Process-Integrity of Deep-Hole Drilling for Small Diameters

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Abstract

Process-integrity in deep-hole drilling with solid-tungsten-carbide-drills of 1 and 2 millimeter diameter requires chip-removal in the bead by the internal cutting-fluid supply. The flow rate of the cutting fluid depends on the internal profile and the length of the drill-shaft. The cross-sectional area of the shaft also determines its stiffness and breaking strength. Tool wear increases the cutting forces and thereby also the stressing of the drill. Optimisation of the progress-integrity can be achieved by careful selection of the cutting-parameters.

Keywords: *Production process, cutting, deep-hole drilling, process-integrity*

Introduction

For producing deep drillings, often the three deep-hole drilling and boring methods [1] single edge drilling, BTA drilling and ejector drilling are used. While BTA- and ejector drilling are only employed on special machines, the single edge drilling method can also be applied to conventional machines, such as machining centers or turning machines [2, 3]. By the help of that method, the investment costs for special purpose machines can be reduced, and high-quality drillings with large length-diameter-proportion are producable on standard machines, e.g. machining centers.

A prerequire thereby is the consideration of the procedure specific and mechanical demands, e.g. a highpressure cooling lubricant equipment, a guiding bush and a sufficiently high speed range so that the necessary cutting speeds can be realized. Because of high surface qualities and shape accuracies, which can be realized by single edge drilling, additional phases of operation are often neglectable. The economic advantages of single edge drilling lead to use the method even at short drillings with a length-diameter-proportion of $L/D < 5$.

By the development of minimal single edge drilling tools in a diameter range between 0,9 and 2 mm, new application areas are supposed to be opened up to single edge drilling, e.g. at the production of injection nozzels and -valves or feeding stuff matrixes. So it is possible to use the typical advantages of the method, such as high drilling quality at a high rate of metal removal also for smallest diameters.

A demand concerning a higher economy of the method is the reduction of the essential operating time. The cutting conditions, which determine the essential operating time, are to chose, that high rates of metal removal can be achieved by the use of the installed engine power. Often the cutting conditions can not only be chosen by economic aspects, for the cutting process becomes instable because of the dynamical behaviour of the tool [4]. Rates of feed, which are too high, or other adjustments of the parameter, which are not optimated, may interfere with the process integrity and the quality of the drilling, and at worst lead to a breakage of the tool. Especially in single edge drilling with minimal diameters, where the tools are comparatively expensive because of their costly production, the mastery of the cutting process to avoid breakages of the drills and losses of production is of high importance.

Problems with Obtaining High Efficiency

Unlike to single edge drilling with larger diameters, the problems of drilling with smallest diameters (1 and 2 mm), especially consist of the supply with coolant lubricants and of the removal of chips. Due to the small cross-sections, and thus small stability against torsion- and bending loads, a banking of chips, caused by a shape of chips, which is disadvantageous to the removal of chips, soon leads to the breakage of the tool. Compared to the single edge drills in the range of diameter over 2 mm, smallest single edge tools need a much higher working pressure of more than 100 bar.

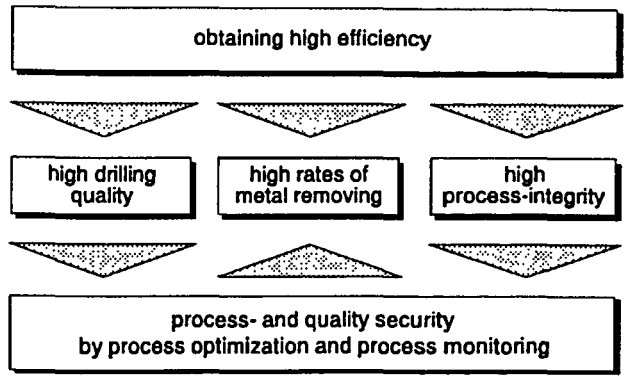


Fig. 1: Obtaining high efficiency

The single edge tool is hollow to allow the supply of cooling lubricant and features a channel formed in the external surface of the drill shaft and running along its length, along which the chips can be removed. Both the cooling lubricant duct, and the bead reduce the tool's cross-section and thus the solidity of the tools. The goal of high drill stiffness opposes a large duct cross-section to guarantee safe supply of cooling lubricant. While the shaft of drills with a diameter bigger than 2 mm usually consists of tenacious 25 CrMo4 V with rolled bead and the sintered carbide head is soldered on, head and shaft of small single edge tools are made of sintered carbide and, depending on the material, more brittle and consequently more at risk from facture.

