FUNDAMENTALS OF TOOL DESIGN

AMERICAN SOCIETY OF TOOL AND MANUFACTURING ENGINEERS

FUNDAMENTALS OF TOOL DESIGN

CONCERNING THE THEORY, PRINCIPLES, AND TECHNIQUES FOR THE MODERN DESIGN OF CUTTING TOOLS, CUTTING AND FORMING DIES, FIXTURES, AND OTHER RELATED TOOLING

Prepared Under Auspices of:

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PREFACE

American industries utilize millions of men, production tools, machines, processes, material handling devices, buildings, other related facilities, and billions of dollars in order to shape and produce materials to meet the needs of mankind. The competitive system forces a methodical selection and utilization of the factors of production in the manufacture of high quality products at a low cost. The many alternative processes available to change the size and shape of materials require complementary tooling. Ingenuity is required in the design of this tooling to facilitate scheduled and economic machining, casting, joining and pressworking of the many engineering materials.

The field of tool and manufacturing engineering encompasses a wide variety of industries. It is concerned with the manufacture of airplanes, food handling equipment, glassware, refrigerators, communications equipment, sewing machines, machine tools, textiles, electronic equipment, sporting goods, automobiles, stoves, furniture, packaging equipment, missiles, farm equipment, space capsules, and so on. It is a necessary function in unit or high volume production and in large or small enterprises. The tool and manufacturing engineer articulates in an environment which requires a thorough understanding of scientific and engineering principles. He must understand the broad manufacturing aspects of the industry in which he is employed and he must also be able to design specific production tooling.

This book has been written to meet a need for a fundamental textbook on the subject of tool design. It is a textbook which describes the basic principles of the design of tools for the material removal, pressworking, casting, joining and inspection processes. Engineering and scientific principles have been considered in all sections of the book in an attempt to explain why tools work the way they do. The various sections of the textbook have been written by authors who are experts in their respective fields of tool and manufacturing engineering.

The allocation of time for a specific course of study depends largely on the instructor, the prerequisite courses, and the time available for the course. An approximate time allocation based on the importance of the subject and teaching ease can be stated as follows:

Tool design for the material removal processes	40 per cent
Tool design for the pressworking of materials	30 per cent
Tool design for the inspection and gaging processes	15 per cent
Tool design for the material joining processes	10 per cent
Tool design for the material casting processes	5 per cent

This time allocation is appropriate for one or more courses on the general subject of tool design.

The Textbooks Subcommittee is indebted to the many authors and reviewers who generously contributed time from their already busy schedules.

The continued interest of Mr. Dale Long, as former President of the American Society of Tool and Manufacturing Engineers, inspired the Textbooks Subcommittee to forge ahead during the difficult periods.

Our thanks also to all the Directors and Officers of the Society for their support and encouragement and to the members of the Technical Publications Committee for their guidance and active participation. The tireless efforts of Mr. W. J. Potthoff, Emerson Electric Manufacturing Company, who helped to coordinate the various phases of the book are indeed appreciated. The editing assistance of Mr. F. W. Wilson, Technical Director of A.S.T.M.E., and his staff is highly valued by all. Thanks also to Mr. R. L. Perlewitz of The George J. Meyers Company, Mr. C. E. Lane of The David Ranken School of Mechanical Trades, Mr. R. E. Nauth of the Detroit Engineering Institute, Professor E. Laitala of Clemson College, Mr. D. J. McKeon of the Pioneer Central Division, Bendix Aviation Corporation, Professor A. B. Draper of the Pennsylvania State University, Mr. Stanley Snorek, Western Electric Company, and Mr. Gilbert Stafford of the Dixon Corporation, who assumed responsibilities for major sections of the book. We are grateful for the patience of our spouses and families who were frequently neglected while the textbook was being written.

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CONTENTS

1

DESIGN OF MATERIAL-CUTTING TOOLS

The primary method of imparting form and dimension to a workpiece is the removal of material by the use of edged cutting tools. An oversize mass is literally carved to its intended shape. The removal of material from a workpiece is termed *generation of form by machining,* or simply *machining.*

Form and dimension may also be achieved by a number of alternate processes such as hot or cold extrusion, sand casting, die casting, and precision casting. Sheet metal can be formed or drawn by the application of pressure. Metal removal can be accomplished by chemical or electrical methods. A great variety of workpieces may be produced without resorting to a machining operation. Economic considerations, however, usually dictate form generation by machining, either as the complete process or in conjunction with another process.

Elements of the Machining Process. Material removal by machining involves interaction of four elements: the cutting tool, the toolholding and/or guiding device, the workholder, and the workpiece. The cutting tool may have a single cutting edge or may have many cutting edges. It may be designed for linear or rotary motion. The geometry of the cutting tool will depend on its intended function. The toolholding device may or may not be used for guiding or locating. Toolholder selection will be governed by tool design and intended function.

