Development of Lithium Ion Battery Charging System by the Exercise Bike with the Brushless Generator Mounted

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***Abstract*—A three-phase brushless generator is mounted to an exercise bike, one kind of health appliances, and charging of a lithium ion battery is evaluated when the exercise bike is being used. The lithium ion battery are developed and evaluated in our research laboratory using same exclusive equipments. The new charging system is developed with brushless generator, lithium ion batter charger and laminate type Lithium ion battery.**

Keywords—brushless generator; exercise bike; battery charger; laminate type lithium ion battery

I. INTRODUCTION

First of all, discussion is made on the procedure for making a three-phase brushless generator, which we could establish winding specifications for and we could make by ourselves. Next, the relationship between the rotating speed and output voltage and output current, which are basic characteristics of a generator, is measured. Specifically, measurement is made on the output characteristics by rotation control when the generator is driven by an induction motor. In addition, the generator is driven by a bicycle rear wheel and the relationship between the rotating speed and output voltage, current, and output power is investigated. Lastly, a charger specialized for the laminate type lithium ion battery is fabricated and charging of the lithium ion battery is evaluated when the exercise bike is used.

II. FABRICATION OF A BRUSHLESS GENERATO

With a goal set for teaching materials applications, a brushless generator which we could set winding specifications for and make by ourselves was developed[1].

TABLE I. PARTS LIST OF BRUSHLESS GENERATOR

No.	Part name	Specifications	Q'ty
1	Rotor unit	12 magnets mounted, with shaft attached	1
2	Magnet wire	Linear 0.7 mm in diameter	1
3	Insulation bobbin	Plastic molding	2
4	Stator core	Core lamination thickness: 27 mm	1
5	Stator base	Metal-worked article	1
6	Bearing	6001ZZ	2
7	C-ring	STWS12	1
8	Hexagon socket head cap screw	CBM6×30	3
9	Power lead wire	AVS5sq 500mm (Red, white, black)	3

Components of a brushless generator used for fabrication are shown in Table 1 and Fig. 1, and an enlarged view of the stator core is shown in Fig. 2.

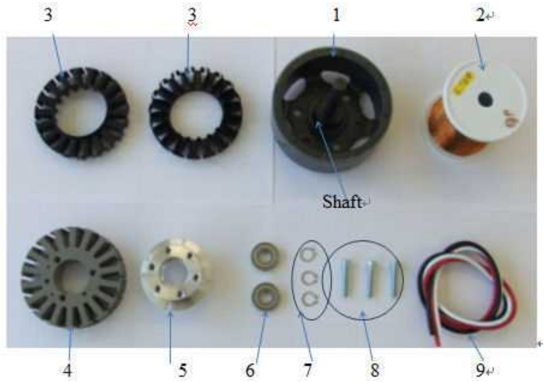


Fig. 1. Parts list of a brushless generator

Fig. 2. Parts list of a brushless generator

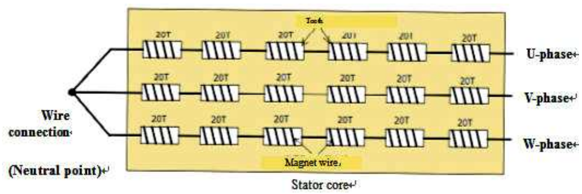


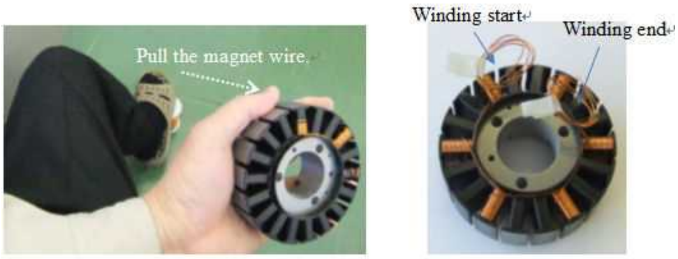
Fig. 3. Image of Y-connection

The stator core was composed with 18 teeth. To each tooth, the magnet wire was wound for 3 phases and finished to form six windings connected in series in a Y configuration. The winding specifications of the brushless generator to be made were ϕ0.7 x 20 T x 6 in series (Y connection). That is, as one phase (U-phase), the magnet wire was continuously wound around 6 teeth and set in series to finish. Around each tooth, 20 T (turns) of the magnet wire was wound.