For the reliable mastery of single edge drilling process and to achieve a high process integrity investigations are carried out, for to gain new knowledges about the relation between cutting parameters, flow rates of cooling lubricant, cutting forces, shape of chips and drilling qualities (see Fig. 2). A process optimization

can be achieved by the help of the determination of the cutting values, the measurement of the cutting forces and the investigation of chip formation, and of the circulatory behaviour. To rise the reliability of the method, a strategy for monitoring the wear and breakage of the tool is being developed. A further objective for achieving a high process integrity, is the optimization of the tool, as shown in Fig.2, there the drill shaft shall be improved with regard to a maximal flow of the cooling lubricant.
Connected with that, the results of investigations concerning the static and dynamical behaviour of tools and the stresses of the tool, which already had been determined, are used.

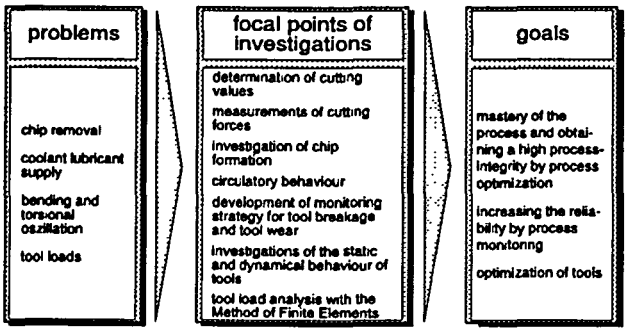


Fig. 2: Focal points of investigations

Mastery of the Process and Process Integrity

Tests to investigate the optimization of the process paramenters of the materials 42CrMo4V, 100Cr6 and Ck45 show, that the cutting speeds and the feed rates can be varied only within very small ranges, otherwise there are resulting unwelcome chip shapes, like ribbon chips or long helical chips [5]. Furthermore, the cutting- and feed forces can become so high, so that the solidity of the tool exceeds, the result are tool breakages. According to the cutting tests there is a dependance of the feed force from the feed (Fig.3).

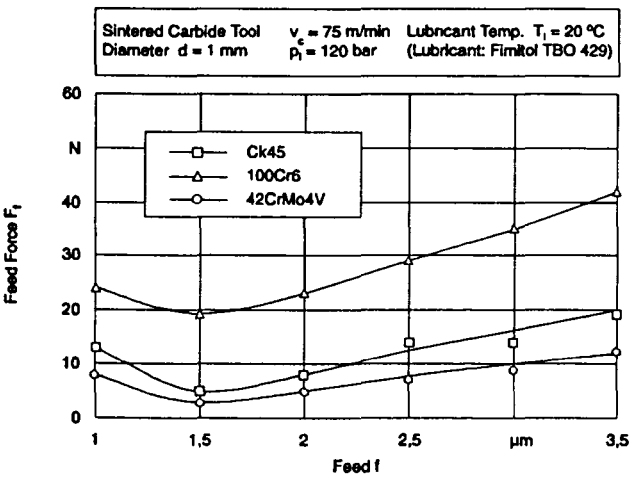


Fig. 3: Influence of the feed on the feed force

Thereby the feed force shows a minimum for all materials at the feed of 1,5 µm. After the minimum the run of forces curves increase. In case of the material 100Cr6, the highest increase of the feed forces progression can be noticed. During drilling, the force arises not only in feed direction by the z-component of the cutting force, but from the total of the cutting force in feed direction and the axial effecting hydraulic force by the cooling lubricant. The feed forces, in Fig. 3, which were found during the drilling process with a 1 mm tool, are cleared of the hydraulic force.

Besides the optimization of the cutting parameters, a continous volume stream of the cooling lubricant is of immense importance for the achievement of a high process integrity. The removal of the chips depends on that volume stream of the coolant. Besides the length of the drill and the cross-section of the coolant duct, the pressure and the viscosity of the medium are of interest [6]. From the results of the tests a small influence of viscosity (Fig. 4), but a high dependance of cross-section area of the duct can be concluded [7].

