Complementary differential expansion measurements with the SKF Multilog On-line System DMx

By Marcel de Boer • SKF

The SKF Multilog On-line System DMx.

As described in Differential Expansion application note number CM3073 EN, the SKF Multilog On-line System DMx (a distributed vibration based machinery protection and condition monitoring system) is specifically designed to perform critical measurements used in the control of large steam turbine generator trains. Perhaps the most important measurement is 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 such monitoring is to prevent 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 (abbreviated to "CDE" or "Comp Diff Exp") which is considered together with the appropriate SKF Multilog DMx channels setup and configuration.

Reasons for measuring complementary differential expansion instead of straight differential expansion include:

- The desired working range of one non-contact eddy current probe is not enough. Using the CDE method, the measuring range doubles.
- Due to machine design, there is not enough radial clearance available to mount a probe of sufficient diameter versus range for a straight measurement.

How does complementary differential expansion work?

In **Figure 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 **Figure 1**) into the working area of the other transducer "b" and eventually out of the measuring range of the "a" 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 the second probe takes over at the end of the first's working range, the maximum range will be achieved.

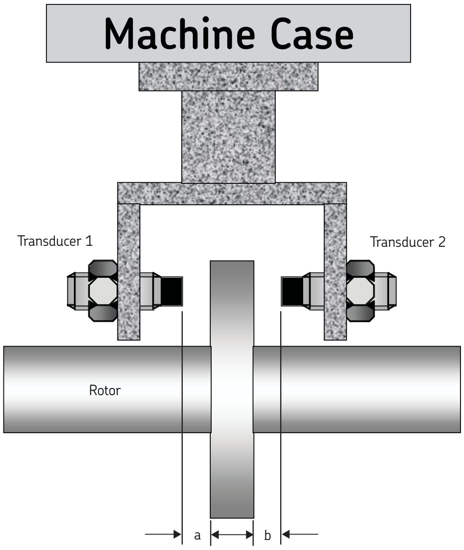


Figure 1

However, the transducers are usually mounted closer to each other, generating an area where both transducers measure the target. In **Figure 2**, transducer 2 is mounted closer to the collar, which generates an area "c" where both transducers measure the target.

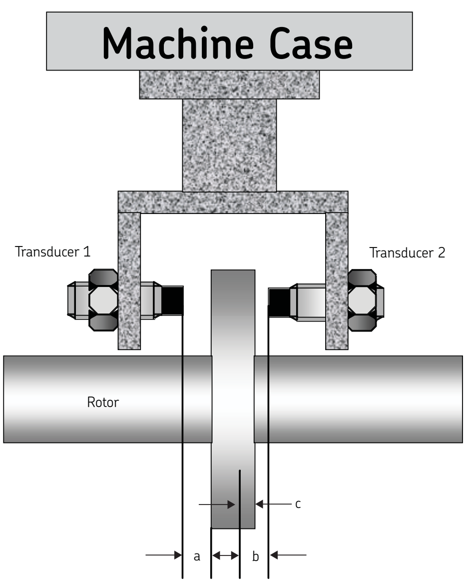


Figure 2

In **Figure 3**, the situation is shown where transducer 1 measures the gap, and transducer 2 is in saturation. As the rotor grows with respect to the case, the gap between transducer 1 and the collar increases as the gap between transducer 2 and the collar decreases, the increase in transducer 1's gap continues until it exceeds its linear range. At the same time, the collar exceeds the linear range of transducer 1, entering the linear range of transducer 2.

This point is referred to as the "cross over point," or the point at which the system stops observing transducer 1's gap, and turns control over to transducer 2. This method allows measurements of two times the linear range of a single sensor.

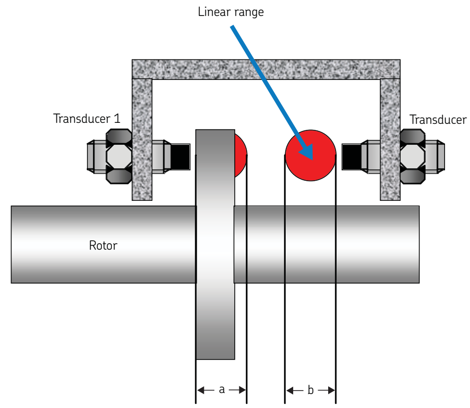


Figure 3

A further consideration in transducer selection is the available radial clearance ("f" in **Figure 4**) for mounting a probe. In general, the longer the measurement range of the probe, the larger the diameter. The probe diameter cannot be larger than the available collar target area divided by 2.5. The probe shall not be affected by any metal other than that of the probe area.

