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Power-operated check valve in abnormal situations

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ABSTRACT

Standard swing disk check valves are typically operated by pressure difference. Alternatively though, the valves might be operated by an active driving force when they cannot be operated by the pressure difference. If this simple concept is realized, the reliability of the check valve could be improved since a great portion of abnormalities currently leading to failure can be corrected. With this intention, this paper proposes a power-operated check valve and describes important factors to be considered. Through an effectiveness analysis, it was verified that the proposed concept significantly improved reliability in an example safety system.

1. Introduction

A check valve is an essential component in a wide range of hydraulic systems, with the basic function to direct flow in one direction and prevent reverse flow. In the case of safety system applications, proper functioning of the check valve is essential to prevent critical consequences. For example, in the optimized power reactor (OPR) 1000, it was analyzed that the contribution of check valve failures to the auxiliary feedwater system (AFWS) failure could be up to 74.3% for some accident scenarios, such as loss of coolant, general transient, loss of main feedwater, and loss of condenser vacuum.

Traditionally, in order to improve the reliability of safety systems containing check valves, redundancy and diversity principles have been applied at the system level, and monitoring, maintenance, and repair-related activities (Mochizuki, 2000; Lee et al., 2004; Seong et al., 2005; Lee et al., 2006; Yan et al., 2015) have been the focus of study at the component level. However, these are all basically the same in that they still treat the traditional working mechanism—passive operation by pressure difference in the forward direction. It is interesting that while a check valve may also be operated by an active driving force when it cannot be operated normally, this approach has not been typically applied to the design of nuclear safety systems.

This study therefore suggests a practical method for the development of a power-operated check valve as well as factors to be considered. This approach will be a relatively efficient way when compared to the redundancy and diversity concepts that may increase system complexity and result in considerable construction costs.

To realize this approach, various additional components should be considered to diagnose any abnormal situations and for forced operation; however, these additional parts should not cause any adverse effects during normal passive operation. When forced operation is possible for some major abnormal situations, the reliability of the check valve can be improved and therefore many abnormalities will not lead to failure.

This article is organized as follows. In Section 2, the functional requirements of the power-operated check valve are identified. Then, a conceptual design of the check valve satisfying the functional requirements is suggested in Section 3, with its quantitative effect demonstrated via an example safety system in Section 4.

2. Functional requirements

2.1. Sequences of check valve operation

Although the failure modes of check valves can be classified into several categories, the failures of the check valve in this study are divided into two cases—failure to open and failure to close—since the probabilistic safety assessment (PSA), which is a reliability analysis method in nuclear safety systems, mainly considers these two failure modes.

In the case of safety systems, the check valves are in a closed state during normal situations and open only for accident situations. Thus, when the closed state is regarded as the initial state and forced operation is assumed possible, all possible state sequences can be expressed as in Fig. 1. In this figure, situation 1 indicates that the valve disk should be opened from the current closed state, and situation 2 indicates that the valve should be closed from the current opened state.

In Fig. 1, $\overline{C}$means not closed and $\overline{O}$means not opened. For forced

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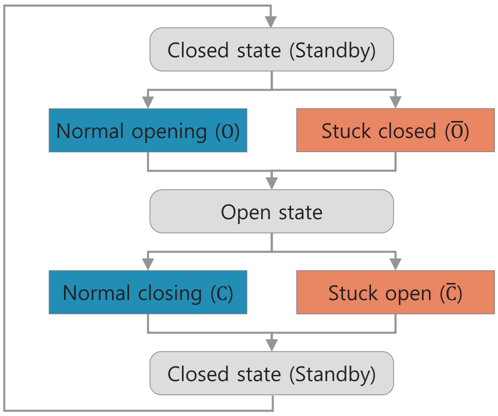

Case	Situation 1	Situation 2
A. Normal operation	O	C
B. Stuck open	O	$\bar{C}$
C. Stuck closed	$\bar{O}$	C
D. Stuck closed and open	$\bar{O}$	$\bar{C}$

Fig. 1. Check valve states in sequence.

operation, as a first step, occurrence of stuck failure at any sequence needs to be identified properly; currently though, there is no means for this purpose in existing general check valves. Proper information for situation identification should therefore be obtained.

