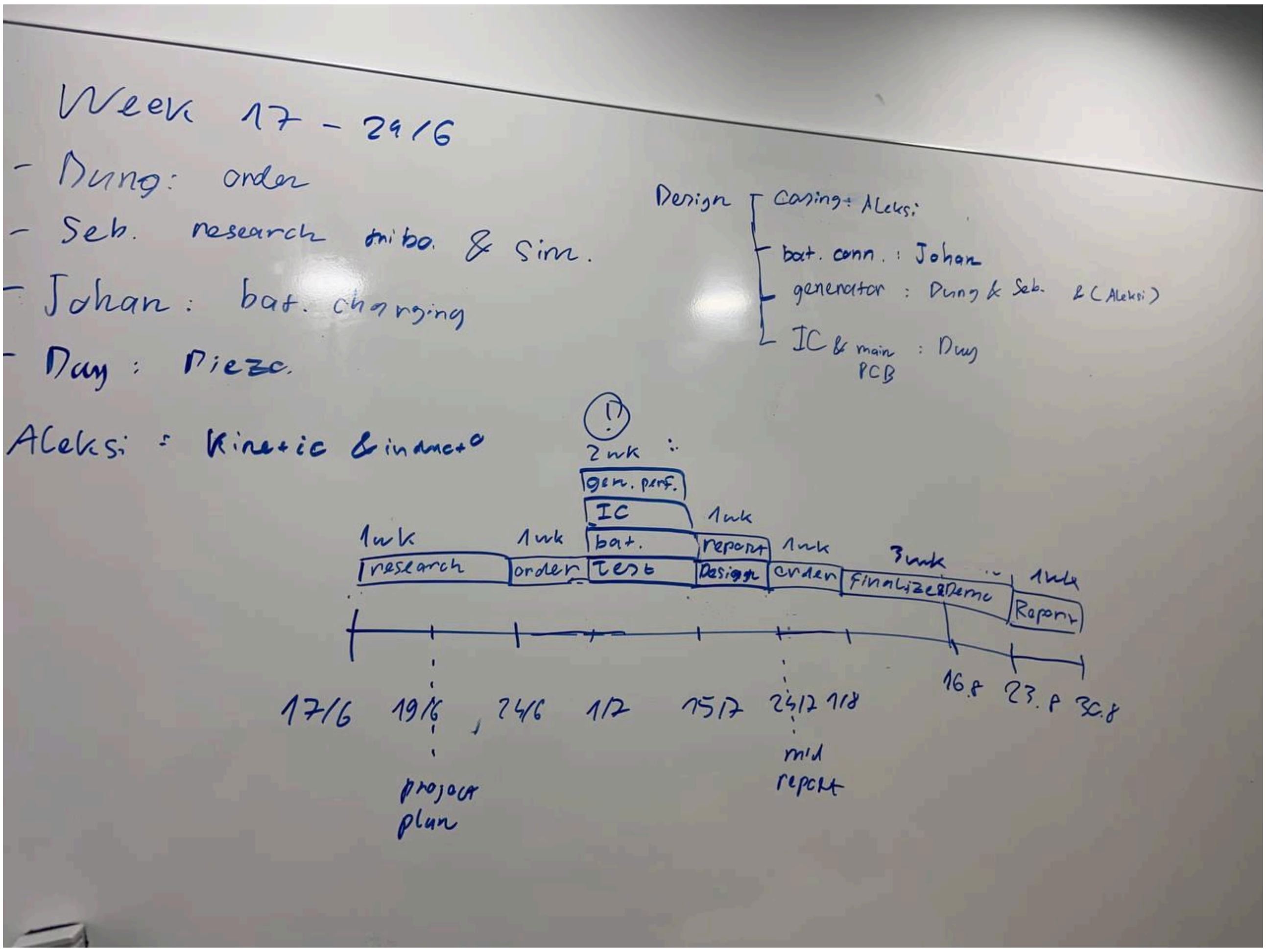
Looking ahead, it's evident that adhering to a holistic and model-driven approach, even under time constraints could have provided clearer insights into the generators and potentially avoided the issues we encountered. To achieve such a rigor however, we would have needed to collectively focus on a single generation approach instead of considering a multitude of approaches.

