Under the Scenes of our Lives

High-pressure Pump

- Technologies and Structure -

In order for a high-pressure pump to operate stably in the place where it should play its role, it must provide an excellent balance and endure high pressures. These requirements are specific to high-pressure pumps. High-pressure pumps are based on technologies for achieving these requirements. This article outlines these technologies and how they are related to the structure of high-pressure pumps.

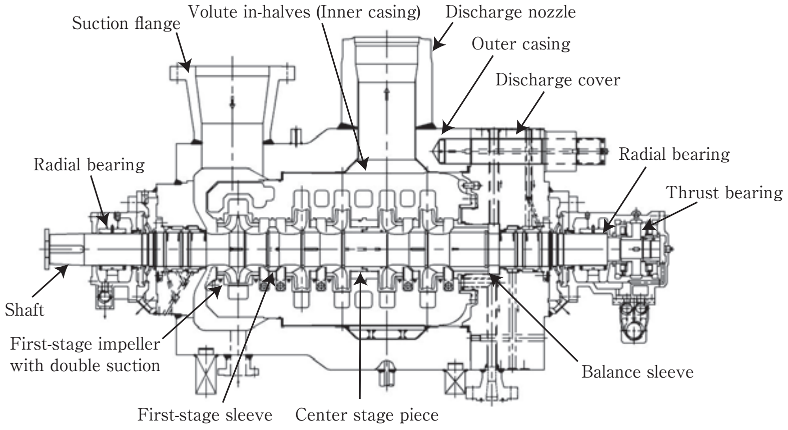


Fig. 1 Structure of a boiler feed pump (Model HDB)

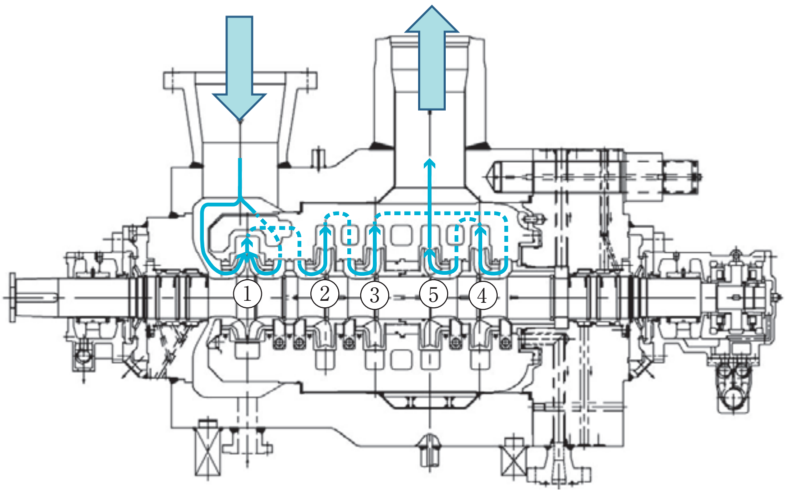


Fig. 2 Water flow inside a boiler feed pump (Model HDB)

Basic structure of high-pressure pumps

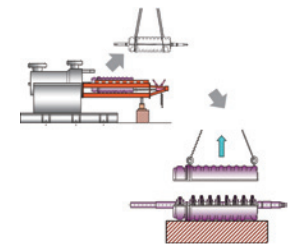
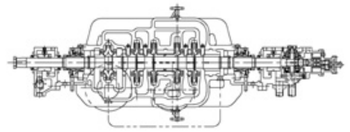
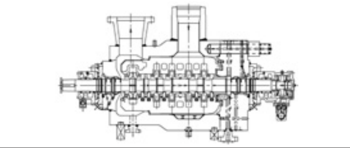
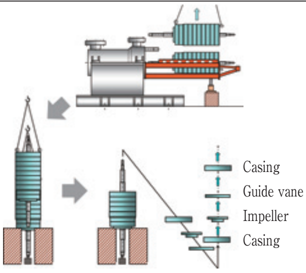
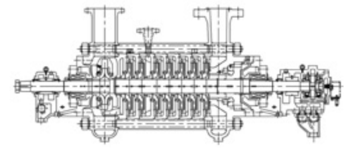
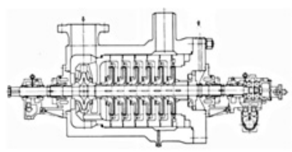
Figure 1 shows a boiler feed pump (BFP) for thermal power plants. This pump uses a back-to-back arrangement of impellers to achieve an axial thrust balance and has double casings to endure high pressure. **Figure 2** illustrates the water flow inside the pump.

