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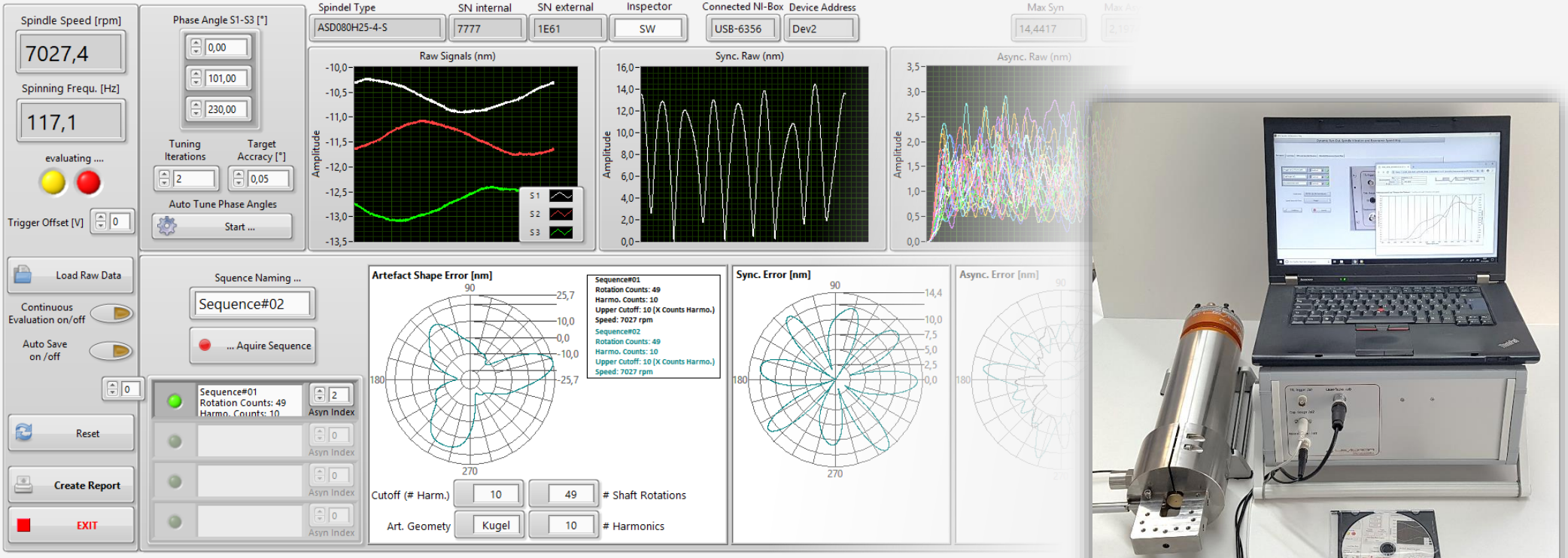
LEVICRON
NON-CONTACT PRECISION MOTION

ULTRA-PRECISION MEETS CNC-PERFORMANCE

New Facility – Good progress on Levicron's new production site and head office

ShakesBear ® – Spindle error analysis and test system with spindle data base

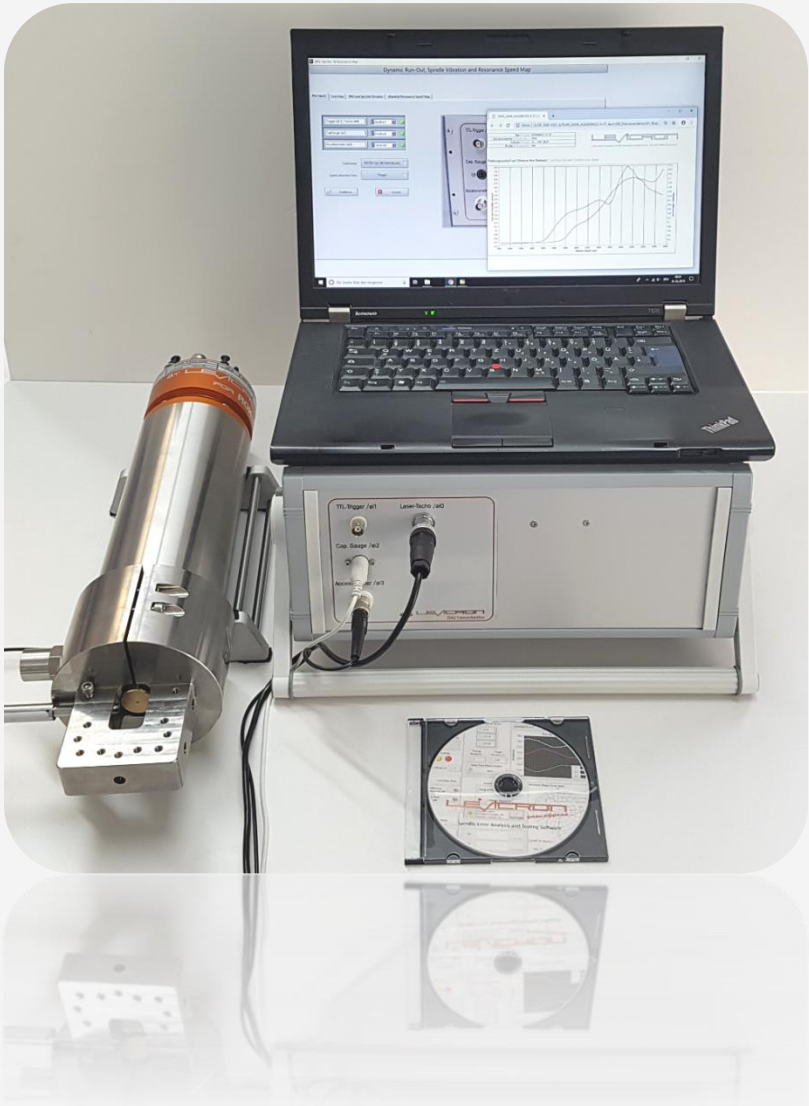
Upcoming Tradeshows – **EMO**, Hannover,
OPTIFAB, in Rochester/NY, USA



New Facility | Good progress on Levicrons new production and administration site

Despite of repeated expansion in the area around our current production site, it became clear that we are running out of options for any further expansion. To meet current and future requirements on development, manufacture and sales Levicron started the construction work for their new production and administration site back in November 2018. We hope to complete our relocation by September 2019, and even if there had not been time for a proper groundbreaking, our management did found the time to try the brand new company excavator.

