Development of TPL and TPS Series Marine Turbocharger

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1. Introduction

In recent years, with the enhancing powers and fuel efficiencies of marine diesel engines, turbochargers are also required to provide higher efficiencies and pressure ratios. Besides these technical requirements for engines, turbochargers are now strongly required to provide such better qualities as longer maintenance intervals, improved workability, and reduced lifecycle costs. To meet these requirements, the Turbocharger Power range Large (TPL) and Turbocharger Power range Small (TPS) were developed, which are the successors to the conventional VTR turbocharger models that were handled as the mainstay. The TPL and TPS models were developed by ABB Turbo Systems (ABB) in Switzerland and have been produced since 1996. In Japan, Turbo Systems United Co., Ltd., a joint venture operation between ABB and IHI, started to import and sell them in 1999. We shipped the TPL85B, the first TPL model, in January 2003, the TPL73B in August 2003, and the TPL77B in January 2004. The volume production for the TPS52D and TPS57D will be ready in 2004.

This document describes the features of the TPL and TPS models and test results of the first model, TPL85B.

2. Structure and features

2.1 Types of turbochargers

The TPL models are divided into the following two types according to the types of applicable engines: Versions A (TPL-A) and B (TPL-B). The TPS models are divided into the following three types according to the sizes of the compressors: Versions D (TPS-D), E (TPS-E), and F (TPS-F). A description of the structures and features of the TPL and TPS models are listed below.

2.2 TPL turbochargers

2.2.1 Feature of the TPL turbochargers

Each TPL model consists of an axial turbine and a centrifugal compressor, along with a bearing placed between the compressor and turbine: the TPL models use a center-support bearing system and are large-size turbochargers. The TPL-A models are mainly installed on the middle-to-large, 4-stroke engines used as accessory machines for large vessels or main machines for small vessels; they are divided into the following seven models based on the volume flow rates: TPL61A, 65A, 69A, 73A, 77A, 80A, and 85A. On the other hand, the TPL-B models are mainly installed on large, 2-stroke engines used as the main machines for large vessels; they are divided into the following four models according to the volume flow rates: TPL73B, 77B, 80B and 85B. **Figures 1** and **2** show the bird's eye views of the TPL-A and TPL-B, respectively. The TPL-A and TPL-B are similar

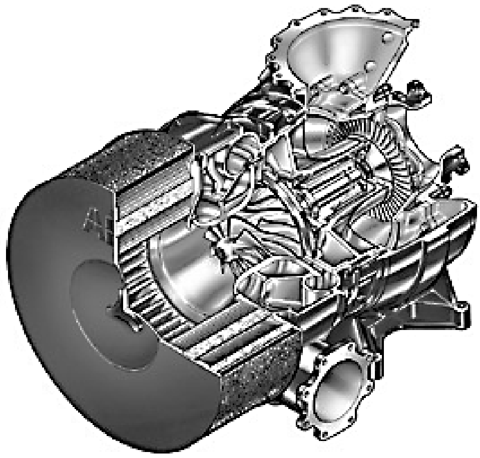


Fig. 1 Bird's eye view of the TPL-A turbocharger

Fig. 2 Bird's eye view of the TPL-B turbocharger

in outer appearance. The main difference between them is that the TPL-A is equipped with a lacing wire placed all around the turbine blades to reduce the vibration of the turbine blades (**Fig. 3**). This is a technology to reduce the vibration of the turbine blades through the friction generated by letting the turbine blades and lacing wire rub against each other.

The TPL-A models are installed on 4-stroke engines, which often use pulse-turbocharging systems that make effective use of exhaust pulses. They are equipped with lacing wires because these exhaust pulses are likely to generate larger vibrations of the turbine blades.

Listed below is a detailed description of the TPL-B models. **Figure 4** shows the outer dimensions of the TPL-B models. The TPL73B, the smallest model among the TPL-B series, has a longitudinal length of 2 622 mm, and the TPL85B, the largest model, has a longitudinal length of 4 338 mm (Dimension C_1 in the figure).

