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EDF R&D new test bench for liquid industrial flow meters calibration

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Abstract

Since 1997, EDF Research and Development Division has been carrying out liquid flow metering studies on the EVEREST experimental loop at EDF Lab Chatou (France). In the last twenty years, industrial flow meters designs have been continuously improved by manufacturers. In the same time, the need for industrial flow measuring instruments with a high accuracy has tremendously increased due to the required economic cost-effectiveness in the energy sector. Flow meters metrological assessment tests consequently need to be upgraded in order to remain relevant. In 2016, EDF R&D has then initiated a complete revamping of the EVEREST test bench which was achieved at the beginning of 2019. This comprehensive retrofit leads to a significant calibration accuracy improvement. The EVEREST reference volume flow uncertainty is now better than 0.1% from 50 $m^3.h^{-1}$ up to 1200 $m^3.h^{-1}$. Moreover, in order to characterize the velocity profile impact on industrial meter metrological performance, two laser velocimetry measurement systems have been purchased. This effort leads also to the design of a mini-loop, called MONT-BLANC, whose purpose is to mimic EVEREST calibration features under a smaller size and a lower flow rate rangeability (from 13 $m^3.h^{-1}$ up to 150 $m^3.h^{-1)}$. This test bench will allow not only to ease optical adjustments of laser-based velocity measurement techniques and their future implementations on EVEREST but also to provide an effective tool to investigate the influence of scale effect on flow meters and pipes flow physics.

1. Introduction

EDF (the French Electricity Generation company) operates 58 “Pressurized Water Reactor type” nuclear units in France (PWR). In these particular power plants, flow monitoring is essential not only for safety reasons but also for economical ones. For instance, accurate measurement of feedwater flow in PWR plants is necessary to quantify the turbine cycle heat rate of the plant, which is a major component of the overall plant efficiency.

Twenty years ago, EDF appointed its Research and Development Division (EDF Lab Chatou, France) to carry out experimental tests on usual or innovative flow meters for evaluating their metrological performance. These tests aimed at assessing flow meters metrological behaviour in a semi real industrial conditions prior to a potential PWR on-site installations. EDF R&D consequently designed a specific test bench for this mission. This loop was called EVEREST.
The basic design concept of EVEREST had two main objectives: one was to duplicate the behaviour of an industrial liquid pipe flow process as closely as possible, and the second was to generate an accurate and steady reference flow rate.
In the last twenty years, industrial flow meters designs have been continuously improved by manufacturers. In the same time, the need of industrial flow measuring instruments with a high accuracy has tremendously increased due to the required economic cost-effectiveness in the energy sector. Flow meters metrological assessment tests consequently need to be upgraded in order to remain relevant.

In 2016, EDF R&D has then initiated a complete revamping of the EVEREST test bench [1] [2]. This task was challenging because it required not only to maintain the specificity of the old bench (generation of a steady liquid flow rate for test/calibration purposes in a semi-industrial scale) but also to add new features such as a better calibration accuracy and a liquid velocity profile characterization for real pipe flow configurations.

This objective was achieved at the beginning of 2019 and leaded to the design of two similar test benches but at different scales: an upgrade version of the old EVEREST loop and a mini EVEREST called MONT-

BLANC for smaller flow rates calibration and an easier modularity for laser-based velocity measurement techniques implementation.

2. EVEREST loop global design

The new EVEREST facility is a closed loop with a liquid flow rate regulation (figure 1). Fluid is clean tap water.
EVEREST consists in three parts: a flow metering reference section, an operation section and a modular flow metering test section (figure 2).

Figure 1: EVEREST test facility overview.

Table 1: Overview of the design specification of EVEREST.

Prime Features	Details
Calibration test type	Closed regulated loop
Flow meter reference	Master meters method
Test section pipe size	From DN100 up to DN350
Pipe compositions	Stainless steel
Fluid	Tap liquid water
Pressure range	From 1 up to 10 bar
Fluid temperature range	From 20°C up to 40°C
Environment Temperature	Minimum and maximum ambient temperature are (respectively) 10°C and 35°C
Flow rate range	From 50 $m^3.h^{-1}$ up to 1200 $m^3.h^{-1}$
Flow metering uncertainty	0.1% (volume flow rate)