ShakesBear | Spindle error analysis and testing system with spindle data base



Due to more and more inquiries from customers Levicron now offer complete spindle analysis and test systems with bespoke hardware components and software modules. Doesn't matter if you require a professional multi-sensor system for error-motion analysis and reporting or a system to measure and verify dynamic tool run-outs, spindle vibrations and resonance speeds up to 100.000 rpm, hard- and software can be tailor made to meet your requirements. Please don't hesitate to contact us.

The following OEM systems are available.

ShakesBear „Hamlet“ – Nanometer Multi-Sensor SEA with Error-Separation

- PC-connection via USB
- Data base for Levicron spindles; others only on request
- Software modules:
  - Database for Levicron spindles (bespoke data base only on request)
  - Radial SEA for speeds of up to 100.000 rpm, with protocol creation
  - Axial SEA for speeds of up to 100.000 rpm, with protocol creation
  - Sensor stand-off set up and digital drag-pointer gauge

ShakesBear „Othello“ – Dynamic tool run-out, spindle vibrations and resonance map for up to 100.000 rpm

- For PC-connection via USB or with integrated touch screen
- Software modules:
  - Data base for Levicron spindles (PC-version; bespoke data base only on request)
  - Resonance speed map, dynamic tool run-out and spindle vibrations with speed
  - Axial shaft growth and temperature with time and speed
  - Sensor stand-off set up and digital drag-pointer gauge

Overview

The requirements on testing methods to prove the quality and properties of Levicron spindle products had always been more challanging than those for other spindles. Higher spindle speeds, significantly better rotor dynamics and errors in motion in the nanometer range in particular require very high measurment resolutions at even higher scanning frequencies. Levicron have combined internal test and analysis methods to their ShakesBear Spindle error analysis and testing system, including a spindle data base and spindle configuration module.

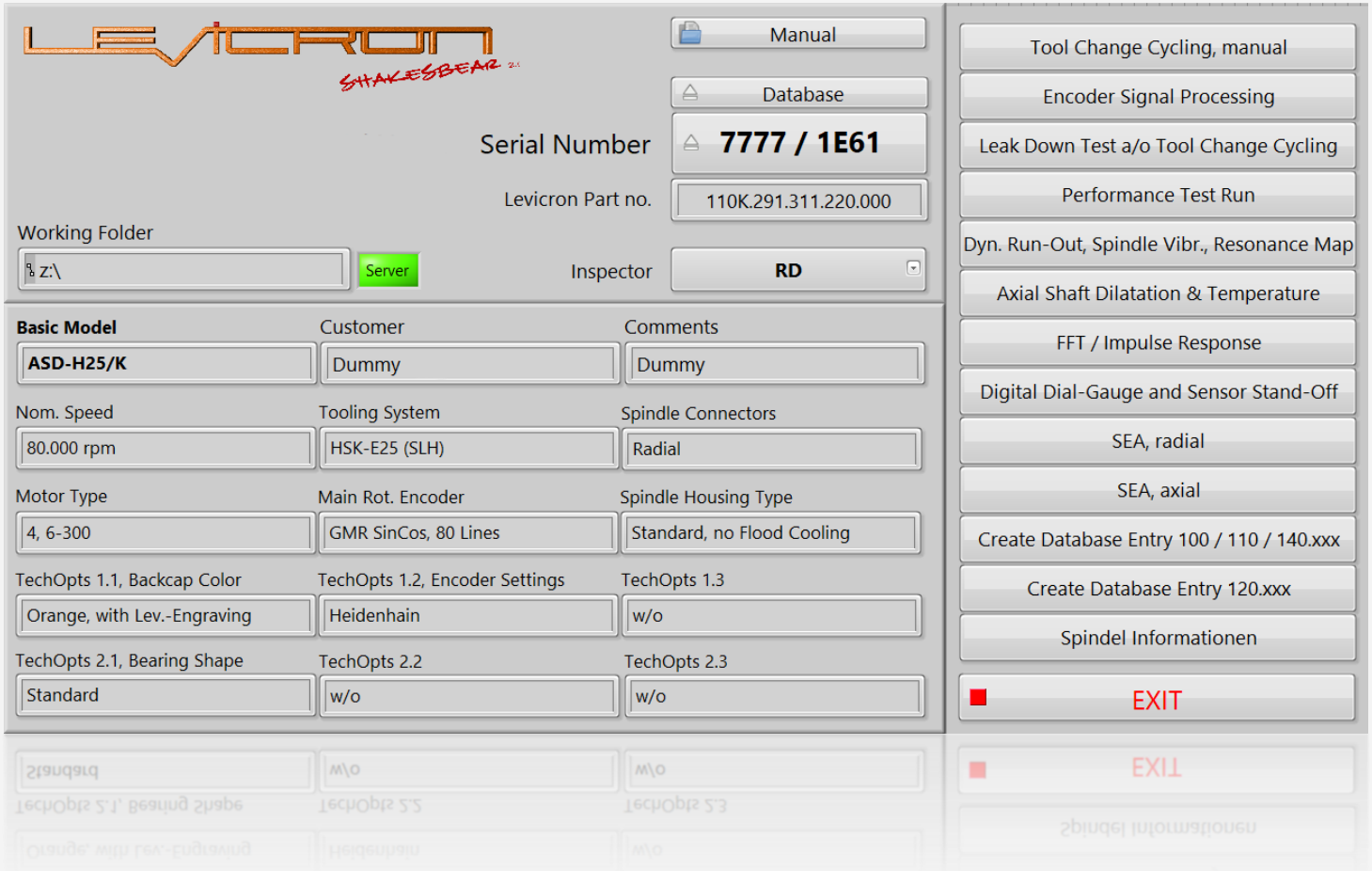
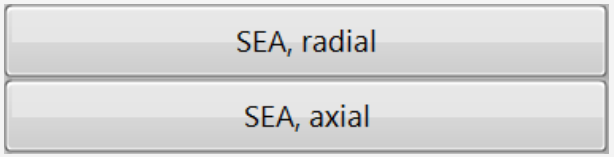


