DRY START BEARING FOR VERTICAL PUMPS

by

Hiroshi Satoh

Manager, Design Department

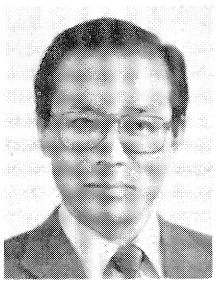
and

Hirohisa Takeda

Section Manager, Design Department

DMW Corporation

Shizuoka, Japan



Hiroshi Satoh is Manager of the Design Department of DMW Corporation in Shizuoka, Japan. He has been engaged in the design of large-sized pumps since 1969, and devoted himself to the development of the mixed flow pump with variable pitch impeller. Since 1985, he has been part-time Turbomachinery Lecturer at Yamanashi University.

Mr. Satoh received his Engineering Master degree from Yamanashi University in 1969, and the license of Consulting Engineer from his government in 1985. He is a member of JSME and Turbomachinery Society of Japan.

Hirohisa Takeda is Section Manager of Design Department of DMW Corporation. He has experiences in Pump Design, Research and Development and Consulting Engineering Sections. He has specialized in treating vibration problems many years at DMW and presented papers on those problems.

Mr. Takeda from graduated Shizuoka University received a B.S. degree in Mechanical Engineering in 1970. He is a licensed Consulting Engineer. He is a member of JSME and Turbomachinery Society of Japan.

ABSTRACT

Compound bearings made of PTFE and synthetic rubber were developed for vertical pumps to startup without initial lubricating water. Through various experiments, they were clarified to be superior to any other bearings of this kind. That is, this compound bearing undergoes rather less wear than the synthetic rubber one; it does not easily produce the unstable motion of rotor; and the degree of influence of the factors that contribute to wear was realized. Moreover, by the adoption of this bearing, it was possible to lower the maintenance cost and to increase the reliability of the pump.

INTRODUCTION

Vertical pumps are extensively adopted for industrial use owing to the benefits of simple handling and small area for installation. Generally, some synthetic rubber bearings which have superior wearing properties are used for these pumps. However, this kind of bearing has a high friction coefficient in dry conditions because of rubbermade sliding surface. Therefore, it needs the injection of lubricating water from the outside facilities and the shaft enclosing tubes as a conduit of lubricating water when the pump starts. In many cases, these outside facilities consist of small pipes, valves and control devices, they are often clogged by obstacles or fur and/or shells or oceanic matter in sea water use. Inevitably, much attention is paid to maintenance.

On the other hand, the adoption of "dry start" bearings that are lubricated by lifting water by the impeller eliminates the shaft enclosing tubes and lubricating water facilities. Up to now, the material of these dry start submerged bearings has been synthetic resin or metal that is self-lubricating. However, the properties of these bearings cannot exceed the synthetic rubber ones.

Roughly divided, the function of submerged bearings for vertical pumps are evaluated from two points. One is based on tribological properties and the other on dynamical ones such as a rotating machine part. The former is concerned with friction and wear, the latter is concerned with the spring and damping coefficients and the occurrence of the unstable motion that tends to cause vibration troubles in large length/diameter ratio pumps. The synthetic rubber bearing is superior in every way, and as for dry start bearings, it is desired to match the synthetic rubber one in bearing properties.

As parts of pumps, the dimensions of submerged bearings are generally from 1.0 to 16 in in diameter, and the price, the handling ability, the reliability, the frequency of operation and the interval of replacement should be considered.

Herein, the dry start submerged bearing that is made of the compound of PTFE (wellknown as the trade name of "Teflon" by E.I. DuPont) and soft synthetic rubber is explained. As an example of practical use, an application of the large sized bearings for circulating water pumps is presented.

BACKGROUND OF DEVELOPMENT

Seven years ago, a vertical pump for sea water use with 8 in column pipes encountered a motor shutdown resulting from over-current after 740 hr operation. It was discovered in overhauling the pump that the bearings made of copper based sintered alloy were abnormally and eccentrically worn out, and considerably fine sand was found by the analysis of sea water.

Through the investigation of the cause by taking the whole pump back into the factory, the following was ascertained. The column pipes vibrated intensively at about 12 Hz during pump operation. This corresponded to the second order of pump natural frequencies and was approximately one-half of the rotational speed. That is to say, the subsynchronous resonance between the column pipes and one-half of the rotational speed raised the bearing pressure extremely high, and accelerated the wear of the bearings. Inevitably, it seemed the sand in the sea water promoted the wear. To understand this vibration phenomenon, nearly ten kinds of bearings consisting of different materials, and different shapes and number of longitudinal grooves were tested. In these tests, the synthetic rubber bearing was the one and only bearing that did not produce the subsynchronous vibration. Taking this opportunity, a new type bearing was developed that enabled pumps to startup without lubricating water and that did not easily cause the subsynchronous instabilities.

