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Developing a pulsed electromagnetic induction generator for pulsed energies harvesting

Jing-Nang Lee¹, Chien-Chih Chen², Da-Yi Tsai²,
Chen-Ching Ting^{3,*}

¹Dept. of Refrigeration, Air Conditioning and Energy Engineering, National Chin-Yi University of Technology, Taiwan

²Graduate Institute of Mechanical and Electrical Engineering, National Taipei University of Technology, Taiwan

³Dept. of Mechanical Engineering, National Taipei University of Technology, Taiwan

Email address

chchting@ntut.edu.tw (Chen-Ching Ting)

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Abstract

Pulsed energies, e.g. water waves, mechanical roadway energy from walking people and vehicles, etc., are generally discrete and temporary, which are difficult to be effectively captured by using the traditional electric generators. To capture such pulsed energies, a piezoelectric generator is often considered and applied, but it is unfortunately until now with low working efficiency. Therefore, a new pulsed electric generator with high working efficiency is always expected. This article presents an invented pulsed electromagnetic induction generator which is patented by our CCT laboratory. Its output power is independent on rotational or moving speed of the generator. A unit device of this generator is an electric coil tube integrated with an inside movable induction magnet. Moreover, two push magnets are built on the two endpoints of the electric coil tube respectively. The push magnets alternately move over the endpoints of the electric coil tube and push the inside induction magnet to run through the electric coil to and fro. This action yields induced electromotive force in the electric coil and its output power is independent on moving speed of the push magnets. Integrating multiple such unit devices in an electric generator can build this special generator. This special generator is independent on rotational speed and is therefore very worthy to be widely applied for unstable energies harvesting, e.g. wind, waves of water, braking of vehicles, roadway mechanical green energies, and so on. Studying on this special generator uses diameter of copper wire, turns of coil, magnetic field of induction magnet, etc. as parameters. The reached maximum working efficiency in this work is now ca. 42%.

1. Introduction

Since 1831, M. Faraday had found the electromagnetic induction law which offers theoretical foundation of energy conversion between mechanical and electric energies. Henceforth, convenience of electric products lets human life

strongly depend on electricity. Although it also appears later several new electric generating technologies, e.g. solar cells [1, 2], thermoelectricity [3–5], piezoelectricity [6–8], etc., electric generator in terms of the electromagnetic induction law still occupies the mainstream market due to it has high energy conversion efficiency, long working life, and extremely large energy density.

An optimum rotational speed is always requested by an electromagnetic induction generator, e.g. a diesel electric generator is ca. 3600 rpm, an exciting electric generator is ca. 1800 rpm, a permanent magnet wind generator is ca. 300–600 rpm, a disk electric generator is ca. 100 rpm [9–14], and so on. In general, an electromagnetic induction generator can't reach maximum working efficiency and even goes down rapidly while the rotational speed leaves its required optimum value. The high rotational speed requirement of an electromagnetic induction generator has already limited its applications and also caused its extra energy loss during speed-up. Therefore, a rotational speed independent electric generator in terms of the electromagnetic induction law is strongly expected to be realized.

A rotational speed independent electric generator is relatively useful to capture the unstable, pulsed, and tiny energies, e.g. wind energy, water wave energy, vehicle's and animal's roadway mechanical green energy [15], potential energy of falling heavy, and so on. Although the piezoelectric generator is often used to capture the pulsed energy, the piezoelectric generator actually exists some problems, e.g. low working efficiency, small energy density, short working life, etc.. This article presents a pulsed electromagnetic induction generator which is rotational speed independent and uses electric coil tube integrated with inside movable induction magnet as unit device. Moreover, two push magnets are built on the two endpoints of the electric coil tube respectively. Fig. 1 shows three dimensional schema of this invented pulsed electromagnetic induction generator. Fig. 1 indicates that two push magnets on the push magnet framework move over the two endpoints of the electric coil tube alternately and push the induction magnet to run through the electric coil to and fro. This action yields induced electromotive force (emf) in the electric coil and its output power is independent on the rotational speed of the push magnet framework. This invented pulsed electromagnetic induction generator is also called as the instant electric generator due to its output power almost appears at start-up of the generator and is independent on rotational or moving speed of the generator. This instant electric generator has both advantages of the traditional electromagnetic induction and piezoelectric generators, but it has not their individual disadvantages. In future, this instant electric generator can be widely applied in a lot of fields, e.g. wind mill, ground surface, water, cuckoo clock, etc. to capture the unstable, pulsed, and tiny energies for instant electricity conversion.

