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TRIANGULAR HOLES – ORIGINATION, IDENTIFICATION AND INFLUENCING PARAMETERS

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Abstract:
In the case of boring with sintered, solid carbide twisted drills, triangular holes can occur dependent up tool geometry and the chosen process parameters. The consequences of different influencing factors on the form of the triangular holes are not completely clarified up to now. This article attends to this question by taking the three aspects origination, identification and influencing parameters on the formation of triangular holes into consideration.

Key Words: Drilling, Hole Quality, Triangular Holes, Whirling Vibrations

1. INTRODUCTION

In the case of metal cutting techniques, boring has a share of 36 % of the entire primary processing time and thus belongs to one of the most important techniques in manufacturing engineering [1]. The fundamental demands on drilling are mainly minimum production costs and guarantee of the quality required at the same time. On the basis of a survey among 145 companies belonging to the secondary sector, it can be concluded, that, in addition to productivity, quality demands such as shape accuracy or surface quality become more and more important [2].

In the case of drilling with sintered, solid carbide twisted drills hole qualities from IT 8 to IT 10 are usual in practise. Reaming is relevant to lower IT classes, i. e. higher quality requirements. Due to improvement of the bore qualities, in the case of boring with sintered carbide drills, a substitution of selected reaming techniques is possible in some cases. A reduction of processing time by shorten the process chain would be the result.

The prerequisite for a high bore quality is a dynamic and stable drilling process with low vibrations. In the case of boring, the different influences upon the vibration characteristics and interdependence between single disturbances are insufficiently known up to now. That also applies to the effects on occurring vibration upon the quality of a drilling. As a consequence, existing rationalization potential to increase bore quality and a decrease of production costs at the same time is still unused.

This problematic nature described before i. e. the effects on various influencing factors upon dynamics of the drilling process and the bore quality are analysed in detail in this article. The main focus is to analyse the formation of triangular holes. Figure 1 shows the results from measurements in different drilling depths of triangular holes. It is quite obvious the triangularity is varying greatly between the three measured holes.

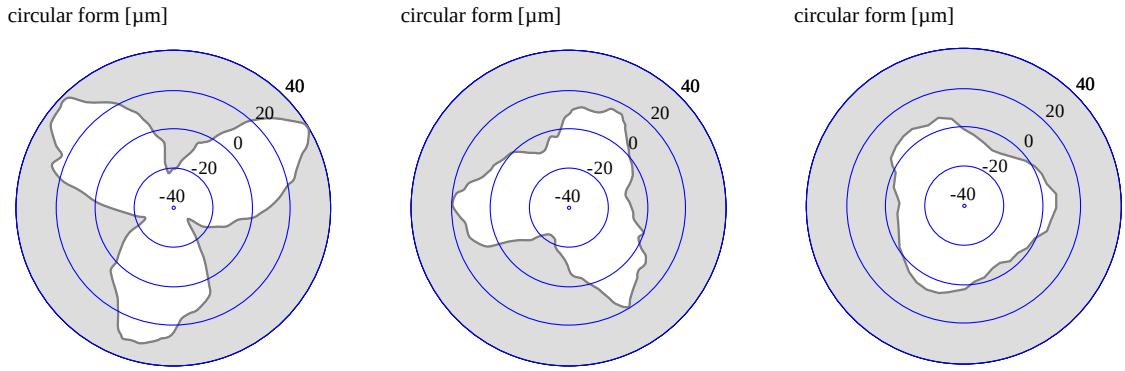

Figure 1: Circular form deterioration of three different triangular holes.

In the case of different quality parameters, accuracy of circular and cylindrical form is strongly affected for triangular holes. Therefore, the manufacturing of circular holes with high-quality using twisted drills holes is not possible. In order to improve the situation, a three-stage procedure consisting of the elements "analysis of origination of triangular holes", “identification of triangular holes”, and "influencing factors of triangular holes” was chosen.

2. ORIGINATION OF TRIANGULAR HOLES

The phenomenon of triangular holes can be attributed to the motion of the drill bit along an elliptical path (hereinafter referred to as whirling vibration). On that occasion, the path motion of the drill bit occurs approximately with a doubled rotational spindle frequency anticlockwise i. e. in opposite direction to the primary motion. Radial forces cause the whirling vibration, which changing the original position of the tool. These radial forces are caused by asymmetrical loadings of the tool, due to differences of cross section in metal cutting between both cutting edges.

Independent of the drill head geometry the whirling vibration can be noticed in the case of numerous drilling processes with twisted sintered carbide drills. The cause of the whirling vibration is the transition from secondary to primary major cutting edge during the spot drilling process. Statements that whirling vibration is initiated by brief slippage of the drill upon the work surface in the beginning of the drilling process can be disproved as follows in “identification of triangular holes” [3].