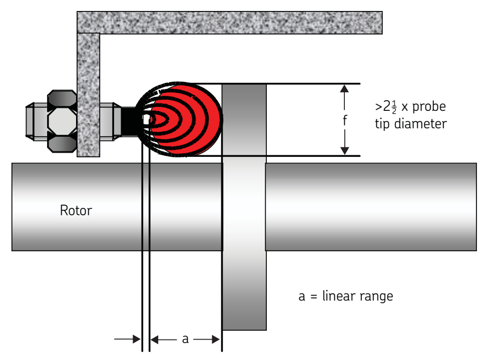


Figure 4

Transducer types

Due to the versatility of the SKF Multilog DMx, different types of eddy current probes (ECP) can be accepted for CDE measurements:

- Normal ECP signals, retrieved from externally powered drivers, where the signal will be in the range between –2 and –18 V DC.
- Normal ECP signals, retrieved from drivers which are powered by the SKF Multilog DMx, the signal will be in the range between –20.3 and –2 V DC.
- Direct ECP signals, where the probe cable is connected directly to the internal digital driver of the SKF Multilog DMx. This internal driver linearizes the "true" probe curve using a digital algorithm, which results in a much larger usable measuring range than an analog driver: "equivalent" voltages from –2 up to –30 V DC can be observed. The "equivalence" comes from an input sensitivity (e.g. 4 V/mm). The SKF Multilog DMx converts by calculation the true curve to the desired straight line of 4 V/mm. In this case the scenario shown in **Figure 3** will still apply, except the ranges are larger than analog driver systems.

Probe calibration

Before adjusting probes that measure any differential expansion type, a calibration curve of each probe should be generated with a target that has similar magnetic characteristics as the final target.

The preferred method for setting the parameters of the CDE configuration will be the positioning of the rotor exactly between the minimum and maximum clearance. With symmetrical danger values, this position is located at 0 mm (or 0 mils).

Next step is the adjustment of both probes; the probe gap should be adjusted close to the end of its linear range, approximately –16 V with normal eddy current probes. A control calculation should be made for the most extreme positions – the probes should always measure a value lower than their Probe OK High limit (with eddy current probes this value is –1.6 V).

Once the probes have been mechanically adjusted, the offset in the SKF Multilog DMx for each of the probes can be zeroed. This is done with the SKF Multilog DMx Manager configuration software. If this zero point has to be displayed as a different value (in case non-symmetrical danger values have to be applied) an additional overall axial offset can be programmed. This last value is normally the average of both danger values and, once set up, the SKF Multilog DMx will show this value if the rotor is in the central position.

g During machine commissioning, it is advisable to show both individual probe measurements together with the CDE result and compare these values. If possible, monitor especially the region where the cross-over point becomes active.

The K-position

In practice, the above procedure can rarely be used on large steam turbines, because rotors aren't easily moved and maximum or "danger value" positions cannot be reached because the clearance between blades also depends on operating temperatures also, and internal temperature increases mean that both stators and rotors expand together.

So what happens for real? The shaft ***must*** be in a known physical position when the stationary and cold turbine is opened up to set the probes. There should be a physical marker provided by the manufacturer that indicates a known position of the rotor in this state. This is known as the K-position or Zero-position. This position will have a differential expansion value of, for example, +0.5 mm.

The two probes are then adjusted so that the measured voltages match the calibration sheets of both probes, with an end result by calculation of +0.5 mm.

Calculation of the complementary differential expansion

For the CDE calculation, the SKF Multilog DMx follows some rules in which both probes are checked for their signal validity.

The probe that is configured for the active direction (if the gap increases, the result becomes more positive) is checked first. If this reading from the probe is not inside Probe OK limits, the CDE value will be based on the probe configured as inactive. If the active configured probe is indeed between Probe OK limits then, a second check is done on the calculated value from this probe. If the value is smaller than the absolute value of the configured offset, the result will be derived from the active probe, otherwise the result is based on the inactive probe (unless this probe is outside its Probe OK limits).

g Due to the versatility of the SKF Multilog DMx (accepting signals from external drivers or the internal digital drivers), different types of Probe OK checks can be applied. With direct ECP inputs, the check can be based on voltage, frequency or a combination of both. To apply the above mentioned rules, voltage checking should be enabled for CDE measurements.

The CDE value

Based on the above rules, and the setup of offset and overall axial offset, the following formula applies to calculate the CDE value (ΔX), where the polarity of the sensitivity depends on the active/inactive configuration of that probe.

The sensitivity will be multiplied with –1 if the probe is configured as active.

$$\Delta X = \frac{\text{measured value}}{\text{sensitivity } (X - 1)} + \textit{Offset} + \textit{“OverallAxialOffset”}$$

Special considerations should be taken with the offset setup, especially when external probe drivers are used. If the offset value is too high, dangerous conditions occur because the behavior of traditional analog drivers show a "flattening" of the signal near the end of their measuring range. If the offset has been calculated (based on sensitivity), the possibility occurs that the offset will never be reached. If this occurs, the CDE value will be derived from the active configured probe and stabilizes, even if the rotor continues moving in the active direction.

Example setup of the SKF Multilog DMx for complementary differential expansion

To cover different types of installations in one example, the following factors should be assumed:

- "non standard" sensitivity
- asymmetrical danger set-points
- External drivers – as more care should be taken with this kind of setup. Where possible, direct ECP probes using the SKF Multilog DMx internal digital drivers are recommended, as they have much higher accuracy and range, and so are more tolerant of user error.