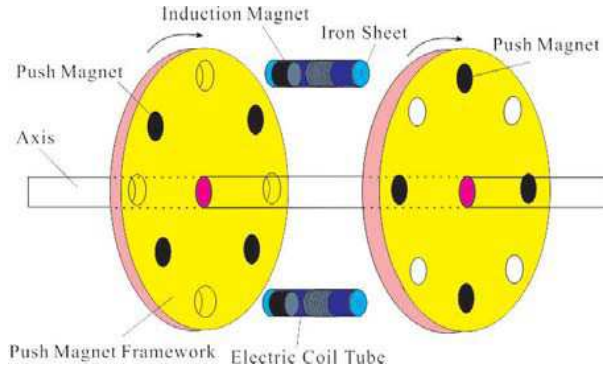


Fig 1. Three dimensional schema of the pulsed electromagnetic induction generator.

2. Basic Theory

It's well known that the general electric generators mainly work in terms of the Faraday's induction law. The induced electromotive force (ε) in a circuit is equal to the rate at which the magnetic flux (φ_B) through the circuit is changing,

$$\varepsilon = \frac{d\varphi_B}{dt} \quad (1)$$

where the minus sign is an indication of the direction of the induced emf. If the magnetic flux (φ_B) is enclosed by N rectangular loops with length l and width x respectively, Eq. (1) can be further rewritten as

$$\varepsilon = -N \frac{d\varphi_B}{dt} = -N \frac{d(Blx)}{dt} = -NBl \frac{dx}{dt} = NBlv, \quad (2)$$

where B is magnetic field and is not zero. Eq. (2) indicates that the induced electromotive force (ε) is influenced by magnitude of N , B , l , and v [16].

This article presents an invented pulsed electromagnetic induction generator which is rotational speed independent and also called as the instant electric generator due to it only requires relatively small rotational speed and its output power almost appears at start-up of the generator. Fig. 2 shows two dimensional schema of the instant electric generator. This instant electric generator is mainly composed of the electric coil tube and the push magnet framework, where the electric coil tube has components of the tube, the induction magnet, the induction electric coil, and the iron sheet. The push magnet framework consists of the push magnet and the framework. The alternate motion of the push magnets on the push magnet framework as shown in fig. 2 pushes the induction magnet inside the electric coil tube to run through the electric coil to and fro due to they have face-to-face magnetic homopolarity. This action yields induced emf in the electric coil and its magnitude depends on the moving speed of the induction magnet rather than the moving speed of the push magnet framework. In other words, this special electric generator is

rotational speed independent while a push magnet framework is in a circular motion.

The working efficiency (η) of this special electric generator is mainly influenced by integration of the electric coil tubes and the push magnets aside from its structural resistances. The main influencing parameters are L , D , d , N , m_{Fe} , m_o , B_o , m_i , and B_i , where L is length of tube, D is width of coil, d is diameter of copper wire, N is turn of coil, m_{Fe} is mass of iron sheet, m_o , B_o , m_i , B_i are mass and magnetic field of push and induction magnets respectively. The working efficiency (η) is defined as

$$\eta = \frac{W_{out}}{W_{in}} \times 100\% = \frac{\int dP \cdot dt}{\int dF \cdot ds} \times 100\%, \quad (3)$$

where W_{in} is input energy, F is input force, s is moving distance, W_{out} is output energy, P is output electric power, and t is working time.

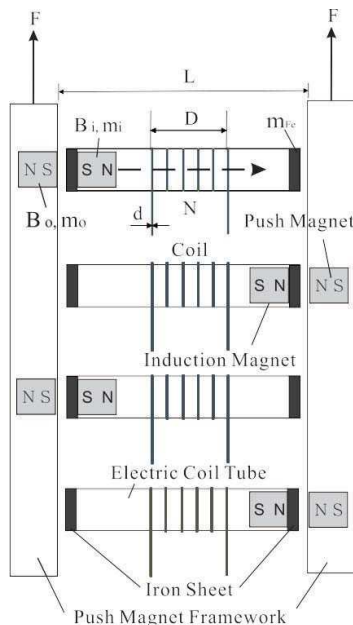


Fig 2. Two dimensional schema of the instant electric generator.

