Power-generating shoes using a magnetostrictive vibration power generator

T.Minamitani, T.Ueno
Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan

E-mail:minamitani@staff.kanazawa-u.ac.jp

Abstract. Luminescent shoes that flash synchronously with walking motion can be used to enhance the safety of night walking. As a means of reducing reliance on batteries, which are typically used as power supplies, the potential use of the energy generated by walking has been investigated, although to date no practical power-generating shoe has been produced. Here, we examine the use of a magnetostrictive vibration generator developed in our laboratory as a power source for power-generating shoes. This generator has advantages over conventional piezoelectric or movable magnet type generators in terms of improved efficiency, higher robustness, and reduced electrical impedance. In this paper, we report on the fabrication method and experimental results obtained from testing the proposed magnetostrictive vibration generator for power-generating shoes.

1. Introduction
Typically, luminescent shoes use a sensor to detect interior vibrations caused by walking to induce LED flashes in synchronicity with footfalls. As a power supply for the sensors and LEDs, batteries are generally used, although power generation using the vibrations created in walking is being investigated as a method to reduce or eliminate the need for batteries [1]. The primary techniques for harvesting vibrational energy include piezoelectric and electromagnetic induction methods. As piezoelectric harvesters employ ceramic materials, they tend toward high internal impedance and brittleness. Electromagnetic induction harvesters employ ceramic materials, they tend toward high internal impedance and brittleness. Electromagnetic induction harvesters require significant magnetic body motion to obtain sufficient changes in flux density change. For these reasons, conventional piezoelectric and electromagnetic induction harvesters are difficult to miniaturize and have not been put to practical use. A magnetostrictive vibration power generator developed at our laboratory is composed of magnetostrictive (Fe-Ga alloy, Fe$_{81.6}$Ga$_{18.4}$) [2] and magnetic materials [3, 4]. Both the Fe-Ga alloy and the magnetic material are iron-based, enabling a simplified generator structure and, correspondingly, a highly durable device. Furthermore, the large reverse magnetostrictive effect of the Fe-Ga alloy results in a large flux density change of 1 T in the Fe-Ga alloy; as this is converted into voltage by the coil, the power generation device has a low output impedance, allowing for high levels of power generation amount from a small device. The magnetostrictive vibration power generator therefore has high power efficiency and is robust, making it suitable as a vibration power generator for use in shoes.

In our laboratory, we developed a U-shaped vibration power generation device; a description of the device and its suitability as a shoe-based power generator are provided on our homepage [5]. Because the generator has a high degree of springiness and operates with a body weight-generated force of ~ 100 N, it requires a strong structure and thus a large size. To improve on this design, we developed a device with a unimorph structure, making it possible to extract voltage using the impact acceleration occurring when the shoe’s sole contacts the floor. In this report, we analyze acceleration as a function of shoe
location, describe the method for fabricating a shoe-based power generator, and assess the output of the generator in action.

2. Structure of power generator and operation principle of power generation shoes

Figure 1 shows the structure of the unimorph-type generator. A magnetostrictive plate composed of Fe-Ga alloy is laminated onto a U-shaped magnetic frame on which a coil is wound. In addition, a permanent magnet is placed in the gap of the U-shaped frame to provide a bias magnetic field. The resonance frequency can be adjusted by changing the mass at the tip of the vibrating component. Because this device has a simple structure, it is easy to assemble and the number of turns of the coil can be increased to ramp up the power.

The principle of power generation is illustrated in figure 2. The generator is affixed to the sole of the shoe and, when the shoe’s sole contacts the floor, the inertial force arising from the impact acceleration acts on a mass at the tip of the generator. This causes the magnetostrictive plate to expand and contract in a bending motion, causing the magnetic flux inside the plate to change as a result of the inverse magnetostrictive effect. As the magnetic flux varies with time, a voltage is generated on the coil by electromagnetic induction. The generator has a resonance frequency at which large amounts of power can be extracted.

