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Studies of flow and cavitation in hydraulic lift valve

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ABSTRACT

This paper presents the results of experimental studies of the phenomena connected with the flow of the working medium in the throttling orifice of the conical head-bevelled or feather-edged seat unit. The critical Reynolds number demarcating the laminar flow from the turbulent flow for the particular conical head-bevelled or feather-edged seat units has been determined on the basis of visualization studies. The dependence between flow ratio C_v and the Reynolds number has been determined for the dilation angle of the conical valve heads and the length of the seat generating line. Acoustic and cavitation tests have shown that valve heads with the smallest dilation angle and the highest critical velocity are characterized by the lowest level of noise in the throttling orifice at which cavitation occurs.

1. Introduction

Owing to their numerous advantages hydraulic poppet valves are commonly used in practice. A typical structural valve node, i.e. a conical head-seat unit, was subjected to analysis to determine the effect of its geometric parameters on the character of the flow of the working medium in the valve orifice and on the level of the noise emitted by the valve. The noisiness of hydraulic components and systems is the subject of EU regulations in the form of obligatory requirements which a machine or a piece of equipment must satisfy in order to be admitted to the market in the EU countries.

Also the relatively high noisiness of microhydraulic system is a major problem. Because of the low flow [1] ($Q_{max} < 5 \times 10^{-5}$ m^3/s, i.e. 3 dm^3/min) in such systems their power is also low, whereas the EU directives [2] relate the permissible level of noise emitted by a mechanical device to the transmitted power. The noise level permissible in microhydraulic systems is relatively low and despite the advantages of this kind of drive it cannot always be used due to the exceedance of the recommended standard indices [3]. One of the major sound generating sources in hydraulic and microhydraulic systems is the unstable operation of the relief valves excited by, among other things, external excitations originating from the vibrations of the machine frame or the feeder cover, on which hydraulic relief valves are often mounted [4]. Therefore the coincidence of the frequency ranges of the mechanical vibrations of, e.g., the foundation with the resonance range of a hydraulic or microhydraulic valve control element (the resonance frequencies of the valve control elements are different in the two cases) should be avoided. This is sometimes achieved through the use of vibration isolators on which hydraulic valves can be mounted to minimize the transfer of vibrations to the valve housing, and so to the control element [5]. Another cause of the vibration of the overflow valve head is the implosion of vapour bubbles, which contributes to noise intensification [6]. In [7]

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the author states, on the basis of the cited literature, that the instability of the overflow valve head is due to: (a) the coupled motions of the head and other system components, (b) the transition of the laminar flow to the turbulent flow, accompanied by an increase or decrease in head displacement, (c) the negative flow restoring force, (d) the pressure difference between valve opening and closing and (e) the fluctuation of supply pressure. Considerable attention is devoted to demarcating local valve stability areas and describing them as well as to the self-excited vibrations of the valve control element. As suggested in [8], an improvement in valve stability can be achieved by increasing damping in the valve, whereby the formation of instability areas can be prevented. In [9] the authors indicate that a working overflow valve emits excessive noise when the ratio of socket bevel length s to orifice height h in the head-nonfeather-edged seat unit is within a range of 1–2.5 for a diverging flow.

Because of the difficulties in investigating the phenomena connected with the flow of the working medium in size-reduced hydraulic elements (or microelements), experimental studies are sometimes conducted on a model element larger than the actual one and appropriate similarity criteria are applied [10,11].

Taking into consideration the literature on the subject, as part of this research an attempt was made to describe the dependence between flow ratio C_v and the Reynolds number for different geometries of the head-seat configuration on the basis of experimental studies. Exemplary results of visualization studies of the working medium flow through the orifice of the overflow valve and results of the measurement of the accompanying acoustic effect are reported. Cavitation is indicated as a significant source of noise, which is confirmed by the literature, e.g., [6]. The experimental studies were carried out on original test stands, which are presented in this paper. The investigated valve was placed in a sound chamber in order to minimize the influence of any disturbing factors.

2. Investigated object

The analysis and the experimental studies focused on a structural node commonly used in lift valves (relief valves, logic valves, distribution valves, etc.), i.e. on the seat-conical head unit. This solution is most readily used in practice owing to the merits of poppet valves, mainly the ease of manufacture (and so low costs), resistance to pollutants and the high leaktightness of the valve in the closed mode [12]. The basic seat-head node adopted for the analysis is shown in Fig. 1.

Valve heads with a positive dilation angle and with a feather-edged seat (Fig. 1a), with a bevelled seat and a positive dilation angle (Fig. 1b) and with a negative dilation angle and a bevelled seat (Fig. 1c) were analyzed.

The aim of the experimental studies carried out on a relief valve model with exchangeable sleeves with a proper seat and a corresponding conical head was to determine:

- the pattern of the flow in the valve orifice,
- the dependence between flow ratio C_v and the shape and the Reynolds number.

Fig. 2 shows an axial cross section of the model experimental valve. Housing *1* contains exchangeable sleeve *2* which constitutes a valve seat. Head 3, loaded with spring 4 from top, constitutes a closing component. The initial tension of the spring is adjusted by means of adjusting screw 5. By replacing sleeve *2* and head *3* one obtains different head-seat configurations. Ferromagnetic core 6, which together with coil *7* forms a gauge for measuring head displacements, is rigidly connected to the head. Connector *8* with a fine thread is used to set the gauge to zero. Epoxy resin was used to seal the hole through which the wires of the displacement gauge pass. The other valve components were sealed with rubber O-rings. The diameter of the liquid inlet channel was $d = 10$ mm. A radial hole for installing a pressure pickup was made in the sleeve and in the housing. The outflow from the valve took place through two holes symmetrically located around the head, whereby the latter was symmetrically loaded with transverse forces.

3. Measurement of flow ratio C_v of conical head-seat unit

The flow of a viscous fluid through a throttling element of any shape can be described, in accordance with theorem π (the Buckingham theorem) of the model theory, by the following equation [10]:

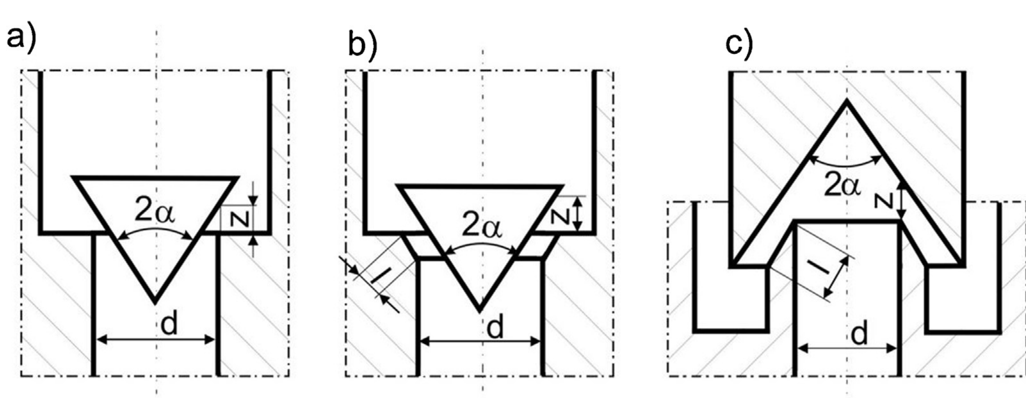

Fig. 1 – Seat-head configuration adopted for analysis: *d* is the seat diameter, *l* is the seat generating line, *z* is the head lift, 2*α* is an angle of dilation of conical head, a, b – positive angle of dilation, c – negative angle of dilation.