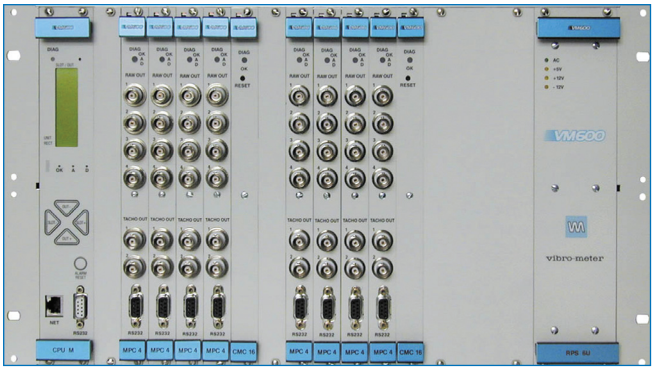
Complementary Differential Expansion Measurements with the VM600

By Marcel de Boer • SKF

As described in Application Note CM3074 "Straight Differential Expansion Measurements with the VM600", the VM600 Machinery Protection System is specifically designed to perform critical measurements that are used in the control of large steam turbine generator trains. One of the most important measurements is that of differential expansion.

Differential expansion monitoring measures the change in axial clearances between the machine rotor and stationary casing caused by thermal changes inherent in most machines. The primary purpose of a differential expansion monitor is to guard against axial rub between rotating and stationary parts, the consequences of which can be catastrophic.

There are many configurations for measuring differential expansion. This Application Note discusses the common sensor configuration of ***complementary differential expansion*** or the ***"shaft collar method"*** as called by the VM600 software. The sensor orientation is considered, together with the appropriate MPC-4 Machinery Protection Card configuration example.



There could be a number of reasons for using complementary differential expansion instead of straight differential expansion:

1 The desired working range of one non-contact Eddy current probe is not enough. Using the collar method, the measuring range will be doubled.
2 Due to machine design, there is not enough radial clearance available to mount a probe of sufficient diameter versus range for a straight measurement.

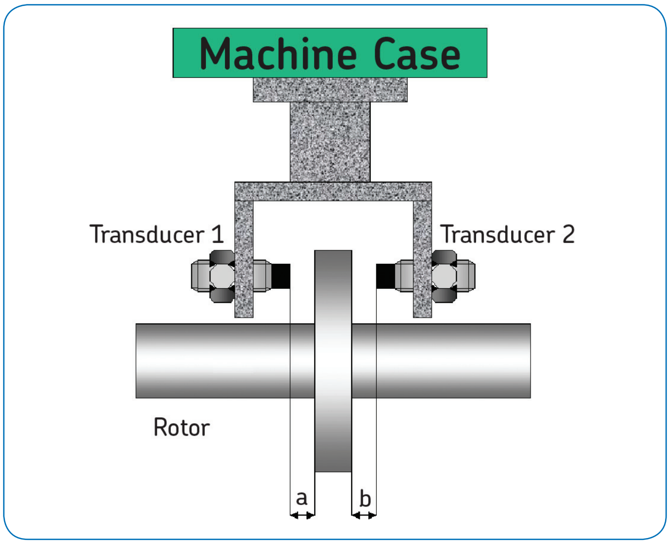


Figure 1.

How does it work?

In **fig. 1**, the complementary differential expansion measurement uses two sensors viewing a collar on the rotor assembly. The amount of differential expansion capable of being measured is based upon the distance between both transducers, but it can never exceed twice the working range of one transducer.

As the rotor thermally expands or contracts, the rotor target area moves from the working area of one transducer ("a" for transducer 1 in **fig. 1**) into the working area of the other transducer (b) and eventually out of the measuring range of the first transducer.

The maximum range that can be measured is twice the working range of one sensor. If the probes are positioned in such a way that at the end of one working range the second probe takes over, that maximum will be reached.

However, the transducers are usually mounted closer to each other, generating an area where both transducers will measure the target.

In **fig. 2**, the second transducer is mounted closer to the collar, which will generate an area (c) where both transducers will measure the target.

