Long Term Stability of Coriolis Flow Meters: DESY experience

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Abstract. The measurement of coolant flow is important operational parameter for reliable operation of cryogenic system with superconducting magnets or cavities as well as for the system diagnostics in case of non-steady-state operation, e.g. during cool-down/warm-up or other transients. Proper flowmeter is chosen according to the different parameters, e.g. turn-down, operating temperature range, leak-tightness, pressure losses, long-term stability, etc. For helium cryogenics, the Venturi tube or Orifice, as well as Coriolis flow meters are often applied. For the present time, the orifices are usually used due to their simplicity and low costs, however, low turn-down range, large pressure drop, restriction of flow area, susceptibility to thermoacoustic oscillations limit their useful operation range. Operational characteristics of Venturi tubes is substantially improved in comparison to orifices, however, relative high costs and susceptibility to thermoacoustic oscillations still limit their application to special cases. The Coriolis flow meters do not have typical drawbacks of Venturi tube and orifices, however long-term stability over many years was not demonstrated yet. This paper describes the long-term behaviour of Coriolis flow meters after many years of operation at AMTF and XMTS facilities.

1. Introduction

For the correct measurements of gaseous helium (GHe) flow at low temperatures, several different types of flow meters have been applied: i) Venturi tube (or Venturi nozzle), ii) Orifice, iii) Coriolis, iv) turbine, v) V-Cone [1-21]. The turbine flow meters have been used seldom due to low reliability aspects of moving components at low temperature [3, 17], and V-Cone attracted only scientific interests, because it brings no advantages over Venturi or Orifice [21]. For the applications, where only very rough estimations of flow rates are needed and relatively high tolerable pressure losses are accepted, the orifice flow meters could be used as low cost solution. For the case, where flowmeter had to be used for the heat load measurement or has to tolerate high magnetic or radiation doses, the Venturi are typically applied. However, several drawbacks are still present:

- Still relative low turn-down, factor 3 to 5 (in some cases to 7).
- Relative large installation area inside a cryostat is still required.
- In some cases, in order to speed-up the cool-down/warm-up, in parallel to Venturi the by-pass valve is added.
- First the standard ISO5167-4 is not always applied (though sometimes manufacturing firms claims that their products are according to this norm), and second, this norm is not applicable to low flow rates and third – discharge coefficient and pressure losses are not always available, which leads to the requirement to test the flowmeter at room and low temperatures [1, 5, 11].
• Relative high costs (3-5k$), if one decides to produce Venturi according to the norm and costs for calibration at low temperatures must be also included.

Enormous amount of work was done by Mr. Manfred Suesser [10, 12, 15, 16, 18, 19], who systematically investigated the flow and pressure loss coefficients for small Venturi. High manufacturing requirements in order to have reproducible results also at low temperatures, e.g. surface flatness and roughness, laser welding for more than 10 pieces, has been applied. This allowed producing Venturies, which did not require calibration at low temperature, though calibration at room temperature with GHe or air was still required.

The Coriolis flow meter does not have typical drawbacks of Venturi, though it is more expensive and needs more space for mounting. Even after the first measurements at the end of 80’s, these flowmeters showed the superior characteristics over other ones, the main drawback was the limited long-term stability over several years, which practically in all cases implied the broken electrical cables inside Coriolis flow meter [2]. However, it seems that with the present state-of-the-art of Coriolis flow meters, the long term stability over several years is not an issue any more and this type of flow meter could be successfully used for cryogenic facilities operating at liquid helium (LHe) temperature level.

In the present paper, the present long-term operation experience with Coriolis at DESY is presented. The main reason to choose this flow meter was to avoid possible thermoacoustic oscillations, which could be caused by orifices or Venturi, and the second one is to use them for the heat load measurements.

In the second chapter, a short historical overview of Coriolis flow meters is given, and in the third one, the DESY experience is presented. In the last chapter, some comments on minor modifications are discussed.

### 2. Historical overview of Coriolis flow meters operated at low temperatures

The first measurements at low temperatures have probably been performed in 1987 [2]. Figure 1 shows the rough sketch of flow meter. Measurement in comparison to other cryogenic flow meters, e.g. Venturi or Orifice showed superior characteristics [21], however after couple of years both tested flowmeters were not operable due to damage of electrical cables. As smaller drawbacks the installation of temperature sensors for LHe temperatures as well as adaptation of additional reading electronics for automation system could be mentioned.

Ten years later, the second attempt was performed to study the Coriolis flow meter by the same authors, see Figure 2. Again, results were very encouraging, and these two flow meters were used for the measurement of cooling parameters of large superconducting coils for LCT, POLO, W7-X prototype and TFMC. However also in this case the flow meter cabling had to be improved, otherwise after a couple of years the flowmeter should be changed.
Next efforts to qualify Coriolis flow meters for helium cryogenics were performed by Luigi Serio at CERN [4, 13, 20]. Very extensive measurements and comparison with other flow meters, e.g. Venturi, turbine, time-of-flight, showed superior behaviour of this sensor. It was planned to install these sensors at the connection boxes between transfer line and LHC accelerator, however, due to very limited available space as well as non-negligible total costs, these sensors were not installed and as a consequence, long-term operation experience on large number of flow meters was not gained.

