Mass Flow Meter Analysis for Reliable Measuring

Review

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Abstract *– The aim of this paper is to show how to analyze and correctly choose a measuring device especially applied to the mass flow meter based on the Coriolis principle. In the beginning, a short description of a Coriolis based mass flow meter is given. Furthermore, comparison analysis of two flow meters indicates the problems of a method wrongly applied to slurry fluid measurement in production of a detergent powder plant. Analysis is made by using the RS Logix 500 software. The diagrams showing causes of wrong measurements and position of the mass flow device determine a few malfunctions. Finally, comparison of measurement by a new mass flow meter shows that the measurement method is applicable to slurry fluids which are especially problematic and complex for measuring.*

Keywords *– Coriolis principle, flow meter, mass flow analysis, problematic slurry fluid*

1. INTRODUCTION

Combining science research techniques with solutions of practical problems in process industry plants (eg. like powder detergent) gives a real purpose and challenge for scientific research.

This paper gives a solution of a correctly measuring device in slurry fluid measurements. The mass flow meter used is based on the Coriolis principle where individual mass particles are influenced in the same way as the body of the person on the turntable [1].

The basic principle comes from forces occurring in the system which will oscillate if the mass passing through it is affected by these oscillations [2]. Mass flow measuring devices based on the Coriolis principle are often used for flow measurement of different media. In [3], a new method for gas measurement is given. [4] presents a model of a mass flow meter with special stress placed on vibration of a general plan tube with a flowing fluid. Devices for measuring mass flow in powder manufacturing plants are given in [5]. A special problem in flow measurement is present when measuring slurry fluids where bubble, plug and wavy flow are present (Fig. 1). These issues are especially dealt with in [1, 6]. Fluid mechanic and fluid measurement principles, devices and problems are explained in [7, 8, 9]. These problems cause wrong dosage in the continuous part of the process [Fig. 5]. These wrong information causes the operator to make wrong assumptions referring to dosing components of the final product. Therefore, a complete analysis of the entire system is performed. By using the RS Logix 500 software, measurements are made to determine the problem. Measurements of two mass flow devices are compared in continuous work for problem detecting.

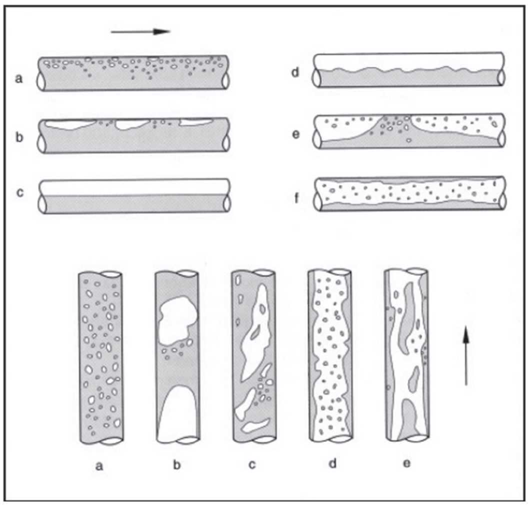


Fig.1. Two-phase flow (liquid/gas) in horizontal and vertical pipes [1]

Measurements of mass flow in kg/h are done in the period of two weeks. Measurement results and their analysis are given further. Problems were detected and solutions were determined by comparing measurements.

Based on measurement comparison, it was determined which device functions correctly and gives real and reliable results.

2. CORIOLIS MASS FLOW METERS

As stated above, process data information on mass flow is more useful than data on volume flow. For these purposes, a mass flow meter was developed, whose functioning is based on measuring the Coriolis force. Fig. 2 shows the physical meaning of the Coriolis force as given in the following equation:

$$F_c = 2 \cdot m \cdot \omega \cdot v_r \qquad (2\text{-}1)$$

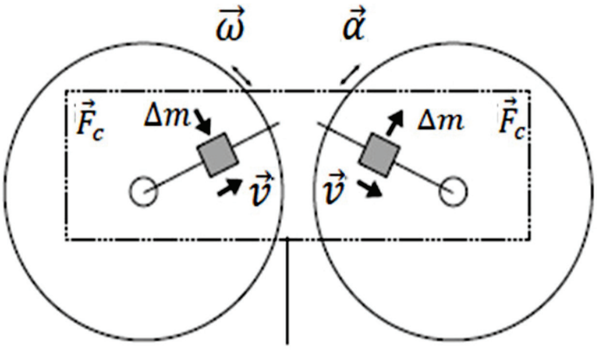


Fig.2. Coriolis force description [1]

In a system with rotation movement, only small reaction against the centrifugal force is enough to keep the position. If movement is present from the center towards the edge of the disk, an additional inertia force is present (Coriolis force). The inertia force is greater when the mass is larger and rotation speed greater.

