TESTING CORIOLIS MASS FLOWMETERS FOR PATTERN APPROVAL

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Paper 1.4

NORTH SEA FLOW MEASUREMENT WORKSHOP 1990
23-25 October 1990

National Engineering Laboratory
East Kilbride, Glasgow

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INTRODUCTION

Coriolis mass flow meters for liquids have during the last few years been developed into high precision metering systems (as a curiosity, the market share of these meters has now reached about 3-5 % of the flow meter market, worldwide). In many flow measurement systems - industrial as well as custody transfer applications - there are great demands for being able to measure mass (-flow) rather than volume (-flow) of fluids. This is because mass is a much more convenient unit to determine (independent of temperature, pressure, density e.t.c).

The danish engineering company PER HORNSVED A/S filed an application in july 89 to the Danish National Agency of Trade and Industry, Metrology Secretariat, for a national danish pattern approval of a mass flowmeter system, based on the EXAC Coriolis mass flow meter model 8300 EX transmitter EX 1200 sensor, which is described briefly in section 1 in this paper.

It was decided that DANTEST was to set up a test programme for the pattern approval. This test programme [r1] was approved by the Danish National Agency of Trade and Industry, Metrology Secretariat and Dantest was authorized to perform the pattern approval tests of the mass flow meter system, according to the test programme [r1].

During late 1989 DANTEST performed the pattern approval tests on the mass flow meter system. The tests include functional tests, flowtests (with water & liquified carbondioxide), vibrational tests, electronic tests and climatic tests. The last 3 test categories are taken from the international OIML draft [r3].
This paper, which is an extract of the original evaluation report [r7], illustrates the procedure in connection with pattern approval in Denmark, and presents the results from the tests.

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1. DESCRIPTION OF THE MASS FLOW METER SYSTEM

The EXAC Mass Flow Meter System (MFMS) - which is a measurement system with built-in "intelligence" - is only described in summary. For further details see [r4] & [r5]. Regarding the theory and the principles of the coriolis mass flow meter, please refer to e.g. [r6].

The MFMS consists in basic of 4 elements :

1) EXAC 8300 EX mass flow transmitter
2) EXAC EX 1200, DN 25 mm mass flow sensor
3) Junction and control box
4) three-way valve

coupled and wired as fig. 1 illustrates. The elements are shortly described in the following.

<u>Re.1) mass flow transmitter</u>
The transmitter receives "massflow proportional" signals from the sensor. These signals are converted in the transmitter, which performs a number of control-operations / calculations and integrates the mass flow to total mass. The LCD-display can provide information of e.g. mass flow rate , total mass , volumetric flow and total volume, density, dry solids, temperature, error messages etc. The transmitter is furthermore equipped with a number of analog and serial outputs , which can be connected to a computer for dataregistration. Further information and the technical data of the transmitter can be seen in [r4] and [r5]. See fig. 2 for an illustration of the transmitter.

<u>Re.2) mass flow sensor</u>
The flowsensor consists in basic of two parallel ovalshaped helically wound flowtubes mounted in a fixture in each side of a steel case. All materials are stainless steel. The sensor receives power supply from the transmitter.Inside the sensor an electromagnetic driving system applies a reciprocating force acting in the middle of the sensor loops , which causes the tubes to vibrate against each other at their natural frequency (approx. 72-78 Hz).
Two electromagnetic sensors (a magnet and a coil) located on each side of the tubes, measure an alternating electromagnetic force (EMF), the phase difference of the to EMF's being a function of the actual mass flow rate. If there is no flow through the sensor, the phase difference is equal to zero. For further information and technical data of the sensor, see [r4], [r5] and [r6]. Fig. 3 shows an "exploded" view of the flowsensor.

<u>Re. 3) Junction and control box</u>
The junction and control box is power supplied with 380 VAC. The box supplies the flow transmitter with 220 VAC. The box is equipped with the following features :

a) push-button to zero the total mass display of the transmitter.
b) key button to perform a zero-point calibration of the transmitter/sensor.
c) a green indicator lamp , showing whether the measuring system is ready or not ready. If the indicator lamp is not on, it indicates that the density of the fluid being measured is not high enough.
d) manual button to operate the 3-way valve. One position means that the valve will open to customer, the other position means that the valve will allow the fluid to return to the tank.
e) on/off contact to heating element (10 W) in the transmitter
f) start/stop pump buttons
g) security motor protection reset button
h) secondary mass totalizer supplied by pulses from transmitter

<u>Re. 4) three-way valve</u>
The valve is a DN 50 mm, three-way pneumatic ball valve. The three-way valve can be in two positions :

1) where the fluid flows to the customer or
2) where the fluid is returned to the road tanker

In position 1 and 2 the fluid is flowing through the flowsensor. The valve is equipped with a μ-switch, giving a feed back signal to the transmitter when the valve is fully open to customer (position 1). Refer to fig. 1.

The following "security"-functions are (among others) built into the measurement system, to ensure that the batch of fluid to the customer is measured with the required tolerances :

A) It is only possible to shift the three-way valve to pos. 1 (by means of button d on the junction and control box), when the actual (measured) density is above preset limits.

B) If the actual density , while measuring a batch of fluid, for some reason drops below the preset limit, the valve will automatically go in pos. 2, and freeze the total mass display.

C) It is only when the valve is fully open to the customer (pos. 1) the transmitter can sum up the total mass, in all other positions of the valve the transmitters totalmass display is automatically freezed.

