UNDERSTANDING 4-20mA DATA ACCURACY IN PARTICLE COUNTING

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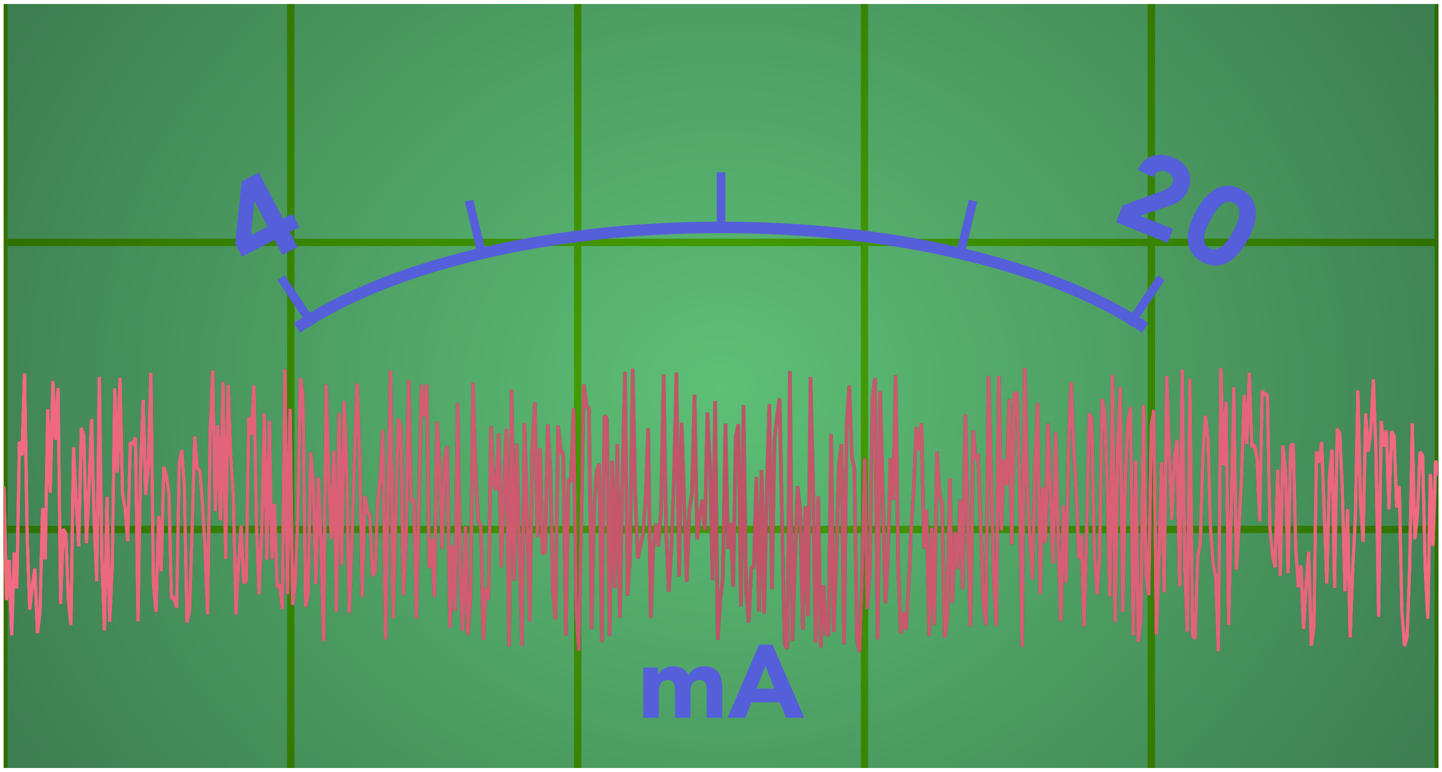
Overview

This tech paper provides an overview of counting efficiency in relation to cleanroom monitoring. It will cover the mathmatical formulae used in determining efficency as well as helping understand how counting effiency relates to the most common cleanroom standards in use today.



4-20mA Considerations

When considering using a 4-20mA particle counter you should verify how this can affect the number of particles that are displayed on your software. Measurement resolution can have an impact on the accuracy of the values of particle counts being seen based upon the analog-todigital conversion process of the device.

Should you use a Modbus (digital protocol) sensor instead of a 4-20mA sensor? That question can only be answered by understanding the difference between an analog (4-20mA) signal and a digital signal such as Modbus.

Modbus is a digital protocol. It is free and open to use by manufacturers, transmitting information digitally between electronic devices. It has become the most widely used network protocol in the industrial manufacturing environment today. As it can run over virtually all communications media – from wireless to microwave – a Modbus connection can be established in new or existing plants with ease. Modbus' main advantage is accuracy. Transmitted data is 100% accurate and can be sent in large volumes.