3. IDENTIFICATION OF TRIANGULAR HOLES

Three techniques are used to identify triangular holes:

- Measurement of radial forces;
- Contactless measurement of tool motion at the tool shank during drilling;
- Measurement of the drilled holes using a 3D coordinate-measuring machine.

3.1 Measurement of radial forces

The radial forces reflect interactions between the drill and work piece in the plane rectangular to drill axis. Therefore, these forces have a high significance in case of evaluation of drilling tests referring to bore quality. The radial force can be subdivided in a resting and rotating part in case of evaluation purposes [4]. Only the frequency of the signal of the rotating radial force has significance to identify triangular holes or whirling vibration. If there is a circular hole, then the frequency of the rotating radial force is equivalent to the spindle rotations. In the case of triangular holes, however, the main frequency in the radial force signal is twice as

high as the rotational frequency of the spindle. The cause of this is a motion of the drill bit on an elliptical path around the axis of the spindle with roughly doubled rotational frequency of the spindle.

The radial force signal also allows details on the beginning of the whirling vibration. This beginning can be identified by the moment from which the signal of the rotating radial force shows approximately a doubled rotational frequency of the spindle. In Figure 2 the transition from phase 1 to phase 2 corresponds (transition from secondary to primary major cutting edge) to the beginning of whirling vibration. Consequently, whirling vibrations do not occur directly in the case of spot drilling, but only after tool is already in operation. If the tool cuts deeper into the work piece, whirling vibration will then be increased until the tool fully cuts into the work piece. In the case of cutting fully into the work piece, whirling vibration is damped by the supporting effect of the drill margin.

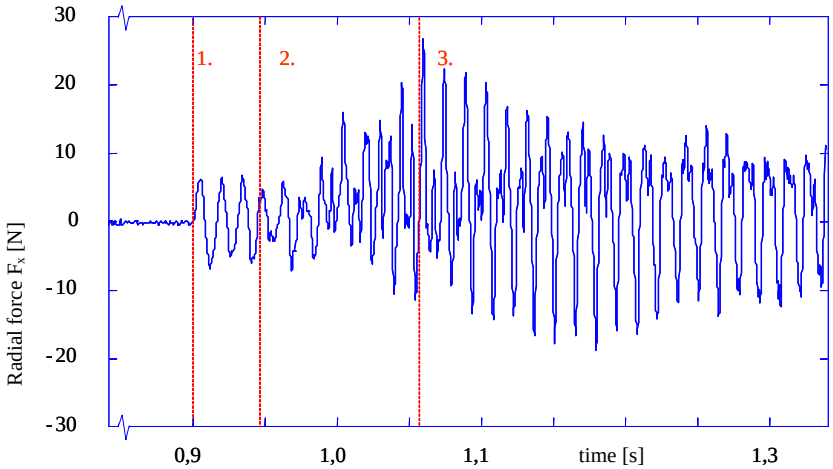

Figure 2: Radial force F_x versus drilling time in case of a “noncircular” i. e. triangular hole.

The intensity of the triangular form can be determined with regard to quality on the basis of the amplitude of the rotating radial force. As an alternative measure to determine the intensity of whirling vibration, differences of cross section in metal cutting i. e. chip width between both cutting edges are used. The differences of cross section in metal cutting are calculated by guideline of a defined elliptical path and the rotational frequency of the drill bit upon the elliptical path. This permits a qualitative prediction of the radial force course for any elliptical paths or forms.

The advantage to identify triangular holes with the help of the course of the rotating radial force is that no 3D coordinate measuring machine must be used. Moreover, the drilling process can be easily retraced by the signal of the force. On the other hand, the necessity of the equipment to measure the force and the pure qualitative assessment of a drilling can be seen as disadvantage.

3.2 Contactless measurement of tool motion at the tool shank during drilling

The use of contactless, inductive sensors attached to the machine tool enables the measurement of the motion of the drill centre at the tool shank in two directions staggered by 90°. On the basis of the measured motion of the drill centre, it can be determined whether whirling vibration arose and triangular holes were produced. Additionally, an additional sensor is employed, in order to recognize the exact rotational position of the tool by measuring a marker on the tool shaft.

3.3 Measurement of the drilled holes using a 3D coordinate-measuring machine

In contrast to the two before mentioned techniques, the use of a 3D coordinate-measuring machine enables to quantify the triangularity i. e. the circular and cylindrical form deviations. In comparison to this advantage a re-clamping is required for the work piece. Also the lack of process information of the drilling is disadvantages. The latter leads to the fact, that the understanding of the process can only be expanded in a reduced manner with this systematic.

