Endress+Hauser
People for Process Automation

Promag 0 x DN full bore

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Executive summary

Electromagnetic flowmeters have been used for decades throughout many industries and have become the major technology for flow measurement. To guarantee full performance, long and straight inlet and outlet runs are required. Electromagnetic flowmeters with 0 x DN full-bore technology from Endress+Hauser provide a solution for challenging applications without inlet and outlet runs. The maximum measuring performance regardless of the mounting location is achieved using multiple optimally positioned electrodes and advanced signal processing to average out the flow velocity across the entire flow profile.

Introduction

Historically standard electromagnetic flowmeters define at least 5 x DN inlet run and 2 x DN outlet run to comply with the specified accuracy. The measuring accuracy of electromagnetic flowmeters is directly affected by changes in the flow profile caused by flow disturbances, such as elbows, t-fittings, insertion devices or nominal diameter differences. *Figure 1* shows a simulation of the flow profile after a 90° bend which is characterized by a strong asymmetry and a pair of Dean-vortices. While electromagnetic flowmeters with sufficient inlet and outlet run average the flow velocity across the cross section of the pipe, averaging a disturbed flow profile is more challenging. For instance, the flow immediately in front of the electrodes contributes more to the signal. As a result, a flow disturbance causing increased flow close to the electrodes is likely to deliver a positive measurement error. Calculating the measurement error resulting from a flow disturbance, requires solving a complex volume integral and for this reason it is very difficult to provide a quick estimate of the error. Consequently, a full simulation or measurement is needed.

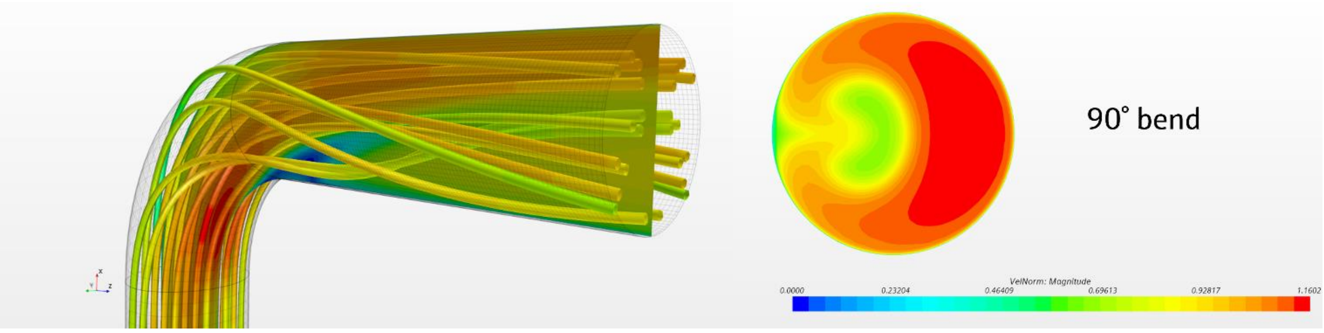

Figure 1: Flow profile after 90° bend

The traditional solution to this problem is to ensure a well-conditioned flow profile at the measuring point by installing sufficient lengths of straight pipe before the flowmeter, see *Figure 2*. Alternatively, flowmeters with a reduced inner diameter attempt to condition the flow by compressing it, resulting in pressure loss, higher energy consumption, build-up and possible cavitation at higher flow rates.

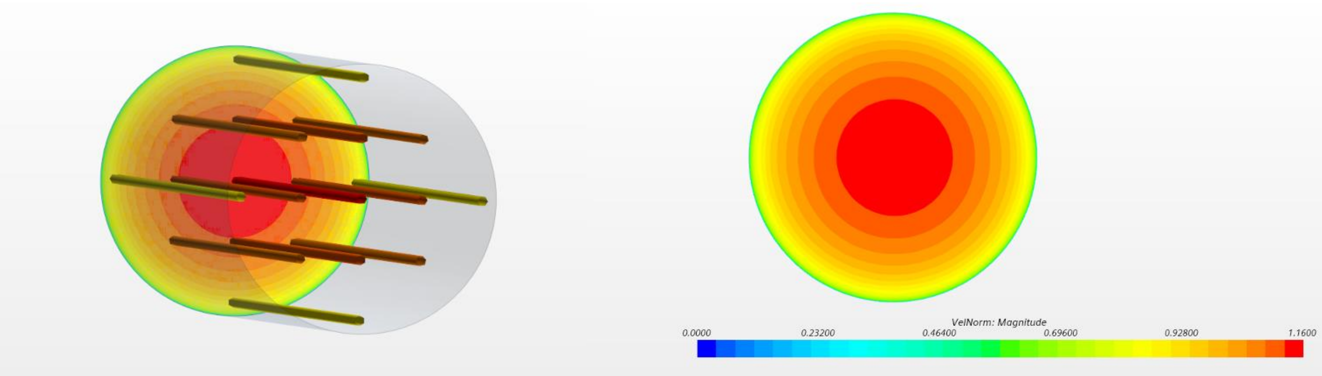

Figure 2: Completely symmetric flow profile as found in a long straight pipe

0 x DN full-bore technology

With the Promag 0 x DN full bore Endress+Hauser offers a solution without constrictions in the flow tube and therefore without pressure loss while at the same time enabling installations without inlet and outlet runs.