3. Experimental Details

Experiments introduce building of the pulsed electromagnetic induction generator, setup of the automation coil winder, setup of the measuring apparatuses for input force and output electric power in the following subsections.

3.1. Building of the Pulsed Electromagnetic Induction Generator

In this work, an experimental pulsed electromagnetic induction generator as round shape was first built for measurements. It is composed of an electric coil tube and a couple of push magnet frameworks, where the electric coil tube has components of a tube, an induction magnet, an induction electric coil, and a couple of iron sheets. The couple of push magnet frameworks are both with four push

magnets in a framework. Fig. 3 shows photo of the pulsed electromagnetic induction generator.

In process, the electric coil tube is fixed and the push magnets move over the endpoints of the electric coil tube alternately to push the induction magnet. The induction magnet therefore runs through the electric coil and yields the induced emf in the electric coil. Fig. 4 shows three dimensional schema of the instant electric generator.

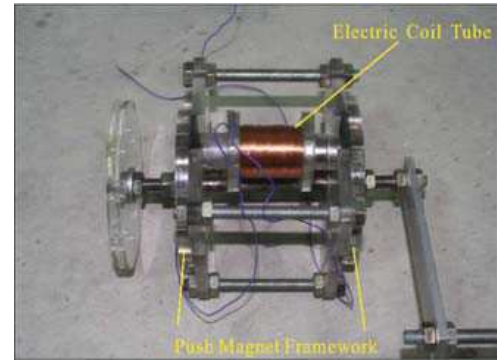


Fig 3. Photo of the pulsed electromagnetic induction generator.

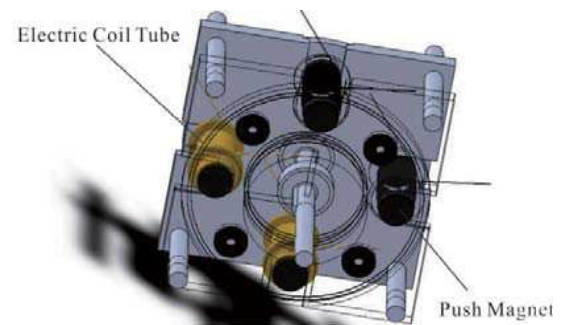


Fig 4. Three dimensional schema of the instant electric generator.

3.2. Setup of the Automation Coil Winder

For quick and exact building of the electric coil tubes, an automation coil winder was first made in this work. The home-made automation coil winder uses motors A and B to feed and wind copper wire for coil winding respectively. Motor A feeds copper wire and determines length of coil. Motor B winds copper wire and determines turns of coil. Fig. 5 shows schema of the home-made automation coil winder and fig. 6 is its objective photo.

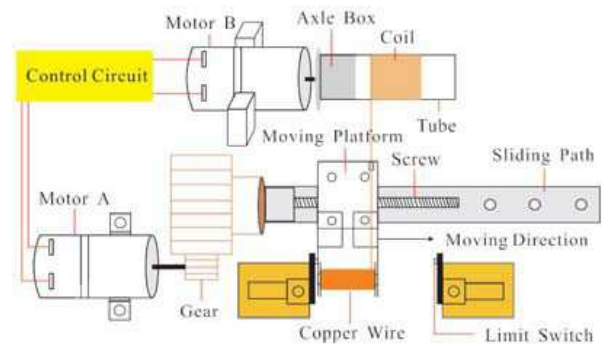


Fig 5. Schema of the home-made automation coil winder.

3.3. Measurements of Input Force

According to Eq. (3), the input work (W_{in}) is the product integral of the distance-varying input force with its corresponding distance change ($\int dF \cdot ds$).

That is, the distance-varying input force and the time-varying output electric power have to be measured for determining the working efficiency of the instant electric generator. In this work, a home-made apparatus for measuring the distance-varying input force uses a tensometer integrated with a motor. Fig. 7 shows photo of the measuring apparatus of distance-varying input force.

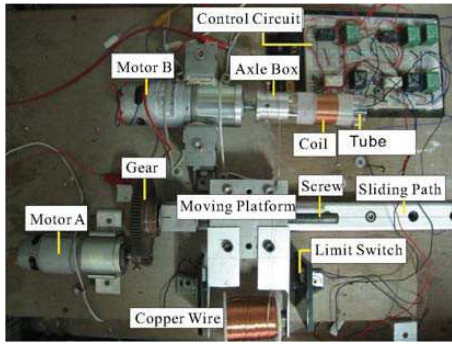


Fig 6. Photo of the home-made automation coil winder.