All of the three methods presented can either be employed indirectly or directly to identify triangular holes. The measurement of the radial forces and the contactless measurement of the tool shaft motion provide high qualitative results with respect to the intensity of the triangular form. They have the advantage of a detailed process analysis. In contrast to this, the measurement of a 3D coordinate measuring machine provides quantitative results but allows no accurate process analysis. Therefore, a combination of the three methods will give the best approach towards a detailed understanding of the formation of triangular holes.

4. INFLUENCE OF PARAMETER IN THE CASE OF TRIANGULAR HOLES

The influences of parameter upon the bore quality are multifarious [5]. This article concentrates on the analysis of selected process parameters having a considerable influence on the triangular form of a drilling. That includes:

- Drill tip geometry;
- Tool wear;
- Technology parameter (feed);
- Tool eccentricity.

4.1 Drill tip geometry

The drill centre geometry is defined by a large number of geometry parameters. Depending on the drill centre geometry and tool manufacturer, the geometrical conditions along the edges change in a different manner, for example. General statements concerning bore quality are scarcely possible, due to this complex context. Therefore, the focus is concentrated on the variation of single quantities such as the relief angle.

Series of tests with differing relief angles show that whirling vibration can be increased or reduced by variation of the relief angle. For one tool noted A, which tends to strong whirling vibrations with the standard relief angle, the radial force signal as well as three measured plains of the manufactured hole is presented in Figure 3. As a result of the whirling vibration, the measured circularity corresponds to a polygon.

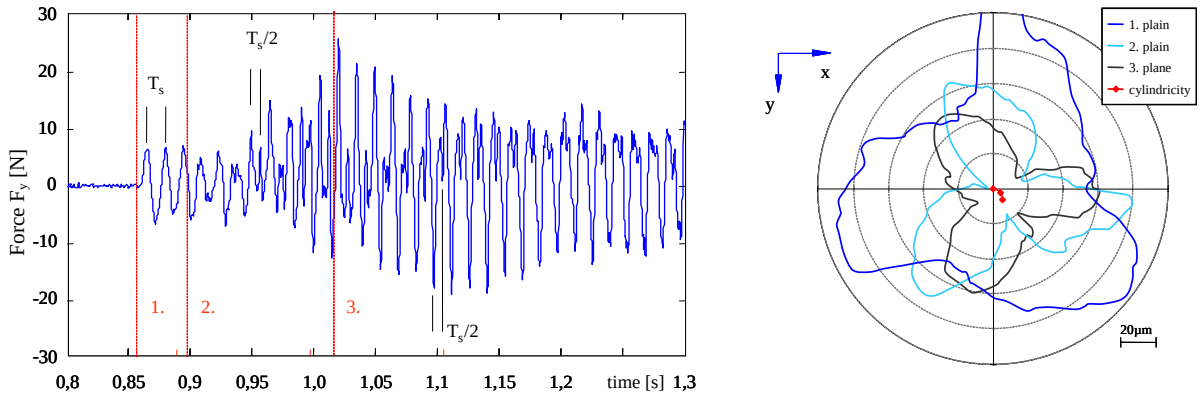

Figure 3: Radial force signal F_y and bore quality in the case of boring with standard tool A (relief angle 10°, v_c = 80 m/min, f = 0.1 mm, t =12 mm).

As mentioned above, the radial force signal F_y in section 1 (chisel edge and secondary cutting edge) corresponds to a vibration with constant amplitude and period T_s. The transition from secondary major cutting edge to major cutting edge stimulates the tool to swing, which is clearly reflected in the force signal. The period corresponds only to half of duration of a revolution of the spindle. When the relief angle of tool A is decreased (in this case from 10° to 6°), the whirling vibration almost disappears, the circular form accuracy decreases and the mean diameter is nearly the same over the drilling depth.

