DEVELOPMENT OF COOLANT-FREE BEARING FOR LARGE-CAPACITY PUMP AND ITS APPLICATION TO PUMPING STATIONS

TATSUNOBU SUGITA
Plant Maintenance Section
Operation, Maintenance and Management Division, the Bureau of Sewerage
in Tokyo Metropolitan Government, Japan

WEFTEC2001
OCTOBER 13-17,2001,ATLANTA, GEORGIA
Title of Session: Collection Systems Symposium: Operation and Maintenance-May the Flow Be with You
Title of Paper: Development of Coolant-free Bearing for Large Capacity Pump and its Application to Pumping Stations
Authors: Tatsunobu Sugita
Keywords: Pump, Bearing, Earthquake
Date of Session: Monday, October 15, 2001 Session No.: Session8, Room268-Poster

Risks surrounding the Metropolis

(1) Earthquakes

Fig.1 shows areas that suffered serious damage by earthquakes in the last decades. Big earthquakes can occur anywhere in the world.

Japan is an earthquake-prone country. Seven years ago, a devastating earthquake hit Kobe, a large city of west Japan. Fig.2 and Fig.3 show the debris of the aftermath. In this disaster, some pump stations suffered damage. One of them lost whole functions because its cooling water tank was broken.

Tokyo, the Metropolis, cannot be an exception. In Fig.4, the vertical lines show past big earthquake occurrences in Tokyo or Edo. Edo is the old name of the Metropolis. Statistically, big earthquake visits Tokyo every seventy years. The last great one, which caused Kanto great disaster, came seventy-eight years ago. That means a big one may fall on Tokyo at any moment.

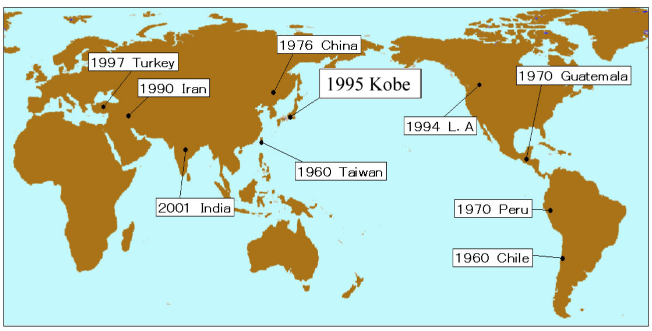


Fig.1 We are NEVER ESCAPABLE from Earthquakes

Fig.2 Kobe-Jan. 6th, 1995

Fig.3 Kobe-A Devastated Water Facility

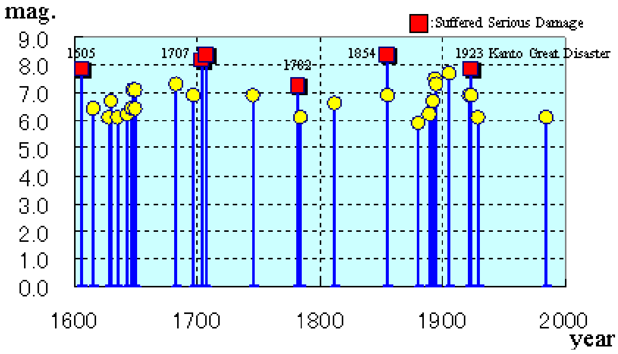


Fig.4 Tokyo (or Edo)'s Past Earthquakes
(Over mag.6.0 in Richter scale)

(2) Floods

Fig.5 shows Tokyo's low-ground areas. Large parts of Tokyo urban districts are lowlands. In these areas, geometrically, natural drainage of rainfall runoff is impossible. Recently, we are often assaulted by abrupt thunderstorms, especially in summer. The cause is said to be "Heat Island" phenomenon. Massive consumption of energy warms the air of urban areas and produces upwind in some locality. During a heavy rainfall, runoff water gathers into lowlands violently and the risk of flood inundation becomes extremely high. Fig.6 shows an example of flood disaster happened in Tokyo several years ago.