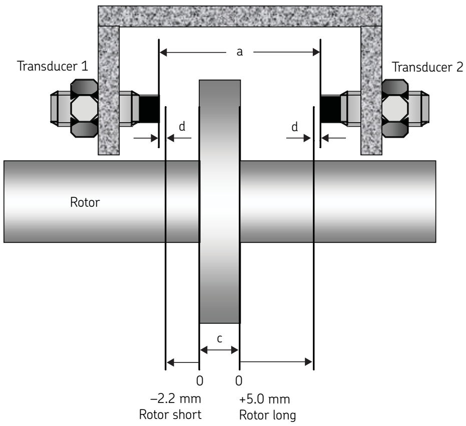


Figure 5

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 **Figure 5**) to 4.06 mm
- Sensitivity: 100 mV/mil = 3 937 mV/mm
- Collar thickness ("c" in **Figure 5**): 100 mm

Alarm setpoints:

- 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 x 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 is the value that can be located between the transducers or added to the usable range.

The first option introduces an area of 0.16 mm, where both sensors measure the differential expansion (the result will only be derived from the active configured transducer).

a = 0.38 + 2.20 + 100 + 5.00 + 0.38 = 107.96 mm

The second option introduces an extra 0.1 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 + 5.00 +0.06 + 0.38 = 108.12 mm

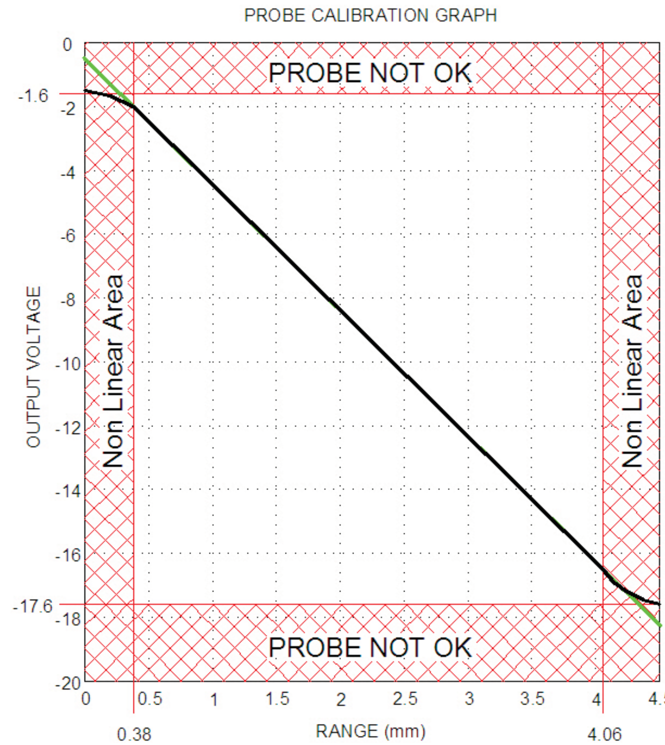


Figure 6

Once the parameters are set up (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 necessary to use a probe calibration graph.

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

- (-16.49 + 2) * 1 000/(4.06 – 0.38) = –3 937 mV/mm.
- Danger low = –2.2 mm = |0.48| mm '
- The average of both danger values = (–2.2 + 5) = 3.6 mm.
- The zero offset for transducer 1 (active setup, thus offset should be negative) = 3.60 + 0.48 = -4.08 mm.
- Above result in an overall axial offset of –2.2 + 3.6 = +1.4 mm.
  - Extra check could be the zero voltage, but this is not used in further calculations. The zero voltage = –1 * –4.08 * –3 937 = –16 063 mV (active setup, sensitivity = negative).
- If transducer 1 is at 4.08 mm, the calculated CDE result is +1.40 mm.

A similar calculation should be done for transducer 2:

- There was 0.06 mm left for transducer 2 clearance '
- The zero offset for transducer 2 (inactive setup, offset should be positive) = 3.60 + 0.38 + 0.06 = +4.04 mm.
- Or zero offset = 2x maximum range – offset (1) = 2 * 4.06 – 4.08 = +4.04 mm. The zero voltage = –1 * 4.04 * + 3 937 = –15 905 mV.

Next step will be the physical adjustments to both probes:

1 The easy solution: Start the configuration software; program both measurements with above values and mechanically position the rotor exactly in the middle between both danger values. Adjust transducer 1 until the software displays a measured (CDE) value for transducer 1 of (–2.2 + 3.6) = 1.4 mm. Adjust transducer 2 until the software displays a measured (CDE) value for transducer 2 of (5 – 3.6) = 1.4 mm. The benefit of this procedure is that both probes are in their measuring range and an easy check can be performed: the result of the CDE measurement should be equal for both transducers and has to be the initial value + the overall axial offset = 1.4.

2 It becomes more complicated when the collar is in another known position (for example +0.5 mm). Transducer 1 can be adjusted according to the above procedure, and should be 'gapped' at 0.5 mm, or –16.06 + (1.40 – 0.50) * 3.937 = –12.52 V.

Adjust channel 1 until result = –12.52 V or +0.50 mm

Name	Status	Value	Units	DC (V)
CDE 1.DC(V)	OK	-12.51	V	-12.51
CDE 1.DC	OK	-0.90	mm	-12.51
CDE 2.DC(V)	OK	-17.34	V	-17.34
CDE 2.DC	OK	-0.37	mm	-17.34
CDE 1.CompdX	OK	0.50	mm	-12.51
CDE 2.CompdX	OK	0.50	mm	-17.34

Similarly, the position of transducer 2 is determined:

- For this example, it is assumed that the probe calibration graph is the same as the one for transducer 1.