The structure of high-pressure pumps is based on two technologies: one for achieving an axial thrust balance, a requirement specific to multi-stage pumps, and the other–double casings–for enduring higher pressure. Here, let me explain these technologies in some detail.

While rotating in liquid, an impeller produces centrifugal force, which increases the impeller outlet pressure (head). The increased pressure produces axial thrust (axial load) according to the size of the impeller.

For a multi-stage pump, each impeller produces thrust. This means that if the impellers are all arranged straight through, the thrust bearing receives a very

Table Basic types of Ebara's high-pressure pumps

<table>
<tr><th>Model *1</th><th>Impeller arrangement</th><th>Axial thrust balancing</th><th colspan="2">Casing</th><th>Maintenance</th><th>Temperature/ pressure*2</th><th>Section view</th><th>Selection standard</th></tr>
<tr><td>SPD
SP</td><td rowspan="2">Back-to-back arrangement</td><td rowspan="2">Balance sleeve</td><td rowspan="2">Volute, axially-split-casing, multi-stage type</td><td>Single casing</td><td rowspan="2">
On-site maintenance is possible.</td><td>150 ℃
15 MPa</td><td></td><td rowspan="2">Emphasis on maintainability</td></tr>
<tr><td>HDB
HSB</td><td>Double casing</td><td>400 ℃
50 MPa</td><td></td></tr>
<tr><td>SSD
SS</td><td rowspan="2">Straight-through arrangement</td><td>*3 Balance piston + balance disc</td><td rowspan="2">Radially split casing, multi-stage turbine type</td><td>Single casing</td><td rowspan="2">
Casings, guide vanes, impellers are disassembled in order on a per-stage basis. Many of them are carried out in a factory.</td><td>200 ℃
20 MPa</td><td></td><td rowspan="2">Emphasis on manufacturing costs</td></tr>
<tr><td>DCD
DC</td><td>Ditto</td><td>Double casing</td><td>400 ℃
35 MPa</td><td></td></tr>
</table>

*1: Single-suction first stage: Model SP, HSB, SS, and DC ; Double-suction first stage: Model SPD, HDB, SSD, and DCD
*2: The values are reference upper limits, some of which were exceeded in the past
*3: For large pumps, only the balance piston is used with an increased capacity of the thrust bearing

large load. To counter this, a special thrust balancing parts are installed or the impellers are arranged back to back so that the axial thrust is offset between the impellers (to be described in detail). The former approach is used in model SS (horizontal, radially split casing, multi-stage turbine pumps) and the latter in model SP (volute-type, axially-split-casing, multi-stage pumps). Model SS is structured with a radially split, casing with a guide vane and model SP with a volute-type, axially split casing. A pump structured with double casings to endure higher pressures is called model DC or HDB/HSB as shown in Fig. 1 and 2 (model HDB uses a double-suction first stage and model HSB, a single-suction first stage, which will be hereafter collectively referred to as model HDB). The above mentioned are four basic types of Ebara's high-pressure pumps. The **Table** shows rough comparisons among them. The other models regarded as high-pressure pumps include some advanced variations (models SSP, SPR, SPRB, and SPL), model HDR (a volute-type, double-suction, single-stage, double-casing pump specialized as a reactor feed pump (RFP) for nuclear power generation), and model KS (a volute-type, single-casing, single-stage pump), if used as a booster pump for BFPs.

Structure of high-pressure pumps

(1) Axial thrust acts on impellers

Figures 3 and **4** show double- and single-suction impellers along with the distributions of the pressures (shown as blue and green arrows) and directions and qualitative magnitudes of the axial thrust (shown as red arrows) that acts on them.

An impeller in operation has a section on which suction pressure acts, and a section on which discharge pressure acts; these sections are separated by a wearing part having a narrow gap. For a double-suction impeller (Fig. 3), thrust that presses the entire impeller leftward is produced by configuring the right wearing diameter to be smaller than the left one so that discharge pressure will act on a larger area. A typical double-section single-stage pump is designed to have the same right and left wearing diameters so that theoretically no thrust will be produced; in some cases, however, thrust is intentionally applied to make the shaft stable. On the other hand, any multi-stage, high-

