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Experimental study in reduction of two phase flow induced vibration

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Abstract. Vibration in mechanical devices is one of the major problems in engineering field including power generated industry. In this study we focused on the method and possible equipment design availability in reduction of vibration level. A brief overview of the outcomings of pipeline vibrations is presented, the sources of vibrations are listed and possible solutions for eliminating vibrations are described. Devices for passive quenching of pressure pulsations in pipelines with a two-phase flow are considered. We presented the description of the experimental stand on the investigation of the influence of a two-phase flow on the vibration of sections of a pipeline under different flow patterns of a coolant, as well as the procedure for conducting an experiment to study the properties of developed and manufactured swirl models. An animated model was developed that reflects the relationship of swirl geometry with the reduction of the vibro-displacement of the pipeline as a result of passive action on a two-phase flow.

1 Introduction

In industrial systems, it is quite often to observe destructive vibrations causing acoustic and noise problems due to hydrodynamic forces acting on the structures or the loading lines. Flow induced vibration (FIV) can cause severe damage to the piping system of the industrial machineries including system failure. Michael G. Porter et al. (1974) reported in their study [1] that because of sustained high amplitude vibrations there can arise problems regarding misalignment, equipment malfunction and structural failure which are very expensive in terms of down-time and component replacement. In case of two-phase flow, due to the combination of stratified flow with separated flow it happens to start occurring unstable flow in terms of oscillations or flow reversals. Two-phase flow is frequently occurred phenomena in plants where boiler produces vapor. This mechanical vibration undermines the operational reliability, maintenance and safety issues of the industrial system.

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2 Methodology

Currently, there are various ways to implement vibration reduction in practice, one of which is the installation of swirling devices - swirlers. They provide twisting in the flow, partial separation of steam and water which leads to the generation of a circular flow regime. An experimental study was done in the laboratory of Ural Federal University to conduct the experiment using different kind of vortex inserts to investigate the hydrodynamic flow characteristics. FIV is driven by flow velocity and results from turbulent mixing with boundary layer separation and pressure pulsations at bends, tees, reducers etc. [2]. By using passive device within the pipeline it is possible to lessen the vibration level in some degree. Regarding this, a number of passive devices have been modeled and designed based on the sizes and number of inside spiral cuts. At low velocities and relatively low flow rates of the two-phase flow (Re <3000), the screw type vortex inserts, involute swirlers work quite efficiently. V. Peter et al. (2003) [3] reported in their article that, the direction and magnitude of resulting force vector depend on the piping layout and for curved piping systems resulting force vector appears as the combination of two vectors from adjusted straight pipes. To measure the vibration characteristics and parameters of the two-phase mixture on the unit prior to modernization, the following test equipment was used: a manometer; Sapphire-22DD flowmeters; Vibration analyzer SD-12M. Siba M. et al. (2016) [4] reported that it was until mid-twentieth century when the nuclear technology emerged, vibration caused a serious damage of those power plants. Researchers, governmental institutions including some private agencies came out to keep a documentation of the possible damage [5-8]. In our study the flow velocity was determined by the formula:

$$W = \frac{Q}{\pi \cdot d^2 / 4 \cdot 3600} \tag{1}$$

where Q is the volumetric flow rate in m^3/h and d is the diameter of the swirler insert in mm. Using the flow velocity, we can determine the Reynolds number (Re):

$$\mathrm{Re} = \frac{W \cdot d}{\nu} \tag{2}$$

where ν is the fluid viscosity. Using the obtained and calculated values, we calculate the hydraulic resistance of the investigated insert-swirler in terms of head loss (Δh), length (L) and local acceleration due to gravity (g)

$$\lambda = \frac{d \cdot 2g \cdot \Delta h}{L \cdot W^2} \tag{3}$$

3 Experimental set up

To study the influence of two-phase flow regimes on the pipeline vibration and the utility of the model passive device, an experimental stand was developed in our laboratory. The framework of the values of vibration acceleration, vibro-speed and vibro-displacement of the pipeline were determined using the SD-12M vibration monitoring sensor under various flow regimes in the range of Reynolds numbers 2000 <Re <4000. At the Department of Nuclear Power Engineering, Ural Federal University a low-pressure stand was developed and designed to investigate the vibration of pipelines.

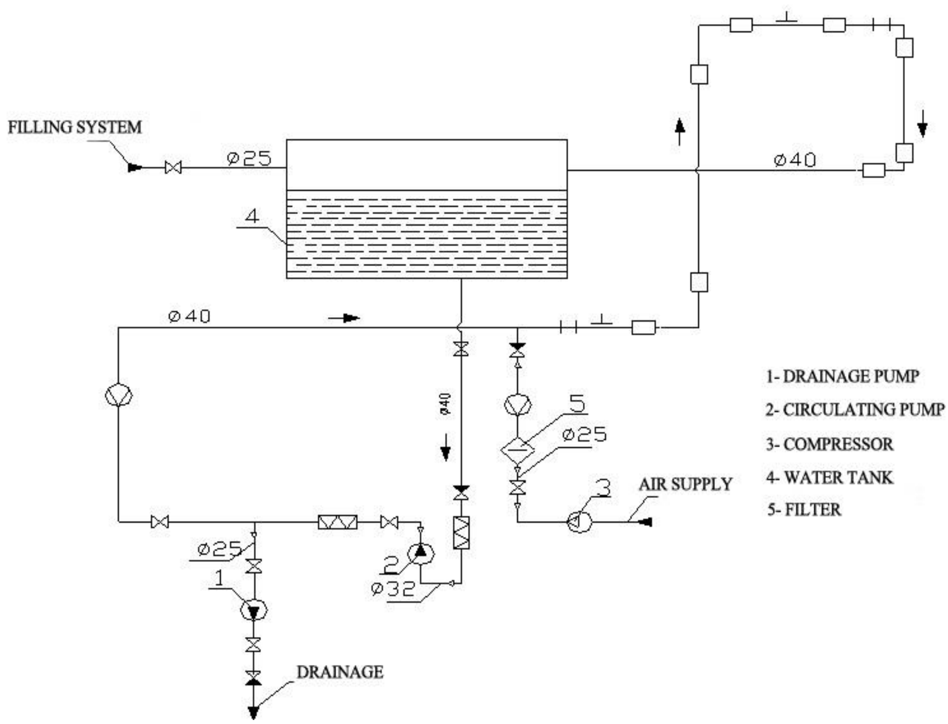

Figure 1. Schematic diagram of the experimental stand

The basis for the development of this stand was the need for industries with extended sections of pipelines in reducing the destructive effect of vibrations that occur during various modes of flow of a two-phase coolant. In Figure 1 the scheme of the experimental stand, which is a closed pipeline, with characteristic areas in which oscillations most often occur, was presented. On the sites there are areas for installing sensors of the SD-12M vibration analyzer. For visual observation of the flow structure, the stand is equipped with visualization nodes. Simulation of a two-phase flow is accomplished by creating a water head with a circulation pump and introducing air through the compressor into this airflow. Tank capacity is of 2000 litre and manometer measures the reading in the range 1-100Pa, Insert material is made of stainless steel. In the reservoir with water, an additional swirler insert and two pressure transducers were installed and displayed on the pressure gauge for the purpose of measuring and processing experimental data on the hydraulic resistance. The test section and the arrangement of the devices are shown in (Figure. 2).