Based on transducer 2, a value of –15.91 V is equal to 1.4 mm, this transducer would theoretically display a value of –15.91 – 1.40 * 3.937 = –21.42 V at 0.00 mm or –15.91 – 0.90 * 3.937 = –19.45 Volts at +0.50 mm.

For transducer 2, this result (–19.45 V) should be the value to adjust if the collar is in +0.5 mm position, except that this voltage is above the Probe OK value (or out of the linear range), therefore another solution is necessary to adjust this sensor. Some of the possible solutions are:

- Move the collar towards the transducer and measure this distance with a dial indicator.
- Manufacture a metal shim (same kind of material as the collar), measure the thickness of the shim, and subtract that value from the –19.45 V.
- Adjust transducer 2 so that the distance between both transducers is between 107.96 mm and 108.12 mm.

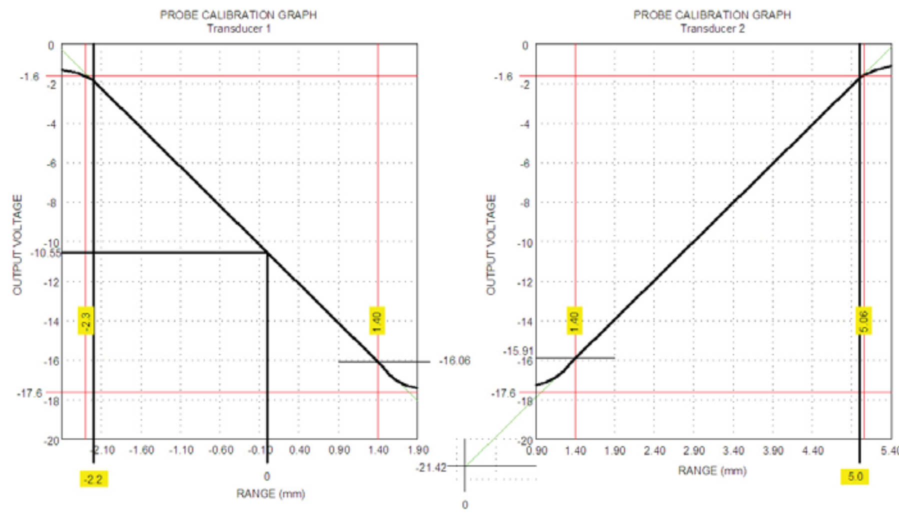


Figure 7

As a result, two calibration graphs are generated with the actual values (**Figure 7**). These graphs can be combined into one CDE result graph that visualizes the measurements behaviour see **Figure 8**.

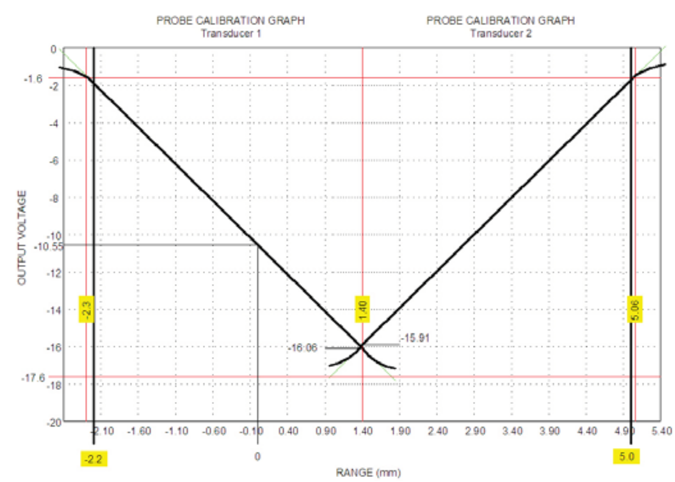


Figure 8

SKF Multilog DMx Manager software setup

Figure 9 to 16 show how to setup the channel properties for the previous example in SKF Multilog DMx Manager.

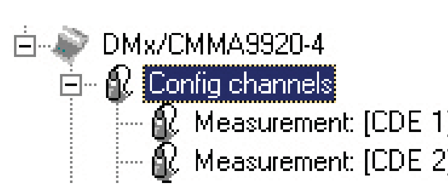


Figure 9

Configuration for channel 2 is similar as that for channel 1, except for “target positive direction” and the “offset”.

The programmed sensitivity should be based on the calibration curve and will be unique for each probe.