It is worth to mention that several other groups are using the Coriolis flow meter, e.g. at GSI, Germany; Fermi Lab (for LCLS-II project), USA; CEA Grenoble, France, etc. It would be interesting to note their experience particular related to the long-term stability.

### 3. DESY experience

| Name                        | Description                        |
|-----------------------------|------------------------------------|
| Manufacturing firm          | Micro Motion                       |
| Sensor Type                 | Elite Serie                        |
| Operation range             | 4-300K                             |
| Pressure range              | PN25                               |
| Flow ranges                 | 2-300 g/s                          |
| Calibration at 300K with H2O| Yes                                |
| Calibration curve for helium| Yes                                |
| Number of flow meters working in the range of 2 g/s maximal | 1 |
| Number of flow meters working in the range of 2-150 g/s maximal | 29 |
| Number of flow meters working in the range of 150-300 g/s max. | 3 |

At the present time, more than 30 Coriolis flow meters have been operated at low temperatures at DESY and 19 are expected to be commissioned at the end of this year. After 3-8 years operation, no breakage of electrical cables was observed. Unfortunately, no specialized test facility for testing of Coriolis flow meter is available, so cross-check of flow meters was done in-situ at working facilities, i.e. mass flow through “cold” flow meter was compared with the flow through “warm” one. For our control purposes and for the heat load measurements, these measurements are sufficiently accurate, because the “warm” flow meters are recalibrated at regular time intervals. In some cases, we compared the flow through the Coriolis with “warm” flow meter having in between JT-valve and LHe vessel with constant LHe level. Table 1 summarizes typical design parameters of Coriolis flow meters applied at DESY and number of sensor installed at different cryogenic facilities.

Figure 3 compares the flows through smallest flowmeter with flow of the “warm” one. This flowmeter is the smallest of this series (CMF010 according to the Micro Motion labelling) and has only one tube with internal diameter of ca. 3mm.

Figure 4 shows the flows over the three Coriolis flow meters (CMF025 with transmitter model 2700), which are installed at different test facilities, and the flow of the “warm” one. Correlation between these flow meters is good for our purposes.

We have also situation, when three Coriolis flow meters are connected between two cryostats in series, but in different flow directions. During LHe transfer from one cryostat to another one, one (or two) flow meters are working in the reverse direction. Our experience showed that difference on flows for forward and revers directions is small and for our purposes could be neglected, so these sensors could be also used for flow measurements in both directions.

As it was mentioned above we do not have a special test facility for cross-checking of Coriolis flow meters at all temperature and flow ranges, so we have to use our present cryogenic infrastructure. For that reason, our measurements were limited to typical relative low flow operation ranges as well as quite limited temperatures, e.g. 40-80K or 5-8K. It would be very interesting to have comparison at whole
temperature range of 5 to 300K, but for present facilities it is not possible without significant modifications. At the present time for the XFEL cryomodule heat load measurements [22], we cross-check Coriolis flow meters used for the heat load measurements on 5-8K temperature level with the warm one at few measuring points, however for the 40-80K temperature level, only rough comparison on single point with uncalibrated warm flow meter is possible. Up to now, no deviations from expected behaviour have been noticed.

It is worth mentioning that in order to apply sensor at LHe temperature, some minor software modifications were done. This is related to the fact that due to temperature variation, the mechanical properties of stainless steel are also changed, so minor correction is done by manufacturing firm to compensate it (according to the information from Micro Motion, this effect is not large, it is expected to be below 6%). Unfortunately flow meters use temperature sensors for the range of ca. 40-300K, and below this range no flow indication was possible. Our solution was not to use this correction factor and to use the mechanical properties at 20K. In the future, it would be helpful to have temperature sensor working down to 5K, so this correction error could be compensated. In addition, we also used flow sensor with the small holes in the body of protection cylinder in order to evacuate the inner space, i.e. to exclude “virtual leaks” and avoid gas condensation, which is sometimes filled into the protection cylinder.

And last but not the least, it has to be noted that significant amount of time and software work must be planned for commissioning in order to reduce the minor errors, e.g. zero-shifting or sometimes permanent offsets.

4. Final remarks and conclusion

Our experience showed that Coriolis flow meters worked reliable over many years without noticeable calibration shifts or abnormal behaviours. So this type of flow meter could substitute the Venturi or Orifice ones, if precise measurements are required and relative high costs, ca. 10 kE per one sensor, are acceptable.

As the further steps it would be very useful to have detailed measurements over whole temperature range as well as up to maximal flow rates.

As final remarks related to the future work on Coriolis flow meter, we would like to mentioned that it would be very helpful to have options for the temperature sensors working at LHe temperature range as well as a hole in the protection cylinder for gas evacuation.

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