Fig. 1: ShakesBear Main GUI, including spindle data base access and single measurement modules

Measurement results and analysis of all single modules are automatically saved in specific spindle folders and its data base. Beside internal test procedures like automated tool change cycling, Encoder programming and a cooling jacket pressure leak-down test this also applies for

- Resonance speed maps, dynamic run-out and spindle vibrations over speed and for up to 100.000 rpm,
- Axial shaft growth and bearing temperature over speed and time,
- Radial and axial Error in shaft motion (SEA) with speed, including automated sensor angle detection and error separation.

Modules



// Radial and axial error in shaft motion (SEA) – Multi-probe technique with error-separation

The error in shaft motion is the maximum deviation of the real shaft spinning axis from the theoretical over a defined number of rotations. A distinction is made between

Synchronous Errors, which repeat every shaft rotation at the same angular position and

Asynchronous Errors, which are not repeatable between any of the shaft rotations.

Run-Out: Not included in the error in shaft motion is the fundamental, or also known as run-out, which corresponds to a perfect circle in the error polar plot and which represents an off-centered tool. Thus, run-out is a tool error, but no spindle error.

Definition: Error-Motion = ∑ SyncErrors + ∑ AsyncErrors – Fund (run-out)

Artefact form error: An important question during the measurement is how spindle synchronous errors and the form error of the artefact the measurement is taken against can be separated from each other, because any form error would spin synchronously with the shaft. For an axial measurement this problem can be solved by an axial measurement against the spinning pole of a sphere. Any form error in the area of the pole would be averaged in this case, if properly aligned. Much more difficult is a separation of the artefact form error from the spindle radial synchronous errors. Although there are single-probe methods that compare two measurements, where the artefact and probe angular position has to be changed by exactly 180° against the spinning axis while maintaining the axial position (Donaldson Reversal), these methods are very position sensitive and time-consuming.

Multi-probe method with error-separation: However, using at least three radially oriented distance sensors, where each gives a time-dependent change in distance to the artefact in a plane around the spinning axis, allows to separate the artefact form error from the spindle radial synchronous errors. For this the time-dependent and synchronized sensor signals have to be transformed into the complex frequency domain in which a system of equations now can now be solved. After retransforming the results back into the time domain the spindle radial synchronous errors in two directions and the artefact form error depending on the shaft angular position now can be extracted. This method allows the measurement of the artefact form error and the spindle synchronous and asynchronous errors in one measuring set up and at the same time.

Levicron have invested and developed a multi-sensor measurement system with 1.2 nm resolution and 120 kHz sampling rate per sensor to measure and prove the error in shaft motion of their spindle products at speeds of up to 100.000 rpm.