In this development, the items to be examined for the dry start bearing of vertical pumps were broken down as shown in Figure 1. Consequently, the targets were laid out where this new type bearing had properties matching the lubricated synthetic rubber one. The production cost was less expensive, and it was possible to produce a bearing with the same dimensions as the synthetic rubber one. From the beginning, the utilization of the synthetic rubber was desired, and a trial was done to show the effect of rubber. Hence, the confirmation of several properties was mainly achieved in comparison with the synthetic rubber bearing.

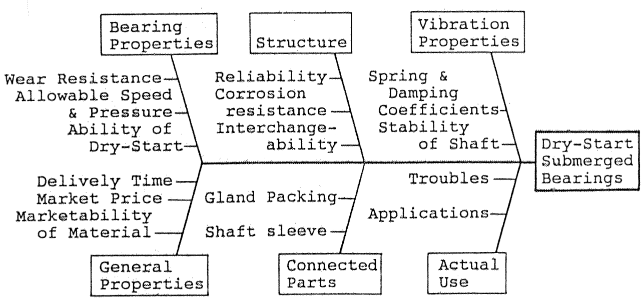


Figure 1. Classification of Important Problems with Dry Start Submerged Bearings.

STRUCTURE AND MATERIAL

The new type bearing is shown in Figure 2 with some generally used bearings. In these bearings, the synthetic rubber one is a two-layer structure of soft synthetic rubber as sliding component and metal shell as reinforcement, and the sliding surface has numbers of longitudinal grooves. The synthetic resin/metal bearing made of self-lubricating material is a tubular solid type and has also some longitudinal grooves. As compared to these bearings, the new one is a compound type and is made of strips of PTFE as sliding components, metal shell as reinforcement and synthetic rubber layer between the PTFE and the shell as a cushion. The rubber has the longitudinal grooves to enhance the function of elasticity.

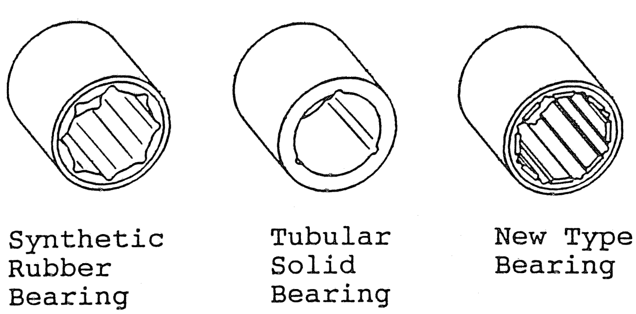


Figure 2. Structure of Submerged Bearings.

To give stability to the shaft, some special features are taken on the journal bearings. One has the shape of multi-arc section, and one has sliding pads that tilt or swing due to the rotation of the shaft (such as DP bearing by KMC, Inc.). However, this presentation does not compare them. The reason is that, on the vertical pumps having column pipes of large length/diameter ratio, the shaft is apt to turn round eccentrically within the bearing clearance on account of the accuracy of machining and assembly. Further, it can not be expected to form a normal wedge film owing to the lack of stiffness of bearing support and the existence of slurry in the lubricating water. The water lubricated bearings for the vertical pumps are considered to be rather a guide, and in this sense, a comparison with the one that has a sufficient wedge film is considered to be unreasonable.

The physical properties of PTFE and the synthetic rubber for the new type bearing are shown in Table 1.

Table 1. Physical Property.

Items	Unit	PTFE	Synthetic Rubber
Specific Gravity	—	2.09	1.30
Hardness	Shore	D/63/1	A/76/15
Tensile Strength	psi	3500	3300
Izod Impact Strength	ft-lb/in	2.5	—
Elongation	%	300	350
Heat Distortion	° F	>400	>200

GENERAL PROPERTIES

The characteristics of the new type bearings are shown in Table 2, with the synthetic rubber and the other conventional dry start bearings. The ability of dry start mainly depends on the friction coefficient. At this point, the synthetic rubber bearing has a high value friction coefficient in dry condition, so that the pump cannot operate without lubricating water. Even though dry start bearings are used, the pump shaft runs unsmoothly within the bearing clearance, during the transient condition of starting up the pump, so that the bearing load by the relative motion between shafts and columns and its direction are not constant. This phenomenon is more severe compared with that under the conditions of constant load and fixed direction as shown on the test facility in Figure 3. Then, the actual pump (column bore 10 in, shaft diameter 2-3/16 in, rotational speed 25 Hz) shown in Figure 4 was used. In the test, two types of PTFE-Rubber bearing were proposed for comparison. One was made of stripped segments of PTFE, and the other was of full mold, tubular shape PTFE having numbers of longitudinal grooves as shown in Figure 5. Eight bearings of four each were installed, starting-and-stopping the pump was repeated in the air until the unusual change occurred. After this, the pump was disassembled to take dimensions of wear. The patterns of repetition of start-and-stop were as follows.

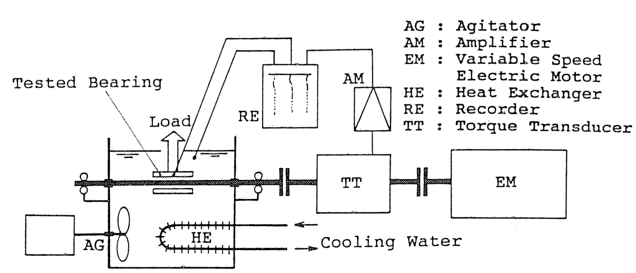


Figure 3. Test Facility for Wearing Property.

Table 2. Comparison of Bearings.

Materials		Friction Coeff.		Properties					Application	
Bearing	Shaft Sleeve (*2)	Dry	Wet	Ability of Dry-Start	Shock Resist.	Corro-sion Resist.	Unsta-bility Resist.	Allow. Press. (psi)	Water with Slurry	Sea Water
PTFE-Rubber	AS	0.2~0.3	0.01	yes	yes	yes	yes	290	yes	yes
Synthetic Rubber	AS	(*1)	0.03	no	yes	yes	yes	45	yes	yes
PTFE	AS	0.2~0.3	0.01	yes	yes	yes	no	360	no	yes
Copper Alloy	AS	0.2~0.3	0.05	yes	yes	no	no	70	no	no
Graphite	AS	0.2~0.3	0.03	yes	no	yes	no	70	no	no
Phenol Resin	AS	0.2~0.3	0.03	yes	yes	yes	no	70	no	yes
Silicon Carbide	TC	0.3~0.4	0.02	yes	no	yes	no	220	yes	no

Note *1. Too high for measurement.
*2. AS=Austenitic stainless steel
TC=Tungsten Carbide

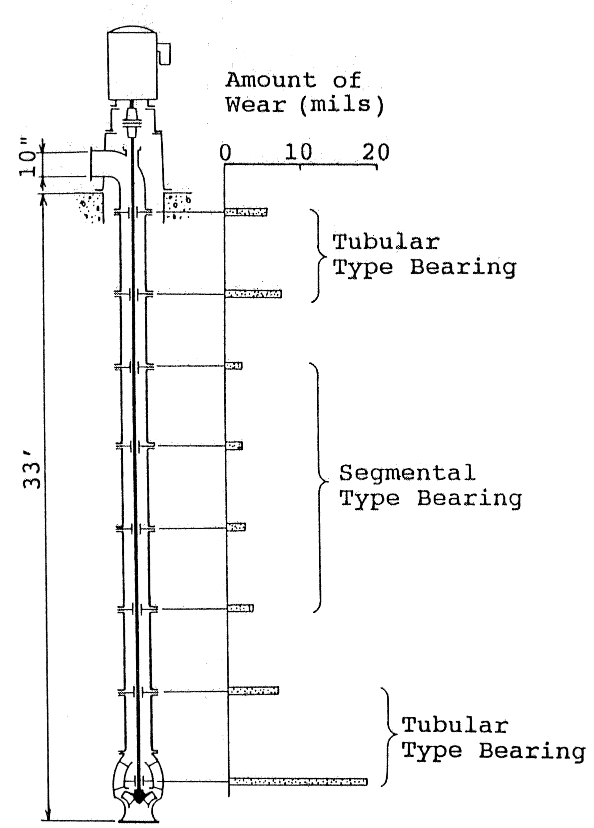


Figure 4. Dry Start Pump and Test Results.

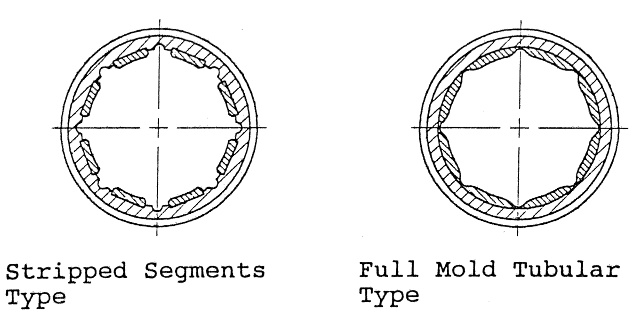


Figure 5. Tested PTFE-Rubber Bearings.

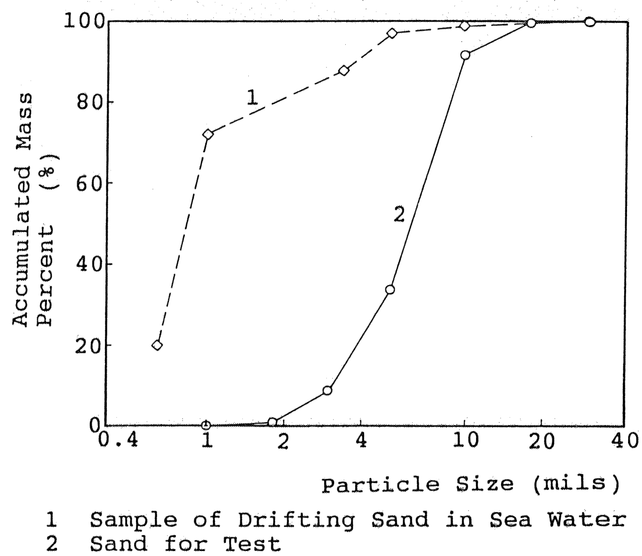


Figure 6. Sand Particle Distribution.