2. RULES AND REGULATIONS

As there are not yet any national Danish or EEC rules for a metrological assessment concerning pattern approval of coriolis mass flow meters, the Danish Metrology Authorities decided that the metrological assessment of the MFMS had to be based on OIML SP5D/SR6, 1. draft international Recommendation, may 1989, "Electronic measuring Assemblies for Liquids other than water fitted with volume meters" [r3].

It was decided that the accept criteria / tolerances for the error of indication (f) of the MFMS should be :

$$f \equiv \frac{\text{MFMSreading} - \text{"true" value}}{\text{"true" value}} \cdot 100\ \% \in [-1.5\ \%\ ,\ +1.5\ \%\ ]$$

This is based on a note from the OIML secretariat SP 5D/Sr1 by Dr. D. Mencke from PTB in Germany, quote :

"Measuring assemblies for liquified gases under pressure (other than LPG-dispensers) :
- the accuracy class is 1.5 at a temperature below -10 °C.
- the accuracy class is 1.0 at a temperature above -10 °C. "

On the basis of [r3] and the know-how and experience in the field of flow measurement Dantest possesses, a test programme [r1] was set up for the pattern approval of the MFMS. This test programme is discussed in section 5.

3. AREA OF APPLICATION

The area of application for the MFMS consists of the physical data and the conditions under which the mass flow meter system is intended to be used, including the installation and mounting conditions :

Products

- fluid : liquified carbondioxide , CO_2
- temperature : -38 to -27 °C
- pressure : 12 to 17 bar. absolute
- density : approx. 1050 to 1100 kg/m3

Measurement system data

- transmitter : EXAC model 8300 EX (software pgm.ver.1.2)
- security code : 6 digits XXXXXX to enter configuration menu
- sensor : type:EXAC type EX 1200, DN 25 mm
- control box : type:IPH (description in section 2)
- 3-way valve : pneumatic, operated manually, and automatically by a signal from the flowtransmitter. Equipped with a μ-switch for feedback signal to transmitter to freeze/unfreeze the total mass display.

Installation and mounting

- stationary inst. : e.g. in a factory
- mobil inst. : on a road tanker
- mounting of sensor: supported in two rigid points. Distance from inlet/outlet flange to 1st. point between ½L to L, distance from 1st. point to 2nd. point between ¼L to ½L. Where L is the length of the sensor house ≈ 600 mm. Connecting tubes must be min. 2" · 2 mm.
- sensor declination: horizontal ± 5 degrees.

Capacity

- minimum massflow : 8 tonnes/hour (≈ 133 kg/minute)
- maximum massflow : 20 tonnes/hour (≈ 333 kg/minute)
- minimum delivery : 500 kg
- digital resolution : min. 0.1 kg

4. CALIBRATION/TESTING FACILITIES

Calibration with water

At Dantest, Fluid & Process Metrology Division, there is a liquid flow testrig (refer to fig. 5 in appendix b) for calibration and pattern approval testing of mass flow meters. A calibration is performed by pumping water through the mass flow meter up into a weighing tank. The principle used has been that of "standing start & standing stop". This procedure was found to be the most appropriate, because this is the way the mass flow meter is operated under "real life" conditions. The overall uncertainty of the testrig is calculated to be between ± 0.05 % to ± 0.1 %.

Calibration with liquified carbondioxide

The MFMS was calibrated with liquified carbondioxide (CO_2) in Fredericia, Hydro Gas, Denmark. The MFMS was mounted on a truck placed on a weighing bridge during the calibration of the mass flow meter. The calibration principle used has been that of "standing start & standing stop". Before starting the calibration the initial (gross) weight (mass of truck + CO_2) was registered. Then the MFMS 3 way valve was operated allowing the fluid to flow via a flexible tube to a separate CO_2 storage tank. After the amount of CO_2 has been measured, the valve was operated back again. Then the final (tare) weight (mass of truck) was registered, and the difference (net value = gross - tare) was compared with the indication of the mass flow meter. The overall uncertainty is estimated to be below ± 0.3 % .

Testing with flowsimulator

In some of the performance tests, it is very difficult to establish real flow trough the mass flow sensor during the tests. Therefore a flowsimulator was uses in these tests. The flowsimulator simulates the (primary measurand) signals from the flowsensor, and is connected to the transmitter as if it were the flowsensor. There are three potentiometers (frequency,flow and temperature). The procedure - using the flowsimulator - is, shortly described : first the flow is turned to an appropriate value on the "flow"-potentiometer, then the disturbance (e.g. EMC) is established, and the reading of the transmitter analog output (to an A/D-converter to a computer) is recorded during the test sequence. Deviations from reference conditions (i.e. no disturbances) can then be calculated. See fig. 4 for an illustration of the flowsimulator in a testarrangement.

5. PATTERN APPROVAL TESTING

On the basis of the agreed rules and regulations, Dantest set up a test programme for the pattern approval testing of the MFMS. The results from the test programme [r1] will not be reproduced in full in this report, as the test results discussed in the following sections (5.1 , 5.2.1, 5.2.2....5.5.3) will provide sufficient illustration. <u>The basic principle of the test programme has been to establish and assess the error of indication of the MFMS within its area of application</u>.

The pattern approval testing programme has been divided in five main categories involving 1) functional tests , 2) flowtests, 3) vibration test, 4) electronic tests and 5) climatic tests and table no. 1 shows the different tests performed.

