A STUDY OF SINGLE - POINT LATHE TOOLS

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CHAPTER I

INTRODUCTION

The machinist has three objectives in mind when using a metal-cutting lathe; (1) reduce the work to an accurate size, (2) obtain a good surface finish, and (3) do the job efficiently. Achievement of these objectives requires a sound knowledge of contributing factors such as the characteristics of the metal in the work-piece and tool, mechanical characteristics of the lathe, and the function of the cutting tool in the cutting process. Without such knowledge, the machinist is forced to resort to the costly trial-and-error method when confronted with difficulties, rather than isolating the cause and quickly obtaining a solution.

Statement of the problem. The problem as presented in this study consists of how to (1) develop and present concepts that would adequately demonstrate the elements of the cutting process as related to successful lathe operation; (2) devise a technique for making case studies to present principles and fundamental ideas; and (3) construct the equipment essential to this technique.

The body of the thesis concerns the first part of the problem. The technique employed in making the case studies is readily apparent to the reader. The third part of the problem is treated in a special section in the Appendix.

Purpose and importance of the study. The purpose in making this study was to investigate the characteristics and functions of single-point tools with respect to the fundamentals of cutting action and their application to specific lathe problems.

Such a study is significant for three reasons: first, it leads to better understanding of the principles of cutting action and the influence of the variables affecting it; second, this knowledge is basic to other machine tools employing single-point and multiple-point tools; and third, too little attention has been given to this problem in machine shop texts.

Limitations of the study. Because of the complexity and number of the contributing factors in the lathe cutting process, and the almost countless different conditions that may be encountered, this study is, of necessity, restricted to a relatively small area. In addition, it is specifically limited to (1) the so-called High Speed Steel type of cutting tools, (2) standard lathe operations, (3) a brief treatment of fundamentals, (4) a brief technical discussion; and (5) only a few of the case studies needed to convey a complete set of concepts.

Methods and procedure. Through a careful study of engineering and technical publications containing articles on cutting tools, cutting processes, and cutting action, data was obtained with which to develop a brief discussion on the fundamentals of cutting action. This data has also been applied to a technical, but practical, discussion of the variables in the lathe cutting process and the influence of these variables on cutting action as it concerns results obtained in lathe operation.

Experimental test cuts have been made and their results used to illustrate principles and concepts of cutting action. The contributing conditions and the outcome of these tests have been photographically recorded and made into case studies, which are grouped together in Appendix B. These photographs show details from two to ten times their actual size.

Standard forms of cutter bits have been ground by hand and by precision methods; these tools have been photographed at ten diameters magnification in order to illustrate the difference in results obtained.

In the case studies on surface finish, effect of built-up-edge, effect of chatter, the tool, the work, and (in cases where practicable) the lathe setup, all are photographed before and after the test is completed. Chapter II, Fundamentals of the Cutting Process, is illustrated in part with photo-macrographs of chips that illustrate the facts under discussion.

An effort has been made to maintain controlled cutting conditions for the tests made in the shop. All the cutting tools used, except those for illustrative purposes, have been precision ground on a Cincinnati Tool Grinder. A medium grade aluminum oxide cup-wheel was used to grind one set of cutter bits. For purposes of comparison, another set was ground using the same grade wheel of the plain type on which the tool is ground on the periphery. The majority of the tests were made on mild steel of cold drawn type.

The principles and fundamentals being illustrated are as follows:

1. Distortion and displacement of metal in the cutting process.

2. Fragmentation of the work surface.

3. Galling of the work surface.

4. Formation of smear metal in the chip.

5. Influence of rigidity on cutting action.

6. Progressive development of the built-up-edge.

7. Effect of built-up-edge on surface finish.

8. Effect of negative rake on surface finish.

9. Influence of cutting speed on surface finish.

10. Influence of precision grinding of the cutting tool on cutting action.

11. Effect of tool chatter on surface finish.

12. Segmentation of the chip.

Definition of terms. The following definitions are limited to a few vital terms. These terms are defined in the manner in which they are used in the study.

Cutting tool. A cutting tool is interpreted as being any tool with which a cut is made. For lathe application, the word is used in a general way. Under the classification of cutting tool there are such specific tools as rough turning tool, facing tool, round nosed tool, finishing tool, and parting tool. Unless otherwise specified, the word usually refers to a standard rough turning tool.

Lathe variable. Any factor in the cutting process which by its change will influence one or more of the other factors in the cutting process is known as a lathe variable. It includes factors introduced by the cutting tool, the work, the lathe, change in cutting conditions, or use of additional aids such as cutting fluids.

Photomacrograph. A picture containing an enlarged image by direct exposure that is magnified up to ten diameters is known as a photomacrograph. Any magnification above ten diameters is a photomicrograph.

Single-point tools. Single-point tools are a class of cutting tools as contrasted to multiple-point cutting tools, which have more than one cutting edge or point. For example, a milling cutter is a multiple-point tool because its many cutting edges are integral with the cutter; whereas, a single-point lathe tool has only one cutting point.

CHAPTER II

FUNDAMENTALS OF THE CUTTING PROCESS

No matter how complex the original process, there are always three basic elements remaining when any cutting process is reduced to its essentials. In the first place, some type of cutting action occurs; in the second place, the cutting tool and the work must be supported; and in the third place, the cutting tool and the work must be controlled during the cut. Consequently, the development of the fundamentals of the cutting process will be based on the three elements--cutting action, support, and control.

A. PRINCIPLES OF CUTTING ACTION

According to the dictionary, the word "cut" can mean many things, such as gash, cleave, sever, separate, penetrate, or shape. As will be indicated later in the chapter, the word also expresses many types of action that take place when metal is removed to shape an object in a lathe.

Cutting action. No matter what type of a cutting process an individual undertakes, whether it be cutting with a knife, a jack plane, a chisel, or a hacksaw, both pressure and motion must be applied to the cutting tool or to the metal being cut. Whether the cut takes the desired direction or not, depends entirely upon how much control is exerted between the cutting tool and the material being cut.

An analysis of some of the common types of cutting, such as slicing bread, chiseling metal, and scraping wood, will reveal that there is a different combination of pressure and motion in each one. In slicing bread, the edge moves at a relatively high speed, with only light pressure being applied to the knife. In the chiseling of metal, the cutting edge of the chisel moves very slowly when pressure is applied, but such heavy pressure is required that strong blows from a hammer must be used. If the material being chiseled were wood, less pressure would be necessary; but, higher speed would result if the same total force were used. In the process of scraping wood or scraping metal, for example, both relatively high speed and heavy pressure are essential.

Similarly, the cutting action of a lathe tool requires high pressure --due to the nature of the metal--and high speed for efficiency. Another reason for using high speed on the lathe is to achieve greater momentum which results in greater energy being applied to the cut; consequently, the chip is more easily removed from the parent metal. This fact is somewhat analagous to the situation where tornadoes have driven wooden splinters through the sides of freight cars. In this case, although the splinter has little mass, the velocity with which it traveled was sufficient to give it the necessary kinetic energy to penetrate the steel.

Characteristics of a lathe tool. In order for a lathe tool to cut at high speed and under heavy pressure, it must possess suitable characteristics to withstand these conditions. As in the chisel, the lathe tool must have a cutting edge with sufficient metal supporting it to withstand the forces and shock to which it is subjected. Results of tests have shown that the forces mentioned above have been as high as 128 tons to the square inch.[1] Considering the cross-sectional area of metal being removed in an average roughing cut, this means that as much as one and one-half tons pressure is exerted on the cutting tool.

Since it is evident that the cutting edge must have metal to support it, it should also become evident, upon consideration, that there must be clearance in back of the cutting edge to allow it to enter the work. A chisel will not cut unless it is raised slightly to allow clearance for it to enter, nor will a lathe tool cut unless it has clearance. In lathe cutting, the tool cuts on the nose as well as the side; it must, therefore, have clearance at the nose or front of the tool in addition to clearance at the side.

There are three important characteristics for a cutting tool: (1) it must have an edge; (2) it must have metal to support the edge; and (3) it must have clearance in back of the cutting edge. All lathe cutting tools have the three characteristics mentioned; and, in addition, the tools must possess other qualities that provide for maximum efficiency under conditions of high speed operation. For cutting most metals, the tool has "side rake" or side slope on the top face. This reduces the size of the wedge angle, hence requiring less force to make the cut. Too great a slope causes the wedge angle to be too small; as a result, the tool has a shortened life. The average turning tool has a wedge angle of about 68°. This angle compares favorably with the 60° wedge angle of a cold chisel.

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[1] Frederick W. Taylor, On The Art of Cutting Metals, Folder 14.

Since the lathe tool also cuts at the front as well as the side, it must have "back rake" with which to form a wedge angle with the front surface of the tool. This angle is generally known as the "lip angle." The surfaces, forming the two angles, come together at a point. This point, lacking metal to support it, does not last very long; therefore, except for special applications, a radius is ground on the tool from the front face to the side face.

The cutting quality of the tool is another characteristic which must be considered. Cutting quality includes the tools' ability to withstand heat, its ability to withstand abrasion and wear, its ability to withstand shock and impact, and its ability to withstand heavy pressures. These qualities are commonly referred to as red hardness, abrasion resistance, toughness, and strength. All are essential to maximum tool life. The kind of metal to be cut, the cutting speed, and the amount of metal to be removed per minute, determine the relative importance of each quality for individual tools.

Dynamics of cutting. It is not sufficient to say that a single-point lathe tool cuts with a scraping action. This is only partially true. There are several distinct types of action occurring almost simultaneously. The tool must wedge itself into the metal in order to start the cut and continue removing metal. Due to the wedging force exerted by the tool, there is a tendency for the metal to split ahead of the cutting edge. This separating force travels through the grain boundaries of the metal, along what metallurgists term, "planes of weakness."[2] Thus the separation which is occurring slightly ahead of the tool's cutting edge is rough; and as this rough surface passes the cutting edge, it is scraped. At the same time, the metal which is being literally torn from the work is pushed away from the parent metal by the top face of the tool. The force of this chip against the tool transmits the pressure up into the parent metal, causing the grains to distort and to be displaced from their original position. The distortion continues until a small portion of the metal is disrupted from the parent metal in the form of a chip. Since the pressure is not uniformly distributed to all the grain surfaces, they are subjected to a form of shearing action. This shear or rupture occurs just behind the tool edge, and at an angle almost perpendicular to the tool face.[3] This action occurs periodically, thus removing the metal in what is known as a "segmented chip." If the metal is relatively plastic in nature, as is mild steel, the periodic shearing occurs more rapidly. The segmentations are not as large, and do not actually separate, but come off the work as a continuous chip. This type of chip is illustrated in Figure 1.

In referring to cutting action, A. M. Swigert, Jr.[4] states, "Cutting with a metal cutting tool consists of pressing, tearing, or shearing the

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[2] ________, Changing the Shape of Metals With an Engine Lathe, p. 125.

[3] Hans Ernst, "Physics of Metal Cutting", Machining of Metals, p. 13.

[4] A. M. Swigert Jr., The Story of Superfinish, p. 176.

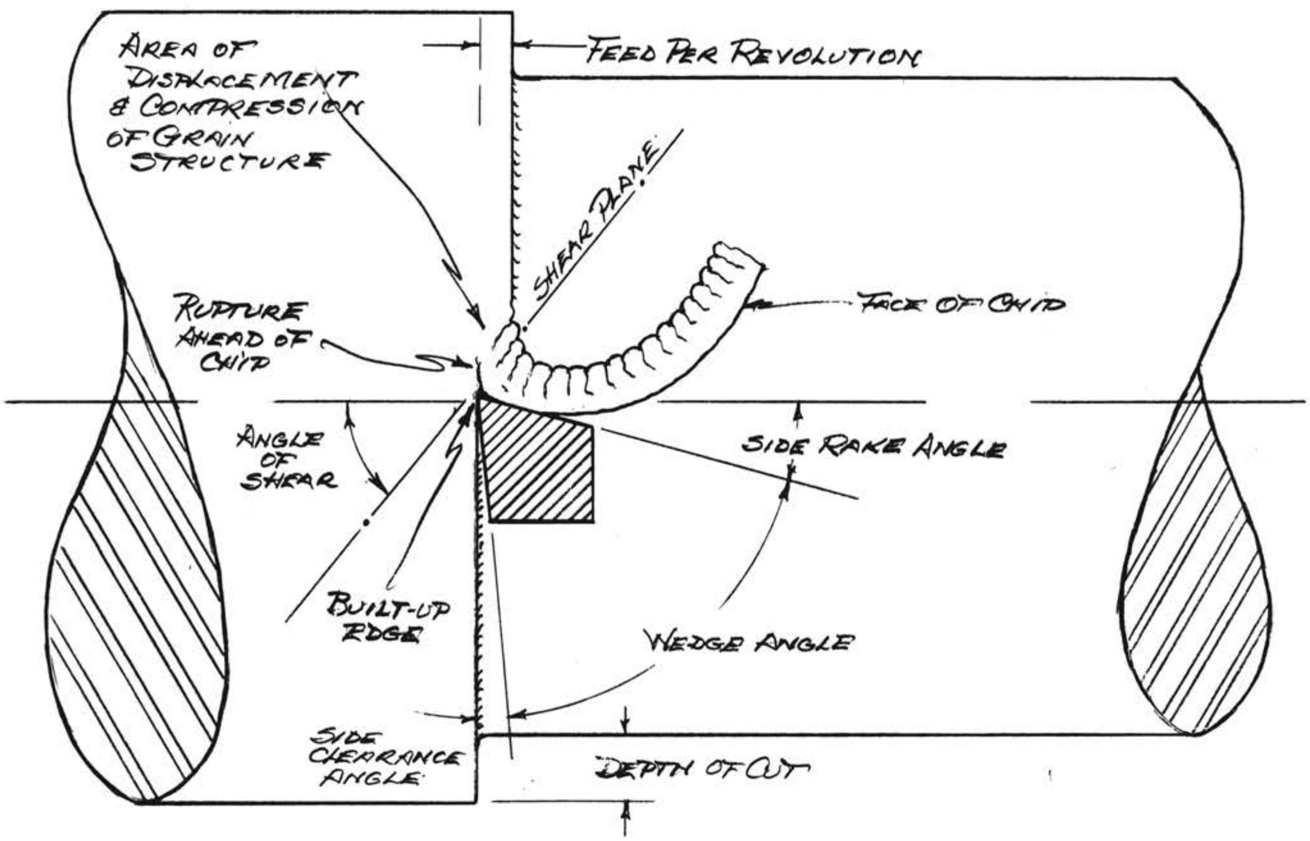

Figure 1

FORMATION OF THE CHIP IN THE CUTTING PROCESS metal away from the body of the part." If one can perceive the magnitude of the forces at work and the distortion, compression and displacement of the grain structure, it is not difficult to understand why pushing, wedging, tearing, shearing, and scraping actions occur in the metal cutting process.

Formation of the built-up-edge. Notice in Figure 1 that the chip begins to leave the body of the parent metal at a point slightly ahead of the cutting edge of the tool, leaving a jagged, irregular surface which is scraped and burnished by the cutting edge. The small flakes thus formed tend to weld to the cutting edge under the high temperatures and pressures of the cut. This built-up continues until size interferes with the flow of metal across the face of the tool; the built-up-edge is then broken away, and the process repeats itself. The built-up-edge is often referred to as a "false cutting edge;" it interferes with the normal function of the cutting edge by reducing its sharpness, and decreasing the penetrating power of the tool. The false edge also produces gouging of the work surface and the chip. Many tests have proven that the cutting pressure increases as the false edge builds up; and it drops back when the false edge is carried away with the chip flow. In cases where heavy cuts are taken at high speeds, the heat and pressure are great enough to bond the false edge to the tool for a considerable time before it finally breaks off. In fact, the built-up-edge is cyclic in nature and the frequency of its cycle is largely determined by the heaviness of the cut. In a finish cut for example, the cycle is so rapid that its effect is hardly noticeable to the naked eye on the surface of the work; but when viewed under a magnifying glass, it is easily seen.

Figure 2 is an excellent example of this effect.