The physical composition of the workpiece will greatly influence the selection of the machining method, the tool composition and geometry, and the rate of material removal. The intended shape of the workpiece will influence the selection of the machining method and the choice of linear or rotary tool travel. The composition and geometry of the workpiece will to a great extent determine the workholder requirements. Workholder selection will also depend on forces produced by the tool and toolholder on the workpiece. The workholder must hold, locate, and support the workpiece. Tool guidance may be incorporated into the workholding function.

Successful design of tools for the material-removal processes requires above all a complete understanding of cutting-tool function and geometry. This knowledge will enable the designer to specify the correct tool for a given task. The tool in turn will govern the selection of toolholding and guidance methods. The tool forces will govern selection of the workholding device. Although the process involves interaction of the four elements, everything begins with and is based on what happens at the point of contact between the workpiece and the cutting tool.

SINGLE-POINT TOOLS

The Basic Tool Angles

Cutting tools are designed with sharp edges to minimize rubbing contact between the tool and workpiece. Variations in the shape of the cutting tool influence tool life, surface finish of the workpiece, and the amount of force required to shear a chip from the parent metal. The various angles ground on a tool bit are called the *basic tool angles,* and compose what is often termed the *tool geometry*. The *signature* is a sequence of numbers listing the various angles, in degrees, and the size of the nose radius. This numerical method of identification has been standardized by the American Standards Association, and is illustrated in Fig. 1-1, together with the elements that make up the tool signature.

Back Rake Angle. This is the angle between the face of the tool and a line that is parallel to the base of the toolholder. It is measured in a plane that is parallel to the side cutting edge and perpendicular to the base. Variations in the back rake angle affect the direction of chip flow. As this angle is increased while other conditions remain constant, tool life will increase slightly and the cutting force required will decrease. Because continual regrinding of this angle reduces the thickness of the tool with its resultant weakening, steep rake angles are usually obtained by alterations in the side rake rather than the back rake angle.

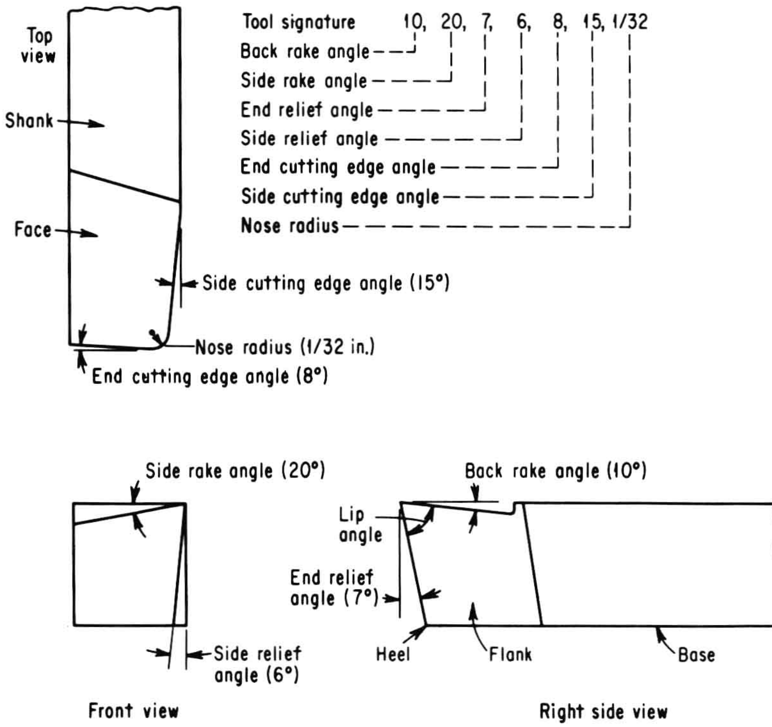

Fig. 1-1. A straight-shank, right-cut, single-point tool, illustrating the elements of the tool signature as designated by the ASA. Positive rake angles are shown.

Side Rake Angle. This angle is defined as the angle between the tool face and a plane parallel to the tool base. It is measured in a plane perpendicular to both the base of the holder and the side cutting edge. Variations in this angle affect the direction of chip flow. As the angle is increased, reductions in cutting force, increased tool life, and improvement in surface finish usually result.

End Relief Angle. This is the angle between the end flank and a line perpendicular to the base of the tool. The purpose of this angle is to prevent rubbing between the workpiece and the end flank of the tool. An excessive relief angle reduces the strength of the tool, so the angle should not be larger than necessary.

Side Relief Angle. This is the angle between the side flank of the tool and a line drawn perpendicular to the base. Comments regarding end relief angles are applicable also to side relief angles. For turning operations, the side relief angle must be large enough to allow for the feed-helix angle on the shoulder of the workpiece.

End Cutting Edge Angle. This is the angle between the edge on the end of the tool and a plane perpendicular to the side of the tool shank. The purpose of the angle is to avoid rubbing between the edge of the tool and the workpiece. As with end relief angles excessive end cutting angles reduce tool strength with no added benefits.