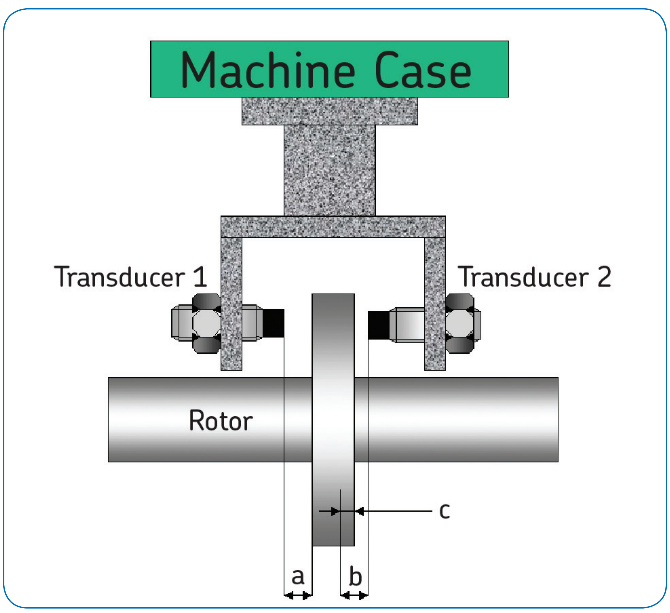


Figure 2.

In **fig. 3**, the situation is shown where the first transducer measures the gap and the second one is in saturation. As the rotor grows with respect to the case, the gap between the first transducer and the collar increases as the gap between the second transducer and the collar decreases. The increase in the first transducer's gap continues until its linear range is exceeded. At the same time the collar exceeds the linear range of the first transducer, it enters the linear range of the second transducer.

This point is referred to as the "cross over point", or the point at which the system stops observing the first transducer's gap and turns control over to the second transducer. Using this method allows measurements of two times the linear range of a single sensor.

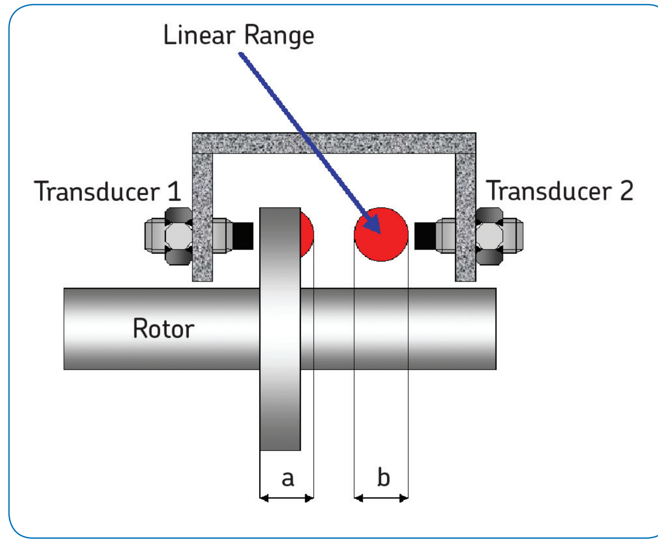


Figure 3.

A further consideration in transducer selection is the available radial clearance ("f" in **fig. 4**) for mounting a probe. In general, the longer the measurement range for the probe, the larger the diameter. The probe diameter cannot be larger than the available collar target area divided by 2,5.

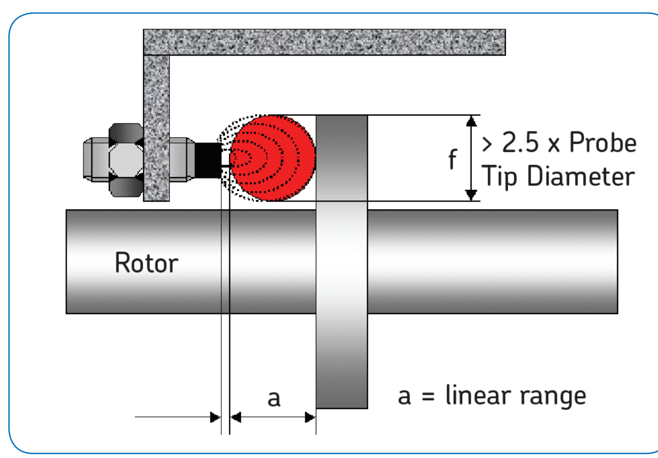


Figure 4.

Calculation of the complementary differential expansion

With the shaft collar method, two possibilities exist:

1 Both probes are operating in their measuring range at the same time **(→fig. 2)**.
2 The probes are operating alternately, with only one probe in its measuring range at a given time. This doubles the measuring range that is possible with a single probe **(→fig. 3)**.