Characteristics of the metal in the work. The formation and segmentation of the chip in the cutting process is largely influenced by the characteristics of the metal that is cut. It is true that the nature of the metal in the cutting tool exerts a similar effect on the cutting process, but this study is limited to one type of cutting tool, namely High Speed Steel. Speaking again of the characteristics of metal in the work, machinists refer to the behavior of the metal during the cut as its machinability. In order to evaluate the relative machinability of different metals, Bessemer screw stock (SAE X112) is used as the standard or normal. It has a machinability of one hundred. Other alloys that are easier to machine have a rating above one hundred; those more difficult to machine have a rating below one hundred. The machinability rating gives an indication of the accuracy and surface smoothness which can be obtained at high cutting speeds and with long tool life. Machinability is considered to be one of the mechanical properties of steel; and manufacturers such as Joseph T. Ryerson & Son, Incorporated list in their handbook the machinability rating of the steels they manufacture.

In the machining of mild steel, the chips normally come off as a continuous piece; this is due to the fact that mild steel has a relatively small grain structure with a fairly strong bond between the grains. Cast iron has larger and harder grains than steel with a poor bond between the grains. In the cutting process, the chips come off in short sections that may readily be crumbled in the hand. The harder, coarser grains in cast iron have an abrasive effect on the cutting edge of the tool; consequently,

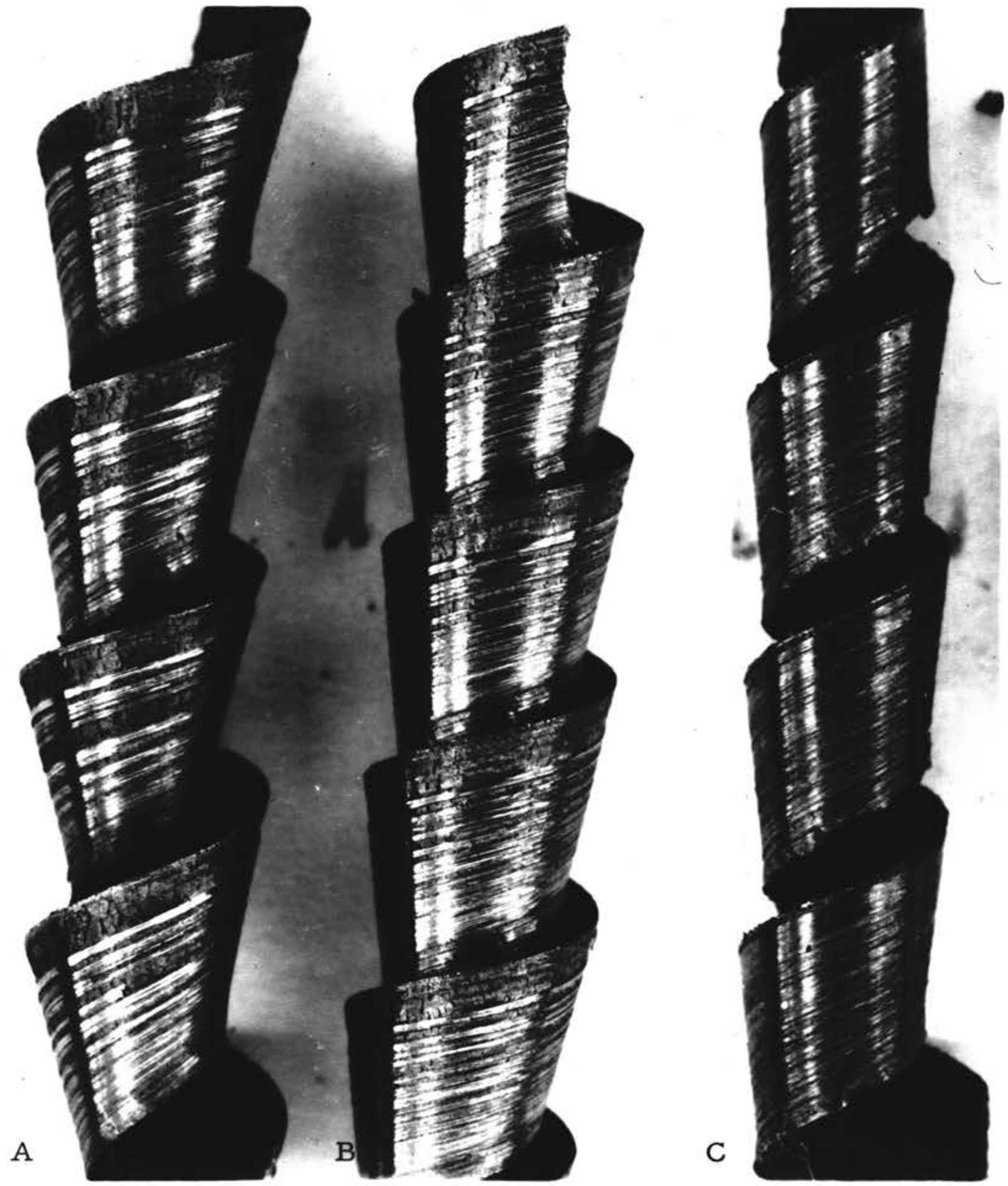

Figure 2

10X PHOTOMACROGRAPH OF CRATERING IN ROUGH TURNING CHIPS
SAE 1020 STEEL

In chip A, cratering from built-up-edge has reached maximum. The end of secondary band of cratering can be see on bottom turn of chip.
In chip B, secondary band has disappeared, cratering is not as deep because built-up-edge has worn away slightly; notice tighter curling of chip B as compared to chip A.
In chip C, evidence of built-up-edge has completely disappeared, chip is curked tighter and beginning to serrate at the edges due to increased vibration and cutting pressure caused by dulling tool edge.

lower speeds must be used for cast iron. Because the tool must withstand heavier pressures and greater temperatures, the cutting edge for cast iron needs more metal to carry off the heat, and absorb the pressure, than does the cutting edge for mild steel. For these reasons, tools for cutting cast iron have little, if any, side rake.

When observed through a slow-motion macro-camera, the cutting action in cast iron consists mostly of a crumbling and scraping process, with no wedge action and an indeterminate shear angle.

The generation of heat in metal cutting. The mechanical energy of the rotating lathe spindle is converted into heat during the cutting process. This heat originates at three different sources.[5] It has been mentioned that pressure is transferred from the tool face, up through the grains of the parent metal, causing the grains to distort and shift their position along planes of weakness. The friction between the grains as they move in relation to each other, creates heat within the body of the metal just above the nose of the tool; the heat thus generated is known as the *heat of deformation.* As the chip curls away from the face of the tool, it is distorted into its characteristic curl. In this process, the chip is separated from the work along a line almost perpendicular to the tool face. When the chip passes off along the face, it is bent almost at right angles to the direction in which it was forced from the parent metal. This causes the metal on the inside of the bend to be compressed, whereas the metal on the

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[5] ________, *Changing the Shape of Metals With an Engine Lathe*, p. 134.

underside is stretched and drawn out. In this action of distorting the chip, internal friction between the grains causes heat, often referred to as the heat of chip distortion. Due to the great amount of friction that occurs as the chip slides over the face of the tool, the greatest amount of heat is generated at the tool face. This is usually referred to as the heat of friction. In reality, all the heat created in the cutting action is heat of friction; but the distinctions are made for the sake of identifying the three different areas which are the sources of heat.

In heavy cuts where large volumes of metal are distorted and heavier pressures are exerted on the tool, more energy is required to make the cut; hence, more is converted into heat. Often this heat is sufficient to turn the chip blue as it comes off the work. According to the color temperature chart,this color would correspond to a temperature of about 850° F. According to the findings of Schmidt and Roubik[6], at a cutting speed of 100 feet per minute, the chip carries away approximately seventy-five per cent of the heat generated in the cut. This would indicate that the cutting temperature in this case would be close to 1200° F. If it were not for the fact that this heat is carried away by the chip and dissipated through the tool and work, the cutting edge of the tool would be quickly destroyed. Interestingly enough, it is the fact of whether the heat generated can be carried away rapidly enough, that sets the upper

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[6] A. O. Schmidt and J. R. Roubik, "Some Thermal Aspects of Metal Cutting," Tool Engineering 21:21-22, (November, 1948.)

limit of cutting speed with respect to economical tool life.

Function and purpose of cutting fluids. From the facts previously discussed, it is rather obvious why cutting fluids play such an important part in high speed lathe operation. Not only does the cutting fluid help to rapidly dissipate the heat, but it also supplies a lubricating film between the chip and the tool face, thereby reducing friction at the greatest source. One theory on cutting fluids maintains that a lubricating action occurs in the cut at the tool edge when a cutting fluid is used.[7] In fact this source lists the functions of a cutting fluid as, "lubricating," "cooling," and "anti-welding." It is a well-known fact that a cutting fluid will reduce the tendency of metal fragments to weld to the tip of the tool and build up an edge; this is not surprising when one considers that the use of a fluid reduces the temperature at the tool point.

Summary of cutting principles. At this point, it might be well to briefly summarize the significant cutting principles that have been discussed:

1. High pressure and relatively high speed are required for the cutting action of a single-point lathe tool.
2. The cutting tool must possess a cutting edge, metal to support the edge, and clearance for the edge to enter the work.
3. The tool cuts by wedging or forcing its edge into the work,

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7 ______, Changing the Shape of Metals With an Engine Lathe, p. 135.

compressing the metal and shearing a chip off the work, and forcing this chip over the face of the tool and away from the parent metal.

4. Very small fragments of metal, broken off in the tearing and rending of the cut, tend to weld themselves to the face of the tool under high temperature and pressure, gradually forming a false cutting edge that periodically breaks away from the tool face and is carried off in the chip flow.
5. The build up and breakdown of the false-edge is accompanied by a concurrent undercutting and smearing of the work surface.
6. The false-edge cycle produces an accompanying rise and fall in the cutting pressure, which is maximum when the false-edge is largest.
7. What occurs in the cutting action is largely determined by the characteristics of the metal in the cutting tool and the metal being cut.
8. In the cutting process, heat is generated in three areas: namely, in the work, in the chip, and between the chip and the tool face.
9. Cutting fluids perform two important functions; they carry off the heat generated in the cut, and lubricate between the chip and tool face. As a result of these functions, higher cutting speeds and better surface finish are achieved.

B. PRINCIPLES OF TOOL AND WORK SUPPORT

The fact has been mentioned that the cutting edge must have metal to support it; but this is only the beginning of the problem of support in the cutting process. Many of the everyday troubles in lathe cutting can be traced back directly to improper or insufficient support of the work or the cutting tool.

Proper and sufficient support. Before continuing the discussion any further, the definition of the use of the two words, proper and sufficient, should be given. Proper support would be achieved in cases where the lathe mechanism has provisions for rigidly supporting the tool and the work; and these provisions are fully utilized. Sufficient support would be achieved in cases where the setup supplied the necessary support to successfully make the cut. As can readily be seen, sufficient support may not constitute proper support. In other words, proper support suggests the greatest amount obtainable; whereas, sufficient support suggests just enough support to get by.

Factors in tool and work support. Generally speaking, lathe manufacturers design their equipment with provisions for proper support of the cutting tool and the work. Whether sufficient support is obtained for a particular operation depends upon a number of factors such as (1) the distance from the point of support to the cutting action which is taking place; (2) the amount of feed and the depth of the cut that is being used; (3) the cutting speed that is being used; (4) the toughness, hardness and elasticity of the metal being cut; and (5) the diameter-to-length ratio of the work.

The main object, in any case, is to obtain maximum rigidity. For the tool, this means keeping the cutting edge as close to the tool post or tool block as possible. For this reason, when the tool is displaced under cutting pressures, the closer it is to the point of support, the smaller will be the arc of its spring or displacement. Even under ideal conditions there is some displacement of the tool; but the heavier the mounting, and the closer the point of support, the more rigid the tool will be. Hence, the smoother the cut. For the work, obtaining maximum rigidity means keeping a low diameter-to-support-distance ratio. In other words, as Taylor states,[8] "It is economical to use a steady rest in turning any piece of metal whose length is more than twelve times its diameter."

Vibration and chatter. When the magnitude of the displacement of the tool or the work by the pressure of the cut reaches noticeable proportions, it leads to a form of periodic vibration known as chatter. Chatter is defined as,[9] "Vibration between tool and work sufficient in magnitude to cause a perceptible irregularity in the tool marks on the finished surface." When the tool or the work have insufficient support, there is a relative displacement between them. As a result, whether the tool is thrust down and springs back gouging out the surface of the work, or whether the work is thrust up and springs back down, makes little difference since the effect on the finish is the same. The magnitude of the

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[8] Frederick W. Taylor, On the Art of Cutting Metals, p. 153

[9] ________, Manual on Cutting of Metals, p. 49.

displacement can be judged from the frequency of the chatter; the lower the frequency, the greater the magnitude of the displacement. In some cases where the metal is unusually tough, as in chrome-molybdenum steel, chatter occurs even with proper tool support. Here, the nature of the metal being cut necessitates changing the cutting angles of the tool to avoid chatter.

Some authorities claim that a certain amount of chatter is beneficial when taking heavy cuts because it breaks up the chip without appreciably affecting the cutting speed. Such a benefit is of small importance compared to the excessive strain that chatter puts on the mechanisms of the lathe. Figure 3 shows a chip produced by chatter caused by the toolholder being insufficiently supported in the tool post. Usually, chatter within a short arc of motion produces chips of the type illustrated in Figure 4.

It is interesting to note that conditions which cause chatter in one lathe, may not cause chatter in another lathe under identical cutting conditions. This is particularly true if a larger or heavier lathe is used. Lathes of various makes and sizes have different natural periods of vibration. When the frequency of vibration established by the cutting condition happens to be the same or a harmonic of the natural frequency of the lathe, excessive chatter usually occurs. Changing the cutting conditions such as speed, feed, or depth of cut often eliminates chatter by changing the frequency to one that the lathe members will absorb, assuming of course, that proper support is used.

As mentioned previously, chatter from lack of sufficient support

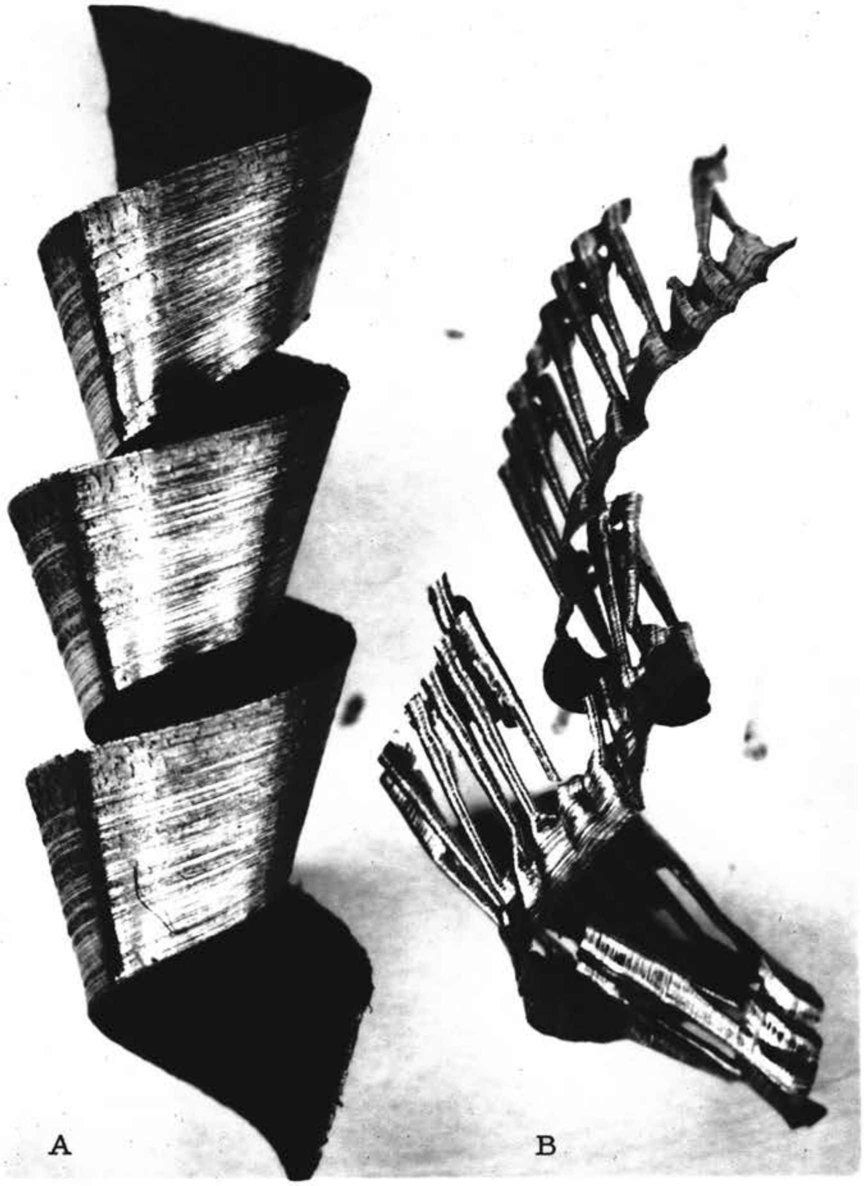

Figure 3

10X PHOTOMACROGRAPH OF TWO ROUGH TURNING CHIPS FROM SAE 1020 STEEL

Chip A resulted from spring in the tool holder, chip B from correcting the condition. Fragmented bands on chip B indicate areas of build-up on cutting tool edge.