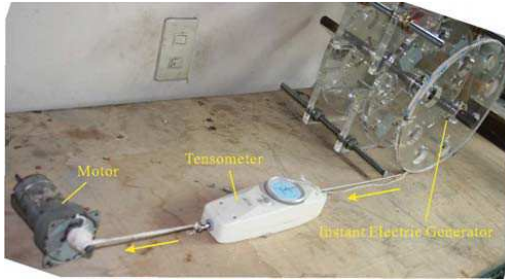


Fig 7. Photo of the measuring apparatus of distance-varying input force.

In process, an excluding force between the push and the induction magnets is yielded and increased while the push magnet moves close to the induction magnet. Magnitude of the input force depends on relative position between the push and the induction magnets. The induction magnet is forced to separate with the iron sheet while the push magnet is nearest to the induction magnet. After separation of the induction magnet with the iron sheet, the excluding force is changed to the attracting force between the push magnet and the iron sheet. The attracting force will progressively decrease while the push magnet leaves the electric coil tube. The distance-varying input force of the instant electric generator is shown as pulse forms in terms of this special working procedure.

3.4. Measurements of I-V Curves

I-V curve is significant characteristic curve of an electric generator, which can determine the maximum output power and further find out the maximum working efficiency. A measuring apparatus of I-V curve is mainly composed of

current and voltage meter integrated with adjustable resistance [17]. The maximum working efficiency appears at the optimum electric circuit load. Fig. 8 shows schema of the home-made measuring apparatus of I-V curve and fig. 9 is its objective photo.

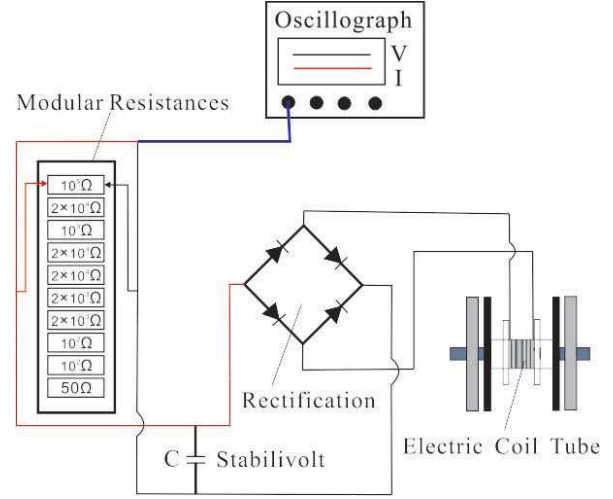


Fig 8. Schema of the home-made measuring apparatus of I-V curve.

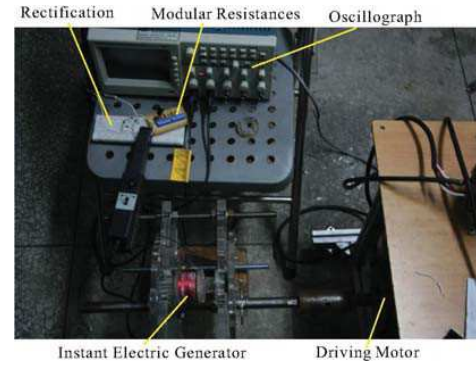


Fig 9. Photo of the home-made measuring apparatus of I-V curve.

Finally, Table 2 shows experimental run conditions in this work. This work used one electric coil tube integrated with four alternate push magnets to simplify procedure of the measurements. The results can be further analogized to the whole electric generator with multiple electric coil tubes.

Table 1. Experimental run conditions.

d(cm)	Bi(G)	N(Turn)
0.15	4300, 5300	1000, 3000, 5000, 7000, 9000
0.29	5300	1000, 1400, 1700, 2300, 2700
0.45	5300	273, 700, 1000, 1300

$L=5\text{cm}$, $D=3\text{cm}$, $B_0 = 4300\text{G}$

Table 2. Experimental run conditions.

d(cm)	Bi(G)	N(Turn)
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0.45	5300	273, 700, 1000, 1300

$L=5\text{cm}$, $D=3\text{cm}$, $B_0 = 4300\text{G}$

4. Results and Discussion

The pulsed electromagnetic induction generator in this work is an alternator which is rotational speed independent. Fig. 10 shows a wave form sample of its original output voltage and current vs. time, where the applied turns of coil (N) is 1300, diameter of copper wire (d) is 0.45 mm, and induction magnetic field (B_i) is 5300 G. The values of the output voltage and current strongly depend on turns of coil, length of coil, diameter of copper wire, density of induction magnetic field, and so on. Certainly, it exists an optimal assemblage to reach the maximum working efficiency.