(a) When both probes are in their operating range at the same time:

$$\Delta X = \frac{\text{measured value1 – Zero Voltage}}{2 * \text{sensitivity}} - \frac{\text{measured value2 – Zero Voltage}}{2 * \text{sensitivity}}$$

If initial gaps (or zero voltages) are equal, the differential expansion is:

$$\Delta X = \frac{\text{measured value1 – measured value2}}{2 * \text{sensitivity}}$$

(b) When the probes are operating alternately:

In the operating range of probe 1:

$$\Delta X = \frac{\text{measured value1 – Zero Voltage}}{\text{sensitivity}}$$

In the operating range of probe 2:

$$\Delta X = \frac{\text{measured value2 – Zero Voltage}}{\text{sensitivity}} \times -1$$

Detail

How to set up the VM600 equipped with an MPC-4 for complementary differential expansion

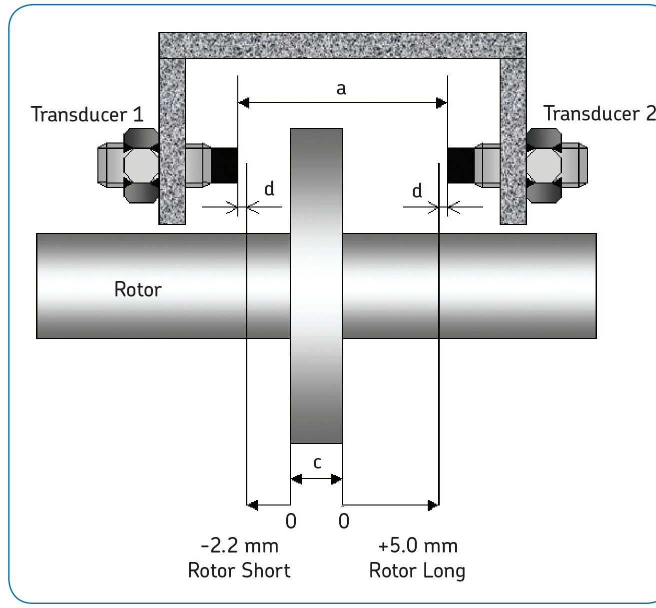


Figure 5.

All dimensions are in metric units. For English units, 25,4 mm = 1 000 mil.

- Probe: CMSS 68
- Driver: CMSS 668-5
- Usable range = 145 mils = 3,68 mm, from 0,38 (“d” in **fig. 5**) to 4,06 mm
- Sensitivity = 100 mV/mil = 3 937 mV/mm
- Collar size = (“c” in **fig. 5**) 100 mm
- Danger rotor short = –2,2 mm
- Alert rotor short = –1,9 mm
- Alert rotor long = +4,7 mm
- Danger rotor long = +5,0 mm
- Maximum detectable range: 2 × 3,68 = 7,36 mm
- Range to detect: 5,0 + 2,2 = 7,2 mm

The difference between the maximum detectable range and the required range will be the value that could be located in the middle between the transducers, or added to the usable range.

The first option will introduce an area of 0,16 mm, where both sensors will measure the differential expansion (a combined measurement).

- a = 0,38 + 2,20 + 100,00 + 5,00 + 0,38 = 107,96 mm

The second option will introduce an extra 0,10 mm clearance between probe tip and collar, besides the 0,38 mm offset of the linear range (d → 0,48 mm).

- a = 0,38 + 0,10 + 2,20 + 100,00 + 5,00 + 0,06 + 0,38 = 108,12 mm

Any value between these values will give a safe situation.

