

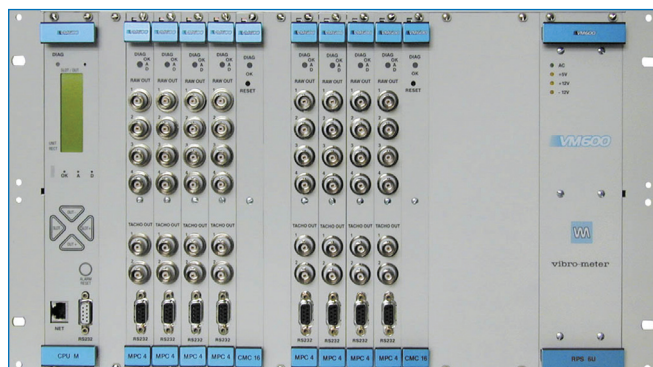
Complementary Differential Expansion Measurements with the VM600

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.

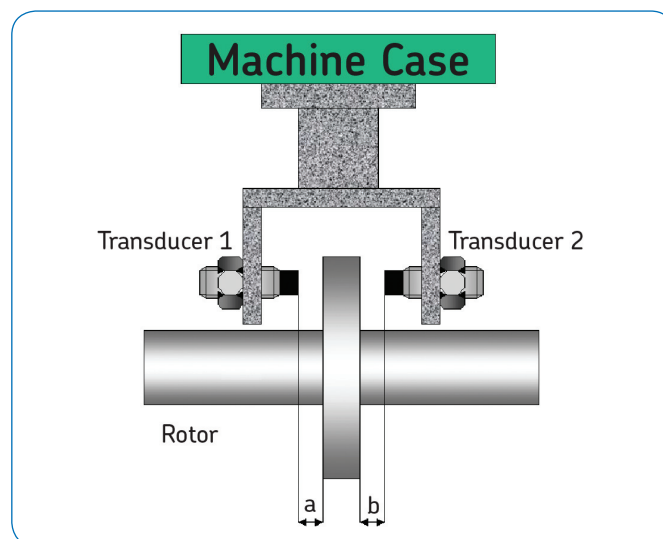


Figure 1.

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.

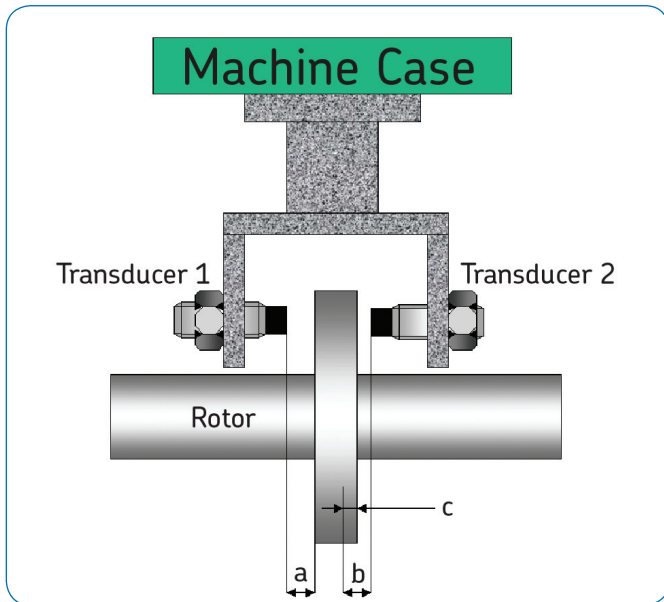


Figure 2.

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.

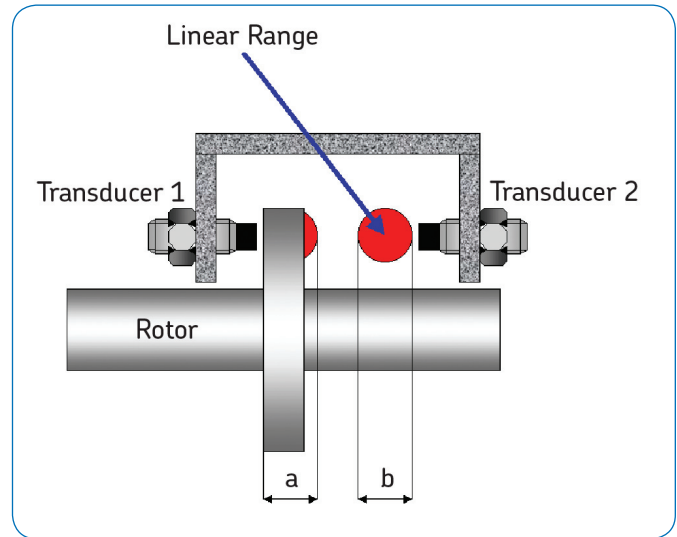


Figure 3.

