DEVELOPMENT OF A DEEP HOLE TWIST DRILL

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1. Introduction: When the depth of the hole exceeds seven times the hole diameter, it is conveniently called a deep hole. The I.S.I. has not yet standardised the parameters of extra long series drills. It is understood that a recent meeting in this connection could not come to a decision on all the parameters. It is therefore timely to discuss the subject. This paper reports part of the collaborative work done by Regional Engineering College, Warangal and Jairamdas Udyog Pvt.Ltd., Bangalore[1].

The problems associated with deep hole drilling are (i) inadequate coolant access and the consequent excessive heating, cracking and chipping of the outer corner; (ii) rubbing of the guiding margin and the resulting poor surface quality; (iii) chip clogging and drill breakage; (iv) low stiffness and therefore poor accuracy and (v) need for web thinning and the consequent increase in cost. Use of heavy web drills is the common solution to this problem. An alternative namely the application of self thinned profile is suggested here (See Fig.1).

2. Drill Rigidity:

2.1 Flute length: A solid section is ten times stiffer than an ordinary fluted section[2]. A small reduction in flute length is therefore very useful. The normal flute length is depth of hole plus 4 to 8 times dia for regrinding plus 5 to 10 mm for swarf clearance. Due to the high cost of extra long drills the tendency is to increase the regrind allowance. If the solid shank is extended, it is possible the drill will enter the hole when the regrind allowance is exhausted. Though there is back taper, due to the run out of the drill the shank may rub. Taking an over-view of the problem it appears possible to allow the shank to enter the hole at the end by upto 2 diameters. Swarf clearance may not be a problem since, due to frequent woodpecking at the end the chips do not anyhow travel the full flute length.

2.2 Web taper: The rate of increase of the torsional stiffness of the drill with the ratio of web thickness to drill diameter (D) is low upto 0.3 and is rapid afterwards[2]. Increasing web by 320% increases the stiffness by 420%. Similarly an increase in web taper by inc. asing the web at shank to twice that at point increases the stiffness by about 2.5 times. But as the drill is successively reground it would need greater and greater web thinning. It is possible, however, to have the standard web taper in the regrinding allowance and a higher value in the rest of the flute length.

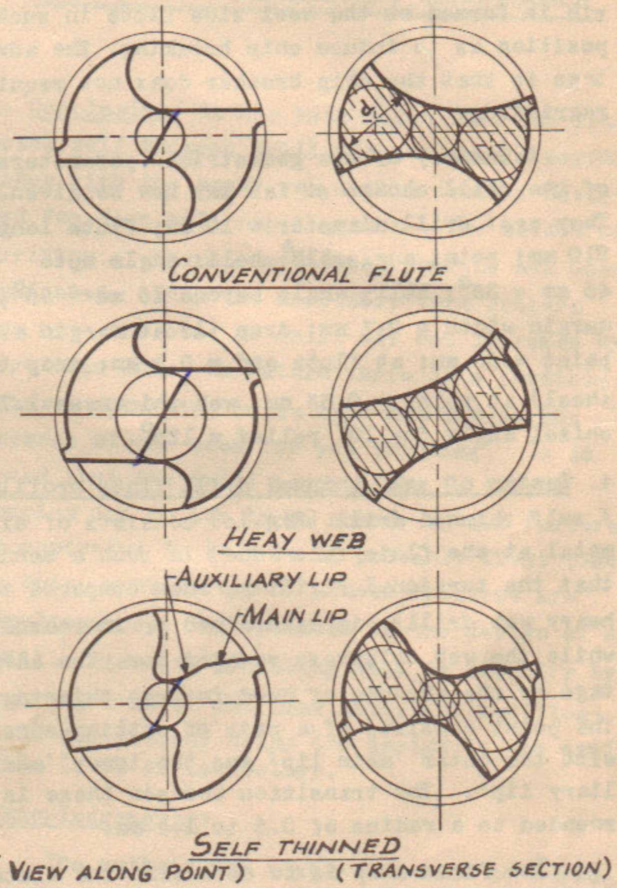

FIG. 1. DIFFERENT FLUTE DESIGNS

2.3 Land width: Land width increases section stiffness. It has been found[4] that torsional stiffness is proportional to the maximum inscribed circle diameter (d) raised to the fourth power (See Fig.1). But if the land is increased the chip space decreases.