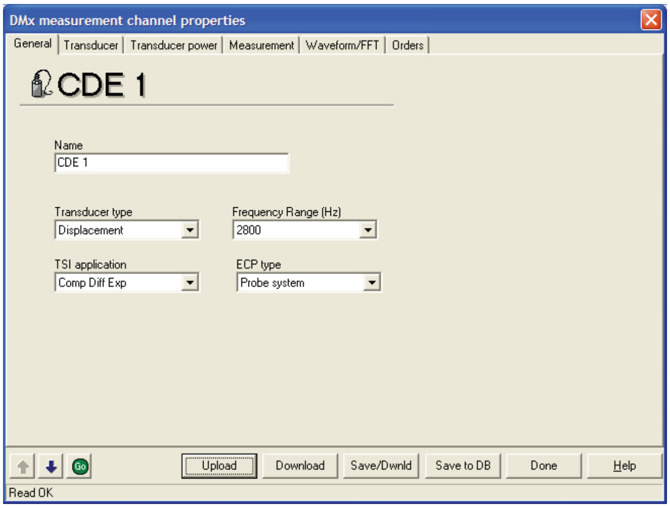


Figure 10

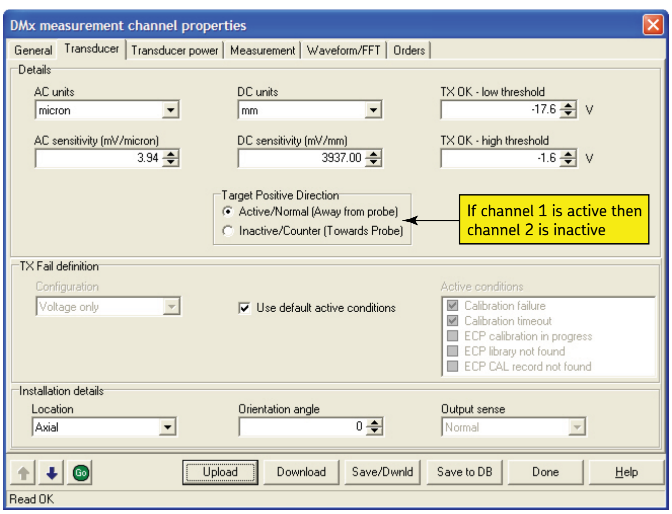


Figure 11

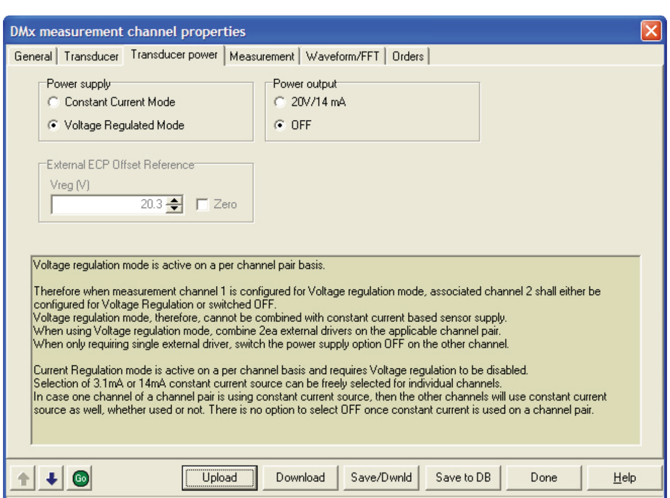


Figure 12

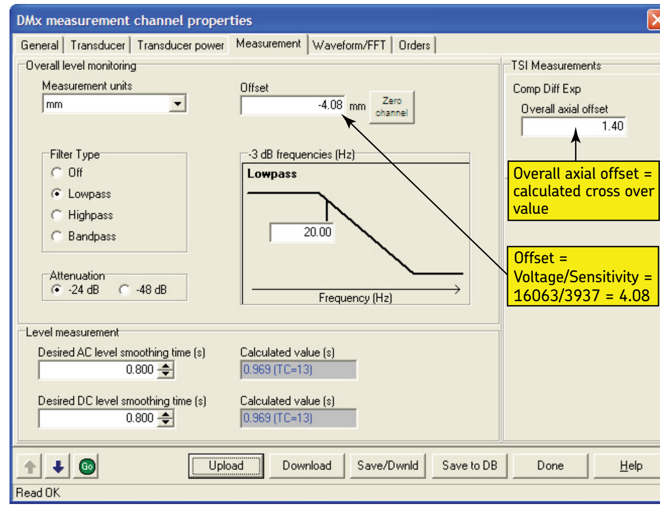


Figure 13

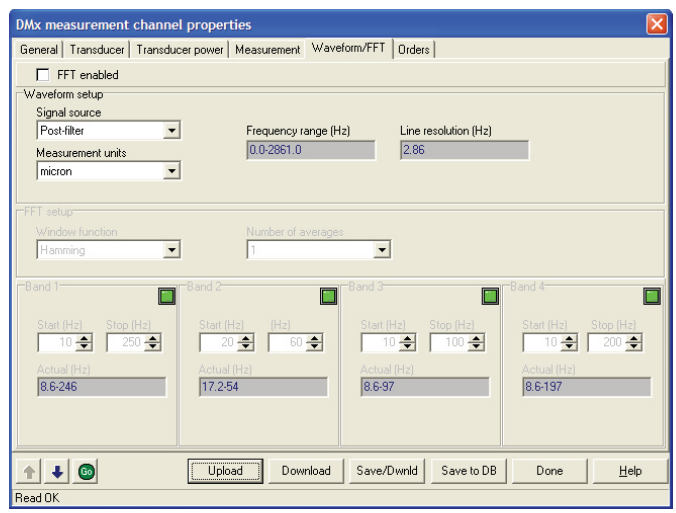


Figure 14

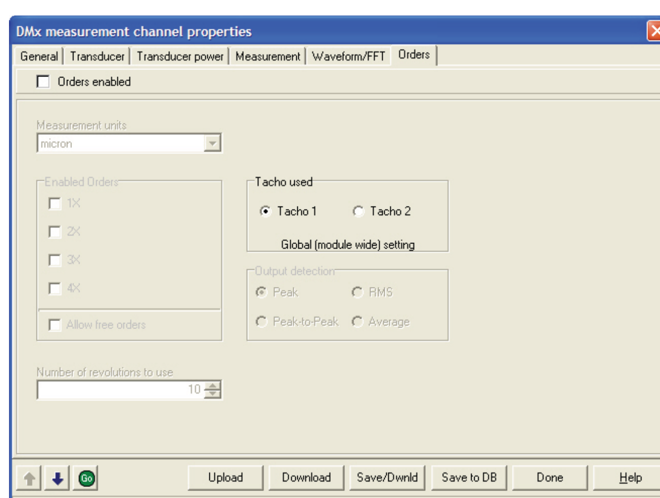


