Advanced Technology of Propeller Shaft Stern Tube Seal

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ABSTRACT

The paper outlines the details concerning historical perspective and recent developments to meet a requirement that lube oil and seawater leakage must be prevented under any circumstances. Using a compressed air chamber, the lube oil in the stern tube is completely separated from seawater by providing a controlled "buffer zone" between lip type sealing rings. A constant quantity of compressed air supplied from within the ship, passes through the air chamber and is spouted into the sea. An air control unit automatically detects any change of draft level and adjusts the pressures to maintain the optimum pressure on each sealing ring. The key mechanism to detect the draft change correctly and to adjust the pressure balance is explained. Specific design and project applications for the stern tube air seal on ocean going and other marine vessels using line shaft propulsion and pod propulsion are explained.

INTRODUCTION

In most mid and large size merchant ships, an oil lubricated stern tube bearing system is applied. There are various kinds of seal systems used, such as lip type or mechanical type for oil lubricated stern tubes. The basic function is to prevent oil leakage from and seawater penetration into the stern tube. The most popular oil lubricated seal is a lip type seal and an example is shown in Fig. 1. The oil pressure in the stern tube is 0.03 Mpa (0.3 bar) higher than seawater pressure and oil pressure in the #2/3 chamber is designed to be lower than seawater pressure. One of the reasons to provide a piping line to the #2/3 seal chamber is to drain both leaking oil and penetrated seawater from #2/3 seal chamber.

In the traditional seal system, stern tube oil is separated from seawater by plural sealing rings and some quantity of oil and seawater leakage through the sealing rings is inevitable.

Many kinds of air seals were developed to solve this problem (Rawland,B.) (Shiomi et. al.) (Kuwabara et. al.). In this paper we define the air seal. There is an air chamber in the aft stern tube seal and the stern tube oil is separated from seawater by this air chamber. We will introduce various legacy designs of air seals. Then the mechanism of air seal, which is classified as "constant air flow type", is explained in detail. We will also show an example application of the air seal to the pod propulsion.

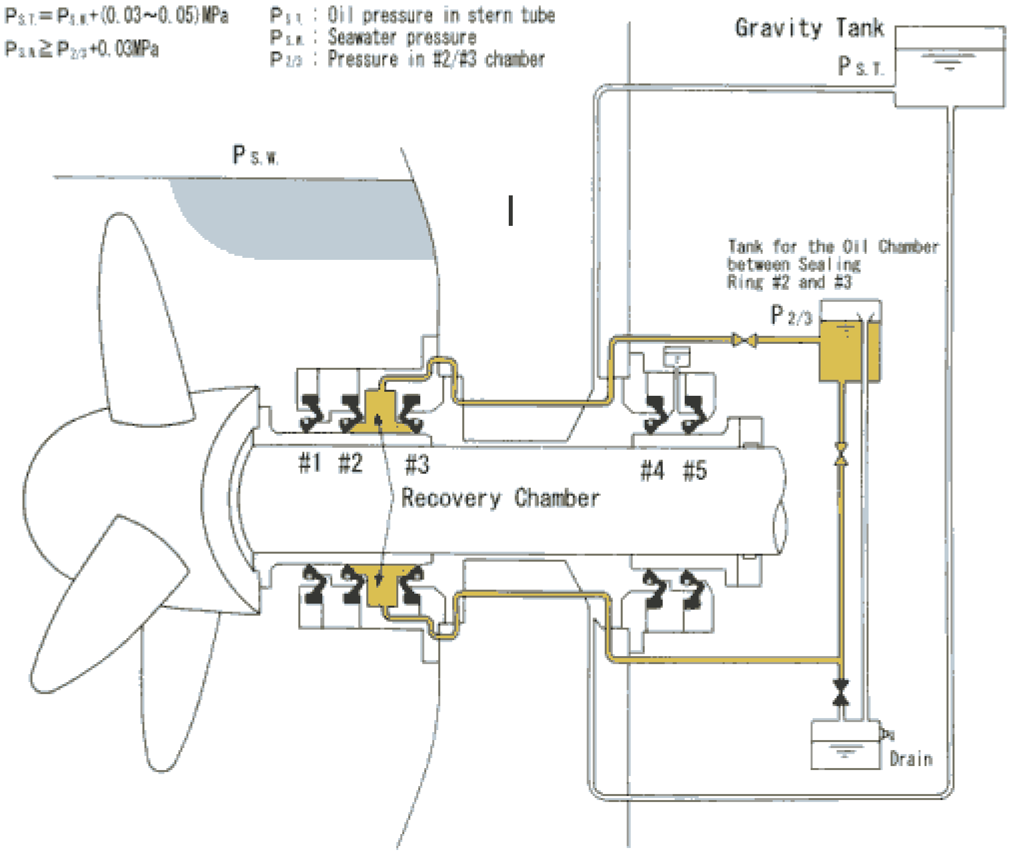

Fig.1 Structure of lip type stern tube seal

HISTORY OF AIR SEAL

Separation of Oil and Seawater

According to our definition of an air seal, the first air seal is the [Coastguard Sternseal System] ®, shown in Fig. 2(Catalogue, Japan Marine Technologies Ltd.) which was developed in 1970. A mechanical face seal is provided to prevent seawater ingress combined with a lip seal, which is provided to prevent oil leakage. In case of seawater ingress through the face seal, it can be drained to a drain tank through a drainage pipe connected to the air chamber. The air pressure in the air chamber is 0 Mpa (0 bar) because it is connected to the ambient air in the engine room.