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.

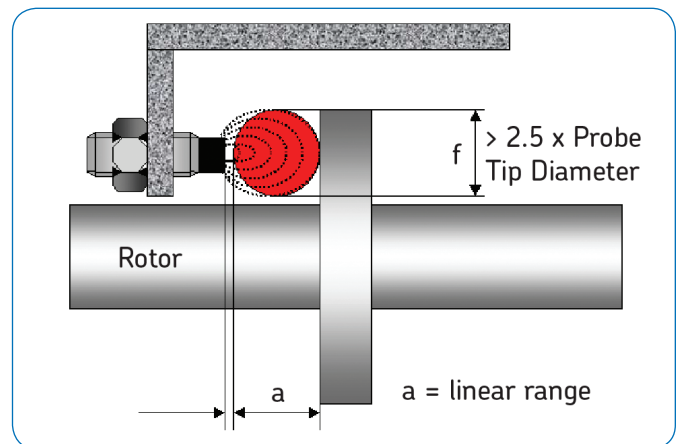


Figure 4.

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:

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

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

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

- (b) When the probes are operating alternately:

In the operating range of probe 1:

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

In the operating range of probe 2:

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

Detail

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

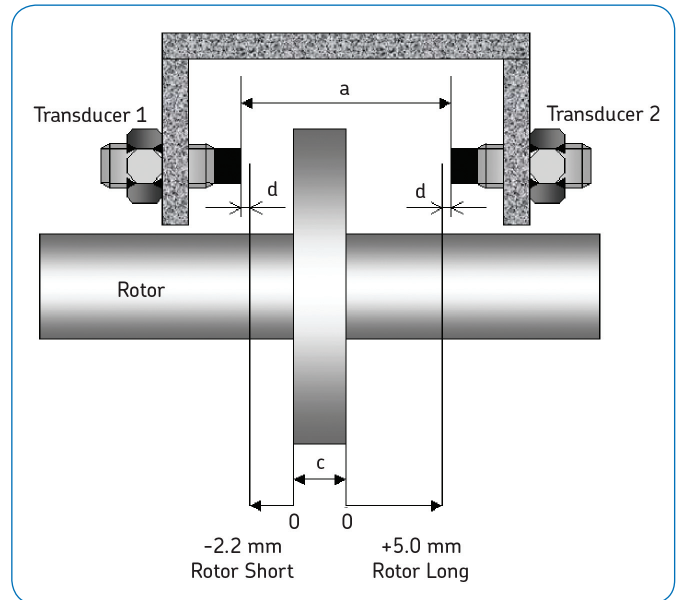


Figure 5.

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: $2 \times 3,68 = 7,36$ 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).

- $a = 0,38 + 2,20 + 100,00 + 5,00 + 0,38 = 107,96 \text{ mm}$

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 ($d \rightarrow 0,48 \text{ mm}$).

- $a = 0,38 + 0,10 + 2,20 + 100,00 + 5,00 + 0,06 + 0,38 = 108,12 \text{ mm}$

Any value between these values will give a safe situation.

