Flow metering tutorial - Part 3: Pulse sampling and counting

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Introduction
In Part 1 of this series, we covered the fundamental concepts and principles incorporated by flow meters along with various flow measurement methods used in mechanical flow meters. It covered in depth the principle incorporated by various flow measurement methods. Part 2 covers the pulse based counting method and the various sensors that are used in industry and the way they generate different pulse waveforms to be used in variety of flow meters. This part will take a deep dive on the methods to perform the measurement of these pulses.

Pulse Sampling Theory
Sensors based on Pulse Counting Theory (discussed in Part 2 of the series) convert the motion of flow into mechanical movement which is converted to electrical waveforms that can be measured using electronic circuits. For flow measurement it is necessary to determine the current and previous states of sensor output (for flow direction) and accumulate every change in state (for determining amount of flow over a period of time). Hence the sampling process must be accurate and should not miss out any state change.

In order to be able to sample a given waveform, it is important to know about the various characteristics of the waveform being measured. Based on the details provided in part II, we can conclude that the various waveforms generated by the sensors can be uniquified and the following properties can be deduced:

- Waveforms are encoded in one of the following schemes
  - 2-bit or 3-bit gray or binary encoding
  - 2-bit quadrature (90o separation) encoding
  - 2-bit, 180o separation encoding
- Waveforms are periodic and the period of waveform varies with the rate of flow of fluid being measured

The figure below shows the various waveforms.
Figure 1: Waveform outputs from different sensors based on Pulse Counting Theory

Each of the above waveforms also represents an angular position of the disc inside the flow meter. In addition to measuring the flow, the angular position must be detected in order to detect forward and reverse flows and perform measurements accordingly.

**Timing parameters**

In order to sample the waveforms from sensors correctly, certain timing parameters must be established based on which a measuring circuit can measure the flow correctly irrespective of the rate of flow at any given point in time.

- **Sampling Period** - By knowing the pipe diameter and maximum design pressure, the maximum flow rate can be determined. Once the maximum flow rate is known the maximum rotation speed of the disc can be determined. Knowing the rotation rate of the disc and the number of states on the perforated disc (e.g. consider optical sensor with 3-bit sensor gray coded disc) the maximum number of changes per second can be determined. Provided the disc is sampled more frequently than the maximum number of state changes, every state change will be detected. This gives us the sampling period to be supported for accurate measurement of the flow. In other words, the sampling period is the minimum time available to sample one sector.

- **Sampling Window** - This is the window within the sampling period when the sensor outputs can be sampled by MCU. This window is also the minimum time needed by MCU to sample its input pins connected to the sensor.
Sensor Activate Window - Further power reduction can be achieved if power hungry components (like LEDs, etc.) could be powered down when the sampling window is not active. The time in which such components need to be active is the sensor activate window. This time should include the ramp up time to allow the components to power up fully much before the sampling window time. Thus, Sensor Activate Window is longer than the Sampling Window.

The timings for these three parameters are shown below:

Figure 2: Sampling Timing Parameters

These parameters can be controlled by the flow measuring circuit and appropriate signals can then be generated for activating sensor components and sampling operation.

Consider for example, a flow meter measuring a fluid flow with max flow rate of 'M' liters/sec which translates to say, 'S' rps (rotations per second) of the disc inside the flow meter. Assuming the meter has an optical sensor with a 3-bit binary encoded perforated disc rotating between three LEDs and three light sensors. This translates to 8 states of the disc and every state must be sampled at least twice (say, 2.5 times) for accurately detecting change in state. This gives us our first sampling parameter, i.e., the sampling period which is

\[ tsamp_{prd} = \frac{1}{8 \times 2.5 \times S} \]
\[ = \frac{1}{20 \times S} \text{ (units: seconds)} \] (1)

Knowing the stabilization time (tsensor) for LED and light sensor and maximum time required by MCU to sample its input pins (tsample_en), the sensor activate time parameter can be established, as

\[ tsensor_{active} = tsensor + tsample_en \text{ (units: seconds)} \] (2)

or

\[ tsample_en = tsamp_{prd} - tsensor_{active} + tsensor \text{ (units: seconds)} \] (3)

Once the sampling parameters are established, a counter or PWM like module on a MCU can be used to generate the necessary signals as shown in Figure 2.

