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Wind turbine generator system utilizing wind flow around the building
The output characteristics of the micro wind turbine generator system

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Abstract

As a micro wind turbine generator system may transforms a wind's kinetic energy into electric energy, so the wind speed decreases. Thus the rotation of the micro windmill can, in effect control the flow of a wind. The wind turbine generator system has two functions, generation of electricity and the control of wind. In combination, these two functions improve our environment and generate renewable energy. This report shows the output characteristics of the micro windmill, the air current which blows the micro windmill, the acoustic noise generated from the micro wind turbine, and the design of charge equipment.

§1. Introduction

Micro wind turbine generator systems are becoming commonplace; the number of companies that manufacturing them is increasing every year.

The definition of the micro wind turbine generator system is one where the diameter of the windmill is ≤ 1m.

In Japan, most companies that manufacture the micro wind turbine generator system do not have the equipment necessary for thorough testing of their systems. There is little data published about the durability and the output characteristics of micro wind turbines. The most serious problem is the acoustic noise when the small wind turbine generator system and the micro wind turbine generator system are installed. There are very few measurements of about the acoustic noise generated from the wind turbine.

In residential areas where micro wind power is installed, nearby residents claim an increase in ambient noise levels. Local residents may also be upset by the visual impact of a rapidly-rotating high speed. Thus, in order to introduce the micro wind turbine generator system as a part of everyday life, it turns out that there may be a number of hurdles yet to overcome.

However, the micro wind turbine generator system is effective in locations where protection against strong wind is needed. Currently, planting of trees or installation of fences are often adopted as protection against strong wind. However many structures (such as inner-city buildings, bridges, farms, shopping centers, artificial fisheries etc.) have no protection against strong wind Micro wind turbines offer a compact solution to providing such protection, and can be particularly effective when installed in groups.

In the urban areas, such as Tokyo, research is taking place into technologies that will reduce the urban heat island effect through the development of 'wind roads'. By creating wind roads, the ventilation of the urban area improves and the hot air collected on the street is dispersed in the

Keywords: Micro wind turbine generator system, power output

summer season. In ~~a~~ summer, pedestrians on the 'wind road' will feel increased comfort, but in spring, autumn, and winter, the increased wind speed will be viewed negatively. Thus, from a pedestrian's viewpoint, the control of wind environment (as well as measures against warming in an urban area) is an important technology.

Photo.1 48 sets of the micro wind turbine generator system in Fujita Technology Development Division, Atsugi City Kanagawa in Japan

Photo.2 10 sets of the micro wind turbine generator system in Fujita Head Office, Shibuya-ku Tokyo in Japan

§2. Output characteristic of the micro wind turbine generator system

The micro wind turbine generator system (hereafter, called the micro windmill) consists of the windmill with a diameter of 50cm and the micro dynamo made from polycarbonate. Since a micro wind turbine generator system can be installed in the wind tunnel, we can make detailed measurements about the relation between the output characteristics, the wind direction, and the wind velocity of the system. Fig.1 is the measuring system figure for investigating the output characteristics of a micro windmill.

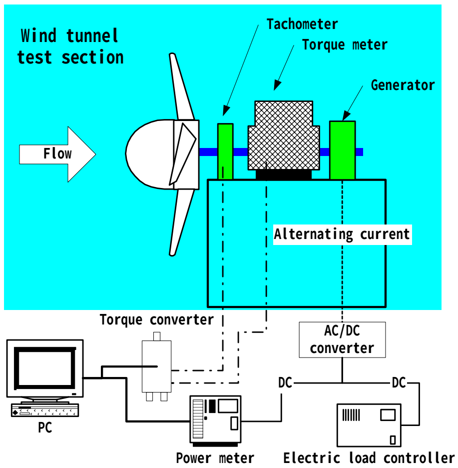


Fig.1 Measuring system of output characteristic of the micro wind turbine generator system

Since the micro windmill outputs alternating current (AC), it is necessary to transform current into the direct current (DC). Fig. 2 shows the electric circuit with rectifier.

