WHAT IS THE MEANING OF 'SELF-PILOTING'?

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The extensive use of deep hole machining in manufacturing has given rise in recent years to an increasing volume of research to improve the efficiency of this process. Because the vast scale on which deep-hole drilling operations are carried out, even a slight increase in the general level of deep-hole drill performance would yield important practical and economical benefits to individual firms and the engineering industry as a whole.

Numerous names have been given to similar deep-hole tools and their components. This interchangeable use of generic names for the same type of tools is confusing. In general, the tools of this type are classified by the method of coolant supply and chip removal. It can be gundrill (gun-)-type tools, BTA-type tools, and Ejector-type tools. All gundrill-type tools are single or multi-edge, end cutting tools with an internal coolant (cutting fluid) supply and external chip removal along the V-shaped flute (Fig. 1a). All BTA-type tools are single or multi-edge with external coolant supply through the annular clearance (formed between the boring bar and bore walls) and internal chip removal through the inner surface of the boring bar (Fig. 1b). Ejector-type tools are single or multi-edge tools with internal coolant supply (through the clearance between the boring bar and the inner tube) and internal chip removal (through the inner tube) (Fig. 1c). The inlet and outlet channels are connected by the ejector nozzle, which can have different design, location, and working conditions. Due to this nozzle, the cutting fluid supplied to an Ejector drill is divided into two portions. First portion goes to the machining zone where is cools and lubricates the cutting edge(s) and supporting elements (areas, pads, etc.). The second portion flows through the ejector nozzle, creating a partial vacuum (the ejector effect) in the inner tube. Due to this vacuum the first portion of the cutting fluid is diverted back to the bore of the inner tube where it is sucked back (from the machining zone) along with the chips.

As seen from the above description, the existing deep-hole drills classification does not reflect the tool design and specifics of deep-hole drilling. Rather, it reflects a specific method of coolant supply and chip removal. Emerging terms, as for example STS Tools (single Tube system) proposed by Sandvik Coromant Co., add further difficulties in understanding the major specific feature of deep-hole tools. A need is felt to clarify the issue.

When a deep-hole drill works, the cutting force generated is due to the resistance of the workpiece material to cutting (Fig. 2). This force is a 3-D vector applied at a certain point of the cutting edge. (In the case of a multi-edge cutting tool, it may be applied at any point defined by the vector summation of the cutting forces on the tool's cutting edges. (Note that it cannot pass through the drill's longitudinal axis because at this point, the drilling torque is equal to zero.) The cutting force R_c (or the resultant cutting force for multi-edge tools) can be resolved into three components, namely: the power *(tangential)* component F_T,

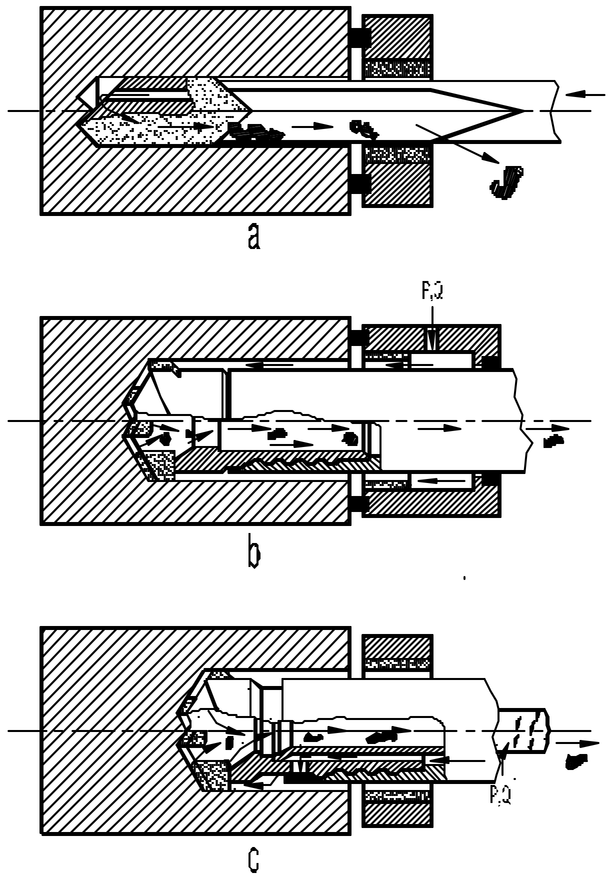

Figure1. Types of deep-hole drills: (a) gundrill, (b) BTA drill, (c) Ejector Drill.