2.2.2 Structure of the TPL turbochargers

(1) Compressor

The compressor is made by machining forged aluminum, it is now made as a one-piece unit instead of the two-piece unit used for the VTR turbochargers. In addition, it uses splitter blades where shorter and longer blades are arranged alternately and a backward-type outlet to achieve higher efficiency, higher volume flow rates, and a larger operational area. **Figure 5** indicates the correlation between the volume flow rate ranges and pressure ratios of the TPL-A and TPL-B. Each TPL-B model supports engine powers of about 5 000 - 21 000 kW and provides volume flow rates of 10 - 43 m^3/s at a compressor pressure ratio of 3.5. **Table 1** shows the fundamental specifications of the TPL-B models.

(2) Turbine

The TPL-B models are often installed on 2-stroke

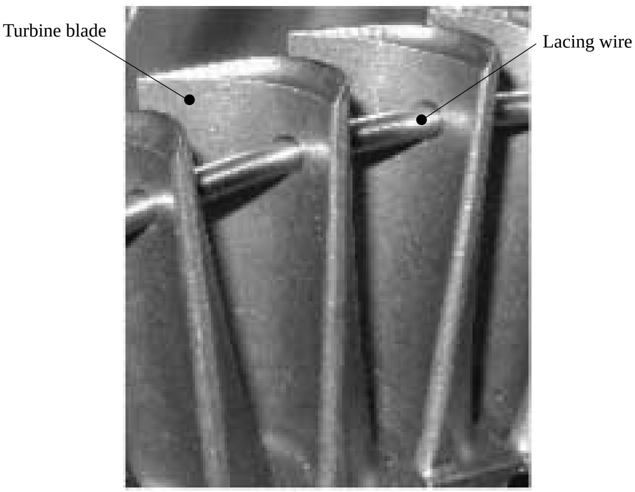


Fig. 3 Turbine blades and lacing wire

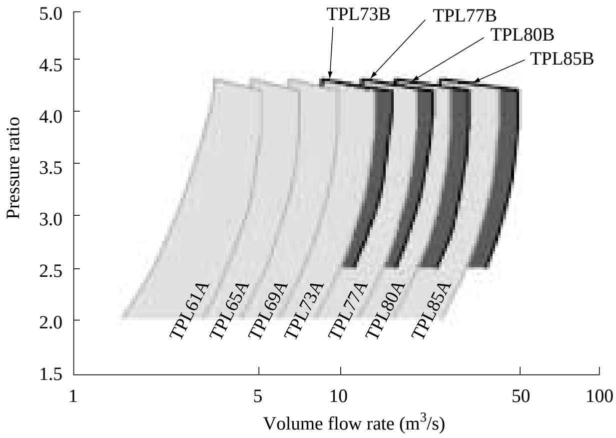
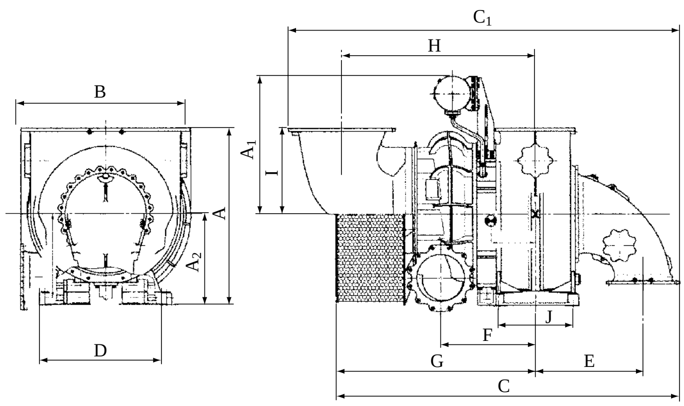


