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PERFORMANCE DEGRADATION ANALYSIS OF CENTRIFUGAL PUMP BY LONG TERM OPERATION

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ABSTRACT

Nuclear power plant has a number of valve and pumps, which are operating at a high temperature–high pressure and radiation environment conditions. Nevertheless, it is important to maintain the reliability of the valve/pumps to ensure safe operation of the nuclear power plant. However, the aging of the valve/pumps by increasing of years of plant operation and the system transients due to the sudden load change are working the failures of the reliability of the valve/pumps. In this paper, an acceleration test apparatus was developed to secure the reliability of centrifugal pumps. And the performance change with the increase of operation time of the pump was experimentally evaluated by the acceleration test. As the operating time of the pump increase, it was confirmed that the pump efficiency and head decrease.

KEYWORDS: Centrifugal Pump, Accelerated Life Test, Pump Performance, Life Time, Reliability, Nuclear Power Plant.

1. INTRODUCTION

Nuclear power plants have many active devices such as valves and pumps operating under high temperature, high pressure and radioactive environments, and each device is required to have high reliability. However, deterioration of the equipment due to the aging of the power plant and transient phenomena of the system caused by rapid load change operation are acting as obstacles to securing the reliability of valves and pumps.

In order to ensure the reliability of machineries such as valves and pumps, it must be ensured that the quality check in the design and manufacturing stages, and the inherent performance of the equipment even under the worst operating conditions. Furthermore, they must meet the given confidence levels under the defined environmental conditions and perform the designed functions without failure during their lifespan.

In the previous paper[1,2], in order to build an integrated quality control means including the management of nuclear plants' valve performance, life, and optimal preventive maintenance, performance verification through a performance test and experimental evaluation of the valve performance changes during thermal aging on 2-inch air-operated valves were executed.

This paper describes that for the purpose of ensuring the reliability of the centrifugal pump such as verifying of performance degradation due to long term operation and predicting the time of failure occurrence, an acceleration test device was developed and used in an acceleration test to experimentally evaluate the pump's performance changes according to increasing of its operation time.

2. MATERIALS AND METHODS

Test Pump

Table 1 describes the basic specification of the pump used for this paper. The pump is a horizontal centrifugal pump with a design flow rate and total head of 430 gpm (1.63 m^3/min) and 370 ft (112.8 m), respectively. The pump motor is a 76 kW (100 HP) three-phase induction motor with a speed of 3600 rpm.

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Table 1 Specifications of test pump

Type	Centrifugal Pump(Horizontal)
Design Pressure [bar]	10(Suction) / 50(Discharge)
Total Head [m]	112 (370 ft)
Design Temperature [°C]	-10(Min) / 100(Max)
Design Flow Rate [m^3/min]	1.6 (430 gpm)
Motor Power [kW]	76
RPM	3600

Test Device and Method

Table 2 shows the major breakdown cases of nuclear power plant's centrifugal pumps by part[3)]. Failure of the main parts of the pump such as bearings, impellers, shafts, etc., is caused by wear, friction, and fatigue. In addition, the cause of the breakdown of mechanical seals, packing, gaskets / o-rings, etc., is leakage.

In this paper, an acceleration test was performed with the flow control method shown in Fig. 1 because it aims to establish DB to observe the progress of the failure occurrence and performance deterioration of the test pump and to use it for reliability prediction (failure prediction).

In the case of centrifugal pumps, the required axial power is large in the high flow region and small in the low flow region. Therefore, in this acceleration test, the pump was operated in the flow range from 120% to 50% of the rated flow in 10-second intervals to accelerate the wear, friction, fatigue damage, deformation and leakage of the pump. On the other hand, the pump flow rate is controlled by the valve installed at the rear side, and it was verified through a pretest that the full pump design flow rate, 50% of the design flow rate, and 120% of the design flow rate corresponds to 61.5%, 31.5%, and 80.0% of the valve opening respectively.

Figure 2 shows a schematic of the test device. The test device is a closed circuit consisting of a water tank with a capacity of 10m^3, two test pumps, a Vortex flow meter, and a 3-inch air-driven flow control valve.