Cutting Speed - - - - - - - - - - - - - - - - - - 80 ft./min.
Depth of cut - - - - - - - - - - - - - - - - - - 1/8 in.
Feed - .004"/rev.
Cutting Tool
Roughing tool, 1/32" nose radius, 10° side clearance, 12° side rake, 16° back rake, H.S. Steel Rex AAA, hand ground and honed. Lead angle 80°.

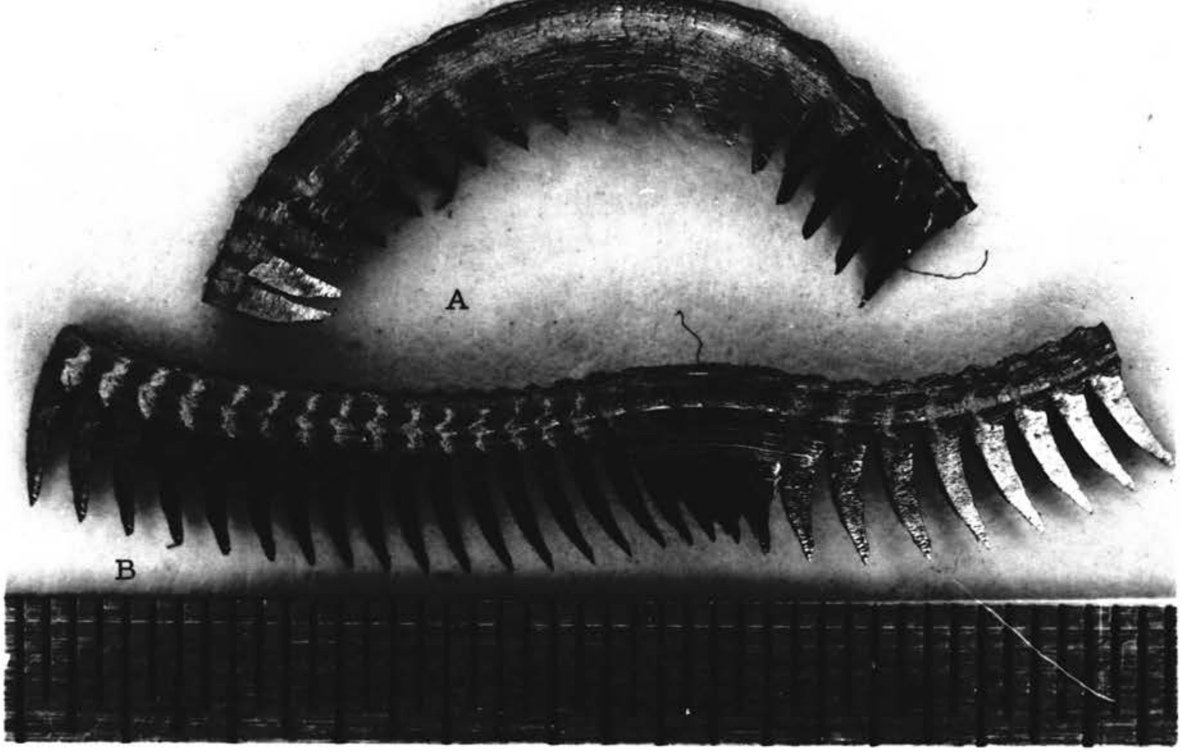

Figure 4 (Scale Graduated in 64ths)

10X PHOTOMACROGRAPH OF CHATTER CHIPS
SAE 1020 STEEL

Chip A
- Cutting Speed - - - - - - - - - - - - - - - - - 273 ft./min.
- Depth of Cut - - - - - - - - - - - - - - - - - - 1/16 in.
- Feed - .008"/rev.

Chip B
- Cutting Speed - - - - - - - - - - - - - - - - - 180 ft./min.
- Depth of Cut - - - - - - - - - - - - - - - - - - 1/16 in.
- Feed - .008"/rev.

Cutting Tool
- Rough turning tool K, (see Figure 21)

may occur in the work, the tool, or a combination of both. In any of these cases, chatter is detrimental to the surface finish and puts extra strain on driving and feeding mechanisms.

C. CONTROL OF THE TOOL AND THE WORK

Discussion of the fundamentals of the cutting process would not be complete without considering the element of control. It is true that the support of the tool and the work gives a measure of control in the cutting process; but this is not the primary factor in control.

Elements of control. In order for the tool to feed into the work, it must be controlled. In the same manner, taking the desired depth of cut requires tool control. The lathe usually is provided with hand and automatic means of executing control on the depth of cut and feed. It is in the use and manipulation of controls that the dexterity, or skill, of the operator plays such an important part in the final results. It is within these elements of tool control that the beginner finds his first difficulties, and the journeyman, some of his most ticklish problems.

The direction in which the tool moves as it continues the cut requires control. In the lathe, this is achieved by rotating the work; but in a machine tool such as the shaper, the tool itself moves in a reciprocating motion to make the cut. It is the linear velocity with which the cutting tool moves with respect to the surface of the work that determines the cutting speed. From this it can be readily understood that being able to change the rate of spindle rotation supplies control for variation in the cutting speed. Two controls are provided through the work; these are cutting speed, and direction of cut.

Shape producing factors. Variation in the rate of feed and depth of cut are obtained by controlling the cutting tool; the direction of the cut, and variation in the cutting speed are obtained by controlling the work. These might be considered as factors of control, for through them are derived what the Shell Oil Company terms, [10] "The shape producing factors;" that is, the line or direction of the cut and the path of consecutive cuts. The contour of the cutting edge is considered as the third shape producing factor, but it should be considered as an indirect element of control.

Strictly speaking, the elements of control cannot be separated from the elements of support because the two are interdependent; but for the purpose of conveying concepts, this liberty has been taken in order to make the meaning clearer.

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[10] ______, *Changing the Shape of Metals With an Engine Lathe*, p. 9.

CHAPTER III

LATHE TOOLS AND THE CUTTING PROCESS

Many contributions have been made by scientists and engineers since the close of the war that have advanced the understanding of the cutting process. Some of these studies are highly mathematical; others are concentrated on a particular technical phase such as the change in shear angle during the cut. Practically all of them are limited to one or two variables of the cutting process. Quite a few significant facts of practical value to the shop teacher may be found in these articles. Some of these facts will be discussed in this chapter as they pertain to the variables which make up the cutting process.

A. LATHE VARIABLES

In the scientific approach to lathe turning problems, the primary obstacle is controlling all the variables except the one being studied. This is one of the reasons why it has been so difficult to reduce cutting processes to a simple mathematical basis. Lathe variables are difficult to isolate because they are inter-dependent rather than independent. For example, if the variable cutting speed is changed, it affects (1) the tendency of the tool to chatter; (2) the cutting life of the tool; (3) the quality of the finish; and (4) in some cases, the accuracy of the cut. Thus, it is difficult to study cutting speed alone without encountering other factors which may or may not be attributed to changing the cutting speed.

Taylor[1] lists twelve variables which he terms, "Variable elements that affect the selection of the cutting speed of the tool.

a the quality of the metal which is to be cut;
b the diameter of the work;
c the depth of the cut;
d the thickness of the shaving;
e the elasticity of the work and the tool;
f the shape or contour of the cutting edge of the tool, together with its clearance and lip angles;
g the chemical composition of the steel from which the tool is made, and the heat treatment of the tool;
h whether a copious stream of water, or other cooling medium is used on the tool;
i the duration of the cut; i. e., the time which a tool must last under pressure of the shaving without being reground;
j the pressure of the chip or shaving upon the tool;
k the changes of speed and feed possible in the lathe;
l the pulling and feeding power of the lathe."

Taylor's interest was primarily in cutting speed to obtain better production; if however, the interest or study is on the cutting process specifically, the variables become more general in their classification.

There are at least sixteen variables in the cutting process which influence, directly or indirectly, any given lathe operation. For clarity and convenience, these may be classified as to type of variable, and the primary influence of the variable on the cutting process. Table I lists the sixteen variables and their influence.

Careful study of the Table reveals the interdependency of variables on one another. For example, by introducing cutting fluid as a variable, its use allows an increase in cutting speed, which in turn increases the rate

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[1] Frederick W. Taylor, On The Art of Cutting Metals, p. 4.

TABLE I

VARIABLES IN THE LATHE CUTTING PROCESS

Variables	Primary Influence on Cutting Process
1. Kind of metal in tool	Cutting speed, tool life, and finish on workpiece
2. Cutting tool angles	Chip formation, tool life, tool pressure, and cutting speed
3. Cutting tool shape	Tool life, finish on workpiece, and tool pressure
4. Method of grinding	Tool life and finish on workpiece
5. Feed angle of tool	Tool pressure, accuracy of cut, and effective angles
6. Mounting height of tool	Tool pressure, finish on workpiece, and accuracy of cut
7. Rigidity of tool mounting	Finish on workpiece, accuracy of cut, chip formation, and cutting speed
8. Kind of metal in workpiece	Cutting speed, rate of metal removal, and finish on workpiece
9. Rigidity of workpiece	Finish on workpiece, accuracy of cut, and chip formation
10. Cutting speed	Tool life, rate of metal removal, finish on workpiece
11. Amount of feed	Rate of metal removal, finish on work-piece, tool life, and chip formation
12. Depth of cut	Rate of metal removal, tool life, finish on workpiece and chip formation
13. Use of cutting fluid	Cutting speed, finish on workpiece, and tool life
14. Size of lathe	Size of work, and available spindle speeds
15. Power of lathe	Rate of metal removal, and cutting speed
16. Condition of lathe	Accuracy of cut, finish on workpiece, and rate of metal removal

of metal removal may improve the finish, and should increase the life of the tool. Finally, a more powerful lathe might be needed in order to take advantage of the increase in cutting efficiency. As another illustration, the lack of rigidity in the work may require reduction in the cutting speed, rate of feed, and depth of cut; chatter may be encountered thereby damaging the surface finish, and a change in tool angles may be necessary to counteract the lack of rigidity. From a further study of Table I, it can be seen that there are twelve variables affecting surface finish, eight affecting the life of the tool, five affecting the cutting speed, five affecting the accuracy, and six affecting the rate of metal removal. This summation is consistent with the fact that obtaining and maintaining surface finish is a difficult factor to control in lathe operation. Likewise, especially in production work, tool life is a significant operating factor.

It is important to note that the relative weight of the influences, as shown by the chart, is not fixed, but may change for different operations, set-ups, or types of work. For example, the influence of the shape of the tool on a thread chasing operation is primarily on the contour of the cut and not on the life of the tool, as it would be in a rough turning operation.

Cutting tool angles. Manufacturers recommend tool angles for cutting tools to be used for each of the general classifications of metals such as mild steel, tool steel, cast iron, brass, bronze, aluminum, and stainless steel. These angles are not intended to be accepted as unchangeable, because within one classification such as cast iron, there are white cast irons, grey cast irons, and malleable cast irons. Included in each type of cast iron, there are literally thousands of variations each of which might require modified tool angles for efficient results. It is true, however, that recommended tool angles will often work for quite a number of different metals of the same general type.

Very often a particular table of recommended tool angles will give no information as to whether these angles are nominal of effective. An effective angle is the actual clearance, rake, or relief that a tool has when mounted in the lathe. The nominal angle is the angle ground on the tool itself. For example, when a Williams tool holder is used, a nominal front clearance of 24° must be ground on the tool so that when it is mounted in the tool holder, it will have an effective clearance of 6°. Usually, however, it can be assumed that the recommended angles are effective angles unless otherwise specified.

In many cases, tool angles are not critical; the rake or clearance may be varied several degrees without apparently affecting the function of the tool or impairing its cutting efficiency. Yet a point can soon be reached, in deviating from recommended angles, at which the function and efficiency of the tool is impaired. For any given cutting condition, this critical point can be determined only by experimentation.

Very often the machinability rating of the metal will provide a key to the criticalness of the recommended cutting angles. Metals with low machinability allow less variation in tool angles before difficulty is encountered. The problem is further complicated by the fact that in many cases tool mounting conditions in reference to the work may render a particular angle inefficient for normal conditions.

Recent investigations and tests in the use of negative rake angles have caused some well worn theories of metal cutting to be discarded. This is due to the fact that cutting speed is a very important factor in the effectiveness of a particular cutting angle. Negative rake tools require much higher cutting speeds, heavier tool mounts, heavier feed mechanisms, and more power to remove a unit volume of metal. The resulting increase in cost of metal removal is in some instances more than offset by increased production from much higher cutting speeds. The use of negative rake is still in the experimental stage and should not be undertaken without a careful investigation of all the factors involved.

With respect to negative rake, Woodcock states: [2]

> "Negative back-rake angles ought to be held within 2 to 10°. The most satisfactory angle seems to be 5°. For average jobs a positive side-rake angle must accompany a negative back-rake, and the side angle should be approximately 2 to 4° greater than the negative; i.e., if the negative back-rake angle is 6°, the positive side-rake should be from 8 to 10°. If the depth of cut is shallow, say from 0.040 to 0.100 inch in a side, steeper negative angles are permissable, especially on hard or tough materials, but the 10° maximum should rarely be exceeded. . ."

Before leaving the discussion of cutting tool angles, the importance of the influence of tool position on effective angles should be pointed out. It is a well established fact[3] that raising the cutting tool above the horizontal center line of the work changes the effective front clearance. If a tool is

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[2] Frederick L. Woodcock, Design of Metal Cutting Tools, p. 279.

[3] A. L. DeLeeuw, Metal Cutting Tools, p. 44.

ground to have a clearance of 6° when mounted at the center line, it will have only 1° of effective clearance if the tool is set 5° above the horizontal center line of the workpiece. This is a matter of simple geometry and can be verified by making a sketch for both conditions. In like manner, if the tool is mounted below center, the effective clearance increases. What is not so generally known, is the fact that changing the tool holder lead angle, changes the effective clearance and rake angles. An experiment was made by the writer in measuring the effective tool angles with the cutting tool mounted in a Williams tool holder and set at various positions. Tables II and III illustrate the positions at which the angles were measured and give data on the results obtained.