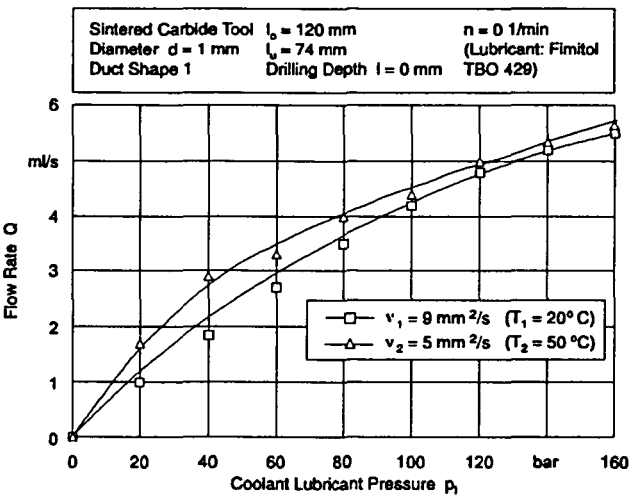


Fig. 4: Influence of the coolant lubricant viscosity on the flow rates

Increasing the Reliability by Process Monitoring

To monitor the deep-hole drilling process, different methods are known. Within all deep-hole drilling machines, there are devices to supervise the pressure of the cooling lubricant, which should stop the machine apruptly in case of a pressure increase, caused by a banking of chips. Furhermore, devices to monitor the feed force, the drilling moment or the power consumption of the actuation motor are in use. Those monitoring devices have been constructed for tools, which cutting forces are much higher than those of single edge drilling with diameters smaller than 2 mm.
For developing a monitoring strategy for tool breakage and tool wear, there are first tests, in which different measurable variables are registrated, such as feed force, drilling moment and acoustic emission. Thereby it should be recognized, whether there are characteristic features in the course of the measured variables, which can show wear and breakage of the tool, and which are thus useful for monitoring.

As a measuring device, on the side of the tool piece, both a measuring platform and a Kistler dynamometer is used. The measuring platform consists of DMS weight cells prestressed between two plates, which allows highly dynamic measurements. By means of the dynamometer, the drilling moments and the feed forces can be measured. For the measurement of the acoustic emission, there are different sensors used, among others a Brüel & Kjaer acceleration sensor is picked-out.

So far investigations concerning the tool breakage have shown, that the signal of the feed force alters impulsively in case of drill

damage. At the same time there could noticed a short increase of the signal before the signal peak caused by the tool breakage (Fig.5). To ascertain the tool breakage, the signal of the feed force can be analysed for impulsive increases. Furthermore, it is possible to observe the course of the signal for the increase, which precedes the breakage signal in order to prevent drill damages perhaps by a reduction of the feed. Like the signal of the feed force, the drilling moment also alters in case of a tool breakage, where quite similar signal increases are accomplished. Measurements of the acoustic emission signals show, that this method is to employ for the tool monitoring of single edge drilling at smallest diameters, if there is an adequate signal processing and a suitable fixing place for the sensor.

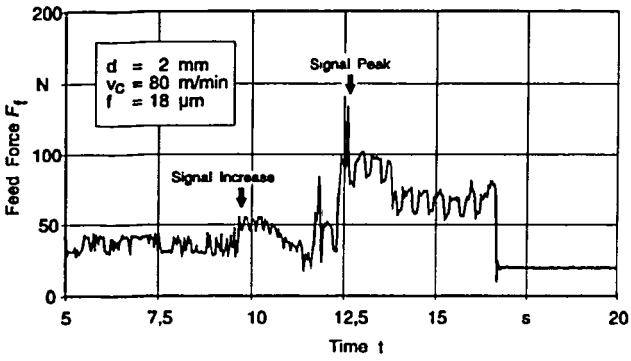


Fig. 5: Run of a feed force curve at tool breakage

In case of a drill breakage, there is a signal peak in all methods investigated. Fig.6 shows the procentual change of the signal in the peak, and the change of the quasi-statical part of the signal in case of a tool breakage. In tests, which are still current, the methods are being investigated, if they are suitable for tool wear monitoring.

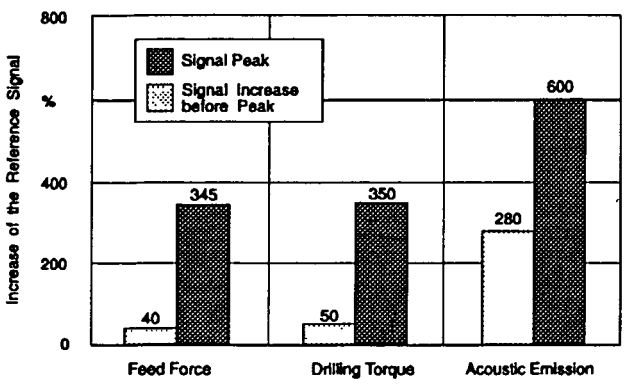


Fig. 6: Increases of references for the investigated signals at tool breakage

Optimization of the Tool

Besides the optimization of the cutting parameters, the improvement of the tool geometry concerning high stiffness at maximal flow of cooling lubricants is a further task. Conditioned by the geometry of the tools both the static and the dynamic stability has to be intensively regarded. Because the cooling lubricant supply and the chip removal is mainly determined by the geometry of the drill's cross-section, a compromise has to be found, which on the one hand meets the demand for high torsion and bending stiffness and on the other hand leaves a cross-section area as large as possible vacant for the cooling lubricant supply. Up to now the cross-sections of such tools had been mainly determined by experimental values.

