Development of Manufacturing Technology for Precision Compressor Wheel Castings for Turbochargers

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ABSTRACT Recently, the demand for turbo chargers for automobiles is increasing worldwide because of the emission regulations in Europe and the expansion of the Asian car market. The compressor wheel is the main unit of a turbo charger, and not only high durability, but also high dimensional accuracy, is required of it by customers. The most important property required is the initial balance (i.e., coaxiality). We have developed a new manufacturing technology at our casting plant to improve the initial balance.

1. INTRODUCTION

An aluminum alloy cast compressor wheel, also known as a compressor impeller, is the main component of a turbocharger. Since 1965 we have manufactured compressor wheels at our casting plant at Oyama, Tochigi Prefecture, delivering high-quality products that meet the needs of our customers.

Figure 1 shows a cross section of a typical turbocharger, comprising a compressor wheel, a turbine and a housing, with the compressor wheel and the turbine coupled to a single shaft. Exhaust gas from the engine turns the turbine, causing the compressor wheel mounted at the engine intake also to turn and supply compressed air to the engine.

Because their exhaust is black, diesel vehicles have tended in Japan to be saddled with the image of having an adverse effect on the environment, but in Europe and other countries the many advantages in terms of economy, including the cost of fuel, and low levels of CO_2 emission have led to steady growth in the demand for diesel vehicles, as shown in Figure 2[1].

In addition, with stricter environmental regulations, it has become necessary for diesel vehicles to be fitted with turbochargers, leading to a strong increase in demand for them.

On the other hand, as turbocharger performance has improved, customer expectations in terms of levels of quality have risen enormously. Because they turn at speeds in excess of 150,000 rpm, there is a need not only for high durability, but also for high dimensional accuracy, and particularly for product coaxiality, also known as initial balance.

To address these user needs, Furukawa Sky-Aluminum

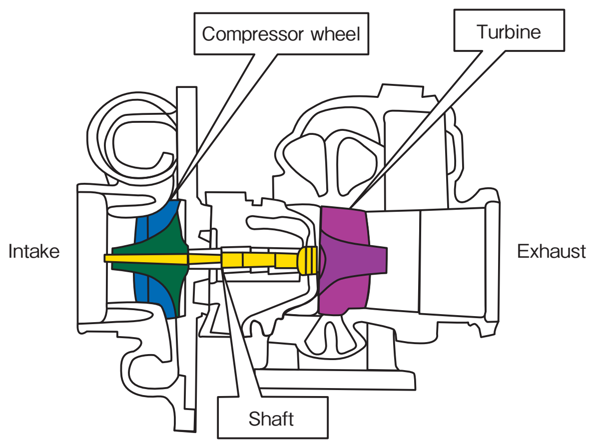

Figure 1 Cross section of typical turbocharger.

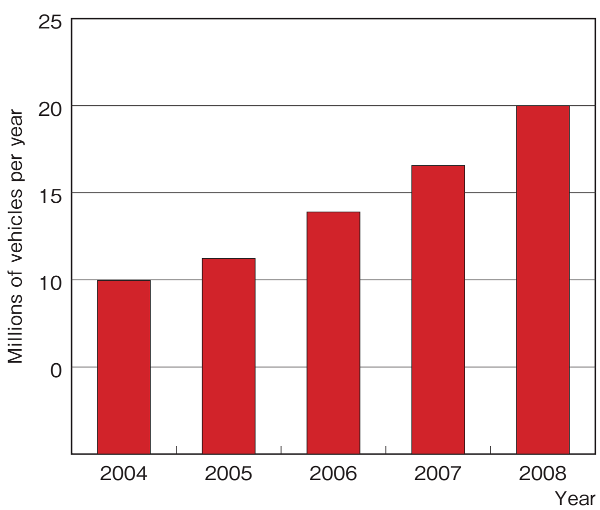

Figure 2 Forecast of diesel vehicle production.

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has developed new manufacturing technology that achieves dramatic improvements in initial balance.

2. PROCESS FOR MANUFACTURE OF COMPRESSOR WHEELS

Figure 3 shows the variety of compressor wheels that we manufacture. These products are characterized by blades having a spiral configuration and a smooth product surface.

We manufacture the compressor wheel castings using plaster dies and a low-pressure casting method. This is known as the PPC method, standing for precision (low-) pressure casting, using plaster dies.

2.1 Outline of Manufacturing Process

The process for the manufacture of compressor wheels is shown below. Except in certain cases, we deliver to our customer (the turbocharger manufacturer) the product blanks prior to final machining.

Die design
(1) Die design
(2) Fabrication of aluminum alloy master model
(3) Master model reversal
(4) Rubber mold forming
(5) Plaster die fabrication
Product manufacture
(6) Drying of plaster die
(7) Casting process
(8) Finishing processes (gate cutting, separating C/W casting from plaster die)
(9) Heat treatment process (dissolving)
(10) Blade correction
(11) Heat treatment process (artificial aging)
(12) Inspection process: shipment of product blanks
(13) Final machining and balance cutting

2.2 Master Model Reversal

A rubber female mold is formed based on a master model having a shape identical to the product.

Figure 3 Selected compressor wheels.

2.3 Rubber Die Fabrication

A rubber die having a shape identical to the compressor wheel is fabricated by filling the female mold formed in the previous process with a silicone rubber that sets at room temperature.

2.4 Plaster Die Fabrication

Plaster is an inorganic substance which, when water is added and stirred, is simply poured in, and hardens by a hydrated cementation reaction. The rubber mold is placed in a frame and filled with a slurry of water and plaster, and the rubber mold is removed to produce a plaster casting die.

2.5 Drying of Plaster Model

As shown in Table 1, cemented plaster can be used as a casting die for the casting process by heating and drying to remove the water of crystallization, transforming it from plaster dihydrate to anhydrous plaster. The final temperature of a plaster drying furnace is generally between 220 and 230°C [2], a temperature at which the process of dehydration to produce anhydrous plaster is definitely complete.

2.6 Casting Process

Figure 4 shows the apparatus for the low-pressure casting process that we use. Air pressure is applied to the surface of the melt that is contained and heated in a sealed vessel in the lower portion of the plaster casting mold, forcing the melt through a stalk connected to the mold and inserted into the melt so that it flows up into the

Table 1 Plaster transformation by water mixing and heating.

Temperature	Form of plaster	Molecular formula	Note
Rm. temp.	Hemihydrate plaster	$CaSO_4 \cdot 1/2H_2O$	Powder before mixing with water
Rm. temp.	Dihydrate plaster including surplus water	$CaSO_4 \cdot 2H_2O$	Cementation after mixing with water
100°C	Evaporation of surplus water	$CaSO_4 \cdot 2H_2O$	
Approx. 120°C	Dehydration from dihydrate to hemihydrate plaster	$CaSO_4 \cdot 1/2H_2O$	
Approx. 200°C	Dehydration from hemihydrate to anhydrous plaster	$CaSO_4$	Cast casting mold

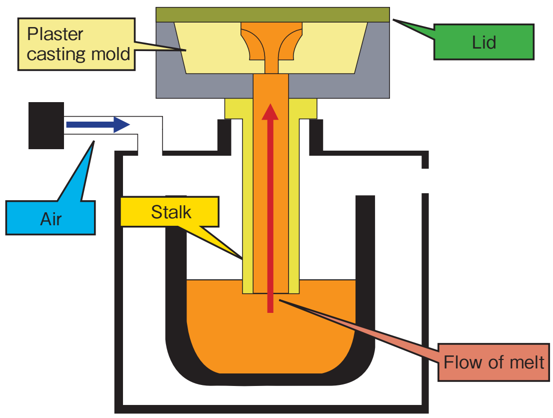


Figure 4 Apparatus for low-pressure casting.

mold. Compared to gravity casting, the pressure method has the effect of reducing shrinkage cavities and other internal voids.

To balance strength and ease of casting, the material used for the compressor wheel is normally an Al-Si-Cu-Mg alloy.

2.7 Final Machining and Balance Cut Process

The compressor wheel blanks that we have manufactured are further subjected by our customers to final machining and balance cutting, and they then assemble them onto the shaft.

2.7.1 Final Machining

In order to satisfy extremely stringent dimensional tolerances, the compressor wheels are machined to their final configuration.

As Figure 5 shows, this process involves the machining of the shaft hole and the cutting of the top, bottom and lateral surfaces.

2.7.2 Balance Cutting

Balance cutting is an extremely important process for a product like this, which operates at high rotational speeds, and involves removing material from the upper portion of the compressor wheel (referred to as the boss) and from the lower surface to achieve rotational balance.

Depending on the product there is an upper limit to the weight, position and number, depth and length of the material to be removed, and if this upper limit is exceeded the product must be rejected. Balance cutting is generally carried out in a series of iterations.