2.1. FLOW METER CONSTRUCTION

In the Coriolis mass flow meter, individual particle mass is influenced by the force in the same way as a person on the rotating disk in Fig. 2. Fig. 3 shows a flow meter construction principle.

Rotation from the stated example is substituted for excitation of the measuring pipe which oscillates on its resonant frequency. When there is no flow and no mass in moving, there is no linear movement and consequently no Coriolis force. Once there is a flow, superposition of linear movement and movement caused by oscillation (rotation) in the measuring pipe causes pipe twist. Sensors in the pipe inlet and the pipe outlet measure signals phase difference Δφ. The higher mass and velocity, the higher phase difference Δφ.

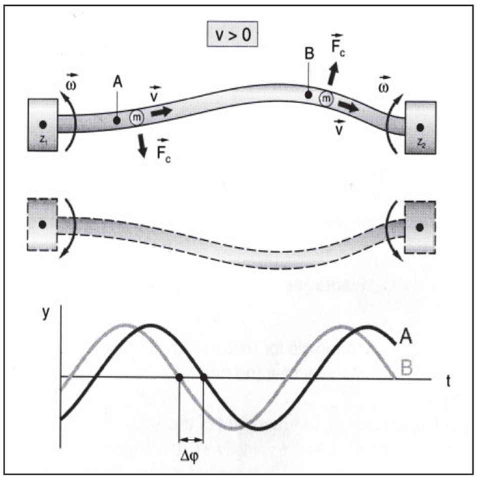


Fig.3. Coriolis forces and oscillation geometry in measuring tubes [1]

2.2. ADVANTAGES & DISADVANTAGES OF CORIOLIS MASS FLOW METERS

Like any other measuring method, mass flow measurement based on the Coriolis principle has advantages and disadvantages, which must be taken into consideration before its application. The advantages are:

- it is applicable to both liquids and gases,
- mass can be measured directly,
- it is affected neither by density nor viscosity,
- it is highly accurate (+/- 0.1%),
- mass flow, temperature and density can be measured simultaneously,
- it is not affected by flow profile.

Disadvantages are as follows:

- a very high price,
- a narrow temperature range,
- application limited when there is high content of gases inside fluids, or when there is a mixture of few different fluids,
- big dimensions for some flow meter types.

Basic characteristic of mass flow measuring devices are given in Table 1.

Table 1. Basic characteristic of measuring devices

	Promass 63	Micro Motion
Measuring range	0-20000kg/h	0-40000kg/h
Measured error	+-0.05%	+-0.1%
Outputs	4-20mA	4-20mA
	Pulse	-
Communic.	HART	Fieldbus

2.3. TYPES AND APPLICATION

There are several types of Coriolis mass flow meters, depending on the number of pipes and pipe shapes. The main two types are devices with two pipes and devices with one pipe.

For most devices with two pipes, the influence of external vibration is nullified through their excitation. Another classification is based on the shape of pipes – devices with curved and devices with straight pipes. The latter has smaller dimensions.

Devices with one pipe are easier for cleaning, cause smaller pressure drop and have smaller influence on media inside the pipe than two-pipe devices. As they contain one pipe only, dimensions are smaller, but they must be carefully designed, in order to nullify external influence.

Knowing the measurement principle, it is obvious when and how Coriolis mass flow meters should be applied. They are not affected by physical factors such as pressure, temperature, density, viscosity and conduction and they can be used for mass flow of any fluid, i.e., oil, gas, grease, alcohol, detergent, vine , chocolate and similar media. However, application is limited to high viscosity media because sometimes they contain air bubbles. These bubbles have a damping effect on pipe oscillation. The bigger an air bubble, the bigger a damping effect, and that can cause instability of the oscillating system. For solids, homogenous distribution inside the pipe is highly important. For inhomogeneous materials, vertical installation of the device, especially for low flow rates, is highly important (Fig. 4).