Fig. 5 Volume flow rate ranges and pressure ratios of TPL-A and TPL-B



Dimension		A	A_1	A_2	B	C	C_1	D	E	F	G	H	I	J
Model	TPL73B	1 192	976	616	1 168	2 287	2 622	822	709	627	1 320	1 280	576	494
	TPL77B	1 416	1 075	732	1 371	2 716	3 090	978	840	746	1 576	1 520	684	586
	TPL80B	1 644	1 277	850	1 590	3 132	3 561	1 134	977	865	1 819	1 761	794	680
	TPL85B	2 013	1 565	1 041	1 947	3 812	4 338	1 389	1 195	1 060	2 216	2 154	972	833

Fig. 4 Outer dimensions of the TPL-B turbochargers (unit : mm)

Table 1 Fundamental specifications of the TPL-B turbochargers

Model	TPL73B	TPL77B	TPL80B	TPL85B
Volume flow rate range*1 (m^3/s)	10 - 16	13 - 22	18 - 30	26 - 43
Applicable engine output (kW)	5 000 - 8 000	6 500 - 11 000	9 000 - 15 000	13 000 - 21 000
Dry mass (kg)	2 510	3 860	6 010	10 110

(Note) *1 : The values shown are based on $\pi_c = 3.5$

engines, which use constant pressure turbocharging systems that provide exhaust pulses smaller than those of 4-stroke engines. Turbine blades without a lacing wire are employed to improve the turbine efficiency. In addition, turbine blades fewer than those of the TPL-A models (wide-code blades) are used to provide durability against the vibration of the turbine blades. **Figure 6** shows the outer appearance of the turbine blades of the TPL-B models. To prevent turbine performance from degrading through exhaust stains accumulated on the turbine components, a cleaning nozzle was incorporated in the casing, facilitating turbine cleaning.

(3) Bearing

While the VTR turbochargers used roller bearings, the TPL models employ sliding bearings. As the journal bearing to support the radial direction load, a semi-floating bearing with the inner radius arranged with three arcs is used. The non-rotating, semi-floating bearings are not fixed in the casing, but float in an oil-filled radial gap that acts as an oil damper. By providing a very small gap between the casing and rim of the bearing, instead of firmly fixing the bearing, and inserting lubricant into this gap, the damping of the rotor vibration is adjusted.

Lubricant also flows into the gap between the rotor and the inner radius of the bearing, and when the rotor rotates, the oil film floats the rotor inside the bearing. Since the inner radius of the bearing is arranged with three arcs, if the oil film is the same thickness, a larger eccentricity is allowed compared with a full-circular journal bearing. This means that the bearing provides excellent rotational stability. In addition, a general feature of semi-floating bearings has excellent rotational stability against imbalance.

The thrust bearing, which receives positive thrust forces, uses a floating disk with its force receiving faces a taper land type. **Figure 7** illustrates the structures of the semi-floating bearing and floating disk. This floating disk is designed to form an oil film on its taper-land portions on both faces to receive the thrust forces from the rotor while rotating. The floating disk provides the advantage that it can lower the relative velocities of the rotating and stationary portions and, consequently, can decrease the heat loss (bearing loss) accordingly. Besides decreasing the bearing loss in this structural way, high-hardness, low-friction ADLC (Amorphous Diamond Like Carbon) coatings were applied to the floating disk and thrust collar to further improve bearing loss/friction and other elements. In addition, to achieve the 35 000-hour bearing design life, a recommended oil filter was applied to successfully make the maintenance interval remarkably longer than before.

2.3 TPS turbochargers

2.3.1 Feature of the TPS turbochargers

Each TPS model consists of a mixed flow turbine and centrifugal compressor. Like the TPL models, the TPS models use center support bearing systems and are small-size turbochargers. The TPS models are mainly installed on 4-stroke engines used as main machines or accessory machines for small-to-medium sized vessels; they are divided into the following four models based on the volume flow rates: TPS48, 52, 57, and 61. **Figure 8** shows the bird’s eye view of the TPS. The TPS-D, TPS-E, and TPS-F are similar in outer appearance. One of the main differences among them is the outer dimensions of the compressors. **Figure 9** indicates the outer dimensions of the TPS models. The TPS48, the smallest model among the TPS series, has a longitudinal length of 924 mm, and the TPS61, the largest model,