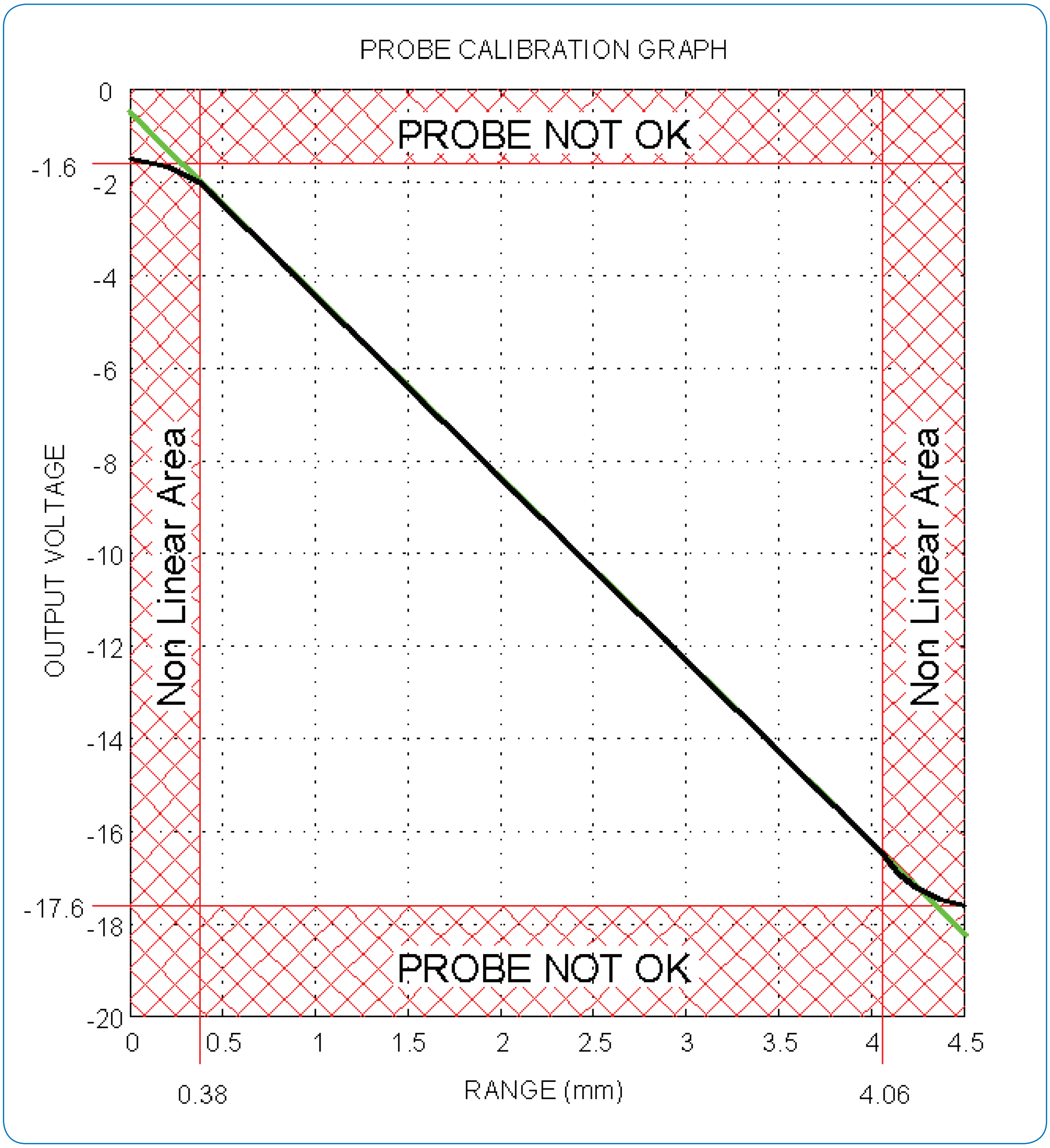


Figure 6.

If the decision has been made about the setup, for example, the danger level of –2,2 mm will be at |0,48| mm, the other values can be calculated.

For any kind of axial measurement, it is absolutely necessary that a probe calibration graph has been made.

From the probe calibration graph **(→fig. 6)**, the real sensitivity can be determined:

- (–16,49 + 2) × 1 000 / (4,06 – 0,38) = –3 937,5 mV/mm

- Danger low = –2,2 mm = |0.48| mm →
  –2,0 – (3,937 × 0,10) = –2,39 V

- Zero position = –2 – (2,3 × 3,937) = –11,06 V [Transducer 1]

For transducer 1, this result (–11,06 V) should be the value to adjust if the collar is in zero position.

If the collar is in another position, for example, +0,5 mm, the voltage to adjust the probe becomes:

- –11,06 – (0,5 × 3,937) = –13,02 V

In a similar way the position of transducer 2 can be determined. For this example, it is assumed that the probe calibration graph is the same as the one for transducer 1.