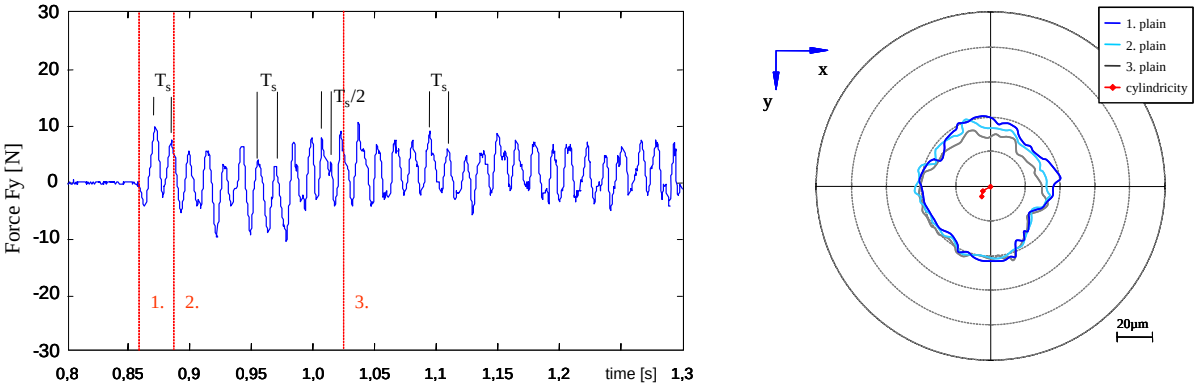

Figure 4: Radial force signal F_y bore quality in case of boring with modified tool B (Relief angle 6°, v_c = 80 m/min, f = 0.1 mm, t = 12 mm).

The positive influence of a minimized relief angle upon the circular form results from the reduction of the effective relief angle at the same time. As a result of the minimized effective relief angle, the process damping increases so that whirling vibration can hardly occur.

4.2 Feed

A similar effect like in the case of the reduction of the relief angle can be achieved by increasing the feed. Here, the static relief angle α_0 remains constant, however, the working angle η increases. In this case, the effective relief angle α_{0e} is also reduced and friction is increased. Basically, the circular form of the hole is clearly improved (see Figure 5).

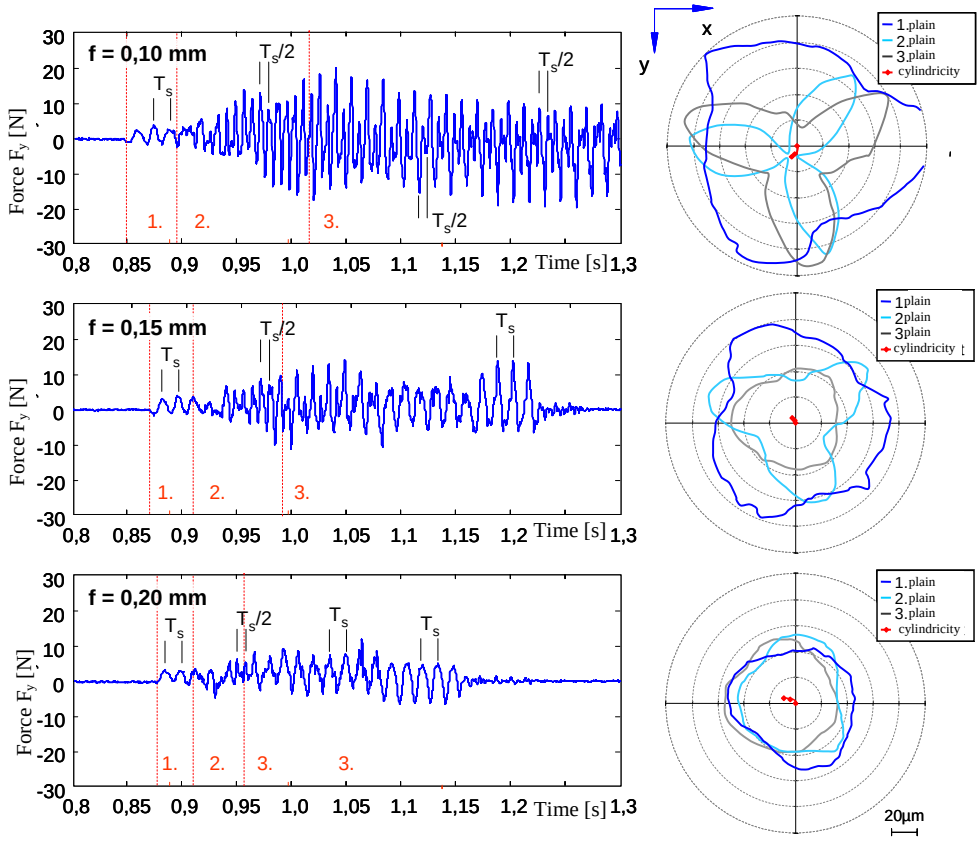

Figure 5: Influence of an increase of the feed upon the bore quality in case of tool A (relief angle 10°, v_c = 80 m/min, f = 0.1 mm to 0.2 mm).

4.3 Wear

The tool wear or the tool life travel represents one of the most important parameter for the use of drilling tools in industrial production. Thus, in addition to the already presented series of tests for tool A and B tool life travel tests were made with identical parameters. According to Figure 6, the tool with a reduced relief angle can almost increases the tool life travel of tool A (left) by a factor of two (see tool B on the right).

