Influence of disturbing part on measurement of the standard for cryogenic flow rate measurement using LDV

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Abstract

Disturbing parts situated on upstream of the flowmeter have influence on inlet velocity field. This change on the inlet of the flowmeter may influence measurement accuracy of the flowmeter. The aim of this article is to determine influence of disturbing parts on the measurement. Typical disturbing part situated on upstream of the flowmeter is elbow, swirl, half-plate, valve etc. The influences will be determined the standard for cryogenic flow rate measurement using LDV which was developed for measurement of the flow rate of liquefied natural gas (LNG) and other cryogenic fluids. The measuring system is simplistically special type of Venturi tube. Principle of this system is measurement of velocity profile using laser doppler velocimeter (LDV) behind the nozzle where the velocity profile is flat. After that the flow rate is calculated from measured velocity profile and diameter of nozzle throat. The influence of disturbing part on accuracy of the measurement will be determined by using numerical simulation. The determination of rate of the influence will be carried out by comparison of numerical simulation with and without the disturbing part. The simulation will be carried out for several disturbing parts.

1. Introduction

The transportation of fuel is accompanied by measurement. The amount of fuel is measured on each unloading and loading point. But each measurement is done with some error and all errors between the first point of the chain (producer) and the last point of chain (customer) are cumulated. This difference means money that one side gets and the other side lose. The difference in measurement can be caused by quality of measurement (procedure, flowmeter etc.). The aim of all members of the transport chain is to reduce the error of measurement. One of several things which can have influence on measurement is disturbing parts. The aim of this article is determinate the influence of disturbing parts situated on upstream of the standard for cryogenic flow rate measurement using LDV on the measurement.

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2. The standard for cryogenic flow rate measurement using LDV

The measuring system is equipment for measuring of cryogenics fluid flow rate using Laser Doppler Velocimetry technique. This system was developed by the CESAME Exadebit - company in France. The principle of this equipment is based on velocity measurement in one point behind the convergence nozzle and then calculation of the flow rate.

The first generation of that measuring system was tested in EMRP project LNG II and the results were published on FLOMEKO 2016 [1]. The partial part of project LNG II was optimization of the nozzle of flow metering system for liquefied natural gas. That optimization was one of more things which were used for development of second generation of measuring system. The simulations in this article were carried out with second generation of measuring system.

2.1 Introduction and geometry
The measuring system consists of front part (inlet part) where the medium is seeded by particles (bubbles or another spherical material). Then the fluid flows through the convergent nozzle to the

measuring space. For measurement by LDV it is necessary to make the equipment with windows or from transparent material. The measuring system (Figure 1) includes special cavities (Figure 2) with windows on the body of the measuring system. The medium continues to the divergent part of the nozzle and goes outside. For satisfactory accuracy of measurement and low uncertainty of the measurement it is convenient to create nearly flat velocity profile behind the nozzle throat (like piston velocity profile) to reduce the shear region influence on the mass flow rate calculation.
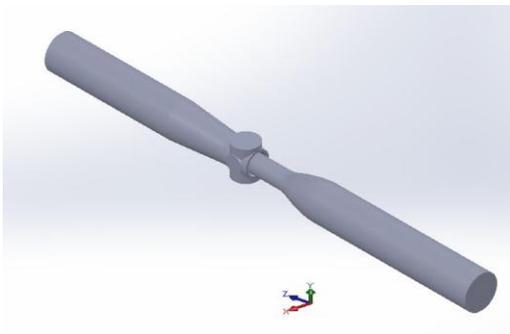
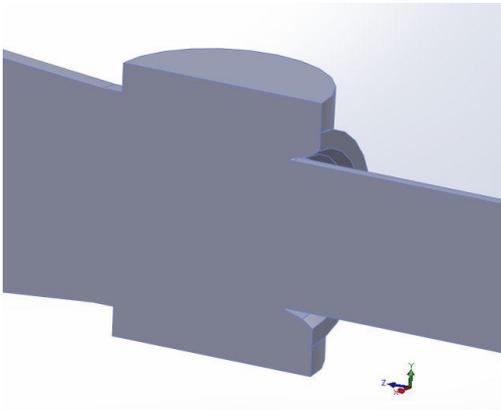**Figure 1:** Internal part of the measuring system.

Figure 2: Internal part of measuring space.

The aim of this part of paper is to simulate the flow through the measuring system. The results will be used as unaffected flow in measuring system. It will be used for determination of influence of disturbing parts on the flow as well as on the measurement.

2.2 Mesh & boundary condition & simulation
Mesh has been created by using of capability of OpenFOAM called blockMesh and snappyHexMesh. The mesh includes coarse part in the core of the stream and refinement in the direction to the wall. It consists of hexahedral cells and the mesh quality fulfils the base condition for successful simulation.

