LOW FLOW CORIOLIS FLOW CONTROLLER WITH PIEZO OPERATED
CONTROL VALVE
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Abstract
We developed a compact conventional steel tube Coriolis mass flow controller for low flow rates
down to 10mg/min and up to 3g/min in one instrument. The mechanical construction of the
flow controller has been optimized to have a low internal dead volume for control speed and
stability. An on board piezo actuated control valve is used as actuator to control the flow. The
advantage of this valve principle is the lack of internal volume, high stiffness and very little
self-heating. A dedicated setup is used to validate the performance of the Coriolis flow controller.
The instrument is capable of controlling 30mg/min over 25hrs within 1% peak to peak of
reading. Due to the small internal volume and stiffness of the actuator the flow controller
response time within 1% accuracy is <6s on the reference. On different liquids the flow controller
shows an accuracy of better than 0.1mg/min ±

Keywords
Coriolis low flow controlled piezo valve.

Introduction
Coriolis flow meters and controllers are widely used in various types of industrial applications.
Conventional steel tube sensor technology with the latest state of the art signal processing enables highly accurate and medium independent flow measurement over a wide flow range with various tube sizes. Since 2008 Bronkhorst High-Tech offers a Coriolis mass flow meter with contactless actuators and sensors based on the technology as described in [1]. This known and commercially available technology enables accurate low flow measurement and control down to 160mg/min. Current control valves strategies are usually based on small electromagnetic control valves. The internal volume and self-heating of these valves result in slower and unstable flow and batch control for lower flow rates. There are
current market demands for even lower flow control with high accuracy as well as for fast
batch dosing. These requirements can be found in e.g. food and pharmaceutical applications
where traceable and direct mass measurement for the dosage of additives is a must.

Novelty
We developed a compact steel tube Coriolis mass flow controller for low flow rates with an
on board piezo actuated control valve and electronic driver for the piezo actuator. This
enables a stably measured and controlled mass flow down to 10mg/min and up to 3mg/min for
liquids and gasses. The controller response time is <6s. This creates opportunities for the
accurate and fast dosing of small batches. Figure 1 shows the inside of the flow controller
with on board piezo valve.

Figure 1. Inside of the flow controller with visible piezo valve
Internal volume
When it comes to accurately controlling low liquid flow rates the used devices and liquid must be free of entrapped gas bubbles. Any gas bubble acts as a hydraulic spring damper resulting in reduced system response time and inaccurate mass flow measurement. Commercially available degassers can provide the system with bubble free liquid. However, the filling of a dry system without entrapped bubbles demands not only bubble free liquid but also a construction without any dead volume. In order to achieve the lowest dead volume, we redesigned the construction. The sensor tubes are continuously and directly led into the inlet of the flow controller and the inlet of the control valve. There are no right-angled bore holes, or other dead volumes. Figure 2 shows a detailed photo of the sensor part and piezo valve and the hydraulic interconnection.

![Image](image.png)

Figure 2. Detail photo of the sensor part and piezo valve without electronics. The rectangle thin sensor tube is clearly visible.

Piezo actuated control valve
For the fast control of small flow rates conventional electromagnetic control valves with elastomeric seal have limited force and stiffness. The elastomeric seal results in non-reproducible behavior and suffers from aging and sticking behavior. These valve principles also suffer from self-heating due to copper losses and have a significant internal volume. The self-heating and internal volume lead to unwanted fluid expansion. This causes an unstable flow at the outlet of the flow controller, especially for very low flow rates. In order to eliminate this, we developed a piezo control valve with steel membrane that has almost no self-heating, a high stiffness and little dead volume.

Experimental
The setup we used to characterize this system is given in Figure 3. The inlet of the flow controller is connected to a pressurized liquid source. Helium is used to pressurize the liquid as it dissolves less into the liquid than nitrogen or air. This helps to prevent issues with gas bubbles. In between the liquid source and the flow controller is a commercially available degasser to remove any leftover dissolved gas bubbles. The tested Coriolis flow controller provides a stable flow that will be checked by an electronic balance. The electronic balance RS232 output signal is continuously differentiated and filtered to calculate the actual reference mass flow. This signal is compared to the measured flow of the flow controller.

![Image](image.png)

Figure 3. Schematic view of the test setup to measure the stability of the flow controller.

The setup is used to investigate the performance on response time, long term stability and medium independence.

Results on response time
To measure the step response of the flow controller the setpoint value is compared to the reference flow on the electronic balance. As the electronic balance suffers from noise due to limited resolution some filtering is necessary. The used filter is an averaging filter over 60s. As filtering also results in a phase delay of the
signal an anti causal filter is chosen to show a quick response of the filtered value. This means that offline data is used to calculate the average over 60s of future samples. In figure 4 the result of the step response is shown for a setpoint change from 0 to 30mg/min at t=0s. The time scale is logarithmic to show the quick response and the longer term stability during the measurement. The figure shows a response time of 6s on the reference flow within 1%.

![Graph of flow rate vs time and error percentage]  
*Figure 4. Response time of the flowcontroller of <6s within 1% at 30mg/min compared to filtered reference flow*

**Results on long term stability**  
The result of a long term stability measurement is depicted in figure 4. It shows the stability of the instrument at 30mg/min over 25hrs. The measured value of the electronic balance is average filtered over 60s. This signal is used as the reference value and stays within 1% of reading peak to peak during the entire measurement. The measurement is carried out with ethyl benzoate.

![Graph showing error percentage vs flow rate]  
*Figure 4. Measurement results long term stability at 30mg/min on electronic balance as reference with 1min averaging*

**Results on medium independence**  
A advantage of the Coriolis measurement principle is its direct mass flow, independent of medium properties. In order to investigate the performance on this subject the flow controller is calibrated with different media. The same setup as depicted in figure 3 is used to validate the accuracy on different media and on different flow rates. The measured data is compared to the reference flow and the error percentage is calculated. The experiment is carried out for water, isopropanol and ethylbenzoate. Before each measurement the instrument is zeroed. The investigated flow range starts from 10mg/min to 3g/min. The results are depicted in figure 5. The outcome is that the accuracy of the instrument is medium independent and shows a performance on accuracy over all measured points within 0.1mg/min ± 0.2% of reading.

![Graph showing accuracy for various liquids]  
*Figure 5. Accuracy of the flow controller for various liquids.*
Conclusion
To conclude we presented a compact coriolis flow controller with no dead volume and a on board piezo actuated control valve. The stainless steel tube and piezo controlled valve result in an all wetted parts stainless steel instrument. The controlled flow rate goes down to 10mg/min and up to 3g/min. The response time of the flow controller is <6s within 1% accuracy. The long term stability measurements show a 1% accuracy over 25hours at 30mg/min. On different liquids the instrument shows an accuracy of better than 0.1mg/min ± 0.2% of reading over the entire range. The flow controller can be used in any application where medium independence, direct mass flow, accuracy and fast dosing is required.

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REFERENCES: