Condition Monitoring for Fault Diagnosis of the Electro-Hydraulic Operator of a Main Steam Atmosphere Dump Valve

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1. Introduction

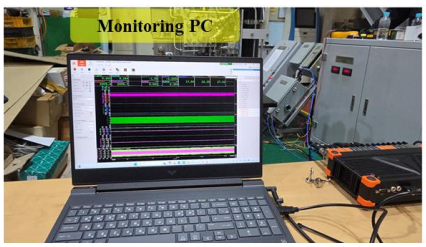
The Main Steam Atmosphere Dump Valve (MSADV) is installed in the main steam system of a nuclear power plant and discharges steam to the atmosphere when required to support reactor cooling. The electro-hydraulic operator (EHO) provides the hydraulic actuation required for MSADV operation. Because the MSADV remains predominantly in standby during normal plant operation, operational data obtained from actual valve strokes are limited, making continuous assessment of EHO condition difficult. Condition monitoring and prognostics and health management have therefore been investigated for nuclear power plant components using measured operating variables [1,2], and previous studies on hydraulic actuators have shown that pressure, temperature, position, and other process variables may provide useful information for condition assessment and fault diagnosis [3]. Although actual MSADV actuation is infrequent, the EHO continuously maintains accumulator pressure, and the hydraulic power unit (HPU) automatically recharges the accumulator when the pressure decreases below the cut-in level. In this study, representative EHO operating characteristics and the influence of ambient temperature on accumulator pressure were investigated to examine their potential use in condition monitoring and future fault diagnosis.

2. Experimental Method

2.1 EHO Condition Monitoring System

The EHO consists of a hydraulic actuator, accumulators, a hydraulic power unit (HPU), solenoid valves, pressure-control components, and associated instrumentation. During standby operation, hydraulic energy required for MSADV actuation is maintained in the accumulators. When the system pressure decreases below the cut-in setpoint, the HPU motor starts automatically and recharges the accumulators until the cut-out pressure is reached.

A multi-channel data acquisition system was configured to simultaneously monitor the major hydraulic, electrical, and mechanical parameters of the EHO. The actuator command and LVDT position signals were measured through 4–20 mA current loops, while oil and gas pressures were acquired from the 0–10 V outputs of the pressure transmitters. Clamp-type current sensors were installed on the HPU motor and solenoid valve power lines to measure current without interrupting the existing circuits. K-type thermocouples were used to measure ambient, motor-housing, and hydraulic-tube temperatures. Control and pressure signals were acquired at 2,000 Hz, while temperature signals were acquired at 250 Hz. For the long-term pressure-holding test, the temperature sampling rate was reduced to 10 Hz. The monitored parameters and data acquisition configuration are summarized in Fig. 1.



DAQ Channel	Monitored Parameter	Output	Test Case
CH1	Actuator Command	4–20 mA	Case2
CH2	LVDT Position	4–20 mA	Case2,3
CH3	Oil Pressure	0~10V	Case1-3
CH4	Gas Pressure	0~10V	Case1-3
CH5	Ambient Temperature	K-type	Case1-3
CH6	Hydraulic Tube Temperature	K-type	Case2
CH7	Motor Housing Temperature	K-type	Case2
CH8	HPU Motor Current	-10~10V	Case1,2

Fig. 1. EHO condition monitoring and data acquisition system.

2.2 Experimental Conditions

Three experimental cases were conducted to examine representative EHO operating characteristics under charging, actuation, and standby conditions.

In Case 1, the hydraulic pressure was released and subsequently restored to the normal operating range to investigate HPU charging behavior, motor-load variation, and pressure-control repeatability.

In Case 2, repeated opening and closing commands were applied to evaluate actuator response, stroke time, HPU cut-in/cut-out behavior, and thermal characteristics during cyclic operation.

In Case 3, the actuator position was maintained for an extended period while oil and gas pressures and ambient temperature were continuously monitored to examine long-term pressure retention and the influence of environmental conditions on accumulator pressure and automatic HPU operation.

These three cases were selected to characterize the major operating states available for EHO condition assessment during normal service.

3. Results and Discussion

3.1 HPU Charging and Repeated Actuation

Cases 1 and 2 were conducted to characterize the EHO operating behavior during initial HPU charging and repeated actuation. In Case 1, the motor peak current and cut-out pressure showed little variation between the two tests, whereas the initial gas pressure and charging time varied with ambient temperature. A lower ambient temperature was associated with a lower initial gas pressure and a longer charging time, indicating that the thermal condition should be considered when evaluating HPU charging behavior.