The boundary conditions were predescribed on three patches – wall, inlet and outlet and for fluid. Fully developed profile was predescribed on inlet patch. The zero gradient of pressure was predescribed on patch outlet. The wall function was predescribed on patch wall.

The simulation was done only for air (pressure 10 bar). The numerical problem was solved as a steady, viscous, turbulent, incompressible flow by a simpleFoam solver with k-ω SST turbulence model which was verified in the article [1]. Converged results were those results which had residuals lower than 10^{-6} for velocity in z axis and 10^{-5} for velocity in y and x axis.

2.3 Results
The simulation was carried out for velocity 2.5 m/s on inlet (fully developed profile). The velocity profile in measuring section is shown on Graph 1. It was generated from velocities in cells lying on a line which is identical to y axis and is situated 5 mm behind the nozzle. The vertical coordinates are given as velocities in the middle of the cell divided by maximal velocity of all cells on the line. The horizontal coordinates are distances from z axis. This profile will be used as unaffected velocity profile in measuring section. The velocity profile is constant in core of the stream and steeply decreases to zero near the cavities.
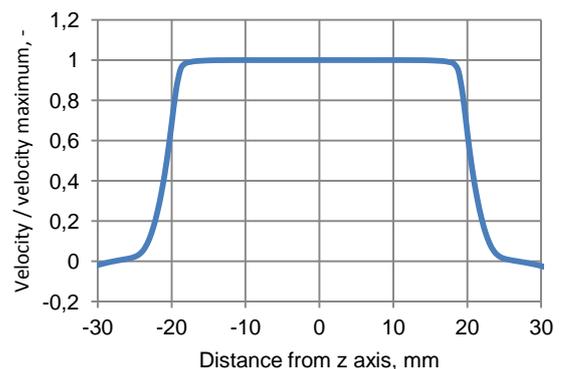
Graph 1: Velocity profile in measuring system without disturbing parts.

3. Disturbing parts

Disturbing parts are parts of pipelines which change character of flow, velocity profile or pressure drop.

3.1 U-bend

The U-bend consists of four elbows DN 80 connected together to shape U. The internal part of U-bend is shown on Figure 3. The U-bend is connected to measuring system on inlet part.
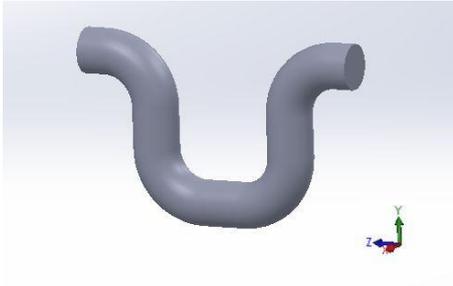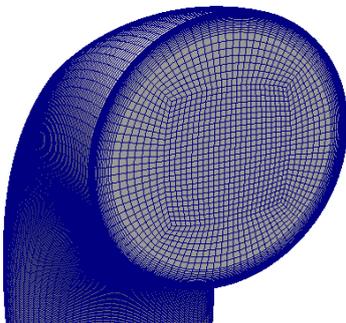

Figure 3: Internal part of U-bend.

The mesh has the same decomposition of cells as measuring system and it is figured on Figure 4. The setup of simulation was carried out as well as in measuring system – a steady, viscous, turbulent, incompressible flow simulated by a simpleFoam solver with k-ω SST turbulence model.

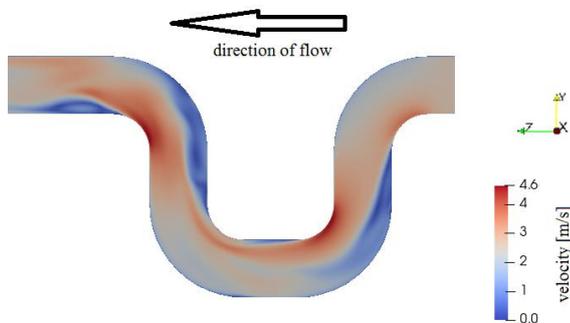**Figure 4:** Decomposition of cells in U-bend.

Figure 5: Decomposition of velocity in U-bend.

The decomposition of velocities in U-bend for inlet velocity 2.5 m/s (fully developed velocity profile) is figured on Figure 5. The velocity profile on outlet of U-bend is not rotary symmetric. This changed profile enters into the measuring system. The flow is accelerated in the nozzle and flows into the measuring section. The velocity profile behind the nozzle is shown on Graph 2. For comparison, on the same graph there is depicted velocity profile from simulation without the U-bend.
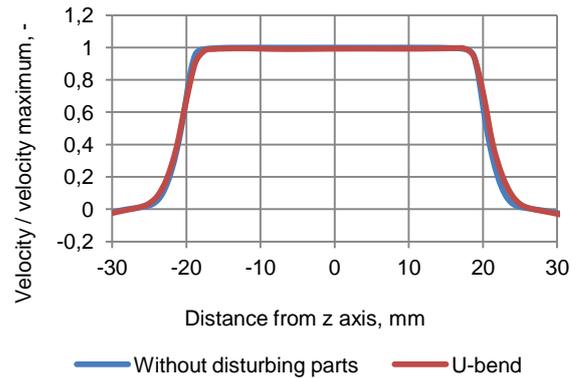
Graph 2: Velocity profile in measuring system with and without U-bend.

