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Technical Paper

Twisted deep hole drilling tools for hard machining

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ABSTRACT

The availability of high performance twisted deep hole drilling tools has been a significant innovation achieved some years ago. The use of these tools in machining centres permits substantially higher productivity and flexibility compared to existing deep hole drilling tools or alternative manufacturing processes for holes with a high aspect ratio. The aim of the present work is the systematic consideration of twisted deep hole drilling tools for reliable and economical hard cutting operations with a high level of quality assurance. In particular, a detailed analysis of manufacturing flaws and tolerances in tool making as well as their influences on the toolís performance and the dynamic process behaviour has been conducted. It is shown that twisted deep hole drilling tools can be successfully applied not only with a high productivity but also for a high quality production of hardened components. A prerequisite to this, however, are holistic and precisely controlled process steps including appropriate clamping devices and a suitable high pressure lubrication strategy as well as the availability of high performance tools manufactured with high precision and low tolerances. In this context the symmetry of the tool shown to be of vital importance for the toolís performance and the quality of the drilled holes.

1. Introduction

The current trend in manufacturing technology towards more flexibility and individualisation of production technologies means challenging manufacturing steps with a large share of cutting time are becoming increasingly significant. A crucial aspect is the increasing shift of batch production from rigidly linked transfer lines and revolving machines towards highly flexible machining centres. This means, concerning drilling operations in the automotive as well as in the machinery and plant engineering sector, that it was previously possible to reduce cycle times by proportioning the cutting operations to the amount of available drilling spindles. Modern manufacturing solutions, based on flexible machining centres, do not usually provide this option. This results in todayís demand for cutting tools and processes with high productivity and reliability.

At the same time, efforts are being made to shorten entire process chains by direct hard machining of components. The aim is to reduce production time but also to substitute conventional, time and resource intensive inflexible grinding and electrical discharge machining processes. This challenge can only be solved by the development of manufacturing solutions, including high performance and wear-resistant cutting tools. These tools must be implemented in precisely controlled process steps in accordance with the particular application. Therefore Uhlmann et al. [1] stated that appropriate process parameters and production devices need to be implemented in order to achieve maximum process stability in deep hole machining.

Abele et al. [2] and Kuttkat [3] has shown that the use of twisted drills in machining centres permits significantly higher productivity and flexibility compared to existing deep hole manufacturing processes, such as single-lip or BTA (Boring and Trepanning Association) deep hole drilling. There is a need for research and development to improve the process reliability and the resulting drilling quality as well as the extension of the application of this process towards high performance materials. However, currently, there is a lack of scientifically based knowledge regarding the behaviour of twisted deep hole drilling tools in hard machining operations.

The current focus of research activities is based on the analysis of the complex dynamic behaviour in deep hole drilling processes based on numerical simulation and comprehensive model descriptions including the component quality and wear prediction models. However, most academic studies consider ideal tool geometries while neglecting manufacturing flaws and tolerances in the production of these complex tools. In this context Arvajeh and Ismail [4] developed dynamic models for chatter in drilling and Roukema and Altintas [5] presented a comprehensive time domain model of the torsional-axial chatter vibrations in drilling. In subsequent research work Roukema and Altintas [6,7] presented a three-dimensional

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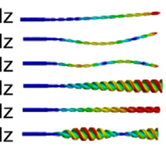
dynamic model of drilling which considers rigid body motion, torsional-axial and lateral vibrations in drilling as well as resulting hole formation and chatter stability of drilling.

The aim of the present work is the holistic consideration of twist deep hole drilling tools for reliable and economical hard cutting operations with a high level of quality assurance.

2. Setup

Prior to targeted investigations of interdependencies of the process behaviour in hard drilling operations, precisely steered process steps with high reliability had to be developed, since conventional process parameters and production devices in many cases lead to total tool failure with uncontrolled tool breakage due to the high hardness of the work piece material [8]. As a test material quenched and tempered steel type AISI 4140 with a hardness of $53^{\pm 2}$ HRC was used. In an iterative adaptation of the kinematic process parameters, the high pressure lubrication strategy and different clamping devices as well as various machining centres, a deep hole drilling strategy was determined, giving clear guidance for a more reliable process. Even small variations in the setup in many cases led to total tool failure with uncontrolled tool breakage. An increased feed from f = 0.08 mm to f = 0.12 mm or an increase of the cutting speed led to a mechanical overload of the chisel or the main cutting edge, resulting in a critical load situation and total failure. A decrease of the feed to f = 0.06 mm not only reduces the productivity but also increased chatter due to reduced friction and due to an increase of the chip thickness. Similarly narrow process boundaries could be observed with concern to the lubrication strategy. Drilling tests with a cooling pressure below p_{KSS} = 80 bar reduced the tool lifetime significantly. At cooling pressures p_{KSS} < 60 bar it was not possible to drill the hard material, due to an insufficient cooling of the tip and an inadequate evacuation of chips. During all hard drilling tests favourable short chips could be observed compared to deep hole drilling of untampered steels or light alloys. The resulting parameters and specification for a reliable deep hole drilling process are shown in Table 1.