Table 2 Failure mechanism of pump

Failure Part	Mechanism	Failure Ratio [%]
Bearing	Wear/Fatigue	18
Impeller	Wear	10
Mechanical Seal	Leakage	24
Gasket/O ring	Transform	9
Packing	Leakage	3
Coupling	Fatigue	7
Shaft	Wear/Transform	6

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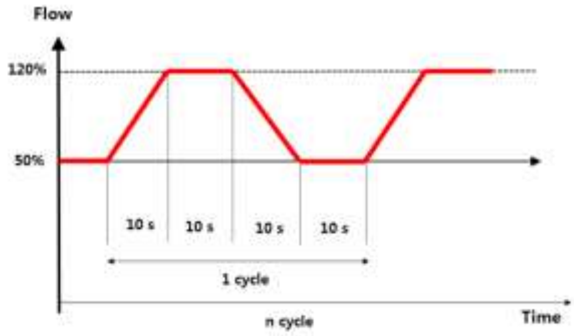

Fig.1 Accelerated life test method

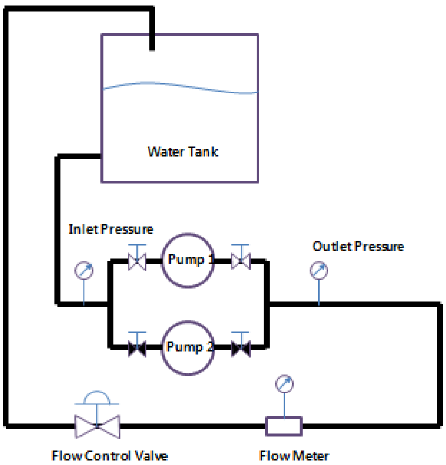

Fig.2 Schematic test facility

Performance characteristic evaluation criteria
Initial performance deteriorates as usage time increases, resulting in failures/defects. The limit immediately before the occurrence of a failure/defect is defined as the lifetime limit and its reference values are shown in **Table 3** for each measurement parameter. For pump head, flow rate, and efficiency, it is determined based on the reference to KEPIC MOB[4)] that the lifespan is up to the point of 10% lower than the initial value.

Table 3 Performance degradation criteria

Check Item	Reference Value	Remarks
Bearing Temp	75 °C	KS B6301
Vibration	17 mm/s	KEPIC MOB
Pump Head	10 %	KEPIC MOB
Flow Rate	10 %	KEPIC MOB
Pump Efficiency	10 %	KEPIC MOB
Lubricant Viscosity	-	

3. RESULTS AND DISCUSSION

Initial performance of the test pump
Figure 3 shows the general performance curve of the test pump. The highest efficiency point of the pump is

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approximately 1.6m^3/min, with an efficiency of about 55% and the pump head is 102 m. Axial power increases with increasing flow rate but tends to decrease slightly in large flow rates. This test result is to be used as the reference performance when evaluating the performance degradation caused by the pump acceleration test.

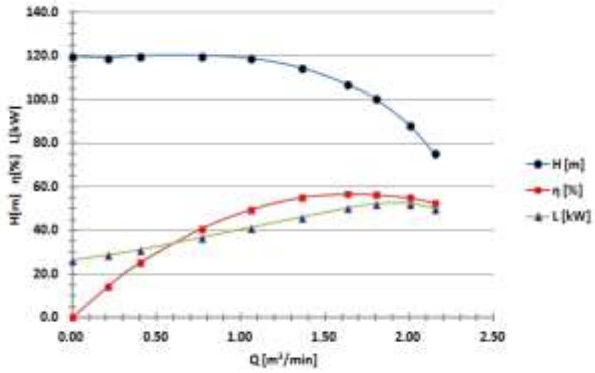


Fig.3 Pump performance curve

Temperature and Noise Characteristics of the Test Pump

Figure 4 shows the change in temperature of the pump bearing as the test pump operates.

The bearing temperature, which was room temperature in the initial stage, increases rapidly as the pump starts to operate, but it can be observed that the equilibrium state is reached within a short time due to heat transfer to the outside atmosphere. At this point, by maintaining about 60 ℃, it can be confirmed that the temperature is lower than the reference temperature (75 ℃, see Table 3) suggested by the Korea Industrial Standard (KS B 6301).