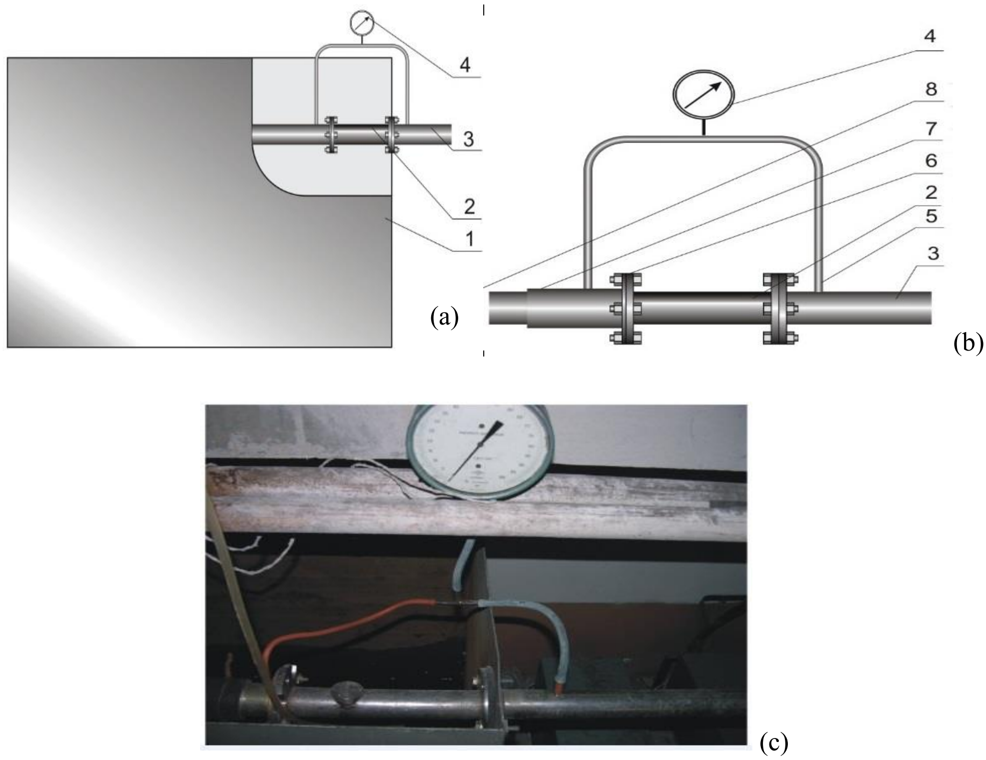

Figure 2. (a) Scheme of the stand section-change in the hydraulic resistance (1-Water tank, 2-Insert swirler, 3-Pipeline, 4-Measuring instrument); (b) Fragment of the section change in the hydraulic resistance (2-Insert swirler, 3-Pipeline inlet, 4-Measuring instrument, 5-Impulse line, 6-Flange connection, 7-Pipe pressure coupling, 8-Pipeline outlet); (c) Real image of the section.

4 Result and discussions

The results showed quite significant changes in flow patterns for different passive devices with various geometry. The values obtained for the smooth inner surface of the pipeline presents quite promising and pragmatic outcome. Vladimir I. Velkin *et al.* (2017) [9] showed in our study a PIV flow visualization of twisting using the passive inserts. It demonstrated that, the use of passive device within the loading line can reduce the vibration level due to flow induced vibration in a remarkable manner. In particular, the insert with involute cuts reduces the vibration displacement by 20-50% compared to a smooth pipeline, depending on the number of cuts. But for large Reynolds numbers, the involute-type insert, even with twelve cuts has no longer a sufficient effect on the flow structure, since it twists a very small fraction of the mixture and the flow has simply very low time to twist and passes through the insert without noticing its effect. Thus, at high speeds, in case of water-gas flow even the most effective involute swirl insert does not have a sufficient effect on the two-phase flow. To solve this problem, a new type of swirler model was constructed to ensure the fulfillment of these conditions. By investigating we came to know that a significant reduction in the vibro-displacement could be achieved by using a swirler having a larger surface area than that of other types of inserts, twisting the two-phase flow. But, at the same time, the vortex insert should not create any kind of significant hydraulic resistance to the flow. A new rope-type swirler was developed to increase the effectiveness for the decrease of vibration displacement. For its rope-like view we called it "Rope-type swirler".

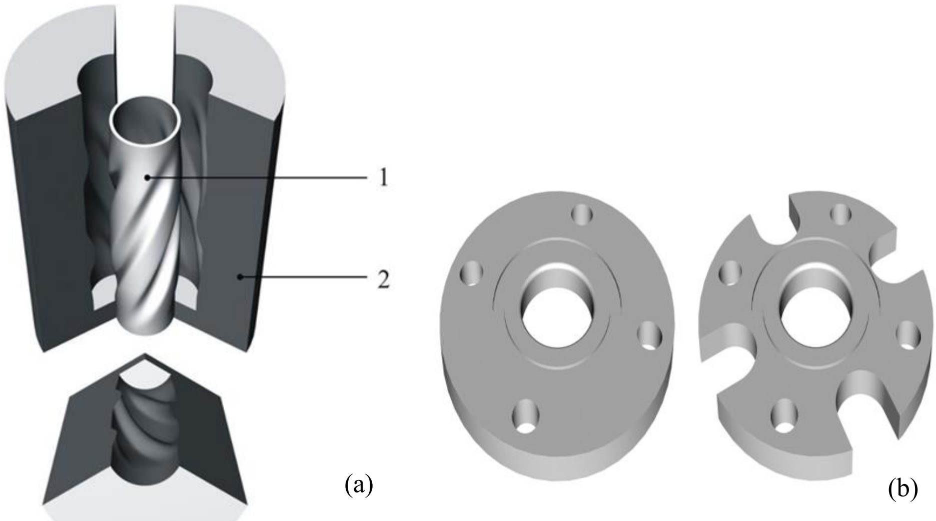

Figure 3. (a) 3D model of the Vortex insert; (b) Base of the insert adjacent to the vortex insert.

