Large Integrally-geared Centrifugal Compressor

Keiichi SAEKI*1, Yasuhisa YAMASHIRO*1, Toshihisa SHIBATA*2, Atsushi SANO*2

*1 Rotating Machinery Engineering Department, Rotating Machinery Business Unit, Compressor Division, Machinery Business
*2 SHINKO TECHNO ENGINEERING CO., LTD

A newly developed centrifugal compressor has a large capacity and incorporates a gear unit. An attempt was made to downsize the compressor, and the cost has been reduced by revising the procurement method of the gear unit, etc. A full load test has been carried out on a prototype machine in the company's proprietary facility to confirm its performance and mechanical stability. As a result of this development, the application range of integrally-geared centrifugal compressors has been doubled, enabling a response to the demands of the expanding market.

Introduction

Integrally-geared centrifugal compressors are being increasingly used, thanks to their energy-saving and space-saving features. In recent years, the demand for compressors with greater capacity has been increasing as plants become larger.

So far, Kobe Steel has delivered integrally-geared centrifugal compressors with processing flow rates up to approximately 160,000 Nm^3/h. On the basis of these achievements and with the aim of greatly expanding their applicability, the company has recently developed an integrally-geared centrifugal compressor that meets the market needs for a greater processing flow rate of up to 400,000 Nm^3/h. **Fig. 1** shows the standard range chart of Kobe Steel products.

A large prototype compressor was built, and operational demonstration testing was conducted under actual load conditions. This paper reports the outline.

1. Construction of prototype compressor

An integrally-geared centrifugal compressor comprises a speed-increasing gear device having a pinion shaft, at least one end of which is overhung for attaching at least one impeller. Increasing capacity accompanies the upsizing of the impellers and whole compressor, exerting a significant influence on the footprint area, etc.

This prototype compressor has achieved downsizing with, among other things, a newly developed high-specific-speed impeller designed to minimize the increase in compressor size associated with an increased process volume. In addition, a cost reduction plan was adopted, which included changing the method of procuring principal components such as the large speed-increasing device.

First, an operational test was carried out using a prototype three-stage compressor (model: VG 683) with a processing flow rate of approximately 300,000 Nm^3/h, to confirm the mechanical stability and power performance of the compressor. Then, the prototype machine was modified to establish a design guideline for further upsizing, and an operation test was carried out with a single-stage