Most devices today are digital, meaning 4-20mA signals have to add a digital to analogue converter (DAC), complicating the meter reading process while losing the benefits of increased accuracy. This is true when discussing a particle counter. To have a 4-20mA output from a particle counter a DAC must be used.

It is also important to understand that the 4-20mA output from the monitoring device must be connected to an Analog Input Module that accepts analog voltage or (4-20mA) inputs. This module will also have to convert the analog signal back to a digital signal using an analog to digital converter (ADC). Measurements from sensors that have a 4-20mA output are very common. Customers always ask how to connect them to a data acquisition system. However, they often overlook a vital measurement component that affects their 4-20mA measurement success: **Measurement Resolution.**

So, What's 4-20mA Measurement Resolution?

An Industrial Control Cabinet, Typically Used to Integrate Multiple Instruments and Sensors.

Good question! The term "measurement resolution" refers to the smallest change in an applied signal that an instrument can detect. Although this change can be described in terms of applied mA, it is more constructive to describe it in terms of measured units. For example, telling you a given instrument has a measurement resolution of 80μA is much less descriptive than saying that your measurement resolution is 0.50psi. If the smallest measured change is too coarse, you need an instrument with higher resolution.

One question that arises quite often is how to calculate measurement resolution in applied engineering units when measuring 4-20mA current loops. We will show you how to make this calculation in four easy steps by using ISO Class 7 and ISO Class 5 (≥0.5μ (352,000) particles/m3 sample for a particle counter with a 4-20mA output) as an example.

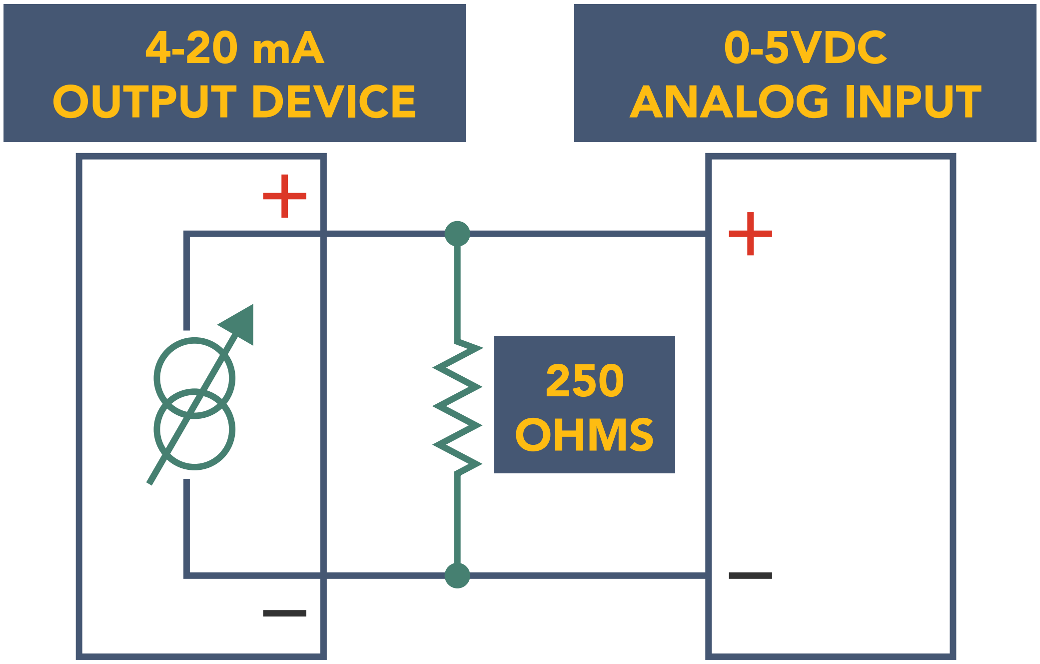


Diagram of a 4-20 Loop

Step 1: Calculating Voltage Drop for 4mA and 20mA

It may be surprising to learn that devices that measure current do not make a direct measurement. Instead, current is always an indirect measurement that produces a voltage output that's proportional to applied current. In 4-20mA current loop applications, this is almost always accomplished by applying a shunt resistor of known resistance in series with the current loop, and then measuring the voltage across it with a voltage measurement device like a data logger or data acquisition system. A typical shunt resistor value (and the one I'll use in our example) is 250 Ohms, since it develops a nice, round voltage drop of 1 Volt for 4 mA and 5 Volts for 20mA of applied current.
Step 1 is the simple application of Ohm's Law (V=IR) to determine the voltage drop across the shunt resistor. In our example, V= (0.004) (250) =1 and V= (0.020) (250) =5.