Cutting speed. Many studies have been made of the influence and effect of cutting speed on the cutting process. Handbooks, textbooks, and manuals usually have at least one table on recommended cutting speeds for various types of metals. Some machinists accept these speeds as being maximum and, in some cases, as being fixed. Such, however, is not the case; these recommendations are intended as being points of departure for arriving at an efficient cutting speed. Recent practices in industry make use of tool life as a criterion for cutting speed. This is done by evaluating cutting speed in terms of tool life and naming it "tool life speed."[4]

In like manner, it is possible to adopt the amount of metal removed

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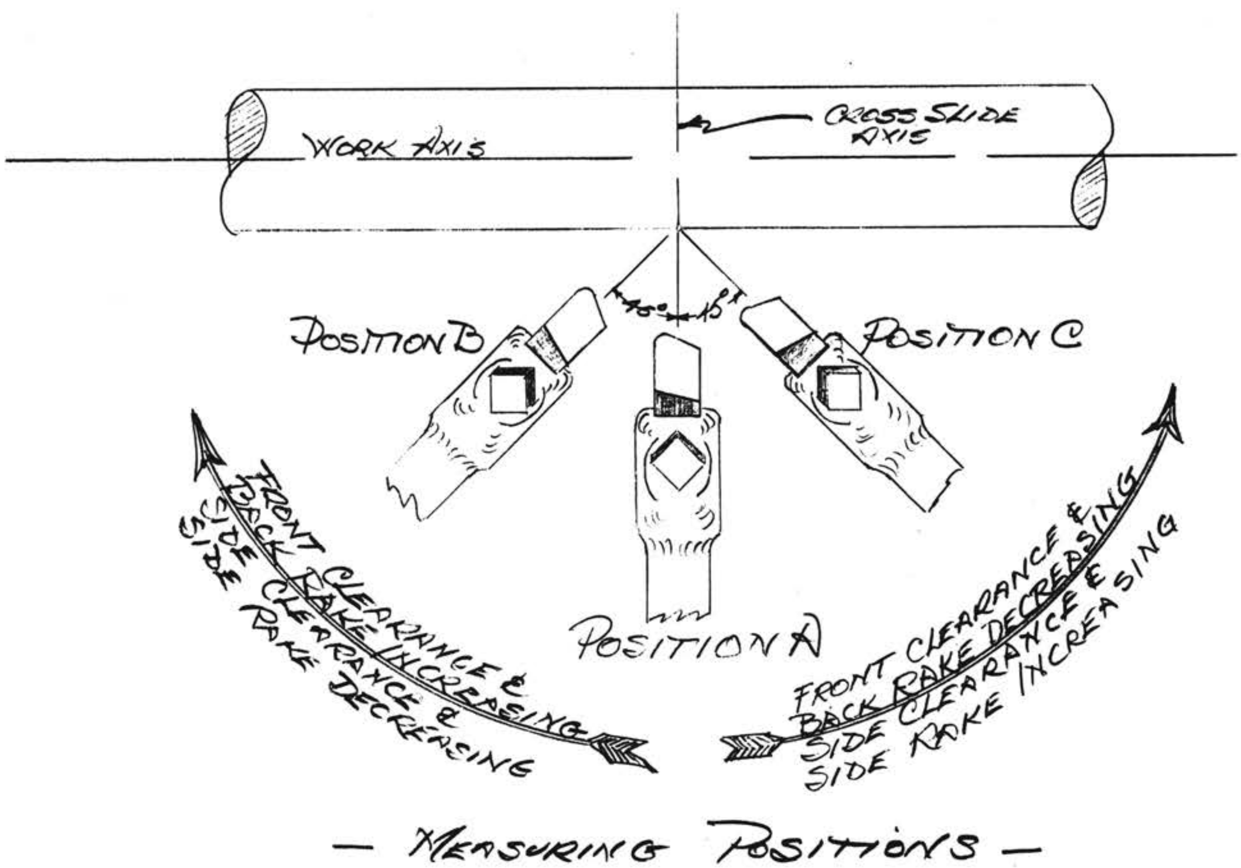
[4] Thomas Badger, "How Do Speed and Feed Affect Tool Life?" _American Machinist_, 93: 89-92, (August 11, 1949.)

Table II
(Illustrated)

CHANGES IN EFFECTIVE ANGLES WITH CHANGE IN POSITION OF ROUGH TURNING TOOL

Tool Angles	Position A	Position B	Position C
Clearance at			
Tool point	10°	10°	10°
Front clearance	8°	11°	16°
Side clearance	8°	5°	3°
Back rake	16°	22°	1°
Side rake	16°	3°	22°
Side cutting edge	0°	45°	45°

Note: **Side clearance and side rake measured parallel to work axis. Front clearance and back rake measured parallel to cross slide axis. Position C is not a cutting position for the tool shown, but is used to illustrate effect on angles noted.**

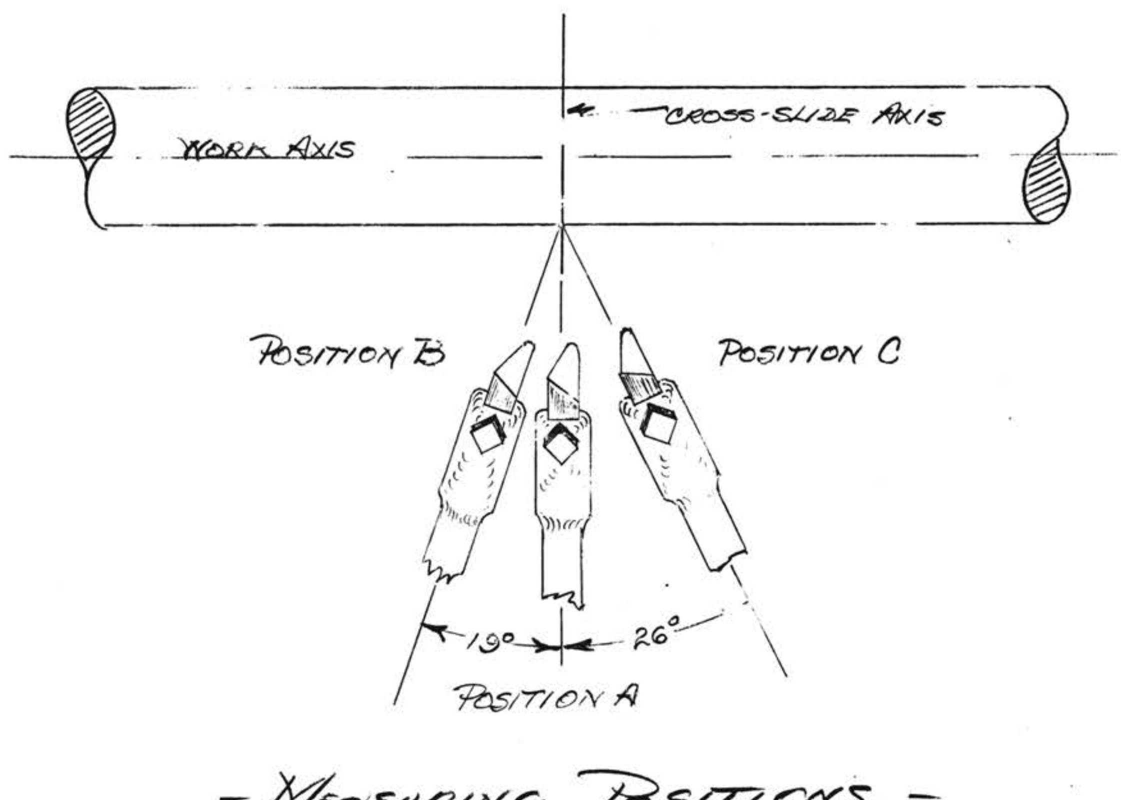


— MEASURING POSITIONS —

TABLE III
(Illustrated)

CHANGES IN EFFECTIVE ANGLE WITH CHANGE IN POSITION OF RIGHT-HAND TURNING TOOL

Tool Angles	Position A	Position B	Position C
Front clearance	8°	10°	8°
Side clearance	10°	10°	8°
Side-rake	16°	9°	24°
Back rake	24°	27°	13°
Side cutting edge	26°	45°	0°



- MEASURING POSITIONS -

per minute as a criterion, or the type of finish desired as a criterion for cutting speed. Consequently, the selection of cutting speed is by no means a chance, or shot-in-the-dark procedure. As mentioned previously, Taylor refers to twelve factors that must be considered in selection of cutting speed[5] for a turning operation. For general shop operation, the usual considerations are rate of metal removal, surface finish, accuracy, and tool life.

It should be realized that cutting speed is directly related to depth of cut and feed. Hence, in selecting an optimum speed, it is possible to use higher speeds when less area of metal is removed per revolution. Also, it should be recognized that in using optimum cutting speeds, it is essential that conditions of work and tool support be the best. Furthermore, it should be understood that the correct cutting tool, properly ground and honed, must be used if maximum cutting speeds are to be achieved.

The Manual on Cutting of Metals contains a complete set of tables for cutting speeds for practically all types of steel, alloys, and cast iron. These tables are based on depth of cut and feed per revolution. Thus, it is possible knowing the metal, depth of cut and feed, to obtain from one of these tables the most efficient cutting speed. The tables are the result of several years of experiment and research by the American Society of Mechanical Engineers. With reference to cutting speed, the Manual states,[6]

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[5] Taylor, op. cit., p. 4.

[6] ________, Manual on Cutting of Metals, p. 29.

> "Variations in chip thickness have more effect on cutting speed than any other variable. Other things being equal, a steel chip 0.003 in. thick can be cut at a speed nearly five times as great as one 0.03 in. thick. . ."

In most cases of general shop practice, the rate at which metal is removed, does not have the importance that it does in production work; consequently, it is possible to use lighter roughing cuts. The lighter cuts may be taken at higher speeds; and finishing cuts may be made at still higher speeds. It is possible, under good cutting conditions, using a high speed steel cutter, to make cuts at speeds as high as 1060 feet per minute in finishing cuts of .010 inch depth of cut and .002 inch feed.[7] This cutting speed is recommended for SAE 1020 cold drawn steel. If Bessemer screw stock is machined under the same cutting conditions, its cutting speed can be double that for SAE 1020. The reason for this unusually high cutting speed is because the machinability of Bessemer screw stock is almost twice that of SAE 1020.

Feed and depth of cut. The combination of feed and depth of cut establish the cross sectional area of metal that is removed per revolution in the cutting process. The amount of feed, or thickness of the metal shaving cut from the work, has more effect on cutting speed than does depth of cut.[8] Considering the factor of tool life speed, it is interesting to note that metal can be removed faster with a coarse feed and fairly slow cutting

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[7] Ibid., p. 172.

[8] Taylor, op. cit., p. 165.

speed, than with a light feed and fairly high cutting speed. The maximum amount of feed that can be used is limited by the feeding power of the lathe.

Changing the rate of feed has three times as much effect on cutting speed as an equal amount of change in depth of cut.[9] This means that it would be necessary when a maximum cutting speed is being used to decrease this cutting speed three times as much for a given increase feed as for the same increase in depth of cut.

Although the heavier feeds exert greater tool pressures, they also tend to reduce the temperature in the tool at the cutting edge; hence, it is economical to use as much feed as the power of the lathe will allow, and still satisfy the conditions of the cut. The influence of feed on tool temperature is discussed at greater length later in the chapter.

One of the primary influences of feed on the cutting operation lies in its effect on surface finish. As every machinist knows, fine feeds usually give better finishes than coarse feeds. This is particularly true with a cutting tool having a small nose radius. Experiments by the writer have shown that a finishing tool with large nose contact with the workpiece can be fed at double the feed used on a tool of small contact area. The setting of the tool is rather critical but a better finish can be obtained because higher feeds tend to reduce the tendency of metal fragments to weld to the tool edge; it is the welded metal on the tool edge that scuffs out the work surface causing poor surface finish. Figures 17 and 18 in

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[9] Taylor, op. cit., p. 77.

Appendix B illustrate surface finishes obtained with the two types of tools discussed above.

One of the most important influences of depth of cut in lathe turning is in the accuracy of the cut. In referring to accuracy of cut, it is meant the actual depth of metal removed in relation to the depth of cut set on the cross-feed micrometer collar. Ignorance of this factor, or carelessness with regard to it, is one of the greatest causes of spoiled work. The actual depth of cut is influenced by the rigidity of the tool mounting, the rigidity of the work, and the lead angle position of the tool holder. The feeding force of the lathe tends to thrust the cutting tool away from the direction of cut. If the lead angle is greater than 90°, the displacement of the tool is in an arc toward the center of the work; hence, more metal in depth of cut is removed than was set on the micrometer collar. In like manner, when the lead angle of the tool post is set at less than 90°, the arc of tool displacement is away from the center of the work; thus, less metal is removed than was intended. The effect of the error caused by this displacement increases with increase of feed, and with decrease in side rake angle. This is because the axial thrust against the tool is increased by greater feed and lesser side rake. As would be expected, errors caused by displacement of the tool are practically nonexistent with light feeds and finishing cuts.

B. GRINDING SINGLE-POINT TOOLS

Probably there are as many ways of grinding lathe tools as there are individuals who grind them. Manufacturers differ in their recommendations on grinding methods, included angles, and shapes for various lathe operations. To attempt to evaluate the different methods of tool grinding is to prodigious a task for this paper. It is however, possible to present some basic considerations that must be taken into account in determining what grinding methods can be employed, and what tool shapes can be adopted.

Every machinist, when he starts to grind a single-point tool, must know in advance (1) the tool shape desired, (2) the correct clearance and rake angles for the tool, (3) the correct grinding wheel to use, and (4) the quickest and best method of grinding the tool.

Selecting tool shapes. One of the pitfalls to avoid in selecting tool shapes lies in adopting a shape in which a considerable amount of metal must be ground from the tool blank. The conventional right or left-hand turning tool is an example of a tool shape that requires excessive grinding. A tool of this type usually has a side cutting edge angle of from 20 to 30°. Figure 5 shows two right-hand tools with 26° side cutting edges. Removing the metal to form a shape such as Tool H in Figure 5 is a waste of both time and tool steel. Just as efficient results can usually be achieved with a tool for right-hand turning that has a 0° side cutting edge similar to the tool illustrated in Figure 6. It is true that a lead angle of 30° is to be preferred because it distributes the thrust components more uniformly;[10]

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[10]Emil Kuhn, "Cutting and Fragmentation Formulas," Tool Engineer, 21:25-28, (July, 1948)

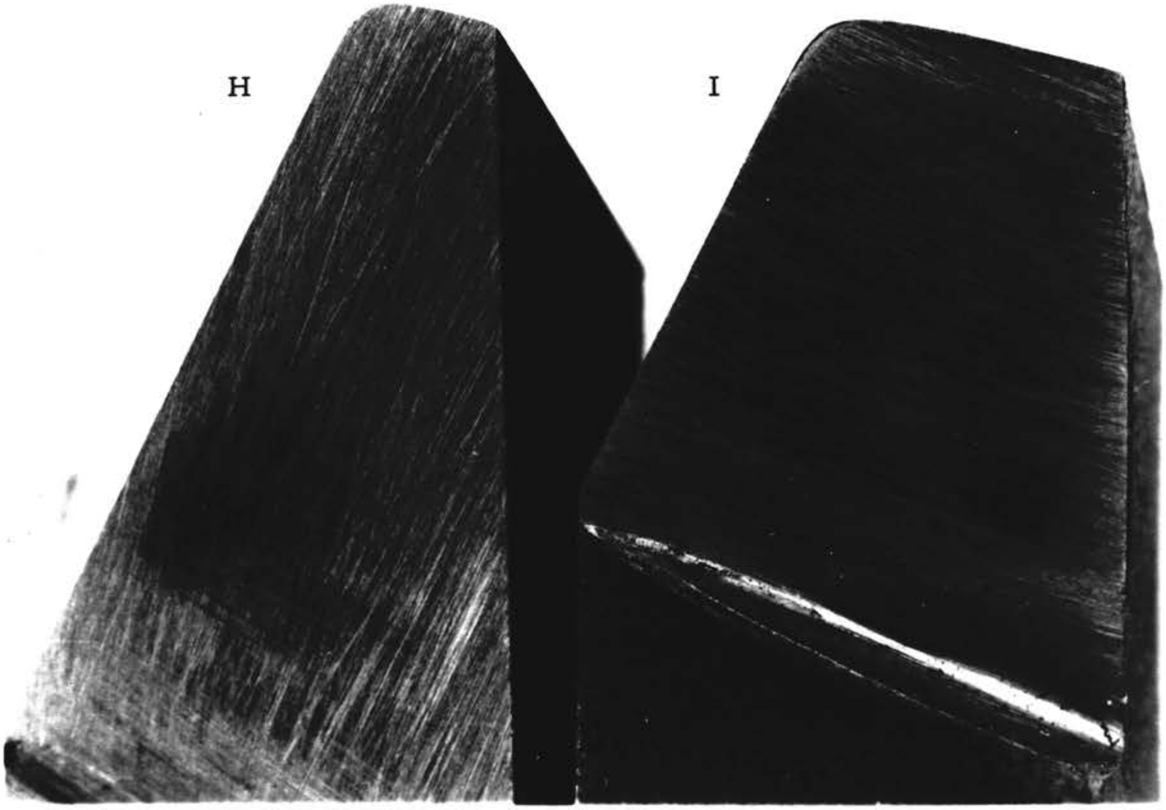

Figure 5

10X PHOTOMACROGRAPH, TOP VIEW COMPARISON
OF RIGHT HAND TURNING TOOLS H & I

Tool H
Precision ground on the face of a 36 grit, aluminum oxide, cup wheel. Nose radius precision ground with a K.O.Lee radius grinding attachment. Tool hand honed with an India Oilstone.

