Optical High Speed Twist Characterisation

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Abstract: Typically, an average car has over 80 dynamically stressed seals. Since many years, the radial seal in combination with the shaft is a critical component for the automotive industry. A helix-like structure due to the manufacturing process (as a fingerprint of said process) can lead to an unacceptable oil consumption. In collaboration with DaimlerChrysler, an objective method for characterising such function-relevant helix-structures better known as twist was developed. The twist parameters, which are relevant to lead tightness, are derived from the position of the most significant peak in the frequency domain and a reconstructed deterministic surface. The basic measurement setup consists of a stylus instrument in combination with a rotation unit. It is shown, that, for in-process measurement reasons, the measuring time can be significantly speed up by an optical chromatic confocal sensor in combination with a high speed drive unit.

1. INTRODUCTION

Systems with dynamic sealing function are wide-spread in vehicular and mechanical engineering. Lubricants must be present in sufficient quantity, for example on tribologically relevant positions of moving parts, but may not leave the system. A multiplicity of assemblies with different functionality-requirements and different media to be sealed, which can be manufactured by a multiplicity of subcontractors, are affected by this.

Twist-metrology was developed by DaimlerChrysler [Rau 1997], in order to enable a uniform, impartial, function-oriented and reliable evaluation of the sealing function under these constraints. The goal of this development was the impartial evaluation of the features relevant to leak-tightness of a surface-structure by characteristics and hence the possibility of tolerance-requirements and -testing. Thus it is possible to pose specific requirements to the surface depending on the application-parameters, such as engine speed, left- or right-handed motion, degree of pollution, working temperature and the medium to be sealed in. Hence it is possible to exchange the non-verifiable requirement “twist-free” with twist-characteristics including boundary values. In contrast to all twisttesting-methods applied hitherto, which try to re-create the conveying action for the fluid to be sealed in by auxiliary means, twist-metrology utilises the metrologically recorded surface as basis for the assessment.

2. TWIST MEASUREMENT

“Twist“ describes all surface occurrences, which contribute to a conveying action of the fluid to be sealed in. Accordant to their dimension and the metrological survey they are distinguished as macro- and micro-twist. The existence of twist, as well as the size and trait of the twist occurrence are determined by the dressing-procedures and the machine-parameters selected.

Macro-twist arises both in turning and grinding. Inevitably due to feed motion, turning results in a usually singly thread-like surface-structure, where the rotary feed determines the twist-gradient (Figure 1). The characteristic of the macro-twist-structure during turning can be strongly influenced by perturbations, such as superimposed oscillations. During grinding with dressing-infeed-motion the dressing-infeed creates a helix on the work-surface of the grinding disc. The macro-twist arises, as this dressing-helix is transferred to the work-piece-surface during grinding subject to the ratio of rotational velocities. The entire work-piece-circumference is surveyed, in order to determine the macro-twist.

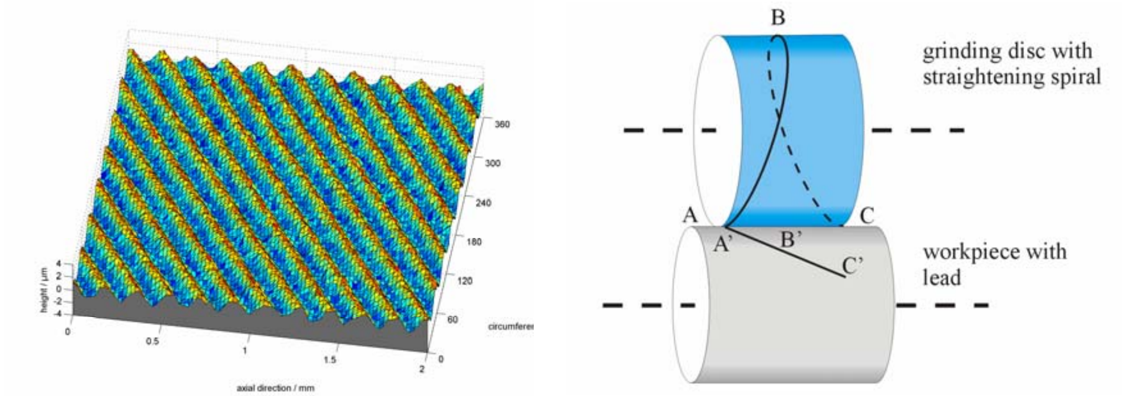

Figure 1 (left) ground surface with macro twist,
(right) projection of the dressing spiral onto the work piece.

“Micro-twist“ describes all structures, which are tilted with respect to the work-piece-axis. These arise from angular deviation of the grinding-disc- and work-piece-axis during grinding. In order to determine the micro-lead, a high-resolution-surface-area is related to the work-piece-axis and evaluated.