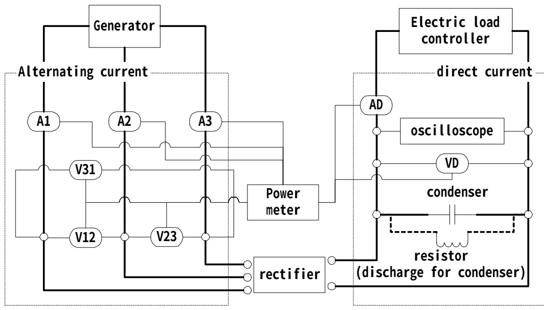


Fig.2 The electric circuit with rectifier

Fig.3 shows the output characteristics of a micro wind turbine generator system in a wind tunnel test. The wind speed in the wind tunnel ~~is~~ varied from 4 to 23 m/s. The electric loads are from 10 to 300 ohm. When the rated wind speed is 12m/s, the rated power by a micro windmill is about 50 watts (the voltage of direct current is 38.5 v. the current value is 1.3 A.). When the wind speed is 4 m/s, the power output is about 0.9 watts (the voltage of direct current is 9.3 v. the current value is 0.1 A.).

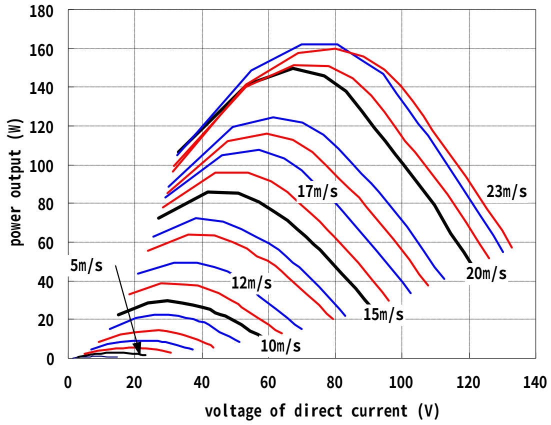


Fig.3 Output characteristics of a micro wind turbine generator system by wind tunnel test

Fig.4 shows the coefficient and power output of a micro windmill in the optimal load by the wind tunnel test. The maximum power coefficient observed is about 0.4. The power coefficient of the ideal wind turbine is about 0.6. The maximum all power recovery co efficiency is about 0.26. For example, the power coefficient of solar panel is about 0.16. Given that the shaft of the micro windmill rotates relatively slowly (about 3 m/s), it is vital that the dynamo technology chosen has minimal rotational resistance. This technology is 16 numbers of the permanent magnets adopted inside a micro generator. Therefore, all power recovery coefficients in all wind speed are low.

The development concept of the micro windmill is power generation using the building. Since the energy density of wind power energy is low, it raises energy density using the building. In the Kanto district including Tokyo in Japan, the wind direction is usually orientated north-south. Generally, the wind direction around a specific building is almost constant. We have excluded the useless function, in order to hold down the cost of the micro windmill and to enlarge the market of the micro windmill.

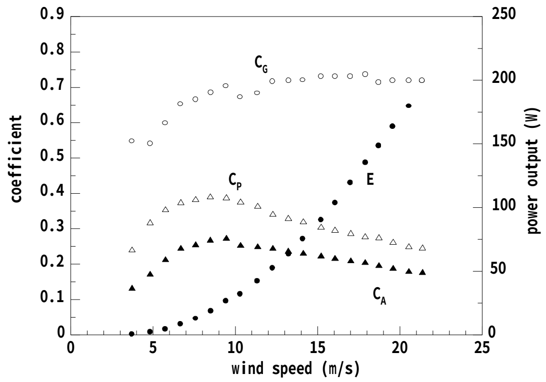


Fig.4 Coefficient and power out put of the micro windmill in the optimal load by wind tunnel test

Table 1 Sign table

$P_R = Q_R \cdot 2\pi \cdot \frac{n_R}{60}$	
P_R	Power output of wind turbine rotor (W), ($m^2 \cdot kg/s^3$)
Q_R	Torque of wind turbine rotor axis (N・m), ($m^2 \cdot kg/s^2$)
n_R	Rotation speed of wind turbine (r/min)
$P = \frac{1}{2} \cdot \rho \cdot u^2 \times u \cdot A$ $A = \frac{\pi}{4} \cdot D^2$	
P	Wind energy resources (W), ($m^2 \cdot kg/s^3$)
ρ	Density of air (kg/m^3)
u	Wind speed (m/s)
A	Swept area (m^2)
D	Diameter of the wind turbine (m)
$C_P = \frac{P_R}{P}$	
C_P	Power coefficient
$C_A = \frac{E}{P}$	
C_A	All power recovery coefficient
E	Power output (W)
$C_G = \frac{P}{P_R}$	
C_G	Electric conversion coefficient

Fig.5 shows the relationship between wind direction and the power output of the micro windmill. When the wind blows on the front of the wind turbine (0°), the power output of the micro windmill is the largest. The directivity of the power output of the micro windmill is symmetrical.

Even when the wind blows behind the micro windmill (in 180 degree of wind direction), it generates some electricity at low efficiency.

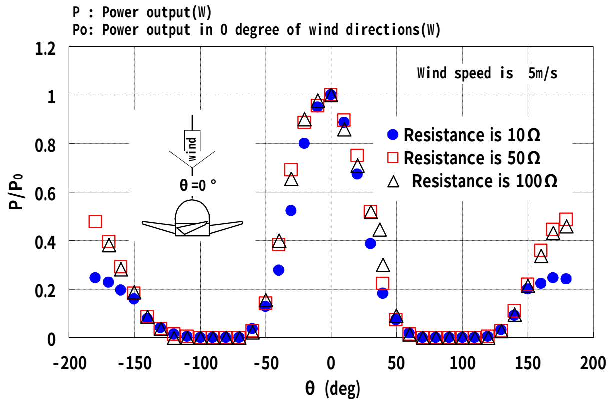


Fig.5 Directivity of the power output of the micro windmill by wind tunnel test

§3. The wind field around a micro wind turbine generator system in wind tunnel tests

The micro windmill reduces wind velocity by transforming the movement energy of a wind into the electric energy. The properties of the wind disturbed by the wind turbine is important data for the full-scale observation carried out from now on. We measured the wind field around the micro windmill in the Fujita Corporation wind tunnel. The anemometer used for the wind tunnel test was an ultrasonic anemometer (so that 3-dimensional measurement ~~is~~ was possible). Sampling frequency is 20 (Hz), measurement time in one measuring point is 30 (sec). The one ultrasonic anemometer is installed in the windward side from the measurement area around the micro windmill. The other ultrasonic anemometer is attached to the traverse equipment in the wind tunnel.

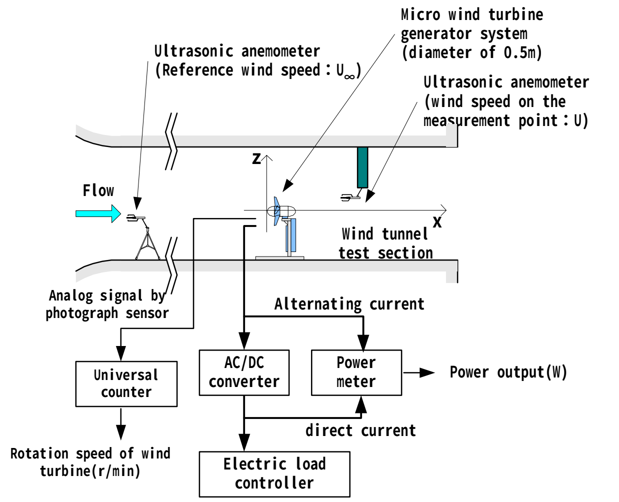


Fig.6 Measuring system of the wind field around the micro wind turbine generator system

Table 2 Sign table

U_∞	Reference wind speed (m/s)
U0	Average wind speed of X directions (m/s) $U(x,y,z)=\frac{1}{N}\sum_{t=0}^{t\max}u(x,y,z,t)$
V0	Average wind speed of Y directions (m/s) $V(x,y,z)=\frac{1}{N}\sum_{t=0}^{t\max}v(x,y,z,t)$
W0	Average wind speed of Z directions (m/s) $W(x,y,z)=\frac{1}{N}\sum_{t=0}^{t\max}w(x,y,z,t)$
k	kinematics energy (m²/s²) $k(x,y,z)=\frac{1}{2}(\sigma_x(x,y,z)^2+\sigma_y(x,y,z)^2+\sigma_z(x,y,z)^2)$

Fig.7 shows the distribution of average wind speed and kinematics energy leeward of the micro windmill in the wind tunnel test. The measuring point is 1.5m (x=3D) to the lee side from the tip of the micro windmill. Wind speed in the wind tunnel is 5 m/s. The plot in a figure shows the influence by the existence of electric load, and the difference in wind tunnel type. The first wind tunnel type is the circulated or 'Gottingen' type; the second is the opened or 'Eiffel' type.

The average wind speed distribution from different wind tunnels and electric load conditions show same tendency.

On the other hand, the kinematics energy distribution measured from different electric load conditions show different tendency. For example, in the leeward from the micro windmill, the value of the kinematics energy where resistance is 50 ohm is about twice that in the situation where resistance is 0 ohm (there is no resistance). This difference is due to the rotational velocity of the micro windmill. The number of rotations of the windmill where resistance is 50 ohms is about 300 rpm. The number of rotations of the windmill where resistance is 0 ohm is about 600 rpm. The kinematics energy shows a small value where the distance from the micro windmill is long.

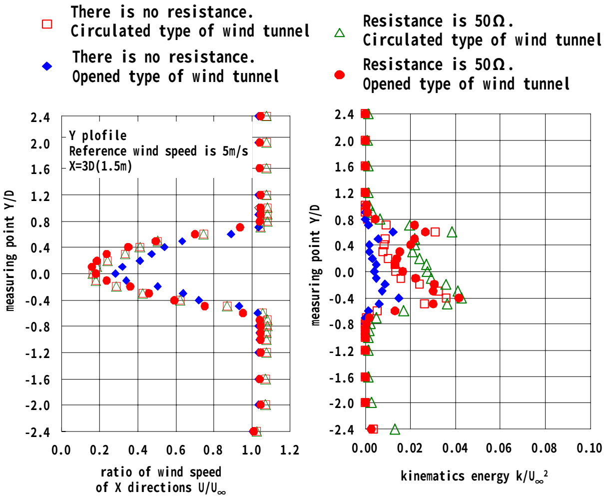


Fig.7 The distribution of average wind speed and kinematics energy in the leeward of the micro windmill by wind tunnel test

Fig.8 shows the ratio distribution of average wind speed of X directions. The change of the wind speed ratio in the range to x/d=10 is large. The wind speed ratio is converged on about 0.9 more than from x/d=10. There is no change of the wind speed ratio under the influence of the electric load.

Fig.9 shows the kinematics energy distribution of X directions. The change of the kinematics energy in the range to x/d=10 is large. There is a change in the kinematics energy distribution under the influence of electric load. The kinematics energy without electric load is large compared with the case where there is electric load.