3. Acceleration at shoe location and performance of generator

3.1. Acceleration at shoe location

To assess the suitability of the generator installation location on the shoe, acceleration as a result of walking motion was detected using an acceleration sensor attached to different locations on the shoe. The acceleration sensor was variously glued to the sole and in front of, next to, and behind the shoe. Figure 4 shows the average power spectrum of acceleration taken from walking 50 steps on corridor tile. Figure 5 shows examples of time response waveforms of acceleration taken over 5 steps. From these results, it is seen that the power spectrum of the acceleration of the sole is nearly flat with an impulse
spike of about 10 G. For the other shoe parts, the peak and frequency of the power spectrum differ by installation location, with the back of the shoe producing 7 G at 300 Hz, the side producing 6 G at 110 Hz, and the front producing 2 G at 50 Hz. These results show that the location of the installation site on the sole is suitable and that the resonance frequency of the device should be set in the target design from 100 to 400 Hz.

3.2. Performance of generator

The relation between the resonance frequency and the output voltage with respect to a test mass at the tip of the generator was then assessed. Figure 5 shows the dimensions of the assembly. The overall generator has the dimension $37 \times 12 \times 6.5 \, \text{mm}^3$, the Fe-Ga component (manufactured by Fukuda Crystal Laboratory [6]) is $16 \times 4 \times 0.5 \, \text{mm}^3$, the SPCC magnetic frame has a thickness of 0.5 mm, the coil has dimensions $10 \times 8 \times 5 \, \text{mm}^3$, and the wire diameter is 0.05 mm. The $3 \times 6 \times 1.5 \, \text{mm}^3$ magnet has 5,275 turns, and the generator has an internal resistance of 775 $\Omega$.

In the experiment, the generator was fixed to the vibrator, a frequency sweep was performed under 0.1 G acceleration, and an oscilloscope was used to measure the resonance frequency and output voltage. The test mass was varied from 0, 0.26, 0.57, 0.97, to 1.7 g. Figure 6 shows the relationship between the resonance frequency and the output voltage of the generator with respect to the test mass at an exciter acceleration of 0.1 G. As the test mass increases, the resonance frequency decreases while the output voltage increases.

![Figure 5. Dimension of generator.](image)

![Figure 6. Relation between voltage, frequency and weight of proof mass.](image)

4. Characteristics of generator attached to shoe

4.1. Output voltage depending on the location of the generator

Figure 7 shows the output voltage, Vp-p, with respect to generator installation location for varying test masses (10 steps). In the case in which the generator is attached to the shoe’s sole, the output voltage is the highest and increases with the test mass. When the generator is attached behind the shoe, the output voltage is the maximum for the test mass for which the generator resonance frequency coincides with the resonance frequency of the shoe. When the generator is attached on the side or front of the shoe, the output voltage is small.

![Figure 7. Output voltage with respect to location of shoe of generator.](image)

![Figure 8. Time response of voltage with respect to location of shoe of generator.](image)
Figure 8 shows examples of output voltage waveform for the 1.7 g test mass. Vibration is sustained when the generator is attached to the sole of the shoe. Several pulses are generated when the generator is attached to the back or side of the shoe. When the generator is mounted to the front of the shoe, pulse peaks occur at two points. The duration of vibration increases with the test mass.

4.2. Confirmation of energy and LEDs operation by walking motion

We then investigated the effect of the weight of the proof mass and the load resistance on energy when the generator was attached to the shoe’s sole. Figure 9 shows the relationship between load resistance and energy calculated from Joule heating. As the test mass increases, the energy increases and the load resistance value producing maximum energy decreases. In this sample, the test mass was 1.7 g and the resistance was 150 Ω, producing a maximum energy of 55 µJ. For a 0 g test mass, the energy was 10 µJ.

Figure 10 shows a photograph of the generator and LEDs attached to the shoe sole with epoxy resin. The total weight of the generator is 10 g and it is connected directly to six LEDs. We confirmed that the LEDs could be caused to flash as a result of normal walking motion.

5. Conclusion

The acceleration of a generator as a function of position on a shoe was assessed and the characteristics of the generator with respect to mass loading were evaluated. It was determined that the shoe sole was a good place for attaching the generator and that a 1.7 g test mass produced optimal output characteristics. In actual walking motion, the generator produced an output voltage of 8 V and an energy of 55 µJ, and it was confirmed that this configuration could enable an array of six LEDs to successfully flash. Wireless modules require several hundred µJ of energy to operate; in future studies, we will assess the efficiency of the proposed generator with the goal of increasing generated energy through downsizing and using its output to power a wireless module.

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