- Maximum detectable value in the linear range =
  –2,3 + (2 × 3,68) = 5,06 mm = –2,0 V

- Danger high (5 mm) = –2 – ((5,06 – 5,0) × 3,937) = –2,236 V

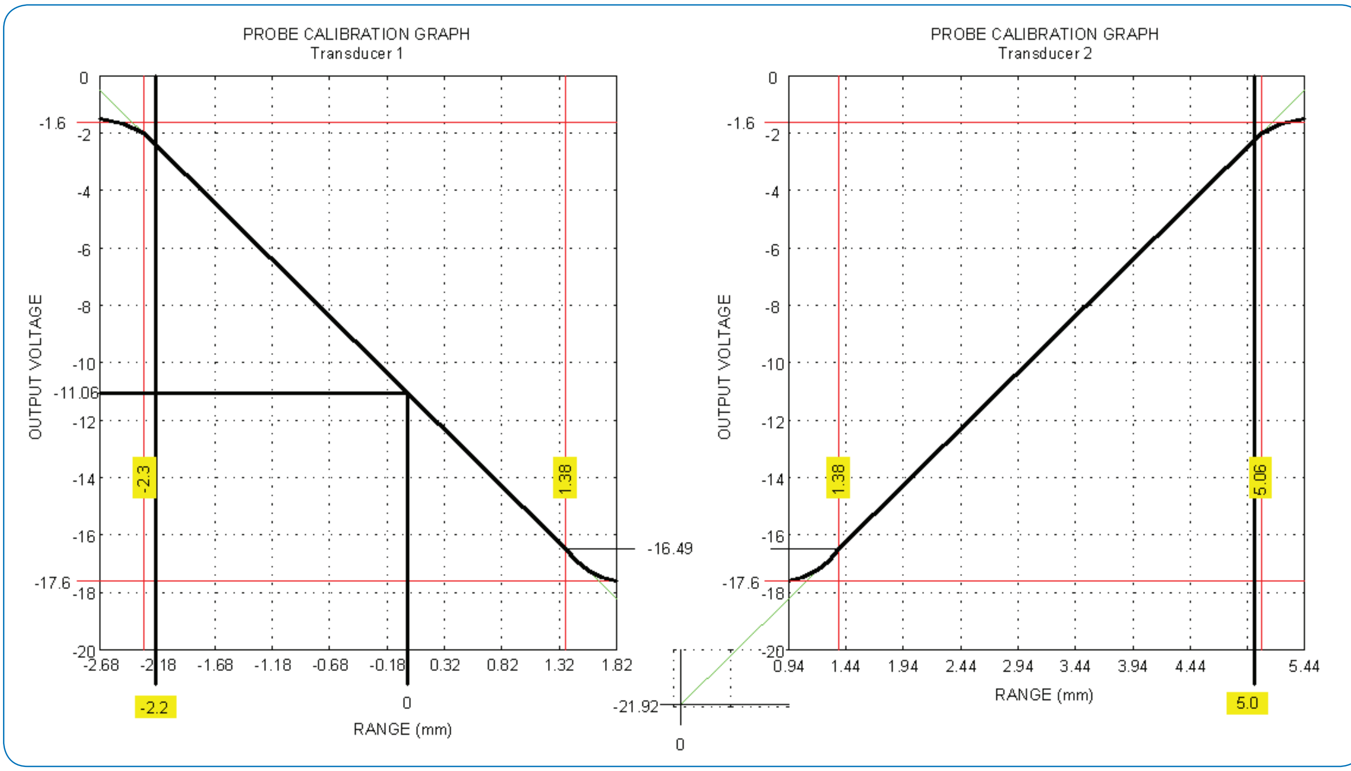
- Zero position = –2 – (5,06 × 3,937) = –21,92 V [Transducer 2]