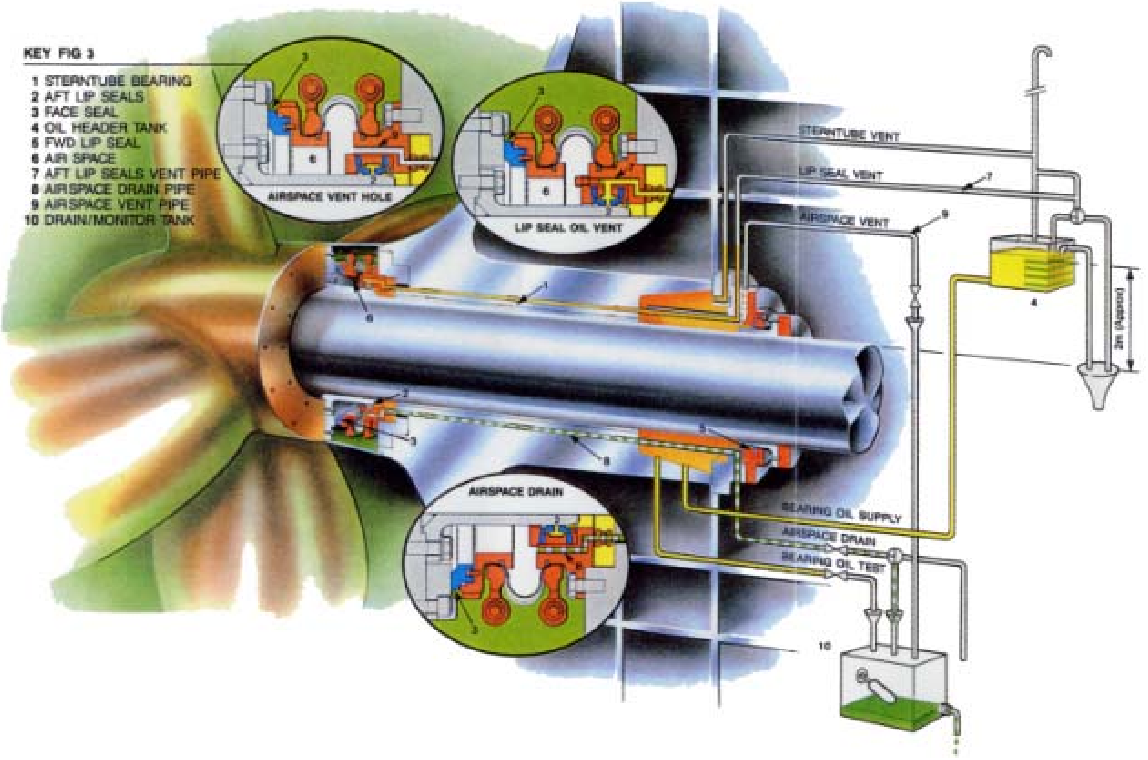

Fig. 2 [Coastguard Sternseal System] ®

Constant Air Pressure Type

[Stern Dry Seal EVS-1] ® was developed in 1983 and the schematic piping is shown in Fig. 3 (Catalogue, Eagle Industry Co., Ltd.). Compressed air is supplied into an air chamber between two segment mechanical seals and the air pressure is maintained constantly to be 0.03 Mpa (0.3 bar) higher than seawater pressure. Additional air must be supplied to maintain the above constant air pressure when air leakage increases through the segment seals and the air pressure between the seals decreases. The key concept of this seal is to keep the air pressure constant and that is why it is classified as a constant air pressure type. The leaking oil and seawater can be drained inboard through a drain pipe.

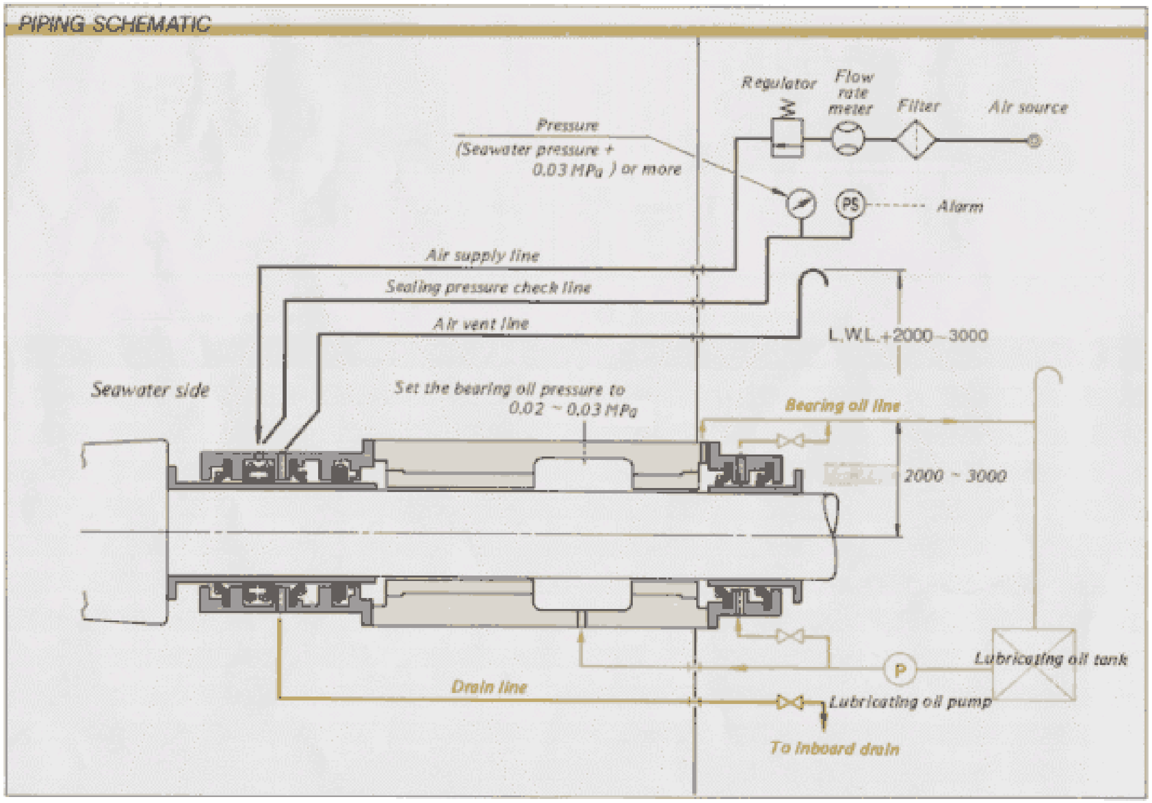

Fig. 3 [Stern Dry Seal EVS-1] ®

The next types of air seals were developed around 1990, after the two air seals mentioned above. We classify [Airspace Seal 1] ® shown in Fig. 4 (Catalogue, Blohm + Voss) is a constant air pressure type. There is a constant air pressure in the space II which is set at 0.01 Mpa (0.1 bar) below the ballast seawater pressure so that no air flows into the seawater. In order to drain leaking oil and seawater, which has accumulated in the air chamber, to the bilge, a solenoid valve is opened at certain intervals, with the pressure condition in the air chamber remaining unchanged.

The main difference between the above two types of constant air pressure seals is that the air pressure in the air chamber is higher or lower than seawater pressure.