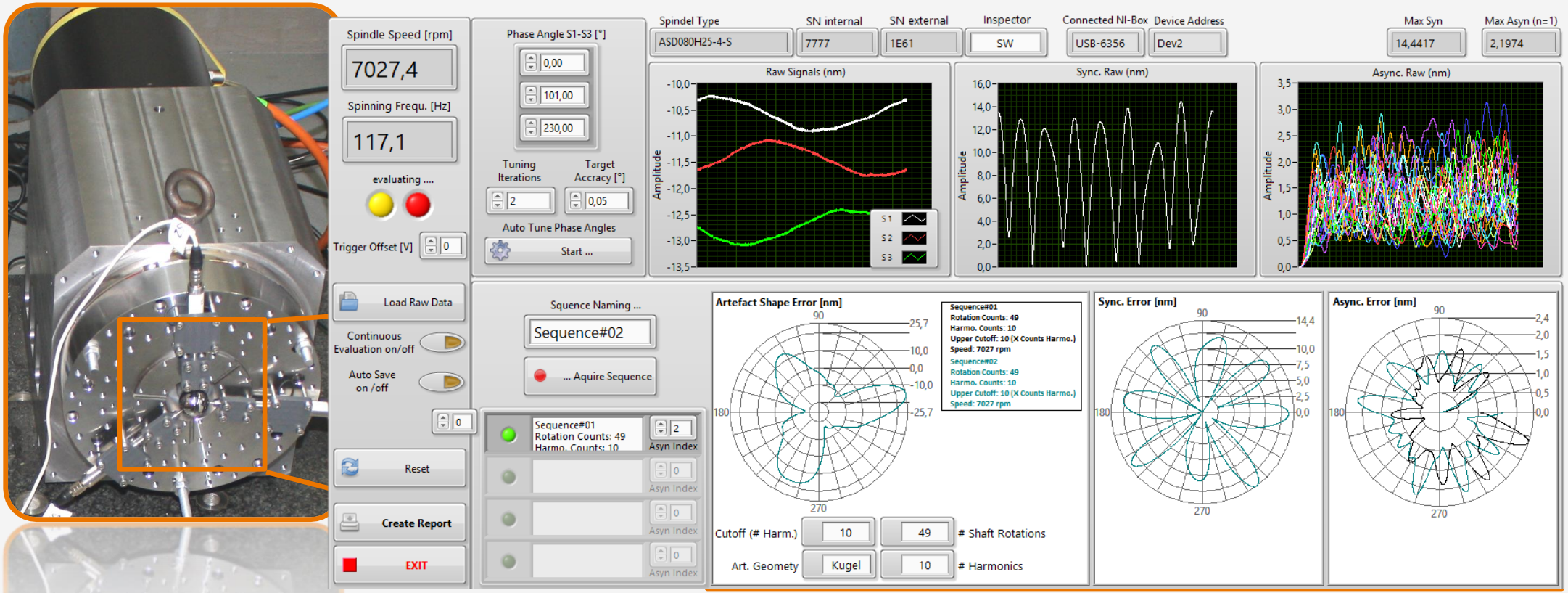


Fig. 2: Error in shaft motion measurement and report system using multi-probe techniques with separation of artefact form and spindle synchronous errors

Dyn. Run-Out, Spindle Vibr., Resonance Map **// Spindle resonance speed map, dynamic tool run-out and vibrations over spindle speed**

Using the entries from the spindle data base measurement ranges and filter settings are set automatically, but can be changed though. Although input channels and calibration values are stored in and recalled from the software, also here the operator can make changes on the fly, should another type of sensor be used or should I be necessary to select another source to detect the spindle speed. The real-time section includes actual RMS, peak or PV values in the frequency domain for tool run-out and vibrations

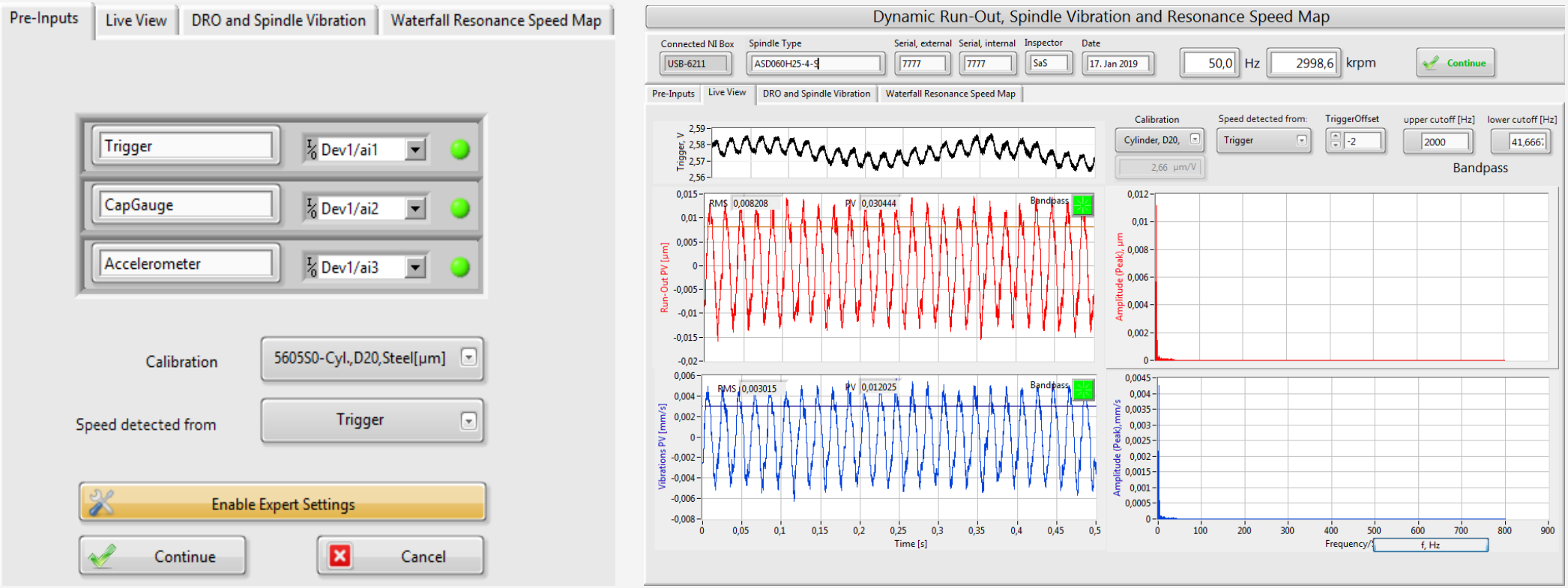


Fig. 3: Software module for dynamic run-out, resonance speed map and spindle vibrations – Raw signals, calibration and sensor choice

The „DRO and Spindle Vibration“ section shows – similar to a FFT peak hold – the largest tool run-out at all spindle speeds detected. Also here the operator can chose between RMS, peak and PV values.

