Current state and problems of drilling hole machining

T.U.Umarov
umarovtalibjan@gmail.com
Tashkent State Technical University named after Islam Karimov
Davron Xoltursunovich Bekturov
bekturovdavron@gmail.com
Tashkent Region Emergency Situations Department

Abstract: *This article analyzes the theoretical foundations, historical stages of development, and the current state of hole machining using drills. The influence of drill geometric parameters on hole quality, as well as the processes of heat generation, deformation, and tool wear occurring during cutting, are scientifically explained. The directions for improving drilling technology under the conditions of machining modern structural materials are also presented.*
Keywords: *drilling, twist drill, cutting process, geometric parameters, surface roughness, accuracy, chip, tool wear, cutting speed, feed*

INTRODUCTION

In mechanical engineering, the production of holes is one of the most important technological operations in manufacturing parts. The accuracy, surface quality, and geometric shape of holes determine the reliability of the entire mechanism. In modern production, the widespread use of heat-resistant, corrosion-resistant, composite, and high-strength materials imposes increased requirements on the drilling process.

The metal cutting process is accompanied by elastic and plastic deformations, friction, heat generation, and tool wear. Studying the laws governing these processes makes it possible to select optimal cutting conditions.

In 1868-1869, Ivan A. Time conducted theoretical and experimental research on the cutting process and established its scientific foundations. He studied the chip formation process, developed its schematic representation, classified chip types, and proposed formulas for calculating cutting forces and chip shrinkage.

After I. A. Time, Professor Pavel A. Afanasyev and Academician Alexander V. Gadolin proposed new equations for determining cutting forces, taking into account friction forces on the rake and flank surfaces.

A significant contribution to the development of metal cutting science was made by Professor Konstantin A. Zvorykin. He developed a force diagram acting on the tool during cutting, designed a hydraulic dynamometer, and was the first to apply it in practice. The force diagram he proposed was later supplemented by Professor Sergei A. Rudnik and remains relevant today.

A new direction in studying the metal cutting process was initiated by mechanic Yakov G. Usachev. If I.A.Time and K.A.Zvorykin can be considered the founders of cutting mechanics, Ya. G. Usachev is regarded as the founder of the physics of metal cutting. Ya.G.Usachev developed methods for measuring temperature on cutting surfaces and experimentally determined the dependence of temperature on cutting speed, depth of cut, and feed rate. In his research, he used a calorimeter and thermocouples of his own design (which are still in use today). He also developed the theory of chip formation and identified the phenomenon of work hardening of the machined surface.

The expansion of the machine tool fleet and the growth of metalworking volumes required the rational use of existing capacities and the creation of scientifically grounded recommendations for selecting optimal cutting conditions and machining parameters. The development of mass production required the introduction of high-performance machining methods using specialized tools.Solving these problems necessitated the expansion of scientific research in metalworking. In 1936, under the leadership of Professor E.P.Nadeinskiy at Bauman Moscow State Technical University, a Commission on Metal Cutting was established. The commission members included A.I.Kashirin, V.A.Krivoukhov, I.M.Besprozvanniy, and S.D.Tishinin.

The current state of metal cutting science is characterized by research into physicochemical phenomena in the cutting zone, interaction processes between the tool and the workpiece material, the development of new tool materials and metal-cutting tools, as well as high-speed cutting processes. Machining by metal cutting is a technological process in which material is removed in the form of chips to give a part the required shape, dimensions, and surface quality. It is performed on metal-cutting machine tools using cutting tools. The regularities of the cutting process are considered as the result of the interaction within the “machine-fixture-tool-workpiece” system. Any type of machining, including metal cutting, is characterized by the cutting mode, which consists of the following main elements: cutting speed, depth of cut, and feed rate.

The further development of metal cutting includes intensifying cutting processes, mastering the machining of new materials, improving machining accuracy and surface quality, applying strengthening processes, and automating and mechanizing production.

Analysis of the Influence of Drill Geometric Parameters in Hole Machining

One of the key factors of technological progress in mechanical engineering is the improvement of production technologies. A distinctive feature of modern manufacturing is the use of new structural materials: heat-resistant, corrosion-resistant, composite, powder, and polymer materials. Machining these materials requires improving existing technological processes and developing new methods that combine mechanical, thermal, chemical, and electrical effects.