Noise Considerations: Since these meters might operate in noisy environments or due any other noise generation source close by to meter can cause the sampling to be incorrect. A noise pulse might be sampled as a valid value. Hence, it is critical that each output from the sensor must be filtered for noise. This noise/glitch filter is a digital filter that allows pulses of valid length to pass through and blocks all other pulses. This filter ensures correct values from sensors are sampled at all times by filtering all outputs from sensors as a whole and not individually to ensure integrity of values driven by the sensor. These digital filters will add some latency in providing the filtered outputs and hence this latency must be factored in when deciding the sampling window duration. It is in this window that the sensor outputs are filtered and filtered outputs are then sampled to
Flow Measurement via Pulse Counting

The key parameters to determine the flow measurement include:

- Direction of flow
- Amount of flow
- Time duration of flow

Determining Flow Direction: Waveforms generated by flow meters having two or more sensors can be linked to the angular position of the rotating disc inside the meter. By determining the previous state and current state of sensor output, the flow direction can be determined. Thus by decoding the 3-bit binary signal as "000", "001", "010" ... indicates a forward flow, while "000", "111", "110" ... indicates a reverse flow. The following table shows the angular position of disc based on the readings from sensor.

<table>
<thead>
<tr>
<th>Forward Flow</th>
<th>Reverse Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>1</td>
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<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1: 3-bit Binary output from sensor and corresponding angular position

However, not all waveforms can help in decoding the flow direction. In a flow meter with 180° separation of sensors will generate signals as "00", "01", "00", and "10". Thus, there is no way to decode the flow direction since there are two "00" positions that cannot tell if it came before or after "01".

Amount of Flow: Since flow in both directions is measured, two counters are maintained for each direction. Using a state machine, the position and direction of flow can be determined and forward or reverse counter can be incremented accordingly. A common state machine can be used to determine states for each type of waveform. Depending on application needs, CPU can be interrupted on every increment or when the counters reach a programmable modulus value. For those sensors from which direction cannot be determined, only the forward counter shall be incremented.

Time Duration of Flow: Another counter (time duration counter), running on a slow clock or real time clock (1 Hz) can be used to determine the time duration of flow. This counter can be a free running which is sampled when the flow counters (forward or reverse counters) interrupt the CPU and difference in reading between interrupt gives the duration of flow or the time duration counter can be reset after every interrupt of flow counters and value of counter on interrupt can be used.
**Basic Measuring Circuit in a Flow Meter**
The basic components of a measuring circuit in flow meter include:

- Glitch or noise filter for ensuring integrity of sensor output before sampling
- Logic for signal generation corresponding to the sampling parameters and clock prescaling
- State machine to detect the states and state changes
- Flow counters i.e. forward and reverse counters for determining the amount of fluid flowing
- Time keeping counter to estimate duration of flow
- CPU register interface to allow software to read and program the circuit

The figure below shows the block diagram of a basic flow measuring circuit.

![Block Diagram of Basic Flow Measuring Circuit](image)

**Figure 3: Basic Components in a Measuring Circuit of Flow Meter**

**Working of Measuring Circuit**
The working of the above circuit can be explained in the following steps:

- Software initializes the registers to generate the necessary sampling and filtering signals
- Software enables state machine which starts monitoring the filtering sensor outputs
- On detecting a state change, the state machine generates the increment signal to either forward or reverse counter, depending on the direct of flow
- The flow counters (forwards and reverse counters) keep incrementing and generate interrupt on reaching a programmed modulus value.
- On interrupt, software reads the flow & time counters and can optionally clear them for the next round of readings.

There are many more methods of measuring flow of a fluid however the scope of this paper is limited to pulse based meters. Part 4 covers ultrasonic meters, a pretty popular choice to accurately measure clean liquids.