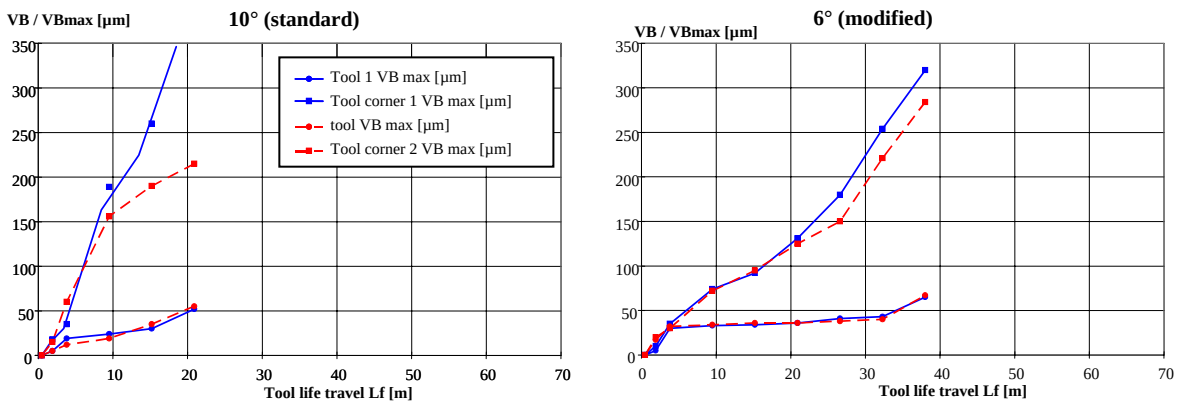

Figure 6: Influence of relief angle on tool life travel.

The increased tool life travel of the modified tool can be attributed to the reduced whirling vibration and to the increased wedge angle. In summary, the tool with the modified relief

angle leads to a higher bore quality as well as to a longer tool life travel. A similar result, which is above average can be achieved with standard tool A in case of increased feed. Here, tool life travel and bore quality also increase considerably, due to the lack of pendulum oscillation and all in all shorter way of friction. Compared with tool A, which has a reduced feed, however, directional stability of the drill slightly deteriorates due to the increased feed power. The wear progress has a very small influence on the accuracy of the circular form or on the whirling vibration. Even a decrease of circular detects of form and defect of directional stability of the drill could be noticed in case of an increasing wear.

4.4 Drill margin

Besides relief angle and feed, the number and position of the drill margins can also influence the bore quality over the drilling depth. As a comparison tool to the standard tool A, a similar type of tool with a double drill margin was tested. The tests showed that in case of greater drilling depths, the additional drill margins do have a positive effect on the directional stability of the hole, on account of a better support at the drilled walls. However, the circular and cylindrical form are, like in the case of tool A, marked by a salient triangular form and great medium diameter in the upper part of the hole due to the degradation of the spot drilling behaviour. That means that in the case of appearance of whirling vibration, the application of a double drill margin cannot achieve its full effect, since the effect of the second drill margin starts too late, independently of the position of the drill margin.

4.5 Tool eccentricity

The influence of tool eccentricity on the bore quality and on the tool life travel is controversial in practise. The common opinion that a small tool eccentricity is a basic prerequisite for an accurate hole and must be completely removed as far as possible cannot be confirmed in the series of tests performed. The tool eccentricity was manipulated artificially in the tests with the aid of a radial adjustable clamping device. The increase of tool eccentricity is reflected in the radial force signal with slightly increased values. However, directional stability of the drill, circular and cylindrical form even in the case of a times-five multiplication of the tool eccentricity does not change. If the feed is increased additionally the findings certify that a reduced, effective relief angle will lead to a higher accuracy of circular form.

5. CONCLUSIONS

Triangular holes can occur in numerous machining situations and require a special consideration. The origination of triangular holes is explained in this article. Beside that some techniques are presented allowing identification of triangular holes. In ideal circumstances, all techniques presented should be employed in a parallel manner, in order to develop a maximum understanding of the process and to avoid appearance of triangular holes. In the final part of the article, effects of the substantial influencing factors on triangular holes are analysed. As a result of a comparison between a conventional and modified standard tool, the existing improvement potential is demonstrated referring to the bore quality as well as to the tool life travel.

Following activities in this area will concentrate on the active influence of the drilling process. The aim is a combination of tool geometry optimization and mechatronical systems, in order to improve bore quality. Only the use of both measures makes it possible to replace selected friction process and shorten the process chain.

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