Tool I
Same methods and equipment as tool H. Tool I will perform all the functions that tool H will, and less metal is wasted in grinding.

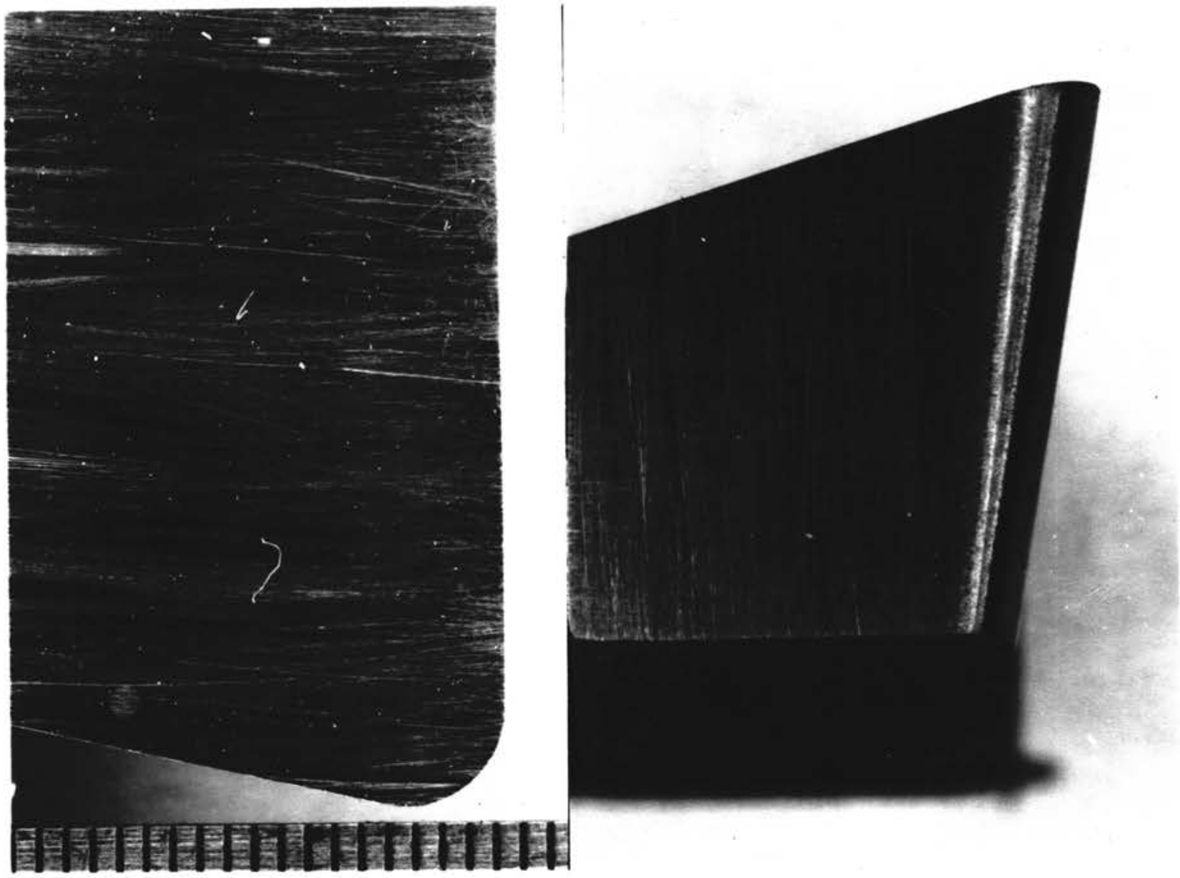

Figure 6

10X PHOTOMACROGRAPH OF A TYPICAL ROUGH TURNING TOOL

This tool shape requires a minimum amount of grinding. It can be easily sharpened or re-dressed. With a slight change in lead angle it serves well as a finishing tool.

but a tool such as the one illustrated in Figure 6 can be ground to set at a lead angle of 30°. Also this tool can be converted to a finishing tool by grinding a flat on the front face similar to the tool illustrated in Figure 7. When heavy cuts are to be taken, it is particularly important to avoid pointed tool shapes that have a small nose area. The less volume of metal there is at the tool point, the slower the generated heat can be carried off.

Selection of clearance and rake angles. In deciding on clearance and rake angles for a particular tool, careful consideration should be given to the influence of the tool holder position on the effective angles. Illustrated Tables II and III (Pages 33 and 34) indicate how important, in some instances, this factor can be. When the cutting tool is ground on a precision tool grinder, it can be set at the angle which will be used on the lathe; the effective angles will then be correct. It is, however, impractical to attempt to achieve equivalent results with hand grinding methods, unless the nominal angles have been carefully calculated to give the desired effective angles, and a protractor is employed to check each angle as it is ground.

Selection of grinding wheels. The selection of correct grinding wheels requires the assistance, or at least the recommendations, of a grinding wheel manufacturer. The A.S.M.E. Manual on Cutting of Metals, page 38, suggest the use of a 20-40 grit aluminum oxide wheel for offhand grinding. For precision grinding they suggest the use of a 36 grit aluminum oxide wheel. Vitrified silicate is the recommended bond, in both cases.

The selection of the correct grinding wheel is important in tool

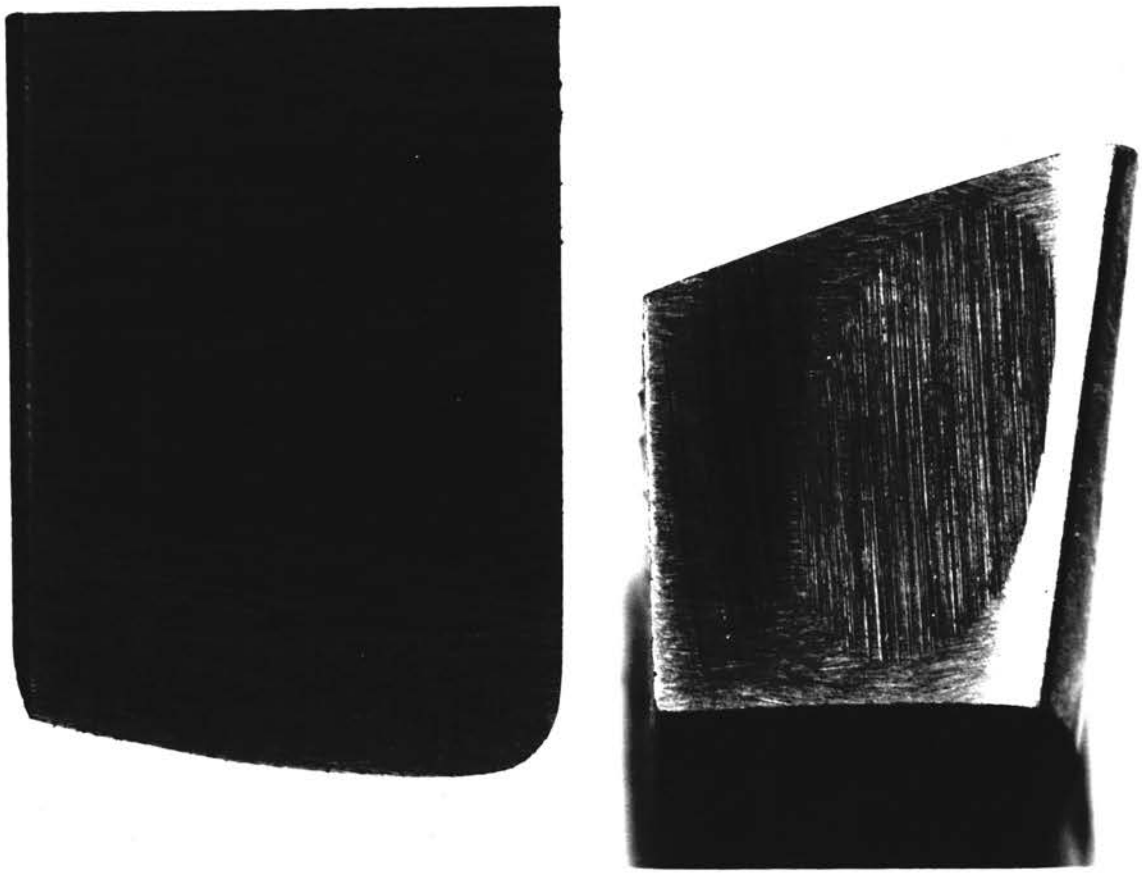

Figure 7

10X PHOTOMACROGRAPH OF FINISHING TOOL J

This tool is ground and honed with the same clearance and rake angles as tool A, except that a flat has been ground on the nose for more surface contact in finishing cuts.

grinding. If the wheel is too hard, the tool face is easily burned, causing heat checks. Recommendations of the manufacturer as to the correct wheel for the type of steel being ground are usually the safest policy to follow in selecting wheels. Cutting tools may be ground on the periphery of a plain wheel or the face of a cup wheel. Using the periphery of a plain wheel offers the advantage of making it easy to hone the tool after grinding. The cup wheel, because it grinds a flat surface, provides a more accurate means of tool grinding. It is necessary to hone the entire surface after grinding with a cup wheel, whereas the hollow surface produced by periphery of a plain wheel requires honing only at the edges. A flat, well honed surface on the top face is a distinct advantage as it reduces friction between the chip and the tool face.[11]

Methods of tool grinding. In the grinding of cutting tools, the use of a precision grinder is to be greatly preferred to hand grinding. Precision grinding gives not only more accurate angles, but also a smoother finish on the tool face. Figures 8 and 9 show the comparative results obtained by two methods of grinding.

Some machinists do not bother to hone cutting tools. This practice contributes to a greatly shortened tool life, and poor surface finish on the work. Figures 10 and 11 reveal the roughness of the cutting edge and tool point on an unhoned tool. The peaks or projections on this cutting edge are quickly worn away in the cutting process leaving a dull tool edge. This is

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[11] Thomas Badger, "Improved Surface Finish Increases Tool Life," American Machinist, 93, 86, (February 24, 1949)

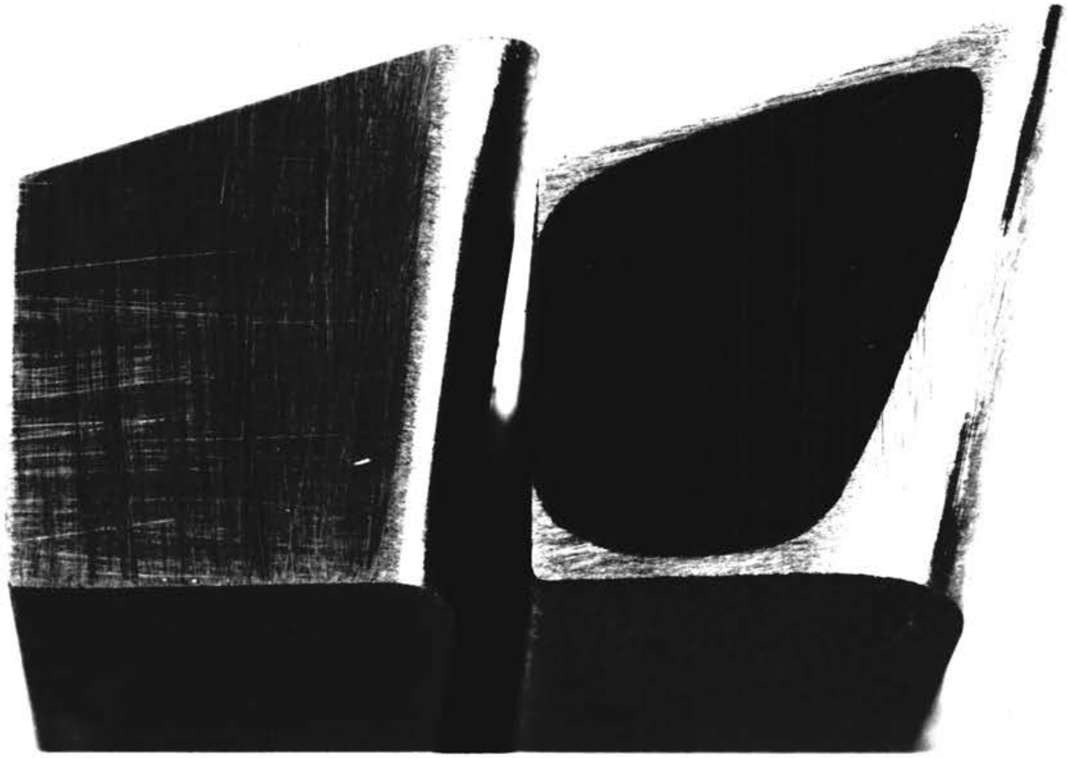

Figure 8

10X PHOTOMACROGRAPH, END VIEW COMPARISON OF ROUGH TURNING TOOLS A & G

Tool A

Precision ground on the face of a 36 grit, aluminum oxide, cup wheel. Nose radius precision ground with a K.O.Lee radius grinding attachment. Tool was hand honed with an India Oilstone.

Tool G

Precision ground on the periphery of a 6", 36 grit, aluminum oxide wheel. Nose radius hand ground on a 46 grit, aluminum oxide wheel. Tool hand honed with an India Oilstone.

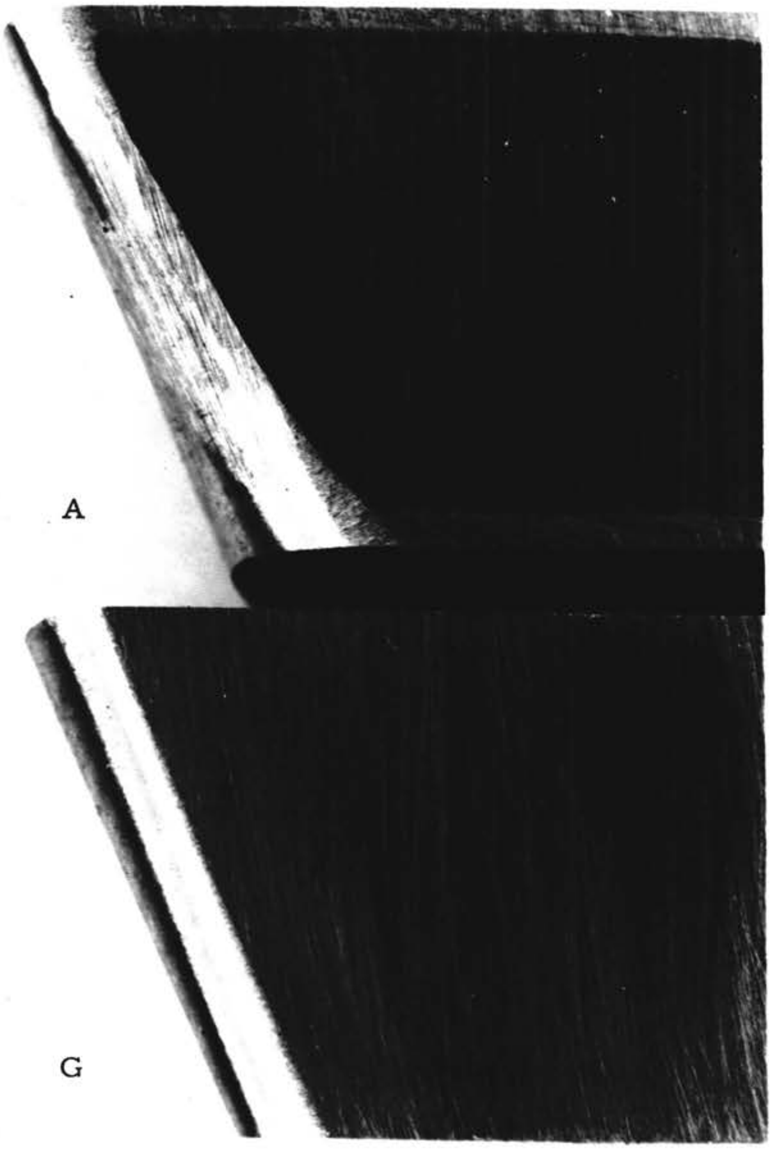

Figure 9

10X PHOTOMACROGRAPH, SIDE VIEW COMPARISON
FLAT GROUND TOOL A & HOLLOW GROUND TOOL G

Notice the difference in amount of surface that must be honed. After honing, tool G has a secondary relief angle considered by some experts as being essential to an efficient cutting tool.