<u>table no. 1</u> : testprogramme

Test No	Test description	CAL1	CAL2	MAV	T.SEQ.
5.1	functional tests	S	U	3	0
5.2.1	reference	W	-	1	1
		C	-	1	9
5.2.2	pulsating flow	W	U	1	2
		C	U	1	10
5.2.3	minimum delivery	W	U	1	3
		C	U	1	11
5.2.4	three way valve , test	W	U	3	17
5.2.5	flowprofile & declination	W	U	1	4
5.3	vibration test	W	A	1+2	12
5.4.1	power voltage variation	W	U	1+3	5
5.4.2	short time power reduction	W	U	1+2	6
5.4.3	bursts	W	U	1+2	16
5.4.4	electrostatic discharge(ESD)	S	U	1+2	14
5.4.5	el.compatibility (EMC)	S	U	1+2	15
5.5.1	dry heat	S	BUA	1+3	8
5.5.2	cold	S	BUA	1+3	7
5.5.3	damp heat , cyclic	S	U	1+2	13

Where the symbols in table no. 1 has the following meaning :

Test no : refer to the following sub sections for an description of the tests and the results.
CAL1 = calibration conditions : W / C / S = calibration with Water / Carbon dioxide / Simulated flow
CAL2 = calibration conditions : U / B / A = calibration performed Under / Before / After test/exposure
TSEQ. : chronological test sequence of the tests performed
MAV = Maximum Allowable Variations : 1 / 2 / 3

"1" : maximum permissible error :
measurement error € [-3.0 , +3.0] % of Minimum delivery (Mmin) with mass from Mmin to 2*Mmin
and measurement error € [-1.5 , +1.5] % of measured quantity with mass greater than 2*Mmin.

"2" = significant fault :
measurement error € [-3.0 , +3.0] % of Minimum delivery (Mmin) with mass from Mmin to 10*Mmin
and measurement error € [-0.3 , +0.3] % of measured quantity with mass greater than 10*Mmin
or the MFMS shall detect and act upon a significant fault.

"3" = all functions of MFMS shall operate as designed

5.1 FUNCTIONAL TESTS

The functional tests of the MFMS comprised an assessment of its construction, operation and indications of recordings. One of the basic tests is to check that the MFMS - in case of power failure - will restore the last mass indication on the display when the power returns. For further details about the functional tests please refer to [r1] or the specific requirements in [r3].

5.2 FLOWTESTS

The flowtests have been performed by calibrating the MFMS with water using Dantests liquid flow testrig and with liquified carbondioxide, CO2.

5.2.1 Reference

The tests in this series make up the reference situation in connection with the calibration of the MFMS. Summary of the results from the calibration with water can be seen in table 2, which is an extract of the original calibration result sheet :

table no. 2 : calibration results, reference tests, water

nom. mass-flow, Qm ton./hour	No.of repeat tests	nom.meas. amount MB / kg	mean error fm [%]	std.dev. s(f) [%]
5	3	1000	-0.15	0.02
9	3	1000	-0.25	0.00
18	3	1000	-0.38	0.01
25	3	1000	-0.53	0.02
33	3	1000	-0.48	0.01

As can be seen from table no. 2, the calibration with water at a nominal flowrate (Qm) from 5 tonnes/hour up to 33 tonnes/hour shows that the error of indication in mean (fm) is within the required tolerances : -1.5 % to + 1.5 % . The linearity of the meter (over the range 5-33 t/h) is appr. ± 0.20 % . Furthermore it is seen, that the standard deviation (std.dev) is extremely low, indicating a very good repeatability of the meter.

The reference calibration test with CO2 is carried out as described in section 4. The temperature and pressure of the liquified CO2 was measured during each calibration, with values between -28 to -32 °C and 14 to 16 bar. Summary of the results from the calibration with CO2 is shown in table no. 3, which is an extract of the original calibration result sheet :

table no. 3 : calibration results, reference tests, CO_2

nom. mass-flow , Qm ton./hour	No.of repeat tests	nom.meas. amount MB / kg	mean error fm [%]	std.dev. s(f) [%]
8	4	1000	0.12	0.76
13	3	1000	0.84	0.58
15	3	1000	0.61	0.56
19	3	500	-0.13	0.39

As can be seen from table no. 3, the calibration with CO_2 at a nominal flowrate (Qm) from 8 tonnes/hour to 19 tonnes/hour, the error of indication in mean (fm) is within the required tolerances: -1.5% to +1.5 % . The linearity of the meter, in the range 8 to 19 t/h, is $\pm$ (0.84+0.13)/2 $\approx \pm$ 0.49 % . The standard deviation (std.dev) is between 0.39 and 0.76 %. The results are obviously not as good as with water. But the calibration uncertainty is greater for CO_2 than for water (refer to section 4), which is part of the explanation of the deviation between the water- and CO_2-calibration.

5.2.2 Pulsating flow

The flowtests with pulsating flow have been performed both with water and CO_2. During the calibration a butterfly valve (after the flowsensor) has been opened and closed 10 times. The valve has been closed for approximately 3 seconds at each "pulsation", with a opening and closing time of approx. 2 sec. Summary of the results are shown in table no. 4.

table no. 4 : calibration results with pulsating flow

test fluid	massflow ton./hour	nom.meas. amount MB / kg	error f [%]	mean error fm [%]	std.dev. s(f) [%]
H_2O	0 - 18	1000	-0.34		
H_2O	0 - 18	1000	-0.34	-0.34	0.01
H_2O	0 - 18	1000	-0.35		
CO_2	0 - 8	1000	-0.40		
CO_2	0 - 8	1000	-0.49	-0.59	0.25
CO_2	0 - 8	1000	-0.87		

As it can be seen from table no. 4, the error of indication in mean (fm) is within the required tolerances : -1.5 % to + 1.5 %. The standard deviation is low for water, higher for CO_2, as in the case of the reference tests.

