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Study on Energy-Harvesting Dynamo Using Both Swing and Rotation ― Investigation of Voltage Up-Conversion with Mechanical Switches ―

振動と回転によるエネルギーハーベスティング ― メカスイッチを用いた電圧昇圧法 ―

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1. Introduction

Ecology has become the most important concept in the world. With ecology movements, energy harvesting techniques have also been very popular. There are many technologies from large-scale energy recovery systems used in electric trains and hybrid vehicles to middle-scale systems such as HEMS (Home Energy Management Systems). Electric trains and hybrid vehicles use their motors as dynamos when reducing velocities or braking, which provides high total-energy performances. Besides above large- and middle-scale energy saving trends, energy harvesting from our living environment has also been a remarkable movement in recent years. A lot of studies have been done about electric power generation from vibrations of objects and temperature differences of human bodies or others. However today's power levels are not so high, i.e. those from 100 µW to several mW, which cannot be used in consumer products. On the other hand, unplugged battery charge for electric handy gadgets such as watches, cellular phones, digital cameras, etc. has become a realistic requirement nowadays.

We are studying an energy harvesting dynamo which can provide such high voltage that it can be used as power supply source for electric handy gadgets. In our proposed dynamo, both swing (vibration) and rotation phenomena of a fan-shape weight are used. Along the fringe of weight several small Neodym magnets are buried. The power density of magnetic dynamos is larger than other generators. However, generated voltages are low compared with other technologies such as piezoelectric and electret devices. So, voltage up-conversion techniques are very important. In this paper, we also proposed a new up-conversion technique using mechanical switches which synchronize swing or rotation of weight. Mechanical switch can also eliminate the threshold problem of diodes.

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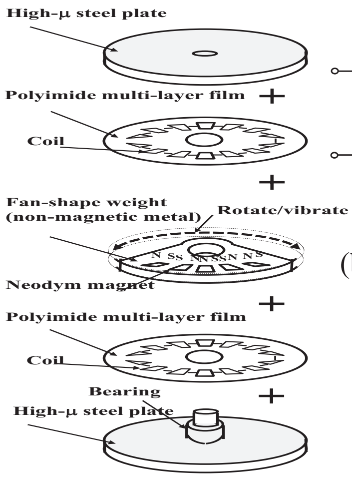
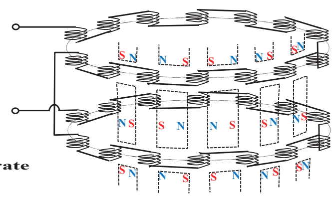
2. Dynamo configuration and magnetic flux density distribution

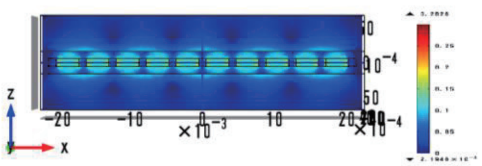
We have proposed a dynamo shown in Fig. 1(a) which can use both swing and rotation of fan-shaped weight to generate voltages. Neodym magnets are buried in non-magnetic fan-shape weight. An equivalent circuit shown in Fig. 1(b) is obtained due to mirror effect of high-µ plates. We also simulated distribution of the magnetic flux density, B, by COMSOL as shown in Fig. 1(c).



(a) Each part of dynamo.



(b) Equivalent circuit of dynamo.



(c) Magnetic flux density distribution (simulated by COMSOL)

Fig. 1 Proposed energy-harvesting dynamo.

3. Cockcroft Walton voltage up-converter using mechanical switches

Schottky-barrier diodes are usually used to rectify small-amplitude AC signals to DC due to their low threshold voltages. But 0.2-0.3 threshold voltages are not low enough to rectify the generated AC signals from the proposed dynamo. So we invented new Cockcroft Walton voltage up-converter using mechanical switches which have zero threshold voltage. As shown in Fig. 2, switches 3-4, 7-8, … are turned on when Vin is positive, while those of 1-2, 5-6, … are turned on when Vin is negative. As simulation will be illustrated later, output DC voltage given by amplitude of Vin times the number of switches can be obtained.