Step 2: Calculate Consumed Measurement Range

The 4-20mA current measurement will produce a voltage measurement with a span of 4 volts (5volts-1volt=4volts). Now we need to calculate how much this span consumes as a percentage from the total measurement range of the device we use to make it. Let's assume that we use an analog input device for the measurement that has a fixed measurement range of ±10 VFS (volts full scale), or a total measurement span of 20V. The percentage consumed by our 4-20mA current loop measurement is easily calculated as 4/20=20%.

Step 3: Calculate Applied ADC Counts

With any digital data acquisition or data logger system we eventually end up talking about analog-to-digital conversion counts, or resolution. For example lets let's say that the analog input device has a 8-bit resolution, or a total of 256 ADC counts (2^8). So, the number of counts we apply to our 4-20mA current loop application is the percentage calculated in Step 2, times total ADC counts: (20%)(256)= 51 counts in this example.

Step 4: Calculate Measurement Resolution in Applied Engineering Units

Referring to step 3, a total of 51 ADC counts can be applied to our 4-20mA current loop measurement, and recall that our sensor had a measurement range (0 to 352,000) particles/m3. Therefore, our resolution in measured units is 352,000/51=6,875 which is the smallest change in load that we will detect with our measurement system. Remember, the term "measurement resolution" refers to the smallest change in an applied signal that an instrument can detect. In this case the resolution would be 6,875 particles/m3 using an 8 bit analog to digital converter (ADC).

To decrease this value (to achieve higher resolution) we can either narrow the measurement span of the instrument, increase its resolution, or do both. For example, if we use a 16 bit ADC the measurement resolution would be 27 particles/m3. Refer to tables 1 and 2 for comparison resolution values in engineering units based on the ADC bit resolution.

Measurement Resolution calculated using: ISO Class 5: ≥0.5µ (3,520) as measurement range			**Measurement Resolution calculated using: ISO Class 5: ≥5.0µ (29) as measurement range**	
ADC bit resolution of the analog input device	Measurement Resolution (particles/m3)		ADC bit resolution of the analog input device	Measurement Resolution (particles/m3)
8	69		8	0.56
10	17		10	0.14
12	4		12	0.04
16	0.27		16	0.002

Table 1 (Measurement Resolution Calculation based on Steps 1 - 4)

Measurement Resolution calculated using: ISO Class 7: ≥0.5µ (352,000) as measurement range			Measurement Resolution calculated using: ISO Class 7: ≥5.0µ (2,930) as measurement range	
ADC bit resolution of the analog input device	Measurement Resolution (particles/m3)		ADC bit resolution of the analog input device	Measurement Resolution (particles/m3)
8	6875		8	57
10	1719		10	14
12	430		12	4
16	27		16	0.22

Table 2 (Measurement Resolution Calculation based on Steps 1 - 4)

Knowing the calculated measurement resolution of your DAC and ADC is very important so that you can understand the accuracy of your particle counters data. Remember the term "measurement resolution" refers to the smallest change in an applied signal that an instrument can detect. That implies when referring to Table 2 **(≥0.5μm)** that the 8 bit measurement resolution would not recognise a change in counts until it read approximately 6,875 particle/m3 compared to the 16 bit measurement resolution recognising a change at approximately 27 particle/m3.

As you can see there can be a very large discrepancy depending on the DAC/ADC that is being used in both the Particle Counter (transmitter) and the Analog Input Module. We have to consider the total possible error when a 4-20mA device (transmitter), converts the internal digital value into an analog value to transmit it, and then convert it back to a digital signal at the Analog Input Module (receiver).

We now circle back to one of the original questions "should I use a Modbus (digital protocol) sensor instead of a 4-20mA sensor?"

As stated earlier Modbus' main advantage is accuracy. Transmitted data is 100% accurate and can be sent in large volumes; whereas a 4-20mA sensor's measurement resolution can impact the accuracy of the data you see, dependant on the bit resolution of the transmitter and receiver.

For most cases MODBUS would be the desired communication mode but for some applications MODBUS may not be possible and 4-20mA is the only option. Then understanding the limitations of 4-20mA signals will assist you in making the best informed decisions when selecting a particle counter to suit your application.

With today's critical process operations and tight controls around Data Integrity and Cleanroom Standards/Regulations it is good to know about this type of data communication and have the ability to understand the possible limitations. This knowledge will enable managers to make better informed decisions regarding the communication mode of their particle counters. Yes 4-20mA is a very flexible form of data communication that allows almost universal connectivity but as we have highlighted – the resolution of the data transmitted makes all the difference in Data Integrity and accuracy.

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