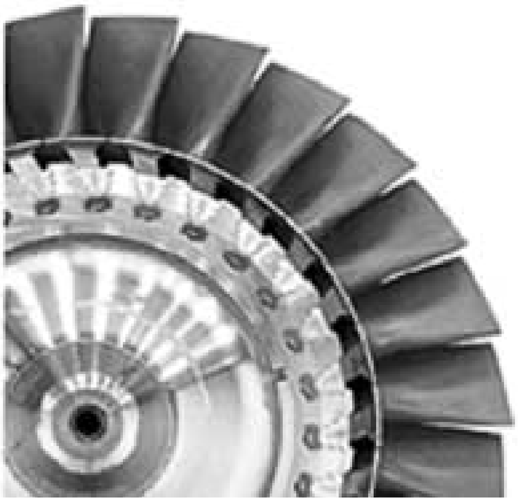


Fig. 6 Outer appearance of the TBL-B turbine blades

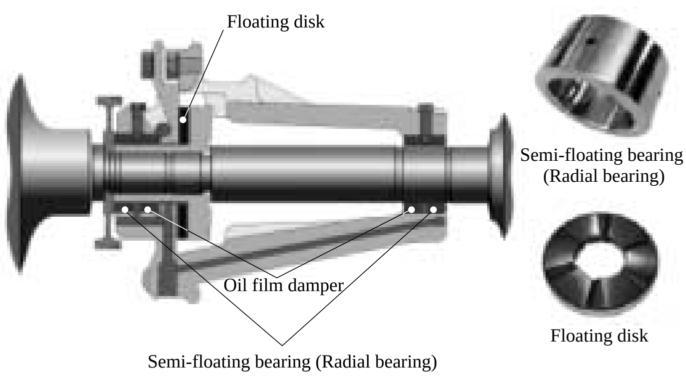


Fig. 7 Structure of the TPL bearing

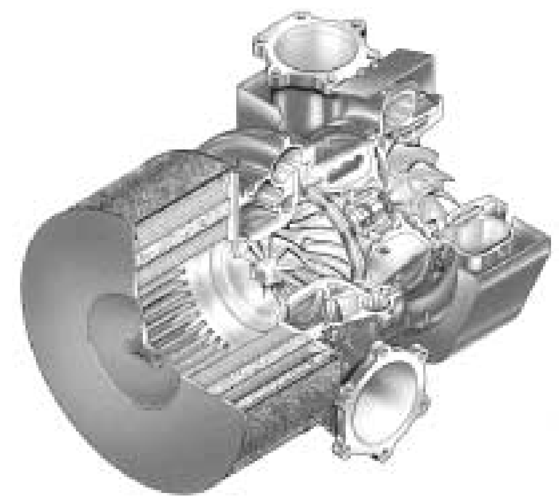
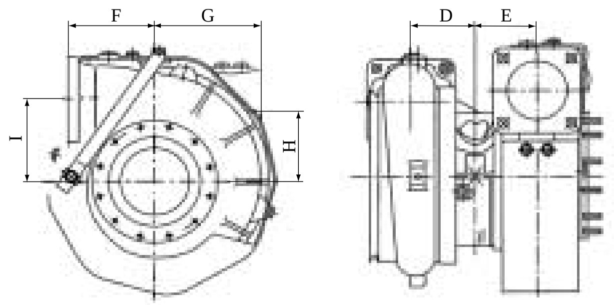
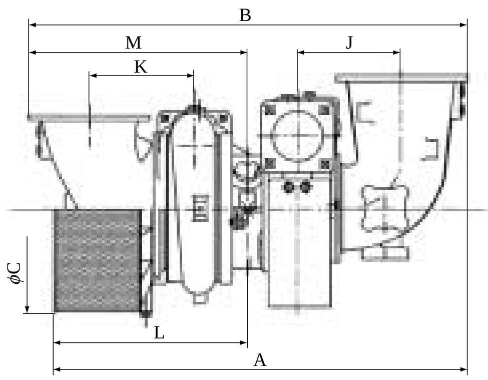