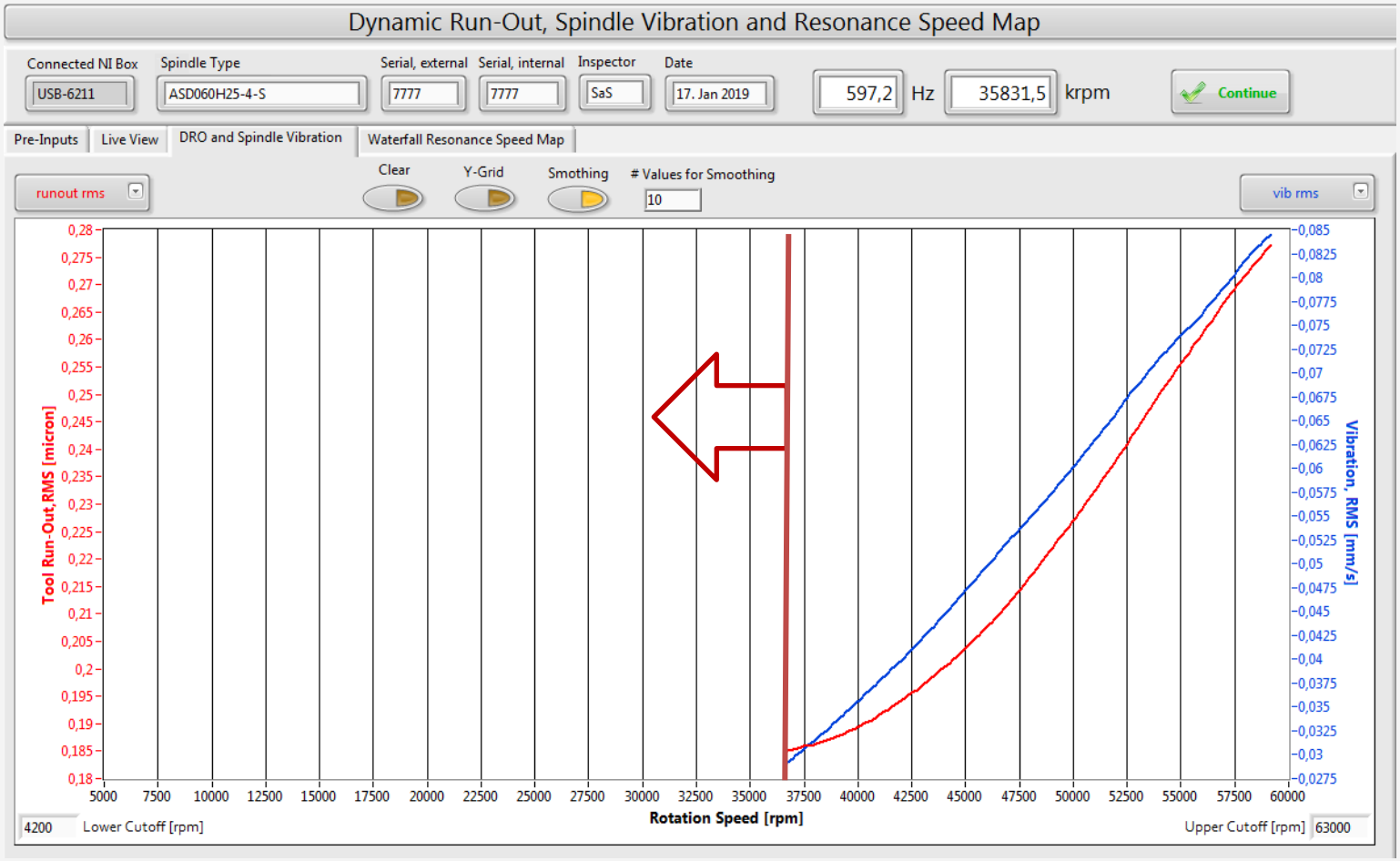


Fig. 4: Dynamic run-out measurement over entire speed range while ramping spindle down from top speed to zero

For a tool run-out measurement over the entire speed range the spindle the speed can be continuously decreased from top speed to standstill or the other way around. After the measurement is done a report is generated automatically and saved in a specific folder for this spindle, including the current date and specific information about the spindle and the customer.

In parallel and in the same way the system natural frequencies are evaluated and displayed in a 2.5D waterfall diagram. As illustrated in Fig. 5 this chart corresponds to a serial sequence of single FFT charts at discrete spindle speeds and where dark areas represent higher values (peaks).