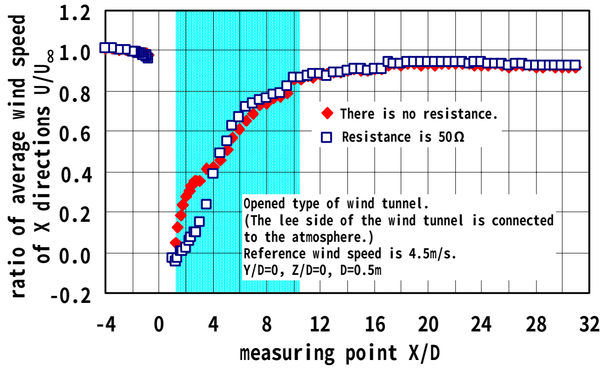


Fig.8 The ratio distribution of average wind speed of X directions

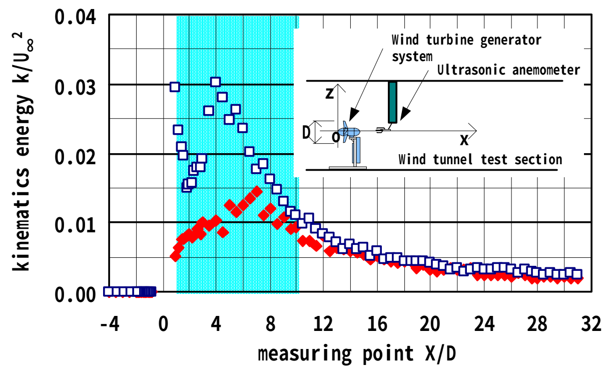


Fig.9 The kinematics energy distribution of X directions

§4. The effect of protection against wind by a micro wind turbine generator system

The index that shows attenuation of the wind power energy is the power coefficient (C_p). The power coefficient is the ratio of the power output of the wind turbine rotor to the wind energy resources. The power output of the wind turbine rotor is computed from the torque of the wind turbine rotor axis and the rotation speed of wind turbine.

Calculations are based on the assumption that when the cross-section area by the side of the windward and the leeward is the same, the thermal energy of the air by the side of the windward and the leeward is the same.

The change in wind speed from the windward to leeward side of the micro windmill is expressed thus

$$\frac{1}{2}\cdot\rho\cdot u_1^3\cdot A_1=\frac{1}{2}\cdot\rho\cdot u_2^3\cdot A_2+P$$

$$\frac{1}{2}\cdot\rho\cdot u_1^3\cdot A_1=\frac{1}{2}\cdot\rho\cdot u_2^3\cdot A_2+C_p\cdot\frac{1}{2}\cdot\rho\cdot u_1^3\cdot A_1$$

The character of 1 shows the space by the side of the windward of the micro windmill. The character of 2 shows the space by the side of the leeward of the micro windmill.

The formula of continuation is shown below.

$$u_1\cdot A_1=u_2\cdot A_2$$

The following formula will be obtained if two formulas are solved.

$$u_2=u_1\cdot\sqrt{1-C_p}$$

The following formula will be obtained, if the power coefficient by wind tunnel test (C_P is about 0.4) is substituted.

$$u_2=0.77\cdot u_1$$

When the diameter of the wind turbine is 0.5 m, the wind speed 10 m/s becomes 7.7 m/s.

§5. Acoustic noise of a micro wind turbine generator system

When the wind turbine generator system is installed in an urban area, the acoustic noise generated from the wind turbine is important. Since rotational velocity becomes high as output from the wind turbine generator increases, it is easy to generate a loud acoustic noise from the wind turbine. By comparison, the power output and the acoustic noise of the micro windmill are low.

Fig.10 is the sound power level of the micro windmill under rotation measured using the microphone in the reverberation room. The wind turbine was forcibly rotated using the motor. The acoustic noise generated by the motor (and other non-turbine generated noise) was suppressed using sound-absorbent material and lead plate. Four microphones were installed in around the wind turbine measure the sound power level of the wind turbine.

When the rotation number of the micro windmill is set to 600rpm, the acoustic noise generated from the wind turbine with diameter of 0.5m is 55dB (A-weight sound pressure level). 600rpm of the micro windmill rotation number is equivalent to wind velocity 8 m/s.

For example, when the wind of wind speed 8 m/s blows against the micro windmill, the acoustic noise 30m distant from a wind turbine is about 30 dB.

