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Development and Application of PTFE Compound Bearings

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Return to session

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ABSTRACT

The PTFE (Poly Tetra Fluoro Ethylene) compound bearing is a water lubricated shaft bearing that is made of synthetic rubber and PTFE compound. This paper outlines the development and applications of PTFE compound bearings, which enable the shaft to start-up without initial lubricating water. The unique characteristic is the three-layer structure using elastic, synthetic rubber which is sandwiched between PTFE compound and the outer metal shell. This special structure is designed to solve bearing issues that are incompatible with each other. That the bearing has sufficient hardness to be excellent against wear and yet is flexible to compensate for shaft misalignment and vibration. Friction characteristics and performance data are introduced comparing PTFE and conventional rubber bearings. Long time running tests are carried our in very demanding conditions and the test data are shown. Over 15 years of actual operational service data on naval vessels and high speed, long-distance cruising ferries are introduced.

INTRODUCTION

There are two kinds of stern tube bearing systems on the present vessels. One is a water lubricated system that is mainly applied to small vessels and the other is an oil lubricated system to large vessels. This classification is made because of economical and technical reasons. From a technical viewpoint the oil lubricated system is good for large vessels because the oil lubricated bearing can bear a high load compared to the water lubricated bearing. B.F. Goodrich in U.S.A. developed the rubber stern bearing 80 years ago. It is very popular for the water lubricated system.

However the application is limited to small vessels because of the low bearing pressure allowable. The PTFE compound bearing, which provides superior performance, especially concerning baring pressure, when compared to the rubber bearing, can be applied to larger shaft diameter vessels. The FFB was developed in 1982 and since then many service data have been obtained from larger naval vessels and cruising ferries. We present the characteristics of PTFE compound bearing and performance test data are shown along with some practical service data (Yamajo, et.al).

STRUCTURE

PTFE compound bearing has a unique three-layer structure as shown in Fig. 1. Elastic rubber is sandwiched between PTFE and the outer shell made of bronze. PTFE is an abbreviation of Poly Tetra Fluoro Ethylene although the composition is not pure Teflon ® and it includes some carbon fibers to improve the abrasion resistance.

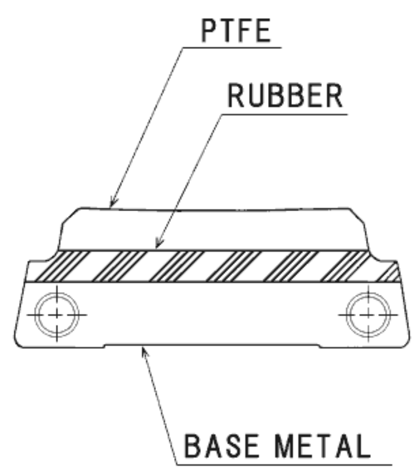

Fig. 1 Structure of three-layer bearing

The water lubricated bearing, must have excellent performance against wear and also be flexible to poor shaft alignment. These requirements are incompatible with each other as shown in Table 1 and the three-layer structure was designed to solve it. The FFB (Friction-Free Bearing) is named after the modified PTFE and special structure outline in this paper.

Required Performance			Rubber	Plastic	Three-Layer Bearing
Excellent Performance Against Wear	⇨	Material must be hard.	Soft	Hard	Hard
Flexible against poor alignment	⇨	Material must be flexible to make bearing pressure small	Flexible	Not-flexible	Flexible

Table 1 Characteristics of three-layer bearing

A key technology to manufacture the bearing is adherence of PTFE with rubber. Special equipment shown in Fig. 2 was developed to manufacture it. The manufacturing process is described as follows :
(a) A bronze shell and some pieces of PTFE are fixed in the mold. An adhesive agent is applied at both the outer surface of PTFE and the inner surface of the shell. (b) Raw material of rubber is kneaded by a screw mechanism to make the viscosity low. Then poured into the mold by high pressure through a long hole.
The adhesive strength between PTFE and rubber is more than the strength of rubber itself. When we try to measure the adhesive strength with the test piece, the rubber is damaged before the PTFE is separated from the rubber.

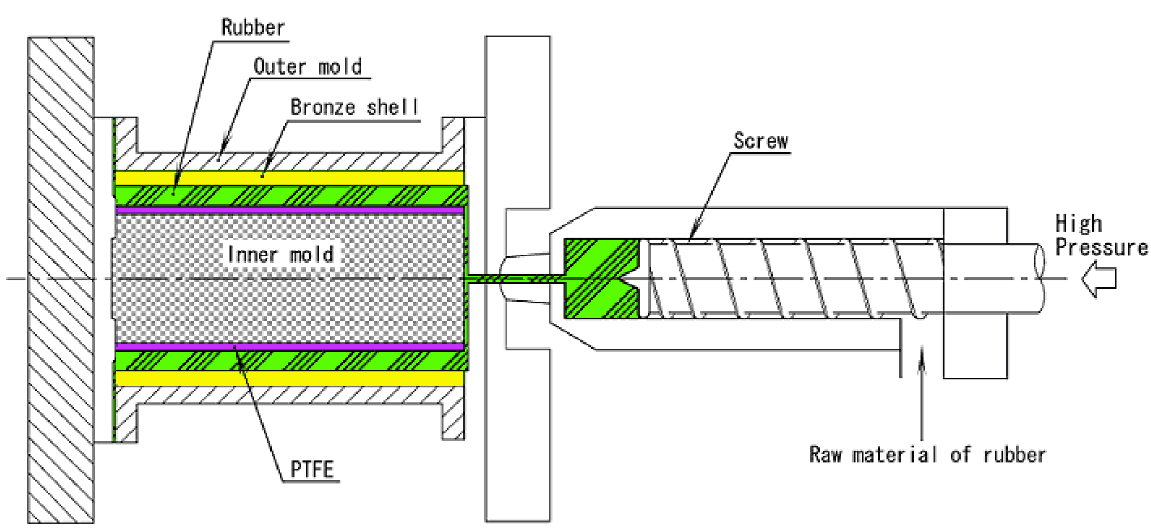

Fig. 2 Manufacturing equipment of PTFE bearing

There are three kinds of PTFE bearing. Full-molded type, segmental type and barrel type as shown in Fig. 3. The segmental type has an advantage in that only the worn pieces can be replaced. The full-molded type is more suitable to small diameter shaft bearings.

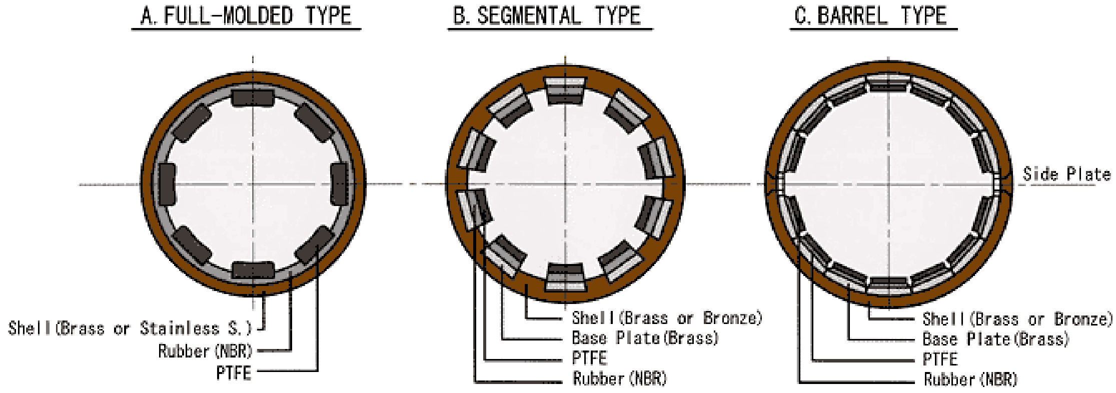

Fig. 3 Construction of PTFE bearing

BASIC CHARACTERISTICS

Comparison with Rubber Bearing

The rubber bearing is the most popular bearing for the water lubricated system. Comparison characteristics between the PTFE bearing and the rubber bearing are shown in Table 2. The coefficient of friction in Table 2 depends on the circumferential speed as shown in Fig. 4.