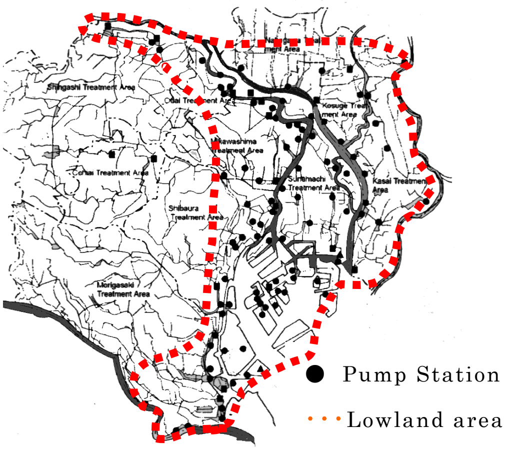


Fig.5 Tokyo's lowland areas and Pump Stations

Fig.6 Tokyo-Inundation by Flood Disaster

Table.1 Summary of Tokyo Sewerage Bureau Facilities

Facilities	Qty	Capacity (m^3/day)
Water Treatment Plants (Also serving as Pump Stations)	15	30,950
Drainage Pumps	74	
Pump Stations	79	97,479
Drainage Pumps	304	

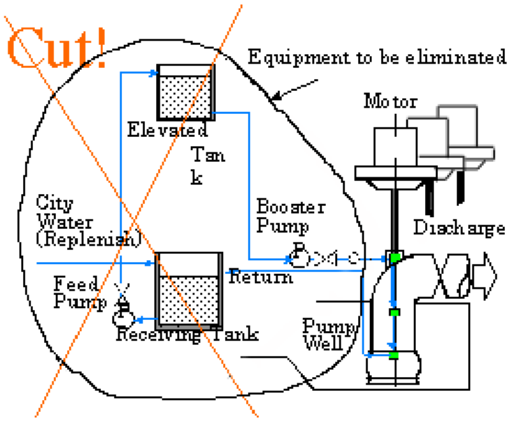


Fig.7 Lessening of Conventional Equipment

Preventive measures by Sewerage Bureau of Tokyo Metropolitan Government

(1) Stand-by Operation Pump

Our pump stations have two important duties. One is to relay wastewater to treatment plants and the other is to discharge rainfall water promptly. Most of them are located in low-ground areas along rivers or water channels. (See Fig.5) These facilities are never permitted to fail. As a countermeasure, we have actively introduced 'Stand-by Operation Pump'. The pump can be operated with its impeller in the air. By starting them beforehand, we can prepare for a sudden inflow of runoff water.

(2) Development of Coolant-free Bearing (CFB)

In order to protect eight million Tokyo citizens from flood disasters, we must establish a highly reliable pumping system that can endure against even the dual crisis of a heavy rainfall and a big earthquake. However, conventional large-capacity pumps need cooling water for their bearings and, for that purpose, city water is supplied through complicated equipment of tanks, feed pumps and pipes. If an earthquake or a fault cripples the water feed line, pumps cannot work. This is a grave weakness of the present system. In Kobe, it took several months until public water delivery was restored completely.

Therefore, we started to design new bearings that require no external supply of cooling water for Stand-by Operation Pump. Due to repetitive operation between air lock and drainage, the pump's bearing is exposed to severe thermal impact. We focused on designing bearings endurable to the condition.

Developed Bearings

Collaborating with three private companies, we have developed three types of Coolant-free Bearings. Features and study descriptions of each bearing are shown below.

(1) A-method: Ceramics Bearing

<u>Features</u>

(Structure)

1) Originally developed ceramic bearings and special alloy bearing sleeves have improved wear resistance and thermal shock resistance to achieve dry operation.
2) Cushioning structure using heat resistant fluorine rubber has enhanced shock resistance plus heat resistance.
3) The simple structure precludes easy tangling of foreign matter.