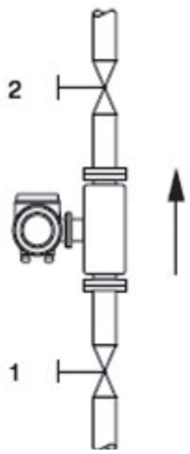


Fig.4. Installation for inhomogeneous materials and low flow rates [10]

3. MASS FLOW MEASURING IN SLURRY PREPARATION SECTION

The section for slurry preparation in a detergent production plant is of batching type. Ingredients are added in two mixers, using three scales over 3 weights. Then, the mixture is sent into the continuous part of the process (Fig. 5).

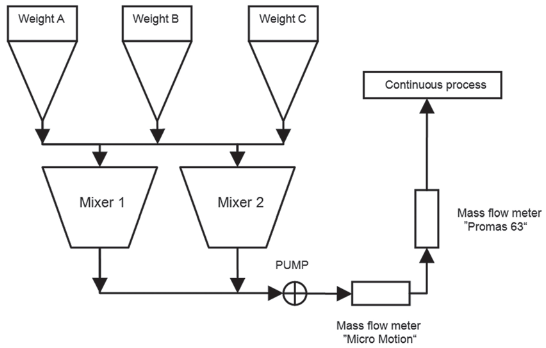


Fig.5. Slurry preparation process scheme

Slurry is a mixture of solids and liquids with high density. Due to this, there is a high level of captured air bubbles inside. The first installed mass flow meter is Emerson's "Micro Motion". The nominal flow rate for this unit is 40 t/h, but the average slurry flow rate is only 8 t/h. This causes low flow rates, which is in collision with specifications in Section 2.3. Also, because of high density and bubbles inside, vertical position of "Micro Motion" is not a good solution. These two wrong parameters caused bad measurement accuracy over years. Therefore, it was necessary to find a solution to achieve highly accurate mass flow measurements. The plan for "Micro Motion" replacement included the following steps:

- purchasing a suitable mass flow meter for testing purposes,
- installing the mass flow meter in accordance with manufacturer's recommendations,
- simultaneous monitoring of data signals from "MicroMoton" and the new mass flow meter,
- comparison of collected information and determining which one is more accurate,
- replacement of "Micro Motion" by a new flow meter.

The chosen device, among those that were available, was Endress Hausser "Promass 63". The measuring range of this device is 0-15 t/h, and it is a one-straight-pipe device [10].

For the purpose of comparison, both signals, from "Micro Motion" and "Promass 63", were directed to a small Allan Bradley PLC MicroLogix 1100 (Fig.6). An application was created for converting current signals to data suitable for analysis.

As seen in Fig. 6, "Micro Motion" is used for receiving information on slurry flow as well as for comparison with "Promass 63". "Promass 63" is used only for comparison with "Micro Motion". RS Logix 500 is software for applications in Micrologix 1100.

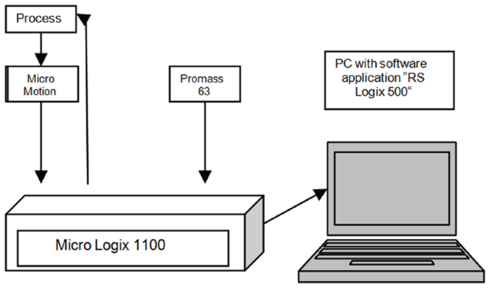


Fig.6. Connection scheme

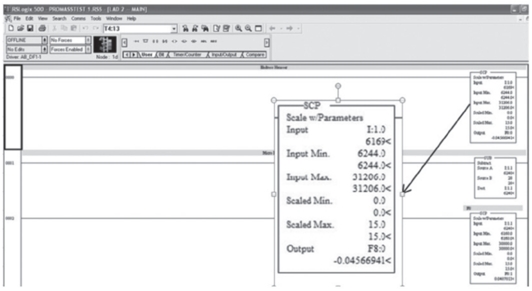


Fig.7. RS Logix 500 interface

Fig. 7 shows RS Logix 500 interface for "Micro Motion" – "Promass 63" comparison application. The application contains a special function for data trending. This trending is used for comparison of simultaneously measured values.