The input force of the instant electric generator is mainly provided to exclude the induction magnet attracted with the iron sheet in the electric coil tube. This work used a single electric coil tube integrated with four alternate push magnets to build the testing electric generator. The electric generator was turned three-quarter turn of the push framework for one time measurement. In process, the push magnet moving close to the electric coil tube causes increasing input force and departure of the push magnet decreases input force. This working procedure yields pulse forms of the distance-varying input force. Every pulse form has theoretically the similar area. That is, the distance-varying input force will appear three pulse forms for one time measurement. Fig. 11 shows curve of the distance-varying input force. Fig. 11 indicates that a pulse form has distance of ca. 40 mm due to diameters of the applied magnets are all 20 mm. Moreover, the input force between two pulse forms is almost zero.

The input work is independent on the output electric power for this instant electric generator. The output electric power is yielded due to the induction magnet runs through the electric coil. The maximum output electric power is decided by the optimum electric circuit load. In other words, the maximum working efficiency of this instant electric generator appears at the optimum electric circuit load due to the input work is always constant.

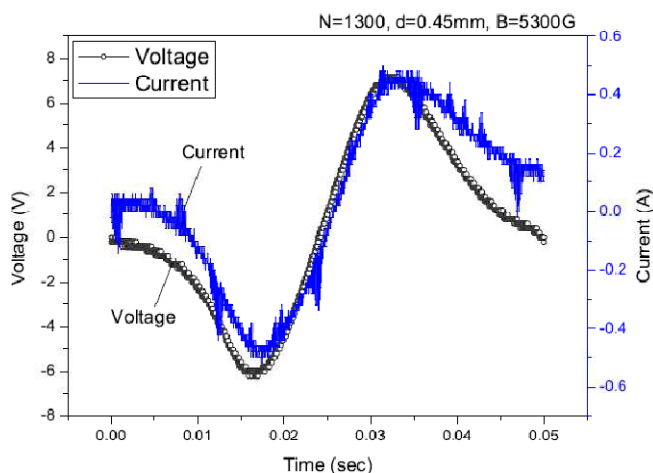


Fig 10. A wave form sample of original output voltage and current vs. time.

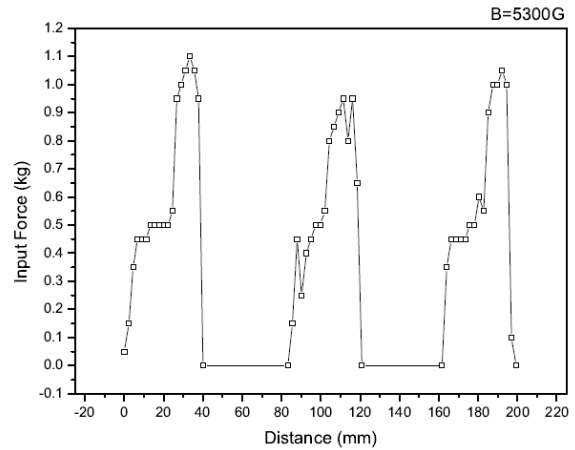


Fig 11. Curve of the distance-varying input force.

4.1. Influences of Turns of Coil and Induction Magnetic Field

Figs. 12 - 15 show I-V and P-V curves of the instant electric generator with length of coil 30 mm, diameter of copper wire 0.29 mm, and induction magnetic field 4300 G as well as 5300 G influenced by different turns of coil respectively. The results show that the more turns of coil receives the larger open-circuit voltage, but its corresponding short-circuit current is therefore smaller. The results agree to theoretical prediction. Fig. 15 exhibits that the maximum output power is ca. 0.68 W which appears at 1400 turns of coil and 5300 G induction magnetic field. Fig. 16 shows the working efficiencies of the instant electric generator influenced by turns of coil and induction magnetic field. The maximum working efficiency is ca. 36.7 % which appears at 1400 turns of coil and 5300 G induction magnetic field.