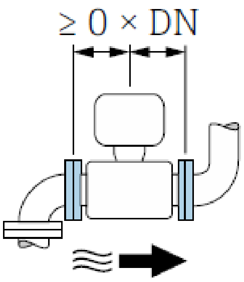

Figure 3: Installation of Promag 0 x DN full bore before or after bends

The patented technology uses multiple electrodes placed optimally within the flow tube to average the flow velocity across the entire pipe, resulting in an improved weight function. Compared to traditional flowmeters with two measurement electrodes this makes the 0 x DN full-bore meter robust against disturbed flow profiles and in fact increases measurement reliability in any installation condition. The electromagnetic flowmeter can be installed as a full-bore flowmeter directly after bends or a variety of challenging situations such as directly after insertion flowmeters, after misaligned sealings, after open valves or directly after nominal diameter differences. As a consequence, this leads to reduced installation costs, since traditional inlet and outlet runs are not required.

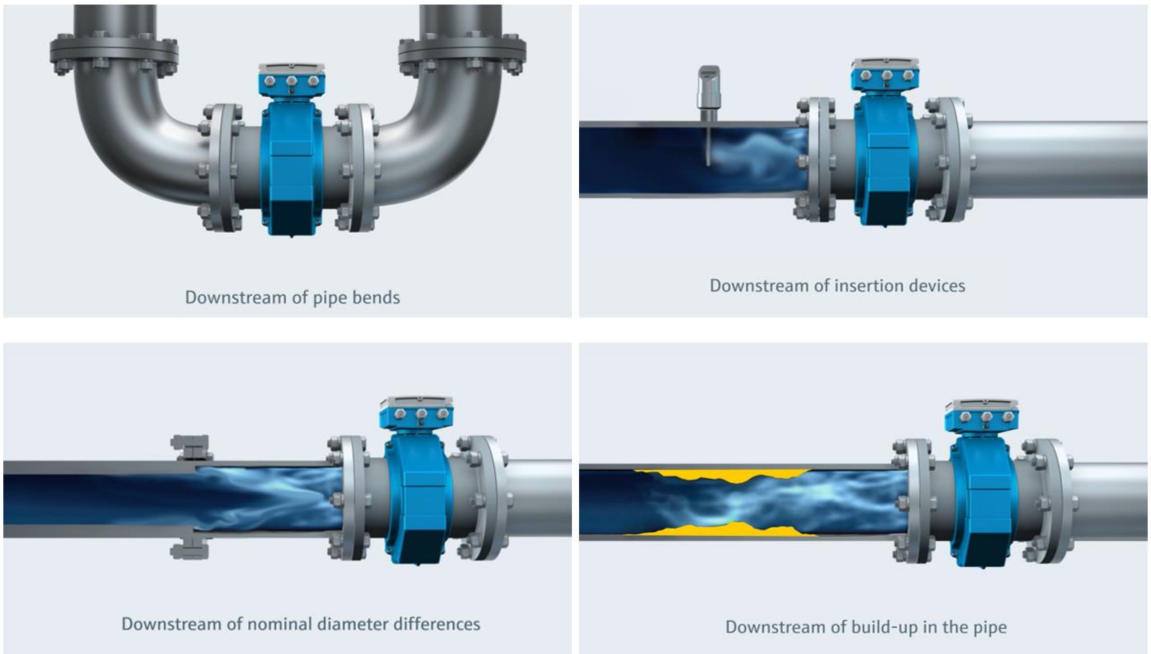

Figure 3: Installation of Promag W 0 x DN full bore with no restrictions

Computer aided simulation

For the verification of the 0 x DN full-bore technology, state of the art finite element method simulation was used to create accurate digital product twins of the flowmeters. Using these models, the performance of the flowmeters can be accurately simulated. Combined with computational fluid dynamics simulations of the flow, virtually any flow disturbances can be tested. A visualization of these simulations is shown in F*igure 4*. The asymmetric flow profile after a 90° bend is shown as a cross section with arrows at the inlet. The highly homogenous weight function is plotted as a half section through the center of the pipe. In addition, the coil current (red arrows) and magnetic field lines (streamlines) are shown. Any 0 x DN full-bore flowmeter can be digitally tested in thousands of possible installation scenarios ensuring optimal performance in the field. Measuring the influence of a bend or a valve on the performance in the laboratory or a field trial would require extensive piping and rebuilding of the setup for every measurement. In the simulation all of this is accomplished, using a few physical measurements to verify the results.