Regarding electronics design, we realized that we could have benefited from a different design approach. Instead of designing each module into a separated PCB, we could have integrated them into a single evaluation board.

Although we did not reach the target performance, the results so far are promising. The power output from the thermal electric system could power low power microprocessors like the STM32L0 series. The induction generators are also promising, and it could potentially power low power processors if we managed to fix the issue with the LTC3109 module.

Timetable / Aikataulu

During our initial meetings, based on each individual and the project timeline, we agreed on the following schedule:



Picture 24.

We have managed to follow this schedule quite strictly, with exceptions to the battery charger and the induction generator. For the induction generator, we have managed to simulate its performance and construct some prototypes for its casing. The approach of the piezoelectric generator has been completely dropped after testing. So far, as of the 24th of July, the thermal electric generator shows the most promising results, and has made the most progress.

By the end of the project, we had followed this quite strictly until the last 3 weeks where we encountered lots of unexpected problems.

Risk analysis / Riskianalyysi

Foreseen risks:

Topic	Description	Solution
Time allocation	Time allocation for planning and building could be inaccurate and requires many adjustments.	Frequent meetings for updates are set up for this.
Ordering	Components may not work, or they may not be the ones we need.	Order spare parts and do comprehensive research before actually ordering.
3D printing	3D could be time consuming and the result could still be inaccurate.	A fairly spacious time window was reserved to counteract this potential issue.
Integrating	Individual parts when combined may not work, and need a lot of troubleshooting.	A lot of time was allocated for this part.
TEG	Due to the slim nature of the TEG module, the heat transfer between the hot and the cold side happens quite quickly and results in the gradual decline in energy. This turned out to be Since the TEG module is a flat ceramic surface, the skin contact with the module is not exactly ideal.	A band that can properly insulate the hot from the cold side, while also helps with skin contact.

Time allocation: We tried setting up frequent meetings for updates so that time is not wasted or inappropriately allocated. However, not all members are always available, so some assumptions and misjudgements were made along the way.

Ordering: Some orders were made way too late into the project, while some arrived early, so quite a bit of time was just us waiting for the components to arrive.

3D printing: Time was thoughtfully and spaciously reserved in case of bad prints. Overall, the 3D printing process went well.

Integrating: Time was carefully allocated, however some parts finished later than others so the process was quite tight and no extra time for troubleshooting was available.

TEG: In this project, we used a thermally conductive silicone band from 3M that is usually used for CPU thermal conduct.The band was very flexible and provided great skin contact. However, the problem of insulation remains, the heat from one side transfers to the other side quite quickly which made this method of generation quite unreliable.

Future Works

Our work can be extended by building a more rigorous evaluation system. A possible approach is connecting the power output to a microcontroller evaluation board with a suitable ADC input, then we can collect data and perform analysis as well as visualization.

7. Discussion and Conclusions / Yhteenveto ja johtopäätökset

Aleksi Hirvonen:

The project was a way for me to delve into topics I was not familiar with like, power electronics and PCB design. Also it strengthened my skills in 3D design and 3D printing. Energy generation was also a topic that was quite foreign for me before. The project made me realize that generators were big for a reason and portable ones are difficult to make effective. Off the shelf products were also difficult to integrate into a system, but DIY methods are time intensive and break easily. More time could also have been allocated to designing and simulations. The ideas on how to optimize different parts of the design came way too late in the course to start rethinking everything which seems to be the nature of doing research and development with time constraints and in an iterative process. A best of both worlds approach would have been required in balancing between off the shelf and DIY approaches as well as finding a balance in allocating time to research and actual building of the product. In the end, when it comes to the linear induction generator the design could have worked better, but techniques to improve the voltage generated are hard to come by without relying on increasing the size of the product. The prototype does work as a proof of concept that the approach can work with further development.