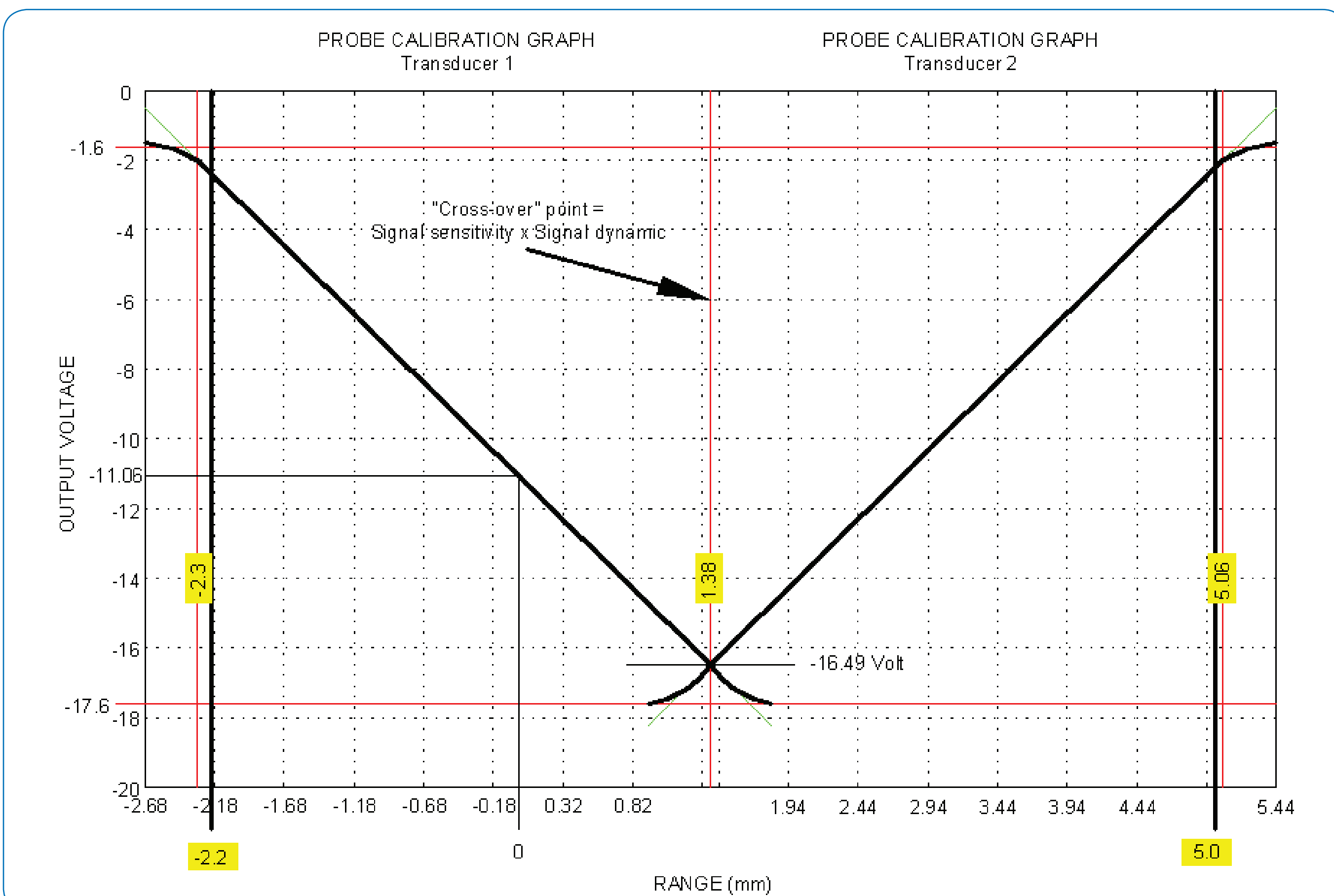
For transducer 2, this result (–21,92 V) should be the value to adjust if the collar is in zero position.

This value of –21,92 V is above the probe OK value (or out of the linear range), therefore another solution should be found to adjust this sensor:

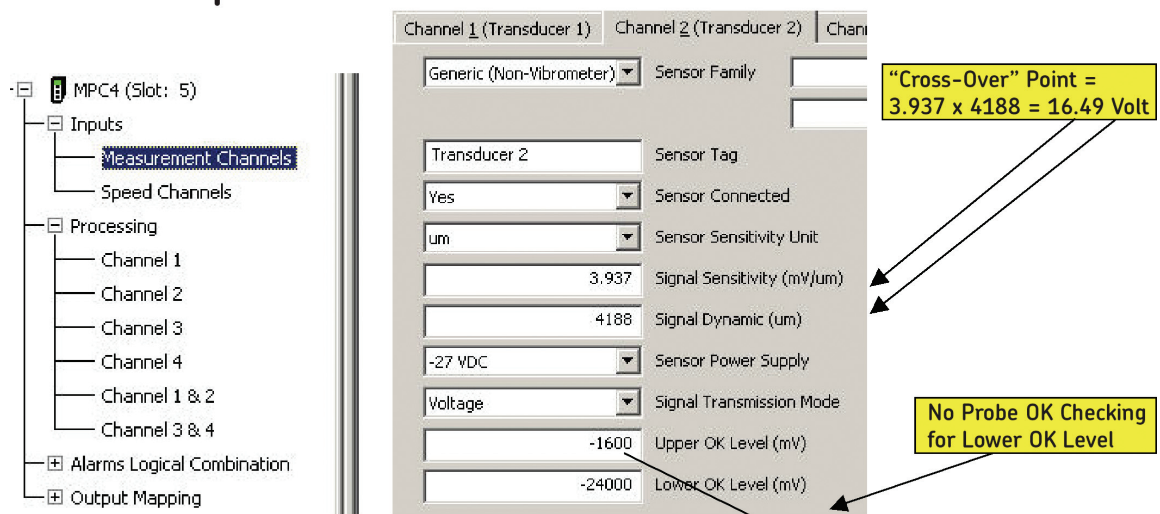
1 Move the collar toward the transducer and measure this distance with a dial indicator.
2 Manufacture a metal shim (same kind of material as the collar), measure the thickness of the shim and subtract that value from the –21,92 V.
3 Adjust transducer 2 in such a way that the distance between both transducers is between 107,96 mm and 108,12 mm.

