SONOTEC

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How Flow Averaging Can Optimize Your Applications

Selecting Appropriate Averaging Settings for Your Processes

Non-Invasive Fluid Monitoring

Content
White Paper

Note:
All italic-formatted terms correspond to features or parameters in the Flow Monitor Software, e.g., *Number of samples*.

How Flow Averaging Can Optimize Your Application

Selecting the Appropriate Averaging Settings for Your Process

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Introduction

Flow measurement is a complex topic influenced by a number of parameters. Depending on the application, there are two general purposes of flow measurement: efficient liquid flow rate monitoring in a process or precise totalizing of the volume flow in the tubing. Both can accurately be determined with calibrated **SONOFLOW®** and **SEMIFLOW®** sensors.

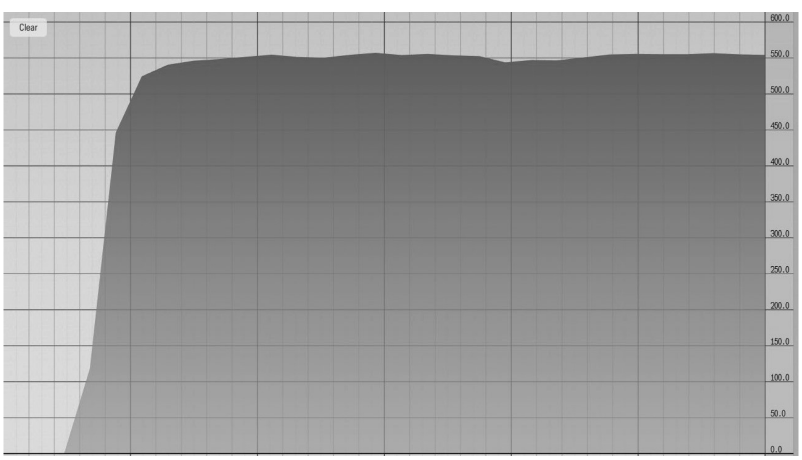
There are different effects influencing every measurement, including flow measurement with SONOTEC sensors:

- Systematic effects, such as temperature changes or variances of the tubing geometry, caused by inserting the tubing into the sensor
- Random effects, described here as noise, including electrical noise of the electronic components and the piezo ceramics, quantization noise by limited resolution of the analog-to-digital converter, etc.. Noise leads to a scattering of the measurement data, even under constant conditions.

Random effects can be eliminated or at least attenuated by digital filters, smoothing the measured data.

SONOTEC flow sensors provide different types of averaging. On the following pages, you learn how you can adjust the sensors to achieve optimum results. Furthermore, it is essential to consider the process, when selecting the settings of the filter.

For example, when a peristaltic pump is used in the process, the flow rate pulsates due to the pump. Depending on the objective of the measurement, it could be appropriate to smooth the pulsation strongly to achieve a constant average flow value. Alternatively, it could be required to display changes in the flow, e.g., to ensure an accurate dosing process. Just taken this example shows the importance of setting the parameters of the filters to appropriate values, meeting the individual requirements of your application.



Typical floating average flow profile

Definition and Limitations

The averaging represents or summarizes a list of numbers. There are different averaging methods used in different contexts, e.g., arithmetic mean or segmented averaging, moving or floating averaging, mode and median. The mathematical equation for the averaging can be summarized as follows:

$$A = \frac{1}{n} \cdot \sum_{i=1}^{n} a_i = \frac{a_1 + a_2 + \cdots + a_n}{n}$$

Depending on the averaging type, there are different calculations methods. In general, the averaging smooths a row of numbers or indicates a tendency. Hence, the application is the key for the averaging method, you use.

Definitions

The segmented averaging is the most common type of averaging. It is the sum of a given list of values divided by the number of values in the list.

The floating averaging is a common method to smooth a series of data. The result is a new series of data, which consists of the mean values of subsets from the original data.