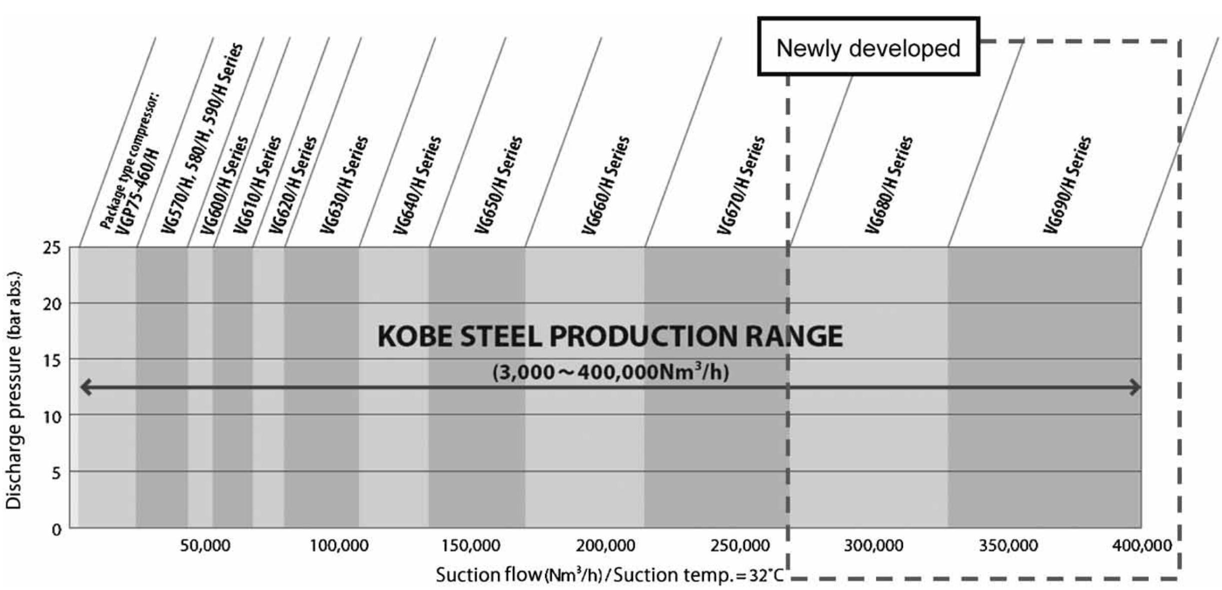


Fig. 1 Standard range chart

machine (model: VG691), which comprises a one-stage impeller having the maximum diameter for a hypothetical model with a processing flow rate of approximately 400,000 Nm^3/h. The appearance, cut model, and specification of the prototype compressor (VG 683) are shown in **Fig. 2**, **Fig. 3**, and **Table 1**, respectively.

1.1 Impeller / casing

A newly developed high-specific-speed impeller was adopted for the downsizing of the compressor. This allowed a 20 to 25% reduction of the impeller, as compared with that of the conventional design guideline. **Fig. 4** compares the meridian shapes of the conventional impeller and new impeller. As for the scroll casing, its cross-sectional distribution

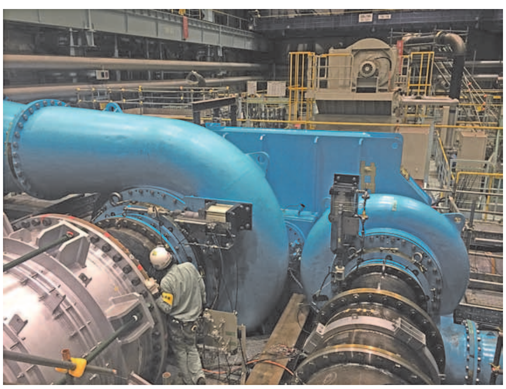


Fig. 2 Appearance of newly developed compressor (VG683)

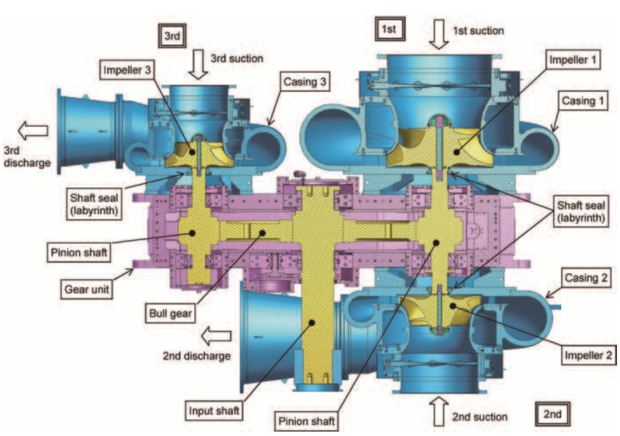


Fig. 3 Cut model of prototype compressor (VG683)

Table 1 Specifications of prototype compressor

Type	VG683	VG691 *1
Application	Main air compressor	← (same as VG683)
Gas	Wet air	← (same as VG683)
Number of stage	3	1 *1
Standard flow	300,000 Nm^3/h	400,000 Nm^3/h
Suction pressure	-1.5 kPaG	-1.5 kPaG
Discharge pressure	0.49 MPaG	0.12 MPaG *1
Rotating speed (piniom shaft)	1st piston: 4,992 rpm 2nd piston: 5,673 rpm	Pinion: 4,357 rpm
BHP	23,000 kW	approx. 14,500 kW
Shaft seal	Labyrinth seal (step seal)	← (same as VG683)

*1 Single stage compressor as prototype for VG690 series (modified from VG683)