As a result, two calibration graphs can be generated with the actual values.

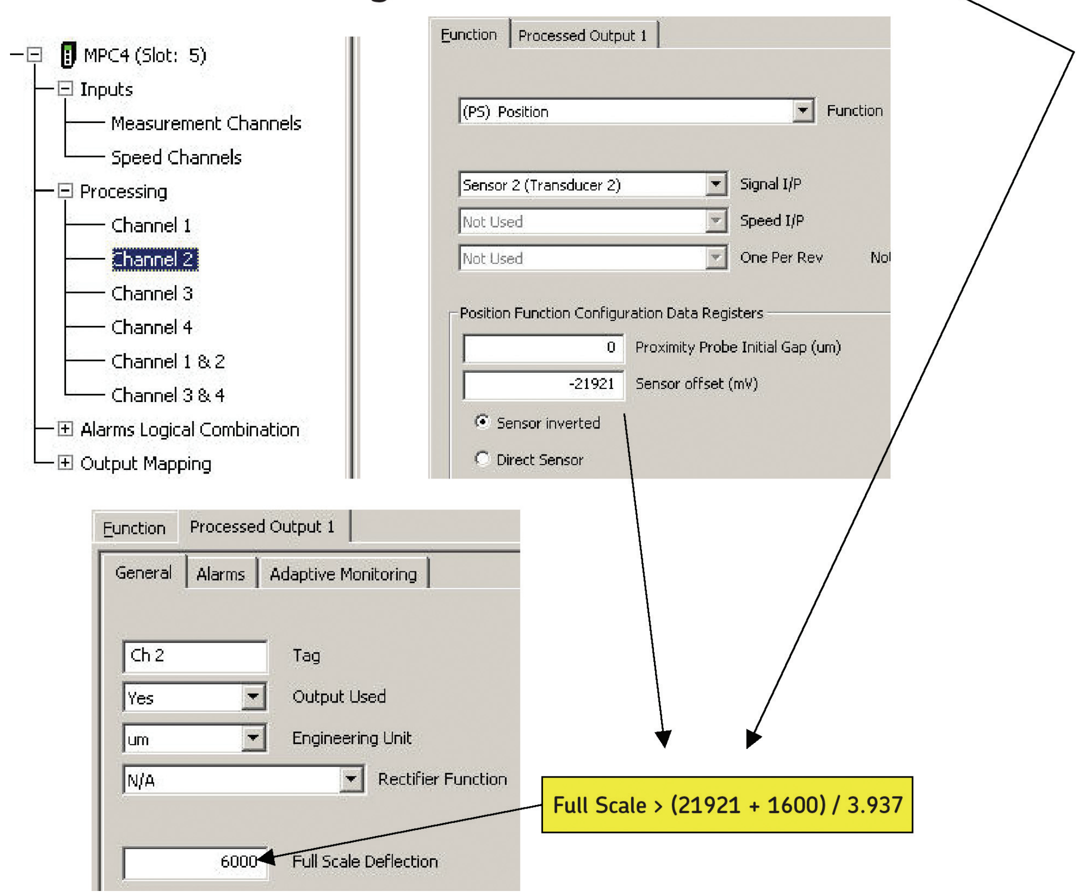

PROBE CALIBRATION GRAPH
Transducer 1
OUTPUT VOLTAGE
RANGE (mm)
-1.6
-11.06
-17.6
-2.3
1.38
-2.2
0
-16.49
PROBE CALIBRATION GRAPH
Transducer 2
OUTPUT VOLTAGE
RANGE (mm)
-1.6
-17.6
1.38
5.06
5.0
-21.92
0


