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Development methodology for a pulsation damper of gas control valves

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Abstract

The background for the proposed methodology is based on the principle of stage throttling with simultaneous equalizing and stabilizing the outflow, as well as elimination of gas-dynamic self-oscillating modes of the control valve. Having conducted an analysis of suppression and dampening means and according to established patterns of occurrence of self-oscillations we have suggested an integrated pulsations damper performing the following functions: elimination of gas-dynamic self-oscillations, reducing pressure pulsations in the source by reducing pressure drop, stage throttling with a reduced flow rate and outflow stabilization. A distinctive feature of our methodology is combining experimental dependencies with numerical simulation of natural modes and gas-dynamic processes taking place in the control valve and pressure pulsation damper. As initial data for designing the damper we have set its desired efficiency while ensuring specified operating modes of the gas distribution station and specified restrictions on dimensions and hydraulic resistance. The methodology allows for a significant reduction of broadband pressure pulsations and vibration by the damper due to the rational and maximum permissible distribution of pressure differences in the control valve and damper under operating conditions in which the total vibrational power of the control valve and damper is maintained close to the minimum.

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Keywords: Gas pipeline system, control valve, pressure ratio, pressure drop, pressure pulsations, noise, damper.

1. Introduction

Gas pipelines control valves operation is accompanied by intense pipelines vibration and external noise. Allen Fagerlund, Denis G. Karczub and Tucker Martin in their work [1] pointed out that pipeline assembles are a potential source of high-level broadband and tonal dynamic loads. In order to reduce these loads, pressure pulsation dampers

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(PPDs) are used which are installed behind control valves or inside them. This article describes methods of designing effective PPDs which eliminate gas-dynamic self-oscillations and reduce broadband spectrum components of vibro-acoustic parameters. Issues of eliminating gas-dynamic self-oscillations were considered in detail by the authors in [2].

An important factor that affects efficiency of the PPD is correct distribution of pressure drops between the control valve and the damper [3]. When a gas distribution station (GDS) is operating in its constant duty (characterized by inlet and outlet pressures and gas flow rate), the greater the pressure drop at the damper, the less the pressure drop is on the control valve, and therefore, the less its vibrational (acoustic) output is. However, it results in increasing inherent noise of the damper, as well as in increasing the likelihood of loss of control valve performance due to its full opening and setting its control unit lever into a "full throttle" position. Therefore, while developing a PPD it is necessary to ensure the distribution of pressure drops on the control valve and the damper in such a way that their total vibrational power would be lower while maintaining control valve performance.

2. The theoretical part

Gas flow rate in throttling elements is determined by a pressure ratio β. The outflow power of the control valve as an oscillation source is known to be primarily associated with its velocity, which in turn is determined by a pressure ratio $\upsilon_i=f(\beta_i)$, where $\beta_i=P_{out}/P_{in}$, i.e. according to Saint-Venant formula [4, 5]:

$$\upsilon_i = \sqrt{\frac{2k}{k-1} \cdot R \cdot T_{in} \cdot \left(1-\beta_i^{\frac{k-1}{k}}\right)} = f(\beta_i), \text{because} \frac{2k}{k-1} \cdot R \cdot T_{in} \approx \text{const} \tag{1}$$

Based on the above, the choice of β values for the control valve (β_{CV}), as well as for the damper stages (β_i) is an important stage of a PPD design. For the purpose of rational distribution of the pressure drop on the control valve and damper defined by values β_{CV} and β_{PPD}, calculation of dependency of pressure pulsations level of the outflow of the control valve from β_{CV}, $L_{CV}=f(\beta_{CV})$, according to ANSI/ISA-S75.17-1989 standard are carried out [6]. The choice of this method is defined due to many factors in the gas flow in control valves, including changes in flow patterns and their relation to acoustic characteristics. According to this method of determining $L_{CV}=f(\beta_{CV})$ the following main parameters are calculated.

Acoustic power of throttling element (control valve).

$$W_a = \eta_a \cdot W \,, \tag{2}$$

where W – mechanical flow power, Watt; η_a– acoustic ouput.

Acoustic output.

$$\eta_a = 10^{-4} \cdot M_i^{3.6...6.6} \,, \tag{3}$$

where M_i – Mach number.

Pressure pulsation level behind the control valve.

$$L_{CV} = 10 \cdot \lg\left(C \cdot W_a \cdot \rho \cdot a \cdot D_P^{-2}\right), \tag{4}$$

where C – numerical constant, $8{\cdot}10^8$; W_a – acoustic power, Watt;ρ – medium density, kg/m^3; a – acoustic velocity in the medium, m/s; D_P – pipeline diameter, mm.

Determination of dependency $L_{CV}=f(\beta_{CV})$ is carried out at a constant inlet pressure P_{in} and mass flow G. Dependence $L_{CV}=f(\beta_{CV})$ is shown in Fig. 1.