5.2.3 Minimum delivery

The purpose of the minimum delivery tests has been to verify, that the error of indication does not exceed the required tolerances when measuring the (requested) minimum delivery (500 kg of fluid).
As can be seen from table no. 5, the tests have been performed with both low and high flowrate, for CO_2 and H_2O. The results (summary in table no. 5), though larger for CO_2, show that the error of indication is within the required tolerances.

table no. 5 : calibration results with minimum delivery

test fluid	massflow ton./hour	no. of repeat meas.	nom.meas. amount MB / kg	mean error fm [%]	std.dev. s(f) [%]
H2O	5	4	500	-0.32	0.03
H2O	33	3	500	-0.50	0.01
CO2	5	6	500	-0.75	1.21
CO2	15	3	500	-0.50	0.19
CO2	16	3	500	0.02	0.49
CO2	19	3	500	-0.13	0.39

5.2.4 Test of 3-way valve and μ-switch

The tests were performed to verify the function of the 3-way valve. During a calibration with water the 3-way valve has been switched manually from position 1 to 2 (see section 2) nine times. It was verified, that the total mass on the transmitter display "freezed", when the valve was in position 2. The results of three repeat measurements performed at nom. 12 ton/hour with nom. 1000 kg of water measured are : fm = -0.89 % , which is within the required tolerances. The standard deviation was as low as 0.01 % , showing a very good repeatability even under these conditions.

Furthermore the function of the valve (and the μ-switch) has been tested by injection of air in the water to lower the density. It was observed that the valve switched properly between position 1 and 2.

5.2.5 Flowprofile and declination

The purpose of these tests has been to determine whether an extreme swirl (45 deg. swirl angle, created by a swirlgenerator) at the entrance of the mass flow sensor inlet tube, and different declinations of the flow sensor (left/right tilt, upwards-/downwards flow) affect the measurement accuracy of the MFMS. The tests have been performed with water, at flowrates between 17 and 18 tonnes/hour, and in each calibration there has been measured nominally 1000 kg. Se table no. 6 below for a summary of the results from the calibrations.

<u>table no. 6</u> : calibration results, flowprofile & declination

testdescription	nom.meas amount kg	no. of repeat meas.	mean error fm [%]	std.dev s(f) [%]
swirl left	1000	3	-0.27	0.01
swirl right	1000	3	-0.23	0.01
left tilt (*1)	1000	3	-0.18	0.02
right -"- (*2)	1000	5	-0.33	0.05
upwards flow (*3)	1000	3	-0.32	0.01
downwards -"-(*4)	1000	3	-0.53	0.01

*1) sensor is tilted approx. 15 deg. to the left side of the flow sensor axis.
*2) sensor is tilted approx. 15 deg. to the right side of the flow sensor axis.
*3) sensor is tilted approx. 15 deg., so that the fluid flows upwards through the sensor.
*4) sensor is tilted approx. 15 deg., so that the fluid flows downwards through the sensor.

As can be seen from the above table the mean value of the error of indication (fm) is within the required tolerances. The standard deviation (std.dev.) is very low. Compared to the results from ref. test, where fm = -0.38 % at 18 ton/hour, there are no significant deviations.

5.3 VIBRATION

The vibration test of the MFMS was performed according to [r3], section A.4.4, the object of which is to verify compliance of the MFMS under sinusoidal vibrations in 3 mutually perpendicular main axis. Both the transmitter, flowsensor and the control box were vibrated.

There were not performed any measurements during the vibration test (it is ambiguous, since a measurement system based on coriolis forces never will work under such severe external vibrations). After the vibration test, the MFMS was calibrated with water. The results showed a slight offset in the error of indication, compared to the reference tests.

5.4 ELECTRONIC TESTS

5.4.1 Power voltage variation

The tests were performed according to [r3] section A.4.5, during calibration with water. The results are shown in table no. 7 :

table no. 7 : calibration results, power voltage variation

voltage var. from 220 VAC	massflow Qm ton./hour	no. of repeat meas.	nom.meas. amount MB / kg	mean error fm [%]	std.dev. s(f) [%]
+ 10 %	18	3	1000	-0.36	0.02
- 15 %	18	3	1000	-0.35	0.02

No significant deviation compared to the ref. test (fm=-0.38%).

5.4.2 Short time power reduction

The tests were performed according to [r3] section A.4.6, during calibration with water. Results in table no. 8 :

table no. 8 : calibration results, short time power reduction

inter-ruption	dura-tion msec	massflow Qm ton./hour	no. of repeat meas.	nom.meas. amount MB / kg	mean error, fm [%]	std.dev s(f) [%]
50 %	20	18	3	1000	-0.41	0.01
100 %	10	18	3	1000	-0.40	0.02

No significant deviation compared to the ref. test (fm=-0.38%).

5.4.3 Bursts

The burst tests were performed according to [r3] section A.4.7, during calibration with water.

1) Prior to the burst test, a reference calibration was made to serve as a check, that the MFMS was in order and functioning.
2) The burst electrical disturbances are applied to the main supply by insertion of an intermediate burst generating unit in the main supply.
3) The bursts are further applied to the signal and communication lines by a capacitive coupling device.

The results from 1),2) and 3) are listed (in summary) in table no. 9 :

table no. 9 : calibration results, burst test

test ID	massflow Qm ton./hour	nom.meas. amount MB / kg	no.of repeat meas.	mean error fm [%]	std.dev. s(f) [%]
1	18	1000	3	-0.40	0.04
2	18	1000	3	-0.39	0.03
3	18	1000	3	-0.41	0.01

It appears, when comparing the results from 2) and 3) with the result from 1), that the burst disturbances have no significant influence on the error of indication of the MFMS.