3.1. HART TO ANALOG CONVERSION

In powder detergent production, important process variables are as follows:

- mass flow,
- density, and
- medium temperature.

"Promass 63" has only one output, so it can directly measure only one process variable, but it can serve all required process variables using HART protocol [11]. It is necessary to convert data from HART into analog form, as a PLC with analog input modules is part of the production plant.

For more data analysis, it is recommended to use the Fieldbus communication protocol [12].

4. ANALYSIS OF COLLECTED DATA

Fig. 8 shows a trend diagram with mass flow values from "Micro Motion" and from "Promass 63".

In Fig. 8, the upper and the lower curve show data from "Micro Motion" and from "Promass 63", respectively. As can be seen from the graph, waveforms of both mass flow values (from both devices) are similar, but the difference in values ranges between 600 and 900 kg/h, whereby "Micro Motion" values are consistently higher. An additional problem is that the "Micro Motions" output value for situations where there is no flow is not zero.

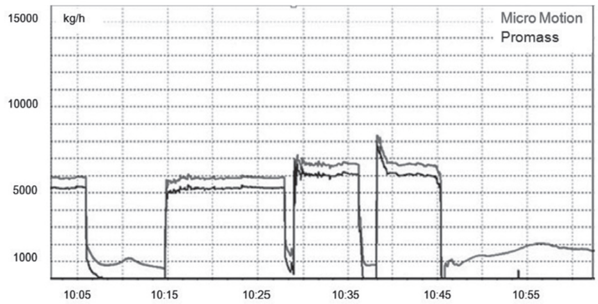


Fig.8. Mass flow trend diagram

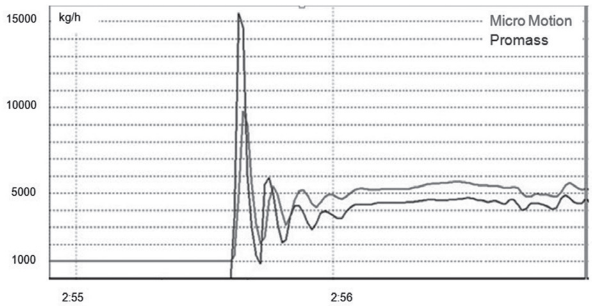


Fig.9. Reaction on flow transient state

Based on the data collected through testing, it can also be concluded that "Promass 63" reactions are much higher when it comes to flow transient states (Fig. 9, upper curve). This can cause a "nervous" regulation valve reaction, later on in the continuous part of the slurry preparation process.

This analysis does not reveal which flow meter gives accurate data and therefore it was necessary to conduct additional testing. "Promass 63" has a pulse output, which can be programmed to provide data on absolute mass flow:

- 3,000 kg of water was put on scale A,
- water was pumped into mixers over mass flow meters,
- absolute flowed mass value is measured using the "Promass 63" pulse output,
- through the comparison of collected values, accuracy of "Promass 63" was confirmed,
- water was used, as it does not contain air bubbles.

Testing was conducted on two occasions, and results are shown in Table 2.

Table 2 Measuring of absolute water mass

Mixer	Weight A (kg)	„Promass 63" (kg)
Mixer 1	3.000	3.027,5
Mixer 2	3.000	3.009,5

These test results reveal that "Promass 63" has a high accuracy of 0.1% when it comes to water mass measuring. However, as slurry is a mixture of solids and liquids, in order to pass the final decision, testing had to be conducted for slurry flow as well. It was decided to conduct measurements for slurry in 4 cycles and to calculate the average value for the absolute dosed mass. This methodology was chosen because some ingredients remain sealed on scale walls after it gets emptied. Using the average value of the absolute slurry mass enables us to reduce the measuring method error. Table 3 shows results of this testing.