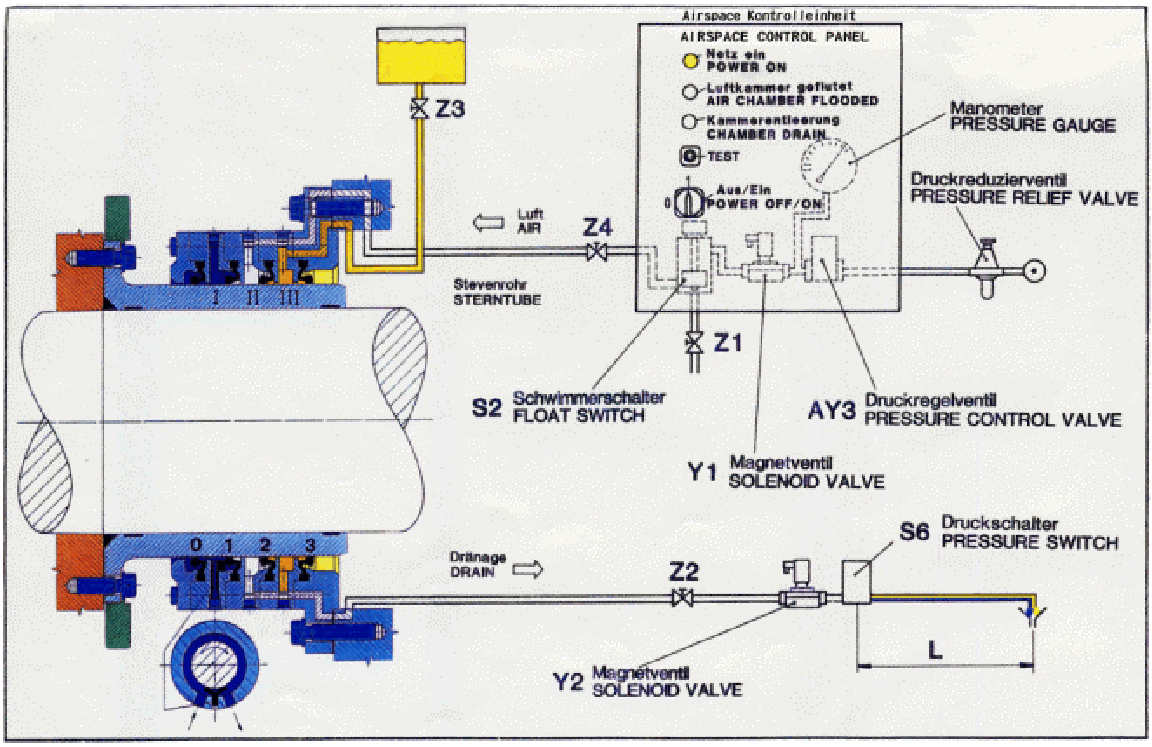

Fig 4 [Airspace Seal 1] ®

Constant Air Flow Type

As an improvement to the aforementioned designs, the constant flow type of seal was designed. An example is shown in Fig. 5. A constant quantity of air supplied from the air source, which then passes through the #2/3 seal chamber and is then spouted into sea. The air pressure is always maintained about 0.01 Mpa (0.1 bar) greater than the seawater pressure so to slightly exceed the tightening force of the #1 and #2 sealing rings. The air pressure is added to stern tube oil tank, which is installed at 3m (0.03 Mpa) above a shaft center. The stern tube oil pressure becomes "air pressure in the #2/3 chamber + 0.03 Mpa (0.3 bar)" and it also follows the draft change. Any draft change can be automatically detected and both the air pressure in the #2/3 chamber and the stern tube oil pressure follow the draft change instantly. Accordingly all pressure differences on the aft sealing rings are always negligible. Leaking oil and seawater can be drained from the #2/3 chamber. In order to drain any leaking liquid smoothly, a small quantity of air is always blown through a flow controller on the drain tank. There are two advantages of the constant air flow system. One is that seawater rarely comes into the #2/3 chamber because the air pressure is always greater than seawater pressure. The other is that the life of sealing rings, especially the #1 and #2 rings, increases because of the small pressure difference maintained.

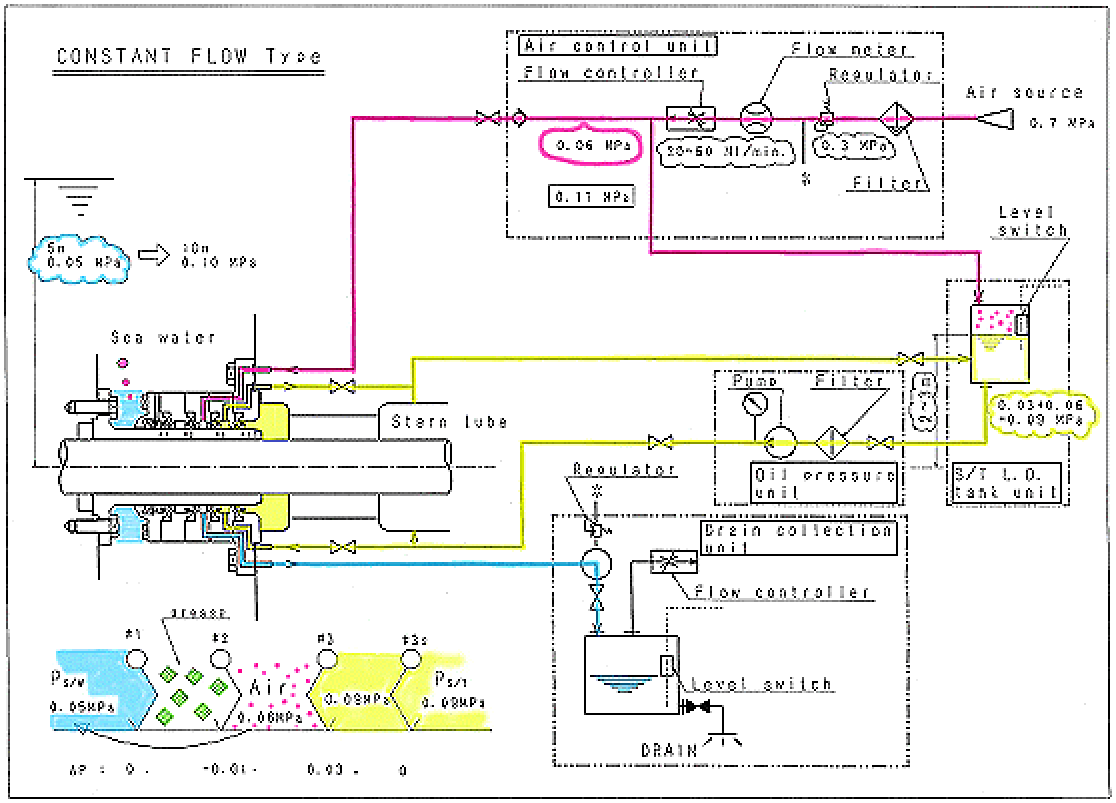

Fig. 5 [KOBELCO Air Seal] ®

THEORY OF CONSTANT AIR FLOW TYPE

Structures of Air regulator and Flow controller

It is shown in detail why the air pressure in the #2/3 seal chamber can follow changes in seawater pressure well with the constant air flow type. There are two important points in the system.

The air pressure in the #2/3 seal chamber must be higher than seawater pressure. The air pressure from the air source is usually 0.7 Mpa (7 bar). It is reduced by an air regulator to 0.3~0.4 Mpa (3~4 bar) against seawater pressure of 0.05~0.2 Mpa (0.5~2 bar) to easily control the air flow. The function of the air regulator is to reduce the source air pressure and to keep it constant. For example, at 0.3 Mpa. The regulator structure is shown in Fig. 6 (Catalogue, SMC). Adjusting a spring below the diaphragm can reduce the source air pressure.

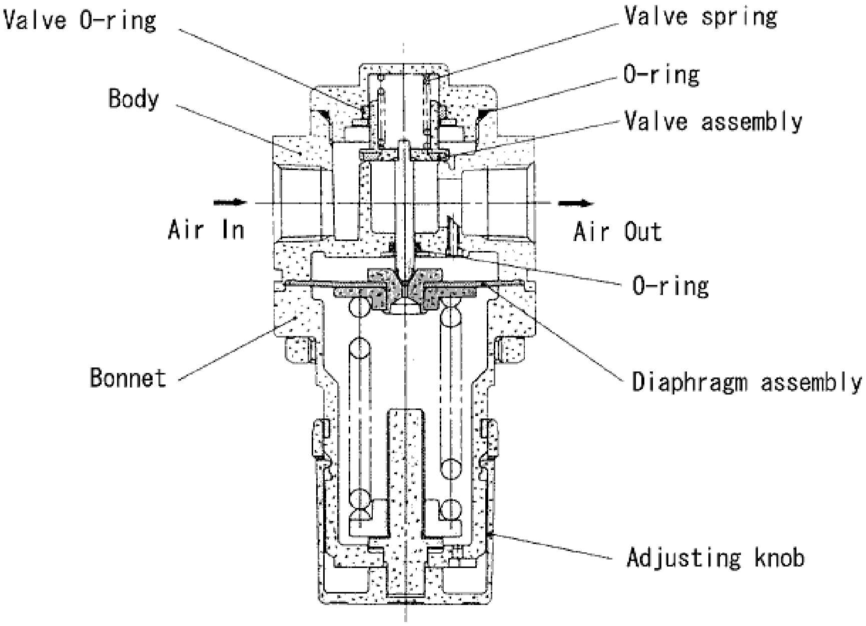

Fig. 6 Air regulator

The air flow rate of 40 Nl/min. (20~60 Nl/min.) which we recommend is a value determined after extensive experiments and field service. The air pressure in the #2/3 seal chamber becomes "seawater pressure + tightening force of sealing rings" with the recommended air flow condition and seawater pressure can be correctly detected. The air pressure in the #2/3 seal chamber becomes greater than the above "seawater pressure + tightening force of sealing rings" in case the quantity of air flow is much greater, such as 100 Nl/min. However, we cannot ignore the large quantity of air consumption from an economic viewpoint. In the case that the air flow is less than 10 Nl/min., seawater ingress into the #2/3 seal chamber may occur if the #1 and #2 sealing rings are damaged. It would eliminate a key advantage of the air seal. The structure of Flow controller is shown in Fig. 7(Catalogue, SMC).