The cutting process involves elastic and plastic deformations, material fracture, friction, tool wear, and vibrations of individual components and the entire technological system. Understanding these phenomena makes it possible to select optimal conditions that ensure high productivity and quality machining. The cutting process is a complex set of phenomena depending on the physical and mechanical properties of the workpiece material, tool quality, cutting conditions, machine condition, and the rigidity of the technological system.

Drilling is the primary method for producing through holes in solid metals and is also used to enlarge pre-drilled holes. Holes produced by drilling typically have a surface roughness of Ra = 5-20 μm and an accuracy grade of IT12-IT14 (in rare cases IT10-IT11). The relatively low accuracy of drilled holes is due to several factors: drill geometry, misalignment of the drill axis relative to the spindle axis, asymmetry of the cutting edges, and insufficient drill rigidity.

Drilling differs from other cutting processes in several specific features. The rake angle varies along different points of the cutting edge. The cutting speed is not constant: it starts from zero at the drill center and reaches a maximum value at the periphery. At the center of the hole, under the chisel edge, cutting practically does not occur; instead, the material is extruded. A characteristic feature of drill geometry is the presence of the chisel edge. The absence of a relief angle on the drill margins increases friction with the machined surface.

Another feature of the process is that the drill operates under confined conditions, surrounded by the workpiece material. This complicates chip evacuation and heat exchange with the environment, worsening cooling conditions.

In the conventional twist drill geometry, the presence of a negative rake angle contradicts fundamental principles of cutting theory.

Drilling and re-drilling can be carried out according to two schemes:

a) the drill rotates while the workpiece remains stationary;

b) the workpiece rotates while the drill remains stationary.

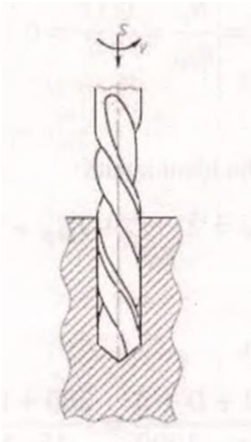

Figure 1.2

On drilling machines, drilling is performed when the tool rotates about its axis (the main motion) and simultaneously moves axially in a linear direction (the feed motion) (Fig. 1.2). The workpiece and the drill rotate in opposite directions.When drilling is carried out according to the first scheme, the hole is cylindrical; however, deviation of the drill axis may occur. Under the second scheme, the hole axis coincides with the axis of rotation of the workpiece and is straight, but tapering may form, and the hole diameter may vary along its length

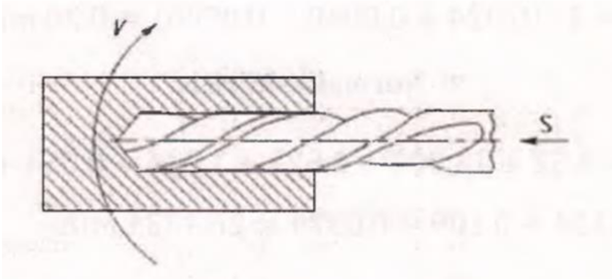

Figure 1.3

Twist drills are used to machine holes with diameters ranging from 0.25 mm to 80 mm. Drills outside this range are rare and considered exceptional cases. The application of large-diameter drills is limited by the rigidity of drilling machines and the structural rigidity of the workpieces, while the use of small-diameter drills is limited by the drill's own stiffness.

When drilling large-diameter holes, the feed force is reduced by opening the hole in two stages: first with a smaller-diameter drill, and then enlarging it to the required size with another drill. In this case, the diameter of the initial drill is taken to be equal to half of the final drill diameter.

According to the shape of the hole being machined, drills are classified into: cylindrical, conical, prismatic, and combined types.

Cylindrical drills are used for machining smooth cylindrical holes. Depending on the type of operation performed, the following cylindrical drills are used in practice:

a) Spade (flat) drills - used when twist drills are unavailable or when drilling hard materials;

b) Straight-flute drills - used for ductile materials, while helical-flute drills are used for various materials;

c) Standard twist drills - used for machining various materials;

d) Deep-hole drills - used when the ratio of hole depth to diameter exceeds d > 5-6 and the use of standard drills is difficult or impossible. This group includes extended twist and spade drills, gun drills, cannon drills, and annular drills;
e) Conical and prismatic drills. Conical drills are designed for machining slightly tapered holes in a single pass;
f) Prismatic drills - used for drilling polygonal holes;
g) Combined drills - mainly used for machining stepped and center holes.
In accordance with interstate standards, the following types of drills are specified:

- Twist drills with cylindrical shank (long series), diameter 1.95-20 mm;
- Twist drills with cylindrical shank (short series), diameter 1.0-20 mm;
- Short twist drills with cylindrical shank (long series), diameter 1.0-9.5 mm;
- Twist drills with tapered shank, diameter 6-80 mm;
- Twist drills with tapered shank (long series), diameter 6-30 mm;
- Extended twist drills with tapered shank, diameter 6-30 mm;
- Twist drills with cylindrical shank equipped with carbide inserts, diameter 5-12 mm;
- Twist drills with tapered shank equipped with carbide inserts, diameter 10-30 mm;
- Reinforced small-size twist drills with cylindrical shank, diameter 0.1-1.0 mm.

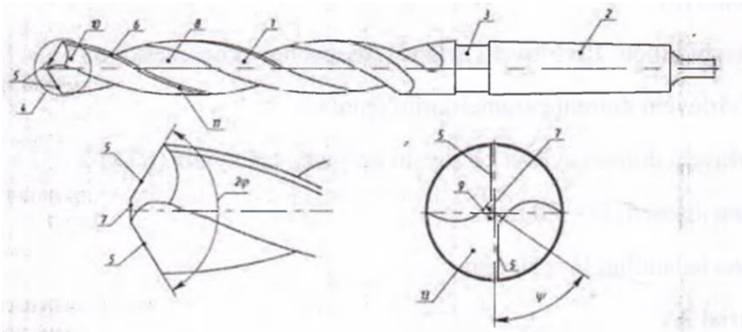

Figure 1.4

A standard twist drill (Fig. 1.4) consists of a working part (1), a neck (3), and a shank (2), which may be cylindrical or tapered.The cutting part of the drill (4) has two main cutting edges (5), two auxiliary cutting edges (6), and one chisel edge (7).

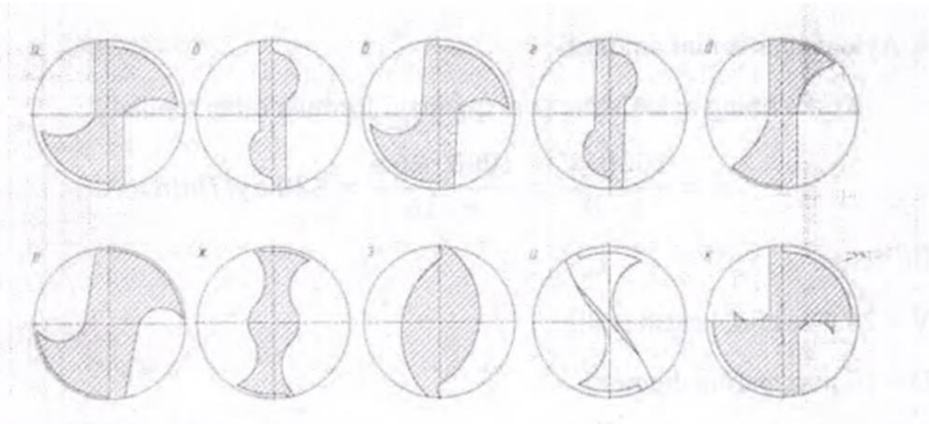

Figure 1.5 - Cross-sectional Profiles of Drills

Thus, improving machining productivity primarily depends on the tool’s service life, i.e., the time it can operate before being completely worn out. The challenge is to select optimal cutting speed and feed rate values so that, on one hand, the required tool life is ensured, and on the other hand, high productivity and the desired surface finish of the hole are achieved.

Standard drills with spiral or straight fluted grooves are used to drill holes in hard materials, and their cutting part design, as well as their cross-sectional profile, have several inherent limitations. The following factors affect the accuracy of the drilled hole and can lead to various defects:

- Plastic deformation of the workpiece surface layer during chip formation;
- Tool geometry, which may cause inherited errors;
- Mismatch between the tool diameter and the hole diameter, which can cause wavelike deviations along the hole due to guiding elements;
- Errors during tool installation or reinstallation, leading to misalignment of the hole axis.

Main Geometric Elements of a Drill

The main cutting edges of the drill are inclined relative to its axis, forming an angle of 2φ. Chips are evacuated through spiral (helical) flutes separated by a central core. Each drill land has a small auxiliary cutting edge that also serves as a guide during drilling.