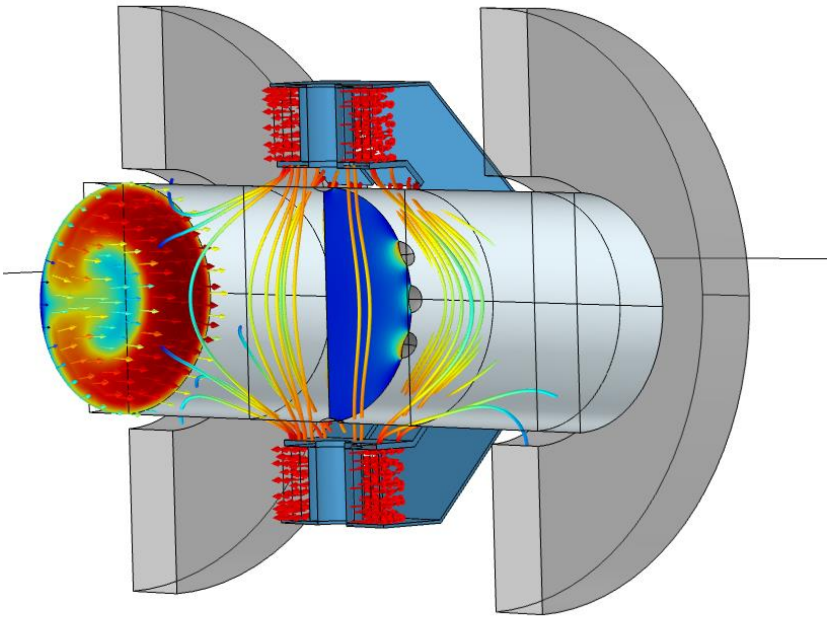

Figure 4: Visualization of a simulation model showing a cut through a Promag W sensor

Figure 5 shows an example of the overlap between physical measurements and computer aided simulations of the measurement error after a change in pipe diameter upstream of the flowmeter. The results deviate on a sub-per-mille level, and additionally illustrate the good reproducibility of the flowmeter.

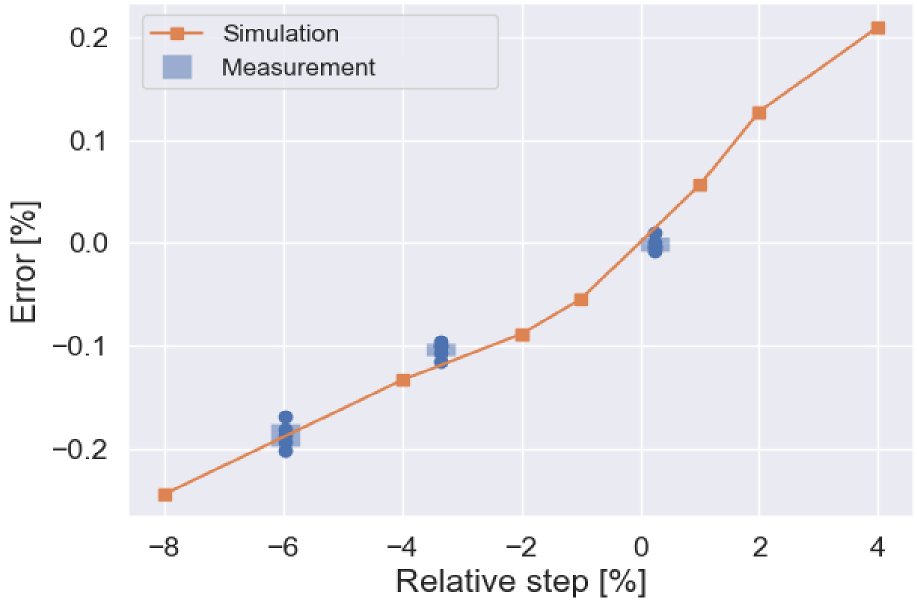

Figure 5: Simulation and measurement of a Promag W 0 x DN full bore DN 200 (8"), 5.0 ms

The relative step indicates the difference in inner diameter of the connecting pipes causing the disturbance in the flow profile. The agreement between simulation and measurement validates the computer aided simulation to support the engineering of the optimal 0 x DN full-bore sensors for the entire range of diameters and installation locations.

Verification of the 0 x DN full-bore technology

The technology was tested in a 3rd party laboratory, TÜV SÜD National Engineering Laboratory in the UK.[1] According to TÜV SÜD NEL the evaluated flowmeters have been fully within the specified accuracy in a variety of tests in after-bend-installations. These tests at the 3rd party laboratory validate the 0 x DN full-bore technology with the specified accuracy of ±0.5% across the entire flow range. *Figure 6* shows the corresponding measurement error of the test of Promag W 0 x DN full bore DN 250 (10") with a remote transmitter installed directly after a sharp 90° bend. The measurement error for this test was around -0.25% and independent of the flow rate.

[1] The laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17205. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system.