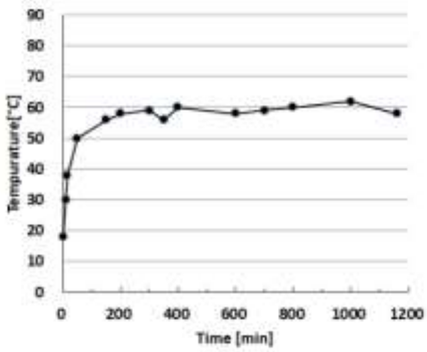


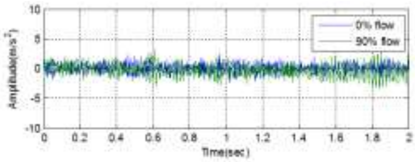
Fig.4 Pump bearing temperature curve

The ambient noise of the pump (measured 150 mm away from the pump) measured under normal flow operating conditions (design point flow rate Q = 100%) fulfilled the reference value of 85 dB. On the other hand, the noise measured under abnormal flow operating conditions (Q = 50%) increased up to 90 dB.

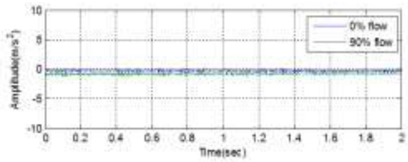
Vibration Characteristics according to Operation of the Test Pump

In order to understand the vibration occurred in the pumps and its characteristics affecting the pipes and valves connected to the pumps, the accelerations in the pumps, the pipes before and after the pumps, the valves at the rear end of the pumps and the pipes before and after the valves were measured(**Fig.5, Fig.6)**. **Figure 7** and **8** show the results of FFT analysis.

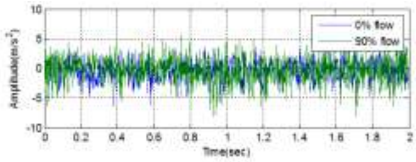
From **Figure 7 and 8**, it can be confirmed that the 60Hz vibration due to the motor RPM (3600RPM) occurred most extremely in the pump(s) that mainly caused excitation. Also, in the case of vibration characteristics in the vicinity of the pump, some vibration characteristics at frequencies such as 120 Hz, 180 Hz derived from the rotational frequency of 60 Hz was observed. The vibration characteristics in the pipe connected to the pumps, however, can be seen that most of the vibration of the main excitation frequency 60 Hz is transmitted.



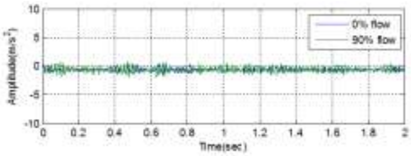
(a) pump inlet



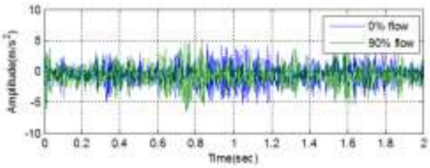
(a) valve inlet



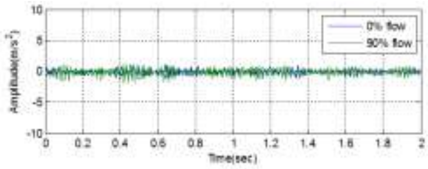
(b) pump



(b) valve

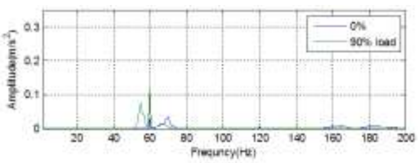


(c) pump outlet

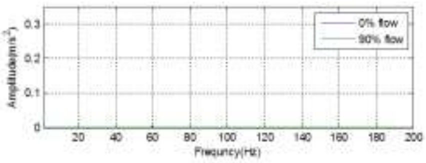


(c) valve outlet

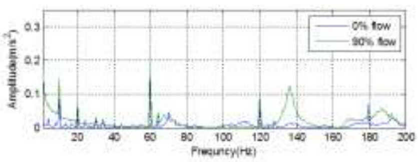
Fig.5 Vibration measurement at pump sideFig.6 Vibration measurement at valve side