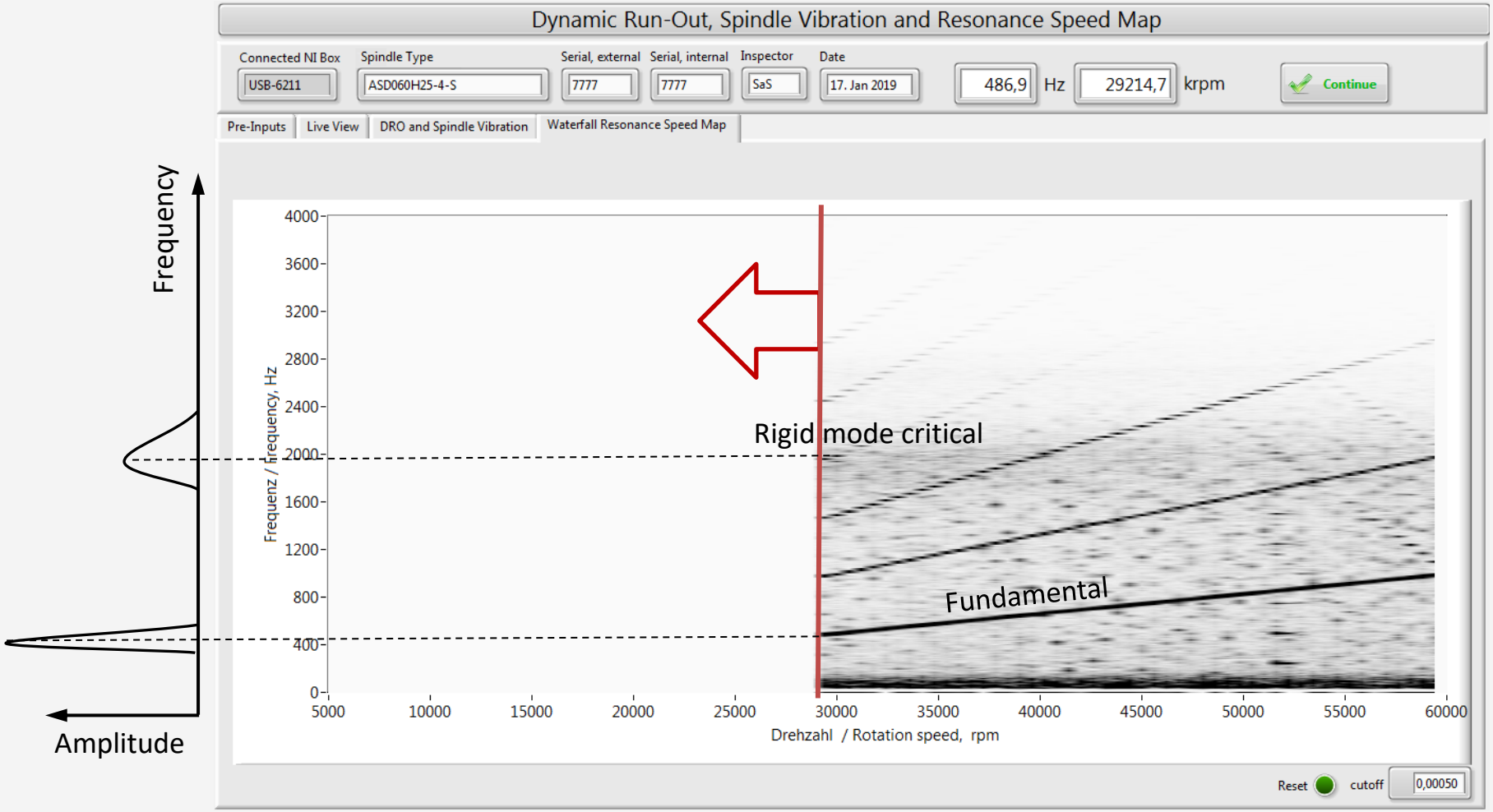
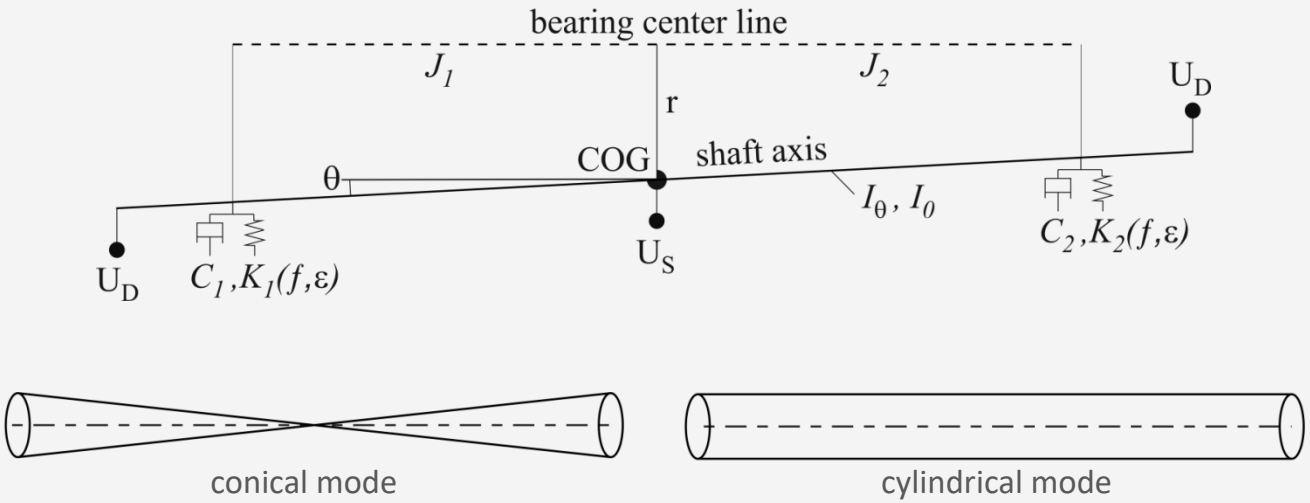


Fig. 5: Spindle resonance speed map generation while ramping down

Should the chart show that the fundamental crosses one of the system natural frequencies, such as a rigid mode critical for example, this would mean a resonance case where the spinning frequency is equal to a system natural frequency. The result would be significantly higher run-out and vibration values. The resonance speed map let the operator know what spindle speeds are to be avoided to avoid resonances. Should the distance sensor be used to detect the vibration of the tool against the spindle housing only the spindle natural frequencies are measured. Using the accelerometer on the spindle housing on the other hand allows to detect the system frequencies, including the machine the spindle is installed on, chillers, pumps or other connected devices.