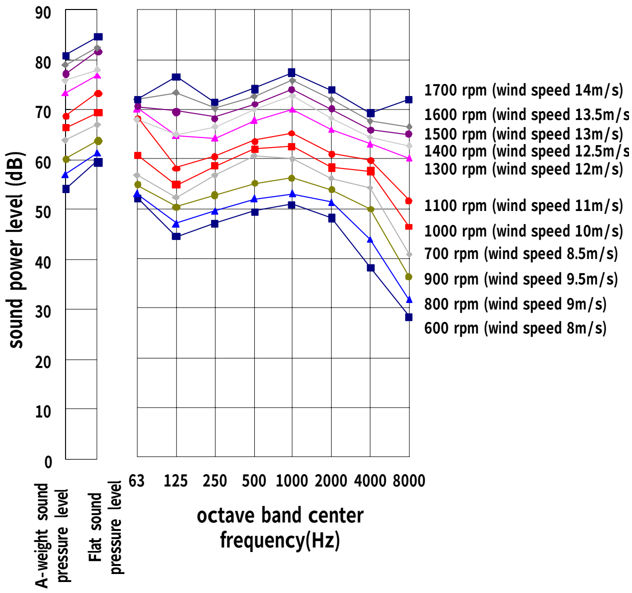


Fig.10 Sound power level of the micro windmill under rotation

§6. The charge method of the micro wind turbine generator system

16 permanent magnets are used for the dynamo of the micro windmill and that output three-phase alternating current. Even when a wind blows at low wind speed, the wind turbine can rotate smoothly. The voltage which the dynamo outputs changes according to the number of rotations of the wind turbine. The charge method of the dynamo of changing voltage is shown below.

(1) The alternating current output from the dynamo is changed into the direct current. The three-phase alternating current is converted to direct current by the rectifiers with six diodes.

(2) The electrode of direct current is directly connected to the electrode of a storage battery.

When the wind turbine has stopped, the voltage of the dynamo becomes the same as a storage battery.

(3) When two or more dynamos connect with a storage battery, the dynamos are connected in parallel.

(4) The amount of accumulation of electricity by a storage battery is determined by the dynamo's characteristics and the wind conditions in the installation site.

(5) The current output from the dynamo is decided according to the capacity of the storage battery. The current that can charge a storage battery is 1/10 of the amount of accumulation of electricity.

(6) When the current that can charge a storage battery exceeds a maximum value and the amount of accumulation of electricity increases, the voltage of the storage battery rises.

(7) Fuses can structure the circuit for excess current prevention at low cost. When the wind turbines rotate with unloaded conditions, the wind turbine generator system becomes critical. When the fuses burn out, electric circuits for consumption of generated electricity are required (Fig.11).

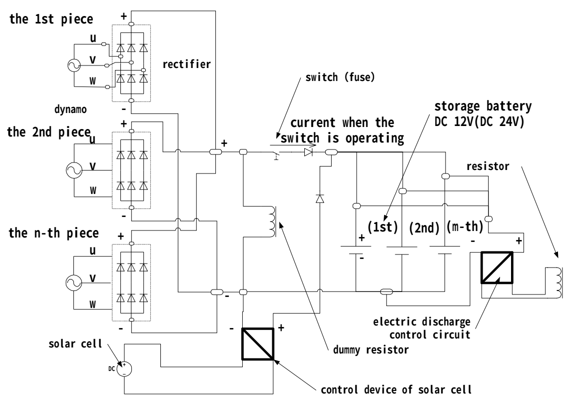


Fig.11 Charge and discharge circuit for the micro wind turbine generator system

§7. The rotation test of the micro wind turbine generator system using the motor

In order to perform durability tests of the wind turbine in the laboratory, we developed equipment for performing the rotation test of the micro windmill using the motor. Photo.3 and Fig.12 show the measuring system of the rotation test with the micro windmill using the motor. The maximum rotation speed of the motor is 10000rpm. The maximum rotation speed of this system that attached the micro wind turbine of two sheets is 4900rpm.