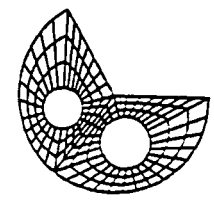
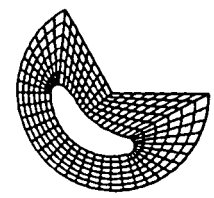
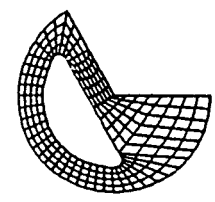
characteristic quantities	cross-section geometries
A_{duct} = 0,343 mm² J_t = 0,4576 mm⁴	2-hole shape 
A_{duct} = 0,269 mm² J_t = 0,4658 mm⁴	kidney shape 
A_{duct} = 0,486 mm² J_t = 0,4370 mm⁴	fictive cross-section 

Fig. 7: Cross-sectional area moments of inertia and cross-section areas

As to the calculations, three drill geometries had been modeled. These are drill shafts with a kidney-shaped cooling duct, such as in sintered carbide tools, a 2-hole shape and a fictive cross-section geometry (Fig. 7).

The characteristic quantities, which are necessary for dynamic calculations, e.g. torsion stiffness, are calculated by the help of torsion models. With these models it is possible to calculate cross sectional area moments of inertia, torsion stiffnesses and cross-section areas, which are necessary for the calculation of the characterizing frequencies, column loads etc (Fig. 8).

Summary

The accurate mastery of single edge drilling process at smallest diameters is a prerequisite for an economical application of the method. Only an exact knowledge of the process characteristic features and their dependances allows a purposeful process monitoring.

For a 1 mm-drill, the courses of the feed forces for three work piece materials were determined in dependance of the feed and by consideration of the chip formation. Further, the circulatory behaviour was tested in dependance of diameter, pressure,

temperature and geometry of the cooling lubricant ducts. The result shows a slight influence of viscosity, but the circulatory shows a high dependance of the cross-section area.

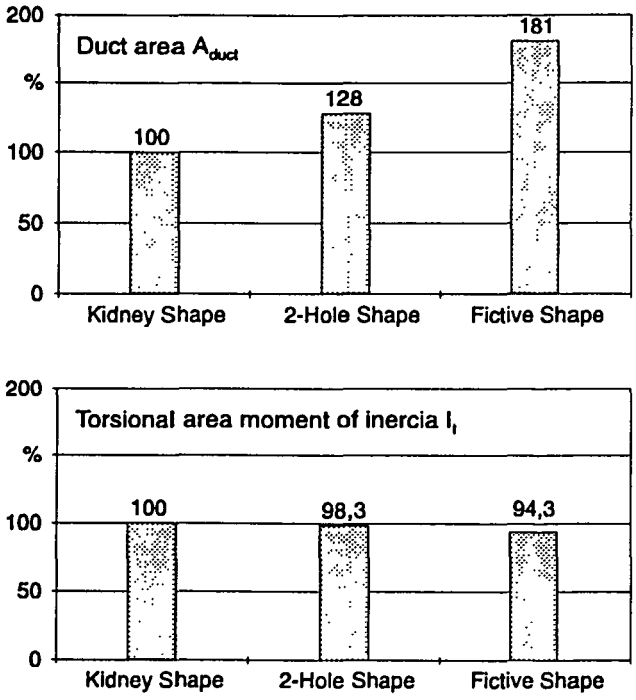


Fig. 8: Percental change of the duct areas and the torsional area moments

The evaluation of the measuring characters feed force, drilling moment and acoustic emmission signal with regard to a tool breakage monitoring shows characteristic signal changes, and such the aptitude of breakage-identification could be proved. FEM-calculations of the load conditions in the cross-sections of the drill heads and shafts give some idea of an optimization of the drill designing and of boundary conditions, which exclude a breakage.

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