Development of 1 000 kW Wind Turbine

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Wind turbines are widely used to generate electricity commercially. Output per turbine generator tends to increase over time, with 500 kW to 600 kW wind turbines most widely used overseas. Mitsubishi Heavy Industries, Ltd. (MHI) has developed the MWT-1000, first installed in Muroran. This new turbine features (1) a strong, large, light 26.8m blade; (2) a very low noise level of 99 dBA using new blade noise reduction and isolated gear and generator mounting; and (3) confirmed excellent efficiency and reliability based on data from operation and evaluation tests for the Muroran unit.

1. Introduction

Wind turbines, environment-friendly generators using wind power as a renewable source of energy, are being constructed in many places in the world.

As of January 1999, wind turbines supplying about 9 200 MW of electric power are being constructed worldwide. Supply capacity is expected to increase to the level of 14 000 MW in the year 2000 and to 21 000 MW in 2002 as a result of increased installations.

Under these circumstances, with the progress of wind turbine technology and to make effective use of available land, attempts have been made to increase the turbine size. Turbines today have an average output of 500 to 600 kW, while units with output of 1 MW or more are being developed and put to field operation. MHI developed a 1 MW wind turbine in 1999 and delivered it to the Shukutsu Wind Power Station in Muroran City, Hokkaido, Japan.

This paper describes the progress of development, the technical features of the 1 MW wind turbine and the actual operation of the first machine delivered to the Shukutsu Wind Power Station in Muroran City.

2. Development of wind turbines by MHI

Following its construction of an experimental 40 kW small wind turbine at its Nagasaki Research & Development Center in Kouyagi Plant in 1980, MHI has continued research and development step by step toward the completion of large-sized turbines. In 1982, MHI delivered the first commercial 300 kW wind turbine to the Okino-Erabu Island Power Station of Kyushu Electric Power Co., Inc., acquiring in the process much useful information and know-how. Subsequently, MHI has developed an up-wind type 250 kW wind turbine as a mass production model. Up to the present time, MHI has manufactured more than 800 units of this MWT-250 wind turbine. In particular, it is notable that 660 units of this model are being operated at Tehachapi, California, U.S.A., which is the world's largest windfarm that is equipped solely with wind turbines of the same model. In 1991, MHI started to develop a large wind power generation system for the New Energy and Industrial Technology Development Organization (NEDO). In this development project, MHI carried out the work from design to installation of a 500 kW wind power generation system, which was completed in October 1996 at the operation site of Tappi Misaki, Aomori Prefecture. Through the operation and research conducted on the installed system, the influence of complicated topography on the performance and reliability of wind turbine operation have been clarified. The first model of the MWT-450, which succeeded the MWT-250 as a mass production turbine, was delivered to Winkra Energie, Germany in January 1996. For this wind turbine, Germanischer Lloyd, a type certification organization certifying the reliability of designing technique, has granted the first-ever official type certification accorded to a non-European manufacturer. To meet the need for wind turbines providing higher output in overseas markets, MHI applied its designing technique and developed a 600 kW-class wind turbine model, the MWT-600, in 1998. In 1999, 131 units of this model were delivered to the U.S.A. and are now in commercial operation.

While European wind turbine manufacturers are putting their 1 MW or larger turbines to practical application in 1998, MHI started to develop a 1 MW wind turbine. This 1 MW wind turbine, the first of its class in Japan, was completed in March 1999 and has been operating satisfactorily since April of the same year.

3. Features and construction of MWT-1000

3.1 Basic specifications and typical features

Up to the present time, MHI has delivered more than one thousand units of wind turbines ranging from 250 kW to 600 kW in output to customers at home and abroad.

The MWT-1000 wind turbine is designed to combine high performance with low operating noise and maintains highly reliable operation in variable wind conditions including violent changes in wind speed particular to the topography of Japan.

The basic specifications for the MWT-1000 are shown in **Table 1**. **Fig. 1** shows a general view of the MWT-500 (490 kW) and MWT-1000 (1 MW) wind turbines installed at the Shukutsu Wind Power Station in Muroran City. Each rotor consists of three blades made of glass fiber reinforced plastics (GFRP) and has a diameter of 56 meters. The wind turbine is of up-wind type[*1] with rated wind speed of 13 m/s. Cut-in wind speed[*2] is 3 m/s and cut-out wind speed[*3] 24 m/s. The speed of the rotor is controlled to 21/14 rpm by a two-speed control method. The output regulation system is based on variable pitch control, where a hydraulic cylinder built into the rotor head optimizes the blade pitch angle according to changes of wind speed. Wind energy received by the blades is transmitted to the rotor head, main shaft, gears, flexible coupling and finally to the generator. An induction generator is used to generate power and the soft-start method[*4] is applied to suppress rush current for interconnected operation. The typical technical features of the

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Table 1 Principal items of MWT-1000

Item	Specification
Type	Variable pitch blade up-wind type
Rated output	1 000 kW
Rotor diameter	56 m
Rated rotating speed	21 rpm/14 rpm
Number of blades	3
Rated wind speed	13 m/s
Cut-in wind	3 m/s
Cut-out wind	24 m/s
Withstanding wind speed	60 m/s
Generator	
Type	Induction generator
Voltage and phase	550 V, three-phase
Frequency	50/60 Hz
Tower	
Type	Mono pole
Height (nacelle center)	60 m

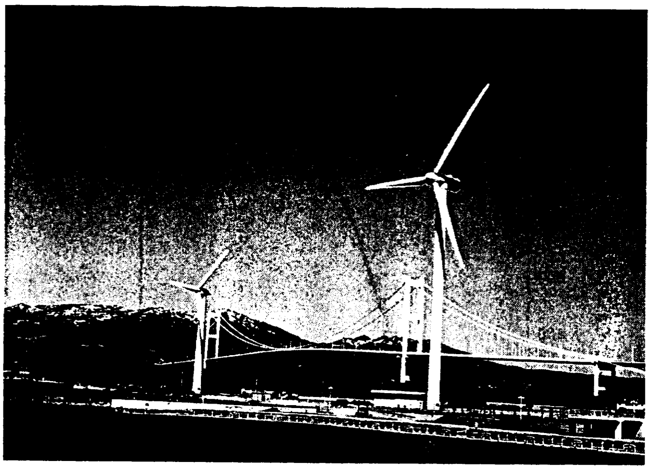

Fig. 1 MHI wind turbines
General view of MWT-500 (left) and MWT-1000 (right) wind turbines in operation at the Shukutsu Wind Power Station in Muroran City is shown.

MWT-1000 are as follows.

(1) Highly reliable construction based on the principal design data which have been verified satisfactorily by field operation of 250 to 600 kW-class wind turbines,

(2) Sound from blades is minimized by sharpening the contour of blade toward tip, and mechanical sound is also reduced by use of soundproof mounting for gears and generator,

(3) Large-sized, light-weight rotor blades (made of GFRP) have sufficient strength to withstand strong winds even in typhoon conditions,

(4) Soft starter system using thyristor limits the rush current in the grid to the level of rated current or below, and

(5) Improved performance and low-noise operation with low-speed wind are realized by use of pole changing method for generator.

Notes)

*1: A type of wind turbine in which the revolving blade surfaces are located on the windward side of the tower.

*2: The minimum wind speed at which a wind turbine takes energy from the wind.

*3: The maximum wind speed at which a wind turbine produces output.

*4: A rush current suppressing method using solid-state switching for power between commercial power line and induction generator.

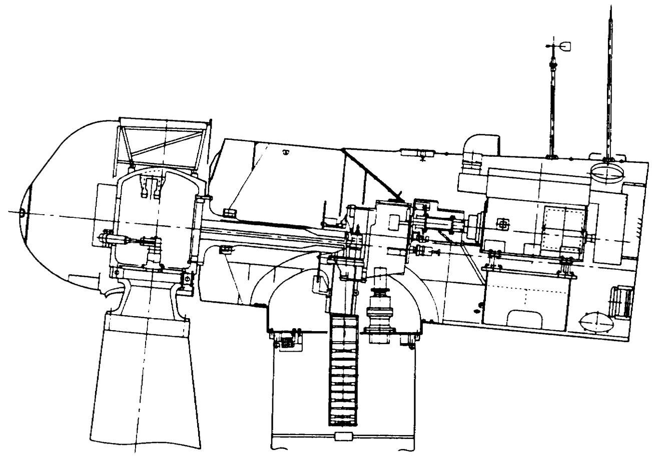

Fig. 2 Nacelle of MWT-1000
Inside arrangement of light-weight nacelle employed for MWT-1000 is shown.