3. EVEREST operation section

Table 1 shows the new EVEREST design specifications. The test bench provides a steady water stream from 5.10^4 up to 2.10^6 Reynolds number. Flow circulation is provided with a variable centrifugal pump (315 kW). Depending on the test section geometrical configuration, flow range generally goes from 50 $m^3.h^{-1}$ up to 1200 $m^3.h^{-1}$. Thanks to regulation systems, a steady flow rate is maintained in the reference and the test sections.
Pump energy is converted into heat which is absorbed by the pumped liquid. Due to EVEREST loop configuration, this phenomenon consequently increases fluid temperature in the test and reference sections. To compensate this phenomenon, water temperature is regulated thanks to a plate heat exchanger (215 kW). The cooling system is provided by a fan coils unit located at the outside of the experimental hall. Fluid temperature can thus be set at a specific value according to the desired test conditions, generally between 20°C and 40°C. Fluid pressure regulation is regulated from 1 bar up to 10 bar thanks to a pressuriser.

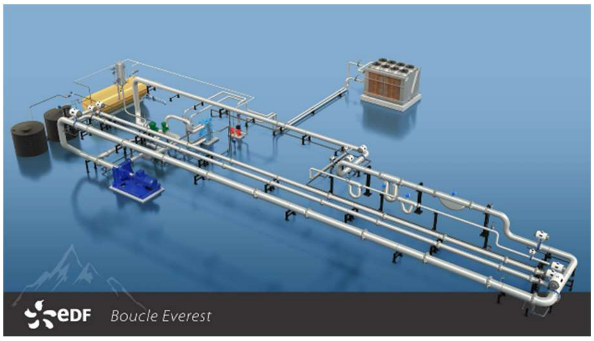

Figure 2: EVEREST test facility layout design.

EVEREST loop is designed to minimize its environmental impact by managing efficiently its water consumption. Two water storage tanks are used for filling and emptying the EVEREST hydraulic circuits between two test campaigns which required different pipe configurations. Moreover, a third tank has been implemented in order to store the entire test bench water volume. When needed, this “waste” water is analysed before a classic evacuation or, if necessary, a reprocessing in a water treatment plant.

4. EVEREST flow metering reference section

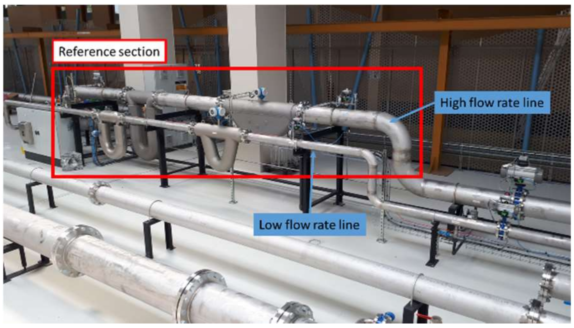

Figure 3: EVEREST flow metering reference section.

The major characteristic of EVEREST loop is the generation of a steady liquid flow rate for test/calibration purposes. This reference flow rate is calculated with the use of four different master meters based on Coriolis technology (Table 2). As shown in

Figure 3, two meters are used for low flow rate calibration tests, from 50 $m^3.h^{-1}$ up to 350 $m^3.h^{-1}$. They are installed on DN100 stainless steel pipe. The other two devices operate under high flow rate calibration tests conditions, from 150 $m^3.h^{-1}$ up to 1200 $m^3.h^{-1}$. They are installed on DN250 stainless steel pipe.
This configuration aims at decreasing uncertainty all over the loop flow rate rangeability, for each meter is used in its nominal operative flow rate. The EVEREST reference flow rate is calculated as a volume flow rate. Reference volume flow uncertainty is better than 0.1% for the overall flow rate range [3] [4].

Table 2: EVEREST Coriolis reference meters specifications.

	Flowmeter	pipe diameter	Flow rate ($m^3.h^{-1}$)	
			Min.	Max.
High flow rate line	Q_{1ref}	DN250	150	1200
	Q_{2ref}			
Low flow rate line	Q_{3ref}	DN100	50	350
	Q_{4ref}			

Usual experimental tests are carried out on steady flow rate. At the beginning of a test, bench operator selects the flow rate on the monitoring screen and consequently the corresponding master meter line which has to be used.
For each reference line, one Coriolis meter is used as the reference flow rate and the other is used as a “drift detection” meter. This choice allows to monitor and to detect any reference sensor drift between two consecutive calibrations.
Furthermore, due to the Coriolis technology, there is no need for a high upstream straight lengths before the meters implementation zone. This feature leads to benefit from a bigger area available for the test section in the experimental hall (figure 4).