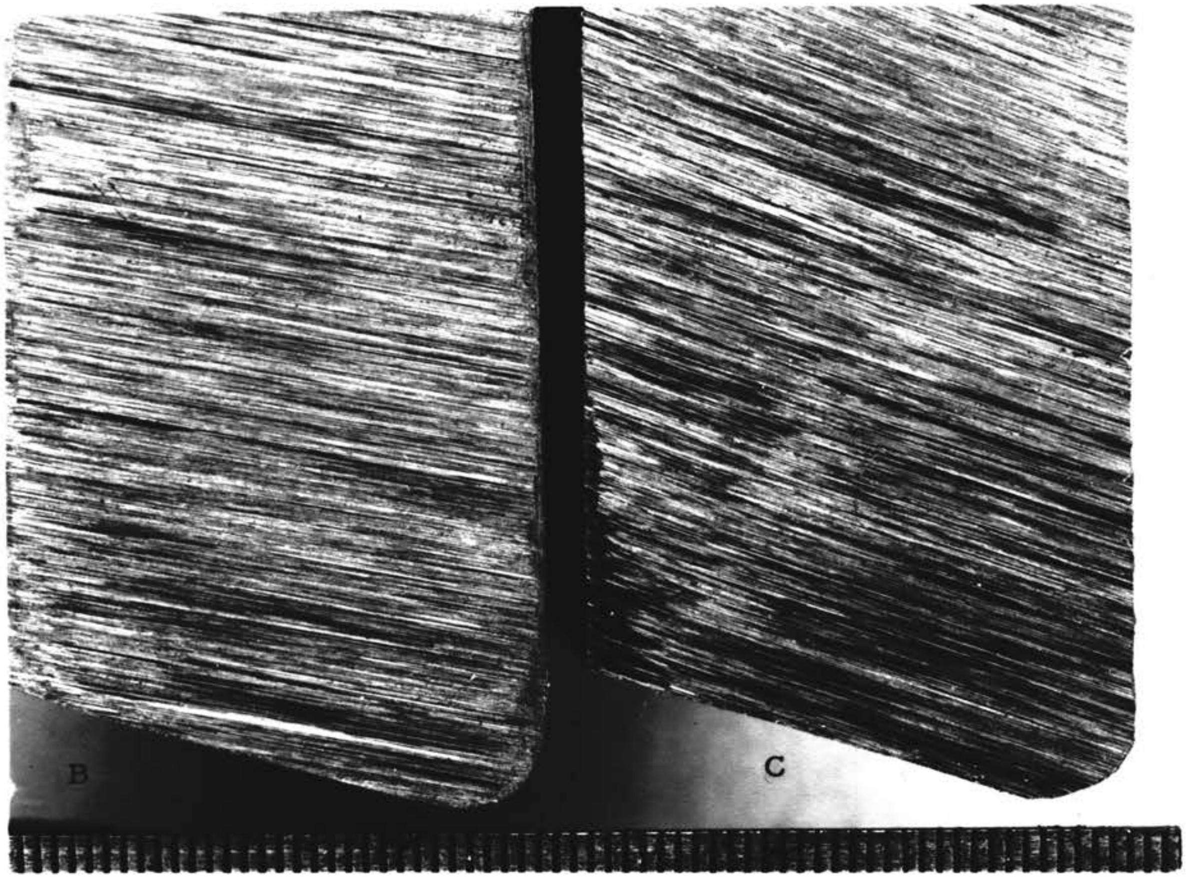

Figure 10

10X PHOTOMACROGRAPH, TOP VIEW COMPARISON
ROUGH TURNING TOOLS B & C

Tool B - Hand ground on periphery of 46 grit Carborundum wheel, 8" diameter. Hand honed with India Oilstone.
Tool C - Hand ground on periphery of 46 grit Carborundum wheel, 8" diameter. Tool not honed.

Tool Angles	Tool B	Tool C
Nose Radius	3/64"	1/8"
End Cutting Edge Angle	8°	9°
Front Clearance	8°	8°
Side Clearance	10°	11°
Side Rake	16°	17°
Back Rake (in toolholder)	16°	16°

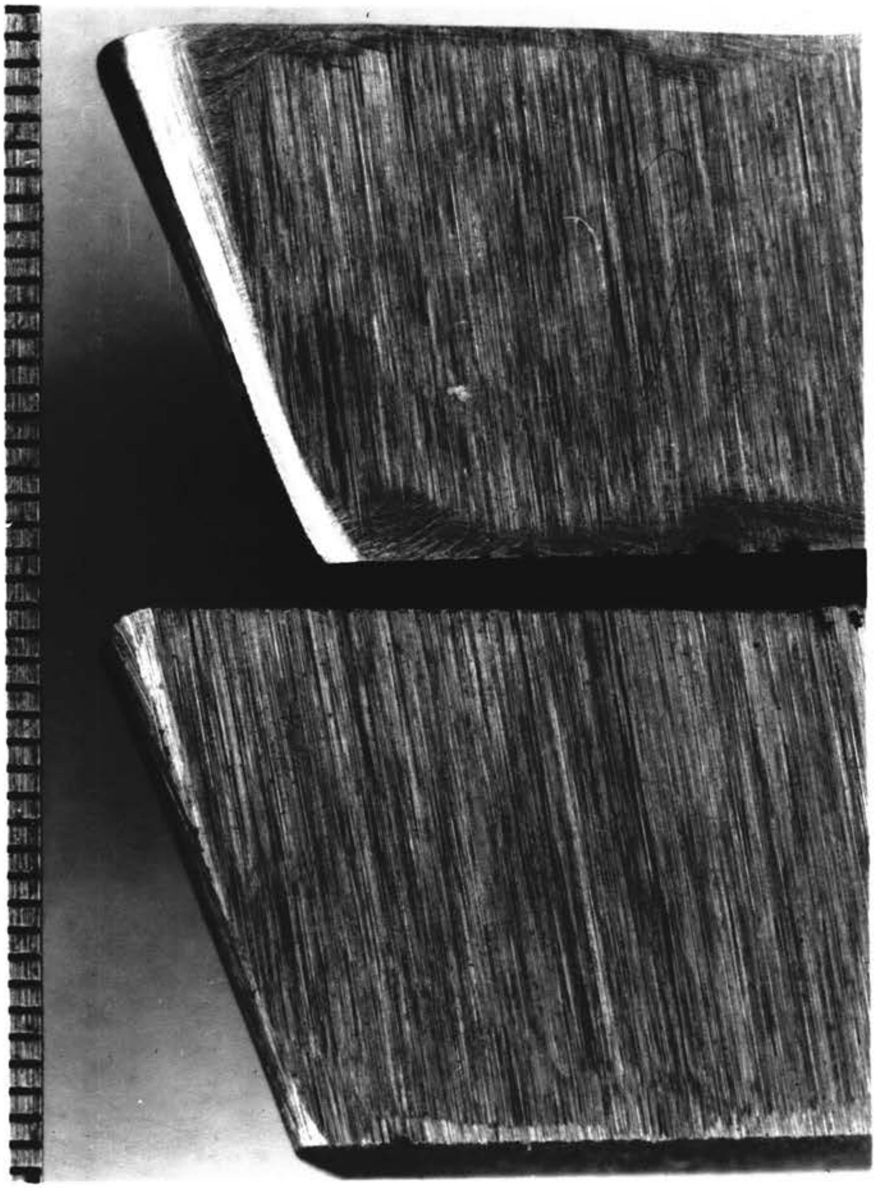

Figure 11

10X PHOTOMACROGRAPH, SIDE VIEW COMPARISON
ROUGH TURNING TOOLS B & C
REX AAA H.S. STEEL

The peaks on the rough edge of tool C would quickly wear off in the cutting process, leaving a dull cutting edge.

due to the fact that the peaks cannot withstand pressures of the cut.[12]

One of the most common malpractices in cutter grinding, especially hand grinding, is the careless misuse of a water quench. The operator usually holds the cutting tool on the face of the wheel until the tool is so hot it is uncomfortable to hold; then the tool is quickly plunged into cold water. Very often, the tool edge has reached a critical temperature by this time, and the rapid quench causes a slight change in the grain structure in the areas affected. As a result, heat checks occur at the tool edge, and in extreme cases where a loaded wheel has been used, minute cracks appear on the faces adjacent to the tool edge. These cracks are the outcome of unequal stresses caused by the sudden contraction at the surface when the tool is quenched.

A. M. Swigert, Jr., on page 186 of his book, Superfinishing, says

> "Methods of tool sharpening, particularly the grinding process either by hand grinders or machine grinders, removes metal at such speed and at such pressure that in particularly every case some or portion of the cutting surface will be heated sufficiently to be heat checked. . . Often the hardness of the cutting edge being ground is materially decreased by sudden localized overheating. . . Many investigations show that high speed, which in most grinding is well over 5000 feet per minute, is the major cause of excessive heat."

Swigert further recommends that a considerably softer wheel be used, at about half the grinding wheel speed, to overcome these difficulties. Proper tool grinding is, without a doubt, as important a factor in the cutting tool process as the angles and shape of the cutting tool, or the metal of which it is made.

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12 Badger, loc. cit.

C. THERMAL EFFECTS IN METAL CUTTING

Heat might be easily considered the greatest single enemy of the cutting process. This is true for the following reasons:

1. The amount of heat establishes an upper limit to cutting speed.
2. The heat from the cutting action shortens tool life.
3. The excessive heat will quickly destroy the cutting edge of the tool.
4. The heat causes expansion in the work affecting, in turn, the accuracy and uniformity of the cut.
5. The heat in the work may cause sufficient expansion to burn the live center of the lathe.
6. The heat causes poor surface finish by contributing to the welding action of metal fragments to the tool edge.

It is possible, through the study of heat and its influence on cutting action, to determine the causes of tool failure. Once the causes are known specific steps can be taken to remedy the effect.

Controlling heat in the cutting process. In order to control the cutting process efficiently and obtain maximum wear from a cutting tool it is necessary to control the cutting speed, depth of cut, and feed with respect to the amount and rate at which the heat is generated. The total amount of heat generated in a specific cut is equal to the amount of energy required to make the cut. Since a high cutting speed with a heavy feed requires more energy than a heavy cut at the same feed, more heat is generated at the heavy rate of feed. Strangly enough, tool failure can occur more quickly, and more often, with a light feed than with a heavy feed. The reason lies in the fact that the chip carries off the greatest portion of the heat of cutting. Therefore, when a light feed is used, at a high cutting speed, the heat is generated faster than it can be carried off by the chips, the tool, and the workpiece. With the heavier feed, the chips carry away a greater quantity of heat because of their larger area. In fact, the rate at which the heat is carried away by the chips is fast enough to offset the increase in amount of heat from the heavier cut. With respect to heat in the chip, Schmidt and Roubik state,[13]

> "In general, the chips contain the greater portion of the total heat, with tool and workpiece following in that order . . . For the thicker chip the percentage of heat in both tool and workpiece is less than it is for the thinner chips."

They have further determined that at a cutting speed of approximately 100 feet per minute, about 75 % of the heat is carried away by the chip, 15% in the tool, and 10% in the workpiece. Increasing the cutting speed up to 200 feet per minute increases the chip temperature and is accompanied by a concurrent decrease in workpiece temperature. Above this cutting speed, temperatures in the chip remain practically constant. With increase in cutting speed, the workpiece temperature remains practically constant at about 100° F. and the tool point temperature rises. At 800 feet per minute cutting speed the tool point temperature reaches almost 1600° F.[14]

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[13] A. O. Schmidt and J. R. Roubik, "Some Thermal Aspects of Metal Cutting," Tool Engineer, 21:20-22, (November, 1948)

[14] A. O. Schmidt and J. R. Roubik, loc. cit.

CHAPTER IV

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study has presented briefly some of the more important aspects of the cutting process. It has included a condensed treatment of the fundamentals of cutting action, and a more detailed discussion of a few significant factors in the cutting process. Wherever possible, magnified photographs were used to augment the explanation of topics and concepts under consideration. In many places in this study additional pictures are needed in order to adequately illustrate the cutting elements.

A. SUMMARY

A brief summary will be given of the content and purposes of each chapter, with the exception of this chapter and the introductory chapter.

Chapter II. This chapter deals primarily with fundamental ideas. These ideas are purposely explained at the level in which they would be used in machine shop training. There are many fundamentals which have not been included that others might consider more important. Such a selection is a matter of individual choice and should be made with consideration for the methods and type of teaching that will be employed.

Chapter III. This chapter concerns a further development of some of the factors in the cutting process. The presentation was made in light of a few of the more recent theories on metal cutting, and the findings of men prominent in the field of metal cutting research. It is hoped that the

Effect of heat on the cutting tool. The red hardness of high speed steel is one of the characteristics which distinguish it from high carbon tool steel. Nevertheless, there is a concurrent decrease in hardness of high speed steel with increase in temperature. Studies made at the University of Illinois[15] show that there is a slight decrease in Brinell hardness at temperatures up to about 1140° F.; beyond this there is a considerable loss in hardness up to about 1475° F. In fact, the Brinell hardness of high speed steel is about 725 at room temperatures. At 1140° F. the hardness is down to about 575 Brinell. At 1475° F. the hardness is all the way down to about 250 Brinell. This would indicate that temperatures above 1150° F. have a detrimental effect on the performance of the cutting tool. At temperatures above 1475° F., tool wear due to loss in hardness becomes considerable, and tool failure occurs fairly fast especially in continous cuts.

Ductile metals with a high percentage of elongation, such as mild steel, tend to create maximum heat just behind the cutting edge, on the top face of the tool. Hard brittle metals, such as cast iron, and some alloys of steel, that have a low percentage of elongation, tend to concentrate the heat in a smaller area, right at the cutting edge. Hence, generally speaking, tool failures occur more quickly when machining hard brittle, metals.

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[15] K. J. Trigger, "Progress Report No. 2 on Tool-Chip Interface Temperatures," Paper presented June, 1948, to American Society of Mechanical Engineers, Cited by Schmidt and Roubik, op. cit. p. 22.

As mentioned previously, the percentage of heat in the tool is about 15%, which is just slightly more than that in the workpiece. However, though the quantity of heat is almost the same, it is concentrated at the point of the tool in a small area, while the workpiece is distributed over a large mass. Schmidt and Roubik determined in an experiment with a high speed milling cutter that at a cutting speed of 400 feet per minute, the tool point temperature was 1450° F., the chip temperature was 750° F., and the work temperature was 100° F.[16] No mention was made as to the life of the cutter, but at a temperature of 1450° F., it could not last very long under continuous service.

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[16] Schmidt and Roubik, op. cit., p. 21.

the discussion will raise questions in the mind of the reader which will motivate a search for more complete information.

Appendix A. The details of the design and construction of the macro-camera were inserted in Appendix A for the benefit of those who might want to make a similar study. There is ample opportunity for further development of the equipment and the photographic technique involved.

Appendix B. Five case studies have been placed in this part of the Appendix. In addition, quite a few other pictures have been included that illustrate ideas or points of discussion not treated in the body of the study. Most of these pictures have informational value sufficiently relative to the study to justify their inclusion.

B. CONCLUSIONS

In the course of this study, the writer has obtained many new ideas about cutting tools and their behavior in the metal cutting process. Furthermore, knowledge which was previously gained by experience and observation has been supplanted, in many instances, by a more complete understanding of cutting action.

In brief, these are the main conclusions reached in this study of lathe cutting tools:

1. Through a study of the physics of metal cutting, it is possible to obtain concepts which will materially aid in the teaching of machine shopwork.
2. An understanding of the function of cutting tools and the principles

rewards for such effort come in the greater understanding, higher production, better finishes and closer tolerances achieved by the worker.

There is need for a more complete study to be made of the elements of the cutting process. Each element should be analyzed with respect to how it may best be explained by using magnified photographs.

Inasmuch as cutting action is completely dynamic, there are limitations to the amount of explanation that may be obtained with static photographs. The research worker needs to be aware of the limitations of this medium if he is to achieve maximum results.