Fig. 8 Bird's eye view of the TPS turbocharger

(a) Fundamental specifications



(b) Additional specifications



Dimension		A	B	φC	D	E	F	G	H	I	J	K	L	M
Model	TPS48	871	924	448	112	106	163	195	134	155	217	223	412	465
	TPS52	998	1 073	516	132	128	188	225	160	185	241	266	474	578
	TPS57	1 211	1 308	629	161	157	230	270	196	226	295	325	570	668
	TPS61	1 432	1 563	745	192	187	274	321	233	269	352	388	666	796

Fig. 9 Outer dimensions of TPS turbochargers (unit : mm)

has a longitudinal length of 1 563 mm (Dimension B in the figure).

2.3.2 Structure of the TPS turbochargers

(1) Compressor

Like the TPL models, the compressor is made by machining forged aluminum. In addition, it uses splitter blades with a backward-type outlet to achieve higher efficiency, higher volume flow rates, and a larger operational area.

Furthermore, to meet the requirements for wide ranges of volume flow rates and pressure ratios, each of the models has three versions: TPS-D, TPS-E, and TPS-F. The TPS-D supports pressure ratios up to about 4.2 and the TPS-E, high-pressure ratios up to about 4.7. The TPS-F supports large volume flow rates and even high-pressure ratios up to about 4.7. **Figure 10** shows the correlation between the volume flow rate ranges and pressure ratios. We will focus our efforts on all TPS models: TPS-D, TPS-E, and TPS-F. Listed below is a detailed description of the TPS-D, the most common model.

Each TPS-D model supports engine powers of about 550 - 3 100 kW and provides volume flow rates of 0.9 - 5.3 m^3/s at a compressor pressure ratio of 3.5. **Table 2** shows the fundamental specifications of the TPS-D models

(2) Turbine

A mixed flow turbine equipped with a nozzle was developed to address pulse-turbocharging, 4-stroke engines. In addition, a turbine nozzle that has an anti-erosion coating on it can be applied to engines that use low quality fuel. Furthermore, a cleaning nozzle specifically for water cleaning was optimized to achieve effective turbine cleaing.

(3) Bearing

As the journal and thrust bearings, sliding bearings are used. Like on the TPL models, the journal bearing is of a semi-floating type. On the other hand, the thrust bearing does not use a floating disk. Instead, it is a sliding bearing with a taper land type, which is fixed on the stationary portion. This structure provides a compact design that

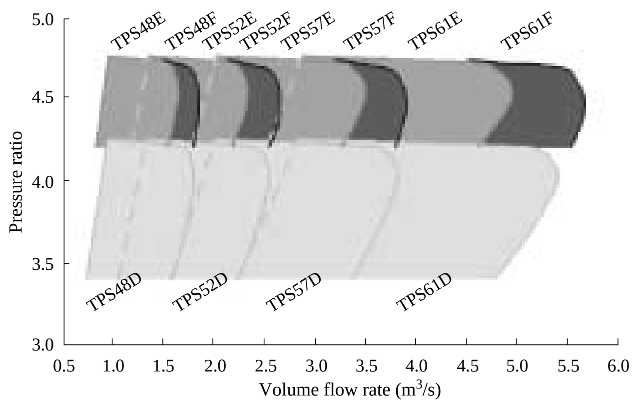


Fig. 10 Volume flow rate ranges and pressure ratios of the TPS-D, TPS-E, and TPS-F

Table 2 Fundamental specifications of the TPS-D

Model	TPS48D	TPS52D	TPS57D	TPS61D
Volume flow rate range*1 (m^3/s)	0.9 - 1.7	1.4 - 2.5	2.0 - 3.7	2.9 - 5.3
Applicable engine output (kW)	550 - 1 000	800 - 1 500	1 150 - 2 200	1 700 - 3 100
Dry mass (kg)	137	202	330	568

(Note) *1: The values shown are based on π_c = 3.5.

delivers excellent rotational stability even at high rotational speeds.