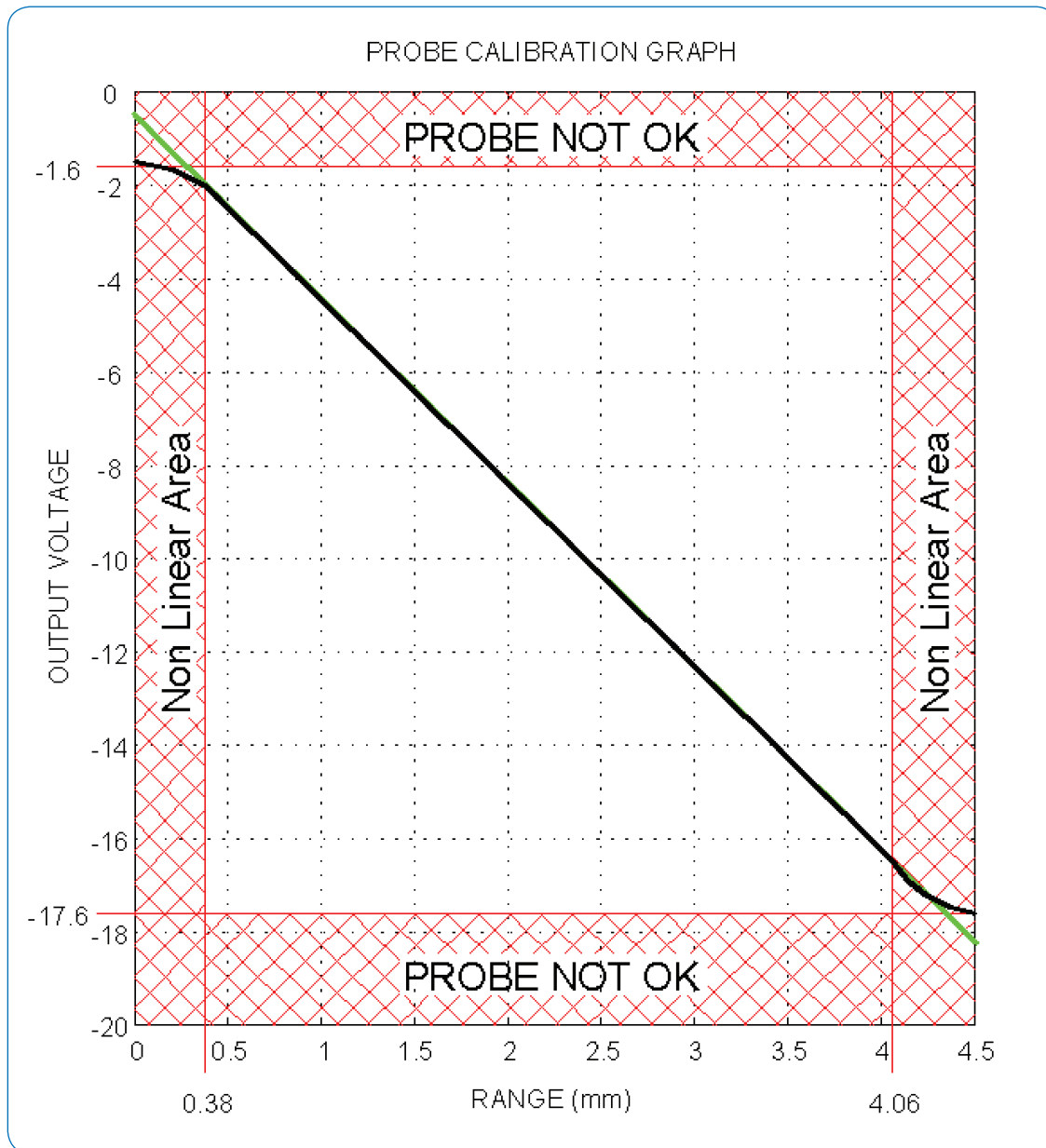


Figure 6.

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 (\rightarrow fig. 6), the real sensitivity can be determined:

- $(-16,49 + 2) \times 1\,000 / (4,06 - 0,38) = -3\,937,5$ mV/mm
- Danger low = $-2,2$ mm = $[0,48]$ mm \rightarrow
 $-2,0 - (3,937 \times 0,10) = -2,39$ V
- Zero position = $-2 - (2,3 \times 3,937) = -11,06$ 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:

- $-11,06 - (0,5 \times 3,937) = -13,02$ 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 =
 $-2,3 + (2 \times 3,68) = 5,06$ mm = $-2,0$ V
- Danger high (5 mm) = $-2 - ((5,06 - 5,0) \times 3,937) = -2,236$ V
- Zero position = $-2 - (5,06 \times 3,937) = -21,92$ V [Transducer 2]

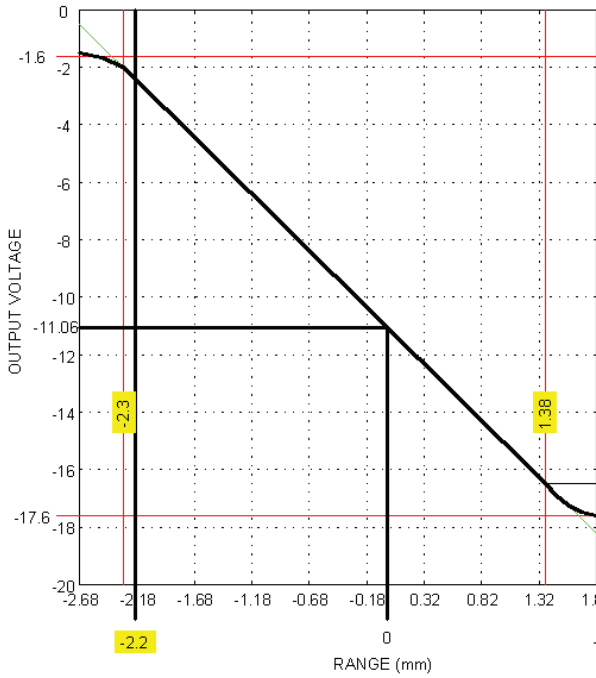
For transducer 2, this result ($-21,92$ V) should be the value to adjust if the collar is in zero position.