In Case 2, the LVDT response delay and the opening and closing times showed highly consistent behavior during repeated actuation. The HPU cut-in and cut-out pressures also showed little variation between the two tests, indicating consistent pressure-control behavior. The representative operating characteristics obtained from Cases 1 and 2 are summarized in Table 1.

Table I: Representative Operating Characteristics of Cases 1 and 2

Test Case	Parameter	Result
Case 1	Peak Current	13.39–13.41 A
	Initial Gas Press.	1,899–2,036 psi
	Charging time	60.57–71.08 s
	Cut-out Press.	2,930–2,933 psi
Case 2	LVDT Delay	0.260–0.261 s
	Opening time	22.0–22.3 s
	Closing time	23.4 s
	Cut-in / Cut-out Press.	2,668–2,669 / 2,918–2,919 psi

3.2 Long-Term Pressure Behavior and Temperature Effect

In Case 3, the EHO was monitored for 76 h under standby conditions to examine long-term pressure-retention behavior. During the test, the actuator position remained nearly unchanged, whereas the oil and gas pressures varied with ambient temperature. As the ambient temperature decreased, the accumulator pressure also decreased, and the HPU was automatically activated when the pressure reached the cut-in level. This behavior indicates that pressure reduction during standby should be interpreted together with environmental temperature rather than being attributed directly to hydraulic leakage.

To reduce the influence of temperature variation, pressure changes were compared under approximately equal-temperature conditions. The results showed that the apparent pressure-loss behavior varied depending on the thermal history of the hydraulic system, particularly before and after HPU recharging. The long-term pressure behavior was further represented using the following pressure–temperature relationship:

$$P(t) = P_0 + k_T \cdot (T - T_0) + k_t \cdot \Delta t + C_0$$

where P_0 is the initial pressure, T_0 is the reference temperature, k_T is the pressure–temperature coefficient, k_t is the time-dependent pressure change rate, and C_0 is the offset correction term.

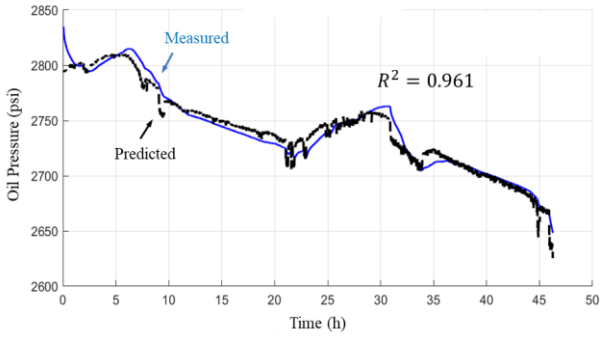


Fig. 2. Comparison of measured and predicted oil pressure during the long-term monitoring test.

As shown in Fig. 2, the predicted oil pressure showed good agreement with the measured pressure, with an R^2 value of 0.961. These results suggest that both ambient-temperature variation and time-dependent pressure change should be considered when evaluating EHO pressure-retention behavior during standby operation.

4. Conclusions

This study examined the operating characteristics of the EHO used in an MSADV for their potential application to condition monitoring and fault diagnosis. The initial charging and repeated-actuation tests showed consistent trends in motor current, actuator response, pressure-control behavior, and HPU recharging characteristics. Long-term monitoring showed that accumulator pressure was influenced by ambient temperature, indicating that pressure changes during standby should be evaluated together with environmental conditions rather than being attributed directly to hydraulic leakage. The pressure–temperature relationship also showed that temperature-related variation and time-dependent pressure change can be

considered together when interpreting long-term pressure behavior. These results suggest that combined monitoring of pressure, temperature, motor current, actuator response, and HPU operation may provide useful information for evaluating changes in EHO operating condition.

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REFERENCES

[1] J. B. Coble, P. Ramuhalli, L. J. Bond, J. W. Hines, and B. R. Upadhyaya, Prognostics and Health Management in Nuclear Power Plants: A Review of Technologies and Applications, Pacific Northwest National Laboratory, PNNL-21515, 2012.
[2] International Atomic Energy Agency, On-Line Monitoring for Improving Performance of Nuclear Power Plants, Part 1: Instrument Channel Monitoring, IAEA Nuclear Energy Series No. NP-T-1.1, Vienna, 2008.
[3] S. Adams, P. A. Beling, K. Farinholt, N. Brown, S. Polter, and Q. Dong, Condition Based Monitoring for a Hydraulic Actuator, Proceedings of the Annual Conference of the Prognostics and Health Management Society, 2016.