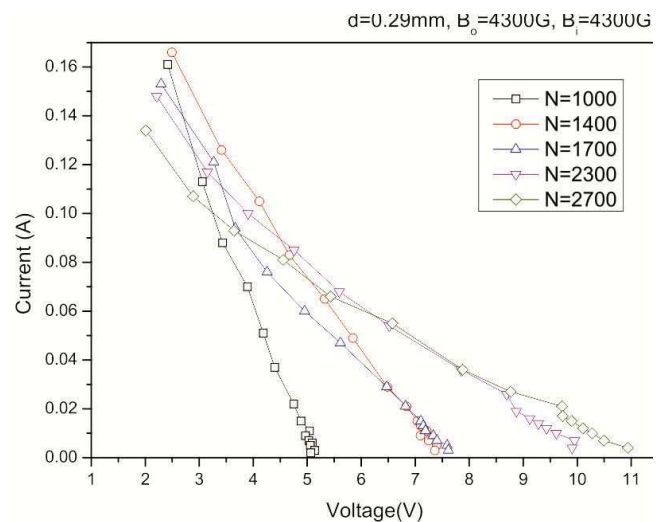


Fig 12. I-V curves of the instant electric generator influenced by turns of coil with induction magnetic field of 4300 G.

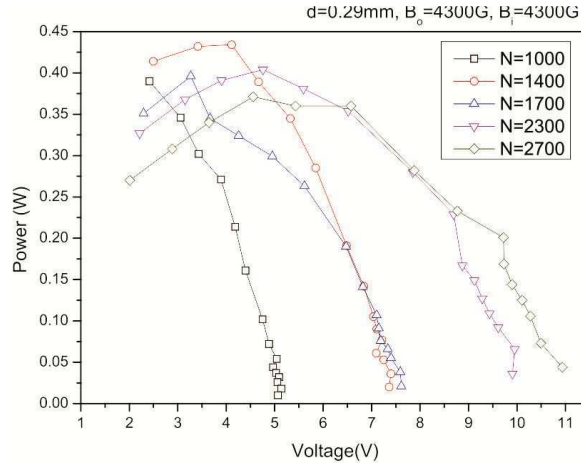


Fig 13. P-V curves of the instant electric generator influenced by turns of coil with induction magnetic field of 4300 G.

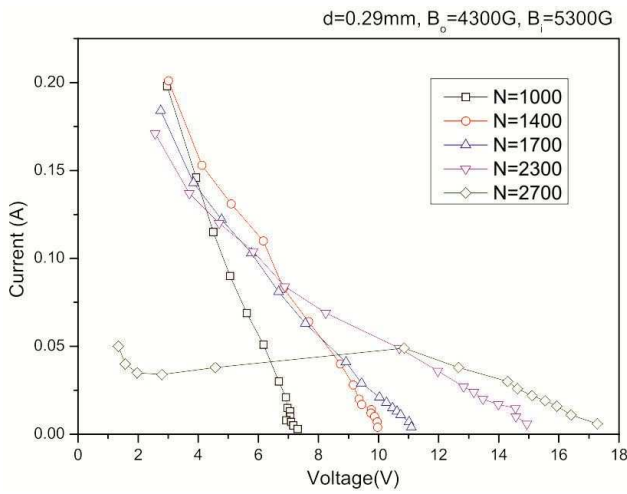


Fig 14. I-V curves of the instant electric generator influenced by turns of coil with induction magnetic field of 5300 G.

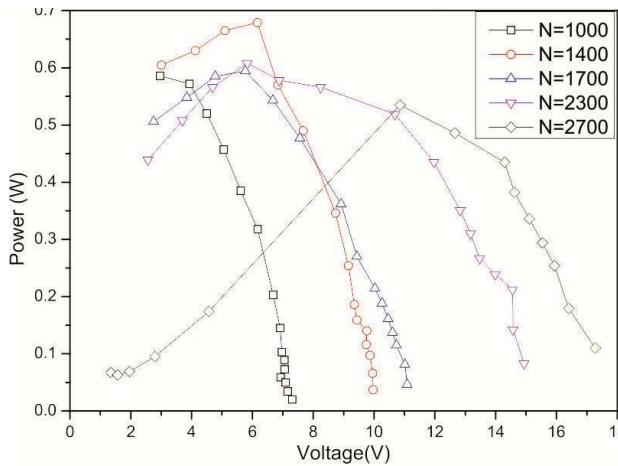


Fig 15. P-V curves of the instant electric generator influenced by turns of coil with induction magnetic field of 5300 G.