> “Averaging is an effective method to optimize the output according to the requirements of your application.“
> Alison Sedler

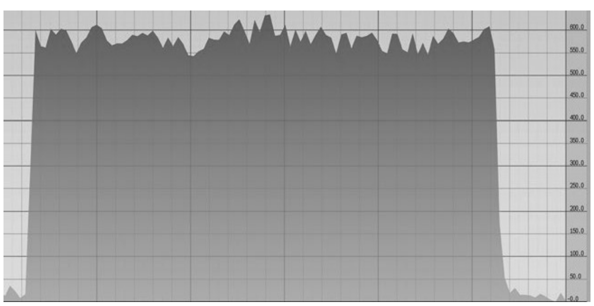
The charts on this page show the necessity of averaging as well as its limitation. In SONOTEC's **Flow Monitor Software** you can conveniently configure the averaging feature. All charts in this document are taken from Flow Monitor Software. Averaging is always active due to the evaluation algorithm. If you set the averaging parameter *Number of samples* to the minimum of 1x, which means disabling the averaging feature, all noise will be visible.

While you see a flow curve with oscillation around the mean value influenced by noise and pump characteristic in chart (A), the curve on chart (B) is smooth without any peak values. Both charts have the same origin, using the same installation with SONOFLOW CO.55 flow meter and pump. The only difference is the configuration of the averaging, showing the lower and upper end of the averaging range applicable only in very specific processes.

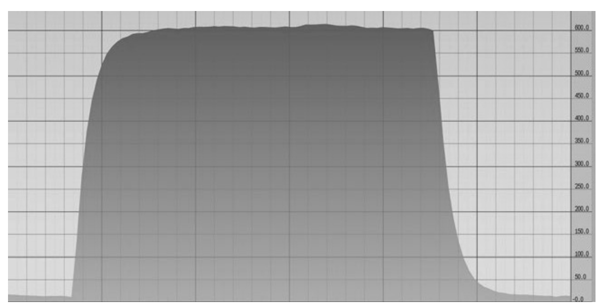
The chart in figure (A) shows the *Segmented averaging* with disabled *Dynamic averaging* option and *Number of samples* set to 2x. Thus, only two measurement values are taken for averaging; the minimum is 1x. You can still see the averaged segments. The curve raises fast after the pump is activated and it immediately goes low after the pump is deactivated.

The settings of the chart in figure (B) consist of *Floating averaging*, disabled *Dynamic averaging* option and *Number of samples* set to 125x. In doing so, 125 measurement values are considered for averaging. You can see that the curve is smoother than in figure (A). After starting the process, the curve raises smooth and keeps its level. When the flow stops or interrupts, the curve flattens smoothly.

Comparing both charts underlines the importance of the correct configuration of the averaging feature. Please refer to the end of the document for recommendations and a number of configuration examples.



(A) Result of *Segmented averaging* with low averaging (*Number of samples*: 2x)



(B) Result of *Floating averaging* with high averaging (*Number of samples*: 125x)

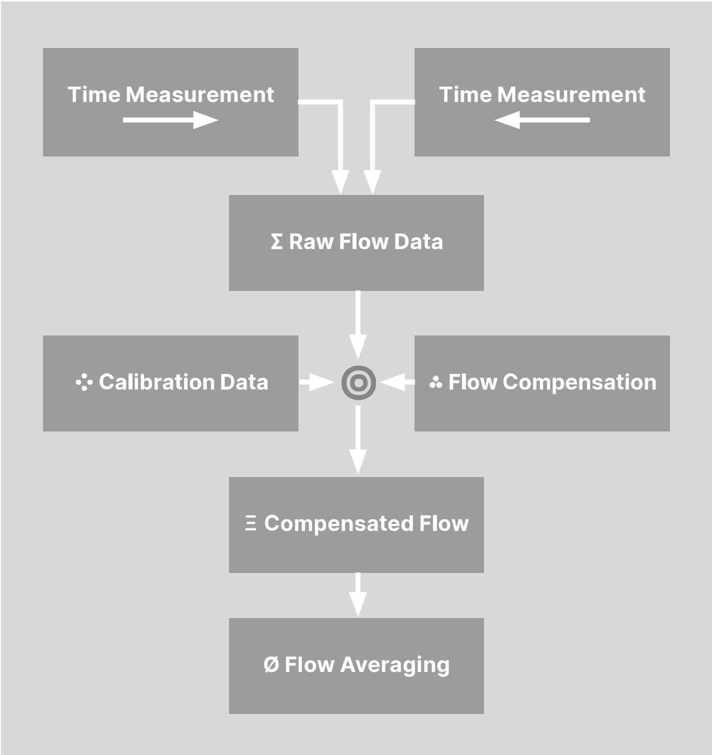
Measurement Method and Data Processing

To get a better understanding of the effects of averaging, it is necessary to learn more about the working principle of the sensor.