(Performance)

The bearing can conduct non-lubricant operation in any operational situation (open air operation, air lock operation, drainage operation) of the stand-by operation pump. It can even withstand rapid temperature changes when changing from stand-by operation to drainage operation

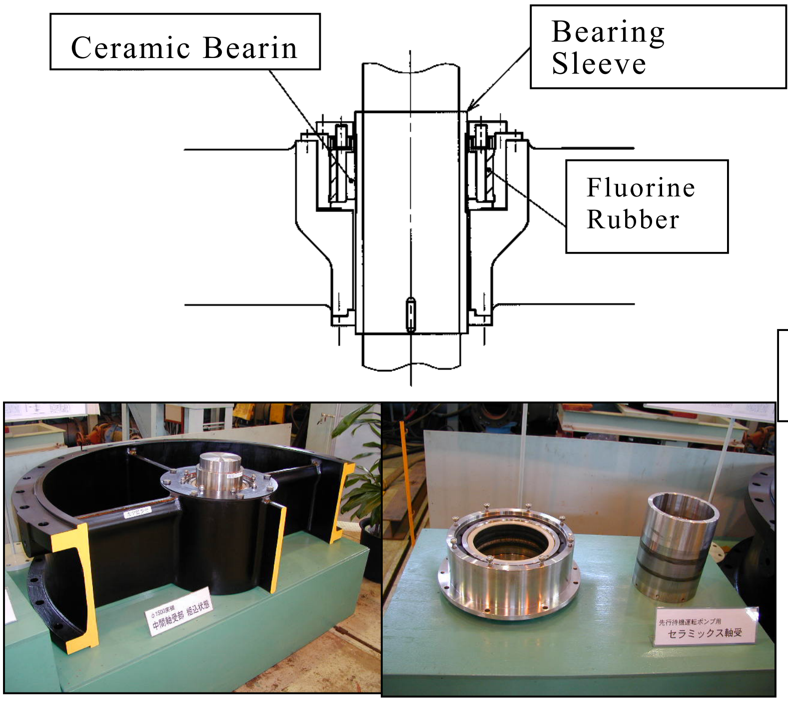
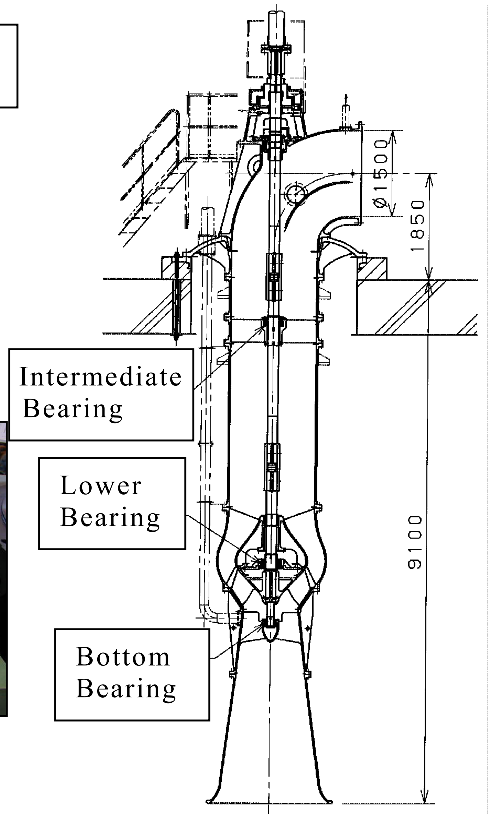