5.4.4 Electrostatic discharge (ESD)

The ESD tests were performed according to [r3] section A.4.8. The tests consist of running the MFMS with a simulated mass flow rate while applying the ESD test voltage (8 kV) to such points on the transmitter, which are likely to be touched by the operator. At the same time the analog output from the transmitter is sent to a PC, where the mass flow rates are stored on disk.

The MFMS passed the test, but 2 events (which were not reproducible) caused us to recommend that the plastic keyboard cover should be coated on either the inside or the outside with a conductive (metal) film, which should be connected (grounded) to the aluminium case. This will highly improve the ESD compatibility of the transmitter.

5.4.5 Electromagnetic compatibility (EMC)

The EMC tests were performed according to [r3] section A.4.9. There were some problems, as the transmitter was not resistent to the EM-fields over all the frequencies from 0.1 to 1000 MHz (especially about 25-30 and 210 MHz).
By different approaches during the test (shortening and screening cables e.t.c.) the MFMS passed the EMC test, but with the following modifications in order to cope with EM-fields :

- A HF filter on the 380 VAC power supply immediately at the entrance in the junction box should be mounted.
- A conductive rubber sealing should be mounted under the lids of both the junction box and transmitter, thus completing their metallic encasing.
- All cables must be screened (including the 220 VAC cable between the two boxes) , the screens terminating maximum 2 cm from the cable-entrances.

These modifications will ensure a proper performance of the MFMS with regards to EM-fields.

5.5 CLIMATIC TESTS

5.5.1 Dry heat

The flowtransmitter has been tested in a climatic test chamber by means of the flowsimulator (see fig. 4). Three tests were performed (according to [r3] section A.4.1) :
a) at reference temperature of 20 °C, following conditioning
b) at temp. 55 °C, 2 hours following temperature stabilization
c) after recovery of the transmitter at reference temp. 20 °C.
The testresults are shown (in summary) in table no. 10.

table no. 10 : results from dry heat test

test	hour from	hour to	no. of flow-samples	mean value simulated flow kg/h	stv dev. kg/h	dev.from a-test [%] (*)
a	13.41 -	13.57	96	28569	7	0
b	06.48 -	07.03	96	28470	3	-0.35
c	08.59 -	09.15	96	28430	7	-0.49

(*) e.g. for b-test : $100 \cdot (28470-28569)/28569 \approx -0.35$ %

The MFMS operated as designed during the test, and the results showed that the deviation from a-test result was within required tolerances.

5.5.2 Cold

The flowtransmitter has been tested in a climatic test chamber by means of the flowsimulator (see fig. 4). Three tests were performed (according to [r3] section A.4.2) :
a) at reference temperature of 20 °C, following conditioning
b) at temp. -25 °C, 2 hours following temperature stabilization
c) after recovery of the transmitter at reference temp. 20 °C.
The testresults are shown (in summary) in table no. 11.

table no. 11 : results from cold test

test	hour from	hour to	no. of flow-samples	mean value simulated flow kg/h	stv. dev. kg/h	dev.from a-test [%]
a	15.03 -	15.18	96	28611	10	0
b	08.46 -	09.01	96	28428	6	-0.64
c	11.25 -	11.41	96	28546	4	-0.23

The MFMS operated as designed during the test, and the results showed that the deviation from a-test result was within required tolerances.

5.5.3 Damp heat, cyclic

The flowtransmitter and the junction-box have been inside a climatic test chamber (temperature- and humidity controlled), and the damp heat (> 93 % RH) cyclic test was performed in accordance with [r3], section A.4.3. The tests were performed:

a) before the 1. cycle of the test started
b) under the test (2.cycle) sequence at 25 °C
c) under the test (2.cycle) sequence at 55 °C
d) under the test (2.cycle) sequence at 25 °C

and summary of the results are shown in table no. 12 :

<u>table no. 12</u> : results from damp heat cyclic test

test	hour from		hour to	no. of flow-samples	mean value simulated flow kg/h	std. dev. kg/h	dev.from a-cal. res.[%]
a	12.25	-	12.40	90	29715	0	0
b	07.40	-	12.55	31	29704	7	-0.04
c	16.04	-	00.59	52	29715	0	0
d	04.08	-	06.56	31	29714	4	.-0.00

The MFMS operated as designed during the test, and the results showed that the deviation from a-test result was within required tolerances. After the damp heat cyclic test, the MFMS was calibrated with water, and no significant deviation from the reference water test was found.

6. NATIONAL PATTERN APPROVAL

When all the tests as described in summary in this paper were performed, and it was verified that the MFMS fulfilled the required tolerances, a pattern approval certificate was set up.

The pattern approval certificate contains a large amount of information. Apart from manufacturer, applicant and type, it also lists the legal measuring data, which specifies the area of application for the MFMS. It also lists the conditions of verification and the demands in relation to sealing. It specifies the components and construction of the MFMS and provides a short description of its operating principle. Finally it covers the installation/mounting requirements and some short instructions for use.

Pattern approval for legal use of the MFMS entails, that accounts are settled (a buyer/seller relationship exists) on the basis of the recordings of the MFMS. To maintain the accuracy of the MFMS and safeguard the interests of the user, all MFMS's must be verified periodically. The verification is carried out by a metrological control body, appointed by the Danish metrological authorities. Before a MFMS may be used as a legal basis for settlements of accounts, it must undergo an initial verification, followed by a sealing. Furthermore, each MFMS must undergo a reverification annually, including a resealing. The initial and subsequent verifications are performed in the same way (very short described) :

1) It is checked that all terms and conditions for the MFMS are as described in the pattern approval certificate. This includes verifying the presence and correct functioning of checking features for the MFMS.