The V-phase and the W-phase were finished in the same manner. Lastly, one sides of a total of six windings, two each of windings belonging to U, V, and W phases, respectively, were series-connected to be a neutral point, and three phases were connected in a Y configuration to finish the winding (Fig. 3).

A. Winding work

Pull out the magnet wire from a bobbin, press the bobbin by foot to apply tension to the wire, and pull the wire to uniformly wind it around the tooth (Fig. 4 (a)). Wind the wire around each tooth in the same direction clockwise or counterclockwise with the core as viewed from the side direction. Fig. 4 (b) shows a stator core with windings completed for one phase. Finish windings for 3 phases in this way (Fig. 5).



(a) Winding work (b) Winding for one phase

Fig. 4. Stator Core Winding

Fig. 5. Stator core with winding work completed

B. Wiring work

After the completion of winding work, undertake wiring work for Y connection. Scrape away coating at the head ends of three magnet wires at the winding start, just hand-twist one another, and solder them. This wire connection serves as the neutral point of Y connection. Thereafter, protect the soldered portion by heat-shrinkable tube.

Then, solder the power lead wires to three magnet wires at the head end of the winding end after scraping away the coating at the head end, and protect the soldered portion by taping (Fig.6).

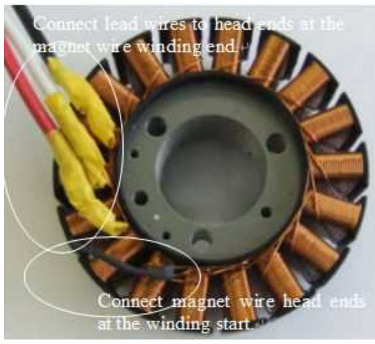


Fig. 6. Process the head ends of magnet wire

C. Fixing the stator base

Set the stator base to the stator core and fix with 3 hexagon socket head cap screws. Thereafter, pass the tie-wrap through the stator base hole and fix the power lead wire (Fig. 7).

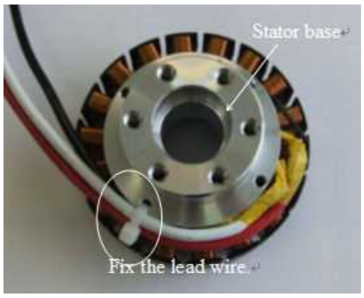


Fig. 7. Mount the stator base to the stator core

D. Assembling bearings

Insert two bearings very far into both holes of the stator base, respectively, until they come in contact with the hole bottoms, assemble and fix (Fig.8).

Fig. 8. Set the bearing to the stator base hole

E. Assembling the rotor unit

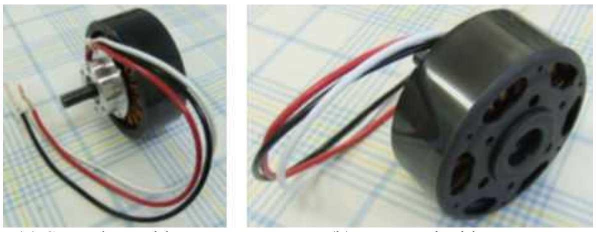
Insert the rotor unit shaft into the bearing hole and mount the rotor unit to the stator base (Fig. 9 (a)). Lastly, insert a C-ring into the shaft and fix the rotor unit (Fig. 9 (b)).

(a) Mount the rotor unit. (b) Insert the C-ring.

Fig. 9. Assemble the rotor unit and set the c-ring

F. *Completion of a brushless generato*

Fig. 10 shows the completed brushless generator and Fig. 11 shows the completion drawing.



(a) Stator base side (b) Rotor unit side

Fig. 10. Appearance of the assembled brushless generator

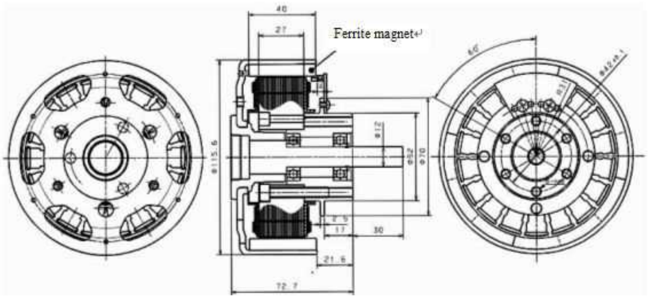


Fig. 11. Completion drawing of the brushless generato

III. BASIC EXPERIMENT OF BRUSHLESS GENERATOR

As a basic experiment of the fabricated brushless generator, the relationship between the rotating speed and output voltage and output current is measured. Fig. 12 shows the experimental circuit configuration. To the generator output terminals (UVW 3 phases), connect bridge diodes, and then, connect an electrolytic capacitor to the diode bridge output side to configure a rectifier circuit. On the output side of the rectifier circuit, connect a load resistor and measure the direct current output characteristics.

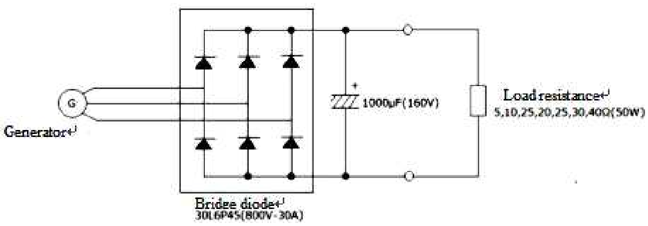
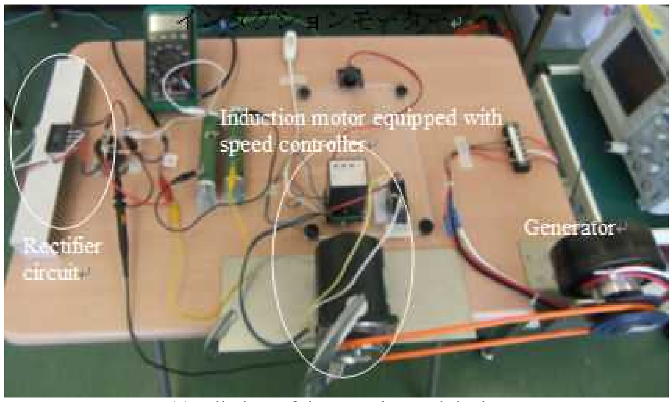
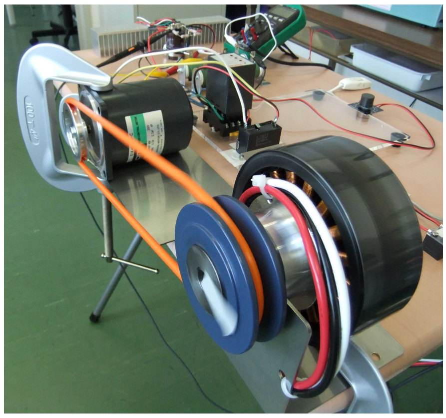