If the shaft mass and moments of inertia are known the measured height of the rigid mode criticals can be used to calculate the bearing stiffnesses at speed where K_i is the actual bearing stiffness, M is the shaft mass, J_i are the distances from the COG to the bearing midpoints and I_0 und I_Θ are the shaft transversal and polar moment of inertia.



$$\omega_\theta(f,\varepsilon)^2 = \frac{K_1(f,\varepsilon)\cdot {J_1}^2 + K_2(f,\varepsilon)\cdot {J_2}^2}{(I_\theta - I_0)} \qquad \omega_r(f,\varepsilon)^2 = \frac{K_1(f,\varepsilon) + K_2(f,\varepsilon)}{M}$$

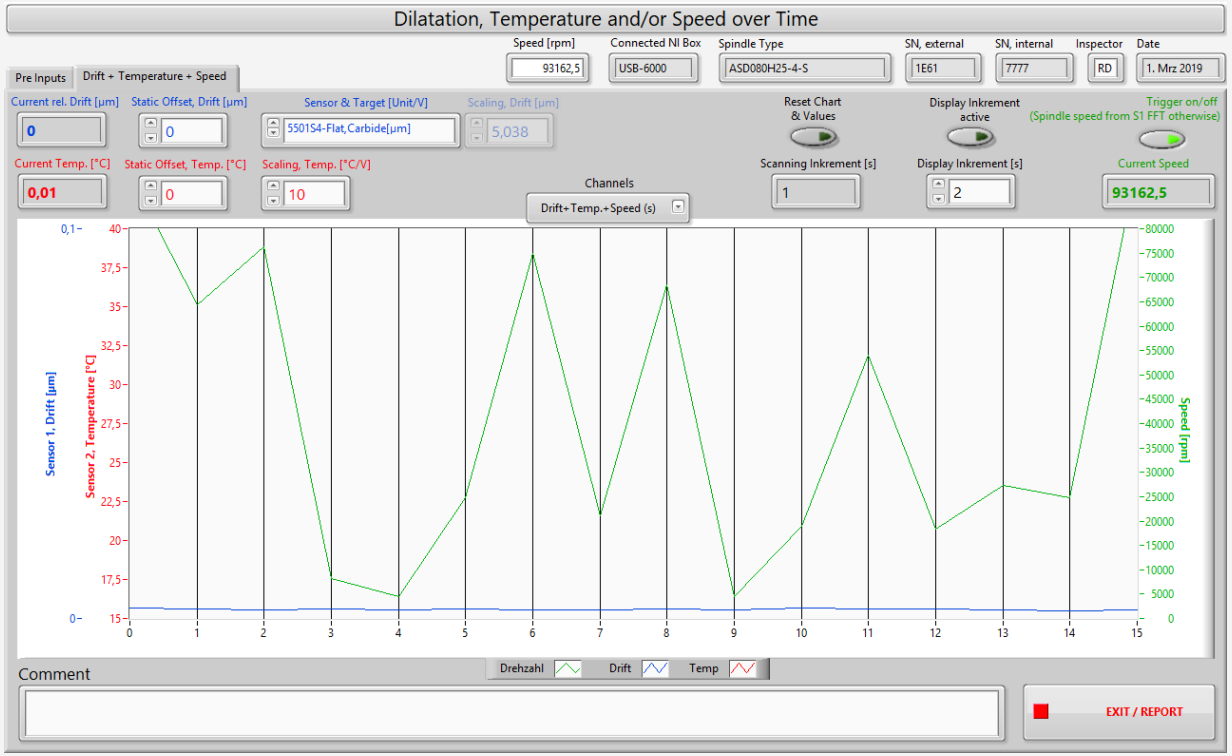
Fig. 6: Calculation of speed-dependent bearing stiffness using measured rigid modes criticals

Levicron Spindles are designed in such way that there are no resonances over the entire speed range. Means, all Levicron spindles runs subcritical at any speed, where the criticals include shaft bending as well as rigid mode criticals.

Axial Shaft Dilatation & Temperature

// Shaft axial growth and bearing temperature with speed and time

Using the capacitive distance sensor of the dynamic run-out measurement in axial direction against a tool allows the measurement of the axial shaft growth with speed and time. Connecting a temperature sensor through a suitable amplifier also allows to record a temperature at the same time, where the calibration for the distance sensor and the temperature sensor can be either chosen from a list or be entered manually. After a measurement a report is generated and saved automatically into the spindle folder. To detect the spindle speed an external trigger can be used, or, if such one isn't available, it can be internally calculated from the sensor signal and an FFT analysis and fundamental search. Only with spindles that show very low vibration values the FFT analysis isn't reliable enough to detect the spindle speed over the entire speed range.



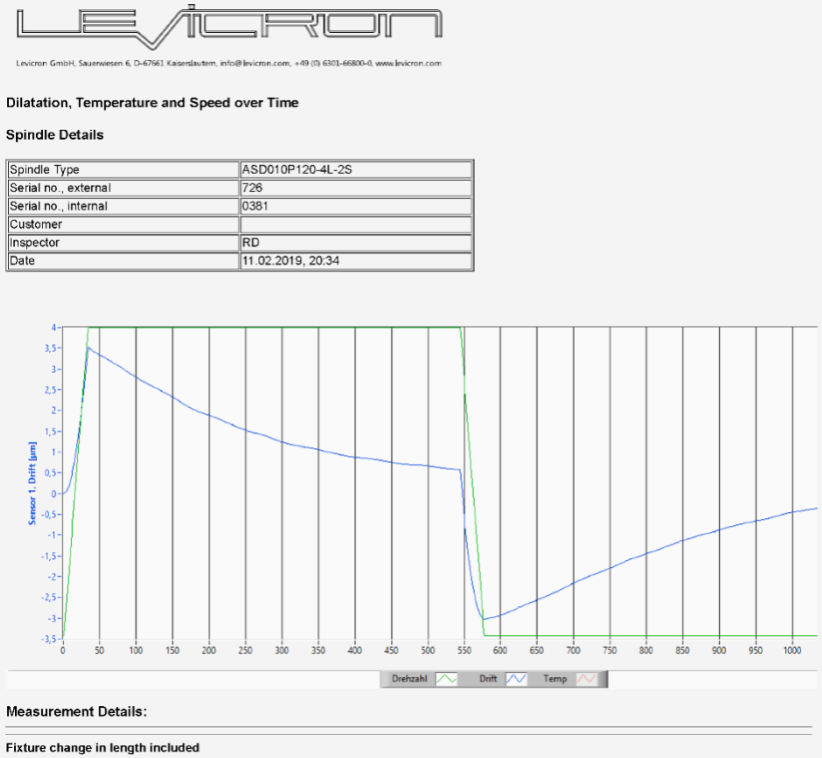


Fig. 7: Axial shaft growth software module and report

Digital Dial-Gauge and Sensor Stand-Off

// Sensor set up tool and digital drag pointer dial gauge

For setting up the distance sensor and to check and/or adjust the static tool run-out before a dynamic measurement this software module can be used.