Item	Rubber bearing	PTFE bearing
Allowable pressure (Average pressure)	0.25 MPa	0.56 MPa
Max. partial pressure	1.0 MPa	2.5 MPa
Coefficient of friction (V > 2.5 m/s)	0.04	0.01
Operating time in dry condition (P = 0.05MPa)	0	1 min. 56 sec.
Necessary water supply	3d liter/min. (d cm = shaft dia.)	2d liter/min. (d cm = shaft dia.)

Table 2 Comparison between rubber bearing and PTFE bearing

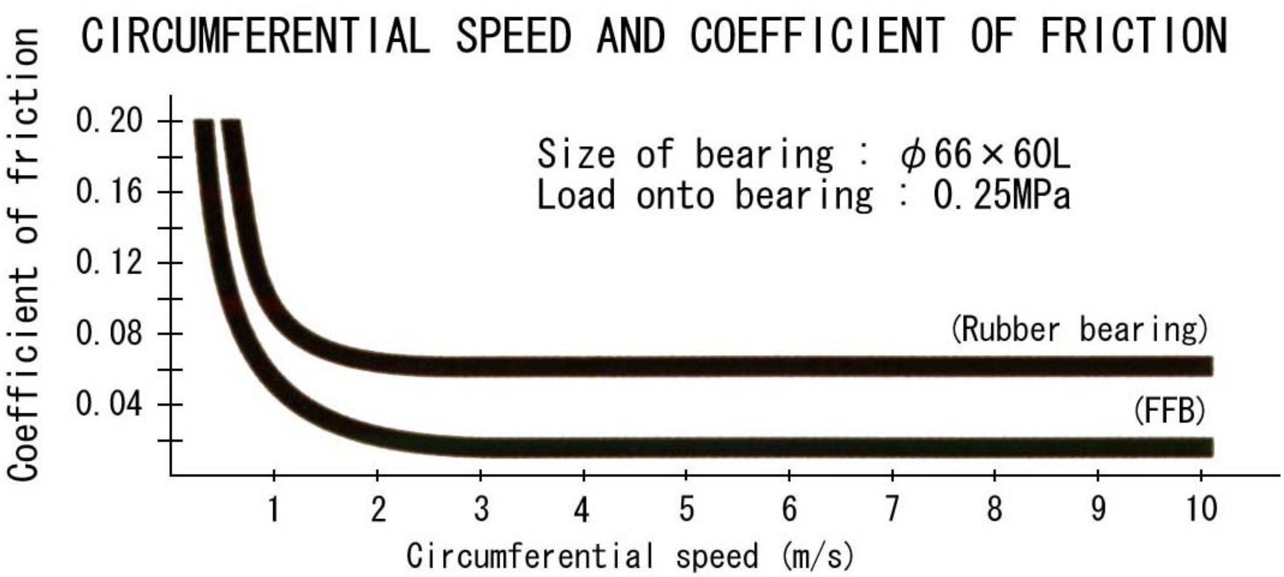

Fig. 4 Friction characteristics

The friction coefficient of PTFE bearing was measured to compare with that of a rubber bearing which is required in Military Specification (MIL-B-17901B (5H) Amendment 3). The test was carried out with the bearing of which the shaft size is 140mm (5.5 inches). The test condition is shown in Table 3 and the test results are shown in Fig. 5.
The test results show that the friction coefficient of PTFE compound bearing is far smaller than the rubber bearing.

Item		Condition
Shaft Sleeve	Material	70-30 Copper-Nickel
	Diameter	140 mm (5½ inches)
Bearing	Material	PTFE Compound Bearing
	Diameter	$140^{+0.5}_{+0.6}$ mm
	Length	140mm
Shaft Revolution		6~490 r.p.m. (0.04~3.5 m/s)

Table 3 Test condition of friction coefficient test

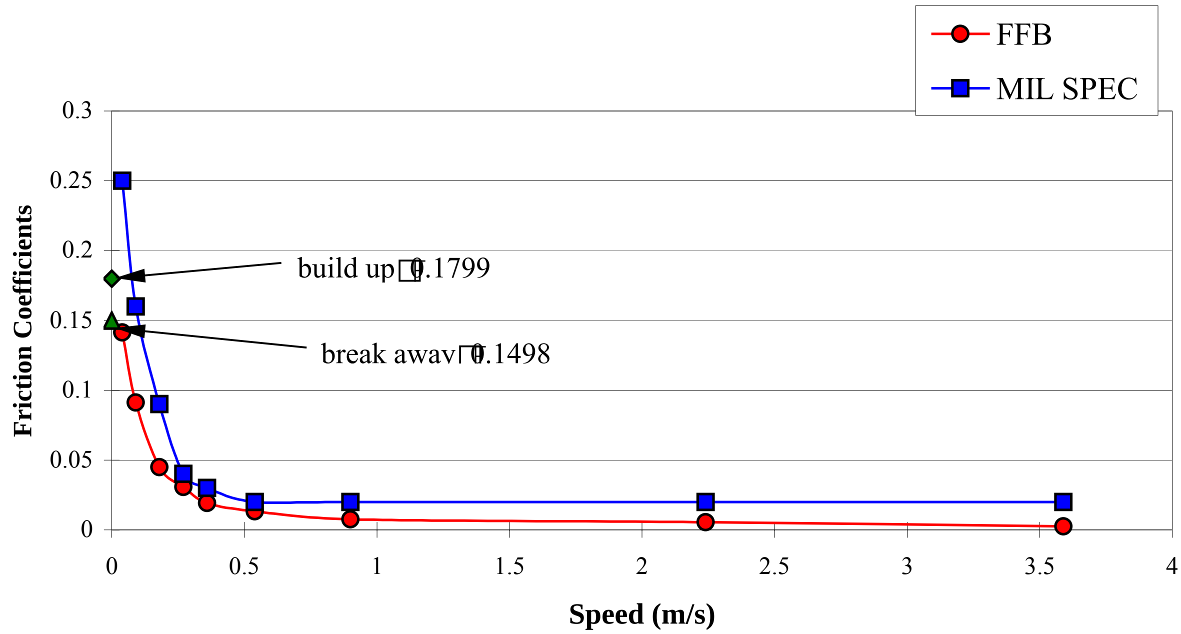

Fig. 5 Dynamic and static friction coefficients

Comparison with Plastic Bearing

The PTFE bearing material, which contacts the shaft sleeve, is a Teflon ® base material including carbon fibers and is excellent as a heat resistant material. The heat resisting performance is shown in Table 4 as compared with Urethane, which is one of the materials for a plastic composite bearing.