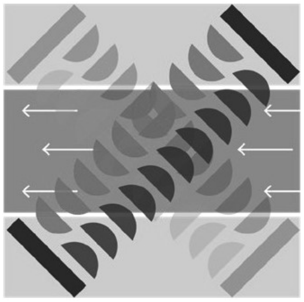
The flow meters use the Time of Flight method for flow measurement. In doing so, time-digital-converters accurately measure the transit-time with and against the flow direction of the liquid.

The time difference between both signals is a measure for the fluid velocity.

Simplified it means that the velocity together with the value of the cross-sectional area allows determining the specific flow volume. The volume results from the product of the flow velocity and the cross-sectional tubing area.



SONOTEC data processing scheme



Transit-time principle for clamp-on flow measurement

After determining the raw flow data, the calibration results of the sensor for fluid characteristics and tubing properties are applied. There are a number of other parameters in the process environment like ambient temperature, temperature of the sensor, fluid temperature, fluid viscosity, and changes in the speed of sound, which also affect the measured flow data.

SONOFLOW and SEMIFLOW sensors provide a number of compensation algorithms, which are applied on the raw flow data. This way, certain effects can be reduced. Further compensations can be adjusted by setting the *Linear correction factor*.

Since the determined flow data from the raw signal data after compensation is still noisy, it is quite often necessary to average the flow. SONOTEC offers a variety of *Averaging methods*. Depending on the selected method, the output is affected.

Flow Averaging Methods

You can use SONOFLOW and SEMIFLOW sensors for multiple applications, e.g., pump feedback, control and calibration, flow rate monitoring, volume totalizing, or dosing and filling. Thus, it is crucial to consider the process before setting the averaging.

There are certain facts that decide about the averaging type. For example: Do you use your flow meter for totalizing or flow monitoring? Which type of pump is implemented in the application?

SONOTEC offers two averaging methods: **Segmented and Floating averaging**. Both methods can be further adjusted by activating the **Dynamic averaging** option. Additionally, each averaging type is configurable for a selectable *Number of samples*. The *Number of samples* indicates the number of values considered in the averaging calculation. The software offers different options for segmented and floating averaging. The table below shows some examples:

	Examples for Averaging[1]			
Number of Samples	1x[2]	8x	125x	1000x
T (100%) - Segmented averaging	0.004s	0.032s	0.5s	4s
T (95%) - Floating averaging	0.012s	0.096s	1.5s	12s

[1] The given time values can deviate slightly depending on the measurement conditions.

[2] Averaging is disabled.

Segmented averaging

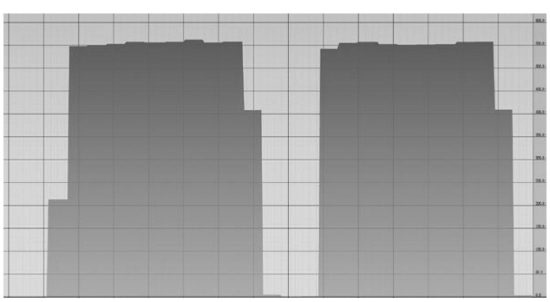
When you choose the *Segmented averaging*, your averaged flow is calculated after a selected *Number of samples* (interval) has been reached. The flow is calculated independently for each interval. So, the refresh of the flow value is quite low, which depends on the selected number of samples for the interval.

The example below shows the *Segmented averaging* with the *Number of samples* set to 500x. You can clearly see the intervals taken for the averaging.

