Vertical sea water pump Al-bronze impeller predictive maintenance technique by using vibration frequency analysis

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1. Introduction

Vertical line shaft centrifugal pumps are widely used in large capacity power generation facilities using seawater as the final cooling source.

As the material of the seawater pump, aluminum bronze alloy (Al-bronze), 316 stainless steel, super austenite stainless steel are mainly used since they are excellent in corrosion resistance, corrosion resistance, and mechanical properties. [1]

Aluminum bronze alloys (Al-Bronze) are advantageous for preventing marine habitats, but are known to be suitable only in environments where uncontaminated seawater operation at a limited flow rate. [2]

However, large-scale seawater cooling pumps require high cooling performance (flow rate, head), and are accompanied by a high impeller circumferential speed. This requires more NPSH (Net Positive Suction Head), and then bubbles collapse on the suction side, causing erosive pitting damage and cavitation on the surface. [3],

Many reports of damage caused by foreign matter in seawater have been published. The inclusion of foreign matter in seawater has also been shown to accelerate the rate of erosion. [4]

In particular, impeller erosion has a direct impact on pump performance, and deterioration impairs cooling of the system in question. In case of nuclear safety class pumps, cooling seawater is supplied to the heat exchanger and cooler of the primary side. Therefore, pump performance parameters are strictly regulated by periodic testing in accordance with the KINS/GT-N024 "Safety Pump, Valve In-Service Test (IST) Guidelines". [5], [6], [7]

Therefore, nuclear power plant operators shorten the predictive maintenance cycle of Al-bronze pumps (about 1 to 3 years) and supplement sufficient spare parts to respond sudden failures. However, even though the impeller is severely damaged and forced outage is frequently performed due to a sudden decrease in performance, there is a necessity for further research because the reason of the damage is not clearly identified.

Cavitation in the pump occurs mainly at the impeller vane. When the fluid is propelled at high speed, an absolute pressure is formed that is equal to or lower than the saturated vapor pressure of the fluid, moving to a higher pressure area, causing the bubbles to collapse and create an impact pressure much higher than 100,000 psi. This produces loud noises and vibrations and causes erosion or pitting. [8]

At this time, the imbalance due to the impact and the mass loss that damages the impeller is expressed by vane pass frequency (VPF) and harmonic frequency vibration. [9] In addition, cavitation generates pulsation of the fluid and amplifies 0 to 1X (reference frequency), so it should be considered with VPF. As other components, wear of the rotating body such as bearing / sleeve / wear ring is represented by 4X according to the shape, and there are 2X components due to loose assembly parts. In conclusion, it is possible to judge by comprehensively examining the effects of the above vibration elements.

Relevant studies have already been conducted to estimate the cavitation of pumps by measuring noise [10] Unlike the laboratory, the field environment has many noise variables that are difficult to control. On the other hand, the vibration is controlled by regulatory requirements and regular measurements are performed, so data is accumulated continuously for further study.

Several studies have already confirmed that impeller cavitation can be detected by analyzing vibration data. [9], [12] In this study, it was detected that the pump damage could be predicted through vibration analysis as the cavitation phenomenon with erosion caused by foreign matter was concentrated on the impeller. Therefore, we propose a predictive maintenance strategy that should be supplemented when using Al-bronze impeller.

2. Methods and Results

Nuclear power plants are operated at base load due to their operational characteristics, and planned predictive maintenance is performed every 12 ~ 18 months based on the fuel combustion. The maintenance cycle is determined by considering the regulatory requirements and the equipment operation environment. The vertical line shaft pump is managed by the in-service test according to KEPIC MOB 5300 as following table. [Table 1]

Table 1: Regulation summary of vertical line shaft and centrifugal pump(KEPIC MOB 5300, 2005Ed.)

Parameter	Test type	Acceptable range
Q(Flow), Δ P(Differential pressure)	Group A(3m)	0.95~1.1(Qr, Pr)
	Comprehensive (2y)	0.95~1.06(Qr, Pr)
Vibration	Group A,	≤ 2.5 Vr and

(≥ 600rpm)	Comprehensive	8.25 mm/sec

Note: Qr, Pr, Vr: Reference value

In case of violating the above requirements due to severe cavitation, erosion of pump performance and increased vibration, forced outage is performed regardless of the maintenance interval.