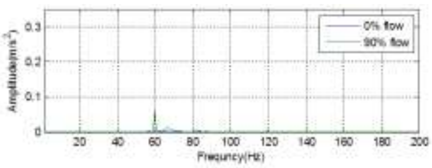
(a) pump inlet



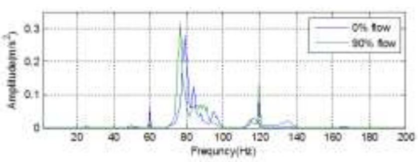
(a) valve inlet



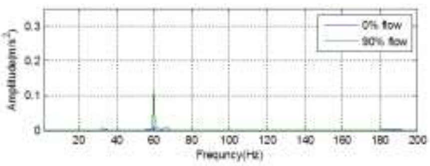
(b) pump



(b) valve



(c) pump outlet



(c) valve outlet

Fig.7 Results of FFT analysis at pump sideFig.8 Results of FFT analysis at valve side

Performance Evaluation by Accelerated Pump Aging

Figure 9 shows the change of the pump flow rate by the pump acceleration test in terms of the valve opening. The change in flow characteristics according to increasing accelerated operation time indicates that the valve opening degree is set low so that the influence of the acceleration test is not significant in the operating conditions where the flow rate through the pump is small. On the other hand, in the operating conditions where the valve opening degree is set high and the flow rate through the pump is large, the flow rate decreases as the operation time by the acceleration test increases.

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Figure 10 shows the change in flow rate at the valve opening (61.5%) corresponding to the pump design point flow rate. The solid lines (upper limit: red, lower limit: blue) in the figure indicates the criteria of the pump flow rate limit of KEPIC MOB 5200. From the figure, it can be seen that the flow rate decreases as the operation time by the acceleration test increases. In the repetitive operation range applied to this paper, although the acceptance criteria of the KEPIC were met, the flow rate through the pump gradually decreased and approached the lower limit even though the same load was applied.

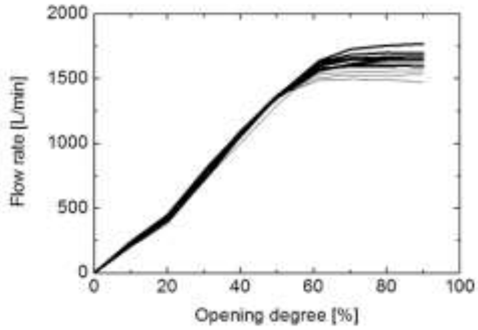

Fig.9 Flow rate by valve opening degree

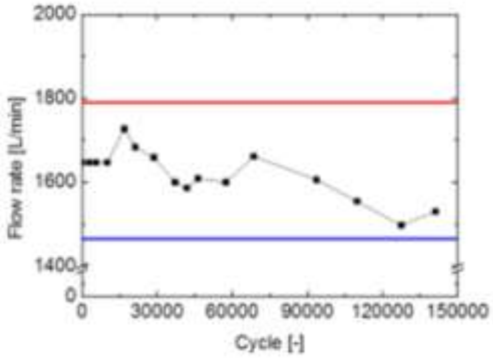

Fig.10 Flow rate at pump design point(Valve opening degree 61.5%)

Inspection after accelerated aging test

After the accelerated aging test on the test pumps (after about 1.4×10^5cycle operation), the post-disassembly inspection on the pumps was conducted to check whether the pumps were normal.

Figure 11 shows the picture of the disassembled pumps. As a result of the post-disassembly inspection, residues adhered to the pump casing were found, and SEM-EDS was performed to confirm the cause. The result is described in **Table 4.** According to the analysis results, it is determined that the unfiltered sludge such as beryllium (Be) and iron (Fe) derived from the use of industrial water, or the corrosion due to the carbon steel pipe adhered to the casing wall inside the pump. Also, it was confirmed that the interference between the impeller (a rotating part) and the casing (a non-rotating part) occurred so that some scratches on the wall and some looseness and spacing occurred. There was, however, no breakage or obvious deformation of the impeller or major components.