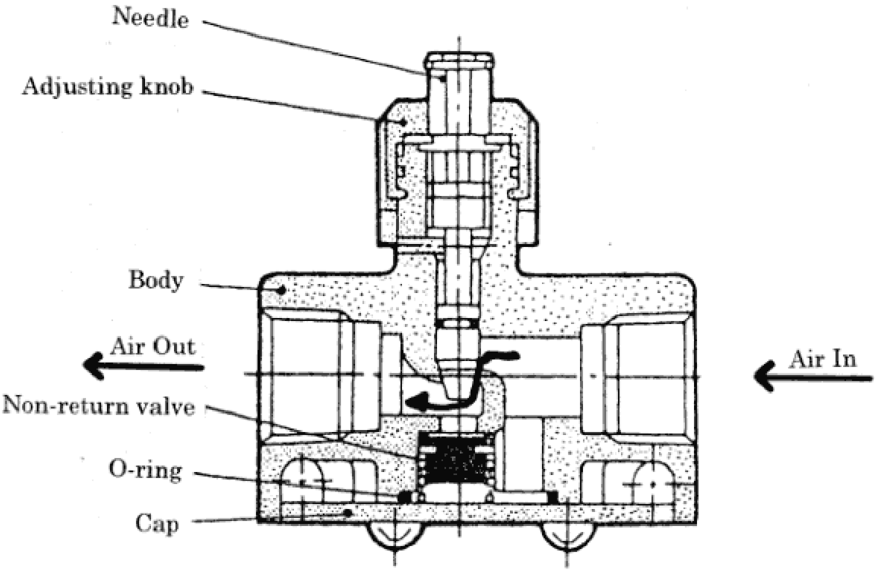

Fig. 7 Flow controller

The air flow is controlled by changing the clearance between “body” and “needle” after the air pressure is reduced to 0.3~0.4 Mpa. The quantity of air flow is noted to be constant in this paper however practically is not constant in a strict sense. The quantity of air flow depends on a pressure difference between In side and Out side pressures in Fig. 7. The exact quantity is expressed by equation (1).

When P1 is set to be 0.3 Mpa and P0 , which is almost the same as seawater pressure, is 0.1 Mpa (draft of 10m) the original air flow is adjusted to be Q = 40 Nl/min. The air flow changes between 45 Nl/min. and 35 Nl/min., when the draft changes from 5m to 15m. This air flow change is negligibly small considering the performance of the air seal and we therefore classify it a constant air flow type.

Why Air Pressure in #2/3 Chamber Follows Seawater Pressure

When seawater pressure is constant, the air pressure in the #2/3 seal chamber is always higher than the seawater pressure. It becomes “seawater pressure + tightening force of #2 sealing ring”.
Refer to Fig. 8-1.

When the seawater pressure increases, the air flow from the #2/3 seal chamber to the sea stops momentarily. The air pressure in the #2/3 chamber increases because compressed air is continuously supplied to the #2/3 chamber. Then the air starts to flow again from the #2/3 seal chamber to the seawater by lifting the #2 sealing ring. The time interval when the air flow stops is momentary. For example about 0.4 sec. when the draft changes from 5m to 8m. Refer to Fig. 8-2.

Equation (1)

$$Q = k \sqrt{\Delta P}$$

Where Q : Quantity of air flow
ΔP = Pressure difference $\Delta P = P_1 - P_0$
P_1 = Air pressure of In side
P_0 = Air pressure of Out side
k = coefficient

When the seawater pressure decreases, the air pressure in the #2/3 seal chamber decreases at the same time. Because in this case, the air pressure in the #2/3 seal chamber becomes greater that the “seawater pressure + the tightening force of the sealing rings” due to the decrease of the seawater pressure. More air flows from the #2/3 seal chamber to the sea by lifting the #1 and #2 sealing rings and the air pressure in the #2/3 seal chamber completely follows the decrease of seawater pressure. Refer to Fig. 8-3.

The practical maximum wave condition where ocean going merchant ships can be operated without serious problems is of amplitude ±3m and frequency of 20 sec. The time delay of 0.4 sec. (as shown in Fig. 8-2) is negligible compared with the above wave condition. Consequently the air pressure in #2/3 chamber can follow wave induced seawater pressure change well. Refer to Fig. 8-4.

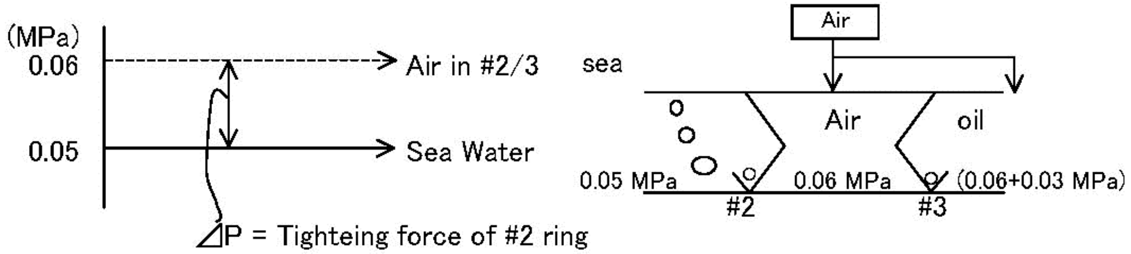

Fig.8-1 Sea water pressure is constant.

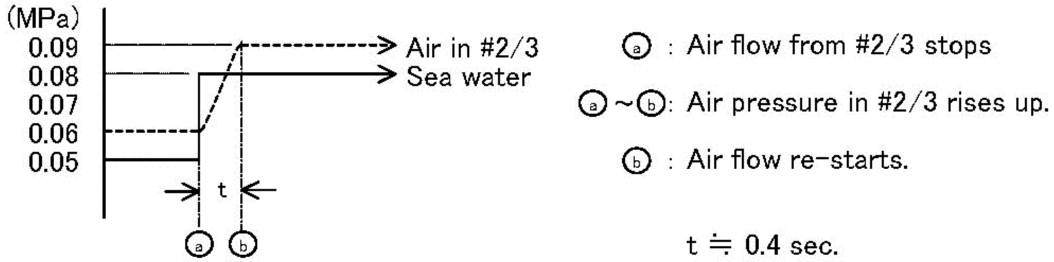

Fig.8-2 Sea water pressure rises up.

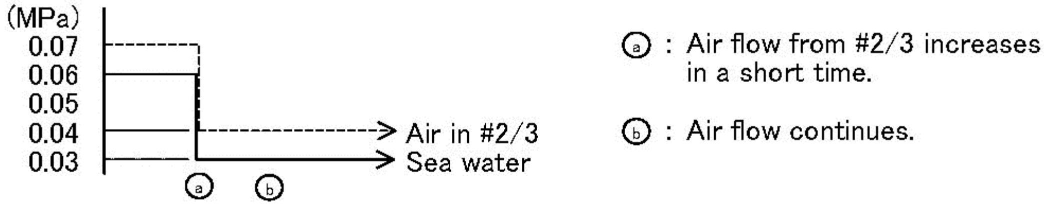

Fig.8-3 Sea water pressure goes down.