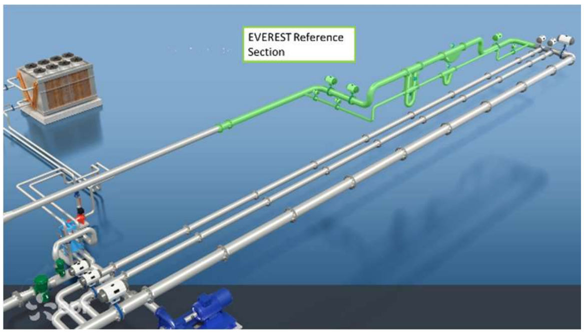

Figure 4: EVEREST flow metering reference section digital model.

5. EVEREST flow metering test section

The last but not least section of EVEREST is the flow metering test section. Tested devices are generally mounted on stainless steel pipes and can be invasive as well as non-invasive according to the sensor technology.

This inner room section constitutes an available space with a length of 25 m, a width of 5 m and with a high ceiling of 5 m. This test section is designed to perform calibration tests not only under ideal thermo-hydraulic conditions (fully developed and swirl-free velocity profile thanks to a high straight lengths at the upstream of the tested meter) but also calibrations tests under non-ideal thermo-hydraulic conditions due to the presence of various fittings located upstream or downstream the tested meter. Figure 4 shows a common test section modification, from a 100Dh (hydraulic diameter) straight lengths DN200 pipe up to a test area located between two double 90° elbow pipes.

The default test section configuration includes three piping lines with different sizes (DN350, DN200 and DN100). However, several pipe configurations can be arranged depending on the meter calibration purposes (figure 5).
This modularity was a key feature of the previous loop and greatly contributed to its recognition within EDF. This characteristic was obviously kept for the new one.

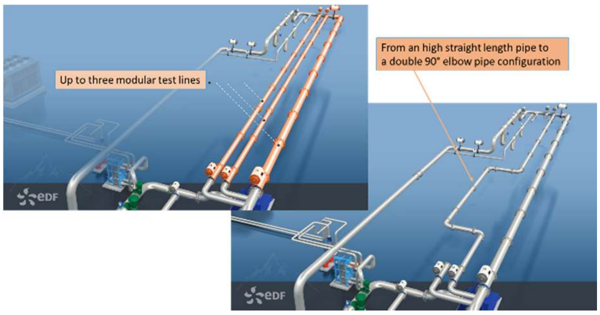

Figure 5: EVEREST modular flow metering test section example.

Thus, the new loop test section is still a multi-purpose test area which allows to re-create numerous process pipeworks or to install a reduced scale mock-up of typical industrial components for metrological purpose. This flexibility will allow EDF R&D to keep on investigating the real installation conditions impacts on flowmeters accuracy: orifice plate installation with no ISO 5167-2 [6] required upstream and/or downstream straight lengths of piping, electromagnetic or ultrasonic flow metering systems under severely perturbed flow conditions, …

6. MONT-BLANC layout

Flow meters metrological assessment tests need to be upgraded in order to remain relevant. EDF R&D has come to the conclusion that, improving flow meters accuracy investigations requires a comprehensive velocity profile understanding. This feature was one of the main cornerstone for the revamping of EVEREST.
Some velocity measurements have been performed in 2014 and 2015 with the previous loop [5]. These tests were performed in a semi-realistic scale pipe configuration which turned out to be quite a challenge for collecting accurate velocity data.

This test campaign led EDF R&D to the idea of designing a smaller version of EVEREST loop dedicated to prepare and adjust velocity measurement systems and configurations prior to any experimental campaigns on a semi-realistic test bench.
This bench, which was named MONT-BLANC, was built during the revamping of EVEREST. It nearly shares the main thermo-hydraulic features with EVEREST except for the size and the flow rate rangeability (figure 6). Table 3 shows the MONT-BLANC design specifications.