- Pattern A: 15 sec on, 5 min off (including the turning time by inertia).
- Pattern B: 23 sec on, 9 min 37 sec off (including the turning time by inertia).

As for the results, the occurrence of noise and the increase of motor current happened after 25 and 74 repeated times in Pattern A and B, respectively. The cause was that the heat generated by friction could not dispersed because of no lubricating water, and thus, the running clearance was lost by the bore reduction of bearings and the expansion of the shaft sleeves. The amount of wear after 99 repetitions is also shown in Figure 4. From the comparing tests using screen wash pumps in the field, the bearings with stripped segments of PTFE were confirmed to be superior to the full mold type. The cause of this was the deflective motion of rubber of full mold type bearing was so restrained, that the stiffness increased and the function of elastomer could not work sufficiently. Hereafter, the new type bearing mentioned herein will be the one with the stripped segments of PTFE, and using the words of"dry start", this bearing shall be called the DS bearing.

WEARING PROPERTIES

As to the wear of the submerged bearing, many factors are related such as the running time, the peripheral speed, the bearing pressure, the density or distribution of solids in the water and even the material of the shaft sleeves. Among these factors, taking into account the previous troubles of submerged bearings, the following three factors were chosen as the variables to examine the wearing properties: the solids density, the bearing pressure, and the peripheral speed. The seawater used in the examination was sandy that had slightly larger particles than actual seawater, to promote the wear as shown in Figure 6. Austenitic stainless steel that is commonly used was chosen as the shaft sleeve. The 50 hr running time was continuous.

Tested DS bearings were all in the same dimensions, 2-3/8 in diameter, 2-3/8 in length. The test facility for this is shown in Figure 3, the uniformity of slurry in the tank was made by using an agitator.

The test was executed based on a "Design of Experiments." To know the influence of aforementioned three factors on wear, each factor was given three levels, as shown in Table 3. The amount of wear of both bearings and shaft sleeves, after 50 hr running were also listed in Table 3, and these were indicated on the graphs according to each factor, respectively, in Figure 7. The numerals (1-9) in Figure 7 correspond to the combination number of Table 3.

Table 3. Wear Test on DS Bearing.

	Factors			Amount of Wear	
Combination No.	Sand Density (ppm)	Bearing Pressure (psi)	Shaft Speed (ft./2)	Bearing (mils)	Shaft Sleeve (mils)
1	30	7.3	6.6	0.4	0.2
2	30	36.3	16.4	1.2	0.2
3	30	72.5	26.2	1.7	0.3
4	300	7.3	16.4	1.5	0.3
5	300	36.3	26.2	1.8	0.3
6	300	72.5	6.6	1.6	0.3
7	3000	7.3	26.2	1.7	0.3
8	3000	36.3	6.6	1.6	0.2
9	3000	72.5	16.4	2.1	0.4

Notes 1. Amount of wear after 50 hours running.
Notes 2. Amount of wear measured as 4 diameters of the bearing in 3 sections along the longitudinal direction.
Notes 3. Amount of wear of shaft sleeve taken at 3 positions along longitudinal direction.

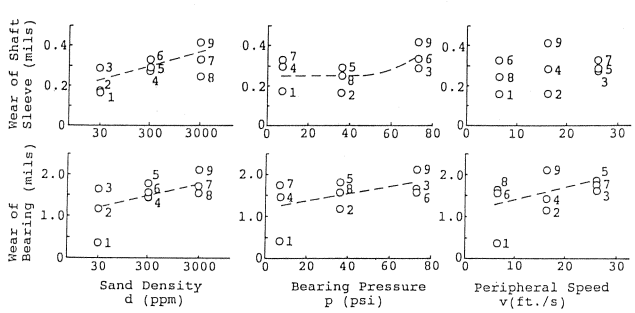


Figure 7. Relation Between Wear and Other Factors.

The analyses of test results indicated that every factor contributes to the wear, except the peripheral speed to the wear of the shaft sleeve. Here, as for the relations between the wear of the DS bearing and each factor, they are expressed subsequently in simple equations.

$$\Delta y = 0.28 \times \Delta d \quad (1)$$
$$\Delta y = 0.0081 \times \Delta p \quad (2)$$
$$\Delta y = 0.028 \times \Delta v \quad (3)$$

where

Δy = variation of bearing diameter caused by wear (mils)

Δd = variation of sand density expressed in common logarithms (ppm)

Δp = variation of bearing pressure (psi)

Δv = variation of peripheral speed (ft/s)

The coefficients of Equation (1)-(3) obtained by this test indicate the rate of diameter change of bearings caused by wear to the change of each factor. In reference to these, it is reported that the rate of linear wear of PTFE in dry condition is proportional to the nth ($n > 1$) power of the bearing pressure [1]. However, the DS bearing does not have such a high value. It is considered to be caused by the existence of a rubber cushion and lubricating water. This was also clarified by other examination [2], where the bearing made of tubular PTFE and metal shell without rubber showed approximately twice the wear compared to the DS bearing. By using the above equations and from the amount of wear of a certain pump, the wear of another pump that is operated under different conditions can possibly be estimated.

