Production Efficiency and Product Quality Improvement through Factory Mechanization and Computerization*

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ABSTRACT

Our mission is to manufacture optimum products using provided design data. Thanks to analysis tools brought in recently, the design of more efficient propellers have become possible. To manufacture propellers with maximum design efficiency, a high level manufacturing technology is essential.

The Tamashima Works, is a specialized facility for manufacturing large-sized fixed pitch propellers. Manufacturing size ranges from 5 meters up to a maximum of 12 meters in diameter, and a maximum weight of 150 tons. Here, we succeeded in developing special facilities, the only one of its kind in the world, such as the blade milling machine which can control 5 axis at the same time, the balancing machine, and the propeller overturning facility. These special facilities resulted in higher machining accuracy.

In this paper, these facilities as well as the productive efficiency and quality improvements that have been achieved over the last 4 years are introduced.

1. INTRODUCTION

a) Background
Tamashima Works was established in 2005, as a specialized facility for large-sized fixed pitch propellers above 5m in diameter. The background of its establishment is as follows.

1. Larger propellers are in demand as size of vessels grow increasingly larger
2. Shortened delivery time can be achieved by relocation of the factory
3. Higher production efficiency can be achieved by using the most advanced facilities

The construction of the factory at the Tamashima Harbor Island, equipped with full port facilities, has settled these problems.

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b) Concept

We focused on the following points for construction of Tamashima Works.
1. Optimize the Flow of Material & Product
2. Friendly work environment (Safety First)
3. Reduction of environmental impact
4. Enhancement of resource recycling

Tamashima Works runs vertically from south to north, and this is the most effective layout for the “one straight line” approach in the production process. The First chapter explains the manufacturing process of large-sized propellers, while introducing the one-of-a-kind facilities and computerization of Tamashima Works. In the last chapter, we analyze the data obtained from the manufacturing process, and provide some examples of our continuous quality improvement.

2. CAPACITY

The main capacity of Tamashima Works is as follows:
- Land Area : 57,739 m²
- Factory building area : 2,643 m²

Productive Capacity
- Propeller Weight : 10 t ~ 150 t
- Propeller Diameter : 5~12 m
- Annual total amount : 360 units 11,000t
  (Record of fiscal year 2008)
- Total number of Employees : abt. 150

3. MANUFACTURING PROCESS (Large-sized Propeller)

“Figure.1” is a flowchart of the manufacturing process. At Tamashima Works, propellers are manufactured thoroughly from the casting process to finishing.

4. CASTING FACILITY

The first step of propeller casting is to create the mold. Next, the materials are melted, and casted onto the mold. After casting, the mold is removed. The molding method is done with a sand-cast, called the “Sweeping-Mold”. This method is suitable for single-products and shorter lead-time can be achieved.

The quality of the propellers is greatly affected by the casting technique. This means that propeller quality depends...
on the casting procedure, thus casting is one of the most important element of propeller manufacturing. Casting procedures vary depending on the size and shape of each propeller.

Nakashima has set up a casting laboratory. At the laboratory, various testing such as for the strength of materials, solidification simulations, and foundry sand analysis, have been performed. We are constantly striving to improve casting quality.

a) Melting and Casting
Temperature control of the molten-metal and adjustment of metal components are important elements. At Nakashima, low-frequency and medium-frequency electrical furnaces which are suitable for copper-alloys melting are used. Tamashima works has five electrical furnaces, with melting capacity of up to 170tons. The capacity of the largest furnace is 60tons, the biggest crucible type furnace in Japan. Furthermore, an exclusive machine for removing the furnace sludge has been brought in. Thanks to this Sludge Remover, longevity of furnace lining material had increased dramatically. This machine is originally developed by Nakashima, and is the only one of its kind in the world.

b) Foundry Sand Recycle
Manufacturing of one super-sized propeller requires over 100tons of sand. Once used, the sand becomes industrial waste. After grinding with a special grinder, approximately 80% is reused on manufacturing. The remaining 20% is recycled and used for asphalt and roadbed materials.

5. MACHINING FACILITY
The machining process is performed using the following steps.
- Riser cutting
- Milling of Boss parts
- Tapping
- Blade milling

For this machining process, Tamashima Works is equipped with many original, specially-developed machines.

a) Milling of the Boss part
After the Riser is cut off, the both edges of the boss and inner surface are milled. By using an exclusive CNC (Computer Numerical Control) Boss Milling Machine, operators have no need to re-setup the propeller when milling the bottom side, the upper side and the inner surface of the propeller boss. "Photo.7" is the new CNC Boss Milling Machine, set up in October 2009. This machine is also the only one of its kind in the world.
b) Blade milling

All the blade milling is performed with the CNC Blade Milling Machine. Tamashima Works is equipped with 3 of the 5-axis simultaneous control CNC blade milling machines. The machine is capable of milling blades for propellers of up to 12m in diameter.