2.2. Two conditions for situation identification

To clearly identify the current situation, two pieces of information are required: the position of the valve disk, and the pressure difference. The current position of the valve disk can simply be recognized by coupling an indicator to the end of the hinge pin that is connected to the valve disk (Val-matic, 2017), while the current pressure difference can be checked by measuring the pressures on each side of the valve disk. This measurement can be made by a number of related well-developed techniques; a specific method though is not described in this paper as it is outside the present main focus.

After obtaining the information regarding valve disk position and pressure difference, the current situation can be identified as follows. A stuck closed failure has occurred when the indicator displays the closed position even though there exists a pressure difference above the designed level in the forward direction. A stuck open failure has occurred when the indicator displays the open position despite no pressure difference. Except for these two failures, all situations with a closed position and no pressure or backward pressure difference, and those with an open position and a pressure difference in the forward direction are regarded as normal. The according situations are arranged in Table 1.

2.3. Functional requirements for each situation

To address the stuck failures, some additional components clearly need to be adopted that should not cause any adverse effect on normal operation, while maintaining the ability of forced operation for abnormal situations. For this purpose, established principles and functional requirements covering all the cases in Fig. 1 are described in this section.

- The established principles are as follows:
- During standby state, spurious opening caused by the additional parts should be prevented.

Table 1
Situations according to valve position and pressure difference.

Valve position	Pressure difference	Situation
Close	In the forward direction	Stuck closed
	Zero, or in the backward direction	Normal
Open	In the forward direction	Normal
	Zero, or in the backward direction	Stuck open

- Normal operation according to pressure difference should not be obstructed because of the additional parts.
- The additional parts should be able to work in any abnormal situation.

The functional requirements for each situation and case from Fig. 1 are listed in Table 2.

The readiness configuration of the additional parts for the first sequence should cover all following possible sequences (second sequence). Likewise, as the second sequence precedes the first sequence again, the functional requirements for each sequence should be treated in consideration of the possible next sequence. For example, the configuration of the additional parts at the end of A-1 (or B-1) should be also the configuration for B-2 (or A-1); this applies to cases C and D as well. To realize this, the neutral configuration of the additional parts is considered. After all sequences, the configuration of the additional parts must automatically return to neutral position, available for all possible next sequences. A conceptual and practical design satisfying these functional requirements is given in the next section.

3. Conceptual design of the power-operated check valve

3.1. Configuration

A conceptual power-operated check valve satisfying all the functional requirements in Section 2 is designed based on the swing type check valve. Assembled and disassembled schematics of the valve are shown in Figs. 2 and 3, respectively.

For forced operation, it is essential to adopt an active driving force. If the active driving force is directly connected to the valve disk, it will obstruct the rotation of the disk during normal operation according to pressure difference. Yet, power should be delivered to the valve disk when a stuck failure occurs. Therefore, the active driving force is semi-connected to the valve disk by using a guider groove and valve control lug Fig. 3. The valve control lug can move freely within the guider groove during normal operation, and in abnormal situations, the active driving force can deliver power to the valve control lug by rotating the guider groove. Although various kinds of active driving force can be applied to the guider, this study considers a motor as an example driving force, which is connected at the top of the circumference gear of the guider to deliver power. Another important component is the mass connected to the guider, which functions to return the guider to its neutral position by gravity after forced opening or closing. During forced operation for both open and close strokes, the guider components rotate together with the valve. After this operation, the guider needs to return to its neutral position in order to ensure free movement of the valve without interference: the mass connected to the guider performs this function. If the motor is in contact with the circumferential gear, the weight of the mass should provide sufficient force to