2.4 Body diameter clearance: This reduces the stiffness considerably. The normal value is

5% which is known to reduce the stiffness[4] by about 25%. The body clearance may be reduced to 2 to 3% except for the fear of 'merging' of the heel and margin during margin grinding due to the outward distortion of the heel. This may be avoided by increasing radial drop taper and rounding the heel.

2.5 Helix angle: A high helix angle aids chip flow. But it also reduces the stiffness and increases the effective rake angle so that the cutting edge strength and heat dissipating capacity are reduced. As a compromise one may have a reduced helix angle in the regrinding allowance and a higher value in the rest of the flute length. A time study on the Cincinnati Semi-automatic Flute Milling Machine (F40) has indicated that the increase in cost due to the dual helix is only about 10%.

3. <u>Chip breaking</u>: Three types of chip breakers are popular, namely the Crisp, Oxford and Kallio types[3]. Oxford type is chosen here, where a rib is formed on the heel side flute in such a position as to induce chip breaking. The advantage is that the chip breaker does not require regrinding.

A summary of the geometrical parameters of the drill chosen so far may now be given. They are: drill diameter = 10 mm; flute length = 210 mm; point angle=118°; helix angle upto 45 mm = 35°; helix angle beyond 45 mm = 55°; margin width = 0;7 mm; drop (1) at margin at point =.40 mm; at flute end = 0.1 mm; drop (2) (heel) at point = 0.55 mm; web thickness=1.7mm; chisel angle for 10° relief = 125°.

4. <u>Design of self thinned drill flute profile</u>: A self thinned drill (Fig.1c) consists of extra metal at the flute face added in such a manner that the torsional rigidity, when compared to heavy web drills, is maintained or increased while the web thickness remains low. The advantage is the absence of need for web thinning. The point consists of a pair of cutting-edges with the outer 'main lip' and the inner 'auxiliary lip'. The transition between these is rounded to a radius of 0.5 to 1.5 mm.

The first step is to determine the flute profile in the transverse section. In Fig.2, circle 1 represents the drill diameter (10 mm). Circle 2 provides the body diameter clearance of 4% (9.2 mm dia). Circle 3 is the web circle (1.7 mm)dia). Circle 4 of 1 mm diameter is drawn to ensure minimum curvature at the root of the flute to avoid cracking during heat treatment. The chisel angle 125° determines the position of line CC. Circle 4 must be so positioned as not to cross the chisel angle of 125°. R is the position of the rib which must be fixed by trial and error. It should not cross the vertical axis. The further it is from the vertical axis greater is the chip space in the secondary flute. But the drill stiffness suffers in this process. The nearer it is to the centre smaller is the curvature of the chip breaker but at the cost of chip space. Simultaneously with this several inscribed circle diameters must be tried. The inscribed circle must be touching the wheel and lip side flute profiles as well as the circle 4 while passing through rib R. The heel side flute profile beyond the rib may be approximated to that used for heavy web drills. By trial and error it is possible to fix the optimum values and positions of the rib R (on a diameter of 0.6 mm and angle from vertical of 16° in the present example) and the maximum inscribed circle (diameter 4.17 mm) while ensuring a smooth flute contour. The lip side profile consists of two parts - one for the main lip and the other for the auxiliary lip. The junction between them must be rounded by a minimum radius of 0.5 mm.