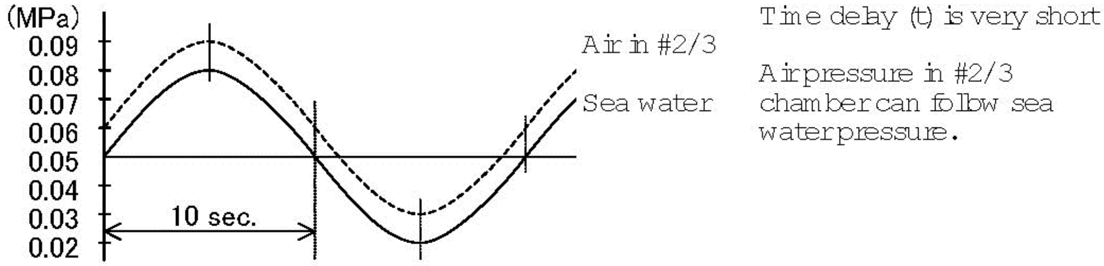

Fig.8-4 Wave condition.

Fig. 8 Mechanism by which air pressure in the #2/3 chamber follows seawater pressure

Pressure In Stern Tube

The air pipe to the #2/3 seal chamber is connected to a closed stern tube gravity oil tank of which volume is about 100 liter and the air pressure in the #2/3 seal chamber is added to the gravity tank. The oil pressure in the stern tube gravity tank completely follows the seawater pressure. There are no time lags in each pressure change due to wave conditions as shown in Fig. 9.

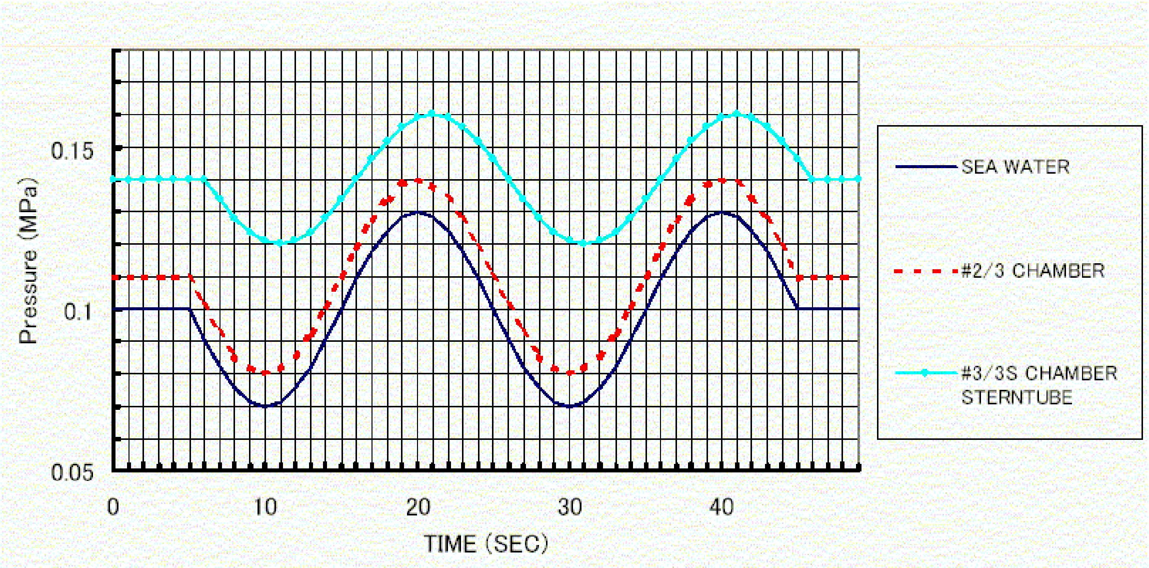

Fig.9 Pressure curve due to wave change in ideal condition

Practically, the stern tube oil is usually circulated through long pipes and oil grooves in the stern bush. Thus a time lag would be expected between changes in the oil pressures near #3S ring and in the gravity tank when the draft changes by a wave. Actually waves cause a difference of pressure between the air pressure in the #2/3 seal chamber and the stern tube oil pressure near the #3S ring. Actual results depend on each ship respectively. A test was carried out on size 670 test equipment shown in Fig. 10 with a piping diagram as in Fig. 5. It was very important to imitate the structure of a practical stern tube. The volume of stern tube oil is designed to be about 600 liters in the test equipment. Fig. 11 shows one of the test results. The stern tube oil pressure becomes slightly out of the air pressure curve in the #2/3 seal chamber under the tested wave condition (Amp. = ±3m, T = 20sec.). However, the condition that the stern tube oil pressure must always be higher than the air pressure in the #2/3 seal chamber, to avoid continuous air leakage into stern tube is maintained. This proved that there are no technical problems in the practical operation.

In the practical design, it is necessary to give a careful consideration to the installation of oil pumps and designing of oil pipes to avoid imbalance of the stern tube oil pressure.