Next, the test on the DS and the synthetic rubber bearing was carried out using the facility of Figure 3 to check the applicability to water that contains slurry like sand in a river or seawater. The solid density of sand was chosen as a factor, and its range was altered from 3 to 300 ppm. This range of density was decided after a long-term survey of sea water from the Pacific Ocean at the pump intake of a certain power station. Three hundred ppm was the condition during a typhoon. The other factors were as follows: The running time was 50 hr, the bearing pressure was 7.3 psi, the peripheral speed was 16.4 ft/s and the distribution of sand particles for experiments was the same as Figure 6. The dimensions of both bearings are also the same.

The result is shown in Figure 8, and a demarcation can be drawn at about 200 ppm, the DS bearing is found to be superior to the synthetic rubber one in the lower range of sand density, and the synthetic rubber one is superior in higher range. This fact seems to become more apparent by the following explanation. The representative mechanism of wear of the submerged bearings was the abrasive wear caused by solid particles like sand, and adhesive wear caused by the friction of sliding surfaces. It is considered that the former is dominant at the higher range of solid density, contrary to this, the latter is dominant at lower range. At this point, the synthetic rubber that passes over the particles by deforming of the bearing itself undergoes slight wear, in spite of running in a higher range of solid density. On the other hand, the bearing that is made of material of low friction coefficient such as PTFE undergoes slight wear in the lower range.

From the above results, it becomes clear that the DS bearing matches the synthetic rubber one when it works in a river or sea water of ordinary solid density, and how the factors of running conditions act on the wear.

DYNAMIC PROPERTIES

The evaluation of the vertical pump as a rotating machine cannot be done independently of the dynamic properties. Among many component parts of the vertical pumps, the water lubricated bearings have a strong effect on the vibration phenomena. Generally, as for the vertical pump that has a large length/diameter ratio of column pipes, the natural frequencies of columns are so small that it is not uncommon for the running speed of the pump to exceed the third order of the natural frequencies.

These bearings of vertical pumps need the clearance as a structural demand, so that the spring coefficients of bearings become nonlinear. For this reason, the vertical pumps easily exhibit a subsynchronous unstable motion, and as the clearances are generally asymmetric, the whirl frequency of this unstable rotor motion tends to exhibit so-called one-half of the running speed. However, actually, this is slightly less than one-half (generally 45 to 48 percent) of the running speed [3]. Specifically, if the natural frequency of column pipes was close to the one-half of the running speed, the relative motion between the shaft and the bearings (installed to the column pipes) would occur intensively, sometimes disastrously, and would raise the high bearing pressure, causing abnormal wear to bearings.

The amount of wear to the copper based sintered alloy that has met with trouble as mentioned in the BACKGROUND OF DEVELOPMENT is shown in Figure 9, and the result of spectrum analysis of the column pipes is shown in Figure 10. As is evident from these two figures, the abnormal wear of these bearings is attributed to the resonance of the second mode vibration of the columns and one-half of the running speed.

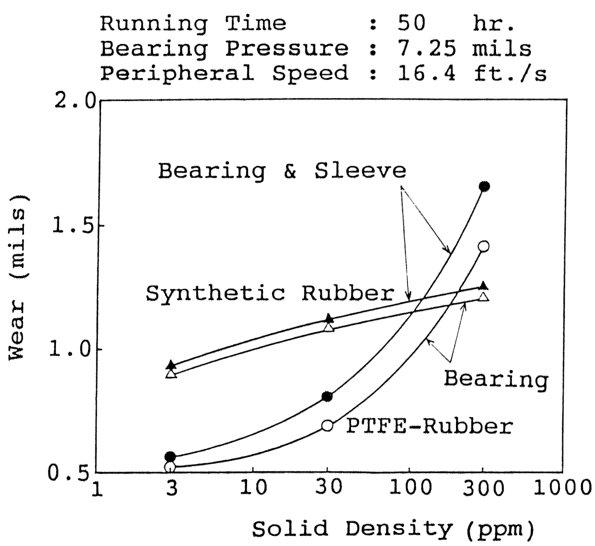


Figure 8. Wear of Bearings Against Solid Density.

It is serious if this so-called "one-half frequency whirl" arises on the dry start (DS) bearing. As far as the water lubricated bearings for vertical pumps are concerned, they have inevitably the nonlinear spring coefficients owing to the existence of bearing clearance, so the occurrence of one-half frequency whirl cannot be denied fundamentally in any bearings. However, it was too hard to treat this analytically, so, a test of the dynamic properties was carried out using the test facilities shown in Figure 11. Two bearings, top and bottom, were fixed rigidly to the stiff frame of the facility, and the bearing load was given by the centrifugal force of imbalance weights attached to the rotor. Furthermore, to avoid the constraining force, a shaft coupling of very low stiffness was used and the rotor was slightly lifted by the hydrostatic pressure bearing set at the bottom. The running speed was able to change continuously by the variable speed electric motor. By this facility, those listed in Table 2 were put to the test.