Performance parameters are always observed in the main control room, but they are not connected to the online, the values entered through operator's regular instantaneous inspection were used. Percentages were used as performance parameters. They are values that indicate the rate of change between measured values, regardless of regulatory or test target reference values.

Vibration measurement was performed by using Emerson's CIS-2130 equipment, and the speed(mm/s) was measured in the Pump Inboard Vertical(PIV) direction based on the vibration criterion of vertical line shaft pump over 600 rpm of KEPIC MOB Table 5300. [13]

The rotation speed of the pump is 885 rpm and the reference frequency is 14.75 hz (1X). In this study, the impeller damage due to cavitation and foreign material erosion is checked through vibration analysis. The main frequencies of interest are shown in Table 2.

Table 2: Vibration frequency of major element

Element	Frequency	Description
0~1X	0~14.75 hz	Fluid induced
1X	14.75 hz	Reference
4X, 8X, 12X, 6X, …	59 hz, 118 hz, 177 hz, 236 hz	Bearing/sleeve wear (and harmonic)
8X, 16X, …	118 hz, 236 hz	Vane pass (and harmonic)

Online vibration monitoring and daily patrol logging are not performed for this facility. Vibration is measured during periodic(every 3 months) performance tests, and after maintenance.

2.1 Forced outage Practices

2.1.1 Case A

For approximately 8 weeks, the pump performance (flow rate, outlet pressure) decreased significantly, and the power consumption also decreased. During the instantaneous inspection of the main control room, the performance degradation was recognized and predictive maintenance was performed. The performance trend is identified as shown below. [Fig. 1.]

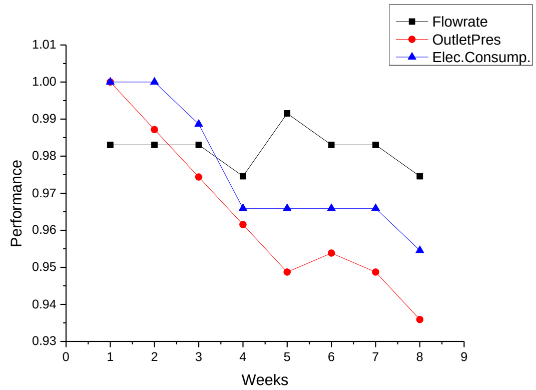

Fig. 1. Case A. Performance parameters(Flow rate, outlet pressure) and electric consumption significantly decreased during only 8 weeks.

The results of major vibration component verification for 36 months after the final maintenance are summarized in Table 3 below.

Table 3: Vibration frequency analysis of Case A

Element	Description
0~1X	Increased from early to mid cycle, calms down at end of cycle
1X	Increased from early to mid cycle, calms down at end of cycle
4X	Increase due to wear at the end of cycle
8X	Intermittently occurred, and it occur again at the end of cycle and maintained

In total, cavitation erosion accompanied by foreign matter occurred at the point where 0 ~ 1X component and 8X peak occurred, and at the end of the cycle, bearing erosion also affected the 4X component. [Fig. 2.]

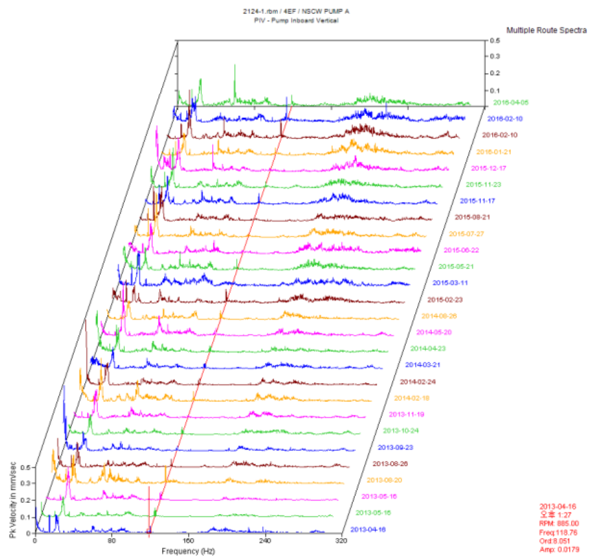

Fig. 2. Vibration frequency waterfall diagram of Case A. (PIV)