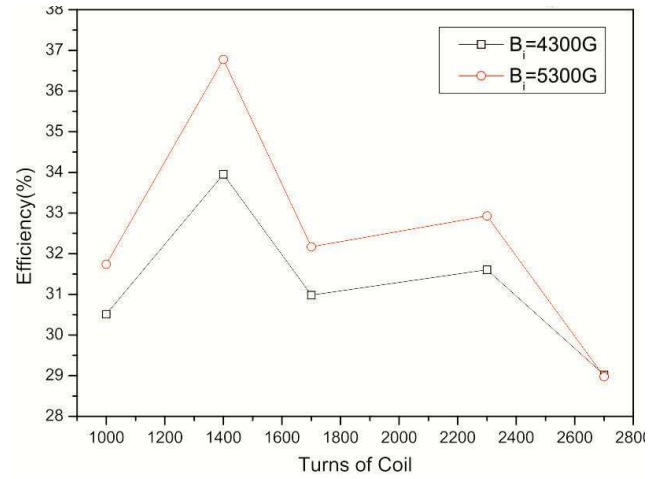


Fig 16. Working Efficiencies of the instant electric generator influenced by turns of coil and induction magnetic field.

4.2. Influences of Copper Wire Diameter

Figs. 17 - 20 show I-V and P-V curves of the instant electric generator with length of coil 45 mm, diameter of copper wire 0.15 mm as well as 0.45 mm, and induction magnetic field 5300 G influenced by different turns of coil respectively. The larger diameter of copper wire also exists the smaller electric resistance, which therefore yields the larger output current. Fig. 20 shows that the maximum output power is ca. 0.78 W which appears at 1000 turns of coil.

Fig. 21 further shows relationship of working efficiency vs. turns of coil influenced by different diameters of copper wire. Fig. 21 indicates that an optimal combination of 1000 turns of coil, 0.45 mm diameter of copper wire, and 5300 G induction magnetic field receives the maximum working efficiency of ca. 19 % in this work.

5. Conclusion

The pulsed electromagnetic induction generator or instant electric generator invented by our CCT laboratory has been successfully established and verified its superiority in this work. An automation coil winder for quick and exact fabrication of the electric coil tube has also been set up. Moreover, for verification of the feasibility and determination of the working efficiency, apparatuses for distance varying input force measurements and I-V curve determination of the instant electric generator have also been successfully established. The results show that the original output electricity is alternate current and its input force is independent on the electric circuit load. In general, the larger the turns of coil, the higher the output voltage of the generator. The larger the diameter of copper wire and the larger the induction magnetic field, the larger the output current of the generator. The all referred situations certainly exist the optimal condition. In this work, the reached maximum working efficiency is ca. 42 % which appears at 0.45 mm diameter of copper wire and 1000 turns of coil with 5300G induction magnetic field.

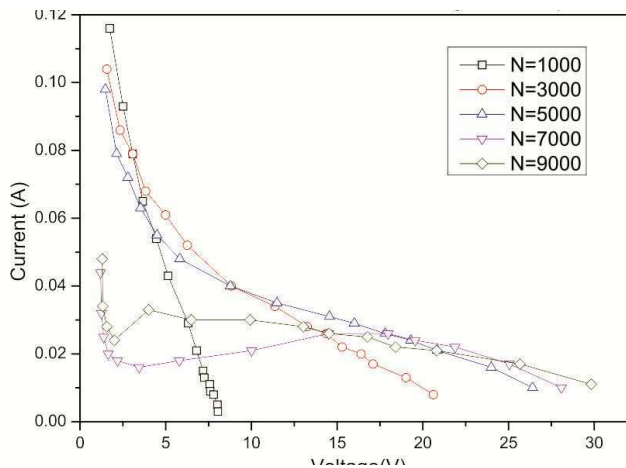


Fig 17. I-V curves of the instant electric generator influenced by turns of coil with 0.15 mm diameter of copper wire.