Table 3 Measuring of absolute slurry mass

Set value (t/h)	Meas. value (t/h)	Prom. 63 (kg)	Weig. A-C (kg)	Error (%)
6.09	6.8	2404	3000	-19.9
6.09	7.0	2563	3000	-14.5
6.09	7.0	3651	3000	+21.0
6.09	7.0	3456	3000	+15.2
TOTAL:		12074	12000	0.616

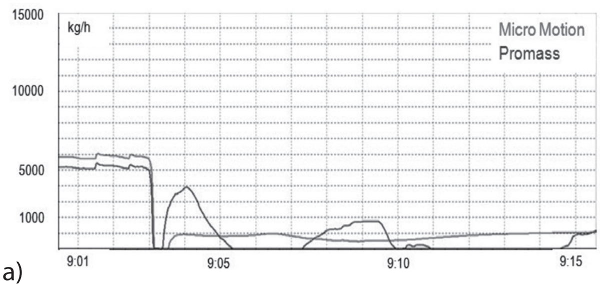
Results in Table 2 reveal that accuracy of "Promass 63" is 0.6%, which is good enough.

4.1. VERIFICATION OF "PROMASS 63"

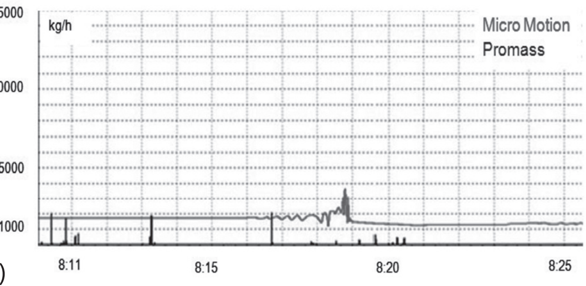
Once that "Promass 63" accuracy was confirmed, it was included in the slurry preparation regulation loop. In order to make the final verification, the following measurement was performed: the device used for the feedback process value was "Promass 63", while "Micro Motion" was used for data comparison only. As Table 4 reveals, "Promass 63" provides much better data on slurry mass flow. When the set value for slurry mass flow in t/h and values obtained from "Promass 63" and "Micro Motion" are compared, it is obvious that "Promass 63" has an almost exact output value, while "Micro Motions" output value is constantly greater than the real one. Proportionally, absolute mass counted value with "Micro Motion" is higher than the value measured with "Promass 63".

A detailed analysis of mass flow trend diagrams measured by "Promass 63" and "Micro Motion" gave a new insight into problems that occurred in the past. Figures 10 a) and 10 b) reveal that outputs on both devices are different from 0, when there is no slurry flow. However, it lasts for only a short period of time for "Promass 63", and for "Micro Motion" it is constant.

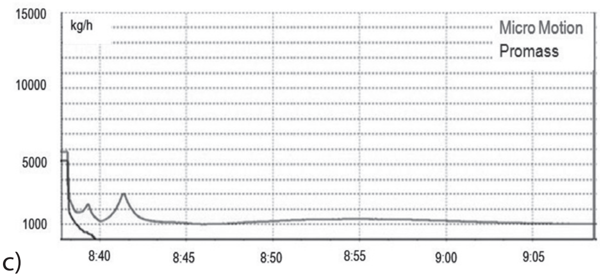
Sometimes the output value from "Promass 63" was enormous (Fig. 10 d) and e)), but it is much easier to detect and ignore this phenomenon than a constantly faulted value from "Micro Motion". This has explained operator confusion with "Micro Motion" data in the past.



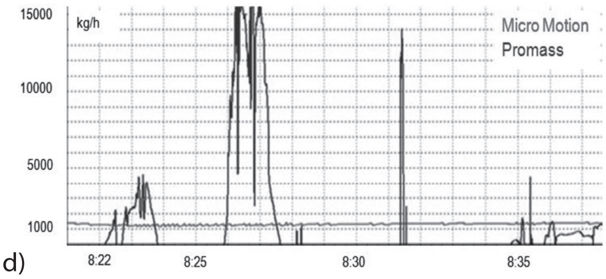
a)



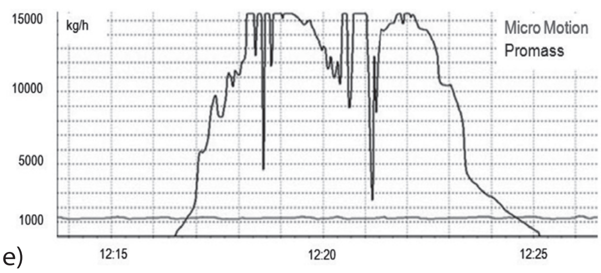
b)



c)



d)



e)