Figure 15

Configuration of the measurement setup for the second CDE channel:

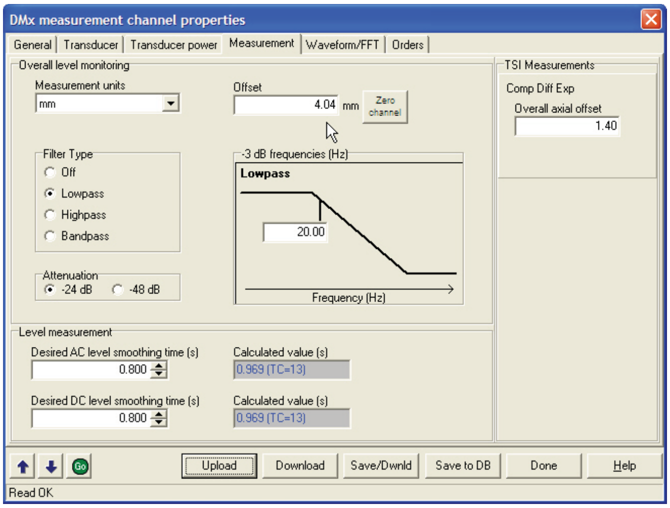


Figure 16

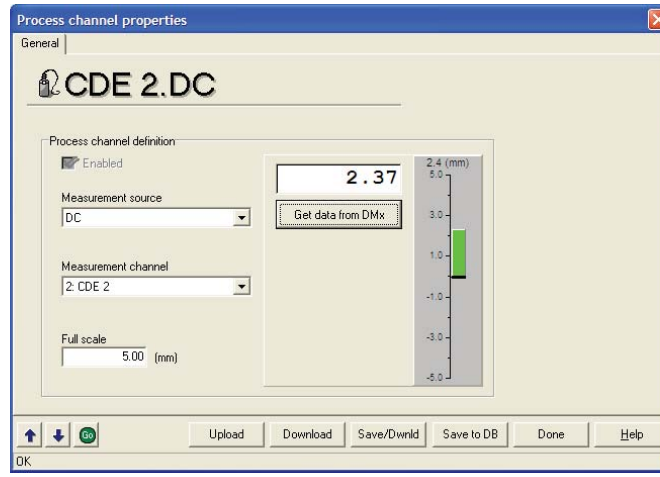


Figure 18

The SKF Multilog DMx processing setup

Figures 17 to 20 show how to setup the processing of collected data in SKF Multilog DMx Manager.