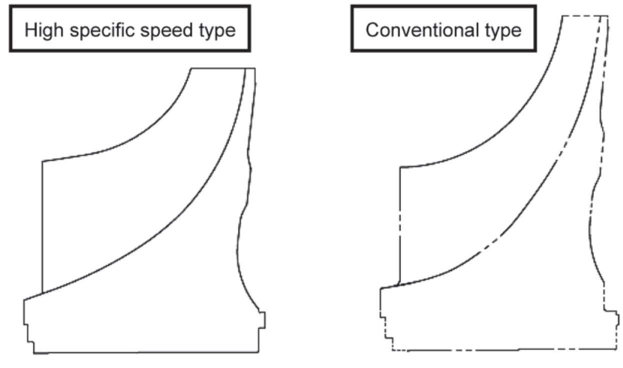


Fig. 4 Comparison of meridian section shapes of impellers

of the flow passages was optimized for the large capacity machine, which led to a weight reduction of approximately 10% compared with that of the product based on the conventional Kobe Steel design.

These efforts have suppressed the size and weight of the compressor body while improving the workability of the assembly.

1.2 Speed-increasing device

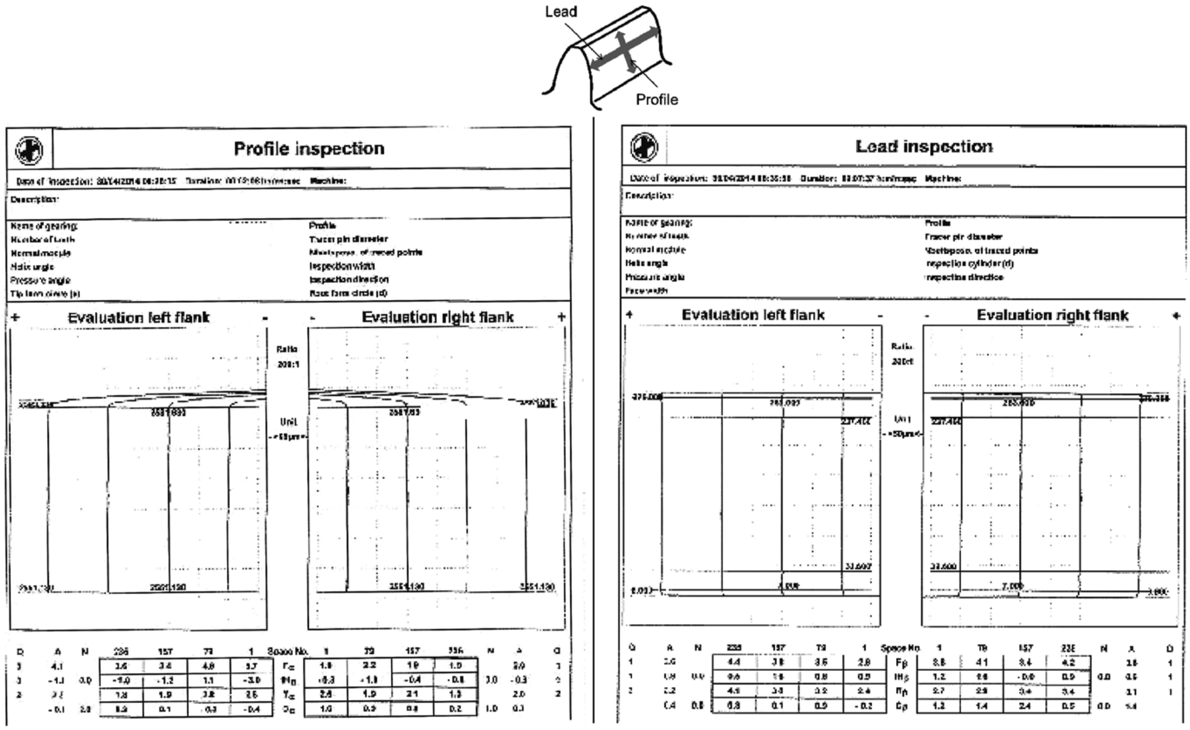
The speed-increasing device is one of the principal components of the compressor, and a gear with a large diameter of ϕ2,500 to 3,100 mm is required for the target specification range of this development. Such a large speed-increasing device for high speed operation requires high quality and can only be fabricated by a limited number of manufacturers.