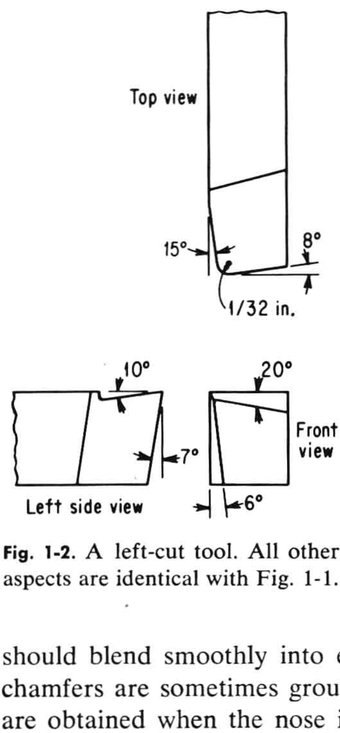

Fig. 1-2. A left-cut tool. All other aspects are identical with Fig. 1-1.

Side Cutting Edge Angle. This is the angle between the straight cutting edge on the side of the tool and the side of the tool shank. This side edge provides the major cutting action and should be kept as sharp as possible. Increasing this angle tends to widen the thin chip and influences the direction of chip flow. An excessive side cutting edge angle may cause chatter and should be avoided. As the angle is increased, increased tool life and minor improvement in surface finish can be expected. However, these benefits will usually be lost if chatter occurs, so an optimum maximum angle should be sought.

Nose Radius. The nose radius connects the side and end cutting edges and should blend smoothly into each to facilitate grinding. Although straight chamfers are sometimes ground to form the nose, most satisfactory results are obtained when the nose is in the form of an arc. Sharp-pointed tools have a nose radius of zero. Increasing the nose radius from zero avoids high heat concentration at a sharp point. Improvement in tool life and surface finish and a slight reduction in cutting force usually result as nose radius is increased. There is, however, a limit to radius size that must be considered. Chatter will result if the nose radius is too large; an optimum maximum value should be sought.

Tool Signature. The seven elements that comprise the signature of a single-point cutting tool are always stated in the following order: back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting edge angle, and nose radius. Figure 1-1 illustrates and lists the signature of a single-point tool as 10, 20, 7, 6, 8, 15, $\frac{1}{32}$. It is usual practice to omit the symbols for degrees and inches, simply listing the numerical value of each component. Unless specified, the rake angles are understood to be positive as shown. Negative rake angles are shown in Fig. 1-3.

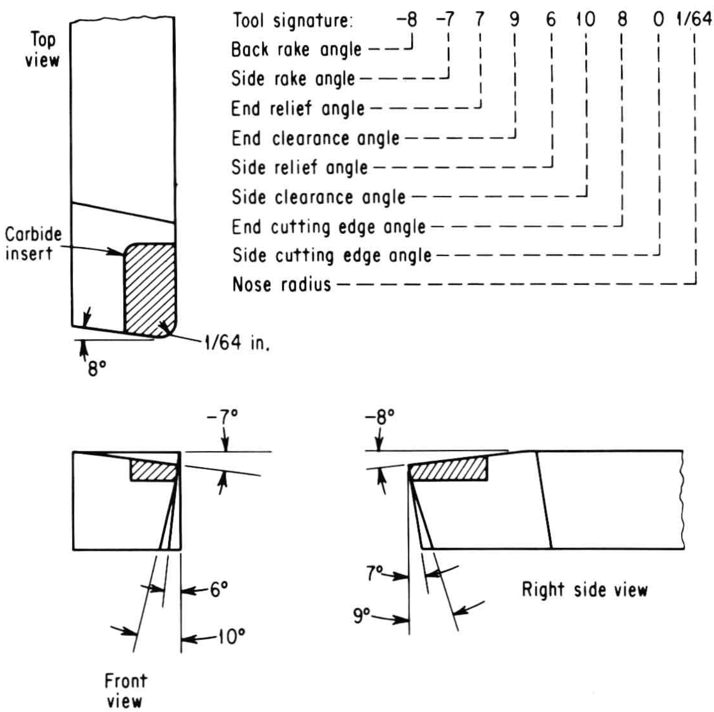

Fig. 1-3. A straight shank, right-cut, sintered-carbide tipped, single-point tool. Rake angles are negative and secondary clearance angles on end and side are illustrated.

A comparison of Figs. 1-1 and 1-2 illustrates the difference between a right- and left-cut tool. Tools are usually ground as the right-cut type. In some cases, secondary relief or clearance angles are employed as illustrated and specified in Fig. 1-3. The additional angles are added to the basic tool signature as shown.

Figure 1-4 illustrates the effect of using a holder that positions the base of the tool in a plane nonparallel with the plane of feeding motion. A 15° toolholder is used, and the tool signature indicates the angles that result