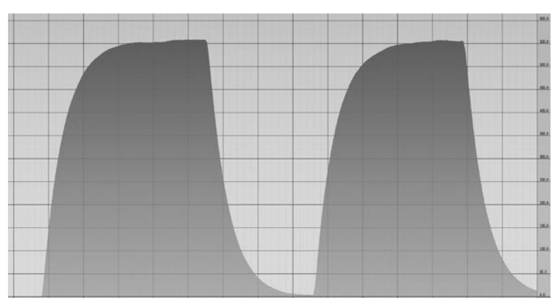
Floating averaging

In contrast to the *Segmented averaging*, the *Floating averaging* has a much higher refresh rate. The flow average is permanently calculated. It changes with each new flow value. Depending on the selected *Number of samples*, you smooth the flow slightly or strongly.

In the example for the *Floating averaging*, we set the *Number of samples* to 500x; the same as for the *Segmented averaging*. Hence, 500 values are taken into account for average calculation. With every new flow value, the flow output is recalculated. As an effect, it takes 3x of the time constant to reach 95% of the real flow value.



Example for *Segmented averaging*



Example for *Floating averaging*

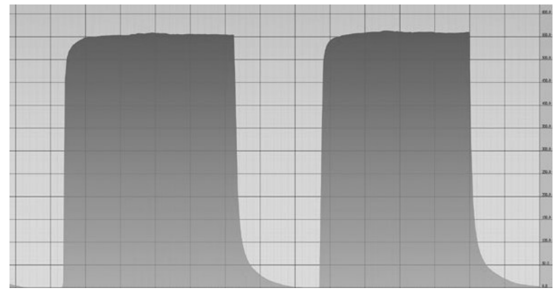
Dynamic averaging

The *Dynamic averaging* is an optional type applicable on *Floating* and *Segmented averaging*. By enabling the *Dynamic averaging* option, you can monitor sudden flow changes while showing a smooth signal, when no flow changes occur.

If an instant high or low flow signal is detected, the count for averaging is automatically reduced. In doing so, the averaging calculation considers new values in shorter intervals to follow the changes. When the flow signal reaches an almost constant level, the selected count is re-applied.

The algorithm for the *Dynamic averaging* combines high noise suppression and high reaction to sudden flow changes. The averaging reacts dynamically to flow changes.

The example shows the floating averaging with a selected *Number of samples* of 500 x and enabled *Dynamic averaging*.



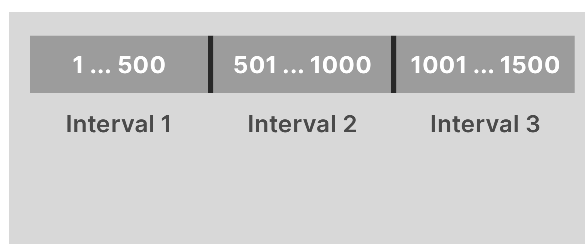
Example for dynamic averaging applied on floating averaging

Difference Between Segmented and Floating Averaging

The *Segmented averaging* calculates the average from each interval separately, whereas the *Floating averaging* calculates the averages from the interval and the next following flow value. Setting the *Number of samples* 500 x for both averaging types, you get the following calculation:

Segmented averaging

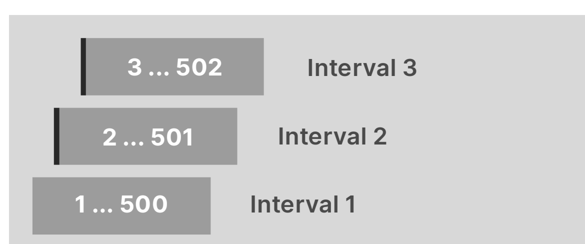
After 500 flow values for the interval have been collected, the average is calculated. Then the next interval starts and the following 500 values are considered for averaging. So you get one average value for each interval. The intervals are considered separately.