In Cases A, pump overhaul results in severe erosion damage from cavitation and debris on the impeller and vane surfaces. More than 5% of the total area of the material was completely lost or thinned like paper due to cavitation and foreign material. [Fig. 3.]

Fig. 3. Serious comprehensive damage of erosion such as pitting on the surface and sharp cross section of the impeller vane.

2.1.2 Case B

During approximately 12 weeks, the pump performance(flow rate, outlet pressure) was similarly reduced with power consumption, and the power consumption also fluctuated. The 3-month cycle performance test was barely satisfactory, but predictive maintenance was performed due to the sharply reduced performance margin. The performance trend is identified as shown below. [Fig. 3.]

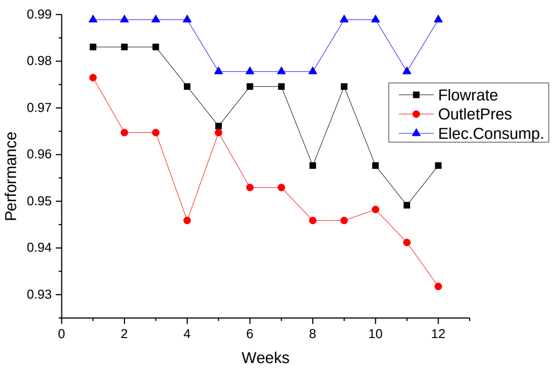

Fig. 4. Case B. Performance parameters(Flow rate, outlet pressure) decreased significantly to approximately 95% and electric consumption fluctuation during only 12 weeks.

Since 2X, 4X and its harmonics are observed from the beginning of the cycle, it is estimated that there was a defect in assembly during the final maintenance. 8X is also a harmonic wave of 2X and 4X, and 0 ~ 1X components are intermittent, but they are rarely observed, so it is difficult to grasp the effects of erosion and cavitation by foreign substances. In conclusion, as a result of the pump failure maintenance, the rope was wound around the impeller. [Fig. 5]

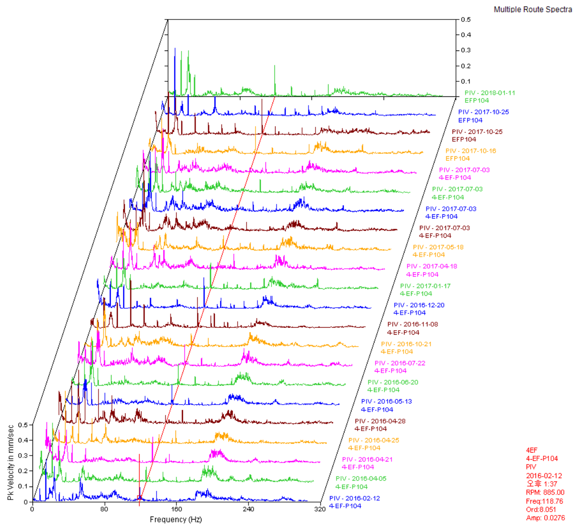

Fig. 5. Vibration frequency waterfall diagram of Case B. (PIV)

2.2 Predictive Maintenance Practices (Case C)

Although Peak is smaller than Case B, 2X, 4X, and its harmonic wave have appeared steadily from the beginning of the cycle, but the 0 ~ 1X component is not so prominent, so it can be judged that the influence of erosion and cavitation by foreign matter is relatively small. [Fig. 6.]

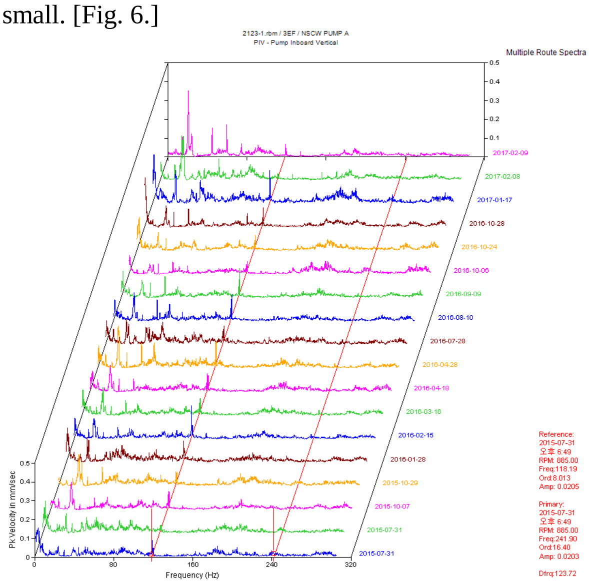

Fig. 6. Vibration frequency waterfall diagram of Case C. (PIV)

As a result of pump disassembly, pitting was widely observed on the surface of impeller and vane. 5 to 10 complete penetration erosion sites of small size (less than 5 mm in diameter) were identified. Appearance is maintained throughout, but material losses have already occurred and surface hardness and mechanical properties significantly degraded. [Fig. 7.]

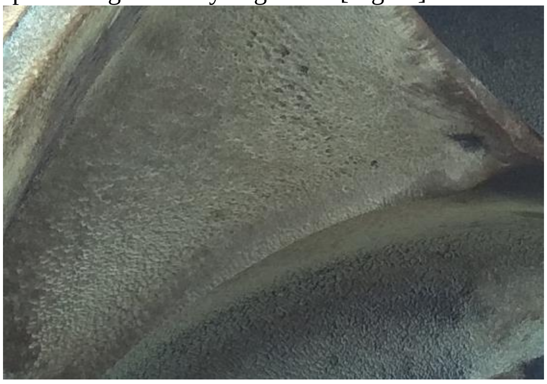

Fig. 7. Al-bronze impeller surface with cavitation pitting after 3.5 years operating without performance degradation and significant vane pass frequency peak.

Including the above cases, we analyzed several cases where sudden performance degradation did not occur during the predictive maintenance cycle. The overall low and irregular 0~1X element and VPF(8X) oscillation peaks indicate that the impeller erosion was not severe and there was no unbalanced damage. Although there is some difference between the operation period and the degree of erosion, a wide range of pitting has been observed such as [Fig. 7.], suggesting that the current maintenance cycle (approximately three years) is appropriate.

3. Conclusions

In this study, erosion damage caused by cavitation and foreign matter of vertical seawater pump Al-bronze impeller could be detected through VPF analysis. The decrease in pump performance (flow rate, pressure) appears rapidly over a short period of time (2 to 3 months) after impeller damage has significantly progressed, and the VPF analysis indicates this before the performance decreases.

Therefore, additionally perform the VPF analysis on the current predictive maintenance criteria managed by KEPIC MOB 5300 of the performance (95%) and maximum vibration velocity (8.25 mm/s). Al-bronze impeller erosion caused by cavitation and foreign material is detected by vibration analysis and performance deteriorates rapidly over two to three months. Therefore, it is necessary to supplement the predictive maintenance strategy by adding a procedure to check major vibration frequency analysis. [Table 4.]

Table 4. Proposed predictive maintenance criteria for Al-bronze pump

Element	Description
0~1X	Pulsation by erosion/cavitation
1X	Increase by effect of erosion/cavitation , VPF
4X	Increased in wear part of shaft, not directly related to erosion / cavitation
8X	Directly related to erosion / cavitation (Vane Pass Frequency: VPF)

However, if the relationship between 0 ~ 1X component and VPF Peak can be expressed by the formula compared with the reference frequency, it can be used as a more reliable preventive maintenance index.

In addition, if sufficient data on the quality of the seawater in the nearby sea are available, it is possible to predict the impeller erosion conditions and speed quantitatively, and further research is needed.

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