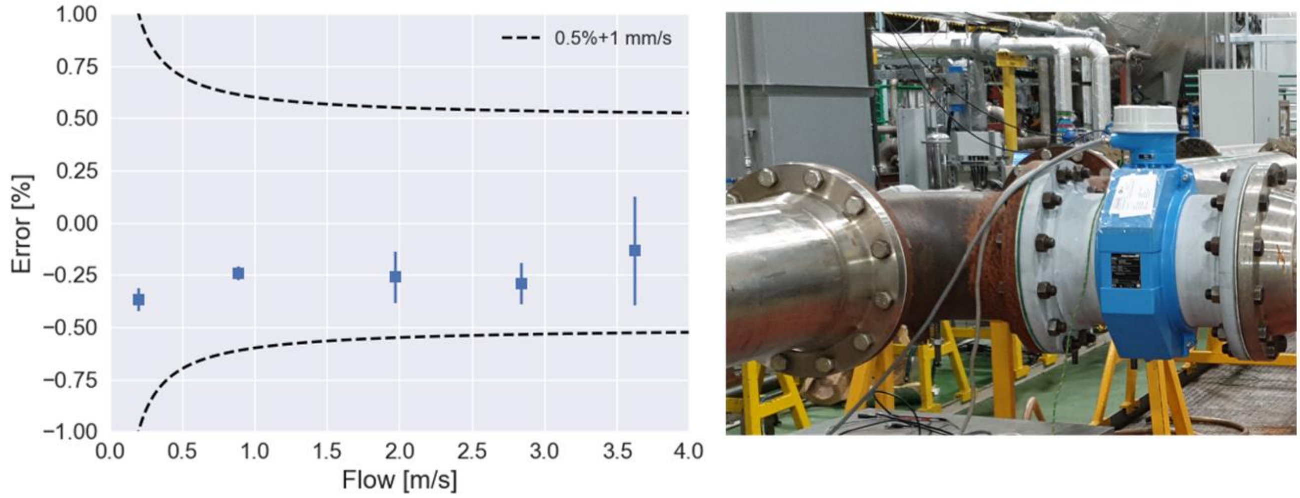

Figure 6: Promag W 0 x DN full bore DN 250 (10") tested in a 3rd party laboratory, TÜV SÜD NEL

Errors from flow disturbances are very linear, meaning that the error is constant across the entire flow range. This is also illustrated in *Figure 7* where the same installation condition is shown for DN 150 (6"). This measurement was done on an accredited rig at Endress+Hauser, with the full flow range up to 10 m/s (33 ft/s).

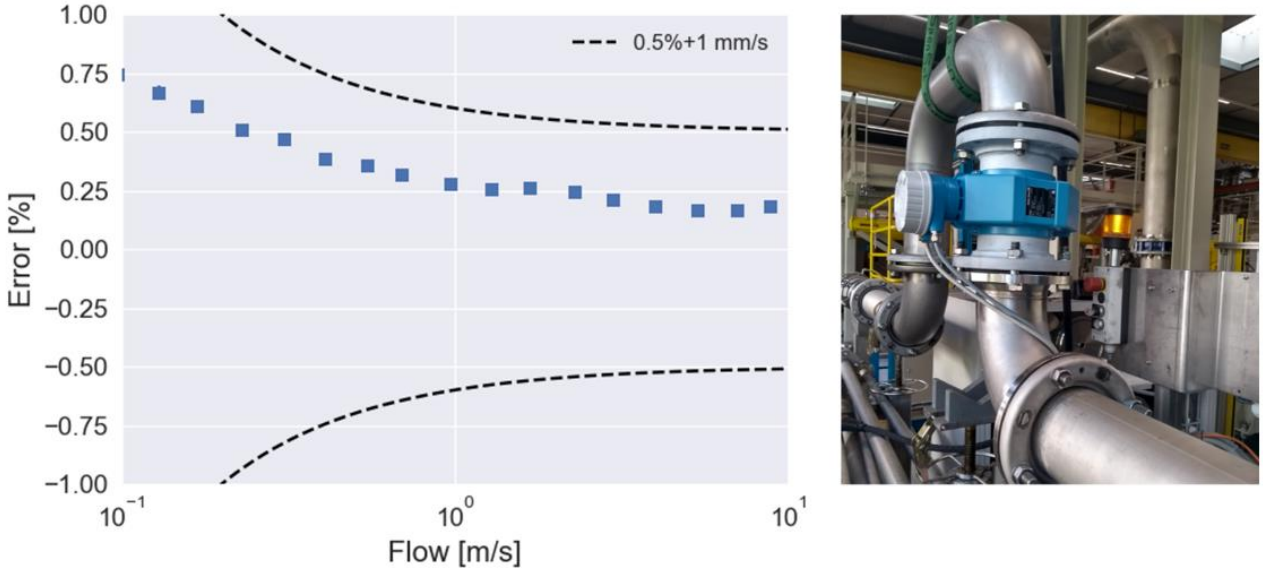

Figure 7: Promag W 0 x DN full bore DN 150 (6"), accredited calibration rig at Endress+Hauser, Switzerland

A common cause for flow disturbances are valves, including control valves, isolation valves and check valves. It is always recommended to install valves downstream of the flowmeter, this applies also to 0 x DN full-bore sensors. Valves placed upstream of the flowmeter, should be operated in a fully opened state (isolation valves).

An example of an open butterfly valve installed in front of a Promag W 0 x DN full-bore flowmeter DN 80 (3") is presented in *Figure 8*. The results show two different installation angles of the valve.