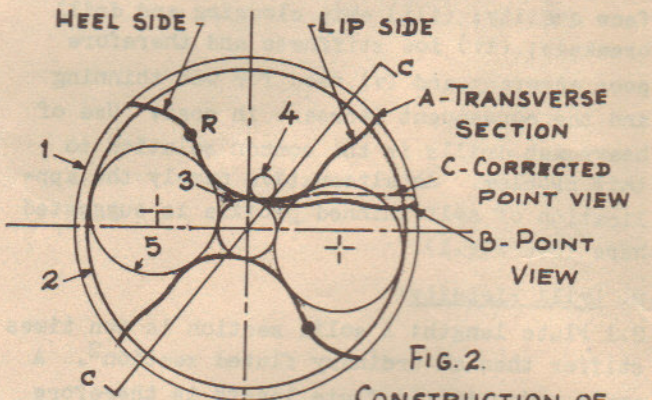

FIG. 2
CONSTRUCTION OF SELF THINNED FLUTE PROFILE

Analytical[5,6] and graphical[7] procedures for converting the flute profile in plan view at point, to the profile in the transverse section are available. Certain refinements to these are discussed in Ref.1. The discussion of these is beyond the scope of this paper. By doing back calculations based on the above procedures the profile (curve A) in transverse section obtained may be converted into the profile at the point (curve B). Notice a dip in the main lip. It is known that straight lips work more efficiently than other forms. Curve B may now be corrected to curve C with straight lips. Applying the procedures of Refs.1,5,6 and 7 again a corrected profile for the flute in the transverse section may now be determined (not shown in Fig.2). It is worthwhile checking the distribution of the normal rake angle along the cutting edge. Methods of determining this are given Ref.9. The rake angle range in this case was -35^{o} to $+35^{o}$.

Having determined the transverse section flute profile ensuring maximum rigidity, a thin web, good chip breaking possibilities and rake angle distribution it is a simple matter to determine the required profiles for the flute and margin forming cutters. Procedures for this are discussed in references 8 and 9. Reference 1 gives a few refinements in the procedures. Note that two different sets of cutters are necessary in view of the dual helix angle used.

5. <u>Relative drill stiffness</u>: It is worthwhile nowto compare the stiffnesses of the conventional flute, heavy-web and self-thinned drills theoretically. While it is desirable to test these experimentally (a good problem for future investigations) a tentative idea can be obtained based on the diameter (d) of the maximum inscribed circle. It has already been mentioned that the magnitude of $(D/d)^4$ is a measure of the relative section compliance. Variation of R.S.C. along the flute length of the three types of drills is shown in Fig.3. The inverse of the area included by each of these curves is a measure of the relative drill stiffness R.D.S.[10]. Computations show that, taking the stiffness of the conventional flute drill as unity, the relative stiffness of the heavy web drill is 2.35 while that for the self thinned geometry is 2.91. The latter is for a self thinned drill with extended shank, two step web taper and axial drop taper. For a drill with these features absent but with a self thinned flute profile the estimated R.D.S. is 1.91. The three above features are thus found to contribute to an increase in stiffness of 49%.

One word of caution here. The above estimates are based only on the maximum inscribed circle ignoring the direct effect of the reduction in web thickness. The effect is worthy of further investigations.

The heavy web drill and the self thinned drill were compared for their performance. On I.S.I. Standard billet of hardness 200 to 216 BHN the cutting conditions were speed of 24 m/min, feed of 0.1 mm/rev., upto 90 mm depth and hand feed beyond, in the presence of 5% SAE-30 soluble oil. The chips obtained with the self thinned drill were continuous conical helical closely wound coiled chip. The criterion of tool life was drill cry. The self thinned drill gave about 30% greater number of holes per regrind in comparision to the heavy web drill.

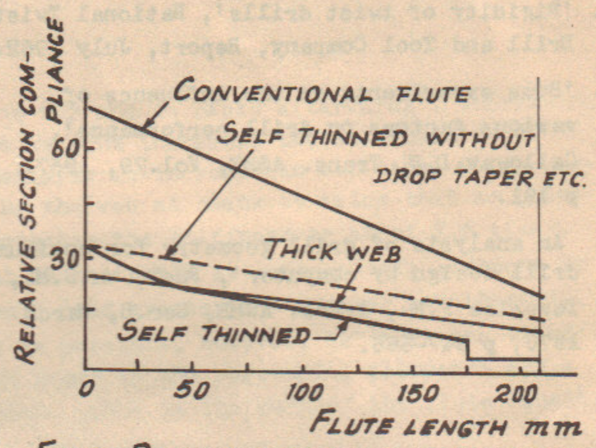

FIG.3. RELATIVE SECTION COMPLIANCE

6. <u>Conclusion</u>: It has been shown that the proposed self thinned drill has comparable performance with the heavy web drills usually designed for deep hole applications. The method of arriving at the optimum flute profile has been indicated. Once the necessary form cutters are made the cost of drill may not increase by more than 10%. In return there is a possibility in operating costs upto 30% due to the absence of the need for web thinning. It is noted that the drill as proposed is fairly complex due to the large number of new features incorporated in it. It is probably first time in this country that all these features are simultaneously incorporated in the design of a drill. Attempts are being made to simplify by removing some of the less important modifications and thereby bring the design to the available level of technology.

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