Fig.8 Ceramic Bearing and Bearing Sleeve



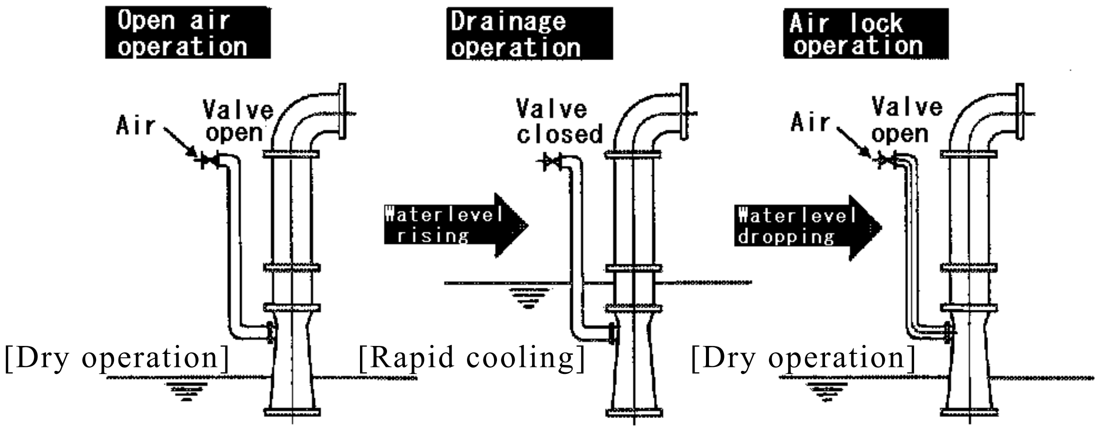
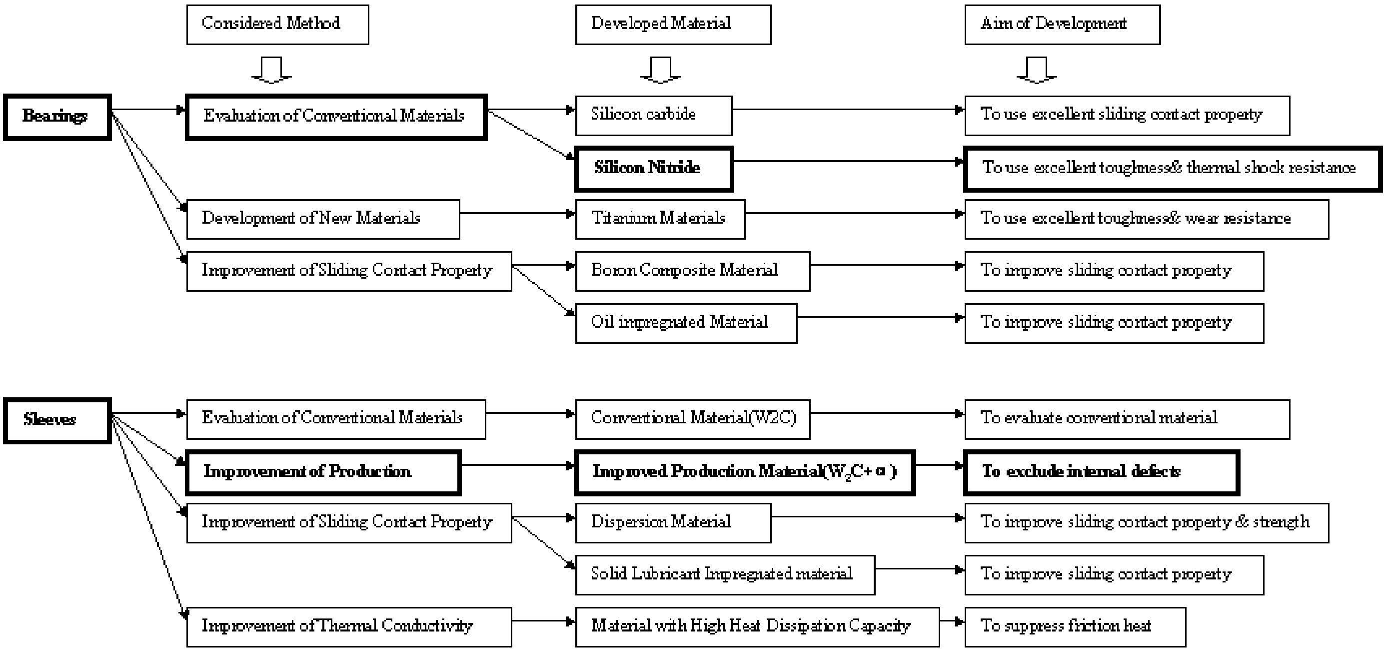


Fig.9 Stand-by Operation Pump-Severe Operational Conditions

Summary of development

(Material) Combined performances of bearing and sleeve were evaluated.