3.2 Development of blade

The blade length is 26.8 meters, which is about 1.5 times longer than the 18.3 meters of blades of 500 kW-class wind turbines. Blades are designed to provide a sufficient safety factor for maximum static load (equivalent to typhoon wind force) and 20 years or longer service life on the basis of simulation analysis using external forces acting on the blade, as well as by taking account of turbulence, changes in wind direction, etc. With regard to blade performance, an efficient NASA LS (1) series blade shape was selected following comparison studies of various shapes.

3.3 Design of nacelle

To reduce weight, a thin-plate cylindrical shell structure was adopted for the nacelle. **Fig. 2** shows the construction of the nacelle. External forces acting on the nacelle were also studied using a simulation analysis method similar to methods used for the blade. The nacelle is thus designed to provide a sufficient safety factor for maximum static load and a service life of 20 years or longer. For reduction of sound, a revolving system was adopted to suppress the propagation of solid-borne sound.

4. Verification tests and operation record

4.1 Strength test for blade-root junction

Testing equipment used to verify the strength of blade root, which is the junction of blade and rotor hub, is shown in **Fig. 3**(a) (Testing method[1]). A moment load estimated as equivalent to the actual load was applied to the blade-root junction by means of a hydraulic jack, and a strength test was conducted by measuring the stress at mounting bolts. The load applied by this test was about three times larger than the load from typhoon wind force. Test results[1] are shown in Fig. 3(b). The blade-root junction did not show any deformation or cracks, which demonstrates that it has sufficient strength against external force.

4.2 Load test for blade

Actual 26.8 meter-long blades of the MWT-1000 were used for this load test. Loads equivalent to rated wind speed and typhoon wind (60 m/s) were applied respectively to the blade using the weighting method[1] illustrated in **Fig. 4**, and stresses and strains of the loaded blade were measured. The test results

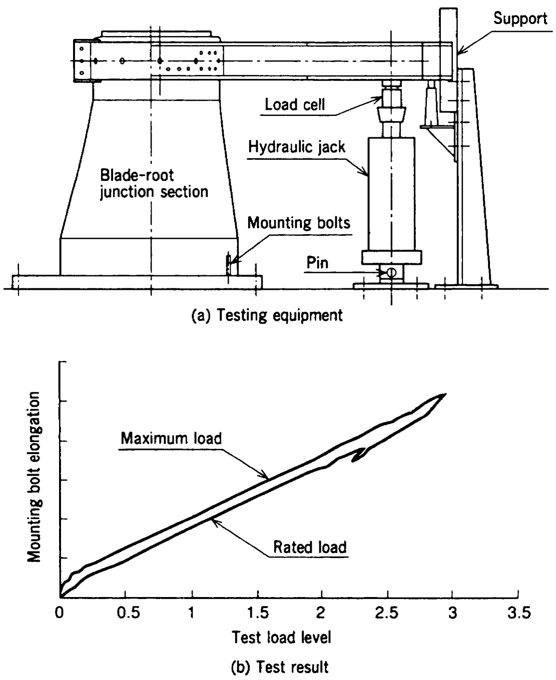

Fig. 3 Pulling-out test for MWT-1000 blade root
(a) Testing equipment used to check the strength of blade-root junction and (b) test result.

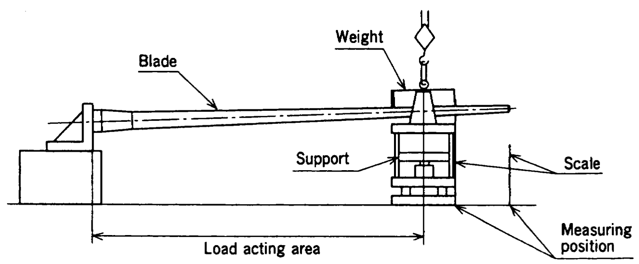

Fig. 4 Rated load test of MWT-1000 blade
A weight equivalent to rated load was placed on blade, and stress and strain were measured.

are shown in **Table 2**. Rigidity of the MWT-1000 blade was shown to be higher than the designed value, which was due to also the effects of reinforcing measures adopted during the manufacturing process.

4.3 Blade dynamic characteristics test

Hammering excitation test was used to investigate the dynamic characteristics of the blade. **Fig. 5** shows a response curve of the blade in the flat direction[1]. This curve confirmed that the characteristic frequency in the flat direction is 1.23 Hz, and that it becomes 3.6 Hz (3.6 times higher than the revolving degree components) at the rated revolutions. The blade was thus confirmed to be well tuned to avoid resonance.

4.4 Qualification test for blade aerodynamic sound reduction effect

The blade operating noise is considered to be mainly responsible for (1) eddy noise of blade trailing edge, (2) eddy noise of blade tip and (3) blade stalling noise. Particularly, blade noise produced during blade pitch angle control is responsible for (1) and (2). To reduce the operating noise of MWT-1000, a low-noise type blade having reduced thickness toward the trailing edge and tapering toward the tip was employed. The noise reduction effect of this blade design has been proved by the verification test for noise level reduction conducted by NEDO on the actual 500 kW wind turbines.

4.5 Actual operation of the MWT-1000 at Shukutsu Wind Power Station in Muroran City[2]

Measured results of output power, main shaft stress, noise level and operation record are shown in **Fig. 6**, **Fig. 7**, **Fig. 8** and **Fig. 9**, respectively. These results show that the MWT-1000 has favorable performance and stress level as expected. In particular, the output power curve shows that output in the low

Table 2 Load test result for blade of MWT-1000

	Under rated load	Under typhoon-equivalent load
Planned value	1 681 mm	3 056 mm
Measured value	1 514 mm	2 856 mm

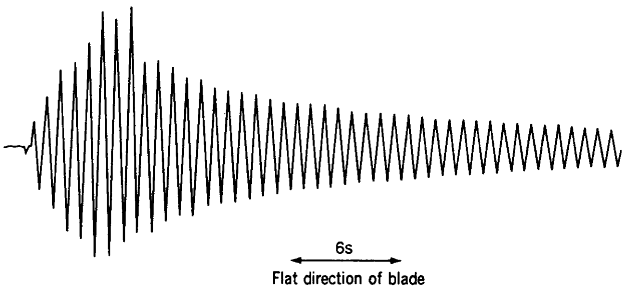

Fig. 5 Response curve of MWT-1000 blade
Result of hammering excitation test (dynamic response curve) for verification of dynamic response of blade such as characteristic frequency, damping, etc. is shown.

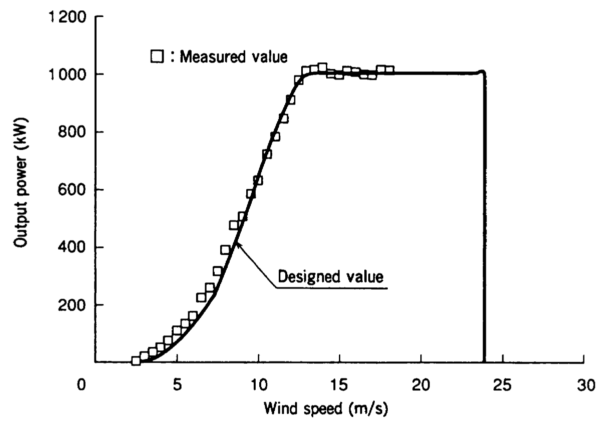

Fig. 6 Power curve of MWT-1000
Designed and measured output power curves with respect to wind speed for evaluation of performance of MWT-1000 is shown.