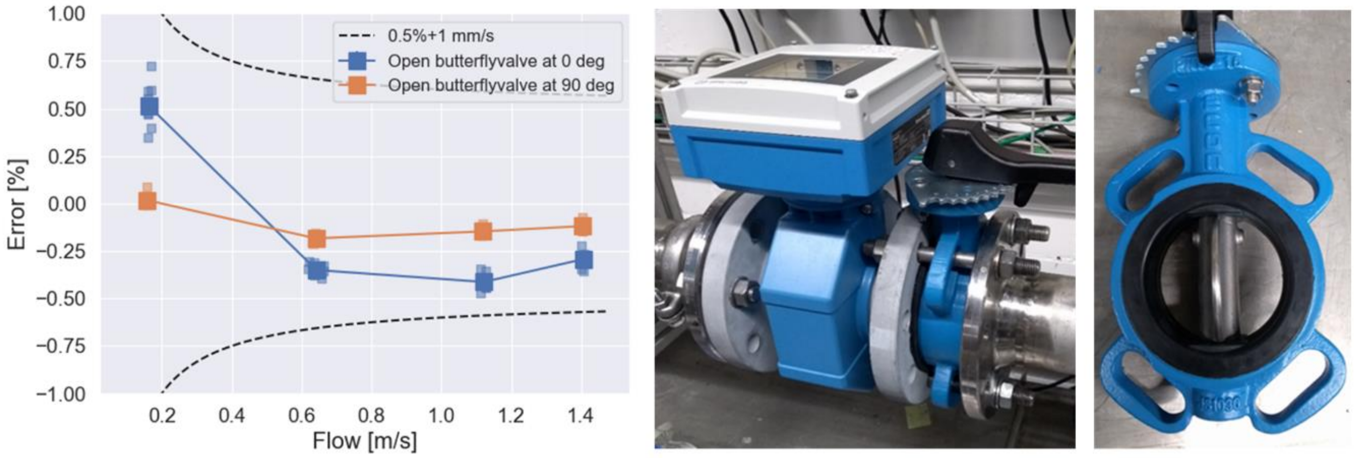

Figure 8: Open butterfly valve installed directly in front of Promag W 0 x DN full bore DN 80 (3")

This installation is not recommended as it might have a negative influence on the measurement error. In an open state the butterfly valve might even protrude into the flowmeter. Despite this serious disturbance the measurements in this test measurement are within specification. However, due to the variety of valves and installation scenarios the specification of 0 x DN full-bore flowmeters in combination with valves are relatively cautious. An open gate valve barely influences the flow profile, some control valves such as globe valves are generally uncritical even when used for regulating the flow. Check valves which are used to ensure that flow only occurs in one direction must, on the other hand, always be placed downstream of the flowmeter.

The OIML R 49 norm specifies a set of flow disturbers used to create disturbances like those found in the field. These include disturbances intended to induce swirl in the pipe, a type of disturbance which generally does not influence electromagnetic flowmeters strongly. In addition, they include a flow disturbance creating an asymmetric flow field "*of a type usually found downstream of a protruding pipe joint, single bend or a gate valve not fully opened*".[2] For large diameters where real test measurements are difficult these flow disturbers offer a practical way to test the performance of a flowmeter. A test with the latter asymmetric disturbance is shown in *Figure 9*. The wafer used to create the disturbance is mounted directly in front of the electrodes of a Promag W 0 x DN full bore DN 800 (32") with a remote transmitter. The measurement error is around -0.25%, well within the specified ±0.5% and better than the best OIML Class 1 of ±1%. This test was performed on the accredited calibration rig FCP 7.2 at Endress+Hauser in Cernay, France, at the flow rate specified in the OIML R 49 norm, inlet is from the right side.

[2] OIML R 49-2

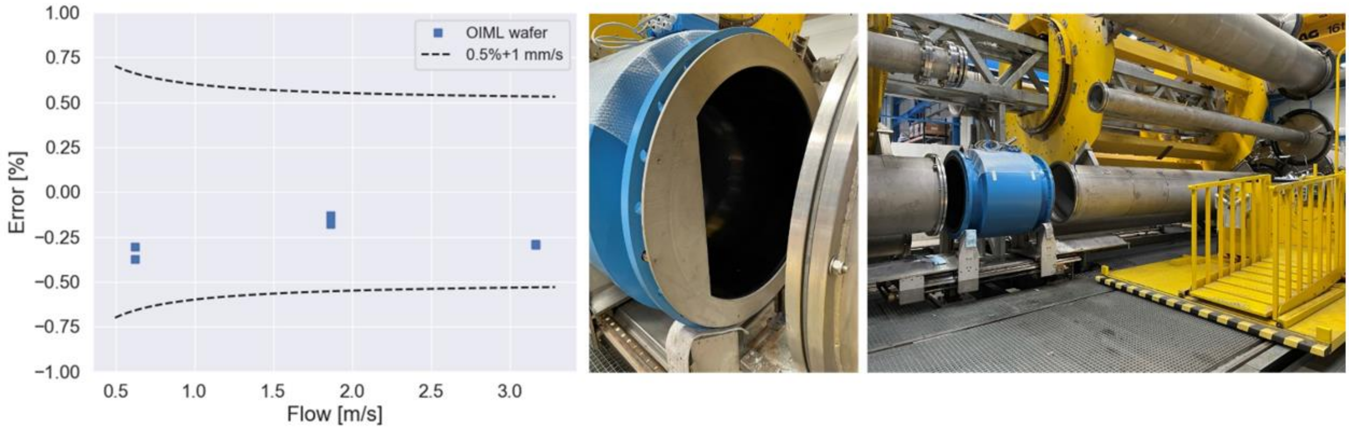

Figure 9: Promag W 0 x DN full bore DN 800 (32") with OIML wafer, in Cernay, France

Limitations

Promag 0 x DN full-bore flowmeter provide a solution with robust measurement performance in the most difficult applications, however, two limitations are worth mentioning.

T-fittings or other joints of two pipes must be handled with care if liquids with different properties are being mixed. A partial mixture results in a two-phase flow in the flowmeter, causing excessive noise or measurement errors even in a 0 x DN full-bore flowmeter. This can occur even if the two mixed liquids are water of different conductivities, something which is often the case when pipes from two different wells meet.

For high measuring accuracy with low flow rates a 0 x DN flowmeter with constricted flow tube is a viable alternative. Due to the constriction the flow is accelerated through the flowmeter resulting in an increased measurement performance at low flow rates with the disadvantage of pressure loss resulting from the reduced inner diameter.