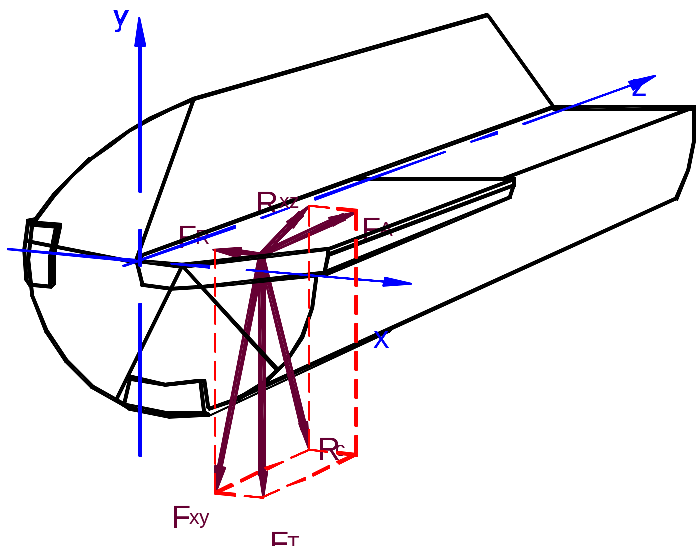

Figure 2. The system of forces

the *axial* component, *Fa,* and *radial, Fr* forces, respectively. The axial force is balanced (equal in magnitude and opposite directed) by the axial force of the feed mechanism of a deep-hole machine while the tangential and radial forces sum to create force F_{xy} (acts in the *xy*-plane) which (in contrast to other axial tools as twist drills, reamers, milling tools) generally is not balanced, regardless of the number of the cutting edges used. To prevent drill bending due to this unbalanced force, some special measures should be taken. The term 'deep-hole drilling' has grown to mean that the unbalanced cutting force generated in the cutting process is balanced by the equal and opposite force due to supporting pads, which bear against the wall of the hole being drilled. As such, the 'deep-hole drill' guides itself initially in the starting bushing and then in the hole being drilled so that it can be considered as self-piloted.

Currently, multi-edge and multi-insert tools also utilize the same principle of self-piloting, although it is not very obvious from their appearance. To clarify this issue, consider the design model of an unsymmetrical multi-edge self-piloting tool (SPT) shown in figure 3. In this figure, the tool coordinate system is described as:

- The *x*-axis is the SPT axis with positive direction toward the SPT shank.
- The *y*-axis is perpendicular to the *x*-axis and passes through the SPT corner (SPT's periphery point).
- The *z*-axis is perpendicular to the *x*- and *y*- axes.

Now, if $\boldsymbol{F}_{zy1}$, $\boldsymbol{F}_{zy2}$, . . . , $\boldsymbol{F}_{zyn}$ are the cutting forces acting on the cutting inserts (it is assumed that the tool has *n* cutting inserts) in the *zy*-plane then the cutting moment $\boldsymbol{M}$ and the unbalanced force resultant $\boldsymbol{R}_s$ in the *zy*-plane are calculated from the equilibrium conditions as follows:

$$\overrightarrow{M} = -\sum_{i=1}^{n} (\overline{r_i} \times \overrightarrow{F}_{zyi}) \qquad (1)$$

and

$$\overrightarrow{R}_s = \sum_{i=1}^{n} \overrightarrow{F}_{xyi} \qquad (2)$$

Expressing equation (2) in the complex form, we have

$$\overrightarrow{R}_s = \left|\overrightarrow{R}_s\right| \exp(j l) = \sum_{i=1}^{n} \left|\overrightarrow{F}_{zyi}\right| \exp j(y_i + \Phi_i) \qquad (3)$$

where λ is the angle of vector $\boldsymbol{R}_s$ with respect to the *y*-axis.