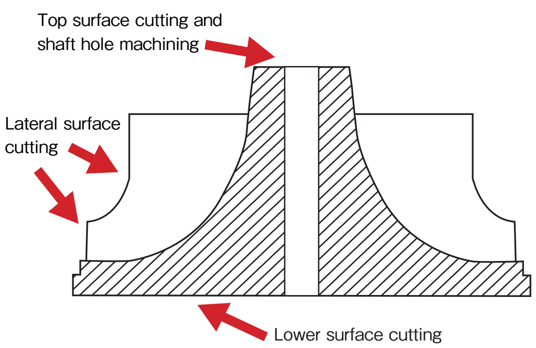


Figure 5 Schematic of final machining of compressor wheel.

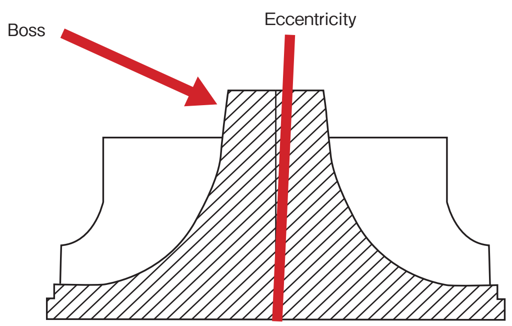


Figure 6 Cross section of compressor wheel.

3. INITIAL BALANCE OF COMPRESSOR WHEEL BLANKS

The aforesaid balance cutting process in products for final machining requires not only a good machining method and machining accuracy, but also good balance in the compressor wheel blank (i.e., initial balance). That is to say if the blank has good initial balance, the amount of material to be removed in balance cutting is less and the number of iterations of the balance cutting process can be reduced.

3.1 Evaluating Initial Balance

The initial balance of a compressor wheel is evaluated in terms of coaxiality, measuring the amount of runout in the product using a 3-dimensional tester. As expressed in Equation (1), the amount of runout represents the deviation with respect to the center of the boss of the product with reference to the center of the lower surface of the product. Coaxiality A is the relationship expressed by:

$$A=\sqrt{x^2+y^2}$$

where: x is runout (x-axis deviation in mm)
y is runout (y-axis deviation in mm)

Figure 6 shows a simplified cross section of the product, where the amount of runout as described above is an indicator for evaluating the eccentricity between the center of the lower surface of the product and the center of the boss (the arrow in the figure).

3.2 Initial Balance before Improvement

Figure 7 shows the distribution of runout and the coaxiality of the compressor wheel blank before improvement. It

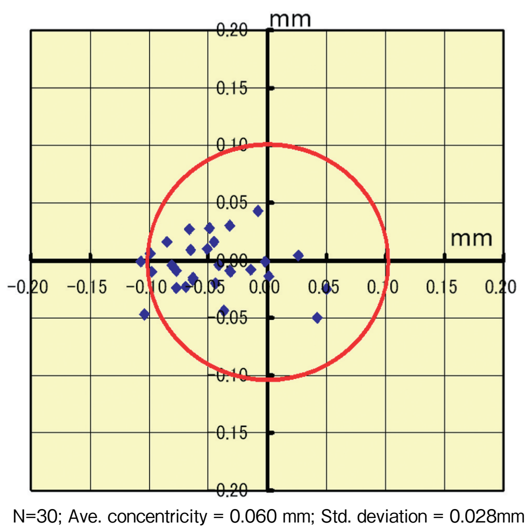


Figure 7 Distribution of product runout before improvement of balance.

can be seen that there are cases in which maximum concentricity exceeds 0.1 mm, and that there are large deviations.

4. TECHNIQUES FOR IMPROVING INITIAL BALANCE

The keys to improving initial balance are increasing die reversing accuracy and reducing the variation in the dimensions of the die itself. Here we describe the results of investigation into the master model reversing techniques that yielded the greatest improvement.

4.1 Investigation of Methods of Master Model Reversal

We have developed a new reversal method to contrast with the method that we have used in the past. Table 2 compares the two methods.

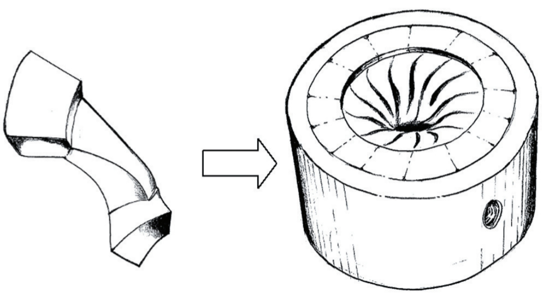
4.1.1 Existing Reversing Method: Split Mold

The technology we have been using to fabricate the female mold for forming the rubber die made use of a split mold. As can be seen from Figure 8 this is the rubber female mold for which portions corresponding to each individual blade were machined and assembled.