This paper presents a high speed measurement setup for evaluating macro-twist.

2.1 The measurement strategy

Macro-twist is a periodically structure in axial direction and circumferential direction. Due to the grinding process a high resolution measurement in axial direction is needed to characterise the roughness structure. In circumferential direction the resolution can be significantly coarser. Hence, twist is measured by parallel roughness traces in axial direction. Two types of measuring systems are common: a standard roughness measuring system in combination with a horizontal placed rotation unit or a standard form-tester with a surface texture probe. Two different grids has to be distinguished: the first one is defined at the circumference with a grid of 5° and the second one is a finer grid with 0,5° over a range of 36°. The evaluation length of each roughness trace is 2mm. That means a total of 136 profile traces are needed for the whole data set.

2.2 Eliminating the radial run out

In the best case the twist data set looks like that one shown in Figure 1. But often a fundamental problem occur because it’s nearly impossible to fix the work piece exactly to the rotation unit. This causes a radial run out and a superimposed sine wave in the data set which leads to a distortion of the twist parameters (Figure 2).

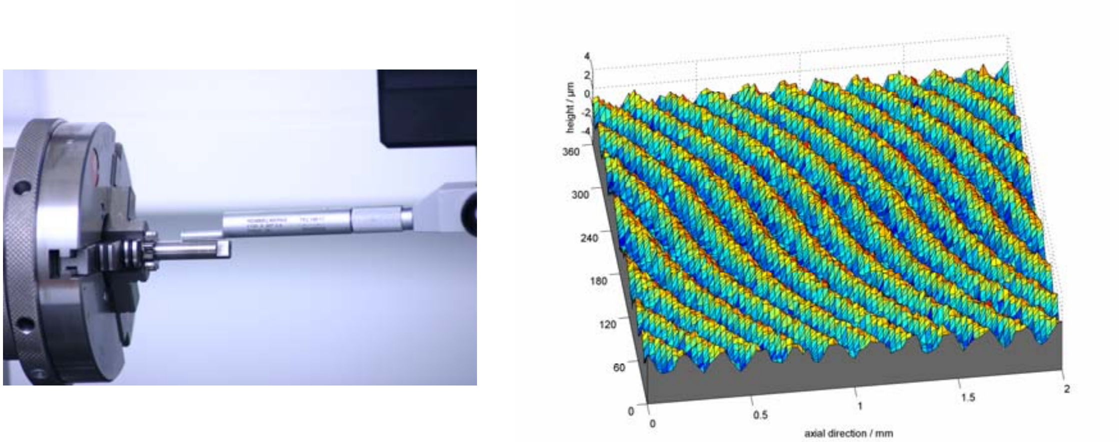

Figure 2 (left) work piece fixed in a rotation unit, (right) distorted twist structure by a radial run out.

To eliminate this superimposed structure a high sophisticated algorithm is needed. A necessary constraint for this algorithm is the known radius of the work piece because the profile traces are recorded relative to a reference plane. The distorted data set itself is influenced by five projection matrices:

$$M = F_d \cdot F_\beta \cdot F_{\alpha_k} \cdot F_\varphi \cdot F_{y_0,z_0} \,. \tag{1}$$

F_{y_0,z_0} corresponds to the axial shift of the rotation axis, F_φ corresponds to an axial inclination of the measured work piece, F_{α_k} corresponds to the gradual rotation of the sample during the measurement process, F_β corresponds to an additional inclination of the drive unit relative to the rotational axis and F_d Corresponds the transition to the coordinate system of the drive unit. Let’s assume the influence of angle β is weak. In this case a closed formula can be given for each profile trace:

$$\left(\sin(\alpha_k)\cdot(\mathrm{z}\text{-}\mathrm{d})\text{-}\mathrm{y}_0\right)^2+\left(\text{-}\sin(\varphi)\cdot\mathrm{x}+\cos(\alpha_k)\cos(\varphi)\cdot(\mathrm{z}\text{-}\mathrm{d})\text{-}\mathrm{z}_0\right)^2=\mathrm{R}^2 \qquad (2)$$

with $\alpha_k = k\cdot\Delta\alpha+\alpha_0$. The next task is to find the unknown parameters by analysing equation (2). The angle β can be calculated by fitting a least square straight line into each trace and building subsequently the mean of the line slopes. To determine the parameters φ, α_0, y_0, z_0 we need to calculate 72 supplementary profiles by subtracting oppositely lying traces. Now fit a least square straight line $y_k(x) = a_k\,x + b_k$ into each new trace and calculate the first coefficient say A_1 and B_1 from the Fourier series of a_k respectively b_k. For the unknown parameters φ, α_0, y_0, z_0 we yield the following expressions:

$$\varphi=\arccos\left(\frac{16\text{-}\|A_1\|^2}{16+\|A_1\|^2}\right),\quad \alpha_0=\arg(A_1),\quad z_0-i\cdot y_0=e^{-i\alpha_0}\,\frac{B_1\cdot\pi\cdot\sin^2(\varphi)}{4\cdot(1\text{-}\cos(\varphi))}. \qquad (3)$$

With the found parameters we are able to calculate the corrected data set by using equation (1).