2) Calibration of the MFMS on a flow calibration test rig with water at 3 flowrates : 1) Qmin, 2) Qmax/2 and 3) Qmax. Verification tolerance : -1.5 % to +1.5 % .

3) When both 1) and 2) have been satisfied, the MFMS is sealed.

The object of sealing is to prevent the measuring accuracy from being diminished as a result of inadvertent access to metrologically vital parts of the system. As the transmitter and sensor are matched (and calibrated) together, it is essential that they are "linked" together so as to make up an integrated unit. Therefore the transmitter and sensor must be equipped with (legal) type signs with identical serial numbers. The actual metrological demands to the content of the type signs are described in the pattern approval certificate. The access to the configuration tree of the transmitter must be prevented by a password of up to 6 digits. The transmitter lid must be sealed, so that access to "security-on/of" jumper-pin is avoided.

7. FUTURE ASPECTS

This paper has described how a testprogramme for a Coriolis mass flow meter was set up, performed and evaluated - leading to a national Danish pattern approval for legal measurement of liquified carbondioxide.

The pattern approval is only valid in Denmark, because there are not yet any international agreed rules for metrological assessment concerning pattern approval of coriolis mass flow meters. The basis for the requirements and tests in this pattern approval was the OIML-draft [r3], which covers volume meters. However (another-) working group, OIML SP 5D/RS10 , has this spring come out with a 2nd. Pre-draft "Direct mass flow assemblies for measuring quantities of liquids", which includes most of the requirements and tests from the above mentioned OIML-draft [r3].

Hopefully this international work will lead to a final common international standard with testdescriptions and guidelines for the metrological assessment concerning pattern approval of coriolis mass flow meters. This will ensure the interchangeability of pattern approvals between the Metrological Authorities in the countries, which reduces costs for the applicants of pattern approval. Furthermore it will contribute to enhance the use of Coriolis mass flow meters used in flow measurement systems - industrial as well as custody transfer applications.

APPENDIX A : References

[r1] Test programme
Test programme for Coriolis mass flow meter EXAC 8300 EX, Dantest , Fluid Metrology Division , by Lars Mandrup-Jensen, Michael Mannstaedt, 1989-08-15. Revised by the Danish National Agency of Trade and Industri 1989-08-29.

[r2] DK-Metrological Directive
Pattern approval of measuring equipment. Guidelines in the case of exemptions". DK-Metrological technical directive no. 20.05-02, date 1987-10-01.

[r3] OIML International draft
SP5D/Sr6, 1. draft international Recommendation, may 89, "Electronic measuring Assemblies for Liquids other than water fitted with volume meters"

[r4] EXAC Instruction manual
EXAC Model 8300 EX Mass flowmeter, Instr. manual nov. 88

[r5] Documantation collection
Documentation coll. "Dokumentation for EXAC model 8300 EX masseflowmåler" with 12 separate clauses.

[r6] Article
"Coriolis based mass flow measurement" Sensors, dec. 1985 by Alan M.Young, Exac Corporation.

[r7] Evaluation report
"Pattern approval of of mass flow meter system based on Coriolis mass flow meter, EXAC model 8300 EX", 1989-12-18, by Dantest, Lars Mandrup-Jensen.