This technology required a very high degree of skill in the machining and assembly of the molds, and suffered from the problem that the joins of the divided mold were transferred to the product, adversely affecting its surface quality. For these reasons the dimensional accuracy of this method was strongly influenced by the skill of the operator, and deviations in initial balance were also large. The distribution of product runout using this reversing method is as shown in Figure 8.

Table 2 Comparison of two methods of master model reversing.

	Split mold (existing)	Electroplate reversing (improved)
Master model	Remains	Dissolved away
Reversing accuracy	Depends on skill of operator	Excellent
Technological level	High	High
Quality of product surface	Inferior	Excellent



(fabrication by assembling individual blades)

Figure 8 Split mold reversing method (existing).

4.1.2 Investigation of Improved Reversing Method: Electroplate Reversal

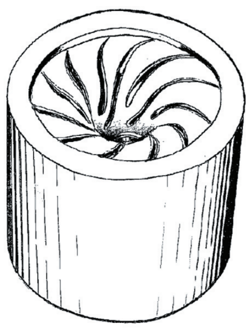
As shown in Figure 9, this method involves plating the master model, after which, by dissolving the master model, a rubber female mold is formed. This method offers the highest reversing accuracy, but requires an extremely high technological level.

Specifically the plating technology requires joint research to be conducted with the plating shop and repeated trial and error. During electroplating, current flows preferentially in the leading end, so there was a problem of inability to plate the master model. However by determining appropriate plating conditions it has been possible to establish technology for the fabrication of a rubber female mold that can stand up to rubber die casting.

Figure 10 shows the coaxiality and the runout distribution for a casting fabricated by electroplating reversal. It can be seen that coaxiality and standard deviation are greatly improved in comparison with Figure 7.

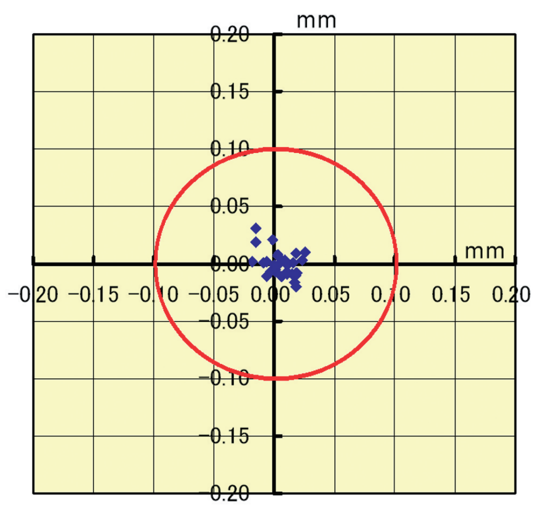
4.2 The Effect of Products with Improved Initial Balance

We thus see that by investigating a reversing method that



(electroplating of the master model, followed by dissolving of the master)

Figure 9 Electroplate reversing method (improved).



N=30; Ave. concentricity = 0.016 mm; Std. deviation = 0.008mm

Figure 10 Distribution of initial runout of plated product.

remains true to the master model we have developed a new electroplating reversal method and have been able to improve the initial balance of compressor wheels.

We have received information that compared to the existing product, this improved product has dramatically lower rejection rates for balance of the finally machined product, and smaller variations from production lot to production lot in terms of initial balance.

5. CONCLUSION

With the ongoing trends to smaller size and higher power for passenger and commercial vehicle superchargers, there will be a need for compressor wheels to withstand higher speeds and temperatures than at present.

In addition to the initial balance discussed in this paper, there are problems for the future in terms of improved fatigue strength and improved high temperature strength.

Meanwhile on the supply side, in an effort to respond to strong consumer demand for increased production, we have established a plant in Vietnam and are in the process of shifting the focus of manufacture from Japan to that country.

We assure you that both in quality and volume we will continue to respond to customers' needs, and will contribute to improving the performance of compressor wheels.

REFERENCES

1) Toyo Keizai Weekly, August 27, 2005, Toyo Keizai Shimbunsha. (in Japanese)
2) Precision Casting, 234, 1981, Japan Foundry Society. (in Japanese)