The vertical coordinates are given as velocities in the middle of the cell divided by maximal velocity of all cells on the line in case without disturbing parts. The horizontal coordinates are distances from z axis. The differences between both curves are very small. The U-bend has negligible influence on the velocity profile.

3.2 Half plate

The half plate reduces flowing surface by 50 percent. Thickness of half plate is 50 mm. This disturbing part is also connected to measuring system on inlet part.
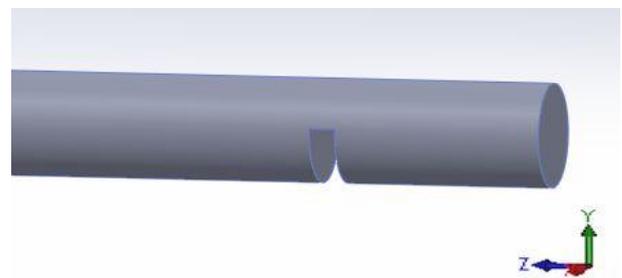

Figure 6: Internal part of half plate.

The mesh has same decomposition of cells as measuring system. The setup of simulation was carried out as well as in measuring system – a steady, viscous, turbulent, incompressible flow

simulated by a simpleFoam solver with k-ω SST turbulence model.

The decomposition of velocities in half plate for inlet velocity 2.5 m/s (fully developed velocity profile) is figured on Figure 7. The half plate has significant influence on velocity profile. The velocities in cells lying under z axis are very high and below the z axis are low. This situation caused higher vorticity in section behind the half plate.
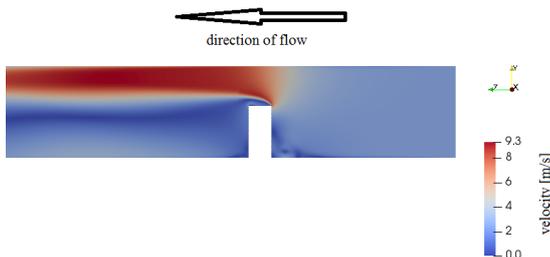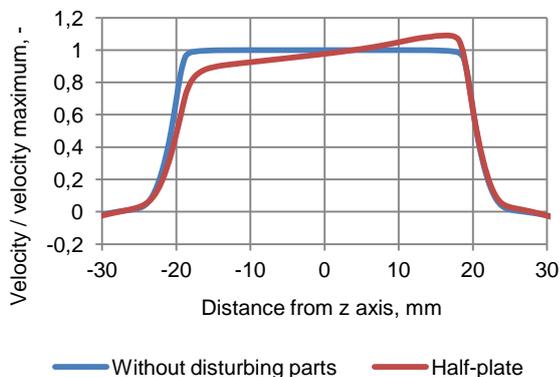

Figure 7: Decomposition of velocity in half plate.

The velocity in measuring section is shown on Graph 3. For comparison, on the same graph there is depicted velocity profile from simulation without the half plate.

Graph 3: Velocity profile in measuring system with and without half plate.

The vertical coordinates are given as velocities in the middle of the cell divided by maximal velocity of all cell on the line in case without disturbing parts. The horizontal coordinates are distances from z axis. The profile is very influenced by disturbing part. This type of disturbing element influences the measurement and it is necessary to use some stabilizing element or longer pipe for stabilization of flow.

4. Conclusion and future work

In this article two types of disturbing parts namely U-bend and half plate were tested. Both of these were connected on upstream of measuring system. The simulations were carried out only for one flow rate (velocity). The results show that U-bend has negligible influence on the velocity profile in measuring section. That negligible influence can be reduced by longer pipe between measuring system and disturbing part. Half plate, on the contrary, very influences the velocity profile. The resulting velocity profile on the border of the stream is changed by more than 10% compared to velocity profile without disturbing parts.

Future work will consist of testing of more disturbing parts as elbow, swirl etc. For testing will be used more velocities and the test will be carried out also with liquefied natural gas. The simulation in this article will be used for verification with experimental data.

References

[1] J. Sluse, R. Maury, J. Gersl, A. Strzelecki, "Numerical simulation of flow metering system for liquefied natural gas", in *17th International Flow Measurement Conference, FLOMEKO 2016*.