Conclusion

The Promag 0 x DN full-bore technology enables installations of Promag electromagnetic flowmeters without inlet and outlet runs, while guaranteeing an accuracy of ±0.5%. This is achieved by using additional measuring electrodes and advanced signal processing. The use of computer aided simulation technologies and computations allows to predict how all line sizes perform in different installation scenarios. This has been validated with a series of tests in a controlled environment and worst case considerations. Based on the internal and external test measurements of Promag 0 x DN full bore in combination with simulations we prove that the 0 x DN full-bore technology achieves an accuracy of ±0.5% without inlet and outlet runs for the line sizes DN 25 to 3000.[3]

[3] Special Documentation SD02761D/06/01.21: Inlet and outlet runs 0 x DN

Attachment: 3rd party laboratory TÜV SÜD NEL confirmation

TÜV SÜD
National Engineering Laboratory

CERTIFICATE OF CALIBRATION

Certificate No: **2020_137**

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Ref: OP091-f08, v 1.6

UKAS CALIBRATION 0009

Issued By: TÜV SÜD National Engineering Laboratory
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Approved Signatory

C.Mills

Date of Issue: 05-Mar-20

Title: Calibration of a 10" Mag Meter U-bend. Up right sn P81D3019000

Customer: Endress+Hauser Flowtec AG
Address: Christoph Merian-Ring 4
4153 Reinach
Switzerland

Date Received: 15-Oct-19
Date of Test: 11-Nov-19
Test No: 6263-s2
Job/Project No: ENH083
Responsible Operator: K.Gallagher

Test Meter:

Description:	Electromagnetic Flowmeter
Manufacturer:	Endress+Hauser
Type/ Model:	PromagW
Output Signal Type:	Pulse
Nominal Size:	10"
Serial No:	P81D3019000
Customer Tag No/ID:	
Condition & Treatment:	"As found"

Additional Information On Device: Configuration Settings:

Test Conditions:

Flow Range, Min:	9.91	l/s	*(Approximate specification)*
Max:	178.06	l/s	
Nominal Temperature:	18	°C	
Nominal Pressure:	1.5	barg	
Test Fluid:	Water		
Nom. Viscosity:	1	cSt	at 18 °C
Nom. Density:	0.998	kg/l	at 18 °C

Additional Test Information: Pipe Straight Lengths: Upstream: 20 D Downstream: 10 D (diameters)
The device was mounted directly after a 90° bend with the sensor out of plane with the bend

Distribution:

No.of copies:		Format:
1	NEL Project File	Electronic
1	Endress+Hauser Flowtec AG	PDF

This laboratory is accredited in accordance with the recognised International Standard ISO/IEC 17025. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system.

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory. Accredited to ISO/IEC 17025: 2005.

1. TEST FACILITIES, MEASUREMENTS AND METHOD

The flowmeter package was installed in the TUV NEL National Standards Water Flow Measurement Facility, as shown in Figure 1.

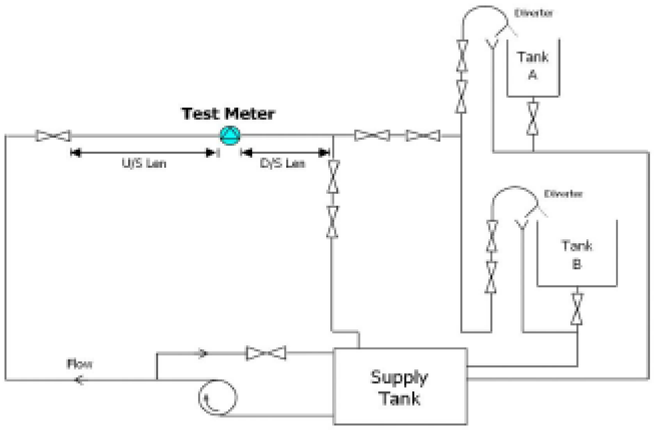


Figure 1: Schematic Diagram of Gravimetric Test Circuit

The device was calibrated by comparison of the output value with the value derived from a reference gravimetric weighing system. The method used was a diversion technique where the flow was continuous and diverted into the chosen weightank for the duration of the test.

The flowrate was calculated using the time taken for the quantity of fluid to pass through the meter. All measurements are fully traceable to National Standards.

The K-Factor (K) of the device under test was derived from the total number of pulses (P) output by the device divided by the reference quantity (Q):

$$K = \frac{P}{Q} \qquad (1)$$

The percentage error was calculated for the indicated quantity (Qi) from the device under test with respect to the reference quantity (Q):

$$E = \frac{Qi - Q}{Q} \times 100 \text{ per cent} \qquad (2)$$

2. UNCERTAINTY

The uncertainty estimates reported on the last page(s) of this calibration certificate are the total uncertainties, U_{tot}, for the calibration process incorporating the uncertainty of the reference values, U_{CMC}, and the repeatability of the calibration process, u_{rep}, for each group of flowrates.

The estimate of repeatability of the calibration process is calculated from the variance in the mean of a group of test points. Test points are considered a group when they are consecutive and are at similar conditions. The repeatability at singular test points not part of a group is estimated from the group(s) closest to their operating conditions.