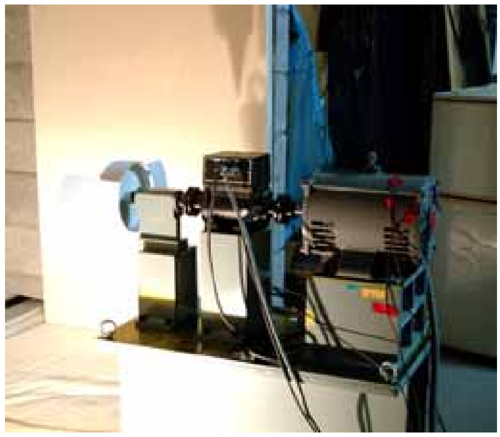


Photo.3 Measuring system of the rotation test with the micro windmill using the motor

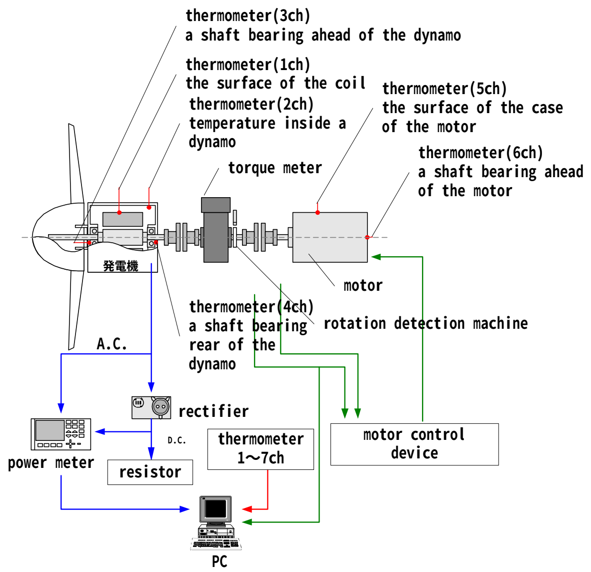
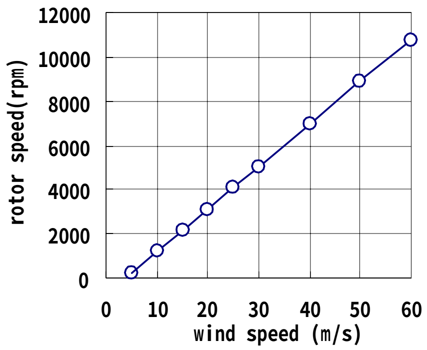


Fig.12 Measuring system of the rotation test with the micro windmill using the motor



wind speed (m/s)	rotor speed (rpm)
5	258
10	1215
15	2171
20	3128
25	4085
30	5041
40	6955
50	8868
60	10782

Fig.13 Relation between wind speed and rotor speed of the micro windmill

Fig.13 shows the relation between wind speed and rotor speed of the micro windmill, when the resistance linked to the dynamo is 50 ohm. The rotational speed varies linearly with wind speed from wind speeds ≥ 5 m/s. The strain of the diameter direction of a propeller is 0.4%. It turns out that the micro wind turbine has considerable endurance until wind speed 30 m/s.

The maximum rotation speed of this system that attached the dynamo is 10000rpm. It turns out that the dynamo has considerable endurance until wind speed 60 m/s.

§8. Conclusion

The micro wind turbine generator system makes reduces high wind speeds in urban areas and the dispersed power generation containing the micro wind turbine generator system is used ordinarily in Japan. The micro wind turbine generator system consists of the windmill with a diameter of 50cm and the micro dynamos with a diameter of 17cm made from polycarbonate.

The feature of the micro windmill is shown below.

(1) When the rotation number of the micro windmill is set to 600rpm, the acoustic noise generated from the wind turbine is 55dB (A-weight sound pressure level).

(2) The maximum power coefficient of the micro wind turbine generator system is about 0.4. The maximum all power recovery co efficiency is about 0.26.

(3) To the lee side of a windmill, the turbulence of the wind flow is large. Any susceptible structures need to be 5m or more distant from the micro windmill.

(4) If the commercial charge circuit is adopted, the charge circuit of the micro windmill can be manufactured at low cost.

(5) Laboratory tests using a motor-driven system show that the micro wind turbine has considerable endurance until wind speed 30 m/s. The maximum rotation speed of this system that attached the dynamo is 10000rpm.

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Yoshitami Nonomura

Short comment

The micro windmill obtained cooperation of many people and was developed. From now on, I tackle development of utilization technology. I feel that it can meet with much more people for pleasure through technical development.