Table.2 Evaluation of Various Materials for Bearing and Sleeve



	Developed Bearing Material	Developed Sleeve Material	Wear Test in Slurry	Dry Sliding Contact Test	Operation Test in Actual Pump	Evaluation
1	Silicon Carbide SiC	Conventional Material W_2C	○	○	○	○
2	Silicon Nitride Si_3N_4	Conventional Material W_2C	○	△	×	×
3	**Silicon Nitride Si_3N_4**	**Improved Production Material $W_2C+\alpha$**	**○**	**○**	**○**	**◎ (Adopted)**
4	Silicon Nitride Si_3N_4	20% Carbide	△	△	×	×
5	Silicon Nitride Si_3N_4	BN＋Carbides＋WC	○	○	×	×
6	Titanium Boride TiB_2	Improved Production Material $W_2C+\alpha$	○	△	△	△
7	Silicon Carbide SiC	Improved Production Material $W_2C+\alpha$	○	○	×	×
8	SiC(Oil Impregnated)	Improved Production Material $W_2C+\alpha$	○	○	○	○

(Outline of field test)

(1) Testing machine

ϕ 1500 vertical mixed flow stand-by operation pump	
Total head	19.5 m
Capacity	280 m^3/min.
Speed	365 min^{-1}
Prime mover output	1240 kW

(2) Operation Result

Number of starting times	51 times
Total operation time	About 41 hours
Open air operation time	About 12 hours
Air lock operation time	About 15 hours
Drainage operation time	About 14 hours

(3) Evaluation

1) Temperature rise of bearings was suppressed at a low level and one hour of stand-by operation is possible.
2) Cleared severe operation conditions not seen at local installation site.
3) No abnormal condition was found upon disassembling and checking.

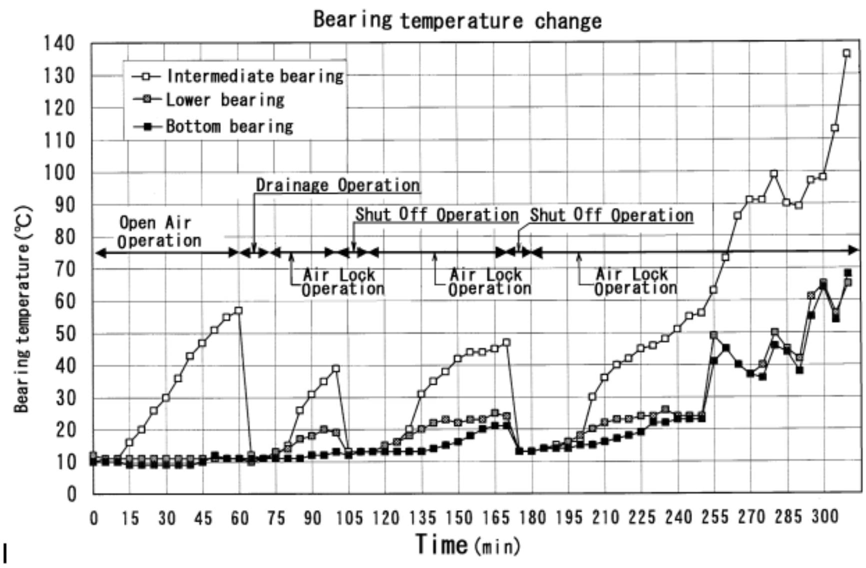


Fig.10 Field test

(2) B-method: Rotating oil-bath type bearing

<u>Features</u>

(Structure)

1) Rotating oil-bath type bearing is an improved type of conventional lubricant-free ceramics bearing. Oil-bath prevents unlubricated condition.
2) Special non-volatile lubricating oil is stored in the rotating oil bath. The oil is heavier than water in specific gravity and doesn't evaporate even during a long-term halt of the pump.
3) Oil is kept sufficiently in the rotating bath during operation,.