The test results are shown in Figures 12, 13, and 14. To avoid the figures being complicated, the synthetic rubber and copper alloy bearings are taken up in comparison. The zone that generates the one-half frequency whirl against the running speed and the bearing pressure is shown in Figure 12. On this test facility, all bearings in Table 2, except both the synthetic rubber and the DS bearing, generated the one-half frequency whirl. Further, by enlarging the clearance of the bearing (here, the copper alloy bearings), there was the tendency to expand into the low running speed area that raised the one-half frequency whirl. The spring and damping coefficients that were obtained from the analysis of the rotor orbits are shown in Figures 13 and 14. In both figures, the values for the copper alloy bearing were taken under a state of no whirl. Regarding the spring coefficient shown in Figure 13, no difference was found between the DS bearing and the two others in the low load range, although in the high load range, the value of copper alloy bearing was highest and that of DS bearing was between the bearings of copper alloy and

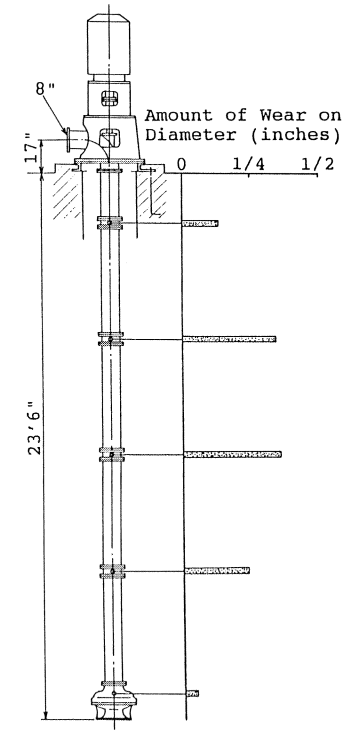


Figure 9. Wear of Submerged Bearings.

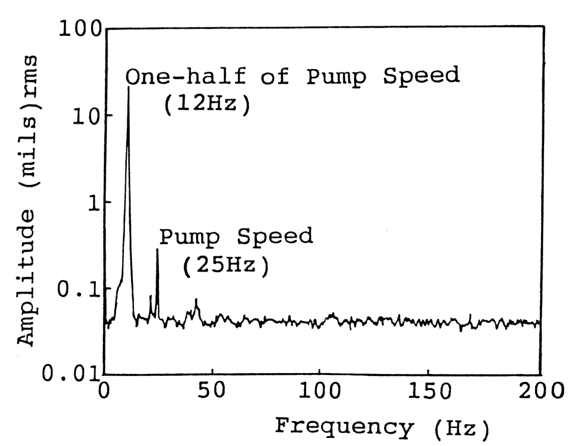


Figure 10. Spectrum Analysis of Column Pipe Vibration.

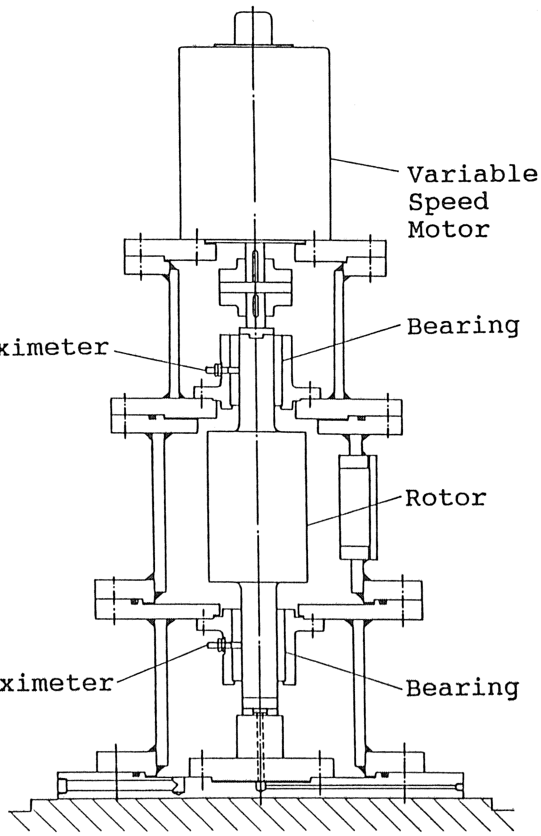


Figure 11. Test Facility for Dynamic Property.

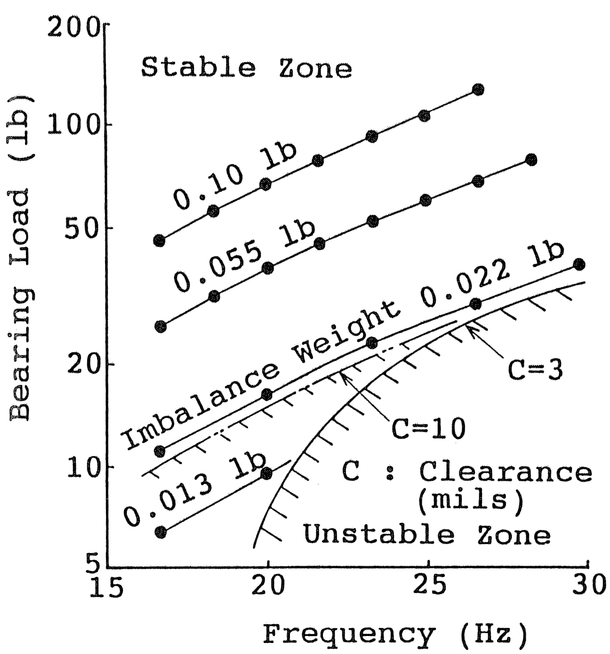


Figure 12. Stability Performance of Tubular Bearing.

synthetic rubber. This phenomenon seemed to be attributed somewhat to the elastic deformation of rubber. Further, on the damping coefficients of Figure 14, although the value of DS bearing was in the middle of both bearings, it was a little closer to the synthetic rubber bearing.

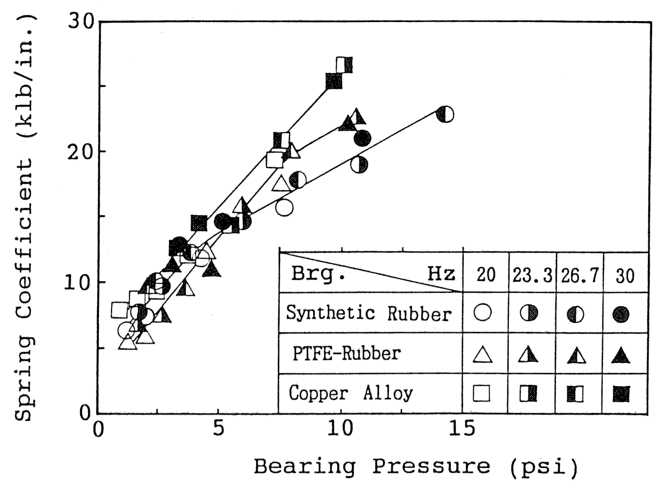


Figure 13. Spring Coefficients.

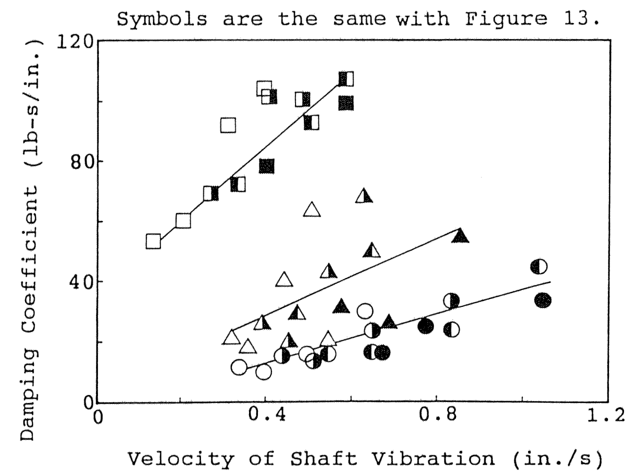


Figure 14. Damping Coefficients.

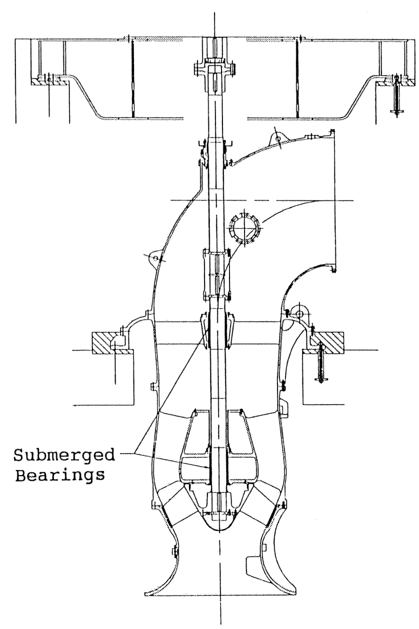


Figure 15. Circulating Water Pump Sectional Assembly.

The high damping coefficients of the copper alloy bearing are considered to be attributed to the bearing clearance, that is 80 percent of other two bearings, and the number of longitudinal grooves is three, compared to eight in the other two.

It became evident from these experiments that the tubular bearings as shown in the middle of Figure 2, which was used to create a fluid film were, in spite of having high damping coefficients, they were apt to raise the subsynchronous instabilities. It seems to be for this reason that the nonlinear form of the spring coefficient which is one of the causes of one-half frequency whirl, is different between the one that utilizes the elasticity of rubber and the one that depending just on the fluid film.

APPLICATION

DS bearings are now applied to more than 100 units of vertical pumps, mainly for seawater use, and all pumps are in operation without problems. Here, as an example, large-sized circulating water pumps with the DS bearings for a 1000 MW power station that has operated continuously for about two years are introduced.