Sebastian Walter:

This project was a significant learning experience for me, especially as it was my first exposure to physical prototyping. I developed skills in electronic circuit design, refreshed my understanding of electromagnetism, and gained practical experience with parametric modeling software and 3D printing. While I am not satisfied with the final outcome, the process taught me valuable lessons. In retrospect, one of the key challenges was the decision to explore multiple strategies simultaneously, which spread our efforts too thin. The project was not so large that it would have been impossible for everyone to stay in the loop about each development. However, this would have perhaps required more focused and cohesive work, and we opted instead to cover as many strategies as possible from the beginning.

In reflecting on the technical aspects, back-of-the-envelope calculations suggested that our goal should have been achievable, especially considering the low power consumption of the headset. The amount of wasted/available kinetic energy should, in theory, have been easily harvestable. However, the lack of a deep understanding of energy generation through rotating a DC motor leaves me questioning where exactly the discrepancy lies. Even now I am unable to pinpoint why we could not recover the expected energy.

Initially, I invested time in the modeling and learning phase, slowly building up my understanding of the problem domain. However, as the project progressed, I gradually abandoned this approach. Faced with the pressure to produce tangible results, I scrambled to get something working, even though I knew the approach might not yield the required power. I felt torn between continuing my research and the risk of not finishing in time, which would have left me with nothing to show for my efforts.

On a more positive note, I particularly enjoyed researching the circuit options for the induction generator. This was an entirely new area for me, and I felt that I learned a great deal about electric circuits, which I found both challenging and rewarding. Despite the difficulties and the less-than-ideal outcome, this project provided me with practical experience in physical prototyping and an understanding in the area of small scale energy harvesting and circuit design.

Dung Nguyen:

Through this project, I gained valuable insights into power electronics, human body energy harvesting, as well as electronic system assembly and integration. Although the approach that I worked on, thermoelectric, produced somewhat promising results, I do feel that I could have done better. One aspect that I could have improved is the research into available TEGs on the market. For this project, I narrowed down to just two TEGs for testing, one is the most commonly used modules in diy projects, and one was chosen based on thickness and sensitivity. There were more experimental models that could yield better results but are harder to integrate. I was too optimistic about the two aforementioned models so I did not consider their low conversion rate nor did I think about ordering and testing out other models. Another thing I could have improved is how much time I allocate to assembling and integrating the different components. Assembling the pcbs took more time than what I had expected, and therefore we had very little time to test them. After that, even if we found errors, we had almost no time left to fix them. Finally, I should have made alternatives for the system, instead of just hoping for the main harvester to work. During my research, I found out about the Joule thief which is a simple circuit that could boost voltage and help with our demonstration. However, since we had no errors with the pcb, I just had that as an idea in mind. The capabilities of the TEGs would have been shown way better had I made the circuit as well.

Duy To:

In this project I learned a lot about power electronics design as well as PCB design. I was very glad that several of my PCBs worked; however, I felt that I could have done better. First, if I had started hardware design earlier, so that the team would have more prototype iterations to find out critical issues. Second, I really wish that I had integrated all modules into a single evaluation board instead of making separate PCBs, and connected the modules by, for example, jumper wires. I just recently realized this when I look at the prototypes of products in the industry. Had I done this, the final prototype would look much more elegant, and testing would also be more convenient. Finally, at the end of the project, I realized that I could have built a more rigorous evaluation system by connecting the power output to a microcontroller evaluation board with a suitable ADC. Then, I could collect data and perform analysis as well as visualization.

List of Appendixes / Liitteet

Test Rig for Pendulum Energy Harvesting Solution

Pendulum Harvester Solutions

Comparison of methods for head-mounted energy generation from head-movement

References / Lähteet

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