Fig. 12. Basic experimental circuit of the generator



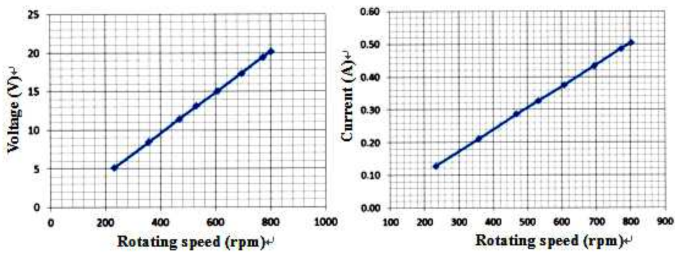
(a)Full view of the experimental device



(b) Rotation of the generator by pulley belt

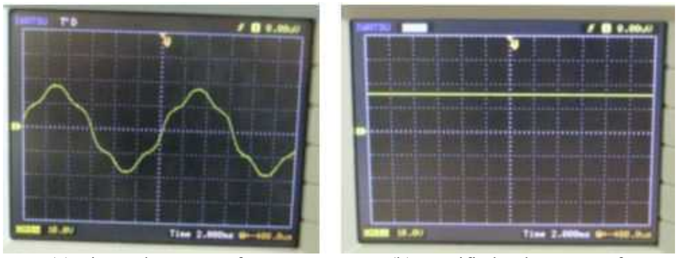
Fig. 13. Basic Experiment of the Generator by Induction Motor

For generator rotation control, connect a pulley mounted to the induction motor (51K40RA-C, 40 W, available from Oriental Motor Co., Ltd.) equipped with a speed controller (SS22M-SSSD available from Oriental Motor Co., Ltd.) and a pulley mounted to the generator shaft by belt, and measure the relationship between the generator rotating speed and output voltage and current while controlling the rotating speed of the induction motor (Fig. 13). The generator rotating speed was measured by a digital photo tachometer by affixing a reflective mark to the pulley mounted to the shaft. Fig. 14 shows the measurement result when the 40-ohm load resistance is connected to the output side of the rectifier circuit in the experimental circuit.



(a) Output voltage (b) Output current

Fig. 14. Relationship between rotating speed and output voltage and current



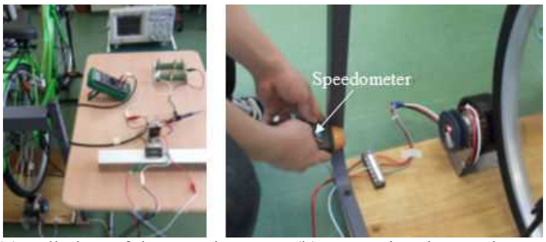
(a) Line voltage waveform (b) Rectified voltage waveform

Fig. 15. Line voltage waveform and rectified voltage waveform of the generator (rotating speed: 600 rpm)

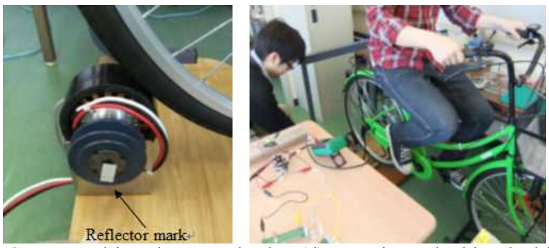
Fig. 15 shows the generator output voltage (line voltage) and the voltage waveform after rectification when the rotating speed is 600 rpm. It indicates that the frequency of generator output voltage in such event is about 83 Hz. It is able to be confirmed that the output voltage and the output current after rectification of the generator increases nearly in proportion to the rotating speed.

IV. CHARACTERISTICS EXPERIMENT OF BRUSHLESS GENERATOR

The output characteristics are measured when the generator rotor portion is brought in contact with a bicycle rear wheel and the generator is rotated. The generator rotating speed is measured by digital photo tachometer as in the case of the drive by the induction motor (Fig. 16).