MATERIAL	HEAT RESISTANCE (DRY)	HYDROLYSIS IN WATER	MELTING POINT
PTFE	260°C	-	324°C
URETHANE	100°C	AROUND 60°C OR MORE	263°C

Table 4 Heat resistance

Generally, plastic composite bearings have swelling characteristics in seawater compared to the PTFE bearing which scarcely swells. Both bearings were immersed in seawater and the changes of inside diameter were measured. The results are shown in Fig. 6.

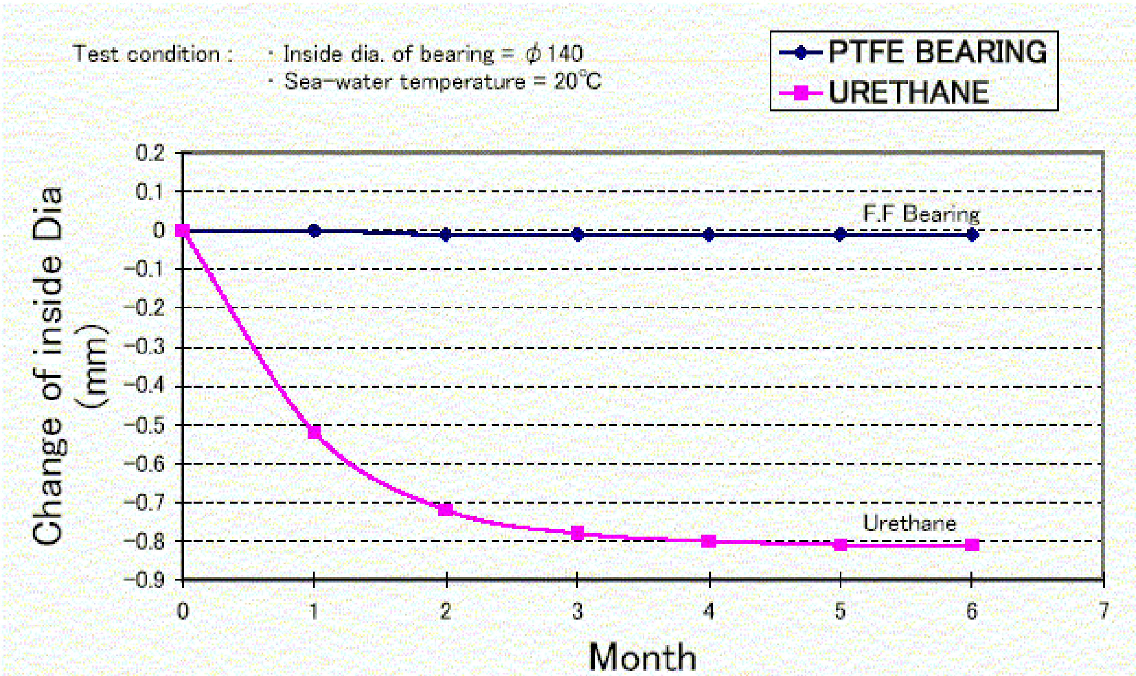

Fig. 6 Swelling in seawater

Flexibility
The flexibility of PTFE bearing is between a rubber bearing and Urethane bearing due to the unique structure. Bearing pressures for three kinds of material were calculated under a condition that the bracket bearing length is 2000mm and the shaft diameter is 459mm. Table 5 shows the Young's modulus of each material, which was used in the calculation.
The calculation results are shown in Fig. 7. Fig. 7 shows that the flexibility of PTFE bearing is very similar to the rubber bearing.

KIND OF BEARING	YOUNG'S MODULUS
PTFE BEARING	50 MPa
RUBBER BEARING	10 MPa
URETHANE BEARING	1500 MPa

Table 5 Young's modulus of bearing

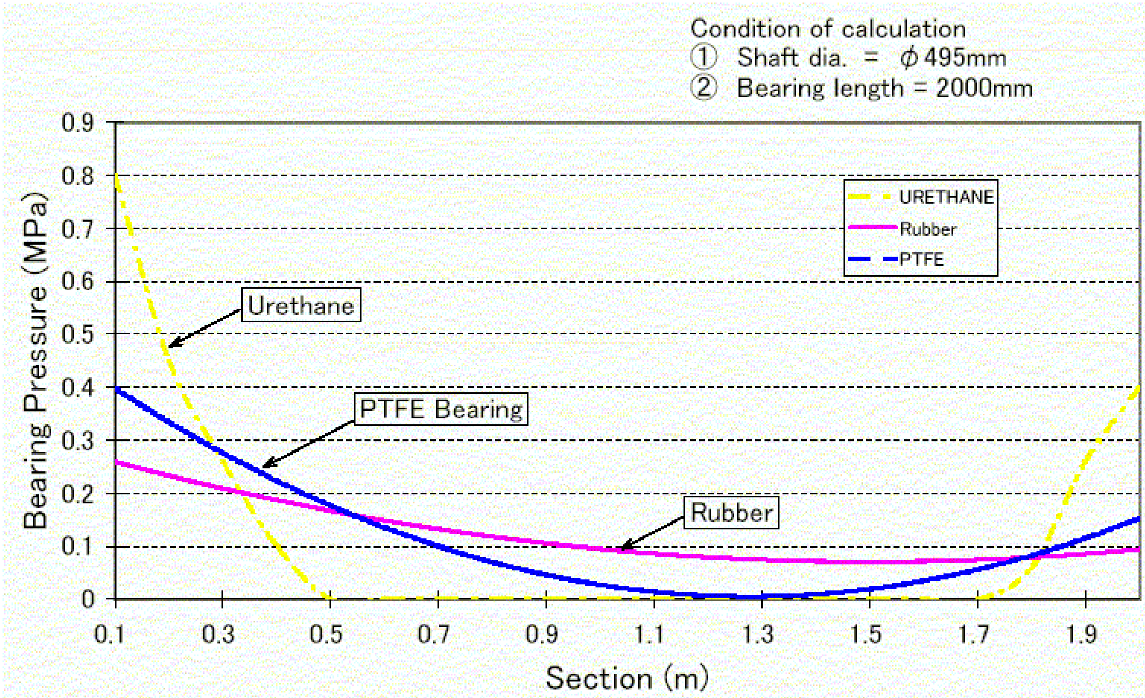

Fig. 7 Bearing pressure on bracket bearing

Durability in Dry Condition

Two kinds of experiments were carried out to investigate the PTFE bearing performance in a dry condition.

Dry Test – The tested bearing diameter is 140mm and the length is 140mm. The running time that PTFE bearing can be operated without burning in a dry condition is measured under various circumferential speeds and load conditions. The test results are shown in Fig. 8.