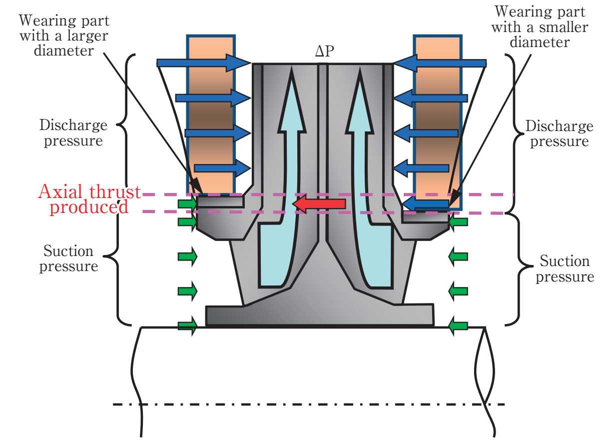


Fig. 3 Double-suction impeller

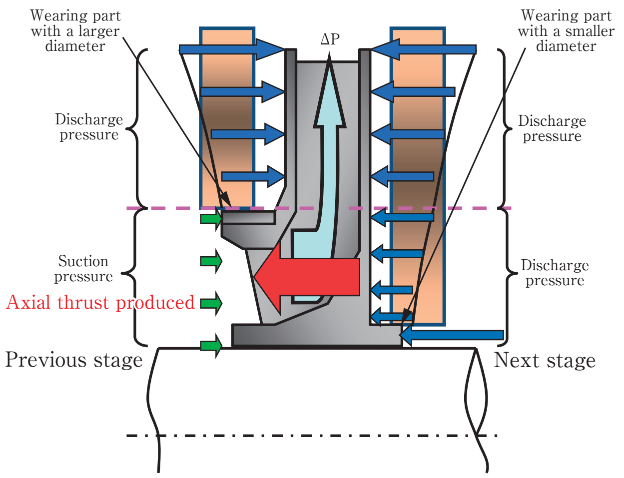


Fig. 4 Single-suction impeller

pressure pump has right and left wearing diameter different from each other to allow thrust to be applied to the shaft always in the same direction.

For a single-suction impeller (Fig. 4), discharge pressure (which will act as suction pressure for the next stage) acts on the side opposite to the suction side of the impeller, causing large thrust to be applied toward the left (suction) side.

(2) Straight-through arrangement (Model SS and DC)

Since a radially split casing, multi-stage turbine pump has all stages arranged straight through as shown in **Figure 5**, the total thrust produced by the impellers becomes very large. This type of pump uses a unique, large-scale balancing parts to offset the thrust. This balancing parts, consisting of a balance piston and a balance disc, is thought to be a theoretically ideal balancing mechanism.