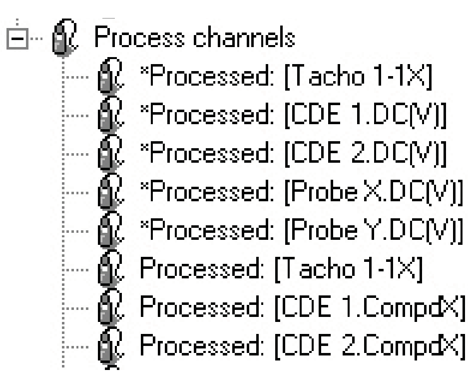


Figure 17

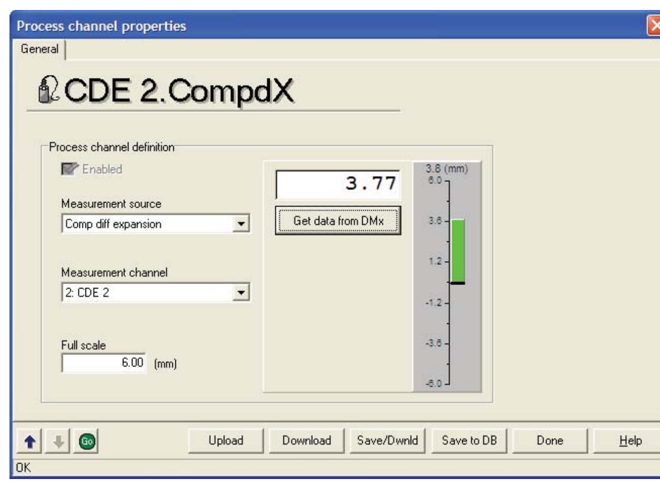


Figure 19

SKF Multilog DMx live data display

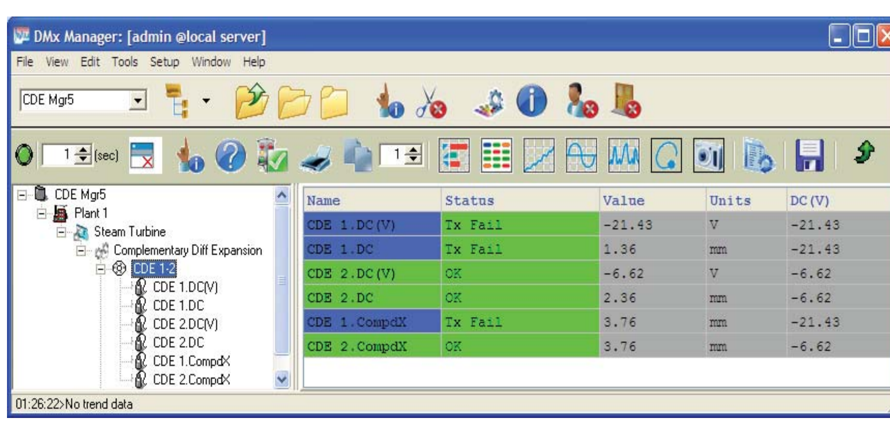


Figure 20

Common pitfalls in the setup of complementary differential expansion

Regardless of the monitor type used (SKF Multilog DMx, SKF M800A, VM600 or other vendor product) there are a number of common mistakes that can be made when setting-up a CDE installation. The CDE measurement is arguably the most critical measurement a TSI system will make, so it has to be right!

Pitfall 1 – calibration graphs

A familiar error is the skipping of the creation of calibration graphs.

Often the cross-over point is selected close to the Probe OK limits, in order to achieve the widest possible measuring range. **Figure 21** exaggerates the behavior of an eddy current probe to give a better visualization of why this is a mistake without true calibration curves:

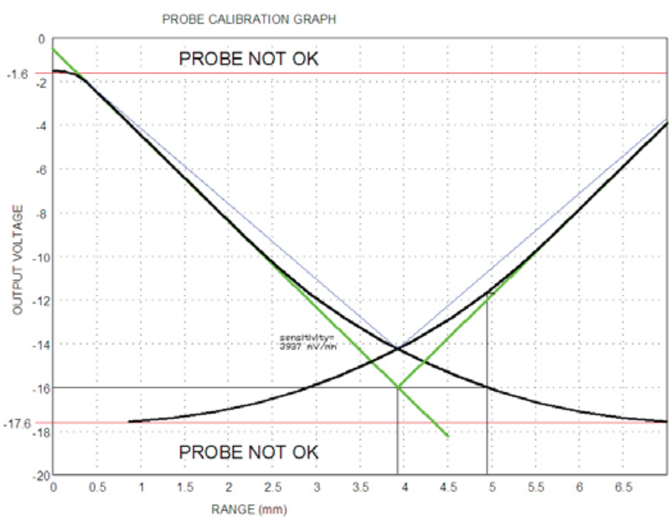


Figure 21

From **Figure 21**, the conclusion could be made that this probe measures up to 7 mm (at –17.6 V). The programmed sensitivity (green line) is 3937 mV/mm. If the crossover point has been selected at –16 V, the SKF Multilog DMx displays a value of 3.9 mm, while the real expansion is already 4.9 mm. If the rotor grows further, the second probe 'takes over and the measurement returns to the real value. In the above example, an accuracy problem occurs between –13 and –16 V for the first probe. Fortunately, this behavior is not close to the danger set points.

This problem can be witnessed as a "jump" in the CDE value reported. A real value of 4.9 mm will be shown as 3.9 mm, the second probe takes over and the next reported value for the CDE measurement will be 5.1 mm. CDE jumps from 3.9 to 5.1 mm.

To improve above measurement, a sensitivity correction can be applied to both sensors, based on the blue thin line, where the crossover point is set at the "true" crossover point of –14 V.

Pitfall 2 – incorrect sensitivity

Another pitfall is the programming of an incorrect sensitivity.

For example, programming the monitor with the standard sensitivity for 4140 steel (3 937 mV/mm), whereas the real target material produces a different sensitivity. **Figure 22** illustrates this error.

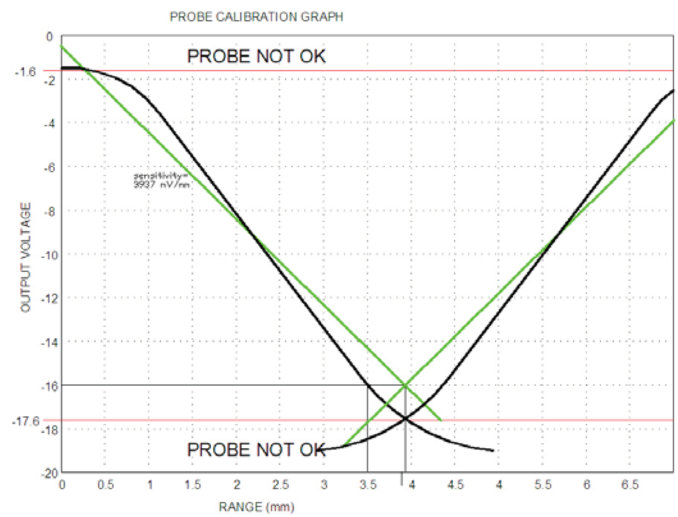


Figure 22

Once probe 1 measures –16 V, the monitor displays again a value of 3.9 mm. The real value will be 3.5 mm.