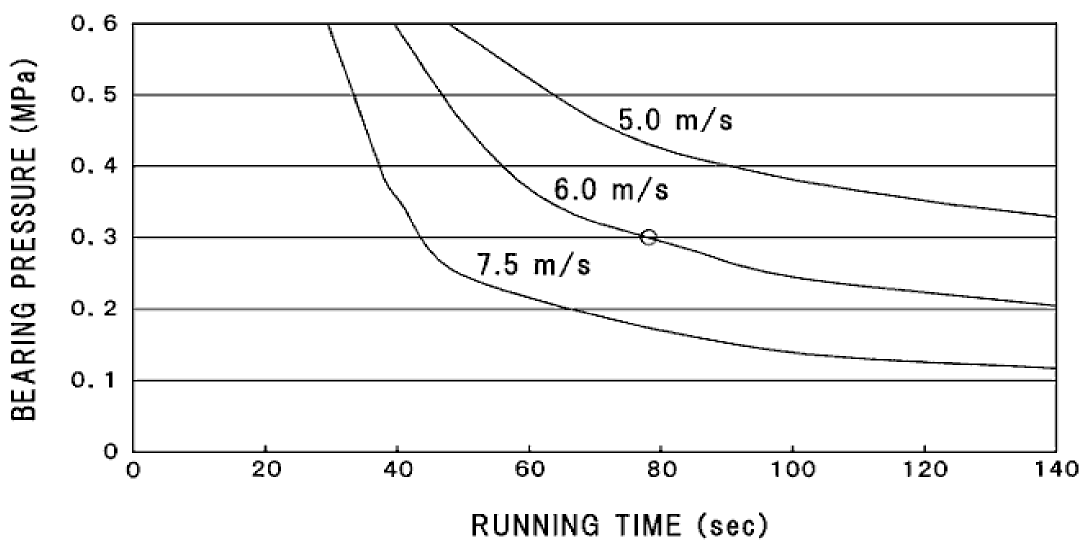

Fig. 8 Durability in dry condition

We can see from Fig. 8 that a critical running time is approximately 80 seconds when the bearing pressure is 0.4Mpa with the circumferential speed at 6m/s. It means that the PTFE bearing can be operated for 1-2 minutes even if the lubricating condition changes from water lubrication to a dry condition due to evaporation of seawater. That is why a shaft provided with a PTFE bearing can start to rotate in a dry condition (Satoh, et.al.).

No Water Supply Test – One of the concerns on a shaft bracket is that the cooling water suddenly stops being supplied to the bearing because of catching a fishing net at both sides. Test equipment in Fig. 9 simulates this situation. The inside of the PTFE bearing is filled with water and then closed at both ends with seals. The water temperature in the tank is maintained constant (32°C) with a cooler and solenoid valve. Three thermometers are put in positions A, B, and C of the bearing.

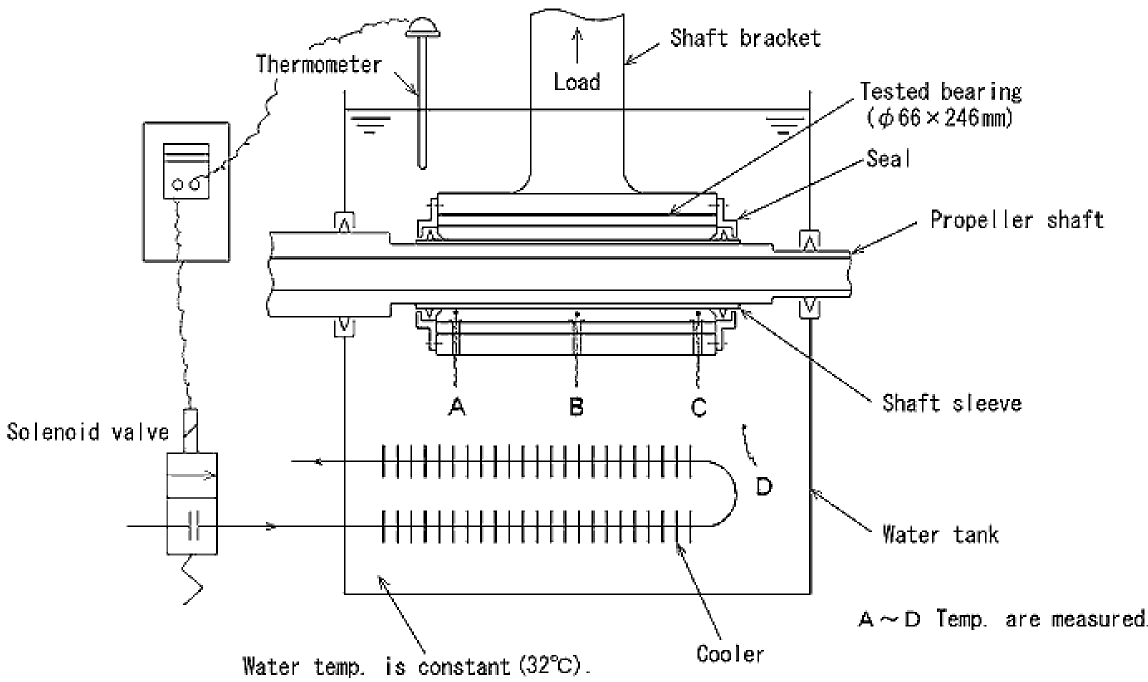

Fig. 9 No water supply test equipment

Fig. 10 shows the change of these temperatures on both the rubber and PTFE bearings. The temperature of the rubber bearing rises up radically and comes to a critical level after two minutes when the water supply is stopped from both ends. In comparison, the temperature of the PTFE bearing rises up only about 10°C and then remains constant. The difference is due to the small frictional coefficient of the PTFE bearing. This data confirms that the PTFE bearing can be used without serious problems even if fishing nets are caught at both ends. We usually comment that it is not necessary to pour water into the PTFE bearing at the shaft turning in dry dock. It is also not necessary to install water supply pipes to the PTFE bearing of the shaft bracket.

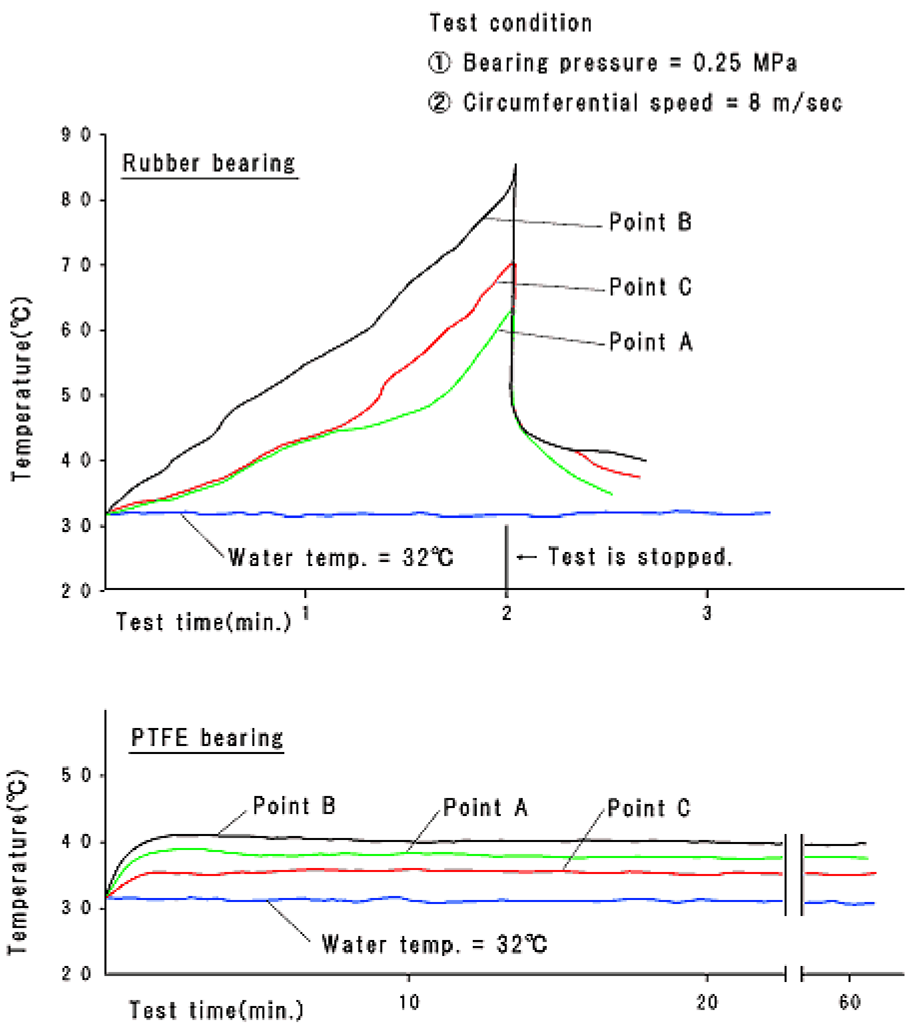

Fig. 10 Temperature of bearing

PERFORMANCE AGAINST ABRASION

The most important characteristic of a water lubricated bearing is the performance against abrasion. Two kinds of test were done to investigate it.