Fig.10. Output values without slurry flowing

Table 4. "Promass 63" measurement results in the regulation loop

Set value (t/h)	Promass 63 (t/h)	Micro Motion (t/h)	Promass 63 (kg)	Micro Motion (kg)
5,85	5,80	6,45	4250	4961
5,85	5,79	6,42	3860	4680
4,90	4,79	5,40	4170	5090
5,70	5,64	6,30	4608	5650
5,85	5,82	6,44	3430	4650
5,85	5,83	6,45	3900	4900

A comparison of trend diagrams for two different detergent types has shown that density had a great impact on measurement results. For the product with lower density (ρ = 1.2), Fig. 11, transient state is shorter and oscillations are lower than for the product with higher density (ρ = 1.2), Fig. 12.

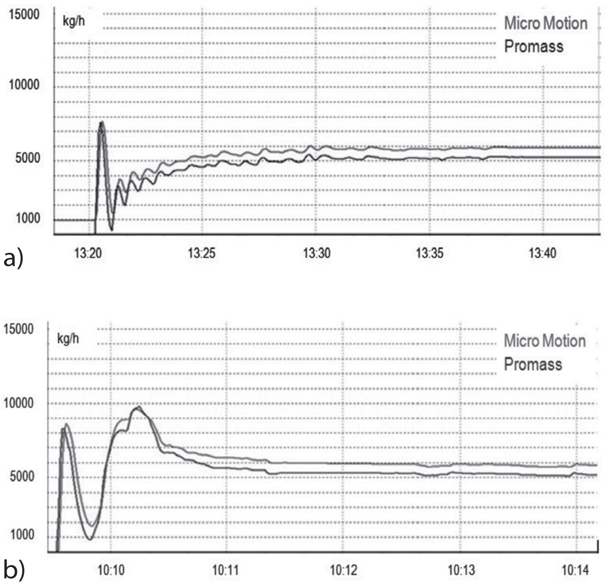


Fig.11. Transient state for product with ρ = 1.2

Also, the difference for actual values between "Promass 63" and "Micro Motion" is greater for the product with higher density. This difference for the product with ρ = 1.2 is around 600 kg/h. For the product with ρ = 1.7 this difference is up to 1,000 kg/h.

If we take into account the fact that "Promass 63" accuracy was confirmed through testing (Table 2), and trend diagrams comparison (Fig. 8-12), we can conclude that "Promass 63" is efficient in the slurry preparation process.

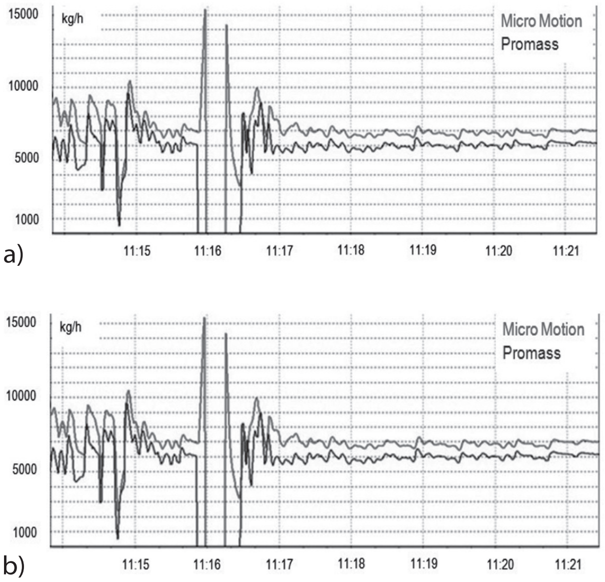


Fig.12. Transient state for product with ρ = 1.7

6. CONCLUSION

This paper has shown the Coriolis mass flow principle and the complete process of device exchange, from problem analysis and technical solution, to results analysis and device suitability confirmation. Benefits of installing a more accurate mass flow meter are significant. Operators got more reliable mass flow meter measuring. Quantity of bad quality products are considerably reduced, which has also reduced production costs. An additional benefit is provision of opportunity for finding other steps in the slurry preparation process which can affect final product quality. All these benefits justify financial expenses in favor of purchasing "Promass 63".

Finally, this paper has illustrated that even a reliable measuring method can provide unreliable results if the equipment is not installed properly.

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