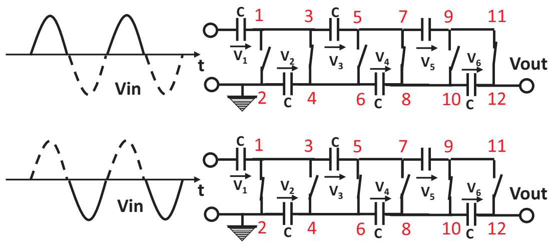
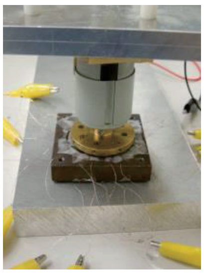


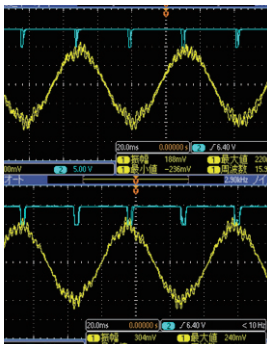
Fig. 2 Cockcroft Walton up-converter with mechanical switches (3-4, 7-8, … are ON for Vin>0. while 1-2, 5-6, … are ON for Vin<0).

4. Generated voltages by CW/CCW swings

From Fig. 2, mechanical switches should synchronize with generated voltage Vg. But Vg is proportional to - dΦ/dt, which means sign of Vg for CW is opposite to that for CCW even at same position of magnets. Using simple dynamo (Fig. 3(a)), we confirmed above characteristics as shown in Fig. 3(b).



(a) Experimental simple dynamo

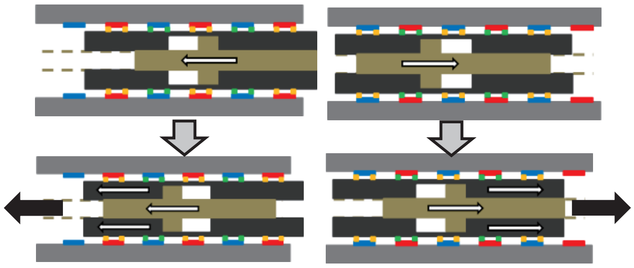


(b) Generated voltages (Upper: CW, Lower: CCW)

Fig. 3 Polarity of generated voltages due to swing directions.

5. Mechanical switches with half idler period

We can solve Fig. 3's polarity problem due to swing directions by introducing half idler period into mechanical switches. As shown in Fig. 4(a) and (b), only the fan-shape weight moves toward left (CW) or right (CCW) with half period first. Then mechanical switches move in same directions together with fan-shape weight due to stopper between switches and weight shown in Fig. 4. Same polarity for both CW and CCW swings can be achieved by this movement of half idler period. Example of fan-shape weight including switches is shown in Fig. 5. Switches and fan-shape weight can rotate together after half idler period. Switches for 1-2, 5-6, … and those for 3-4, 7-8, … become ON state alternately synchronizing with rotations.



(a) Left swing of fan-shape weight (b) Right swing of fan-shape weight

Fig. 4 Mechanical switches turned ON/OFF by swings of fan-shape weight with half idler period.

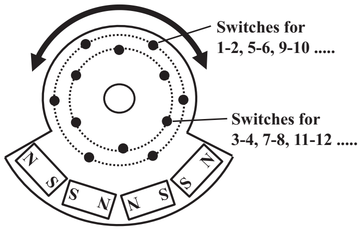


Fig. 5 Example of fan-shape weight including Fig. 2's switches.

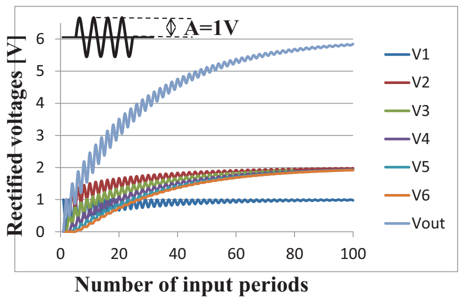


Fig. 6 Simulation results of Fig. 2's output assuming 1-V input amplitude.

6. Conclusion

Simulation of Cockcroft Walton voltage up-converter using mechanical switches shows very promising results for our proposal (Fig. 6). By using 3D printer, we will make fan-shape weight which mounts Neodym magnets and has half-idler-period stopper to drive switches. Switches can also be made by 3D printer. Optimum magnetic flux density distribution can be obtained by COMSOL simulator.

Reference

1. T. Nishi, T. Haremaki and M. Hikita, in Proc. of USE Vol.35, pp.51-52, 2014.