High Load Test

A bearing of 200mm diameter is assembled in test equipment and high pressure is applied by springs as outlined in Fig. 11. The bearing is put in a water tank to cool the bearing and sand is mixed in the water as shown in Fig. 12. The test condition is shown in Table 6.

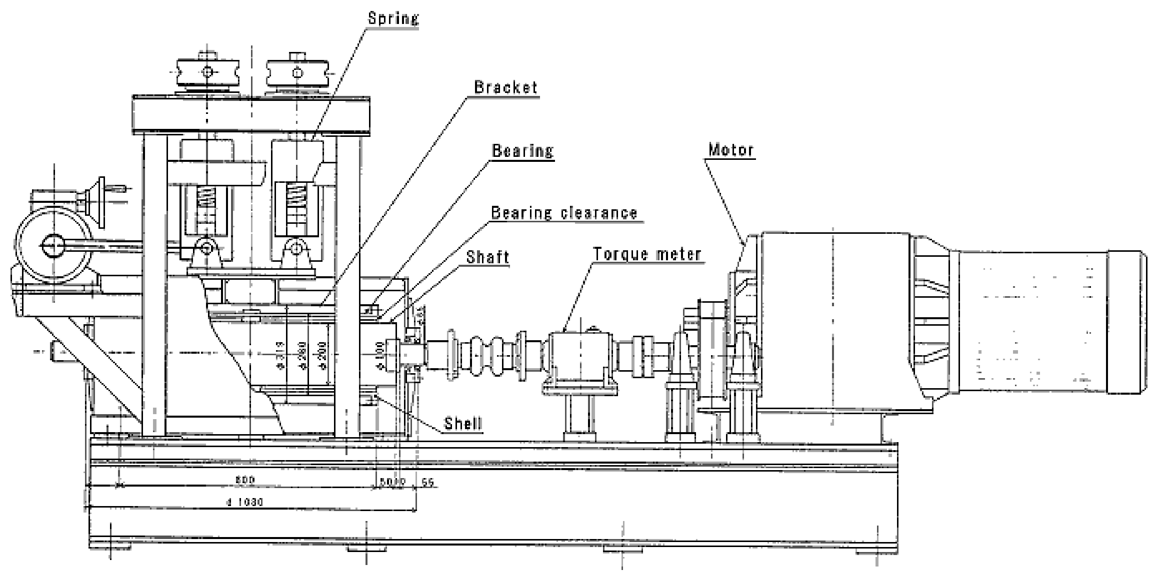

Fig. 11 Abrasion test equipment (Shaft dia. – 200mm)

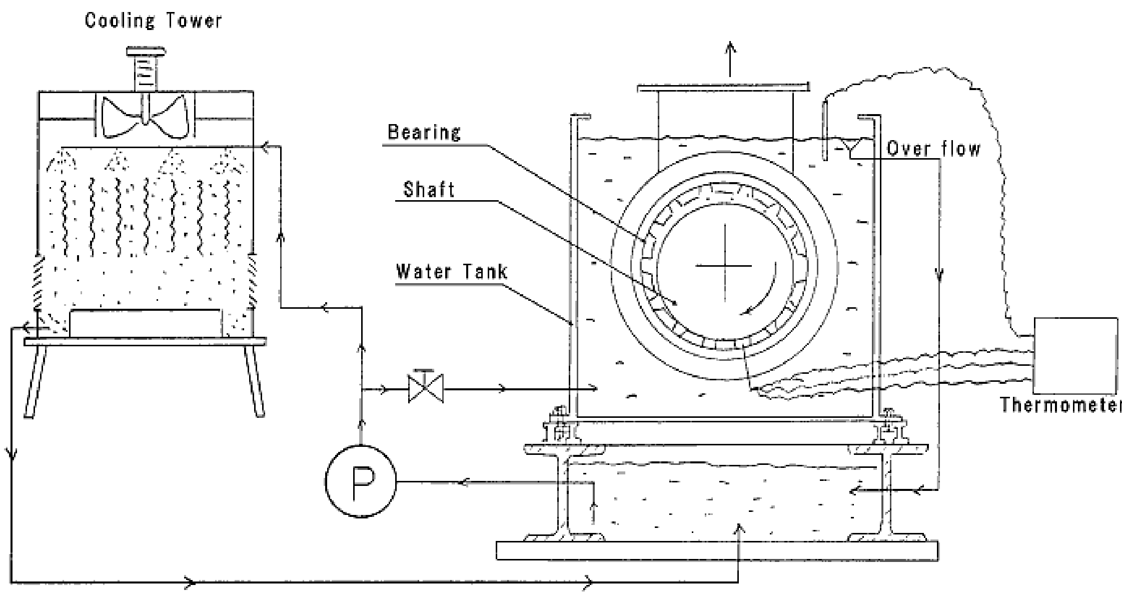

Fig. 12 Water supply line of test equipment

Item		Condition
Shaft sleeve	Material	BC2 + 0.5% Ni
Bearing	Type	Barrel Type
	Size	φ200 mm × 400 mm
	Clearance	0.7 ~ 0.8 mm
Test condition	Average pressure	1 MPa
	Revolution	600 r.p.m. (v=6.28 m/s)
	Volume of sand	0.3 % (weight % in water)
	Water temperature	20°C ~ 25°C
	Test hours	1000 Hr

Table 6 Test condition (1)

Both the wear of the bearing and shaft sleeve were measured after 90 hours, 500 hours, and 1000 hours respectively. The maximum wear rates are shown in Fig. 13. Most of the wear was caused within 100 hours after the starting and it is generally termed as initial wear. The wear rate does not advance so much after the initial wear.