Intervals of the segment averaging with *Number of samples* set to 500 x

Floating averaging

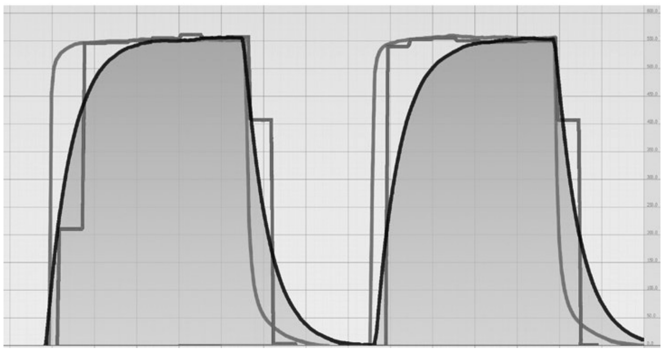
After 500 flow values for the first interval have been collected, the average is calculated. With the next flow value a second calculation starts, which takes the values from the first interval and the next value by excluding the first flow value from the previous interval. For performance reasons, this algorithm was implemented in a slightly different way, although reacting slower to changes of the flow value.



Intervals of the floating averaging with *Number of samples* set to 500 x

By comparing both types, you can see that the main difference between both types refers to the response time of the averaging types. All measurements are taken with the *Number of samples* set to 500 x. The *Floating averaging* shows the slowest reaction followed by the *Segmented averaging*.

The fastest response has the dynamic averaging as it immediately detects jumps in the flow and recalculates the average by instantly reducing the *Number of samples* for the intervals. At a constant flow all three averaging types show identical flow rates.



Floating averaging
Segmented averaging
Floating averaging with Dynamic averaging option

Comparison of all averaging types

Impact of Averaging on the Data Output

The configuration of averaging is essential for your measurement purposes.

Your application is the key for the averaging settings. It is crucial to select the right averaging in conjunction with the application to get best results for your processes. There are significant differences between the settings for flow monitoring and volume dosing.

Based on the measurement method, certain algorithms including average calculations are implemented from the very first internal data processing. It is important to be aware that you cannot completely exclude averaging from your measurement. You can set the *Number of samples* for averaging to 1 x, which reduces the intervals to the minimum of 1 sample. This way, you disable averaging for the data output.

The averaging has a direct effect on volume calculations as well as on flow monitoring and as a result on the available sensor output. Due to the mean calculation you can accidently exclude peak values occurring for example when opening or closing a valve. In doing so, you might get deviations in the sum calculation of your dosing applications as flow highs and lows are flattened.

To get smooth and readable flow data for composing processes or pump monitoring, you focus on highly averaged flow data with a high *Number of samples* to reduce pulsation caused for example by peristaltic pumps. Thus, you achieve data sequences representing the mean flow speed.

If your application is volume dosing, you should set the *Number of samples* for averaging as low as possible. Thus, you might get even strong alternating flow data, but you achieve accurate totalizing results.

On the following pages, we list a number of applications and our recommended settings.

Recommended Settings for Selected Processes

Your application is the key for the averaging configuration. The following table highlights characteristics of the different averaging types.

Averaging Method	Characteristic
Segmented averaging	• Constant output of flow rate • Good reaction to fast and slow flow changes, depending on the *Number of samples*
Floating averaging	• Good noise reduction at steady flow, depending on settings for *Number of samples* • Flow output is calculated with every measuring cycle
Dynamic averaging option	• Fast reaction to flow jumps, whereas smoothing the signal at steady flow • Not suitable for peristaltic pump systems

Reviewing the characteristics of the averaging types, we assume that certain applications require certain averaging settings. Hence, be careful with the settings and in case of any doubt, please contact SONOTEC or our local partners.

The following overview shows typical measurement tasks and its recommend settings.

	Segmented averaging	Floating averaging	Dynamic averaging	Comment
Fast dosing process	✓✓	✓	—	• Select low *Number of samples* (e.g. *Number of samples* ≤ 16 x)
Flow monitoring at constant flow rate with fast data acquisition	✓	✓✓	✓✓✓	• Select high *Number of samples (e.g. 125 x)*; enable *Dynamic averaging* for this setting with low *Number of samples*
Flow monitoring at constant flow rate with slow data acquisition	✓✓	—	—	• Select *Number of samples* higher than the reading frequency
Flow monitoring in a peristaltic pump system	—	✓✓	—	• Select low *Number of samples* for displaying the pulsation of the pump

Examples

In this section, we list typical applications with their settings for your accurate flow measurement.