4 years ago, dramatic improvement of machining precision was actualized by refurbishing our processing software. Major improvement was made with increased data points of the blade section, used at NURBS (Non-Uniform Rational B-Spline) Interpolation. This has enabled smoother shapes of curved surfaces. This improvement has brought significant decrease in small uneven edge shapes and finishing work time, as well as decreasing the amount of final work done by our craftsmen. As a result, the shape connect blade contour (defined r/R) has a smoother finish. This new software has also been updated on milling machines at our head factory.
An interesting statistic of the sea trial of Panamax Bulk Careers (same type) shows that after the software update, the propeller performance improved by 0.1knot with the same Main Engine condition as compared to the propellers manufactured before the software update. This statistic is shown in Figure 2.

c) Propeller Overturning Facility
The propeller edge is very thinly finished, (quite close to final finishing) using a CNC Blade Milling Machine. Therefore we have to pay close attention to avoid damaging the propeller edge when it is overturned in the subsequent process. For each propeller, we need to overturn it at least 4 times during the process. Previously, we used to overturn propellers by using a crane. However the process was time-consuming and dangerous. To improve working condition, the Propeller Overturning Facility was introduced to Tamashima Works. With this facility, working time on overturning was reduced and it became a safer process. This facility is also the only one of its kind in the world.

6. FACILITY FOR FINISHING

After the machining process, the propeller is hand finished by our experienced craftsmen. The blade edge, the most crucial part for the propeller, is finished using edge gauges. The surface roughness of the blade has a significant influence on propeller efficiency. Our propellers are normally finished with blade surface roughness of about less than 3μmRa, equivalent to ISO484/1 S-class (ISO 484/1 1class:6μmRa). Finally, our skillful craftsmen do highly accurate finishing by hand.

a) Load Cell Balance Machine
Our Load Cell Propeller Balance Machine is an exclusive instrument for checking imbalance of propellers. With the target on improved accuracy, this balance machine was developed with the following things in mind.

①Adoption of a spherical roller bearing for less friction as friction has a significant influence on precision balance.
(Friction spherical bearings μ=0.00002~0.00003)

②A precise core revealing is inevitable for correct balance measurement. For this, we implemented the following method.
- Measure the core position of the propeller
- Compensate the deviation from the first core position measurements
- Calculation of the unbalanced amount
③Horizontal level of machine table is measured by the sensor and adjusted within ±0.1mm by an electric precise jack.
④To maintain measurement accuracy, a self-diagnostic function is equipped. The machine is regularly checked before use to confirm the accuracy of each sensor and load cell. Meanwhile, all the past data are electrically stored so quick analysis of such past data can be processed.
7. CASES OF QUALITY IMPROVEMENT

In case an imbalance is detected during the final process (even after it is finished by a Blade Milling Machine), the blades are re-polished by our craftsmen to rebalance the propeller. For ISO 484/1 1class propellers, there might not be problem. However, there are some cases that further specifications are required. We have been undertaking various improvements in order to avoid Balance Adjustment (Fig.4-③) after the final polishing.

Fig. 3 The Load Cell Balance Machine for propeller

- a) Analysis
  By checking on each manufacturing data, we analyzed the cause of imbalance after the blade milling process (Fig.4-①). According to our analysis of data on 2006, 67% of imbalance is caused at the propeller boss area, while 24% of imbalance is caused at the propeller fillet area, and 9% at the blade area. It shows that the imbalance of the blade section is eliminated by fully milling the machining process on the blade area and we have almost succeeded in limiting the imbalance section to around the propeller boss area.

- b) Improvement
  Furthermore, we focused on reducing the imbalance on the boss area by reviewing the shape of the propeller boss during the casting process.
  ① Analysis of the statistics of imbalanced propellers revealed that some certain wood boss patterns were causing such imbalance.
  ② Improving the accuracy of manufacturing wood boss patterns has reduced occurrence of such imbalances.

Fig. 5 Area of the imbalance after Blade Milling (Result 2006)
The chart below illustrates the margin achieved by our improvement effort. Our tolerance standard is half of the assigned imbalance tolerance. As a result of our improvement effort made since 2006, imbalance percentage within our standard tolerance range after Blade Milling Machining has increased from 33.5% to 44.7%, an improvement of 11.2%. Meanwhile, imbalance propellers exceeding the tolerance point of +20kg has been reduced from 7.7% to 1.4%, 6.3% improvement.

Currently, 5% or less of our propellers requires re-balancing after Blade Milling Machining (Fig.4③). This improvement also allowed us to establish a way to keep the propeller balance without changing the designed dimensions of the blade tip, which is a crucial point for a propeller’s cavitation performance.

For further improvement, we are aiming to define the more detailed shape of the fillet part by broadening the Blade Milling Machining area.

8. COMPUTERIZATION

a) Production Control System
(Tamashima Works is controlled by our original production control system. Optical fiber Network is running through Tamashima Works. This enables us to control the propeller’s real-time location, manpower management, and daily inventory. Various other systems are also brought in to Tamashima Works, e.g. Operating of equipment status, the Camera Monitoring System, and the Monitoring Electric Demand System.)
Our systemized processing method for propellers enables us to promptly retrieve CAD/CAM data from the design results (Drawings/Form) without data preparation by human operation. Unification Management of these designed data has shortened input time of the machining processing program, thus preventing input error. For CAM dedicated propellers, we are reducing the processing hours by reviewing any unnecessary approaches.

9. CONCLUSION

Digitalization and accumulation of manufacturing information are actualized by linking production machineries to the system. And through analyzing the information, we are going to perform continuous improvement activities, such as review of work processes and equipment investment for upgrades of product quality and production efficiency.