2.3 Twist parameters

To detect the periodical twist structures a two dimensional Fourier series is applied. The location of the peak gives us the information about the wavelength in axial direction as well as the counts of circumferential threads. The detection algorithm starts with calculation the Fourier series of the coarse data set. In circumferential direction we always have an integer number of threads. Therefore the coefficient with the highest amplitude in this direction correlates to the wanted thread number. In axial direction we get a problem because Mother Nature doesn’t ensure that the number of waves per evaluation length is an integer number anymore. To avoid this problem the evaluation length is adapted to the wavelength in axial direction. By zero padding the data set, the coefficient with the highest amplitude gives us a rough idea of the underlying wavelength. To get the true peak we successively reduce the data set until the amplitude of the coefficient with an integer number of waves per evaluation length is a maximum. To avoid aliasing in circumferentially direction the algorithm switches to the finer data set if the number of threads is greater than ten.

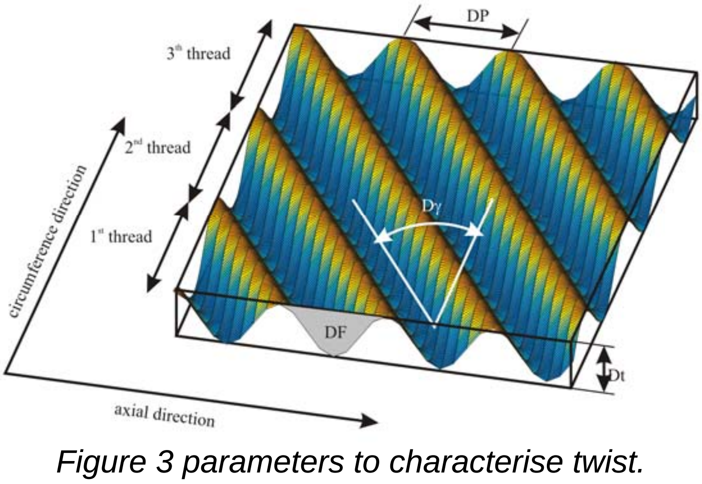

Figure 3 parameters to characterise twist.

The reconstruction of the function relevant twist structure is defined by using the Fourier series of the found coefficient and it's first respectively second order harmonic. All twist parameters are derived from the position of the found coefficient and the reconstructed surface. Figure 3 shows all relevant parameters to characterise the function relevant properties.

The twist parameters are defined as follows: Dt in µm is the totally depth of the reconstructed structure. $D\gamma$ is the twist angle between the structure orientation and the circumferential of the shaft. DP in mm is simply the periodically wave length in axial direction. DG gives the number of threads in circumferential direction. DF in μm^2 is the theoretical supply cross section e. g. to describe the oil volume between the sealing ring and the shaft.

3. OPTICAL HIGH SPEED TWIST MEASUREMENT

As described in 2.1, a total of 136 profile traces is required for the macro-twist analysis. In combination with a tactile measurement system with a speed of 0.5 mm/s this leads to a required measurement time of more than 15 minutes. The measurement time can however be significantly reduced, if the tactile measurement system is replaced by an optical point-sensor in combination with a high speed drive unit with a speed of 5 mm/s. The measurement system composed of rotation-unit, drive unit and optical point-sensor is illustrated in figure 4. The point-sensor works according to the principle of chromatic aberrations, i.e. the objective has different foci depending on the wavelength of the light. Each of these foci is mapped to a specific z-coordinate by calibration. During the measurement, the wavelength of the light reflected back from the work piece is detected via spectral analysis and the corresponding z-coordinate of the object-surface is then determined. A specific feature of the sensor is the fact, that it contains no mechanically movable components and can be driven at an appropriately high sampling rate. With the optical sensor it was possible to reduce the measurement time to approximately 4 minutes.