Hence, a supplier having equipment capable of manufacturing large diameter gears has been selected to expand Kobe Steel's previous policy of in-company designing and outsourced-processing, the policy for the small-to-medium sized speed-increasing device. Furthermore, the prototyping and demonstration testing of large diameter gears was carried out while studies were repeated to optimize the processing conditions of the equipment.

Among the standards for the design and production of centrifugal compressors, the American Petroleum Institute (API) standard[1), 2)] is widely recognized and applied globally. As shown in **Fig. 5**, the gear flank tolerance satisfies the gear accuracy requirements specified by the API standard, ISO 1328 Grade 4.[3)] Moreover, as shown in **Fig. 6**, the static tooth contact between the bull gear and pinion gears was also confirmed to satisfy the standard required by API.

1.3 Other accessories

The shaft seal device employs a step-type



Satisfied: ISO1328 Grade 4

Fig. 5 Gear flank tolerances

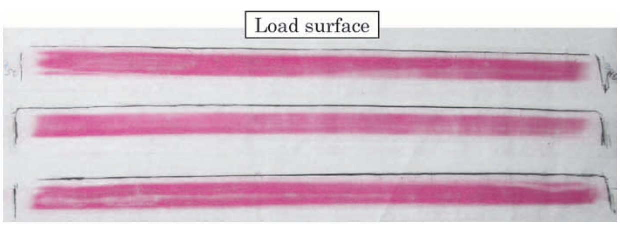


Fig. 6 Static gear contact result

labyrinth seal, which is simple and capable of suppressing leakage loss.

The rotating shaft of a compressor receives the thrust load caused by gas and the thrust load caused by the meshing of gears, as well. Adopting rider rings in large compressors can cause a problem in that the axial movement of the pinion shaft becomes excessive, due to the inclination of the bull gear in the speed increasing device. In order to avoid this, a method of individually mounting a thrust bearing on each pinion shaft was adopted to improve the reliability of the machine. In addition, assuming a turbine drive and to reduce resistance torque at the start-up, a hydrostatic bearing was used for the journal bearing of the low-speed shaft to ensure reliability at low speed operation, and the effect was verified.

As for the intermediate cooler, which accounts for a large proportion of the cost of the peripheral devices of compressors, a new vendor was selected, and their quality and capability were confirmed.

2. Operational test

2.1 Operational test results for speed-increasing device alone

The peripheral speeds of gears were specified to exceed Kobe Steel's conventional standard design criteria. Hence, an operational test was carried out on the speed-increasing device alone, and it was confirmed that both its vibration and bearing-temperature characteristics were favorable, without any problems. **Fig. 7** shows the measurement results for the speed-increasing device operating alone. The mechanical loss was also measured using a torque meter to verify Kobe Steel's method of loss calculation for large high-speed gears.

2.2 Actual-load test of compressor

Following the operational test on the speed-increasing device alone, an actual-load test of the compressor was carried out using the company's proprietary test-run apparatus to confirm its mechanical stability and to evaluate the power performance.

2.2.1 Mechanical stability

Table 2 shows the measurement results for the bearing temperature and bearing vibration during