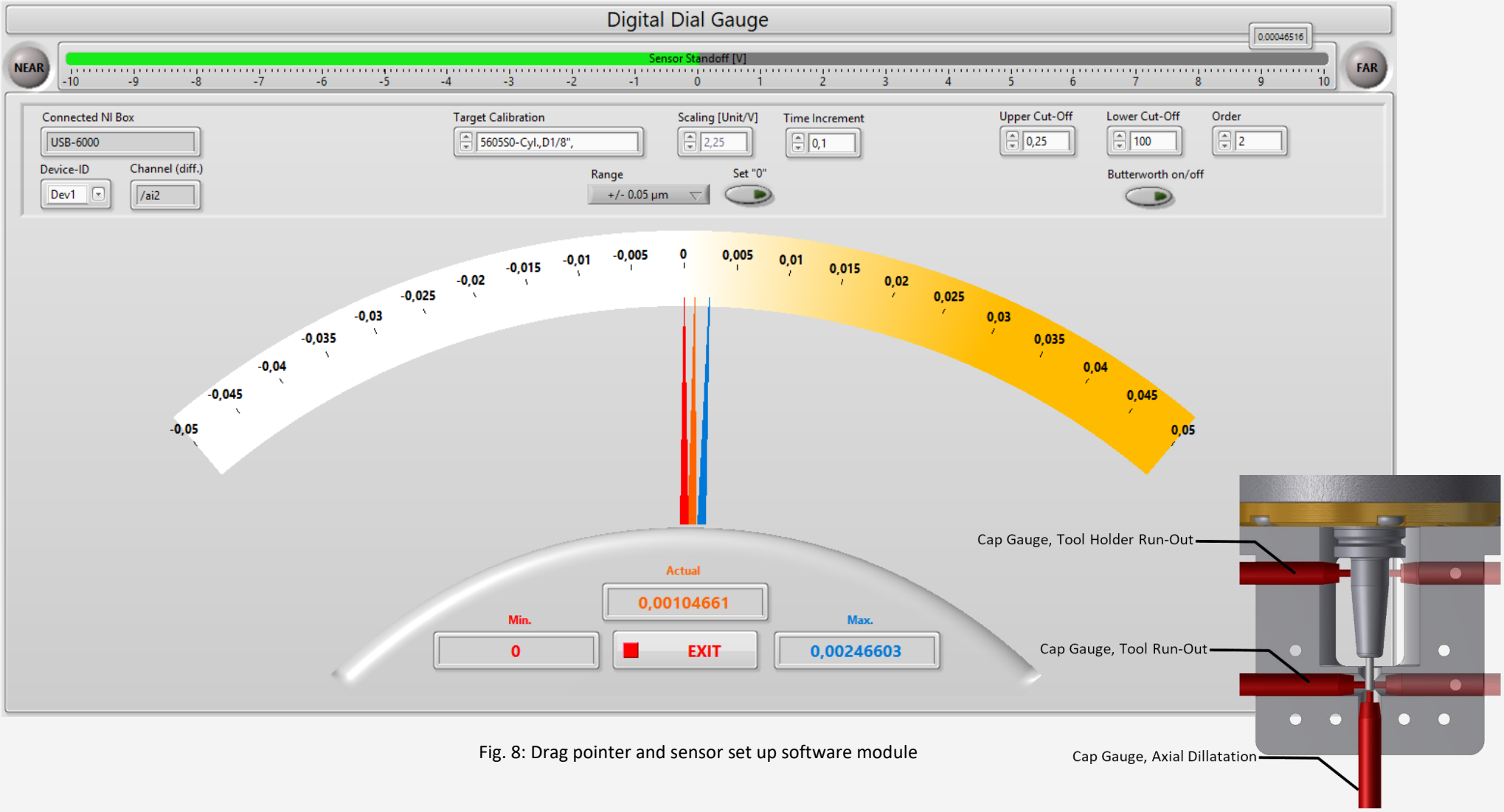


Fig. 8: Drag pointer and sensor set up software module

Upcoming trade shows | EMO and OPTIFAB

EMO, Hannover, September 16-21

Smart technologies driving tomorrow's production!

EMO Hannover presents an unparalleled width and depth of products and services throughout all production areas, from machine tools and production systems for cutting and forming which form the heart of machining, precision tools, accessories and controller technology, to system elements and components for automated manufacturing. For more information please visit https://www.emo-hannover.de/

OPTIFAB, Rochester (NY), USA, October 14-17

The premier optical manufacturing conference and exhibition

SPIE OPTIFAB, organized jointly by SPIE and APOMA, is the largest optical manufacturing conference and exhibition held in North America. This is the premier event to meet with top companies and to learn about the latest optical fabrication technologies. Levicron is grateful that Precitech, an international leading force in ultra-precision machining solutions and distributor for Levicron products, will be hosting Levicron in their booth. For more information visit http://spie.org/conferences-and-exhibitions/optifab