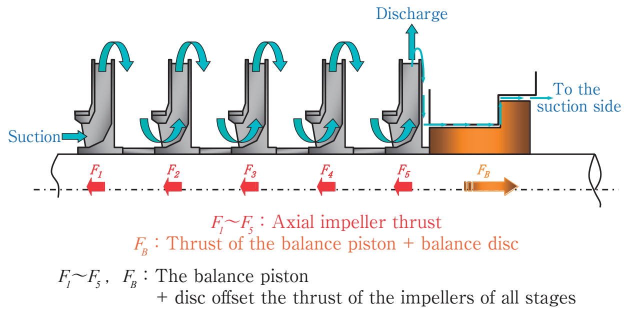


Fig. 5 Balance of the axial thrust of impellers arranged in the same orientation

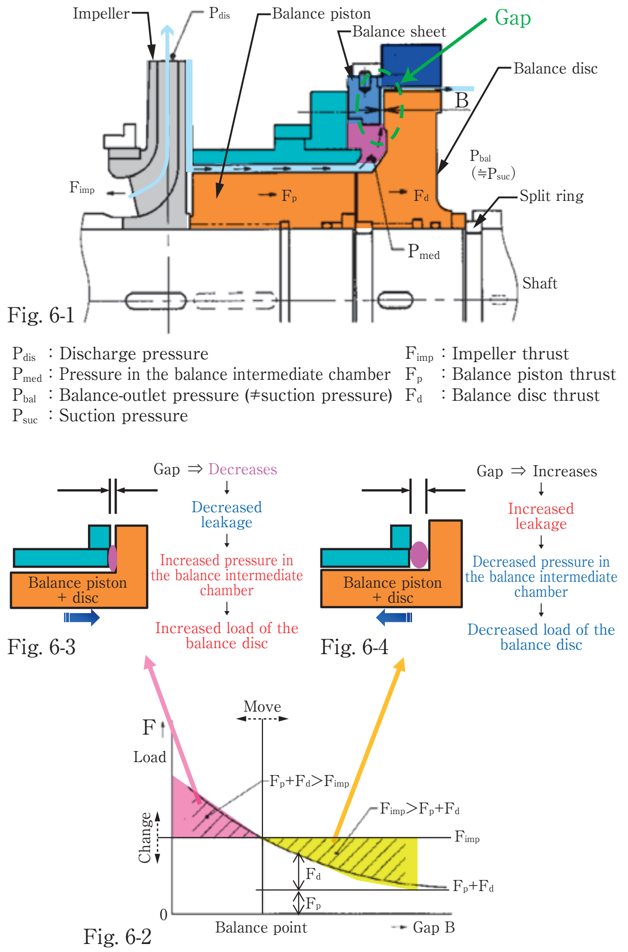


Fig. 6 Operating principles of the balance disc

Figure 6-1 shows a balancing parts and partial structure of the last-stage impeller. The curve in the chart in **Figure 6-2** indicates how the total load of the balance piston + disc changes according to changes in the gap between the balance disc and the balance sheet opposed to the disc. The total load to all impeller stages is indicated as a horizontal line. The load of the impeller is applied leftward and the load of the balance piston + disc rightward; the intersection of both loads is the point where the rotor thrust is balanced. The load of the impeller (horizontal line) moves up and down according to the fluctuations in flow rate during operation.

With an increase in the load of the impeller, the horizontal line in Fig. 6-2 moves upward and the intersection with the balance-disc load curve moves leftward. As **Figure 6-3** shows, an increase in the load of the impeller moves leftward the rotor equipped with the impeller and the balance piston + disc, which reduces the gap between the balance disc and the balance sheet fixed to the casing. This reduces the leakage from the gap to increase the pressure in the balance intermediate chamber, resulting in an increased load of the balance disc. **Figure 6-4** shows a case where the load of the impeller has decreased and consequently moved the intersection rightward to increase the gap between the balance disc and balance sheet, resulting in an increased leakage from the gap; this reduces the pressure in the balance intermediate chamber, resulting in a decreased load of the balance. This mechanism corrects excesses in the loads of the impeller and of the balance to make the intersection try to move back to a new point, so that the fluctuating load of the impeller will be balanced with the load of the balance. This is how the mechanism achieves ideal balancing.

If the casing, which acts as the base for securing the balance sheet, is deformed by the load to the piping or by non-uniform heat application, the balance sheet is inclined accordingly. While rotating, the balance disc is always trying to be parallel to the sheet surface. In addition, the disc is fixed to the shaft via the split ring, and consequently the squareness of the disc to the shaft is lost. This may produce excessive bending stress at the load-receiving section of the shaft (specifically, the corner of the split-ring groove). This may also happen when the casing itself or the shaft or disc is not finished with machining accuracy according to the design requirements (squareness and parallelism).

Since the gap in the concerned section is as small as 0.1 mm, the fluid should contain no foreign matter. It is required to pay careful attention to the machining and assembly accuracy for the section affected and the materials used for the section and their hardness as well as to the inspection of the section during maintenance.

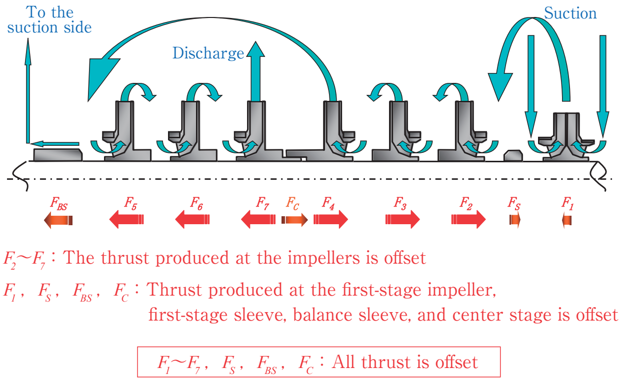


Fig. 7 Axial-thrust balance of the impellers arranged back to back

(3) Back-to-back arrangement (Model SP and HDB)

Since a volute-type, axially-split-casing, multi-stage pump has impellers arranged back to back as shown in **Figure 7**, the thrust is offset between the right and left groups of single-suction impellers. For the double-suction first stage, the thrust is calculated based on the concept described in (1) above. For the first-stage sleeve, balance sleeve, center stage piece (all these shown in Fig. 1), single-suction, single-stage impellers in the odd-numbered stages, and the other sections where the thrust is not offset, the thrust is calculated according to the pressure receiving area and differential pressure. The wearing diameters are thus designed so that the thrust is balanced throughout the rotor. Compared with the radially split type mentioned before, the shaft of the axially-split-casing type is relatively easy to design because the thrust that acts on the shaft is decentralized and no balance disc is required

Why double casings are required

For a pump that uses a single casing, like model SP, the split surface of the casing tries to open because the internal pressure is higher than the atmospheric pressure. Bolts are evenly arranged along the circumference, except in the areas where passages run complexly, so that the casing will withstand the pressure and the pressurized fluid will not leak out from the boundaries that separate the impeller stages (**Figure 8**). A further increase in pressure requires larger and more bolts, which cannot be arranged.