The specifications and the structure of the pumps are shown in Table 4 and Figure 15, respectively. The DS bearings used here are much larger ones, i.e., inside diameter 13-3/8 in × length 27-1/2 in. Usually, as for the large-sized circulating water pumps, the synthetic rubber bearings have been exclusively used. For the adoption of DS bearing based on the results of the aforementioned examination, a couple of experiments [4] for confirmation of safety, using actual-sized bearing, were added. Total running time of these pumps at the site exceeds 14,800 hr,

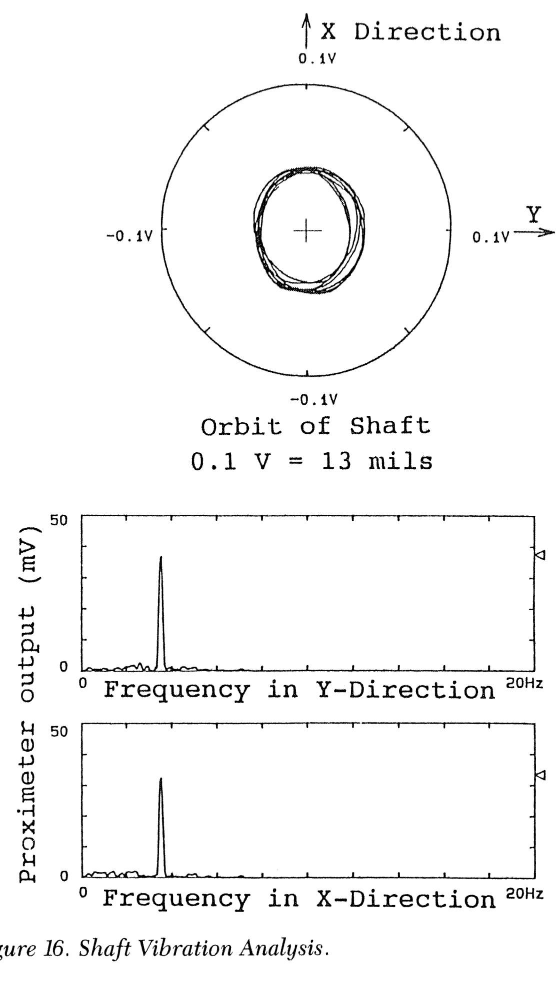


Figure 16. Shaft Vibration Analysis.

Table 4. Pump Specifications.

Service	Circulating Water Pump	
Number	2 Sets	
Bore	110	in.
Total Head	46.6	ft.
Capacity	341000	gpm
Speed	211	cpm
Power	3850	kW
Liquid	Sea Water	

and the second overhauling was executed recently. In the middle of the periodical inspection, the first overhauling after 2700 hr operation and several shaft vibration checks were performed, and it was confirmed that there was not any harmful wear to sliding parts or any unstable vibration. The shaft vibration analysis reflected in Figure 16 was done at the exposed part of the shaft, just above the packing gland by using proximeters from orthogonal direction just before the overhauling. The average wear was less than 3.9 and 4.3 mils after 2,700 and 14,800 hr, respectively. The sliding surface of bearings and shaft sleeves showed the luster of good operating conditions.

As a matter of course, the lubricating water facilities were all removed, the sequential program of operation became simple, the reliability of starting-and-stopping of pumps increased, and the cost for maintenance decreased at the same time.

CONCLUSION

The DS bearing was developed to have the ability of "dry start," besides having the properties that match the synthetic rubber one. The results obtained by some experiments and the applications to the actual pumps are as follows.

- The DS bearing can be put to use for vertical pumps without lubricant, due to the low friction coefficient of PTFE as a sliding component.
- In comparing the amount of wear between the DS bearing and the synthetic rubber one, the former is excellent at the lower density range of solids. Contrary to this, the latter is excellent at a high density range.
- The influence of three factors, the peripheral speed, the bearing pressure and the slurry density, on the wear of the DS bearing was clarified.
- It was found by experiment that the dynamic properties of the DS bearing were close to synthetic rubber one, and the occurrence of one-half frequency whirl could not be recognized as different from the other tubular bearings.
- The DS bearing has less restriction on manufacturing, so that it has wide applications from small sized to large sized pumps for use with sea, river, and industrial water. As for the application to petrochemical products, especially to organic solvents, there is a problem from a point of endurance against swelling of synthetic rubber.
- As this bearing does not need lubricating water facilities, a decrease of maintenance cost and an increase of reliability can be attained.

REFERENCES

1. Uchiyama, Y., and Tanaka, K. "Wear Laws for Polytetrafluoroethylene," Wear, *58* p. 223 (1980).
2. Satoh, H., et al., "Development of Dry Start Water Lubricated Bearings, "Dengyosha Technical Review, (2), (1984).

3. Ehrich, F., and Childs, D., "Self-Excited Vibration in High-Performance Turbomachinery." Mechanical Engineering, (May 1984).

4. Takeda, H., et al., "2800 mm Vertical Circulating Water Pumps with Dry Start Intermediate Bearings," Dengyosha Technical Review, (2), (1987).