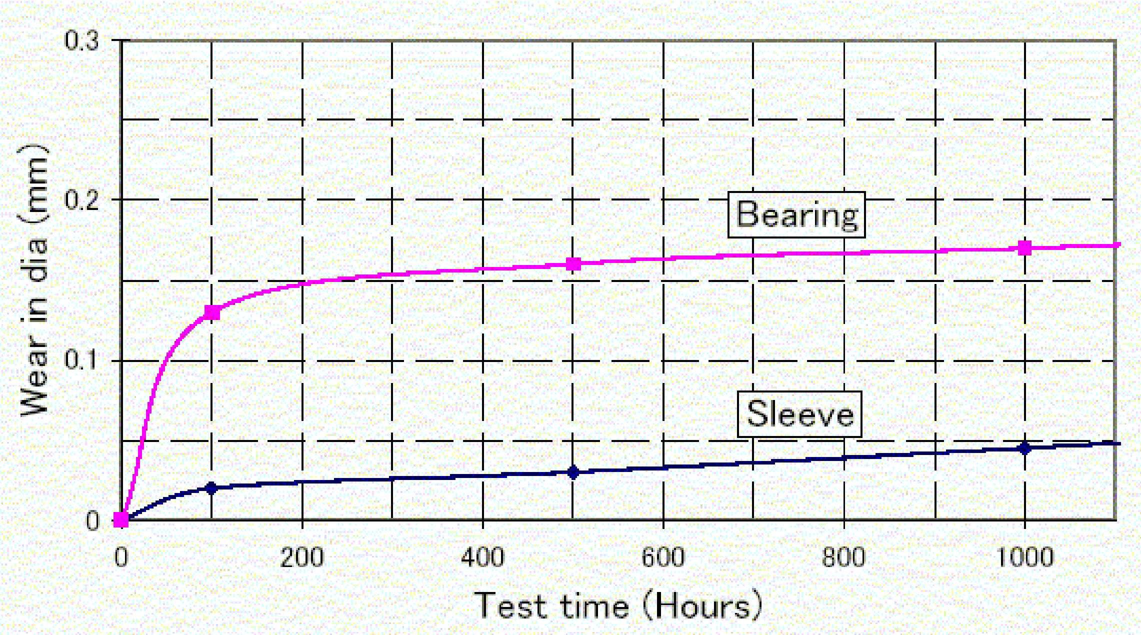

Fig. 13 Wear after 1000 hours

It is shown in Fig. 13 that the PTFE bearing has excellent performance against abrasion under high load conditions. The wear of the shaft sleeve after 1000 hours is 0.05mm and it is less than the bearing. According to our experience in practical ships, the wear of the shaft sleeve is almost the same level as the wear of the bearing.

Low Revolution Test

The abrasion performance under high load condition such as 1 Mpa is shown in the previous section. The abrasion performance under more demanding conditions is investigated in this section and thus the bearing failure is presupposed in the test. The test condition is as follows;

(a) Shaft diameter is larger. d = 300mm
(b) Bearing pressure is higher. p = 1.5 Mpa
(c) Number of shaft revolution is lower. N = 60 r.p.m. (v = 1 m/s)

The wear of the bearing is expected to be very much accelerated with the low number of shaft revolution and the above condition (c) is expected to be very severe. The arrangement of test equipment is shown in Fig. 14 and the test condition is shown in Table 7.

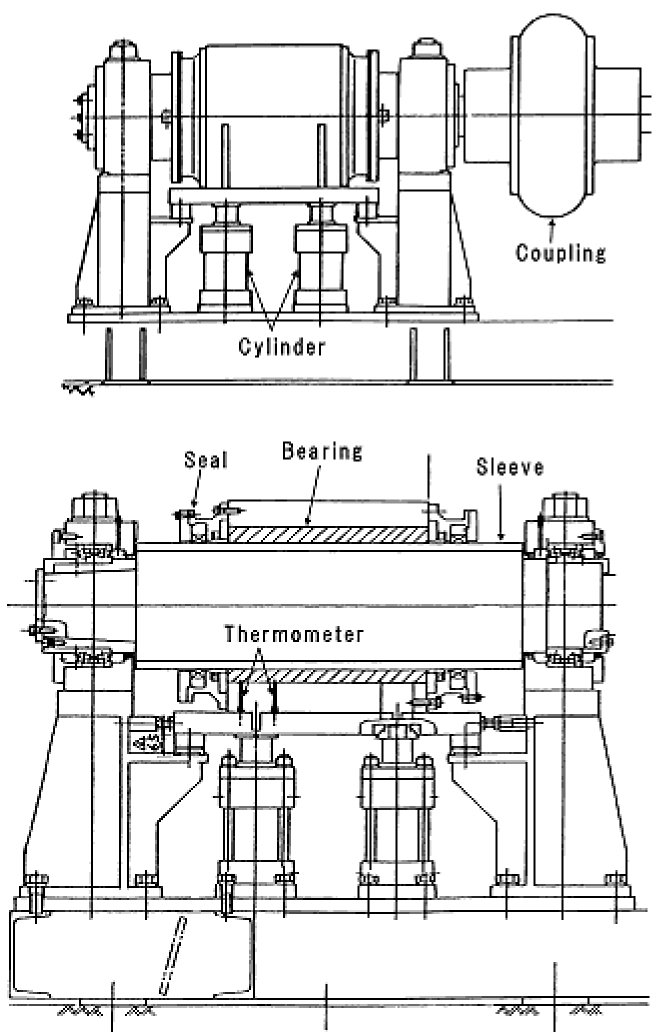

Fig. 14 Abrasion test equipment (Shaft dia. = 300mm)

Item		Condition
Bearing	Type	Full mold type
	Dimension	L=450mm, Do=φ380mm, Di=φ300mm
Sleeve	Material Dimension	BC2 + 0.5% Ni L=650mm, Do=φ300mm, Di=φ260mm
Bearing Clearance		1.0 mm
Supplied water	Kind	Pure water without sand
	Quantity	2000 liter/hr
	Temperature	24°C~ 27°C
Test condition	Revolution	60 r.p.m.(1m/s)
	Test period	4 months

Table 7 Test condition (2)

The ratio of the load on the bearing is 7(AFT) to 3(FWD) with the higher load put on the aft side. The loading condition is shown in Table 8.

Load	Average bearing pressure	AFT : Center : FWD	Tested period
A	0.5 MPa	P_{AFT}=0.7MPa, P_{CENTER}=0.5MPa, P_{FWD}=0.3MPa	1 month
B	1.0 MPa	P_{AFT}=1.4MPa, P_{CENTER}=1.0MPa, P_{FWD}=0.6MPa	2 month
C	1.5 MPa	P_{AFT}=2.1MPa, P_{CENTER}=1.5MPa, P_{FWD}=0.9MPa	1 month

Table 8 Load condition

The experiments were carried out for four months and the wear of the bearing and sleeve were measured every month. The maximum wear is observed at the aft end and are shown in Fig. 15. The appearance of the bearing after the test is very smooth on the surface while there are some scratches in the rotating direction on the surface of the shaft sleeve.