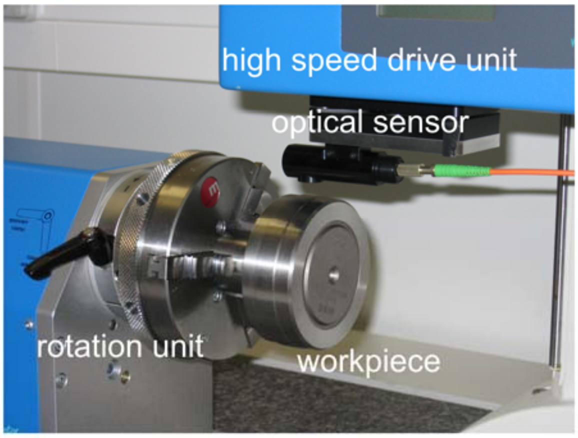

Figure 4 twist measurement with hommel-etamic high speed drive unit in combination with an optical chromatic sensor from digital surf.

3.1 Results

In order to compare tactile to optical macro-twist-measurement, a 10-thread (work piece dn10) as well as a 30-thread (work piece dn30) macro-twist-normal were measured. Exemplarily, the topography-data of the 10-thread normal is displayed as greyscale values in figure 5. Visually, a good conformance can be ascertained. The evaluation was performed according to the method described in chapter 2.

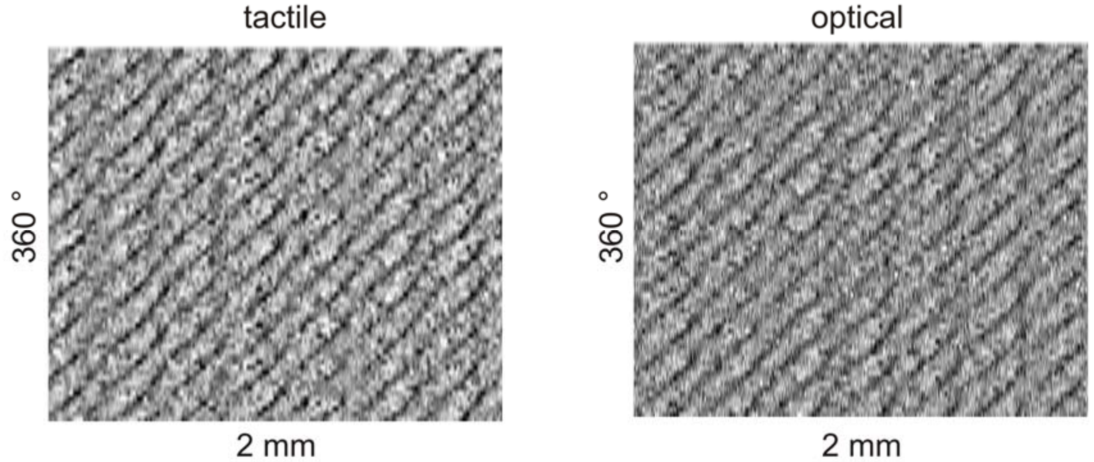

Figure 5 gray coded twist data sets measured by a standard tactile measuring instrument (left) and an optical chromatic sensor in combination with an high speed drive unit (right).

As can be gathered from table 1, the number of threads DG and the period-length DP are identical. Minor discrepancies occur with the macro-twist-depth Dt and with the conveyed cross-section DF.

work piece dn10	DG	Dt / µm	DP / mm	DF / µm^2
tactile	10	1,57	0,15	80,93
optical	10	1,44	0,15	73,85

work piece dn30	DG	Dt / µm	DP / mm	DF / µm^2
Tactile	30	1.26	0,2	90,10
Optical	30	1,21	0,2	83,59

Table 1 measuring results using the standard tactile system and the high speed measurement setup.

A cause for these discrepancies are stochastic deviations due to different measurement positions. A further cause could however also be the heightened background noise of the high speed drive unit or the sensor. For a detailed analysis of the discrepancies, especially those due to background noise, an investigation on optically cooperative cylinder-normal will be carried out in a further step. Decisive is, that the evaluation of the measurement data occurs integrally, so that statistical discrepancies will average out and hence have only a small impact on the measurement result.

4. CONCLUSION

In this paper a measurement system for fast macro-twist-measurement was introduced. It is composed of a speed drive unit and a chromatic point-sensor. The basis for the macro-twist-evaluation is formed by 136 profile traces on the circumference of the work piece. The measurement time could be reduced from 15 minutes (tactile measurement system) to mere 4 minutes with the optical measurement system. Measurements on two macro-twist-normals yield a good conformance between the tactile and optical measurements. A further reduction in measurement time can be achieved by further synchronisation between the axial high speed drive and the rotation unit. Further analyses will deal with the background noise of the drive unit and the sensor.

It should be mentioned, that the tactile system is still the reference for twist measurement.

5. REFERENCES

[Rau 1997] N. Rau, M. Seibold, Drallstrukturen geschliffener Dichtflächen beurteilen, Werkstatt und Betrieb 11 (1997) 1013-1016