The estimates of standard uncertainty for these sources are combined using the root sum square method to give the total standard uncertainty. The total standard uncertainty is then multiplied by the coverage factor (k=2) using effective degrees of freedom calculated by the Welch-Satterthwaite formula to give the total expanded uncertainty for each group. The total uncertainties are expanded values at a confidence level of approximately 95 per cent. The uncertainty estimate has been carried out in accordance with the methods recommended in international standards (GUM and ISO 5168), also in accordance with UKAS requirements.

3. RESULTS

The results are tabulated in Table 1 and shown graphically in Figure 2. The total uncertainties for the flow calibration are tabulated in Table 2. Test Point numbering may be non-consecutive due to intermediate checks, which are not shown.

Table 1: Table of Results

Facility: **NEL Water Flow Facility**

Test Desc: **Calibration of a 10" Mag Meter U-bend. Up right sn P81D3019000**
Quantity Type: **Volume**

Device Under Test:
Description: **MAG Pulse**
Serial No: **P81D3019000**
NEL DAQ ID: **68**

Fluid Properties:
Rel.Density: **1.000075**

Test Details:
Project No.: **ENH083**
Test No.: **6263-s2**
Test Date: **11-Nov-19**
Operator: **KG**
Calib. Method: **Gravimetric**
Line ID: **D2**

Test Point	Diverted Time s	Line Ave. Temp. °C	Total Corr. Mass kg	Total Corr. Volume l	Ref. Vol. Flow l/s	Meter Signal pulse	Meter Est. Value m³/s	Frequency Hz	Velocity m/s	K Factor pulse/m³	%Err (Ref.Vol) %
1	56.67	16.30	10080.761	10090.239	178.060	202061	0.178	3565.722	3.514	20025.393	0.127
2	56.81	16.49	10102.580	10112.399	178.001	202437	0.178	3563.357	3.513	20018.692	0.093
3	56.76	16.71	10090.880	10101.064	177.975	201849	0.178	3556.456	3.512	19982.944	-0.085
4	56.81	16.83	10098.417	10108.827	177.947	201817	0.178	3552.610	3.512	19964.433	-0.178
5	56.74	16.96	10083.191	10093.796	177.907	200837	0.177	3539.822	3.511	19897.074	-0.515
6	56.83	17.08	10099.743	10110.584	177.903	202462	0.178	3562.465	3.511	20024.759	0.124
7	56.73	17.23	10086.001	10097.090	177.975	200913	0.177	3541.364	3.512	19898.109	-0.509
8	72.35	17.53	10086.230	10097.933	139.578	201333	0.139	2782.908	2.755	19938.041	-0.310
9	72.40	17.64	10090.040	10101.958	139.539	201760	0.139	2786.919	2.754	19972.365	-0.138
10	72.31	17.79	10079.615	10091.787	139.558	200923	0.139	2778.541	2.754	19909.557	-0.452
11	72.42	17.93	10094.623	10107.066	139.555	201593	0.139	2783.538	2.754	19945.748	-0.271
12	72.43	18.10	10095.951	10108.716	139.570	201601	0.139	2783.483	2.754	19943.285	-0.284
13	62.38	17.89	6044.802	6052.182	97.018	120785	0.097	1936.218	1.915	19957.266	-0.214
14	62.42	17.79	6049.264	6056.542	97.032	121044	0.097	1939.254	1.915	19985.660	-0.072
15	62.65	17.70	6069.445	6076.648	96.995	121255	0.097	1935.469	1.914	19954.257	-0.229
16	62.63	17.64	6065.245	6072.374	96.961	120924	0.097	1930.861	1.914	19913.794	-0.431
17	62.38	17.57	6042.776	6049.807	96.984	120557	0.097	1932.643	1.914	19927.414	-0.363
18	138.44	17.44	6032.158	6039.061	43.621	120440	0.043	869.951	0.861	19943.497	-0.283
19	138.70	17.31	6030.181	6036.947	43.526	120445	0.043	868.394	0.859	19951.308	-0.243
20	139.02	17.20	6036.729	6043.380	43.472	120612	0.043	867.593	0.858	19957.706	-0.211
21	138.83	17.14	6032.998	6039.579	43.504	120546	0.043	868.317	0.859	19959.339	-0.203
22	138.91	17.27	6031.268	6037.990	43.468	120426	0.043	866.954	0.858	19944.718	-0.276
25	61.40	17.67	607.915	608.644	9.912	12128	0.010	197.518	0.196	19926.277	-0.369
26	61.32	17.68	606.916	607.645	9.910	12113	0.010	197.553	0.196	19934.344	-0.328
27	61.34	17.70	607.258	607.989	9.912	12107	0.010	197.380	0.196	19913.186	-0.434
28	61.39	17.72	607.697	608.430	9.910	12133	0.010	197.622	0.196	19941.477	-0.293
29	61.27	17.74	606.697	607.431	9.913	12098	0.010	197.440	0.196	19916.651	-0.417

(End of Data)

