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Manufacturing of Twist-Free Surfaces by Hard Turning

Andreas Schubert[a, b], Ran Zhang*[, a], Philipp Steinert[a]

a Technische Universität Chemnitz, Faculty of Mechanical Engineering, Professorship Micromanufacturing Technology, 09126 Chemnitz, Germany
b Fraunhofer Institute for Machine Tools and Forming Technology, 09126 Chemnitz, Germany
**Corresponding author. Tel.: +49-371-5397-1948; fax: +49-371-531-23549; E-mail address: ran.zhang@mb.tu-chemnitz.de*

Abstract

Currently grinding is commonly used as the finishing operation to manufacture seal mating surfaces and bearing surfaces, especially in the automotive industry. It would lead to more resource-efficient production if the cost- and energy-intensive grinding process could be replaced by machining with geometrically defined cutting edges, such as hard turning [1, 2]. However, turning operations usually cause a twist structure on the surface, which can convey lubricants like a pump. Several methods exist to overcome this problem, for example, tangential turning, rotation turning and turn broaching, etc. Due to the high costs of tools and special machines required by these methods, the industrial application is still limited. This paper describes a more efficient approach by applying a modified feed kinematic. When using this approach, hard turning produces twist-free surfaces. The results of the latest twist test methods have confirmed that the surfaces are free of twist, hence free of conveying effect of lubricant and that they are suitable for application in manufacturing of seal mating surfaces and bearing surfaces. Furthermore, this method requires only minimal investment in any turning machine.

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1. Introduction

The conventional process chain for the production of rotationally symmetric components with a high level of hardness, such as crankshafts and camshafts, is characterized by several manufacturing processes and long non-productive time, such as for transport, storage, etc.

The extension of the scope of turning steels with high hardness allows the increase in productivity due to complete finishing in one single stage. Compared to grinding, hard turning does not only save cost and time but it is also environmentally friendly (omission of treatment and less disposal of slurry) [2, 3].

However, many grinding applications cannot easily be replaced by hard turning. This is the case for manufacturing seal mating surfaces and bearing surfaces. The reason for this phenomenon is that the feed motion of the tool will cause twist structures, which will then lead to the conveying effect of lubricant between contact surfaces and sealing or plain bearing [4, 5, 6], which will be further described in this paper.

2. State of the art

Twist structures are characterized by microscopic structures which are comparable with a thread structure on a shaft surface. Figure 1 shows the surface of a turned shaft schematically. The parameters are described in the Mercedes-Benz standard MBN 31007-7 [7] in 2009.

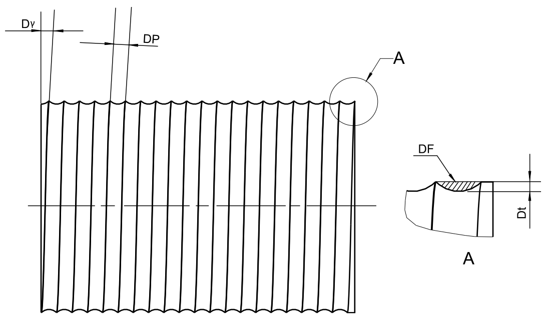

Fig. 1. Twist characteristics of a turned shaft

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The parameters shown in Fig. 1 describe the properties of twist structures, which are dependent on process parameters (feed, nose radius etc.) and theoretically can be calculated for turning as follows:

Twist angle Dγ [°] is the angle between the circumferential direction and a periodic spin structure; in case of turning it can be calculated as follows:

$$D\gamma = \arctan(\frac{f}{D \cdot \pi}) \quad (1)$$

Twist depth Dt [µm] is the vertical distance between wave peaks and troughs of a structural profile, and while turning it is equal to:

$$Dt = Rz = r_\varepsilon - \sqrt{{r_\varepsilon}^2 - \frac{f^2}{4}} \quad (2)$$

Lead number DG is the number of pitch distances advanced in a single rotation (360°) of the shaft; during turning DG is equal to:

$$DG = 1$$

Conveying cross section DF [µm²] is the cross-sectional area of a twist structure in an axial section, during turning DF can be calculated as follows:

$$DF = \pi \cdot {r_\varepsilon}^2 \cdot \frac{2 \cdot D\gamma}{360°} - \sin D\gamma \cdot r_\varepsilon \cdot \cos D\gamma \cdot r_\varepsilon$$

$$DF = {r_\varepsilon}^2 \left[\frac{2 \cdot \pi \cdot D\gamma}{360°} - \frac{\sin(2 \cdot D\gamma)}{2} \right] \quad (3)$$

Conveying cross section / turn DFu [µm²] is the cross-sectional area of a period length in an axial section of the twist surface multiplied by the lead number DG:

$$DFu = DF \cdot DG = DF \quad (4)$$

Period length DP [mm] is the length between two successive periods in the axial direction. During turning the characteristic is equal to the feed:

$$DP = f \quad (5)$$

Percentage of support length DLu (in %) is the size of the theoretical confinement of the surface in circumferential direction by the sealing lip support in relation to the total circumference.

During the rotation of a turned shaft, the liquid entrains in the circumferential direction and is deflected axially because of the twist structures [8]. Therefore the liquid (e. g. lubricant) will be conveyed depending on the rotational direction of the shaft, see Figure 2. This will cause many problems, for example, leakage in the sealing system, a local deficiency and irregular distribution of the lubricant in the plain bearing system.

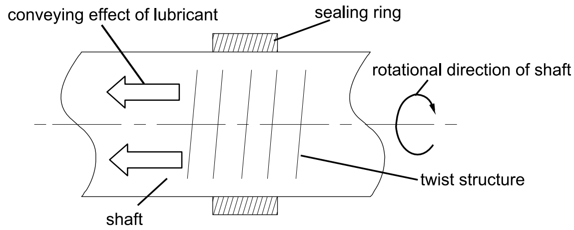

Fig. 2. Conveying effect caused by a twist structure on a seal mating surface

Shaft surfaces such as seal mating surfaces and bearing surfaces are currently manufactured by grinding [9]. This method is widely used, but it is expensive and not 100 % successful. A very long spark-out time is required for the grinding process in order to ensure a twist-free surface [3]. However, due to cost pressure, this spark-out time could not be considered in practical applications. In addition to that, grinding is a machining process with geometrically undefined cutting edges, which inhibits the reproducibility of the process. The undefined surface texture may cause excessive pumping effects in response to the rotation of the shaft, which is much more critical than the roughness of the surface. [10] Therefore industry is currently looking for alternative manufacturing processes, for example hard turning, milling, burnishing or laser polishing. This applies especially for the industries of automotive and automotive suppliers.

Hard-turning has been used increasingly in recent years to produce twist-free shafts. [10] The latest research shows that hard turning is a very suitable alternative to grinding. Thus a number of patents have been developed with different methods:

- 1993 Vibration-processing method [11],
- 2001 Tangential turning [12],
- 2005 Rotational turning [13],
- 2007 Twist-free turning with suitable feed motion [14].

The methods of vibration-processing, tangential and rotational turning have the disadvantage of requiring a special machine structure and thus demanding significant investment. Furthermore, the special tools are expensive because of the required high quality at the cutting edge. Moreover, only a limited length can be processed on the shaft surface with tangential or rotational turning. The method of suitable feed motion has the disadvantages of the processing time being significantly prolonged and the machine requiring a very stable repeatability for the positioning of the tool.