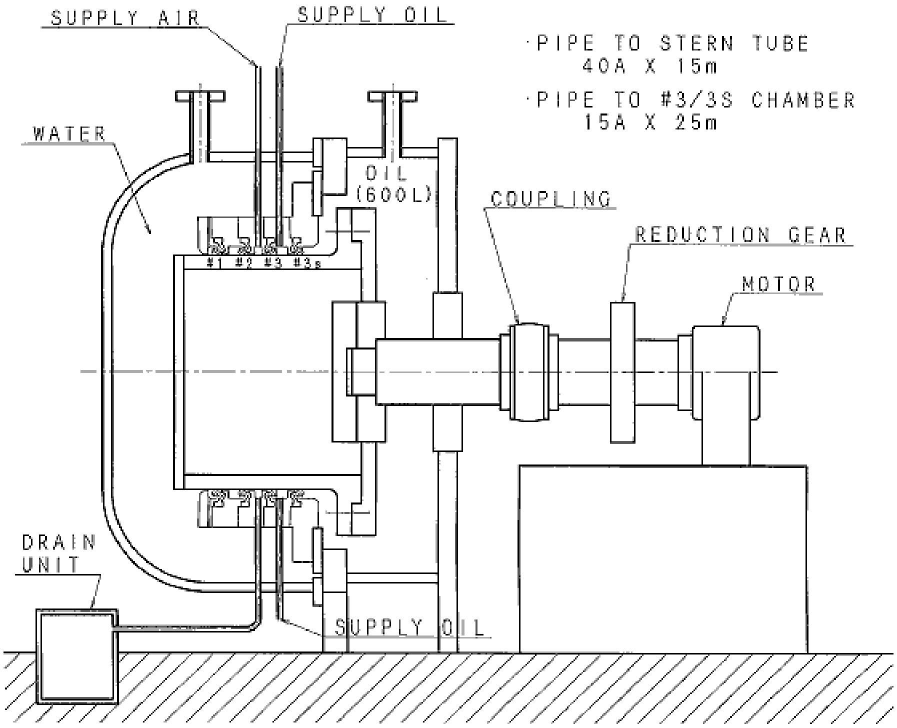

Fig. 10 Size 670 test equipment

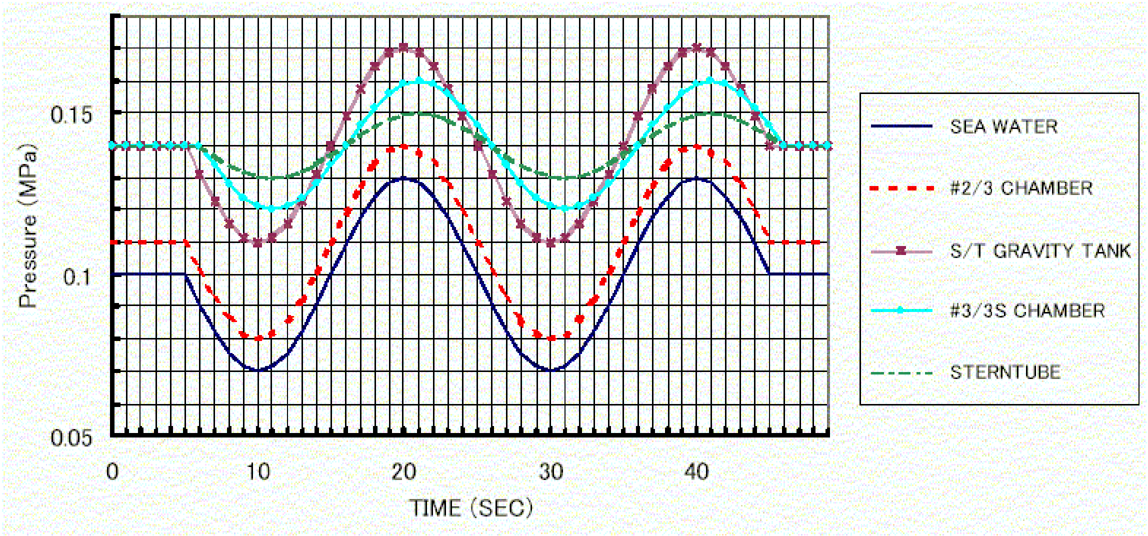

Fig. 11 Pressure curve due to wave in a practical condition

Air Relay

A stern tube oil tank is provided at 3m above the shaft center and the stern tube oil pressure is designed to be 0.03 Mpa (0.3 bar) higher than the air pressure in #2/3 seal chamber. In case it is difficult to provide an oil tank at 3m above the shaft center in a practical ship, the oil tank can be installed at any convenient place by including an air relay in the air control unit. In the above case, in order to keep an adequate pressure difference on the #3 sealing ring, which is positioned between air and oil, the air pressure in #2/3 seal chamber should not be added to the stern tube oil tank directly. It is necessary to adjust the air pressure in #2/3 seal chamber and the adjusted air pressure should be added to the oil tank. The Air relay is a device to adjust the air pressure and an example is shown in Fig. 12(Instruction Manual, Fairchild). The air pressure in the #2/3 seal chamber is sent to the air relay as a pressure signal. Then the pressure signal is revised properly by setting an adjusting valve. The adjustable range is –0.12~+0.07 Mpa on the air relay. The revised pressure signal is added to the stern tube oil tank and the air pressure in the oil tank can be controlled to be "air pressure in #2/3 seal chamber + revised pressure". Compressed air is supplied to the oil tank when the signal pressure rises up and air is discharged from the oil tank when it goes down.

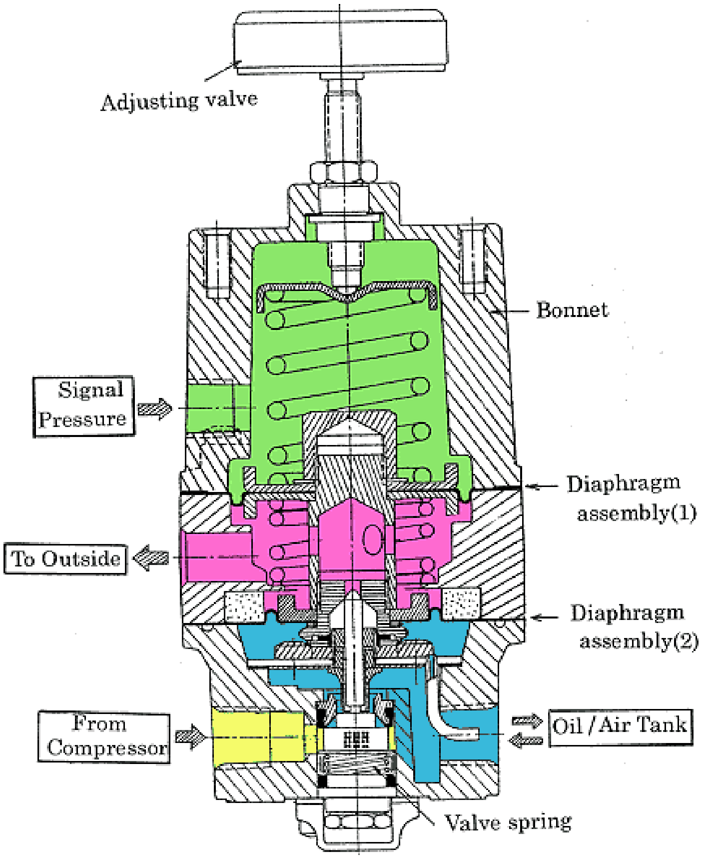

Fig. 12 Air relay

CONVERSION INTO AIR SEAL ON EXISTING CONTAINER SHIP

The main characteristics of KOBELCO Air Seal ® are to make the life of sealing rings longer and to prevent seawater coming into the #2/3 seal chamber. In addition to these characteristics, it has excellent performance against shaft vibration and the practical example is introduced. A container ship of which the specification is shown in Table 1 was built in 1998. A conventional oil seal (Seal size is 1060mm) was adopted on the ship and the piping diagram is shown in Fig. 13.

Large axial shaft vibration was found at the sea trial and pressure fluctuation was caused in the aft stern tube recess because the oil in the recess was compressed by the axial movement of liner as shown in Fig. 14. This pressure fluctuation was propagated to the #2/3 seal chamber through the movement of the #3 and #3S sealing rings. (Miyashita) (Yamajo).

Consequently the oil pressure in the #2/3 seal chamber momentarily becomes higher than the stern tube oil pressure as shown in Fig. 15. The oil in the #2/3 chamber leaks into stern tube by lifting the #3 sealing ring.

Item	Specifications
Dead weight tonnage	69,000
Capacity	5300 TEU
Total HP of engine	7400
Normal shaft Revolution	100 r.p.m.
Seal Size	DX-1060