(a) Full view of the experiment (b) Measuring the rotating speed

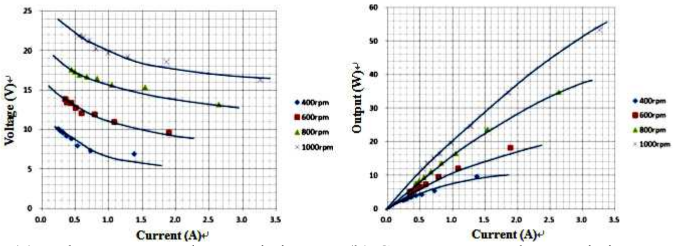


(c) Generator driven by rear wheel (d) Experiment by bicycle drive

Fig. 16. Experiment of generator output characteristics by bicycle's rear wheel drive

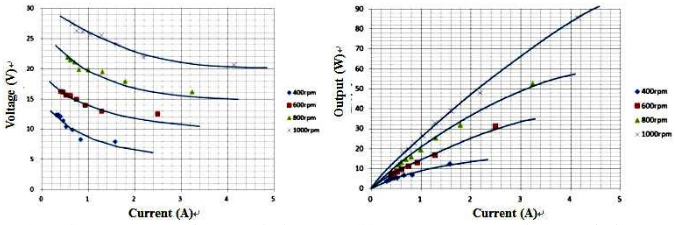
As generator characteristics, measurement was made on the voltage-current characteristics and current-output characteristics, respectively, when a load resistance is directly connected across generator output terminals (any line of UVW phases) (in the case of alternate current) and when a load resistance is connected to the output side of the rectifier circuit connected to the generator (see Fig. 12) (in the case of direct current). Fig. 17 and Fig. 18 show measurement results.

In all the characteristics, as the generator rotating speed increases, voltage, current, and output power increase.



(a) Voltage-current characteristics (b) Current-output characteristics

Fig. 17. Generator output characteristics (in the case of alternate current)



(a) Voltage-current characteristics (b) Current-output characteristics

Fig. 18. Generator output characteristics (in the case of direct current)

V. CHARGING OF LITHIUM ION BATTERY BY BRUSHLESS GENERATOR

The brushless generator made by ourselves was mounted to an exercise bike, one kind of health appliances, and a belt was used to connect across a pulley mounted to the drive shaft of the exercise bike pedals and a pulley mounted to the generator rotary shaft (Fig. 19).

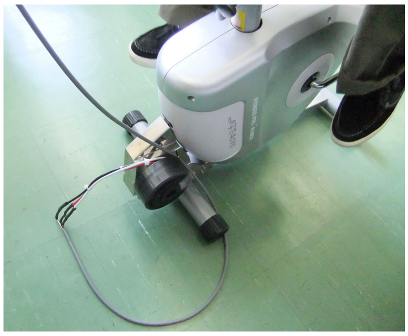


Fig. 19. Generator mounted to an exercise bike

Fig. 20. Constant current-constant voltage charger

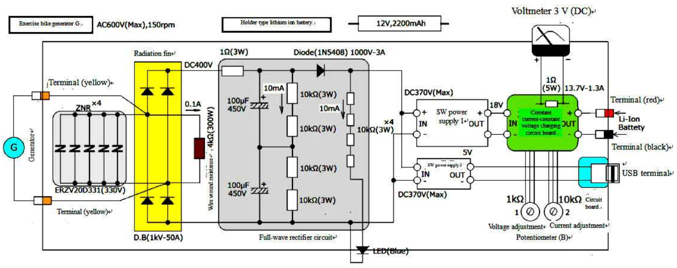


Fig. 21. Overall circuit configuration of the charger

Then, a charger that could enable constant current-constant voltage charging when the lithium ion batteries were charged from the generator was designed and fabricated (Fig. 20 and Fig. 21). On the charger output side, prototype lithium ion batteries prepared at the laboratory were connected, and charging characteristics when the exercise bike pedals were rotated were measured (Fig. 22).