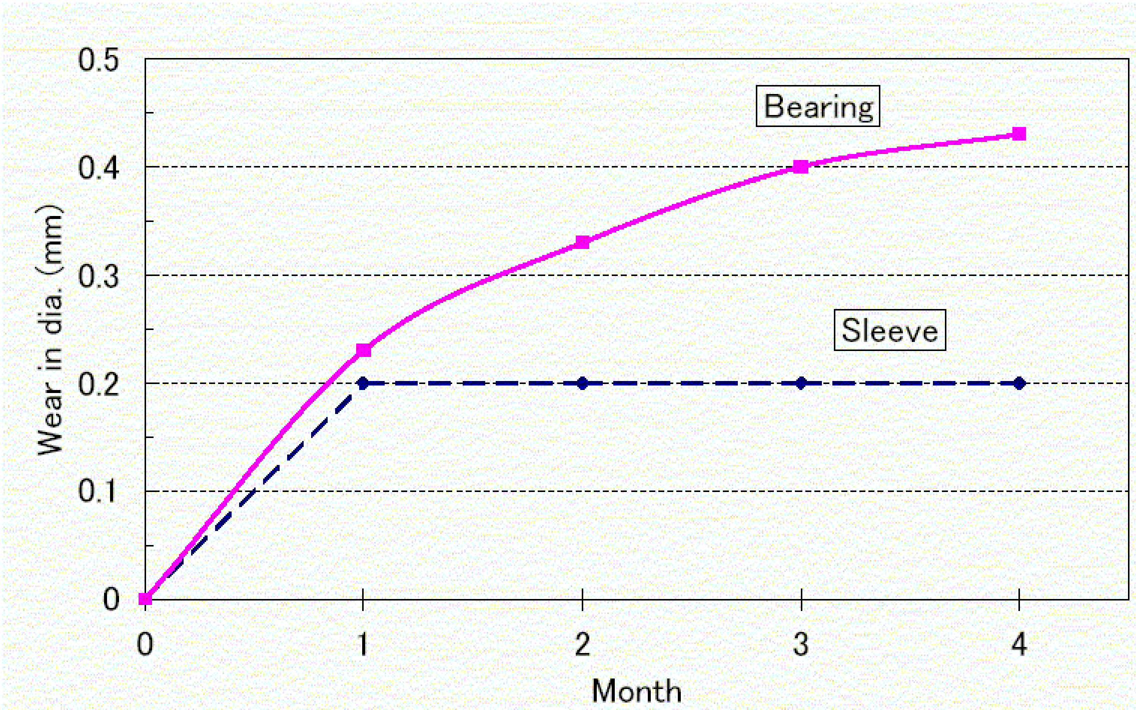

Fig. 15 Wear test for four months

Maximum bearing wear of 0.43mm in diameter was observed after four months. It is more than two times of the wear in the previous test of the 200mm diameter bearing. The difference comes mainly from the low number of shaft revolution. It is very interesting that there was no serious wear, cracking and burning on the bearing even under the very demanding test condition. The excellent performance of the PTFE bearing was confirmed through the tests.

DESIGN AND APPLICATION

PTFE compound bearing is approved by ABS and NK classification societies. The Design Assessment of ABS is shown in Table 9.

Item		Condition
Lubrication		Water Lubricated Stern Tube Bearing
Shaft Diameter (D)		40mm (1.6 inch) ~ 1,000mm (40 inch)
Bearing Length (L)		L ≥ 2 x D
Load on Bearing	Average Pressure	Less than 6 kgf/cm²
	Max. Local Pressure	Less than 20 kgf/cm²

Table 9 ABS Design Assessment

DESIGN AND APPLICATION

Fig. 16 provides very interesting data in which a rubber bearing and PTFE bearing are applied to the same ship. A rubber bearing was provided on a Destroyer class vessel for the first five years and then changed to PTFE bearing. It has been in service for eight years from the change. The clearance between the bearing and shaft sleeve has been measured for thirteen years as shown in Fig. 16. The change of clearance in Fig. 16 means "wear of bearing + wear of sleeve". The difference between rubber and PTFE bearings can be clearly seen from the data in this figure.

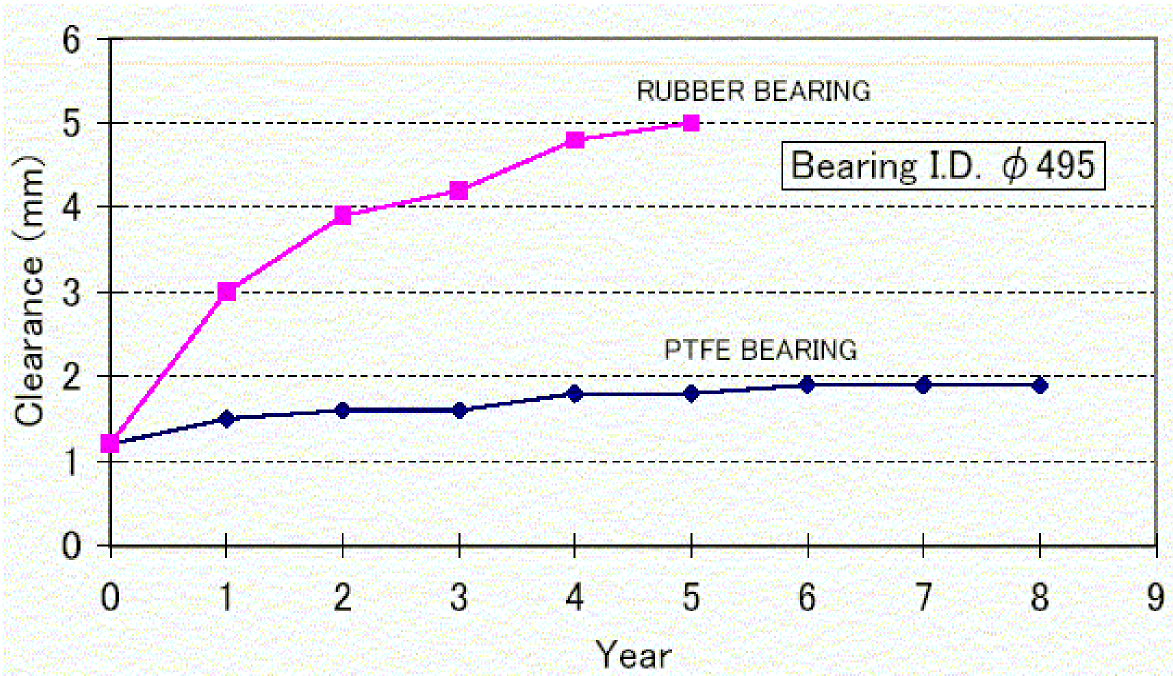

Fig. 16 Change of clearance on a Destroyer

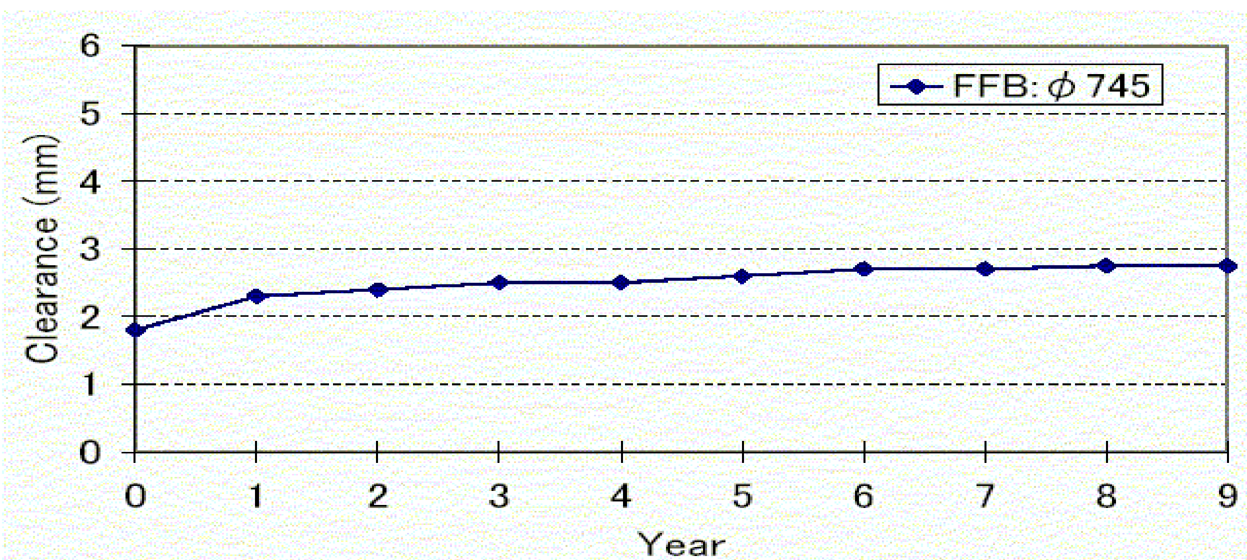

Fig. 17 Change of clearance on a Guided Missile Destroyer

Fig. 17 shows the change of clearance of a Guided Missile Destroyer for nine years. The inside diameter of PTFE bearing is 745mm and the clearance increases on 1mm after nine years. The appearance of the bearing after nine years is shown in Fig. 18.