In a pump that uses double casings, the inner casing is confined inside the outer casing so that the outside

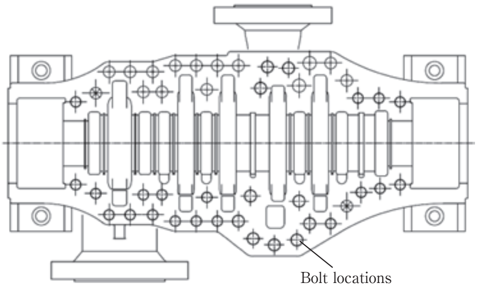


Fig. 8 Example of arrangement of casing bolts for Model SPD (for withstanding pressures up to 15 MPa)

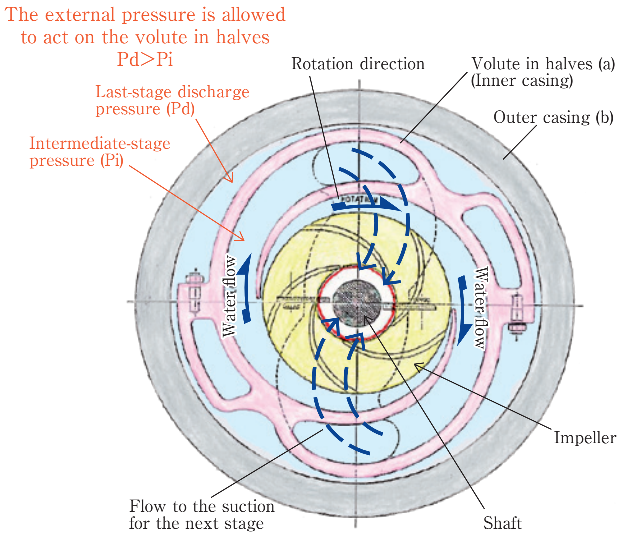


Fig. 9 Longitudinal section of Model HDB

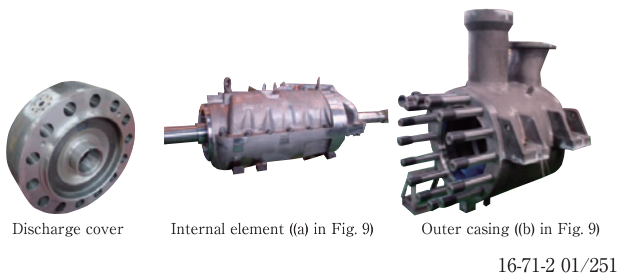


Fig. 10 Model HDB (with an outer casing that withstands pressures up to 55 MPa)

of the inner casing is filled with the discharge pressure of the last pump stage to allow the external pressure to act on the inner casing. This enhances the strength of the split surface to ensure the seal. This structure is adopted in model HDB (**Figure 9**). After the internal element (an assembly of the inner casing and the rotor) is inserted into the outer casing, a thick cover is installed and the gaskets are fastened with a dozen or more bolts (**Figure 10**). The outer casing is a simple cylinder that withstands the pressure that a single casing cannot withstand in terms of design. A variation of model SS, single-case, radially split pump, that uses double casings instead of a single casing, is model DC.

Conclusion

In this short article we introduced the high-pressure pumps associated with our everyday life in the first half and the basic structures of high-pressure pumps in the second half. I hope that you now understand high-pressure pumps to some extent.

I am confident that Ebara's high-pressure pumps are on the world's top level in any area. This status was achieved, I believe, through the basic technologies described in this article as well as our detailed consideration and expertise about the design and manufacturing of pumps and our customers who highly rate the performance of our pumps. It is also the result of our long experience as well as occasional collaboration with our customers.

As an engineer, I hope that Ebara, not content with the status-quo, will support the next generation society by continuing to manufacture high-pressure pumps toward further development of the product.

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