Table 1
Parameters used for deep hole drilling hardened steel.

Tool				
Twisted deep hole drilling tool with coiled inner cooling channels				
S-shaped main cutting edge with protective chamfer				
Tool material: Ultrafine grained tungsten carbide with 10 % cobalt binder				
Coating: Nanocomposite, (TiAlSi) N - (TiAlX) N				
Aspect ratio:	l/d	=	30	
Diameter:	d_1	=	5 mm	
Point angle:	σ_S	=	143.5°	
Flank angle:	α	=	14.5°	
Angle of twist:	δ	=	30°	
Eff. rake angle:	γ_{eff}	=	-48.5°	
Eigenfrequencies (calculated by FEM)				
1th bending mode	f_{b1}	=	90 Hz	
2nd bending mode	f_{b2}	=	608 Hz	
3rd bending mode	f_{b3}	=	1729 Hz	
1th torsion mode	f_{t1}	=	3584 Hz	
2nd torsion mode	f_{t2}	=	8089 Hz	
3rd torsion mode	f_{t3}	=	19567 Hz	
Machine tool				
Milling centre: Hermle C50 U				
Tool clamping: Short shrink fit chuck				
Cooling lubrication with 5 % emulsion				
Cooling pressure:	p_{KSS}	=	80 bar	
Process parameter				
Cutting speed:	v_c	=	50 m/min	
Feed:	f	=	0.08 mm	

3. Manufacturing flaws and tolerances in tool making

To clarify the relationship of commonly occurring manufacturing tolerances at the twisted drill and the operational behaviour as well as the resulting performance of the tool, a wide range of measurements were taken. Starting with the definition of measurement technologies and strategies suitable for the high-precision and accurate repeatable description of complex twist drills for deep hole operations a CNC tool measuring machine Helicheck plus from Walter Maschinenbau GmbH, Tübingen, Germany was used for comparative analysis of more than 80 geometrical characteristics of the tools. The tool coating and the tool's microgeometry was analysed in line with the work of Uhlmann et al. [9]. Furthermore some of the tools were prepared by eroding into x = 10 mm long pieces to precisely analyse the geometric dependencies of the inner cooling channels in the toolís cross section.

These geometrical characteristics and values are correlated subsequently to each step of the entire process chain of tool making to indicate possible recommendations for improvements. It could be shown that within single tool specifications varying deviations and tolerances occur, which can clearly related to manufacturing flaws and tolerances in tool making.

It could also be shown that the carbide substrate is very homogenous without any noticeable production related defects like large pores or coarse grain. The relative position of the cooling channels to each other and in relation to the tool centre is very closely toleranced. However, the diameter of the inner cooling channels varies significantly with Δd_{KK} = 20–80 μm between different tools of the same specification indicating possible future improvements in the field of production of carbide blanks by sintering.

Further examination of the tool's macro geometry indicates that all tools are within customary tolerances for high precision drilling tools characterised by an overall ISO-tolerance h8/h9 (<30 μm at tool diameter d = 5 mm). In this context, particular consideration is given to geometrical asymmetries of the tools due to manufacturing tolerances, since these deviations can significantly influence the process dynamics and thereby the tool lifetime and drilling quality. Noticeable deviations of the tool symmetry were identified for the:

- Depth of the flutes,
- Distance between cooling channels and cutting edge corner and
- Distance between the cooling channels and the flute.

These manufacturing flaws can be clearly assigned to the flute grinding operation during tool grinding. This manufacturing step is one of the most challenging operations regarding the precision and costs of high performance cutting tools as described by Chen et al. [10] and Uhlmann and Hübert [11].

Asymmetries in the tool geometry could also be measured for the position, the length l_{HS} and the symmetry Δl_{HS} of the main cutting edges as shown in Fig. 1. In close collaboration with an industrial tool manufacturer the progressive improvement of manufacturing quality of the twisted deep hole drills was undertaken in four steps A–D. Fig. 1a shows the iterative improvement of the deviation of the length of the main cutting edge l_{HS} resulting in the lowest standard deviation for tool speciation D.

Particular consideration was given to the tool's symmetry to enhance the performance of the tools by reducing dynamic instabilities in the drilling process. Fig. 1b shows the resulting increase