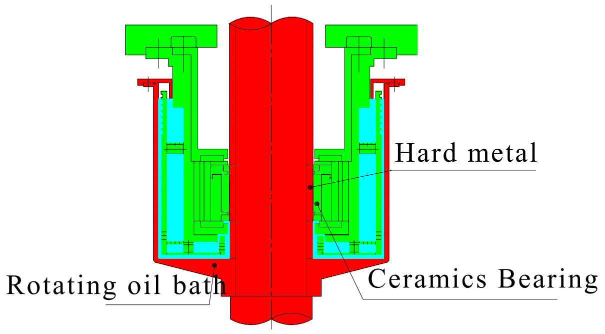
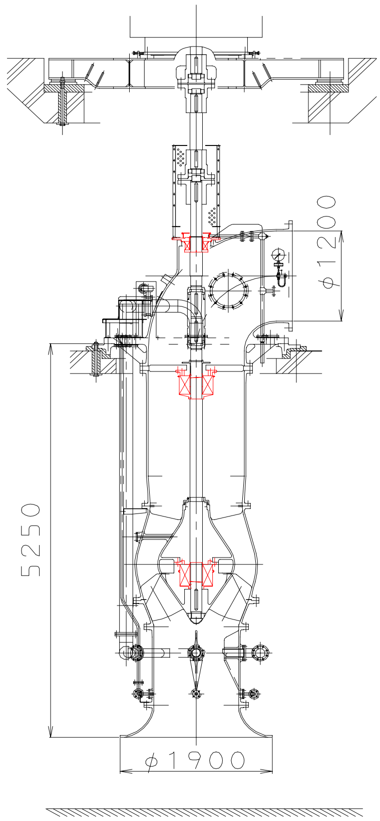


Fig.11 Rotating oil bath type
Ceramics bearing



Pump specification	
Bore size	1200mm
Discharge	210m^3/min
Head	5.2m
Rotational speed	250min^{-1}
Motor	250kW Induction motor

(Performance)

Applicable pump bore	3,000 mm
Peripheral speed	4.8 m/s
Dry operation time	60 minutes
Bearing temperature	Max. 100℃
Oil temperature	Max. 70℃
Span of life	Min. 10 years

Inspection/maintenance items

Item	Description	Remarks
Maintenance items	Unchanged from conventional pumps	—
Inspection items	Replenishment of special lubricating oil	Once per year
Maintenance interval	10 years	The field test revealed that the bearing and the sleeve have more than ten years lifetime when annual operation time is under 1,000 hours. But, considering the problem of corrosion etc., it is reasonable that maintenance interval is regarded to be the same as that of conventional one.
Durability	Approx. 10,000 hours	Durability is the same as that of conventional ceramics bearing.

Description of Study

(Elemental Test)

①Preservation of special lubricating oil

Confirmed that sufficient quantity of oil for lubrication is preserved in the bath.

②Temperature rise of special lubricating oil

The rise was 33.5℃ after 60 minutes' operation.

It was sufficiently lower than the allowable limit of 70℃.

③ Sliding characteristic, load-withstanding capacity

Confirmed that the friction coefficient of the lubricating oil is almost equivalent to that of tap water. However, applicable bearing surface pressure is higher to the oil than to tap water.

④Durability

The bearing was burdened with a two hundred hrs' endurance test in an atmosphere containing foreign particles. After the test, no corrosion was found on the bearing or the sleeve, revealing their excellent corrosion resistance. The test result also showed that the bearing has a life of ten years or longer when annual operation time is under 1000 hours.

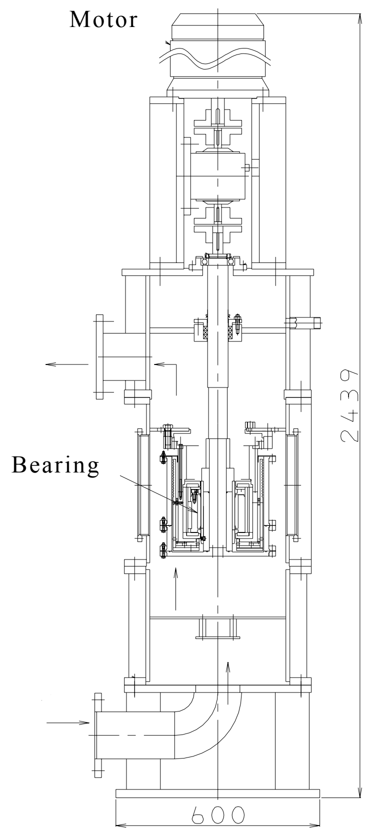


Fig.12 Machine for Elemental Test

(Field Test)

The bearing that had been subjected to the elemental test was mounted on an actual pump.