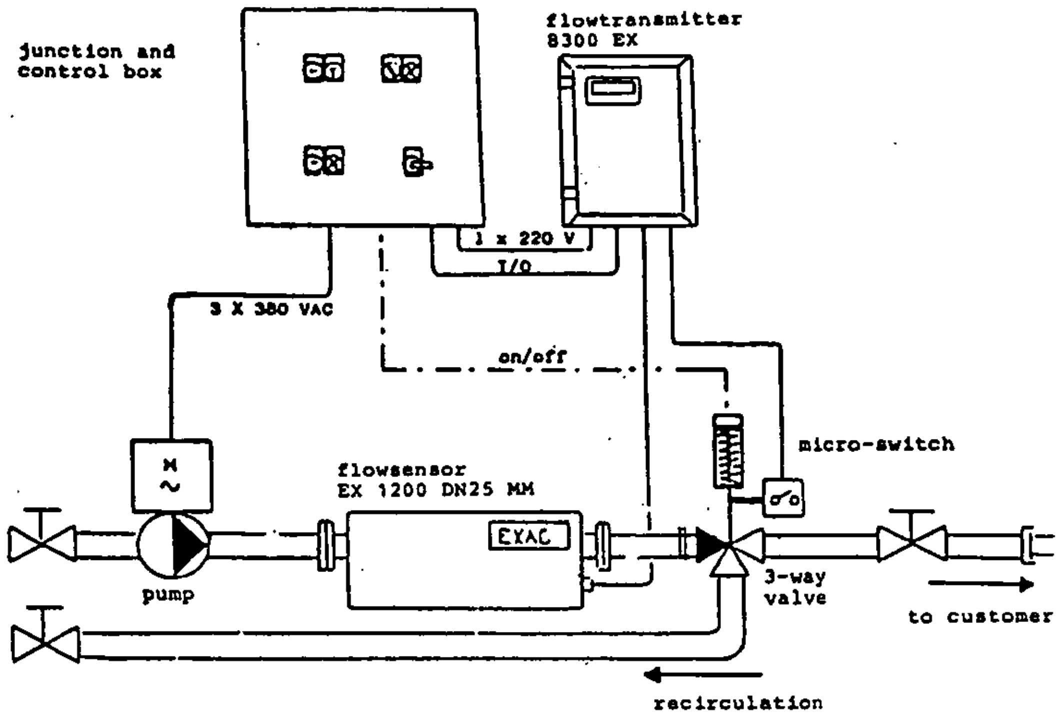


figure 1 : mass flow meter system

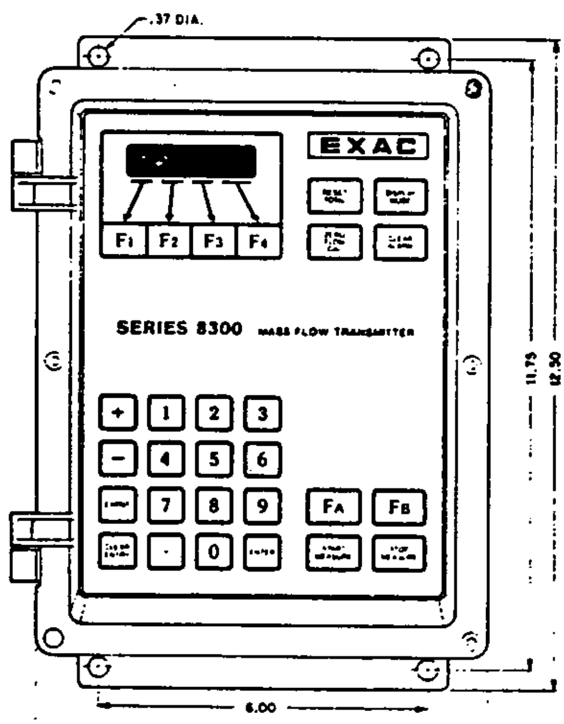


figure 2 : EXAC coriolis mass flow transmitter

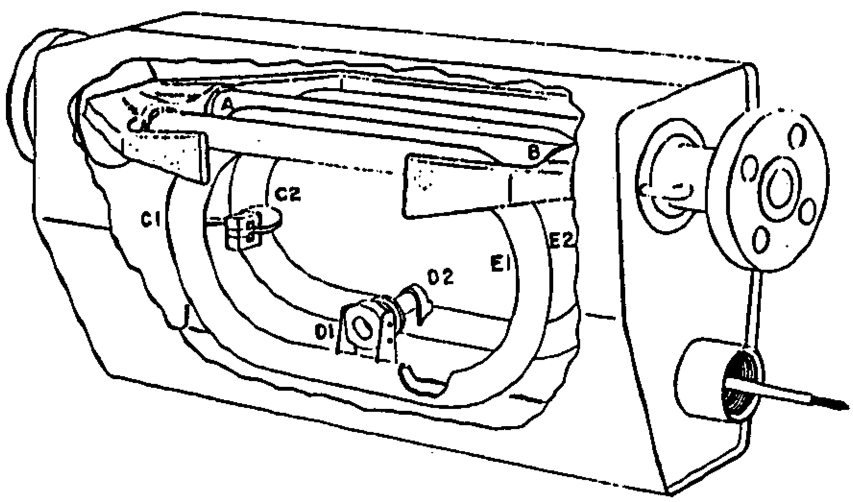


figure 3: EXAC coriolis mass flow sensor

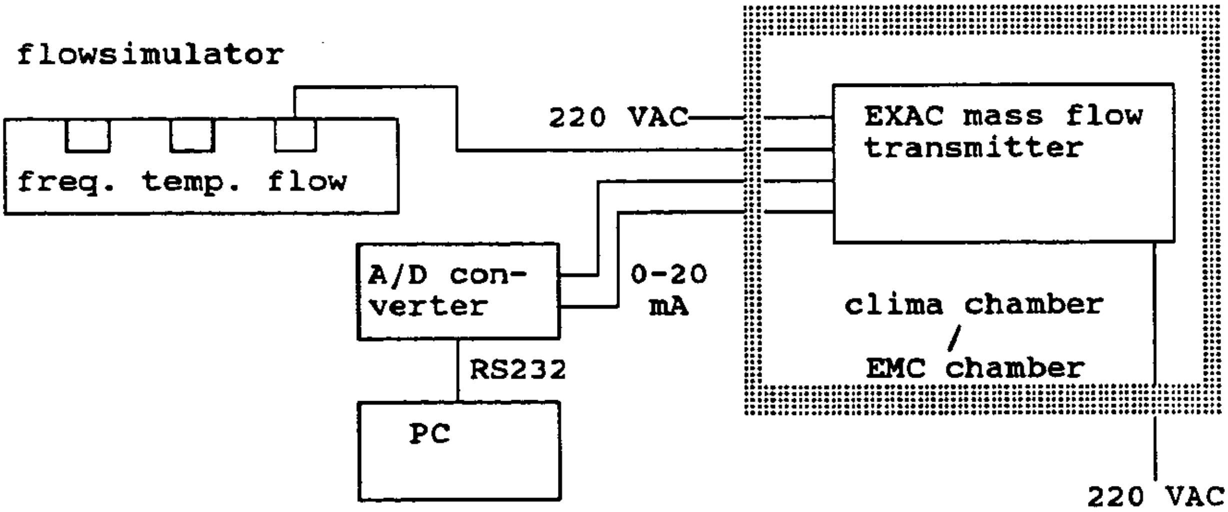
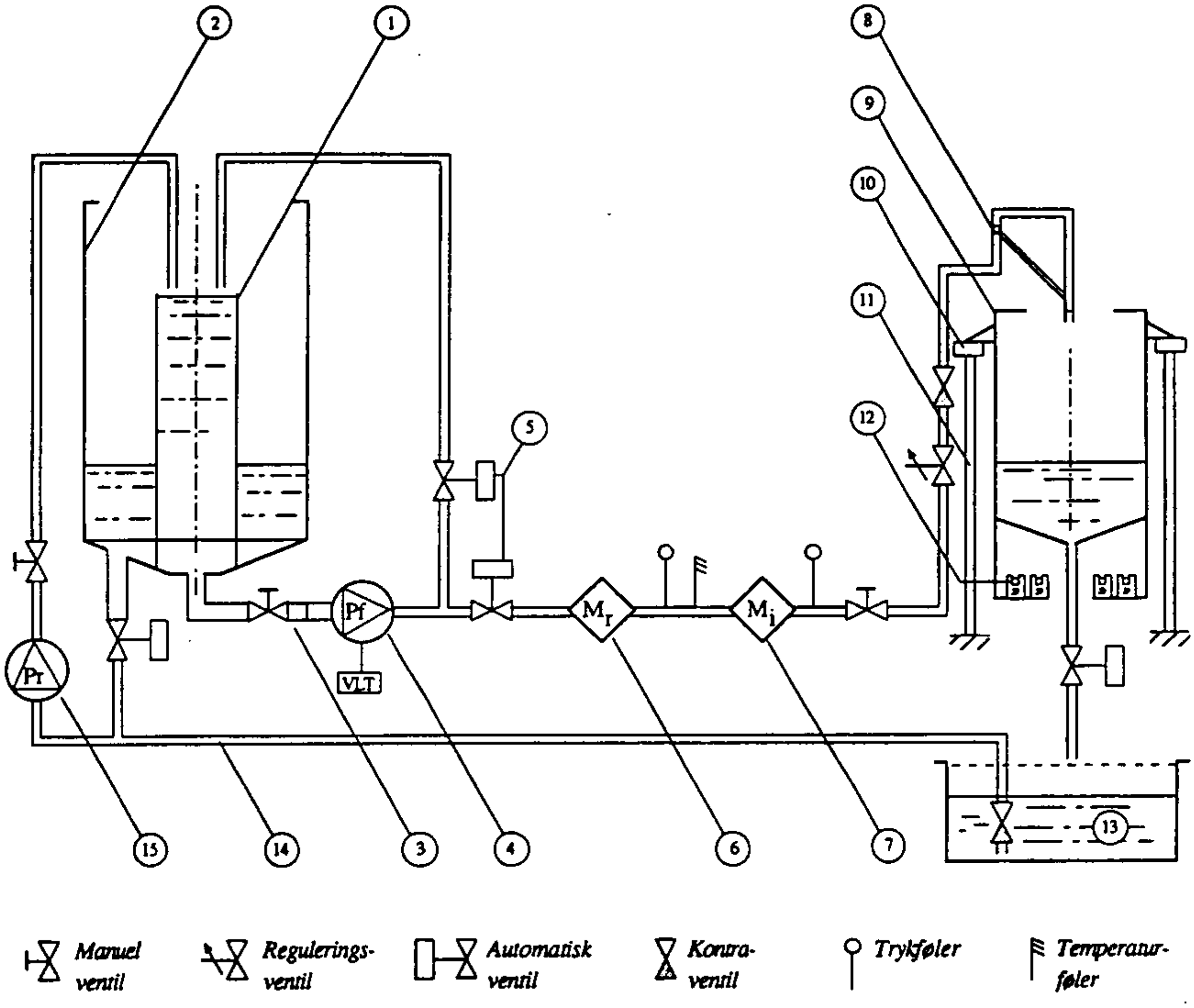


figure 4: flowsimulator arrangement

LIQUID-FLOW TESTRIG

The liquid-flow testrig is used for calibration, testing and pattern approval testing of mass- and volumeflowmeters. Furthermore determination of flow/pressure-characteristics of valves (control/safety- e.t.c).The liquid is weighed in a weighing tank, placed/mounted on loadcells. The weighing system is calibrated with control weights, with traceability to NPL, UK Teddington. When volume flowmeters are calibrated, the density (kg/m3) is either calculated or measured, dependent on the required accuracy. The flow test rig is accredited by STP (no.254) to calibrate mass flowmeters. The supply reservoir, weighing tank tubes and fittings are made of stainless and acidproof steel (AISI 316). (refer to principal drawing below).



manual valve | automatic valve | control valve | non-return valve | pressure gauge | temperature probe

1. Inner suction tank in feed reservoir
2. Outer suction tank in feed reservoir
3. Filter
4. Pump (forward)
5. Pneumatic butterfly valves
6. Control/reference flowmeter
7. Mass flow meter under calibration
8. Discharge device ("svan-neck")
9. Weighing tank (max. 1100 kg)
10. Loadcells
11. Loadcell/weighing tank, frame
12. Control weights (22*50 kg)
13. Reservoir (sump)
14. Return-tube system
15. Pump (return)

Selected technical data, liquid-flow testrig

length * width	:	7 m * 3.5 m
calibration liquids	:	as required
massflow range	:	1 to 1400 kg/min
tube dimensions, nominal	:	1", 2", 3", 4"
liquid temperature	:	15 °C -> 70 °C
meter surrounding temp.	:	-20 °C -> 55 °C
liquid pressure	:	max. 12 bar abs
calibration uncertainty	:	< ± 0.05 %

For further information, please contact :
Dantest, Amager Boulevard 115
DK 2300 , Copenhagen S, Postbox 1915
phone/fax : 31 54 08 30 / 31 95 47 00

figure 5: Dantest liquid flow testrig

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.