A smartphone battery can be charged without an external power source by applying a portable charger that transforms mechanical energy into electricity by means of magnetic induction. Its essential part is a permanent magnet made of a rather expensive and, from the point of view of availability as well ecology, problematic material. The magnet is usually assembled from cylindrical parts. In order to reduce the raw-material consumption and to simplify the production, we propose a single-piece design in the form of a cylinder with notches. By means of the finite-element modelling, we optimize the dimensional parameters and prove that our proposal is more efficient than standard solutions.

Keywords: permanent magnet, electric generator, smartphones, self-recharge, finite-element modelling

1 INTRODUCTION

Energy consumption is one of the main problems faced by society. It is of strategic importance to put efforts into energy saving during all activities. At the same time, it is also necessary to reduce the consumption of raw-material resources for ecological and economic reasons. On the other hand, technological progress is unstoppable; therefore, the goal must be to stimulate innovations, acceptable in the present situation. An example is a smartphone, a small device which is nowadays indispensable in many aspects. Although it is not a significant energy consumer, its operation depends on the battery capacity – one of the crucial topics of contemporary applied science. It would be desirable to avoid inconvenient situations occurring due to an empty battery by not burdening the environment or drastically increasing the price of the device. A possible solution is to use a portable battery self-charger, which is basically an electric generator producing electricity from the kinetic energy associated with walking or shaking by the phone’s carrier. Various studies have been conducted to characterize different moving activities as a potential energy source.

The idea is to exploit human motion, which excites a vibration of the coil in a magnetic field, inducing a voltage. A scheme of such a charger is presented in Figure 1. So far, the size of the only commercially realized example exceeds the size of a smartphone. It must be carried separately in a bag, which is inconvenient and reflected in only limited commercial success. The problem is how to produce a sufficiently strong, non-uniform magnetic field using a reasonably small, light and easily manufactured magnet. The fulfilment of the first two criteria obviously contributes to a light weight and small size as well as to a low price of the final product, needless to say, crucial for the applicability. Similarly, a simplified manufacture without assembling the magnet from different pre-magnetized parts, as it is the case with the existing self-chargers, would certainly have a positive impact too. We propose a design, suitable for additive manufacturing by means of 3d printing, making a single-piece magnet that can be magnetized in a uniaxial direction. It should be small enough to be embedded in the housing of the smartphone. The objective is to determine the shape of a tube-like magnet that yields the optimum performance, defined by the estimated induced voltage per volume of the magnetic material. To achieve this goal, we optimize the magnet-geom-
2 DESCRIPTION OF THE CHARGER

As presented in Figure 1, the charger under consideration comprises a rectifier circuit, a magnet, and an oscillating coil coupled to a pair of springs.\textsuperscript{2,12} Whereas the springs must be tuned to match the walking and oscillating-coil frequencies, and the rectifier circuit should supply an appropriate voltage to charge the battery, the focus of the present research is to find the ideal shape of the magnet as the source of the magnetic field.

According to the Faraday’s law the induced voltage is expressed as the time derivative of the magnetic flux \( \varphi_m \):

\[
U_i = - \frac{d\varphi_m}{dt}
\]

\[
\varphi_m(t) = NBA
\]

where \( N \) is the number of turns in the coil, \( A \) represents the coil’s cross-section, and \( B \) denotes the magnetic-flux density. The target average induced voltage is about 10 V.

Under consideration is a cylindrical shape with notches, which makes it possible to stick to a planar problem due to the rotational symmetry. The length and the maximum diameter are set to 10 mm and 4 mm, respectively, which implies a reasonable size of the device, and, as a rule of thumb, matches to \( N = 400 \) turns in the coil.

We adopt the magnetic properties of a state-of-the-art sintered magnet (NdFeB-50) with sufficiently high remanent magnetization. An example of the proposed magnet shape is presented in Figure 2, with the dimensions defined in Figure 3 and Table 1.

Table 1: Magnet dimensions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner diameter</td>
<td>(D0)</td>
</tr>
<tr>
<td>Height of the notch</td>
<td>(L1)</td>
</tr>
<tr>
<td>Width of the notch</td>
<td>(L2)</td>
</tr>
</tbody>
</table>

The notches in the magnet design are the key innovation, contributing to a lower weight, reduced consumption of the raw material, and the required field inhomogeneity necessary for a non-zero time derivative in Equation (1).

3 METHODOLOGY

The complete flow chart of the magnet-modelling procedure is presented in Figure 4. The finite-element calculations of the magnetic flux density were carried out with FEMM software.\textsuperscript{14,17}

The first-type (Dirichlet) boundary conditions and a triangular mesh were applied. Its density was determined...
on the basis of the convergence tests.\textsuperscript{15,16} Figure 5 presents the meshing for the magnet geometry under consideration. The mesh is denser close to the magnet, where the field gradients are more pronounced. The time dependence of the calculated flux is modelled by examining various displacements between the coil and the magnet assuming a harmonic motion.

For simplicity, the angular frequency was set to $\omega = 1 \text{ s}^{-1}$. The time derivative in Equation (1) is carried out in terms of the finite-difference method, and the average value $B$ of the magnetic-flux density for a given cross-section is applied in Equation (2).

4 RESULTS AND DISCUSSION

The following geometry parameters yielding the optimum performance were optimized: $L_1$ (height of the notch), $L_2$ (width of the notch), and the inner diameter of the tube ($D_0$) of the magnet. The optimization criterium was the induced voltage divided by the magnet volume.

We adopted the simplest optimization procedure by fixing one and optimizing the other two parameters at the first stage. It makes sense to compare the calculated output average voltage normalized to the volume of a particular magnet with notches. First, we fixed the diameter $D_0$ and plotted the normalized voltage for four different notch heights $L_1$ as functions of the notch width $L_2$ in Figure 6. Although a bigger notch certainly contributes to a smaller volume and simultaneously to a less homogeneous magnetic field, there is obviously an optimum combination of $L_1$ and $L_2$ corresponding to 4 and 6, respectively in Figure 6.

In the second stage, we applied this combination $L_1$ and $L_2$ and examine the influence of the diameter $D_0$. To check the stability of our solution, we fixed the width $L_2$ to 6 and present the results of several values of $L_1$. Again, $L_1$ equals four yields the highest normalized voltage for diameter $D_0$ value equals 8 giving the optimum set of the three parameters.

To prove that our concept makes sense, we present a comparison between the calculated voltages resulting from applying the optimized magnet geometry and different conventional solid (without notches) magnets magnetized uniaxially (Normal), axially (Axis) as a sequence of segments magnetized periodically in the left or right direction, and along the Halbach pattern (Halbach): Figure 8. Although the solid magnets, particularly the one magnetized along the Halbach pattern, might yield a higher absolute voltage, the benefit of the notches due to a reduced amount of the used material is obvious and even a non-optimum solution ($L_1$ equals 5) gives a higher normalized voltage.
CONCLUSION

The subject of our investigation was a self-charging device for portable electronics, for example, smartphones, adopting magnetic induction generated by a permanent magnet surrounding an oscillating coil. The focus was on the magnet geometry, to save raw material and to simplify the production. Therefore, we introduced notches in a uniformly magnetized tube-like magnet, which at the same time contribute to the required non-homogeneity of the produced magnetic.

A comparison with the performance of conventional cylindrical magnets of equal outer dimensions proved that our proposal, which can be produced by means of 3d printing, indeed yielded the highest output voltage normalized to the volume of the consumed material. The overall result might contribute to the general efforts for sustainable development.

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