①Run time

Dry operation time: 21 minutes

Two-phase (Air & liquid) flow operation time: 21 hours and 52 minutes

Normal operation time: 15 minutes

Air-lock operation time*: 1 hour and 8 minutes

*Note; Air is clogged at the inlet side of the impeller while the operation of the pump is carried on.

②Result

Bearing temperature: Max. approximately 39℃ (lower than the allowable limit of 100℃)

Oil temperature: Max. approximately 34℃ (lower than the allowable limit of 70℃)

Temperature of the sliding part of mechanical seal: Max. approximately 41℃

(lower than the allowable limit of 100℃)

No foreign matter was stuck on the outer surface of the bearing, nor other abnormality was found.

No corrosion was recognized on the bearing and on the bearing sleeve after the test.

Surface roughness slightly increased by 0.75 μ m after the test.

③Practicality of lubricant-water free shaft seal

In order to complete lubricant-water free operation of a pump, the lubricant-water free structure is needed not only for the bearing but also for the shaft seal. Therefore, the shaft seal was also subjected to the field test. The test revealed its practicality.

(3) C-method: Internal Circulation System

<u>Features</u>

(Structure)

1) Two mechanical seals set on its upper and bottom parts seal the shaft enclosing tube up. An automatic pressure-regulating device constitutes a closed loop through the main shaft for internal lubricant circulation. A circulation pump in the closed circuit circulates the lubrication liquid forcibly. Heat is transferred to the discharged water through the shaft enclosing tube. Water can be used as the lubrication liquid
2) A bellows in the automatic pressure-regulating device absorbs the pressure difference between the lubrication liquid and the discharged water in order to prevent the latter from migrating into the former.

(Characteristics)

1) Application to the existent pump of large size and high discharge pressure is easy.
2) Longevity of the bearing is equivalent to that of the conventional submerge rubber bearing, which is constantly fed with water from external equipment.
3) Easy maintenance is resulted from the simplicity of the

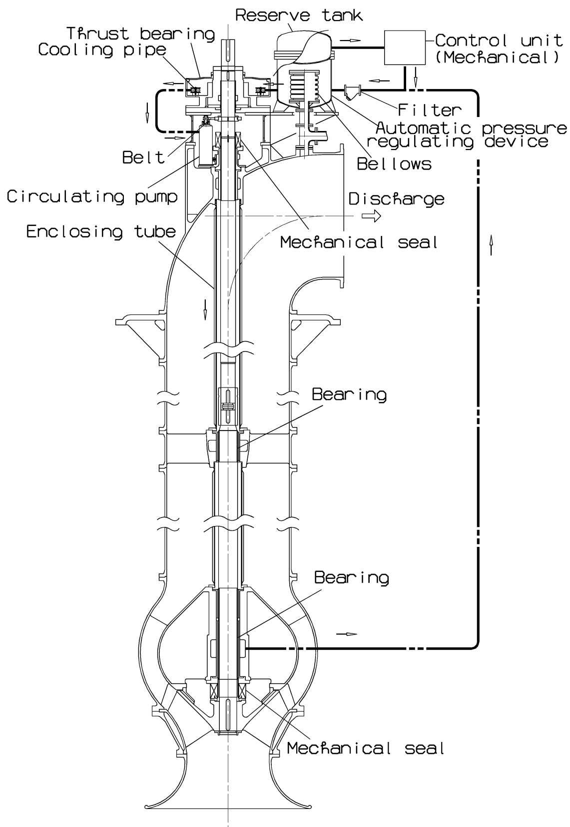


Fig.13 Internal Circulation System

circulation system. Only checking of the reserve tank water level is necessary.

4) The lubrication liquid never falls insufficient, even if evaporation or leakage occurs. The lubrication liquid is secured sufficiently in amount.
5) Because of the closed circuit structure, the debris such as grit never damages the bearing. Even if sand is mingled, the filter will remove it.
6) Germs or duckweed never generate in the lubrication liquid because the heat of the bearing has a pasteurization effect.