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:

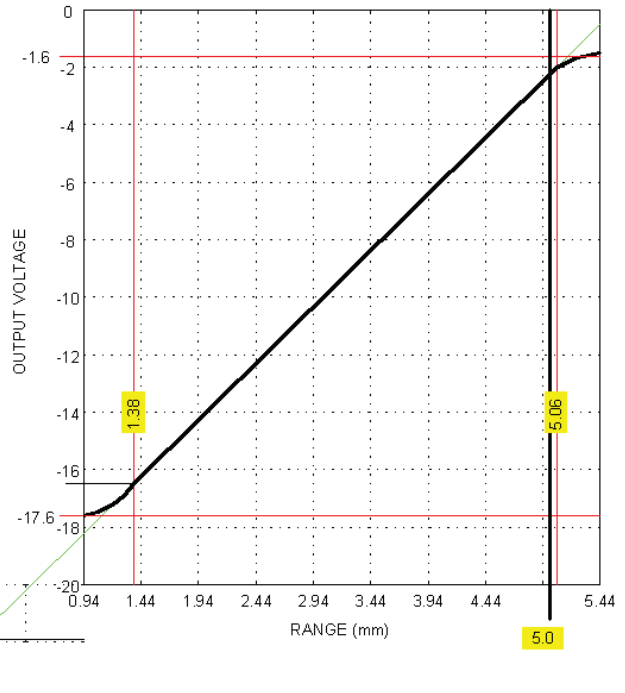
- 1 Move the collar toward the transducer and measure this distance with a dial indicator.
- 2 Manufacture a metal shim (same kind of material as the collar), measure the thickness of the shim and subtract that value from the $-21,92$ V.
- 3 Adjust transducer 2 in such a way that the distance between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