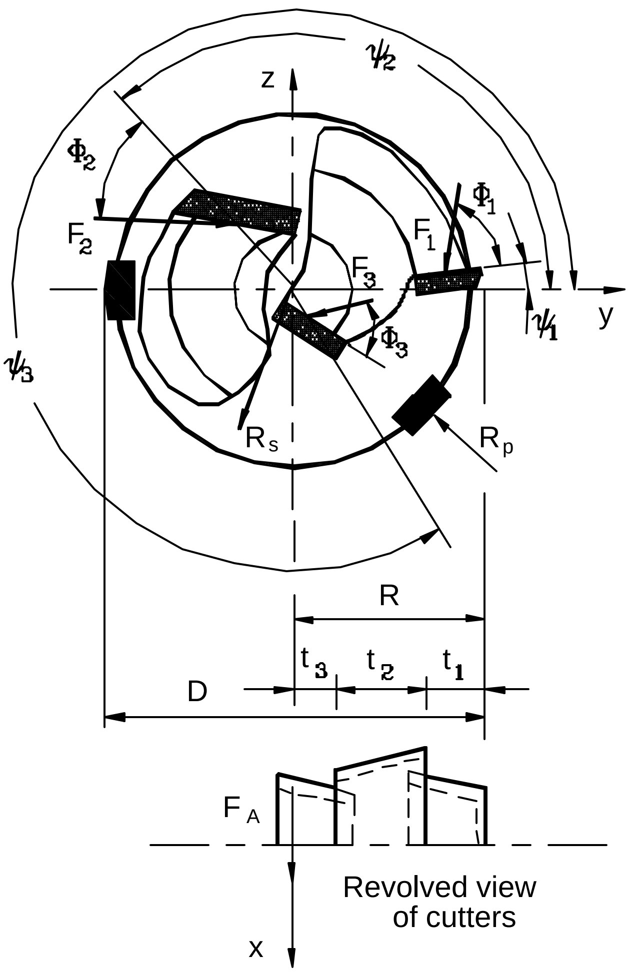

Figure 3: Design model of an unsymmetrical multi-edge self-piloting tool.

Equation (3), written in the trigonometric form, gives the magnitude $|\boldsymbol{R_s}|$ and the direction angle λ of the resultant $\boldsymbol{R_s}$

$$\left|\vec{R}_s\right| = \left[\left(\sum_{i=1}^{n}\left|\vec{F}_{zyi}\right|\cos(y_i + \Phi_i)\right)^2 + \left(\sum_{i=1}^{n}\left|\vec{F}_{zyi}\right|\sin(y_i + \Phi_i)\right)^2\right] \qquad (4)$$

$$l = ar\tan\left(\frac{\sum_{i=1}^{n}\left|\vec{F}_{zyi}\right|\sin(y_i + \Phi_i)}{\sum_{i=1}^{n}\left|\dot{F}_{zyi}\right|\cos(y_i + \Phi_i)}\right) \qquad (5)$$

Here angles R_i are the location angles of SPT cutting inserts with respect to the tool coordinate system.

Having defined the resultant force and its direction, it is possible to locate the supporting pads relative to the cutting inserts to achieve the identical pad reactions. The analysis of the force system shows that the identical pad reactions are achieved by their unsymmetrical location relative to the direction of the resultant. By controlling the insert locations ψ_i, directions of the cutting-force components $\boldsymbol{F}_{zyi}$ (angles Φ_i), and number of SPT cutting inserts, n, the conditions necessary for tool guidance, static stability, and stability at the entrance of the hole being drilled can be achieved.

Having completed the design procedure, one can determine the force components, which are necessary for the machining process. The drive torque, T is calculated as

$$T = M + 2 f_p R_p \qquad (6)$$

Here R_p is the defined supporting pad reaction; f_p is complex friction coefficient in the pad-workpiece contact .

The axial force, F_A is defined as

$$F_A = \mathrm{Pr}oj_x \left(\sum_{i=1}^{n} \overrightarrow{F_{xyi}} \right) \qquad (7)$$

Here F_{xy1} - F_{xyn} are the forces acting on the xy-plane.

Bearing in mind the foregoing analysis, we may suggest that the terms 'self-piloting drilling' (SPD) and “self-piloting tool” (SPT) which convey the idea of the drill guiding or steering itself during a drill operation could replace the widely used terms as 'gundrill' and ‘gundrilling’, 'BTA' and BTA drilling’, 'Ejector drill' and ‘Ejector drilling’ which reflect, as mentioned above, methods of coolant supply only. For example, instead of ‘gundrill’, a SPT with the internal coolant supply and external chip removal should be used.

Although it may appear to someone as more complicated and thus unnecessary, the proposed terminology in fact reduces confusion. For example, the term ‘two-flute gundrills’, which is currently wide used in the automotive and tool industries to describe a deep-hole drill with two identical cutting elements symmetrically located with respect to the drill longitudinal axis. Because there is no (at least, theoretically) unbalanced radial force, it is simply wrong to regard such a tool as a gundrill. It is not self-piloted although it is a drill with internal coolant supply and external chip removal along straight V-flutes. Unfortunately, such drills are treated as SPTs and thus often misused. In our opinion this became possible because the so-called “deep-hole drilling experts” from the leading gundrill producer in this country have no idea about the working principles of SPT. Multiple proofs to this point can be easily found examining the basic design of their SPT’s. I can predict that more knowledgeable competitors will extinguish this company from the market in the nearest future. Moreover, the first signs of this process are already evident.