Fig. 22. Charging experiment by an exercise bike

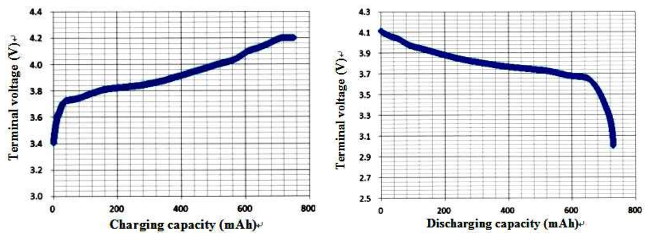
For the lithium ion battery, the positive electrode sheet with an activator coated to both surfaces of aluminum foil and the negative electrode sheet with an activator coated on both surfaces of Cu foil were cut into a size of 650L and 80W mm, respectively, to which tabbed electrode terminals were spot-welded[2]. Then, with a separator (650 L x 80 W mm) sandwiched, using a winding system jig, electrode body was fabricated (Fig. 23 and Fig. 24). Lastly, in a vacuum glove box, the electrode body was set to a fabricated aluminum laminate cell (pouch cell) and an organic electrolyte was injected. The pouch cell was sealed by laminator and finished into a lithium ion battery cell (Fig. 25). Fig. 26 show charging and discharging characteristics of the prototype battery cell (battery capacity: 1000 mAh).

Fig. 23. Positive (upper) and negative (lower) electrode sheets

(a) Spot welding (b)Vacuum glove box

Fig. 24. Spot welding of electrode terminals and operation inside the vacuum glove box

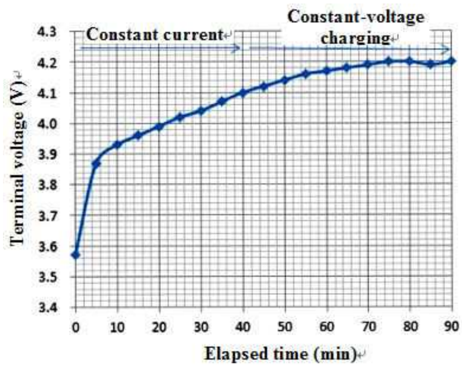
Fig. 25. Laminate type lithium ion battery



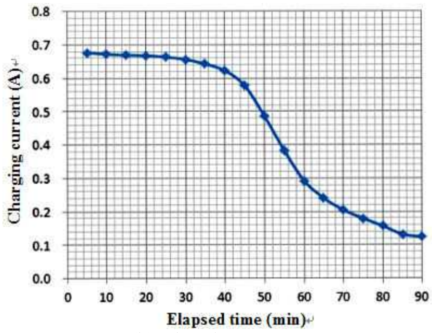
(a)Charging (b)Duscharging

Fig. 26. Charging and discharging characteristics of lithium ion battery

Fig. 27 show charging and discharging characteristics of lithium ion battery by an exercise bike. Two persons took turns at pedaling the exercise bike for 5 minutes each continuously for about 1 hour and 30 minutes. The measurement results indicate that at the initial charging period, constant-current charging took place and when a fully charged state was nearly reached, constant-current charging was moved to constant-voltage charging. In addition, temperature rise at the time of charging the lithium ion battery was monitored by infrared thermography but no marked temperature rise was recognized.



(a) Terminal voltage



(b) Charging current

Fig. 27. Charging characteristics of lithium ion battery by an exercise bike

VI. Conclusion

A brushless motor was made by hand from the winding work and the generator output characteristics in rotation drive by induction motor and a bicycle were measured. With the prototype generator, by increasing the number of windings, larger output was able to be obtained, though this was a case of stator core windings of 20 T. The hand-made brushless generator was assembled into an exercise bike, a kind of health appliances, a charger that could be used for generators was newly fabricated, laminate type lithium ion batteries fabricated at the laboratory were connected, and charging characteristics were measured as a charging system comprising an exercise bike, generator, charger, and lithium ion batteries.

By combining a vehicle utilizing self-rotation such as bicycles or exercise bikes with a small-sized large-capacity lithium ion battery, the electrical power energy can be effectively utilized.

References

[1] Shouji Usuda: "2013 Version Engineering Software, the General," issued by Ohmsha, OHM, May 2013.

[2] Shouji Usuda: "Introduction of circuit design for Lithium Ion Battery", issued by Nikkan Kogyo Shinbun, Ltd., 2011.

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