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

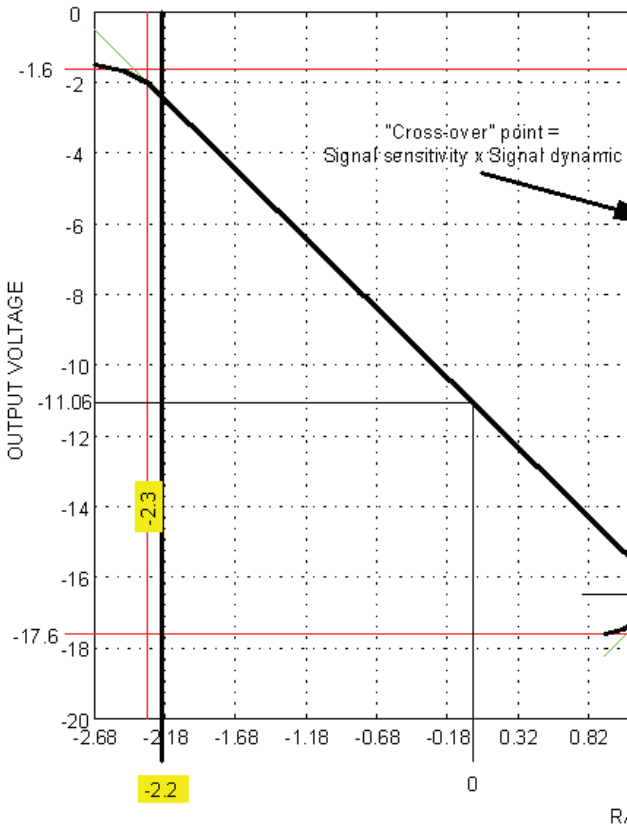
PROBE CALIBRATION GRAPH
Transducer 1



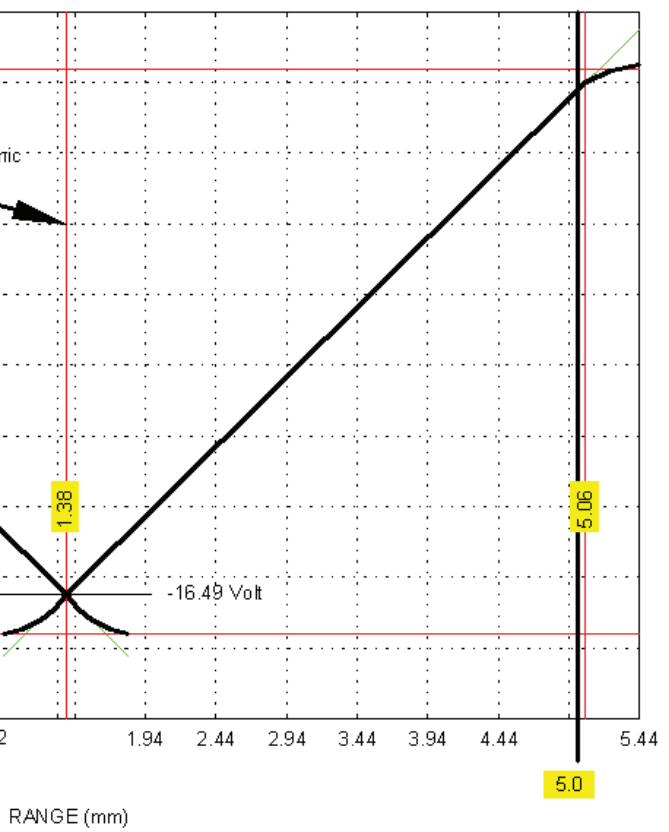
PROBE CALIBRATION GRAPH
Transducer 2



PROBE CALIBRATION GRAPH
Transducer 1



PROBE CALIBRATION GRAPH
Transducer 2



MPC-4 Input:

The screenshot shows the configuration for Channel 2 (Transducer 2) in the MPC-4 Input interface. The settings are as follows:

- Sensor Family: Generic (Non-Vibrometer)
- Sensor Tag: Transducer 2
- Sensor Connected: Yes
- Sensor Sensitivity Unit: μm
- Signal Sensitivity (mV/ μm): 3.937
- Signal Dynamic (μm): 4188
- Sensor Power Supply: -27 VDC
- Signal Transmission Mode: Voltage
- Upper OK Level (mV): -1600
- Lower OK Level (mV): -24000

Annotations:

- A yellow box states: "Cross-Over" Point = $3.937 \times 4188 = 16.49$ Volt
- Another yellow box states: No Probe OK Checking for Lower OK Level

MPC-4 Processing:

The screenshot shows the configuration for Channel 2 in the MPC-4 Processing interface. The settings are as follows:

- Function: (PS) Position
- Signal I/P: Sensor 2 (Transducer 2)
- Speed I/P: Not Used
- One Per Rev: Not Used
- Position Function Configuration Data Registers:
 - Proximity Probe Initial Gap (μm): 0
 - Sensor offset (mV): -21921
- Sensor inverted: (Selected)
- Direct Sensor: (Not Selected)

Annotations:

- A yellow box contains the formula: $\text{Full Scale} > (21921 + 1600) / 3.937$

Below this, another screenshot shows the "General" tab of the "Processed Output 1" configuration:

- Tag: Ch 2
- Output Used: Yes
- Engineering Unit: μm
- Rectifier Function: N/A
- Full Scale Deflection: 6000

Channel 1 and Channel 2 Processing:

The screenshot displays the configuration for MPC4 (Slot: 5). On the left is a tree view with 'Channel 1 & 2' selected. The main area shows three configuration panels for 'Processed Output 1':

- Function Panel:** Shows '(RSC) Relative Shaft Expansion (Shaft collar)' as the function and 'Measurement Input Channels 1 & 2' as the input.
- General Panel:** Shows 'Comp.Diff.Exp' as the tag, 'Yes' for 'Output Used', 'um' for 'Engineering Unit', and '6000' for 'Full Scale Deflection'.
- Adaptive Monitoring Panel:** A table with columns: Level (um), Hysteresis (um), Delay (s), Enable, and Latch.

	Level (um)	Hysteresis (um)	Delay (s)	Enable	Latch
Danger + High	5000	10	0.3	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Alert + High	4700	10	0.3	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Alert - Low	-1900	10	0.3	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Danger - Low	-2200	10	0.3	<input checked="" type="checkbox"/>	<input type="checkbox"/>

Live Data:

The screenshot shows the 'MPC Running' status for 'MPC Outputs (Slot 3)' on 04/21/2004 06:05:16 p.m. The interface displays data for two transducers and a combined RSC output:

- Transducer 1:** 1_PS, OUTPUT 1: 1466 um, D+ A+ A- D-
- Transducer 2:** 2_PS, OUTPUT 2: -5001 um, D+ A+ A- D-
- 1 & 2 RSC:** 5000 um, D+ A+ A- D- (highlighted with a yellow circle)

Other indicators include 'OK' status for various channels and a 'Saturation Trk' section with 'CMR PGA Lost'.

This is the reading for Complementary Differential Expansion

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