Application	Achieve very smooth flow values using a continuous pump	
Recommended averaging type	*Floating averaging* with enabled *Dynamic averaging* option	The noise of the flow is almost eliminated. In case of a sudden flow change, the *Dynamic averaging* option ensures that these changes are not delayed. If required, the *Creeping flow limit* can be used to reach a stable 0, when there is no flow.
Recommended Number of samples	250	
Creeping flow limit	optional	

Application	Display of the pulsating flow of a roller pump on current output	
Recommended averaging type	*Floating averaging* with disabled *Dynamic averaging* option	The flow data shows the pulsation of the pump, and all other changes. Noise is attenuated, but still visible. If required, the *Creeping flow limit* can be used to reach a stable 0, when there is no flow.
Recommended Number of samples	4	
Creeping flow limit	optional	

Application	Smoothing the pulsating flow of a roller pump on current output	
Recommended averaging type	*Floating averaging* with disabled *Dynamic averaging* option	The noise of the flow data is almost eliminated. Please be aware that the flow changes are delayed by the averaging. If required, the *Creeping flow limit* can be used to reach a stable 0, when there is no flow.
Recommended Number of samples	250	
Creeping flow limit	optional	

<table>
<tr><th>Application</th><th colspan="2">Calibration of a sensor using a continuous pump by elevating the volume via serial interface and a balance as reference</th></tr>
<tr><td>Recommended averaging type</td><td>Floating averaging with disabled Dynamic averaging option</td><td rowspan="3">The flow averaging is not too high to follow the changes. The Dynamic averaging option has to be disabled. The Creeping flow limit needs to be off. If the reference volume is high enough and the calibration period is longer than 10 seconds, you will get the best result.</td></tr>
<tr><td>Recommended Number of samples</td><td>32</td></tr>
<tr><td>Creeping flow limit</td><td>off</td></tr>
</table>

<table>
<tr><th>Application</th><th colspan="2">Reading current of current output with a PLC every 500 ms
(not time-critical)</th></tr>
<tr><td>Recommended averaging type</td><td>Segmented averaging with enabled Dynamic averaging option</td><td rowspan="3">Select a value for the Number of samples, which is at least higher than the reading frequency, e.g., double. Thus, the PLC will not miss any information. If required, the Creeping flow limit can be used to reach a stable 0, when there is no flow. If the flow starts or stops, the flow value can follow fast by means of Dynamic averaging.</td></tr>
<tr><td>Recommended Number of samples</td><td>500</td></tr>
<tr><td>Creeping flow limit</td><td>optional</td></tr>
</table>

Conclusion

The application is the key for choosing the best averaging method. You can optimize your processes by selecting the correct configuration. However, you can also have difficulties when the selected averaging does not correspond to your process. There are certain parameters that influence the flow output. After reading the document and considering the examples, you should be confident enough to select the appropriate settings.

In general, we can summarize that in most cases the *Floating averaging* can be applied. The *Segmented averaging* shows its advantages at fast dosing processes or when the data acquisition rate of the PLC's current input is very low. The *Dynamic averaging* option is a great method to fulfill specific needs, but it has to be carefully selected.

Finally, if you are unsure or you have any doubt, please contact SONOTEC or our local partners.

SONOTEC
Ultrasound is our Strength

SONOTEC is specialized in ultrasonic sensor technology in the field of non-contact and non-invasive liquid flow measurement and air bubble detection in flexible tubes and hard plastic pipes.

As a global technology leader, we offer first-class measurement performance, excellent product quality and outstanding service to our customers in medical technology, biotechnology, and the semi-conductor industry.

In order to guarantee highest product quality we are certified according to ISO 9001 as well as EN ISO 13485 and fulfill the directives for the manufacturing of products to be applied in potentially explosive atmospheres according to ATEX/IECEx.

In addition to our off-the-shelf products, we offer customized sensor solutions responding to application-specific requirements.

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