Table 4. Constituent on attached substance of pump

Element	Weight[%]	Atomic[%]	Net Int.	Error[%]
Be	68,58	73.17	11.59	9.23
B	29,28	26.04	48.05	12,86
C	0,45	0,36	5.57	18.78

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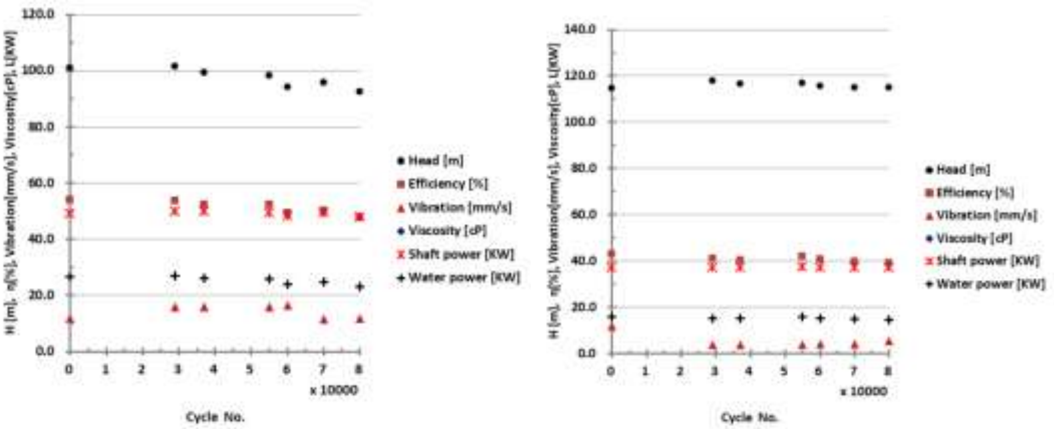
O	0,31	0.19	32.27	12,13
Fe	1,37	0.24	210.94	3.08

(a) casing(b) impeller
Fig.11 Inspection after pump test

Analysis of Pump Performance Degradation According to Long Term Operation
Figure 12 shows the change in the pump head (H), efficiency, vibration, lubricating oil viscosity, axial power, and hydraulic power at the pump design point flow rate (Q = 100%) and 1/2 of the design point flow rate (Q = 50%). As shown in the figure, each performance parameter decreases (decreases in performance) as the operation time increases (the number of acceleration cycles increases). First, the pump head (H) is larger at Q = 100% than Q = 50%. Besides, when comparing the hydraulic power and the axial power, the decrease of the former is slightly larger than the latter, and this caused the efficiency decrease. In addition to this, it is determined that the decrease in the pump head mainly caused the efficiency decrease.



(a) at Q=100%(b) at Q=50%
Fig.12 Pump performance

The main causes of the decrease of the pump head (H) at the same RPM, flow rate, and axial power conditions include impeller wear/damage, gaps between the impeller and the casing, and problems with the flow itself (cavitation).

Through the pump disassembly inspection in the previous section, it was confirmed that there was no issue in the impeller wear/damage.

The pump head decrease is more prominent at the design point Q = 100% than Q = 50%, and the vibration is also greater at Q = 100%. The velocity of flow is faster at Q = 100% than Q = 50%, and thus the static pressure is relatively low and cavitation may affect it. There is no change, however, in the net positive suction head as the operating time increases, so the direct relationship with the development/expansion of cavitation is not clear.

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Namely, the decrease of the pump head is considered as gap problem between the impeller and the casing, so to maintain the pump performance, it is very important to keep the looseness and the gap normal between the impeller and the casing through periodic maintenance.

4. CONCLUSION

In this paper, the performance change of the pump was experimentally evaluated through the accelerated lifespan test on a horizontal centrifugal pump commonly used in nuclear power plants. The results are summarized as follows.

(1) Performance decreases with increasing acceleration test time (increasing the number of acceleration cycles), prominent especially in the section with large flow rates.
(2) The decrease in performance is mainly due to the decrease of the pump head (H).
(3) The cause of the decrease of the pump head as the operation time increases is the looseness and spacing caused by the interference between the impeller and the casing.

5. ACKNOWLEDGEMENTS

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