As the gap increases towards the "true" crossover at –17.6 V, the measurement needs to be taken over by the probe 2. Then two conditions can apply:

- If probe 2 is not yet between Probe OK limits, the end result will still be derived from probe 1 and remain incorrect until probe 1's OK limit is passed.
- If probe 2 is within Probe OK limits, the end result will cross over to probe 2. In this example, the value will be reported as 4.3 mm while the real gap is 3.8. When gap increases further to 3.9 mm, the CDE result falls back to 3.5 mm.

Also, combinations of incorrect sensitivity and calibration errors can occur, together with incorrect programming of other parameters, especially offset values.

Pitfall 3 – incorrect interpretation of the crossover point

Different monitor systems detect the crossover point in different ways. Some use the Probe OK detection limit of each sensor, others use the average point between the offsets.

As the internal digital drivers of the SKF Multilog DMx offer significantly longer probe measurement ranges (compared to traditional probe systems), the crossover point is determined by the offset of the active probe only. Once this offset is reached, the reading switches to the inactive probe.

A problem occurs if this methodology is not accounted for when a normal external eddy current probe system is used.

This is illustrated in **Figure 23** (overstated for clarity, as in the previous examples).

In this scenario the guidelines for configuring the SKF Multilog DMx have been followed correctly, and the sensitivities have been determined from real probe curves. The rotor is positioned between Danger limits and the two probes are adjusted to reach each of their offset values, and hence show a 0 value in the SKF Multilog DMx Manager display software.

Adjust channel 1 until result = 0.00 mm

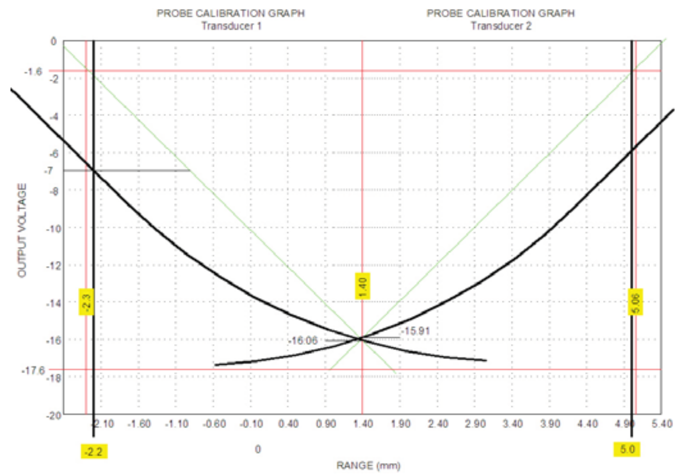
Name	Status	Value	Units	DC (V)
CDE 1.DC(V)	OK	-16.06	V	-16.06
CDE 1.DC	OK	0.00	mm	-16.06
CDE 2.DC(V)	OK	-15.91	V	-15.91
CDE 2.DC	OK	0.00	mm	-15.91
CDE 1.CompdX	OK	1.40	mm	-16.06
CDE 2.CompdX	OK	1.40	mm	-15.91

Adjust channel 2 until result = 0.00 mm

The complementary differential expansion for both probes display the calculated +1.40 mm and the conclusion will be made that the setup is correct.

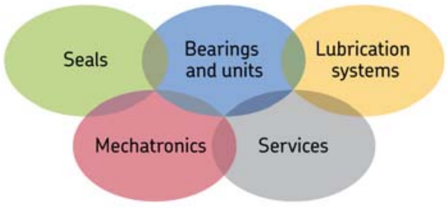
However, because of a "flattening" of the driver response, an incorrect interpretation of the probe curve can occur, see **Figure 23**.

Figure 23



Transducer 1 measures –16.06 V and the displayed CDE is 1.40 mm. The shaft starts moving towards the probe tip until it reaches the real danger value (–2.2 mm) following the curve of the black line. At –2.2 mm, the measured voltage is –7 and therefore the displayed CDE result will be –0.9 mm, not even close to the real danger limit of –2.2 mm!

The problem is avoided by ensuring a correct calibration of probe and driver to the true target material of the collar. This is easily done with the inbuilt drivers of the SKF Multilog DMx which eliminate this potential error because of the better linearization of the probe calibration curve.



The Power of Knowledge Engineering

Drawing on five areas of competence and application-specific expertise amassed over 100 years, SKF brings innovative solutions to OEMs and production facilities in every major industry worldwide. These five competence areas include bearings and units, seals, lubrication systems, mechatronics (combining mechanics and electronics into intelligent systems), and a wide range of services, from 3-D computer modelling to advanced condition monitoring and reliability and asset management systems. A global presence provides SKF customers uniform quality standards and worldwide product availability.

For additional information on SKF products, contact:

SKF USA Inc.
5271 Viewridge Court • San Diego, California 92123 USA
Telephone: +1 858-496-3400 • FAX: +1 858-496-3531

Web: www.skf.com/cm

Publication **CM3118 EN** • March 2009