The drill's rake surfaces are the flute-adjacent parts of the cutting edges. The flank surfaces are formed by grinding and provide the flank angle α and the relief; they can be flat, conical, cylindrical, or helical. The flank surfaces of the drill lands intersect to form the chisel edge, and its shape, size, and the inclination angle ψ relative to the cutting edges are defined by these surfaces.In standard drills, the cutting edge is usually straight, which simplifies inspection. For heat-resistant machining, the flute profile should have smooth transitions to prevent cracks and improve chip evacuation.

The cross-sectional profile of a drill is not strictly standardized. Figure 1.5 shows the most commonly used profiles. In Fig. 1.5a, the standard profile is illustrated, where a large portion of the cross-section is located at the periphery. This results in low torsional resistance and reduced stiffness.

Methods to increase torsional resistance include forming a maximum-sized core web and increasing the thickness of lands near the center relative to the periphery (Fig. 1.5b-z) and increasing the helix angle ω of the flutes by 1.2-1.8 times.

A drill profile with a curved cutting edge (Fig. 1.5i) ensures a uniform rake angle γ_n along the main cutting edge. Profiles with stepped projections in the flute create favorable conditions for chip breaking and twisting, facilitating chip evacuation from the cutting zone (Fig. 1.5k).

Improving workpiece surface quality is achieved by increasing the drill's stiffness, vibration resistance, and wear resistance, as well as optimizing its geometric and structural parameters.

Drilled Hole Quality and Drill Parameters

The quality of holes obtained by drilling depends on the drill's geometric and structural parameters. Geometric parameters include:

- Rake angle γ;
- Flank angle α;
- Point angle 2φ;
- Chisel edge angle ψ;
- Helix angle of the flute ω.

Structural parameters include the drill material and grinding shape.

The helix angle ω affects chip formation, chip evacuation from the cutting zone, and the effectiveness of coolant and lubricants. Optimizing this parameter increases productivity, reduces costs, and improves hole accuracy, especially when machining difficult-to-cut materials.

The sharpness of the cutting edge tip facilitates penetration into the metal. Reducing this angle improves heat removal but decreases the cutting area at the tip, increasing overheating and tool wear.

Modern Challenges and Development Directions

When machining new structural materials, cutting forces and temperatures increase, accelerating tool wear. Therefore, the following directions are particularly relevant:

- Development of high-strength carbide tools;
- Implementation of high-speed cutting technologies;
- Application of strengthening machining methods.

CONCLUSION

Drilling is a complex process based on physical and mechanical phenomena. Hole quality and accuracy depend on drill geometry, cutting conditions, and the rigidity of the technological system. The widespread use of new materials in modern manufacturing requires scientific optimization of the drilling process. Correct selection of geometric parameters and the use of modern tool materials ensure high productivity and quality.

References

1. Umarov T. Reliability of High-Speed Steel Cutting Tools. International Remote Scientific-Technical Conference "Technology-2001," Orel, Russia. Internet: www.OSTU.ru/conf/tech2001/html.

2. Umarov T. Reliability of Drills Equipped with Carbide Inserts. Journal "Metalloobrabotka," St. Petersburg (Russia), 2002, No. 5, pp. 5-6.

3. Turonov M. Z., Umarov T., Normatov S., Bekturov D. Wear Resistance Analysis of HSS Drill Bits P6M5 and Special Round Carbide Drill Bits VK8 for Drilling Alloyed Steels and Alloys. E3S Conf., 2023. Link

4. Odintsov L.G. Strengthening and Finishing of Parts by Surface Plastic Deformation: Handbook. Moscow: Mashinostroenie.

5. Mostalygin G.P., Tolmachevskiy N.N. Mechanical Engineering Technology, 1990.

6. Kovshov A.N. Mechanical Engineering Technology: Textbook for Students of Mechanical Universities. Moscow: Mashinostroenie, 1987.

7. Tursunov Sh.E. Fundamentals of Mechanical Engineering Technology. Tashkent: Transport Publishing, 2023.

8. Industrial Applications of Lasers / Ed. G. Köbner; Transl. A.L. Stirnova; Ed. I.V. Zueva. Moscow: Mashinostroenie, 1988.

9. Umarov E.O. Theory of Cutting and Tools, Part 1. "Science and Technology," 2019.

Umarov T., Aliqulov D.E. Possibilities of Reducing Technological Cycles of High-Speed Steel Tool Machining. Journal "Metalloobrabotka," St. Petersburg (Russia), 2002.