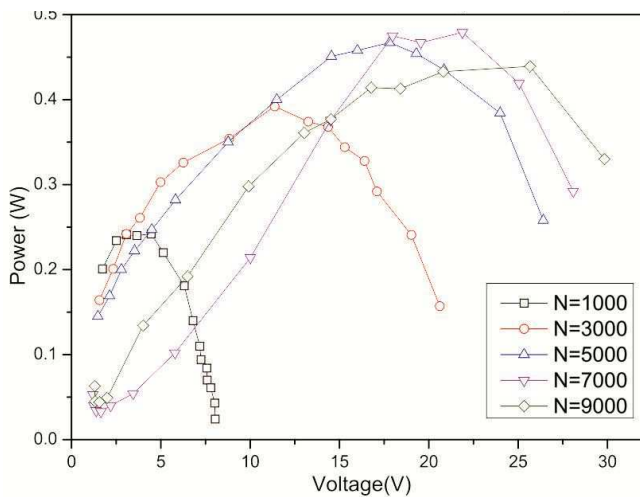


Fig 18. P-V curves of the instant electric generator influenced by turns of coil with 0.15 mm diameter of copper wire.

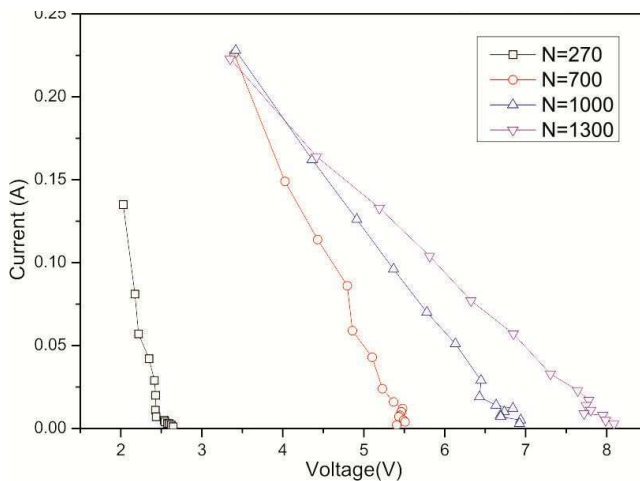


Fig 19. I-V curves of the instant electric generator influenced by turns of coil with 0.45 mm diameter of copper wire.

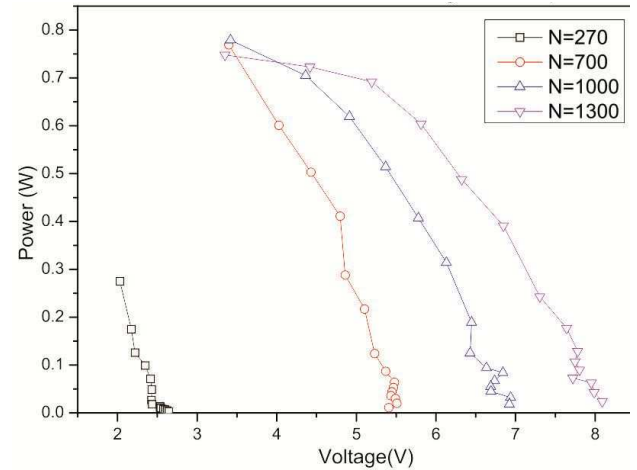


Fig 20. P-V curves of the instant electric generator influenced by turns of coil with 0.45 mm diameter of copper wire.

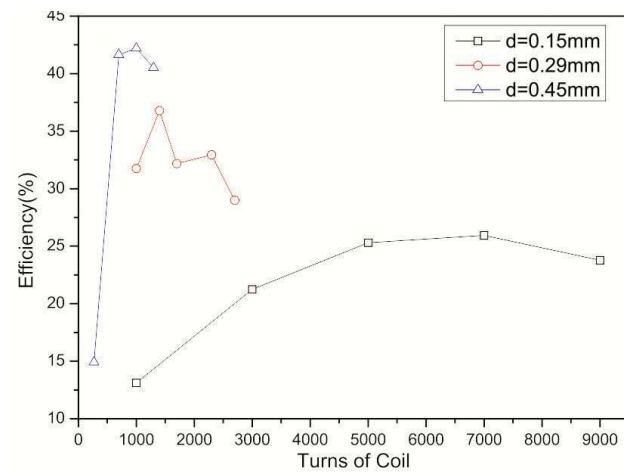


Fig 21. Relationship of working efficiency vs. turns of coil influenced by different diameters of copper wire.

Acknowledgment

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