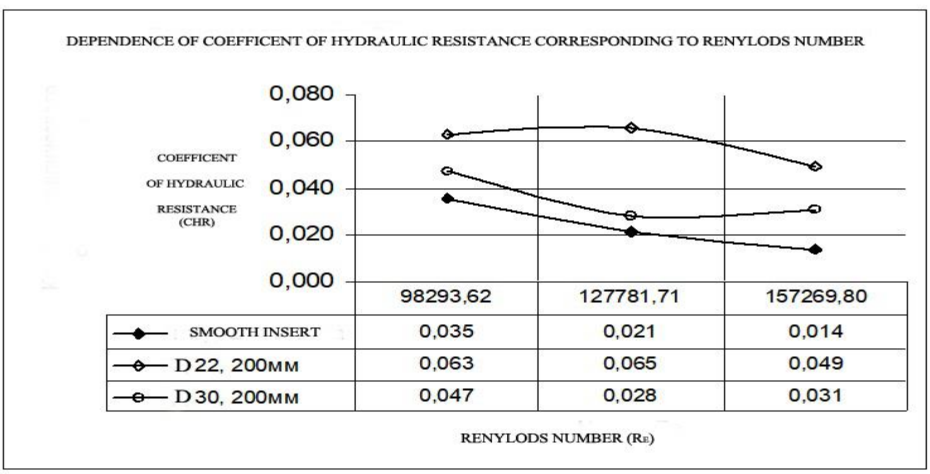

Figure 4. Coefficient of hydraulic resistance corresponding to Reynolds number

However, when analyzing natural frequencies in the projected and operating loading line there were considerable difficulties due to the lack of information on sources of pressure pulsation. Figure 5 shows the envelope spectrum of high-frequency vibration frequency and perspective noise generation due to the vibration.

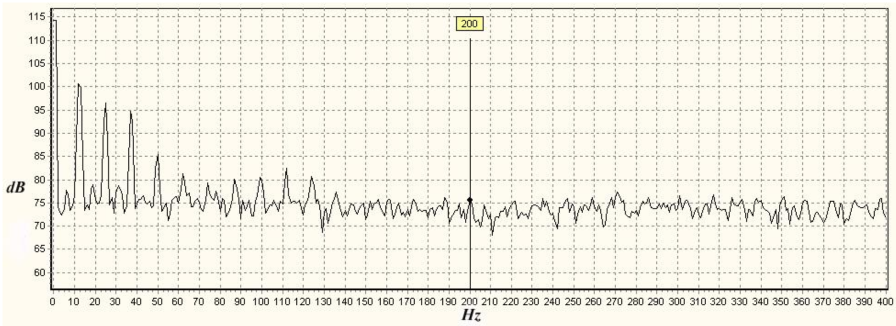

Figure 5. Spectrum of high frequency vibration and perspective noise generation.

By introducing the vibrational measurement using SD-12M vibration analyzer we found that the possibility of a resonance phenomenon is large enough. The spectra of such intrinsic acoustic frequencies and natural vibration frequencies of the structures are sufficiently dense and the proximity of some frequencies of these two spectra can lead to acoustic-mechanical resonance, which is unacceptable in pipelines. In the design of the equipment to reduce the vibration phenomenon, there will be a small increase in production cost due to installation of a new device but at the same time this will ensure the durability and safety of the whole construction.

5 Conclusions

The impact and the importance of the passive insert were discussed at the same time hydrodynamic property of the flow was determined. The impact of passive inserts of different geometrical shapes and sizes were presented. Under various flow regimes of a two-phase flow with the use of the same type of swirlers of different lengths as well as their hydraulic resistance were investigated. The hydraulic resistance of single-type vortexers of different lengths under various flow regimes of a two-phase flow was investigated. It was found that the maximum effect on reducing the vibration level on the elevating part of the experimental installation pipeline was given by a 300 mm insert with twelve guide involute grooves, but it has higher hydraulic resistance than a similar insert with a length of 200 mm.

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