D. FINAL STATEMENT

Some shop teachers have a tendency to avoid teaching principles of the cutting process. This may be due to the fact that they did not receive adequate training, or it may be due to the lack of available data on metal cutting. Most probably, however, the complex variables in metal cutting have discouraged them from concentrating on this phase of teaching because specific factual statements are difficult to make without including too many qualifying conditions.

All indications seem to point to the lack of a good text in which the various machine processes are developed on the basis of their cutting principles as they pertain to the purpose and function of these machines. The writer believes that magnified photographs can contribute to a considerable extent toward the eventual solution of this problem.

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upon which they are designed provides a strong basis for the intelligent presentation of the purpose, operation, possibilities, and limitations of machine tools.

3. Complex automatic or semi-automatic machine tools can be better understood when the principles of their cutting processes can be identified in relation to their function as a part of the complete machine.

4. Since such equipment is beyond the reach of the average school shop, it is even more essential that the students be taught the necessary concepts with which to understand and eventually operate such equipment.

5. Because metal cutting occurs at such high speeds, it is practically impossible to learn what occurs in the cutting action by direct observation. Hence, even in limited teaching circumstances, magnified photographs may be used to illustrate stages in the progress of the cut as well as the effect of the cut on chip formation and surface configuration.

6. The study of metal cutting involves so many physical, chemical, and metallurgical factors that the combined efforts of a great number of individuals are needed to develop more completely the techniques essential to machine shop learning.

C. RECOMMENDATIONS

The possibilities of using magnified photographs as an aid to machine shop training needs to be further explored and developed. The

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APPENDIX A

APPENDIX A.

DESIGN AND DEVELOPMENT OF THE PHOTO-MACROGRAPH CAMERA

Magnified pictures show details that are not apparent to the unaided eye. Often these details, when revealed, are of sufficient significance to stimulate thought and present new ideas. In metal cutting, the action occurs in a small area at a very high speed; and the individual must rely on the visual evidence to interpret what has occurred. The average operator is little concerned with this cutting process because he, literally, can see neither what occurs nor the evidence of what has happened. Magnify these details and present them to the same operator, and he is amazed at what he sees. Therefore, in order to capitalize on this method for presenting ideas, an effort was made to design and build equipment with which to make magnified pictures of chips, work surfaces and cutting tool edges.

Camera principles. Larger pictures of the same object can be obtained by moving the camera closer to the object, or by enlarging the negative of the picture. The grain of the emulsion on the negative limits the amount of enlargement that can be obtained without loss of detail. The usual limitations are about eight times the orginal size of the negative, depending on how large the image is as related to the grain size. To overcome this limitation, the usual procedure is to move the camera close to the object, thereby obtaining a larger image. Such a procedure is limited by the design of the camera. Many cameras of the commercial or technical type are capable of a bellows extension equal to three times their focal length. If a camera of this type has an eight-inch focal length lens, a 2X magnification can be obtained when the bellows is fully extended.

Optical explanation. The optical relationship between magnification and focal length provides the rather simple mathematical expression with which the magnification or reduction of a camera lens may be computed. This expression is:

$$m = \frac{q - f}{f}$$

Where:

f = the focal length of the lens

q = the distance from the center of the lens to the film

m = the magnification

Since it was desired to obtain 10X magnification with a 5 x 7 view camera of 55 cm. bellows extension, the formula was transposed to solve for f:

$$f = \frac{q - f}{m} \qquad f = \frac{q}{1 + m}$$

Substituting the values for q and m:

$$f = \frac{55}{1 + 10} = \frac{55}{11} = 5$$

f = 5cm.

Therefore, a 5 cm. lens on a 5 x 7 camera with a 55 cm. bellows extension, would give 10X magnification.

When a camera lens that normally is used at 5 cm. is used at 55 cm., it is necessary for the object to be very close to the lens. This distance can be readily determined from the primary lens equation:

$$\frac{1}{q} + \frac{1}{p} = \frac{1}{f}$$

Where:

f = focal length of lens

q = lens to film distance

p = lens to object distance

Substituting the values for f and q:

$$\frac{1}{p} = \frac{1}{5} - \frac{1}{55}$$

1 = 5.5 cm.

Therefore, when the object is placed 5.5 cm. from the lens, and the film is 55 cm. from the lens, 10X magnification is achieved.

Illumination of the object. It is difficult to get proper illumination on the object when the camera lens is only 5.5 cm. away. Spot lights can be used; but they are directional and cause heavy shadows. If several spot lights are used, multiple shadows result; and the camera stand is surrounded by equipment. The logical solution is to use diffused light. For this purpose, floodlights and diffusion screens can be employed. Again the camera stand is surrounded by equipment, and the heat generated by placing the lights close enough to give satisfactory lighting is so great that the camera bellows would soon dry out and perhaps scorch. To further complicate the problem, it is desirable to have 45° illumination for photographs of metal surfaces[1]. Due to the limitation of space, and the size of normal

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[1]A. M. Swigert, Jr. The Story of Superfinish, p. 101.

lighting equipment, obtaining 45° lighting with conventional reflectors is practically impossible when the object to lens distance is under two and one-half inches.

Solution of the lighting problem. In order to solve the lighting problem, four conditions must be met: (1) the light should be diffused; (2) the source must be relatively small; (3) the heat generated must be low; and (4) the illumination should fall on the object at an angle of 45°. Fluorescent lighting will meet the conditions for diffuse light and low heat, but the size of standard equipment is fairly large. There is, however, a circular fluorescent lamp that is only ten inches in diameter. The possibility was carefully considered and it became evident upon investigation that the lighting would fall at an angle of about 10°. Obviously, this would be too oblique and result in heavy shadows with consequent loss of detail. If the light could be directed from the lamp by using some refracting medium which would control it and direct the light at the desired angle, the principles of the problem would be solved. As a result of this line of reasoning, the idea was hit upon to use clear plastic as a refracting medium to control and direct the light.

Design of the light refractor. Light can be bent in an arc through a refracting medium such as glass or plexiglass, if the light rays strike the interior surface of the medium at an angle which is less than the critical angle for the medium. When the angle is less than the critical, the light is reflected away from the interior surface instead of passing through. This fact is based upon the well-known law of optics which states, "the angle of incidence is equal to the angle of reflection."

Here then was the solution to the problem. A refracting disc made of clear plastic, machined or formed in a correct shape would direct the light on the object at the desired angle. The light refractor was then designed; a piece of Lucite 10" x 10" x 1 1/4" was purchased, and the refractor turned on a large lathe.

Making the refractor. The refractor had to have two fairly large radii formed on the upper and lower surfaces of the Lucite. These surfaces curved the light by internal reflection down to a small area three and one-half inches in diameter at the center of the refractor. This was accomplished by cutting a hole in the center of the plastic, two and one-half inches in diameter. The hole would allow the camera lens to be lowered close to the object. The surface of this hole was beveled at 45° in order that the light would pass through the Lucite to the object just below.

Two templets were made, one for each of the two radii; the upper and lower surfaces of the plastic were machined to conform to these radii, the inside of the hole was beveled, and then the whole piece was polished. The finished refractor was then mounted inside the fluorescent lamp, and the unit mounted in a reflector.

Making the camera stand. After the light source was completed, a special stand was necessary to mount the light unit and the camera, and provide a table on which to place specimens to be photographed. The stand was built as shown in Figure 12; provision was made for mounting the lamp ballast and the starter on the stand so that it would not interfere with the light unit.

Other provisions. The camera stand was designed and built to be flexible enough in its operation to accommodate three different focal length lenses. In this way, if larger objects were to be photographed, supplementary light could be added to give the desired angle of illumination.

Figures 12, 13, 14, and 15 show three pictures of the complete photo-macrograph camera and one close-up of the refractor unit.

Testing the lighting unit. After the lighting unit was completed, a series of tests were made to determine the efficiency of control and distribution of the light from the fluorescent lamp. A series of readings were taken across the diameter of the lamp at 5 cm. from the center line of the refractor, and at 15 cm., with a Weston photo-electric cell. Twenty readings were taken at each of the two distances; these readings were plotted on graph paper with footcandles on the X axis and distance in inches on the Y axis. The values were obtained with the refractor unit mounted in a reflector. The reflector increased the readings at 15 cm. by about eight per cent as compared to readings without a reflector. The reflector did not materially affect the readings obtained at 5 cm. in the central zone.

Figure 16 shows the distribution curve obtained from plotting the values from the test. A cross section of the refractor is included to illustrate the relation between the design of the refractor and the light output.

It is interesting to note that photographs taken with conventional 100 watt incadescent lamps, mounted in parabolic reflectors, required

PHOTOMACROGRAPH CAMERA

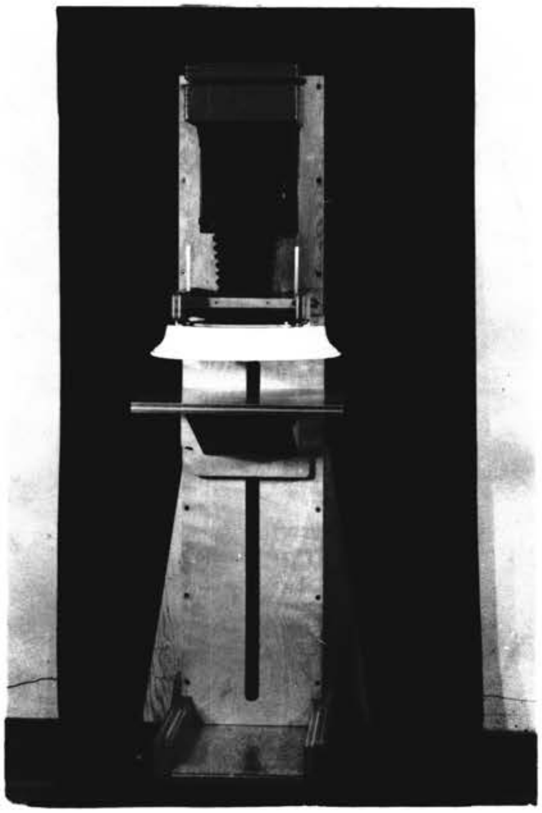


Figure 12 Front View

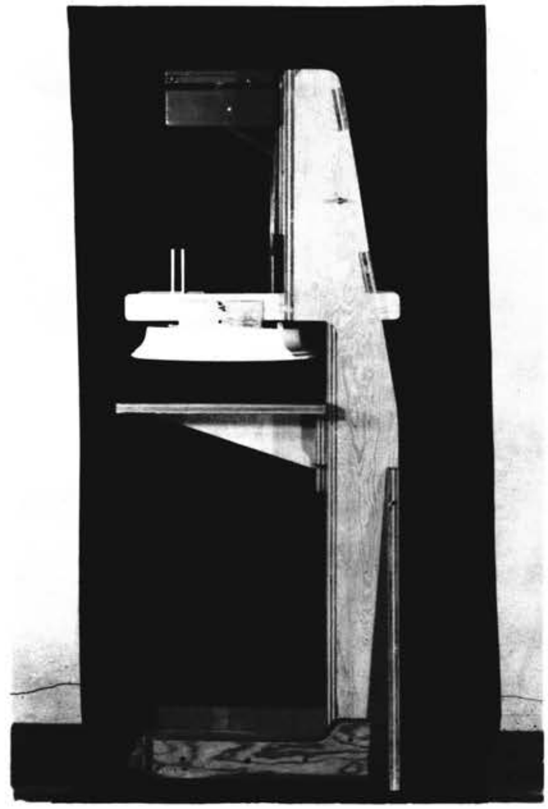


Figure 13 Side View

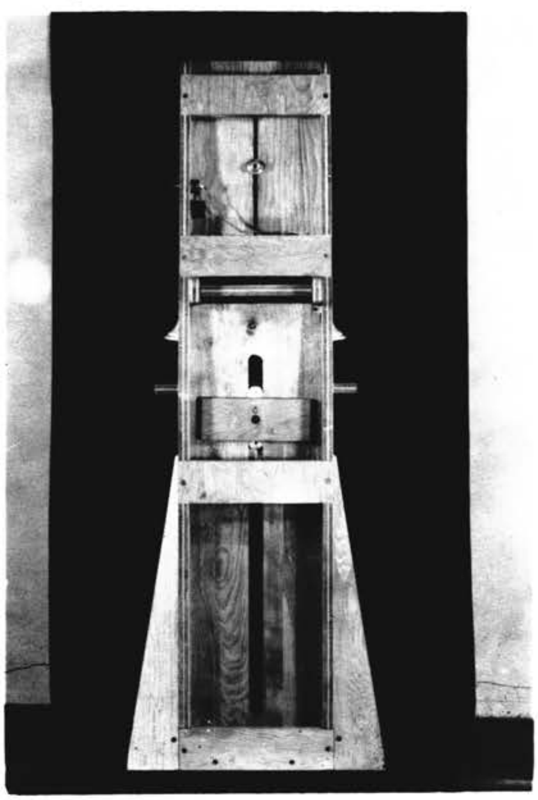
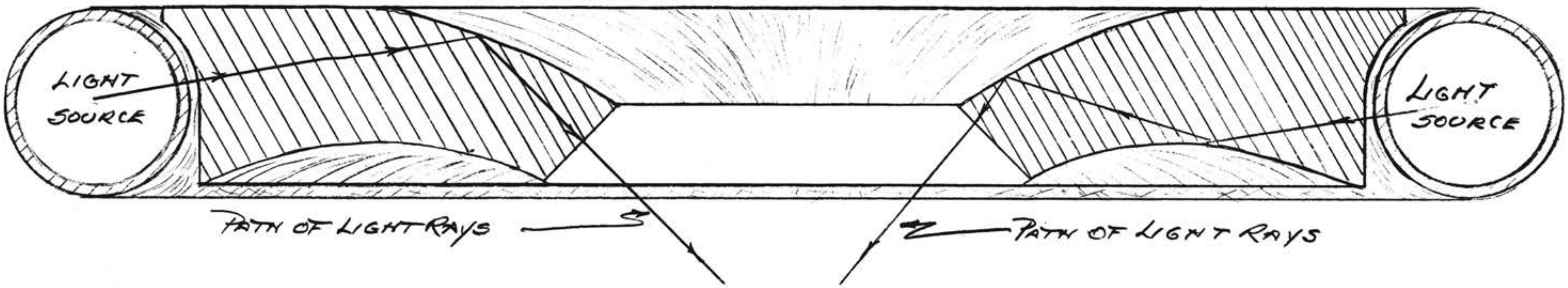
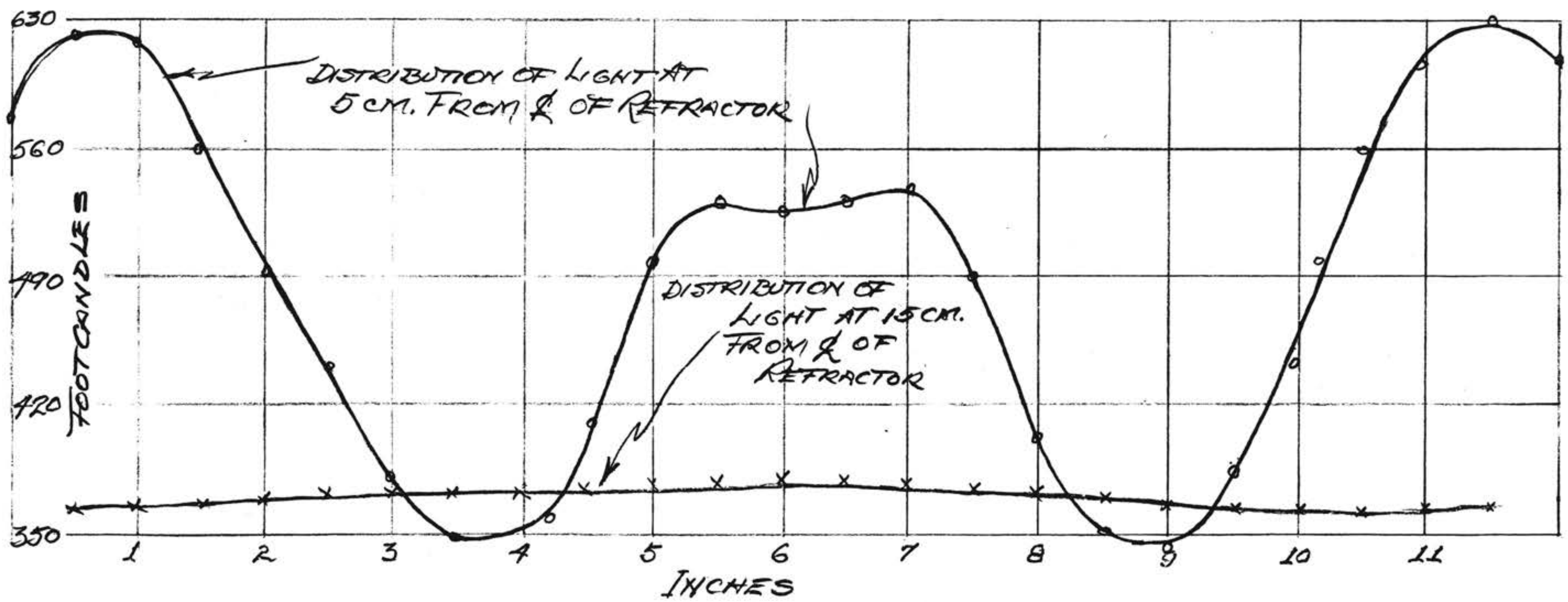


Figure 14 Back View

Figure 15 Close-up



CROSS SECTION OF REFRACTOR & CIRCULAR LAMP



LIGHT DISTRIBUTION FROM REFRACTOR

Figure 16

an exposure of eight minutes. With the same film, the same diaphragm setting, and the same subject, but using the fluorescent lamp and refractor, an exposure of twenty-five seconds produced a negative of equal density. The fluorescent lamp consumes 33 watts, the ballast about 17 watts; hence, pictures are now taken with one-fourth the power consumption and one-nineteenth the original exposure time.