Fig. 18 Outlook of bearing on a Guided Missile Destroyer

The service result of a long-distance cruising ferry for eleven years is introduced. It has twin propeller shafts and the structure is shown in Fig. 19. The PTFE bearing is applied on to the aft bracket bearing position ① because the bearing pressure is the highest of the three bearings. Rubber bearings are provided for the other bearings ②& ③. The aft bearing diameter is 493mm and the operating hours of the cruising ferry is 6200 hours/year.

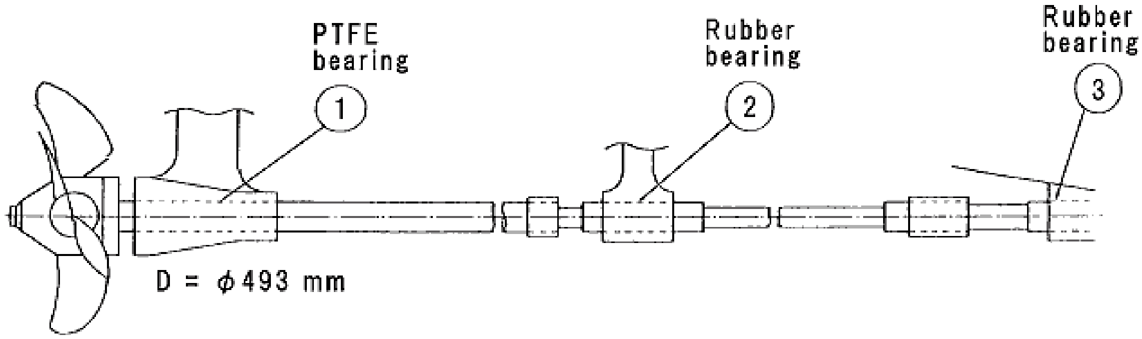

Fig. 19 Structure of cruising ferry

The practical service data are shown if Fig. 20. Both of PTFE bearings at the port and starboard sides have been used for eleven years without being replaced. A rubber bearing and shaft sleeve at the position ③ of the port side were found to be seriously worn after seven years and both of the rubber bearings and shaft sleeves were replaced. That is why the clearance of the port side after eight years becomes smaller than that of seven years. The clearance after eleven years is approximately 1mm. We expect from this data that the PTFE bearing can be used for twenty years without being replaced.

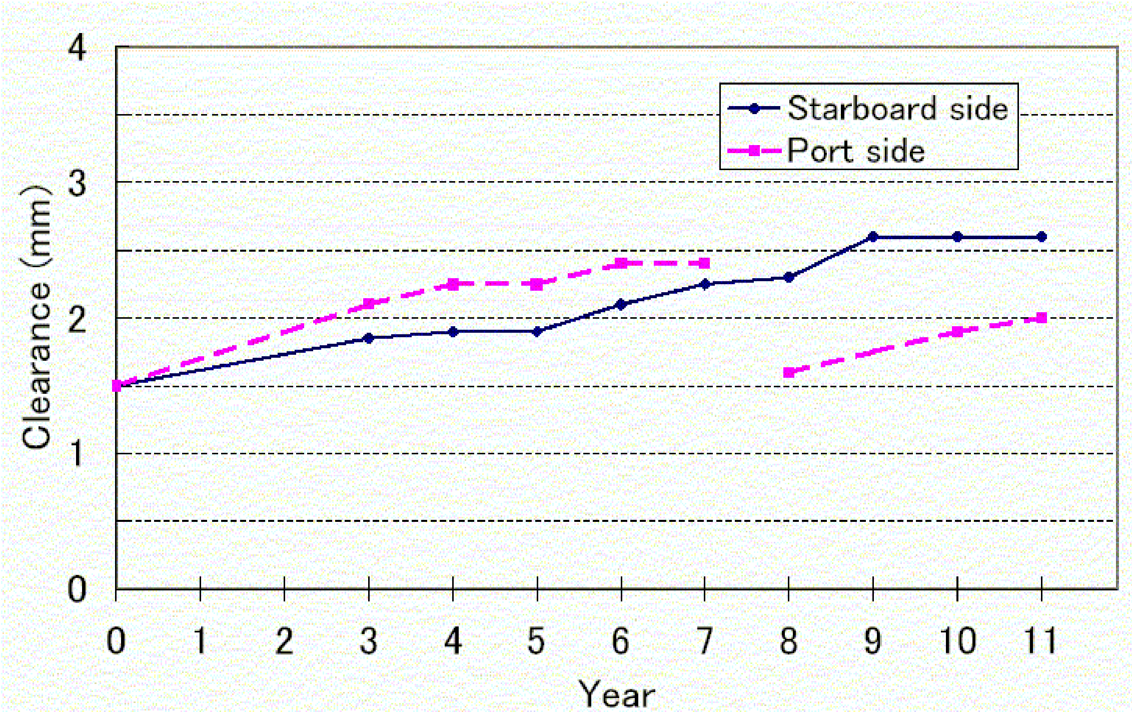

Fig. 20 Clearance of bearing at position ①

REFERENCE LIST IN U.S.A.

PTFE compound bearings have been applied to U.S. commercial vessels from May 2003 as shown in Table 10.

No.	Type of Vessel	Delivery	Bearing Size	Q'ty
1	Fishing Boat	May-03	Strut ; Ø305 x 1180L	2
			S/T ; Ø305 x 1180L	2
2	Fishing Boat	Jun-03	Strut ; Ø198 x 600L	2
			S/T ; Ø198 x 600L	2
3	Fishing Boat	Oct-03	Strut ; Ø241 x 900L	2
			S/T ; Ø241 x 900L	2
4	Fishing Boat	Feb-04	Strut ; Ø165 x 570L	2
			S/T ; Ø165 x 570L	2
5	Ocean Tug Boat	Apr-04	Strut ; Ø368 x 1300L	2
			S/T Aft ; Ø368 x 700L	2
			S/T Fwd ; Ø367 x 700L	2
6	Supply Boat	May-04	Strut ; Ø203 x 700L	1

Table 10 Reference list of PTFE compound bearing

CONCLUSION

Various characteristics of the PTFE bearing have been shown and some practical service results are introduced. The total supply record is more than 120 vessels at the end of 2003 and they have all shown excellent service results on all vessels. Unfortunately the application to usual commercial vessels except cruising ferries has been limited because of the high initial cost at new building compared with a rubber bearing. Recently the running cost of PTFE bearing has been found to be less because it can be used for more than 15 years without any replacement at dry dock. PTFE bearing is now being reconsidered from an economical point including the running cost. That is why the PTFE bearing has been applied to U.S. commercial vessels. We expect the further application in the future.

REFERENCES

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Satoh, H. and Takeda, H. "Dry Shaft Bearing for Vertical Pumps", 6^{th} International Pump Users Symposium, April 1989