3. Evaluation tests

3.1 Overview of evaluation tests

A variety of evaluation tests were conducted so that we can produce and sell (localization) TPL and TPS turbochargers. The tests include an oil tightness qualification test, evaluation assembly clearances/ tolerances, verification of a one-hour mechanical run at maximum rotational speed and highest allowable turbine inlet temperature, and a performance test.

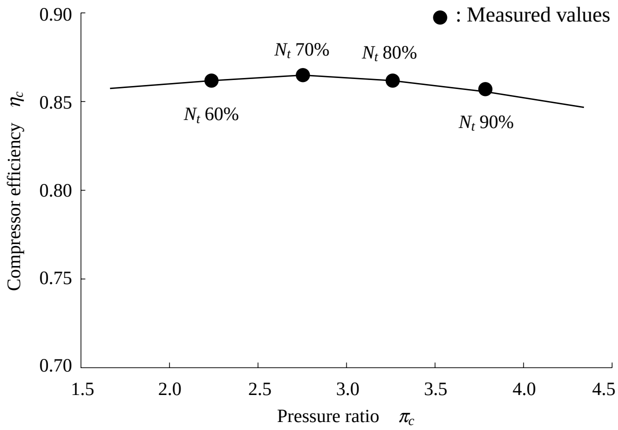
Of the tests conducted on the TPL85B, which has accomplished localization, the performance test is described below.

3.2 Performance test results for the TPL85B

As for the rotor used for the evaluation test on the TPL85B, the maximum outlet diameter of the compressor impeller is about 850 mm and the maximum inlet diameter of the turbine is about 830 mm.

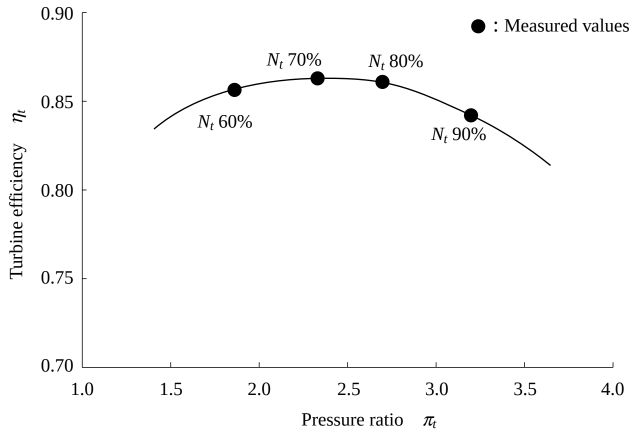
Figure 11 shows the results of the performance test on the compressor. The horizontal axis (π_c) of the chart represents the ratio between the total pressures at the compressor inlet and outlet, and the vertical axis represents the compressor efficiency (η_c). The measurement points, which are selected near the middle point, were made at four rotational speeds: 60, 70, 80 and 90% of the maximum rotational speed of the turbocharger. **Figure 11** indicates that the measurements at most of the rotational speeds showed high compressor efficiencies greater than 85%.

Figure 12 shows the results of the performance test on the turbine. The horizontal axis (π_t) of the chart represents the ratio between the pressures at the turbine inlet and outlet of the combustion gas that flow into the turbine, where the pressures at the turbine inlet are total pressures and the pressure at the outlet are static pressures. The vertical axis represents the turbine efficiency (η_t). The measurements were made at four rotational speeds, the same as for the compressor performance measurements, because the measurements were carried out along with the compressor performance measurements. **Figure 12** indicates that the measurements at most of the rotational speeds showed high compressor efficiencies greater than 85%.



(Note) N_t: Represents the maximum rotational speed of the turbocharger

Fig. 11 Compressor performance test results



(Note) N_t : Represents the maximum rotational speed of the turbocharger

Fig. 12 Turbine performance test results

4. Conclusion

With the environmental deterioration seen in recent years, the introduction of high-performance turbochargers on the market provides very high expectations for addressing the raised awareness of environmental issues and the laws regulating exhaust gases. It is hoped that this document will help develop turbochargers.