<u>Descriptions of Study</u>

(Process)

① Verification test for the elemental technology on the ϕ 300mm model pump

② Performance shop test on the ϕ 1800mm stand-by operation pump

③ Field test on the ϕ 1800mm stand-by operation pump

1) Result of the verification test for the elemental technology on the ϕ 300mm model pump

Temperature rise and performance	Lubrication liquid (＊This antifreeze solution was evaluated in consideration of the usage in the cold climate.)	
Test method and Pump operation	Water	Propylene glycol aqueous solution*
Dry startup running test (Running in the air)	Temperature rise rate 5.5 ℃/hr	Temperature rise rate 5.5 ℃/hr
Stand-by operation mode running test. (Running in the air lock situation)	Temperature rise rate 12.0℃/hr	Temperature rise rate 10.7℃/hr

Mechanical element	Test results
Automatic pressure regulating device	The lubrication liquid pressure follows pump delivery pressure automatically.
Circulating impeller	The rated flow rate for submerged bearing is secured.
Amount of feed water	0.131litter/hr (0.14%/hr of the whole reserved water)
Pump vibration	Acceptable enough for unrestricted long-term operation
Bearing	No abnormality (abrasion loss: less than 1 μ m)
Mechanical seal	No remarkable breakage except for usual sliding scar in the end face of seal ring surface

Test result on the ϕ 1800mm stand-by operation pump

(Specification)

Stand-by operation pump

Pump type and Discharge diameter	Vertical mixed flow ϕ 1800mm
Flow rate	420m^3/min
Total head	20m
Total efficiency	86%
Pump length under foundation plate	10.5m
Synchronous speed	300min^{-1}
Shaft power	1850kW

Circulation pump

Pump type	ϕ 32mm 3-stage turbine pump
Flow rate	0.1m^3/min
Head	16.5m
Synchronous speed	1,500min^{-1}
Shaft power	0.75kW
Shaft power Ratio	0.04 %

Result of the shop test on the ϕ 1800mm stand-by operation pump

Items	Test results
Heat balance and temperature rise	Temperature increment was stable in a span of maximum 4 degrees during the 3hours' dry startup running. Therefore, continuous operation in the air was confirmed.
Automatic pressure regulating device	The pressure of the lubrication system changed automatically to the pump delivery pressure.
Amount of feed water	The amount of lubrication water was under 1litter after the 6hours-running test in the stand-by operation mode.
Lubrication liquid circulation pump	The necessary lubrication flow rate of submerged bearing and thrust bearing was secured.
Pump vibration	No specially large vibration didn't occur in the air-water stirring running (air-water mixture and air lock).

Result of the field test on the ϕ 1800mm stand-by operation pump

Items	Test results
Heat balance at the actual field	Heat generated on the submerged bearing, the thrust bearing and the mechanical seal, was transferred through the shaft enclosing tube to the discharge water. No additional air-cooler was needed.
Automatic pressure regulating device	The pressure of the lubrication system changed automatically to the pump delivery pressure by the pressure-regulating device.
Amount of feed water	The amount of lubrication liquid feed water was 39.2 litter (total value) after the stand-by operation running of 23 hours and 12 minutes. The rate of the amount of feed water against the whole volume of reserved water was 0.11(% /hr.).
Lubrication liquid circulating pump	No abnormal vibration and noise occurred, nor any problem in the lubrication circulation pump mechanism.
Pump vibration	No specially large vibration didn't occur in the air-water stirring running (air-water mixture and air lock) at the pump field.
Lubrication liquid water quality	No generation of germs and duckweed in the lubrication water. The quality of the liquid was kept being good.

Conclusions

With CFB, even if public water delivery were stopped, pump system will be intact. And another impressive merit will be gained from this development. By making conventional cooling equipment useless, we can expect forty-percent reduction of pump troubles.

This research stimulated other pump manufactures. They have started their own design. Some of them are nearing to completion. That means administrative need can be a strong tractive force for technical improvement.

Application to existing pumps is easy. Already we installed CFB to three pump stations. After this, giving priorities to pump stations built on soft-ground lowlands, we will continue the installation of CFB.