Table 1 Specifications of a Container Ship

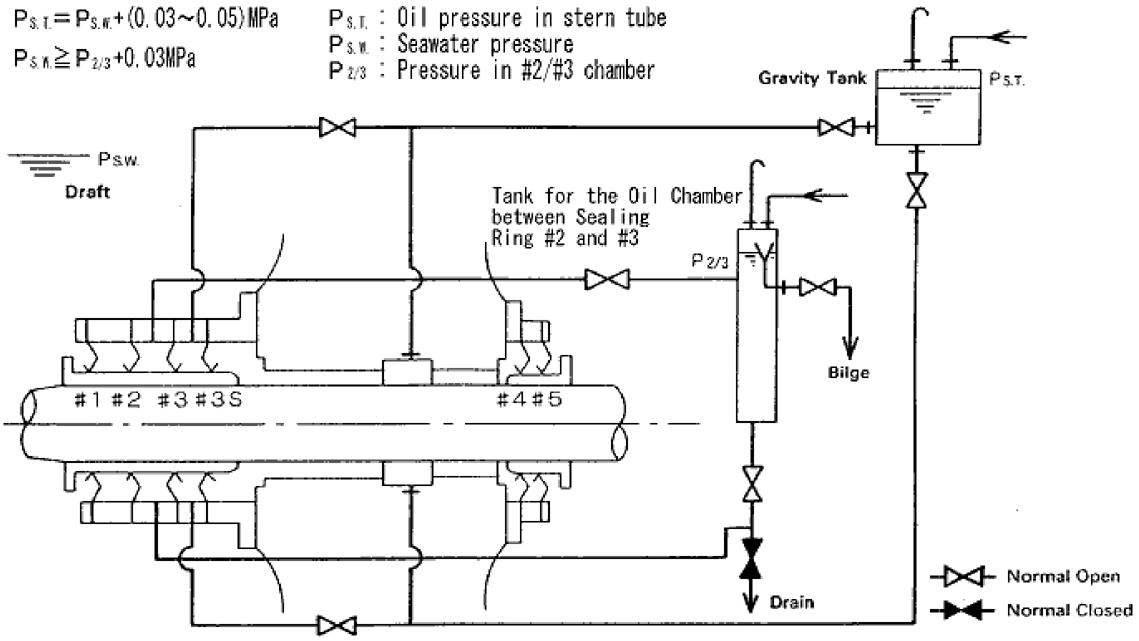

Fig. 13 Piping diagram of conventional oil seal (Size 1060)

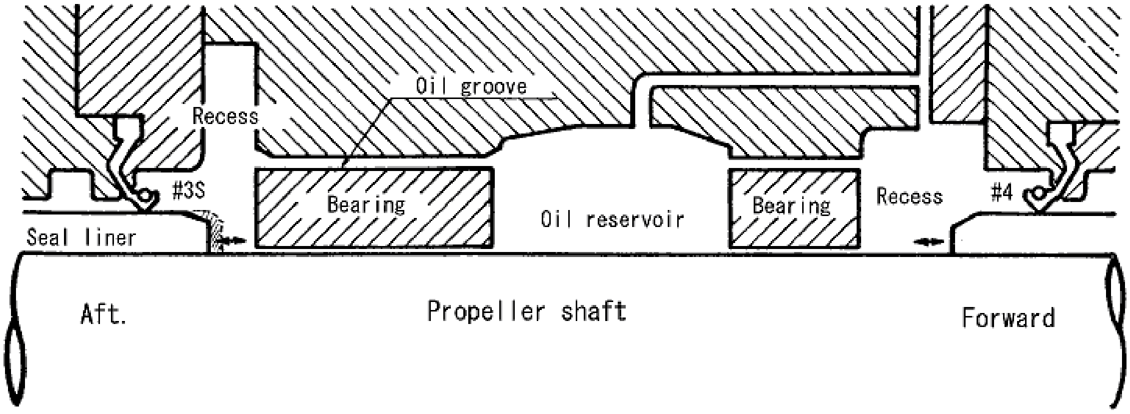

Fig. 14 Mechanism of pressure fluctuation caused by axial shaft vibration

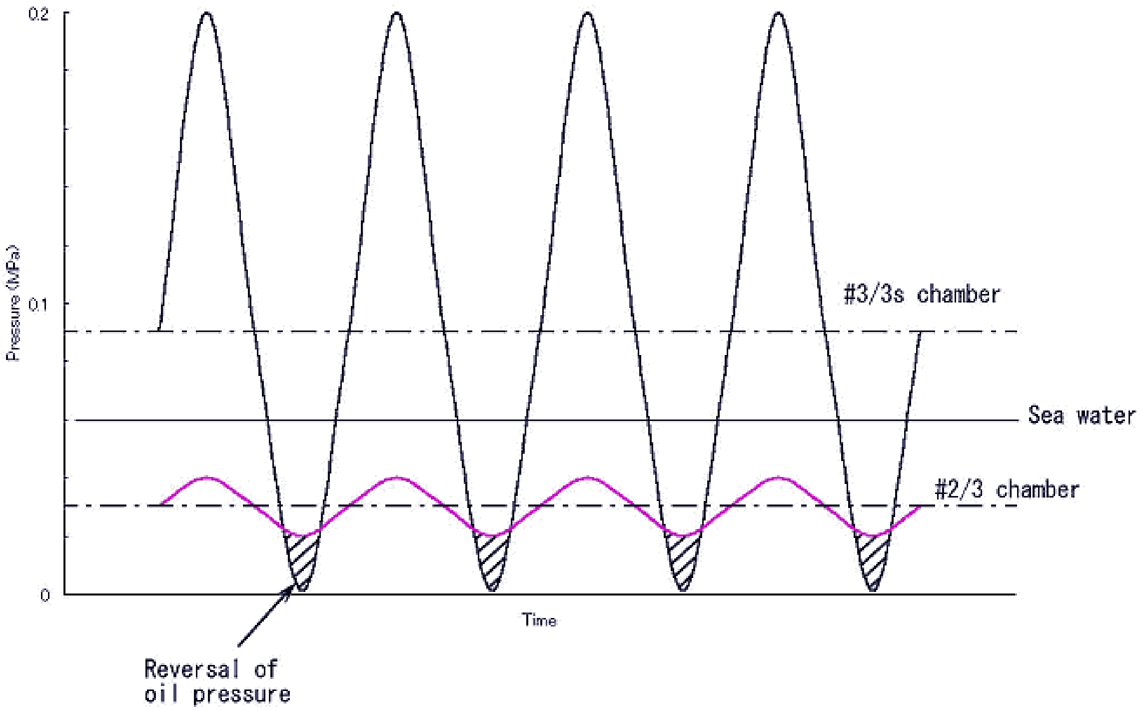

Fig. 15 Pressure curve caused by large axial shaft vibration

The conventional oil seal was converted into an air seal to solve the above problem when the ship was docked in 2002. There were four pipes installed in the stern tube of container ship as shown in Fig. 12. It was not absolutely necessary to install an additional pipe for the conversion. An Air control unit, L.O. tank unit and Drain tank unit were provided to the existing system. It was confirmed at the sea trial, that after the conversion, the oil leakage could be stopped completely. We can note two reasons why the oil leakage problem could be solved by the conversion to the air seal.

(1)The #2/3 chamber is filled with air in the air seal and there are no pressure fluctuations.

(2)When the air pressure in #2/3 chamber becomes higher than the stern tube oil pressure, small quantity of air leaks into the stern tube. The air in stern tube reduces the pressure fluctuation in stern tube. The air is circulated in the stern tube and returns into #2/3 chamber through the stern tube L.O. tank.

APPLICATION TO POD TYPE PROPULSION

Recently electric type pod propulsion has been developed and applied to many ships as well as the conventional mechanical type propulsion. There are different kinds of issues when the constant air flow type air seal is applied to the pod propulsion. The design concept is the same as with conventional stern tube air seal in that compressed air is spouted from the #2/3 seal chamber and the air pressure in #2/3 seal chamber is added to an oil tank.

However, there is no stern tube in pod propulsion and some changes have been made to apply the air seal for the pod propulsions. ABB's Azipod ® is an electric type pod propulsion and was provided for two ice breaking tankers "TEMPERA" and "MASTERA" which have been in service from 2002. Fig. 16 shows the piping schematic of the constant air flow type seal installed on the Azipod.