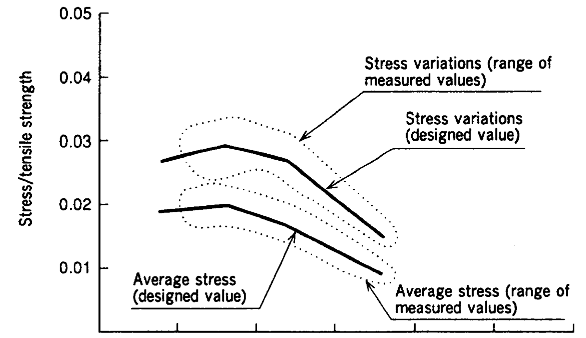

Fig. 7 Result of main shaft stress measurement
Measured result of main shaft stress with respect to wind speed.

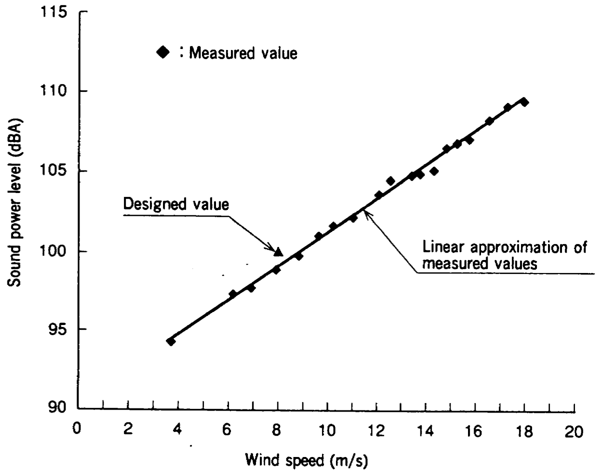

Fig. 8 Results of noise measurement
Measured sound power level and wind speeds are shown.

wind speed range of less than 10 m/s exceeds the planned power level, and also that the rated output is maintained constant even when the wind speed exceeds the rated level. Also, as can be seen from the graph of Fig. 8, the measured sound power level of 99 dBA at a wind speed of 8 m/s was lower than the designed value of 100 dBA. From the operation record of the MWT-1000 shown in Fig. 9, we see that output power is controlled by varying the blade pitch angle according to changes in wind speed, while there are some fluctuations in output power due to the variable response speed of the pitch angles. However, as the fluctuations are generally controlled to be within the range of rated output, the operation record shows favorable results.

As mentioned above, the various measurements made on the MWT-1000 being operated at Shukutsu Wind Power Station in Muroran City since April 1999, show clearly that the

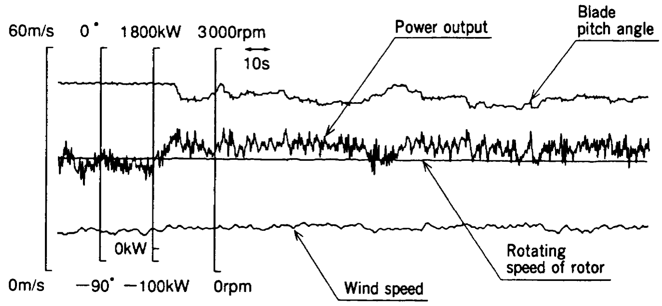

Fig. 9 Operation record of MWT-1000
A recorded chart of MWT-1000 operation is shown.

performance, stress and noise level of MWT-1000 conform satisfactorily to each designed value and are highly reliable as expected.

5. Conclusion

To tackle the current issue of global environment protection, demands for wind turbines as a clean power generation system using wind energy are increasing rapidly, while development of 1 MW or larger wind turbines is eagerly anticipated. In addition, it has become necessary to develop low-noise type wind turbines to meet the growing need to reduce operating noise in neighboring areas. Accordingly, MHI will continue to develop not only large-sized wind turbines but also high-performance, low-noise types by optimizing blade contour to reduce blade noise and by constructing gearless variable speed wind turbines. In this way, MHI hopes to contribute to the introduction, spread and progress of more environment-friendly wind turbines.

References

(1) Osada, I., Development of 1 MW Wind Turbine, ICOP '99
(2) Kato, E., Operation Report of 1 000 kW Mitsubishi Wind Turbine, Thermal and Nuclear Power Engineering Society (1999)