PROBE CALIBRATION GRAPH
Transducer 1
PROBE CALIBRATION GRAPH
Transducer 2
"Cross-over" point =
Signal sensitivity x Signal dynamic
OUTPUT VOLTAGE
-1.6
-11.06
-17.6
-2.3
1.38
5.06
-16.49 Volt
-2.2
0
5.0
RANGE (mm)

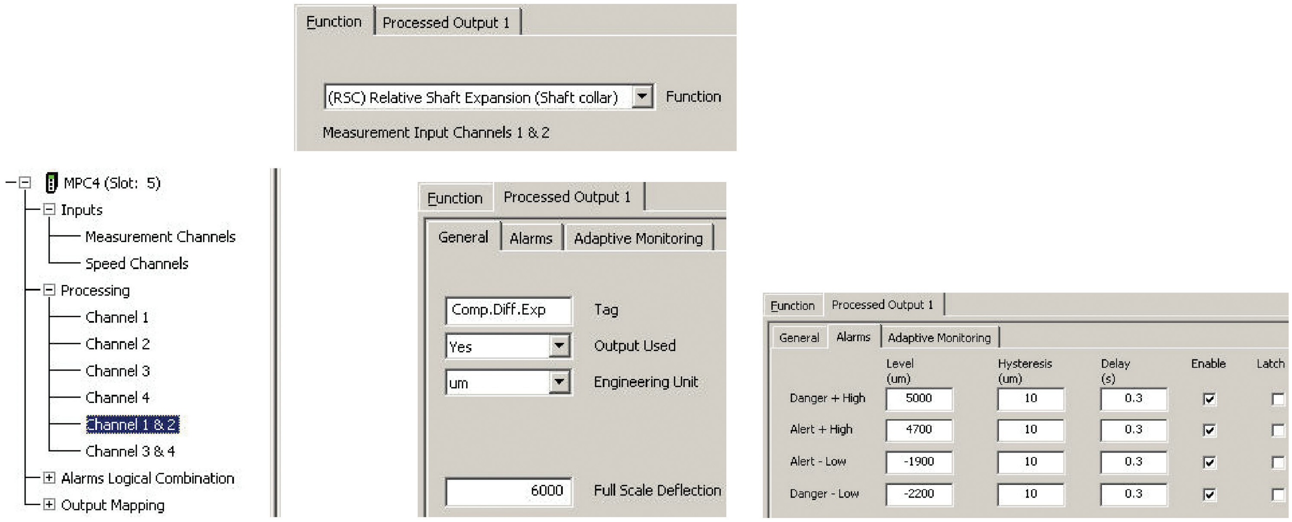
MPC-4 Input:



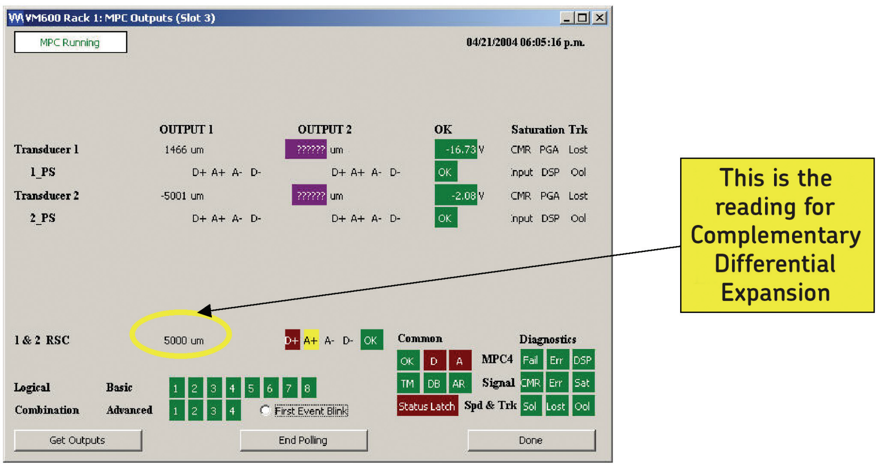
MPC-4 Processing:



Channel 1 and Channel 2 Processing:



Live Data:



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