Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2016,28(4):629-636
DOI: 10.1016/S1001-6058(16)60667-4
www.sciencedirect.com/
science/journal/l0016058

Numerical simulation of flow characteristics for a labyrinth passage in a pressure valve*

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(Received April 3, 2015, Revised March 3, 2016)

Abstract: A tortuous labyrinth passage consists of a series of right angle turns in a disk of high pressure control valve. In this paper, numerical simulations are made for the velocity and pressure distributions in this passage. It is shown that the “series passage” can induce a pressure dropping more effectively. The main function of the “series passage” is to induce a pressure dropping while the “parallel passage” is mainly to regulate the flow-rate. As a cross sectional area process, a series of reduction and expansion, the pressure will also see dropping and partial recovery, which is called the multistage pressure drop. By this way, the velocity can be controlled in a reasonable level anywhere in this tortuous labyrinth passage. With the fluid pressure dropping in a downwards serrated way, the pressure is higher than the local saturate vapor pressure, therefore, no cavitation is induced by the phase transition.

Key words: tortuous labyrinth passage, right angle turns, multistage pressure drop, pressure recover

Introduction

The high pressure pump recirculation is one of the most difficult issues and severe duty control valve installations are demanded by the power industry. There are two significant features in this respect. First, the flow must be controlled during a very high pressure drop and second, when not in the controlling flow mode, a tight leak proof shut off is required. Failure to achieve either of these functions will quickly result in a plant shutdown or the loss of the valuable energy over an extended period[1].

The recirculation valve must perform two important functions[2]. Firstly, it must control the fluid during the large pressure letdown while it is open at all plug positions and secondly, it must ensure that there is no leakage when the valve is closed. This paper will focus on the control of the large pressure drop[3]. The kernel throttling component is a stack formed by welding a number of disks together, and each disk consists of a few tortuous paths just as shown in Fig.1[4].

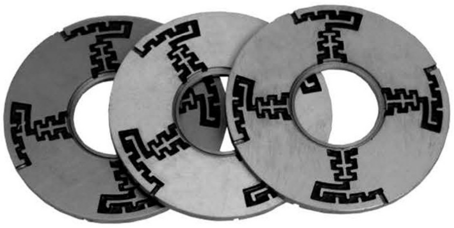

Fig.1 The disks with 4 tortuous paths on both sides

Figure 1 shows three significant features of the disk channel. (1) Right angle turns. To yield a great pressure drop and to consume the energy of the fluid, a series right angle turns make up the passage. (2) Expanding passage size. The flow area is continually

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* Project supported by the National Natural Science Foundation of China (Grant Nos. 51176127, 51106099), the Shanghai Science and Technology Commission (Grant No. 13DZ2260900).

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increasing as the fluid pressure decreases. (3) Large number of stages. When the fluid flows through a right angle turn, the pressure will drop at once and then we will see a expanding size, the pressure will recover partly, thus the fluid will experience a number of stages before it flows into the pressure equalizing ring.

As the pressure drop in the passage is mainly caused by the loss of the local resistance. The structure of the passage and the boundary conditions are both the key factors that determine the pressure drop results[5]. Many types of orifices or orifice tubes were used to yield a high pressure drop. For example, as the flow zoning in the different subassemblies of the reactor core is formed by installing permanent pressure dropping devices in the foot of the subassembly, Pandey et al.[6] developed orifices having a honey-comb type geometry to meet the requirements of a fuel zone for the flow zoning. Senocak and shyy[7] studied the pressure loss characteristics of the square-edged orifice and the perforated plates. Wu et al.[8] modeled hydraulic control systems that contain flow modulation valves, and the results are highly influenced by the accuracy of the equation describing the flow through an orifice. Abou El-Azm et al.[9] investigated the pressure drop after such fractal orifices and measured the pressure recovery at different stations downstream the orifice. Jankowski et al.[10] developed a simple model to predict the pressure drop and the discharge coefficient for incompressible flow through orifices with length-to-diameter ratio greater than zero (orifice tubes) over wide ranges of Reynolds number.

The tortuous passage is widely used to reduce the fluid pressure through multistage throttling in many engineering applications. In our previous work, different passages were used to produce the multistage pressure drop and they were studied by experimental and CFD approaches[11,12]. Xia et al.[13] proposed a new modified relation for predicting the pressure drop in the helical rectangle channel. Moraczewski and Shapley[14] investigated the pressure drop of concentrated suspensions flowing through an axisymmetric contraction-expansion channel at a low Reynolds number. The passage structure and the boundary conditions are both the key factors that determine the pressure drop results. Adachi and Hasegawa[15] studied the transition of the flow in a symmetric channel with periodically expanded grooves. Zhang et al.[16] performed a multi objective optimization to improve the structure of trapezoidal labyrinth channels. Pfau et al.[17] presented a highly resolved experimental data set taken in an inlet cavity of a rotor tip labyrinth seal. Parvaneh et al.[18] revealed the hydraulic performance of asymmetric labyrinth side weirs located on a straight channel. Crookston and Tullis[19] increased the discharge capacity and the hydraulic efficiency of a labyrinth weir with an Arced cycle configuration. Novak et al.[20] focused on the flow at the side weir in a narrow flume.

In this paper, the tortuous passage investigated is different from previous studies, especially, the geometric configuration and the passage size. The distinctive feature of the passage is the narrow dimension, with the smallest cross section being only 0.0025 m× 0.0040 m. Based on this structure, the CFD approach will be used to analyze the pressure drop and the pressure loss coefficient under different operation conditions.

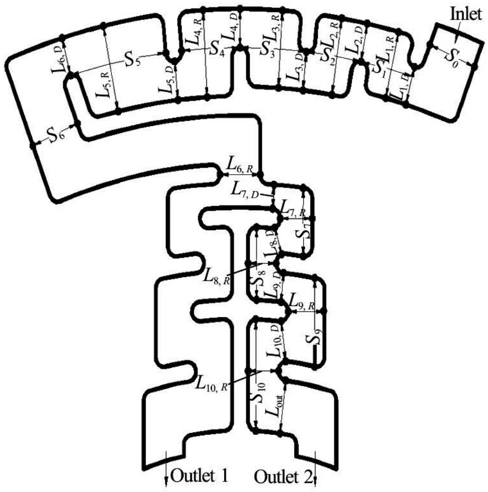

Fig.2 The geometric configuration of a labyrinth passage (prototype)

1. The geometric features of labyrinth passage

The sketch of a labyrinth passage is shown in Fig.2, where the flow direction and path are shown. The flow enters the tortuous pathway and flows inwardly to the plug. Each flow channel consists of several right angle turns (stages), which accounts for more than one velocity head of the pressure drop. With the flow area continually increasing, the fluid pressure decreases. Thus the velocity is continuously reduced to a very reasonable level at the expanding passage section. There are no local pressure recovery points for the cavitation to take place in the pathway such as what occurs with a drilled hole type pathway. This is the one of the great advantages of the labyrinth passage as compared to the hole type ones.

There are 24 right angle turns in this labyrinth passage. In order to illustrate the features of right angle turns and expanding passage size, along the flow direction, a series of dimension sizes are defined in Fig.2, such as the inlet S_0, the first throttling section $L_{1,D}$, and the first expanding space in the tangential and normal directions S_1, $L_{1,R}$ and so on. All these sizes are given in Table 1.