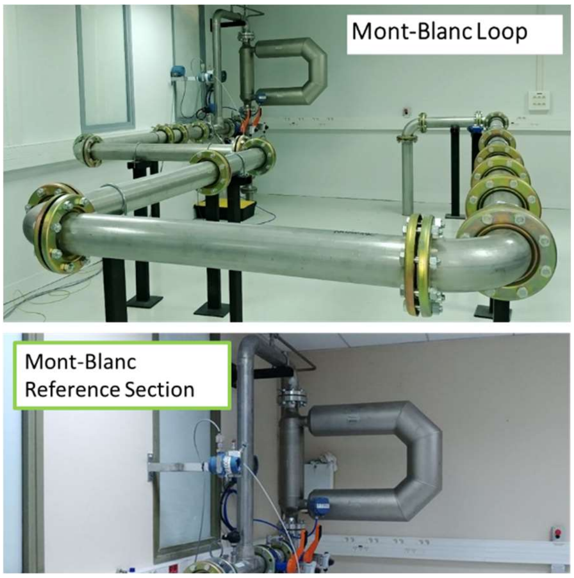

Figure 6: MONT-BLANC test facility overview (top) and details of the reference section (bottom).

In addition to ease velocity profile investigations MONT-BLANC allows also to perform calibration tests under low flow rate (from 13 $m^3.h^{-1}$ up to 150 $m^3.h^{-1}$). Maximum flow rate was set up to 150 $m^3.h^{-1}$ which provides some possible inter-comparison calibration tests with EVEREST. Reference flow rate is elaborated thanks to a Coriolis meter. Reference volume flow uncertainty is better than 0.1% for the overall flow rate range [3] [4].

Usual experimental tests are carried out on steady flow rate. Reference and test sections are set in the same floor while the operation section is set at the lower floor. It includes the circulation pomp, the regulation valves, and the heat exchanger (cooling unit). A by-pass pipe is implemented in the reference section in order to inject, where appropriate, seeding particles for velocimetry measurements which use Laser-based technologies.

Table 3: Overview of the design specification of MONT-BLANC.

Prime Features	Details
Calibration test type	Closed regulated loop
Flow meter reference	Coriolis master meter
Test section pipe size	From DN40 up to DN150
Pipe compositions	Stainless steel
Fluid	Tap liquid water
Pressure range	From 1 up to 8 bar
Fluid temperature range	From 23.5°C up to 24.5°C
Environment Temperature	ambient temperature is regulated near 20°C
Flow rate range	From 13 $m^3.h^{-1}$ up to 150 $m^3.h^{-1}$
Flow metering uncertainty	0.1% (volume flow rate)

Since March 2019, some preliminary tests have been performed on MONT-BLANC with Particle Image Velocimetry (2D 3C PIV) system (figure 7). Later this year, some 3D3C PIV tests are scheduled before hopefully planning the implementation of this system on EVEREST loop next year.
With such a feature, MONT-BLANC constitutes also a tremendous experimental tool for assessing Computational Fluids Dynamics (CFD) software for liquid industrial pipe flow configurations.

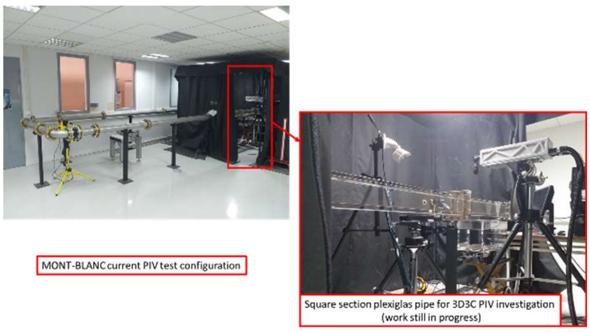

Figure 7: MONT-BLANC velocity profile investigation with 3D3C PIV system.

7. Conclusion

In 2016, EDF R&D has initiated a complete revamping of the EVEREST test bench which was achieved at the beginning of 2019. This comprehensive retrofit leads to a significant calibration accuracy improvement. The EVEREST reference volume flow uncertainty is now better than 0.1% from 50 $m^3.h^{-1}$ up to 1200 $m^3.h^{-1}$. Moreover, in order to characterize the velocity profile impact on industrial meter metrological performance, two laser velocimetry measurement systems have been purchased. This effort leads also to the design of a mini-loop, called MONT-BLANC, whose purpose is to mimic EVEREST calibration features under a smaller size and a lower flow rate rangeability (from 13 $m^3.h^{-1}$ up to 150 $m^3.h^{-1}$). This test bench will allow not only to ease Particle Image Velocimetry and Laser Doppler Velocimetry system preparations, adjustments and future implementations on EVEREST but also to provide an effective tool to investigate the influence of scale effect on flow meters and pipes flow physics.

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