National Engineering Laboratory

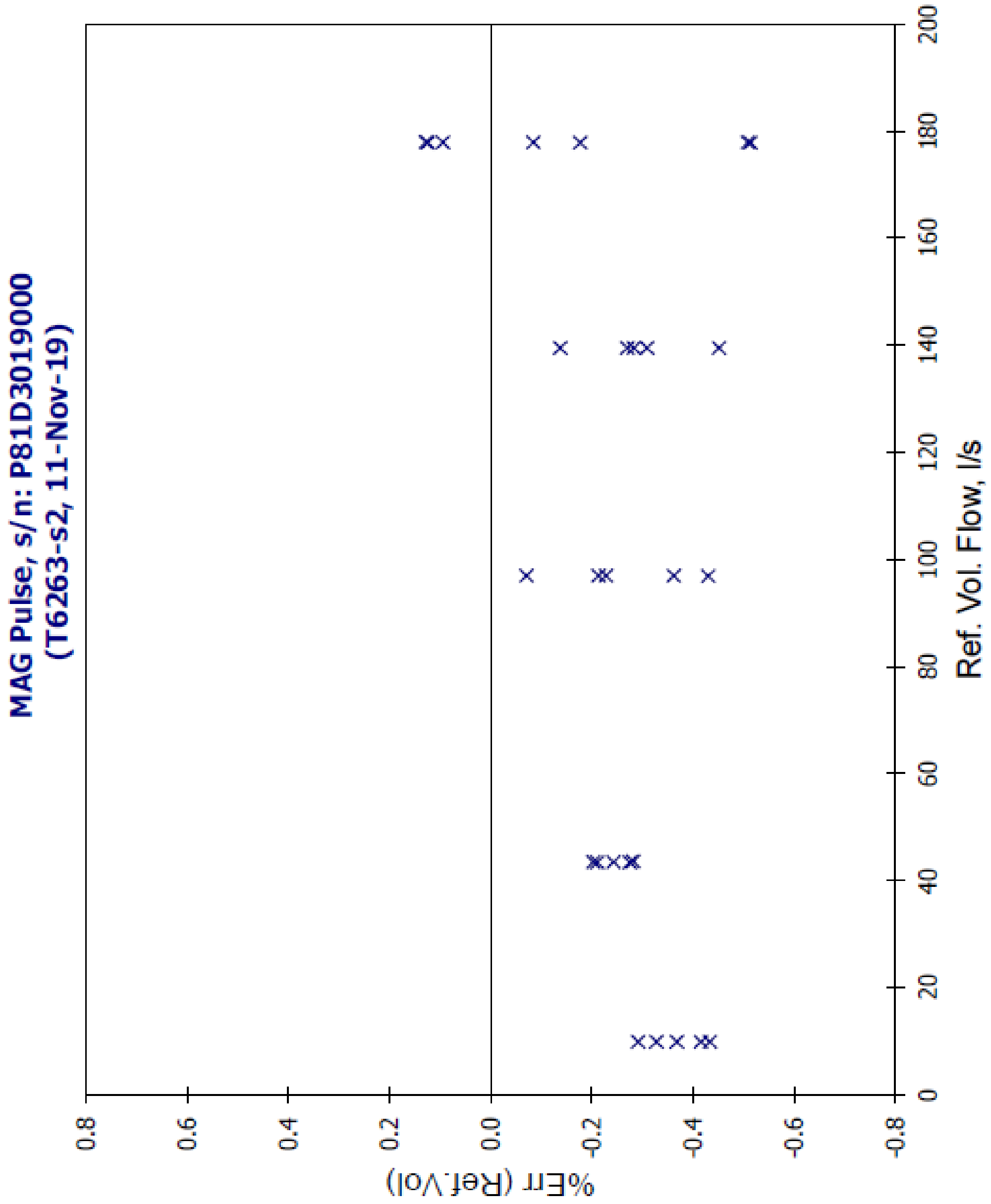
CERTIFICATE OF CALIBRATION — CERTIFICATE NUMBER: **2020_137**

Title: **Calibration of a 10" Mag Meter U-bend. Up right sn P81D3019000** — Page 4 of 5

For: **Endress+Hauser Flowtec AG**

Using: NEL Water Flow Facility (UKAS Calib.Lab.No.0009) — Date of Issue: 05-Mar-20

Figure 2: Calibration Results



	CERTIFICATE OF CALIBRATION		CERTIFICATE NUMBER: 2020_137
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	For:	Endress+Hauser Flowtec AG	
	Using:	NEL Water Flow Facility (UKAS Calib.Lab.No.0009)	Date of Issue: 05-Mar-20

Table 2: Total Uncertainty for the Flow Calibration Process

Test Point	Ref. Vol. Flow l/s	K Factor pulse/m³	Average Ref. Vol. Flow l/s	Average K Factor pulse/m³	u_{rep} %	U_{CMC} %	U_{tot} %
1	178.060	20025.393					
2	178.001	20018.692					
3	177.975	19982.944					
4	177.947	19964.433	177.967	19973.058	0.107	0.10	0.279
5	177.907	19897.074					
6	177.903	20024.759					
7	177.975	19898.109					
8	139.578	19938.041					
9	139.539	19972.365					
10	139.558	19909.557	139.560	19941.799	0.050	0.10	0.155
11	139.555	19945.748					
12	139.570	19943.285					
13	97.018	19957.266					
14	97.032	19985.660					
15	96.995	19954.257	96.998	19947.678	0.063	0.10	0.183
16	96.961	19913.794					
17	96.984	19927.414					
18	43.621	19943.497					
19	43.526	19951.308					
20	43.472	19957.706	43.518	19951.314	0.016	0.10	0.105
21	43.504	19959.339					
22	43.468	19944.718					
25	9.912	19926.277					
26	9.910	19934.344					
27	9.912	19913.186	9.912	19926.387	0.027	0.10	0.115
28	9.910	19941.477					
29	9.913	19916.651					

(End of Data)

End of Calibration Certificate