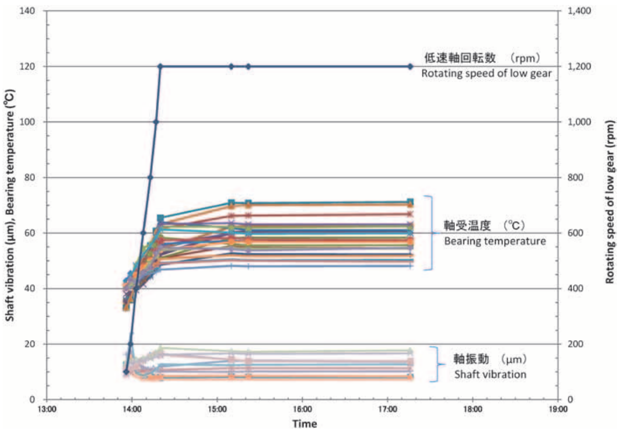


Fig. 7 Test operation results for speed-increasing device alone

Table 2 Records of running test

KOBELCO

RECORDS OF SHOP RUNNING TEST

Mechanical Running Test of Centrifugal Compressor

Model VG683

Item	Unit	11:50	12:15	12:52	13:40	14:30
BEARING TEMPERATURE						
High speed, 1st stage	℃	69.7	70.3	71.8	72.3	72.0
High speed, 2nd stage	℃	79.1	80.2	80.9	81.1	79.5
Thrust1-2, sideA	℃	51.8	52.0	52.5	52.8	52.7
Thrust1-2, sideB	℃	65.6	64.2	63.7	63.7	62.7
High speed, 3rd stage	℃	79.4	79.8	80.7	81.3	81.2
High speed, Anti-3rd stage	℃	66.2	65.6	67.0	67.2	66.7
Thrust3, sideA	℃	77.5	71.6	78.5	79.6	80.3
Thrust3, sideB	℃	58.1	58.3	58.6	58.4	58.4
SHAFT VIBRATION						
H.,pinion ,1st stage	μ	21.74	21.23	20.05	20.09	19.64
V., 〃 , 〃	μ	20.82	21.76	19.87	19.23	19.11
H.,pinion ,2nd stage	μ	17.24	16.71	16.50	16.29	16.21
V., 〃 , 〃	μ	19.24	18.82	18.95	18.47	18.12
H.,pinion ,3rd stage	μ	16.26	16.26	16.43	16.36	15.70
V., 〃 , 〃	μ	14.38	14.28	14.52	14.08	13.87
H.,pinion ,Anti-3rd stage	μ	14.67	14.67	15.11	15.62	15.39
V., 〃 , 〃	μ	10.91	10.50	10.95	11.07	11.13

the actual load test of the compressor. The bearing temperature was within approximately 80°C for all the bearings, confirming that there are sufficient margins against the Kobe Steel's criteria values. Also, the shaft vibration was within approximately 20 μm (p-p) for the compressor in fully-loaded conditions, and the results were favorable, satisfying the requirements of the API standard.

The above results confirm that the prototype compressor has sufficient mechanical stability. Also, through disassembly and inspection after operation, such parts as the impeller, shaft-seal device, and bearings, as well as the dynamic tooth contact of the speed-increasing device were checked to confirm that they are all satisfactory.

2.2.2 Power performance

The API standard cites ASME PTC-10 (Performance Test Code on Compressors and Exhausters)[4] as a method of evaluating the performance of the compressor. The power performance of the compressor was confirmed on the basis of this test standard.

The results of the power performance measurement indicate that the polytropic efficiency is improved by 1.5 to 2.0 points over that of the conventional Kobe Steel impellers. The working performance of the new impeller with a large diameter for high specific speed has been confirmed to achieve the target efficiency.

2.2.3 Ancillary equipment

Through the prototyping, the intermediate cooler has been confirmed to have sufficient quality. Furthermore, in terms of capacity, the upper limit value for the increase of cooling water temperature was successfully raised, and it was confirmed that the water consumption could be reduced. The future plan includes efficiency improvement through optimizing the internal fin shape and further cost reduction.

Conclusions

An integrally-geared centrifugal compressor for applications ranging from 300,000 to 400,000 Nm^3/h has been developed, and its manufacturability and compressor performance have been demonstrated. In addition, the applicability of integrally-geared centrifugal compressors, which excel in space saving and energy-saving performance, has been greatly expanded.

Customers, including manufacturers of air-separation-units, engineering companies, and end users, witnessed the actual load tests through which Kobe Steel's capacity for producing large machines has been confirmed. It should be noted that the prototype compressor was subsequently delivered to a customer and has been running smoothly to date.

In the future, a newly introduced 40-MW test-run apparatus will be used to further expand the applicability of integrally-geared centrifugal compressors. Kobe Steel will also strive to develop element technologies and products, taking into consideration the fields of higher pressure, such as carbon dioxide storage applications.

References

1) API STANDARD 617 EIGHTH EDITION, SEPTEMBER 2014.
2) API STANDARD 672 FOURTH EDITION, MARCH 2004.
3) ISO 1328-1 CYLINDRICAL GEARS - ISO SYSTEM OFACCURACY.
4) ASME Performance Test Codes (PTCs) 10-1997.