A drain tank was provided below the shaft center in the pod and a gravity oil tank was provided at 3m above the shaft center. An oil chamber between #3 and #4 sealing rings is equivalent to the stern tube of merchant ships.

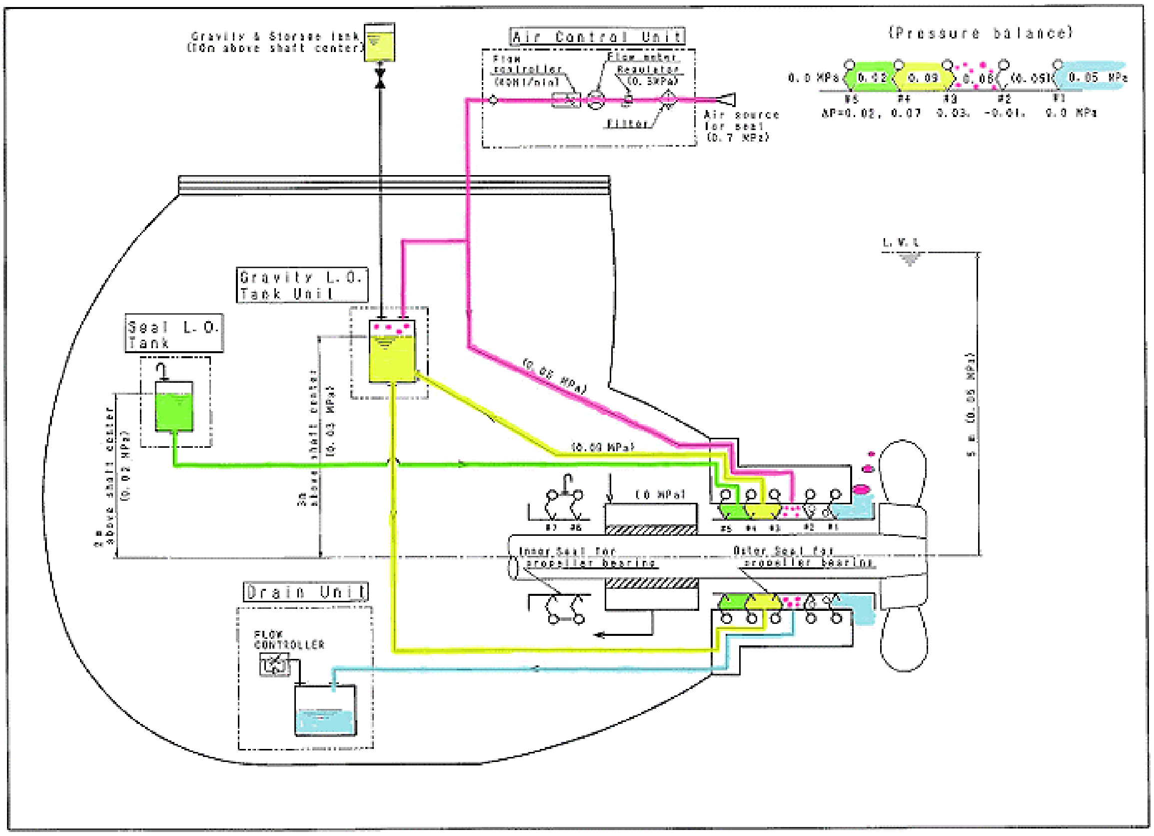

Fig. 16 Schematic piping of seal for Azipod ®

In case there is insufficient space to install a drain tank at the bottom part, one solution is to provide a solenoid valve in the drain line instead of the drain tank as shown in Fig. 17. Any oil and seawater that penetrates the #2/3 seal chamber can be drained by periodically opening the solenoid valve. This idea, however, is available only when the seawater draft from shaft center is less than 5m. Any oil and seawater that penetrates can be drained sufficiently when the opening time of solenoid valve is long enough. On the other hand, if the valve is opened too long, the air pressure in #2/3 seal chamber goes down and large pressure differences are put on #2 and #3 sealing rings. According to our test results, it is recommended to open the solenoid valve for 3~10 seconds. The operation is done a few times a day.

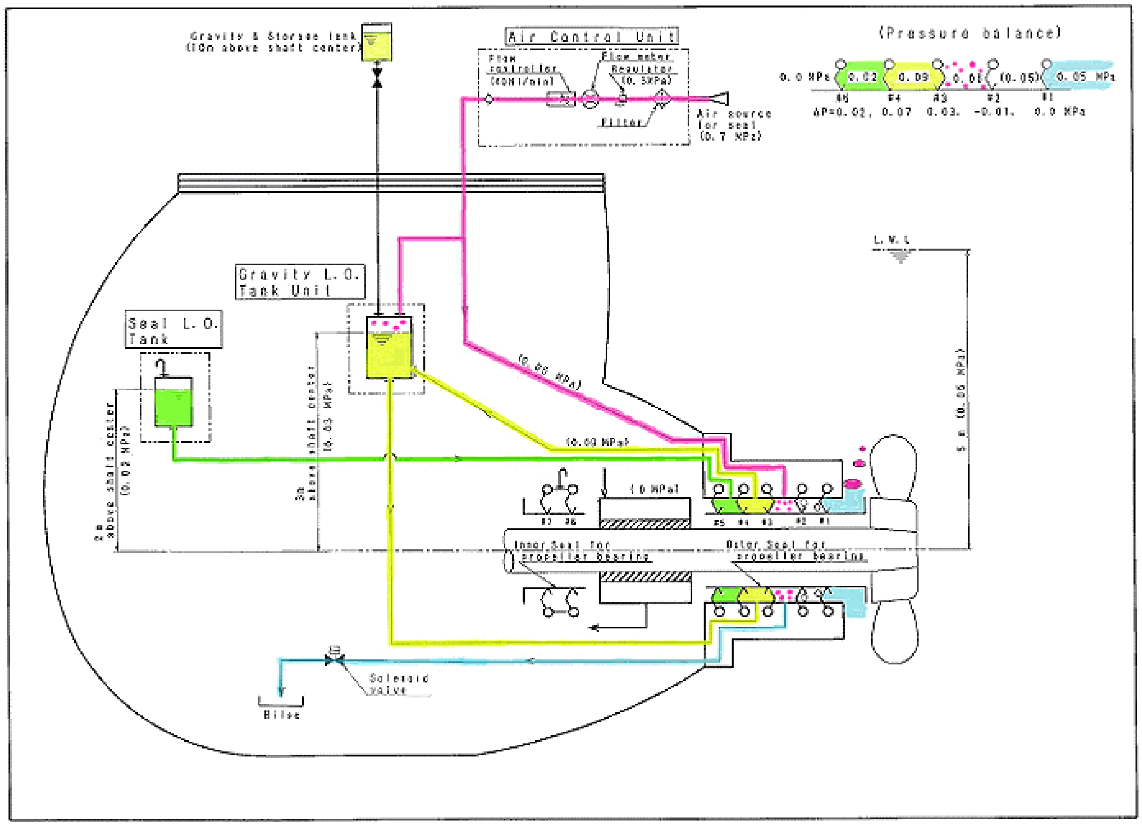

Fig. 17 Solenoid valve instead of drain tank

CONCLUSION

The application of air seal will increase in future from a viewpoint of pollution free seal system. We have already supplied the constant air flow type seal to more than 150 ships and obtained excellent service results on all ships. The application of the air seal has been limited to stern tube seals of merchant ships until now. The subject air seal, however, has proved to be very effective to the electric pod propulsions. The application to the other types of propulsion would be expected to increase from now on.

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