APPENDIX B

CASE STUDY NUMBER 1

THE EFFECT OF THE TYPE OF TOOL ON SURFACE FINISH

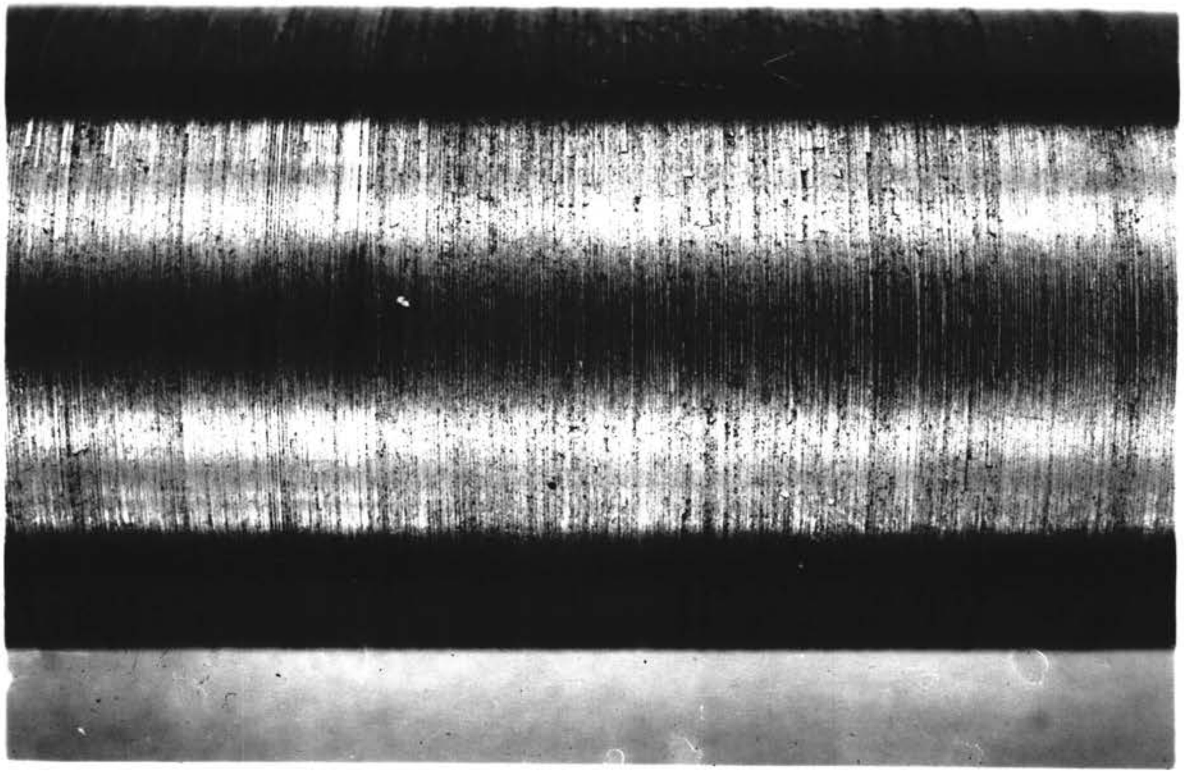


Figure 17

10X PHOTOMACROGRAPH OF POOR SURFACE FINISH
SAE 1020 STEEL

Evidence of undercutting and fragmentation with intermittent bands of burnished metal caused by scraping action of built-up-edge.

Cutting Speed - 60 ft./min.
Depth of Cut - .002"
Feed - .0018"/rev.
Cutting Tool
Finishing tool, 1/32" nose radius, front clearance 6°, side clearance 8°, side rake 16°, back rake 16°, lead angle 90°.

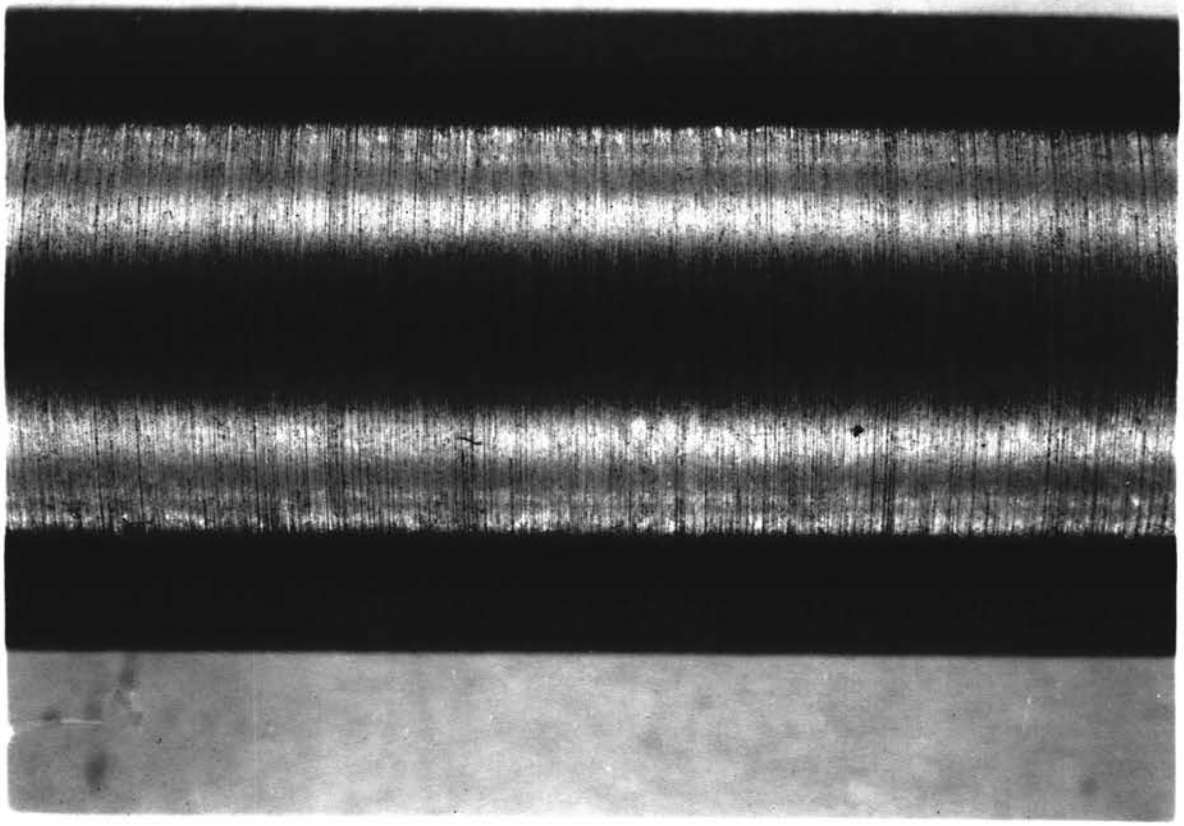


Figure 18

10X PHOTOMACROGRAPH OF GOOD SURFACE FINISH
SAE 1020 STEEL

No evidence of undercutting, cratering, or spalling of the surface. Comparable to a ground surface but not as fine.

Cutting Speed - 60 ft./min.
Depth of Cut - .002"
Feed - .0018"/rev.
Cutting Tool
Round nose finishing tool, 1/16" nose radius, front cutting edge angle 5°, side clearance 8°, front clearance 6°, back rake 16°, side rake 16° negative, lead angle 85°.

CASE STUDY NUMBER 2

THE FORMATION OF THE CHIP

Figure 19

10X PHOTOMACROGRAPH, FORMATION OF ROUGH TURNING CHIP
SAE 1020 STEEL
TOOL STOPPED IN CUT

Cutting Speed - 92 ft./min.
Depth of Cut - - - - - - - - - - - - - - - - - - - 1/16"
Feed - .016"/rev.
Cutting Tool
Rough turning tool C, (see Figures 11 & 36)
Tool was not honed. Tip broke off at front of radius when cut was stopped. Honed tool A did not break off under identical cutting conditions. Note how built-up edge, still in cavity of cut, forms face of chip.

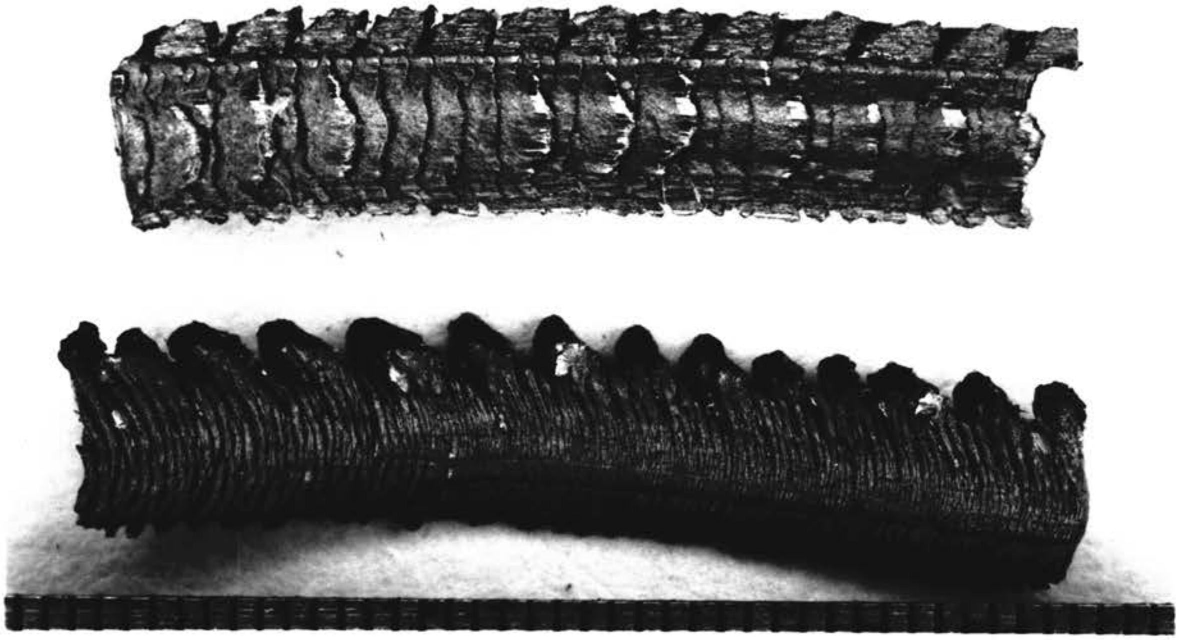


Figure 20

10X PHOTOMACROGRAPH OF ROUGH TURNING CHIPS
FROM CUT ILLUSTRATED IN FIGURE 19

Heavy serrations along edge seem to be caused by a wave-like variation in feeding pressure which makes a low amplitude chatter in the cut. Shiny areas on chip face result from periodic sloughing-off of built-up edge.

CASE STUDY NUMBER 3

C H A T T E R   C U T

COMPARISON OF THE WORK SURFACE, THE TOOL, AND THE CHIP

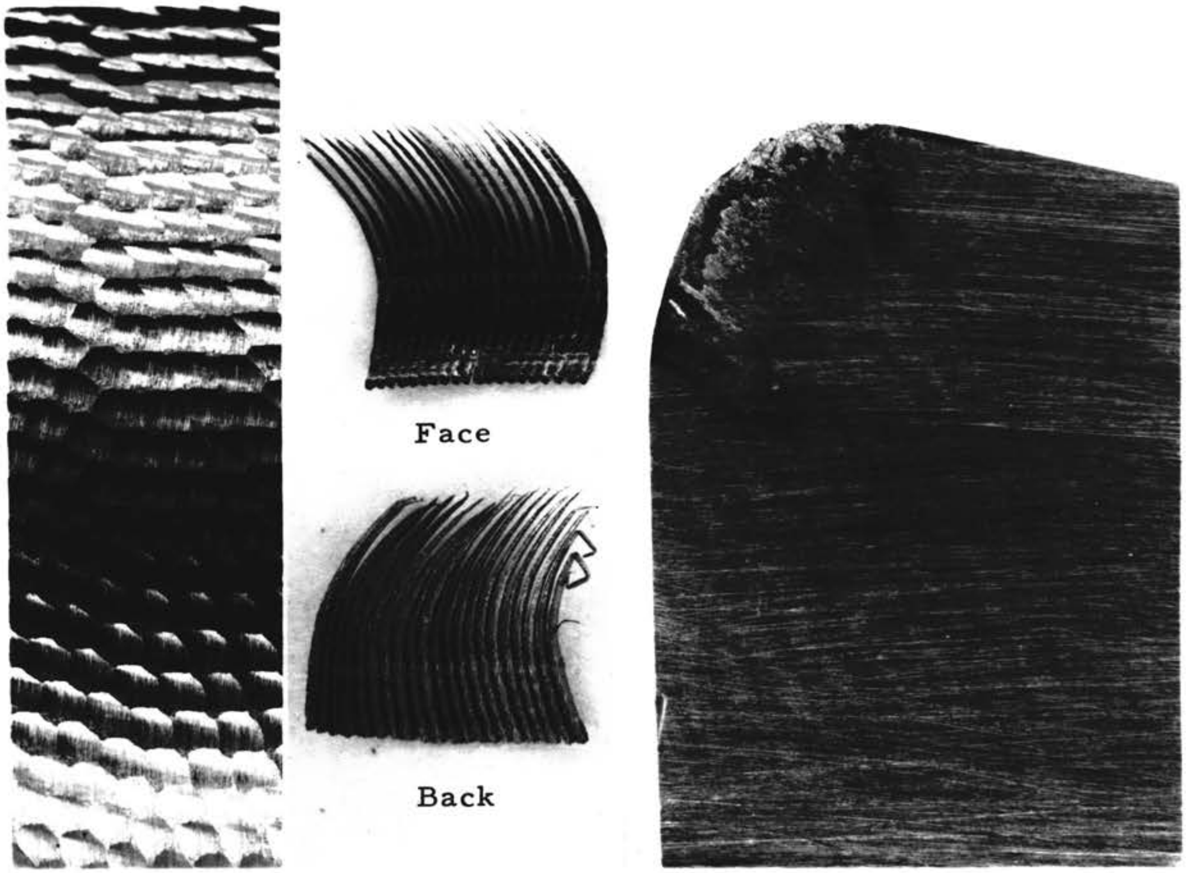


Figure 21

10X PHOTOMACROGRAPH OF WORK SURFACE, CHIP, & TOOL
SAE 1020 STEEL

Cutting Speed - - - - - - - - - - - - - - - - - -	100 ft./min.
Depth of Cut - - - - - - - - - - - - - - - - - -	3/32"
Feed -	.004"/rev.

Chatter was produced by 3" overhang of toolholder, and 1 1/4" overhang of tool.

CASE STUDY NUMBER 4

EFFECT OF CUTTING SPEED

ON CHATTER

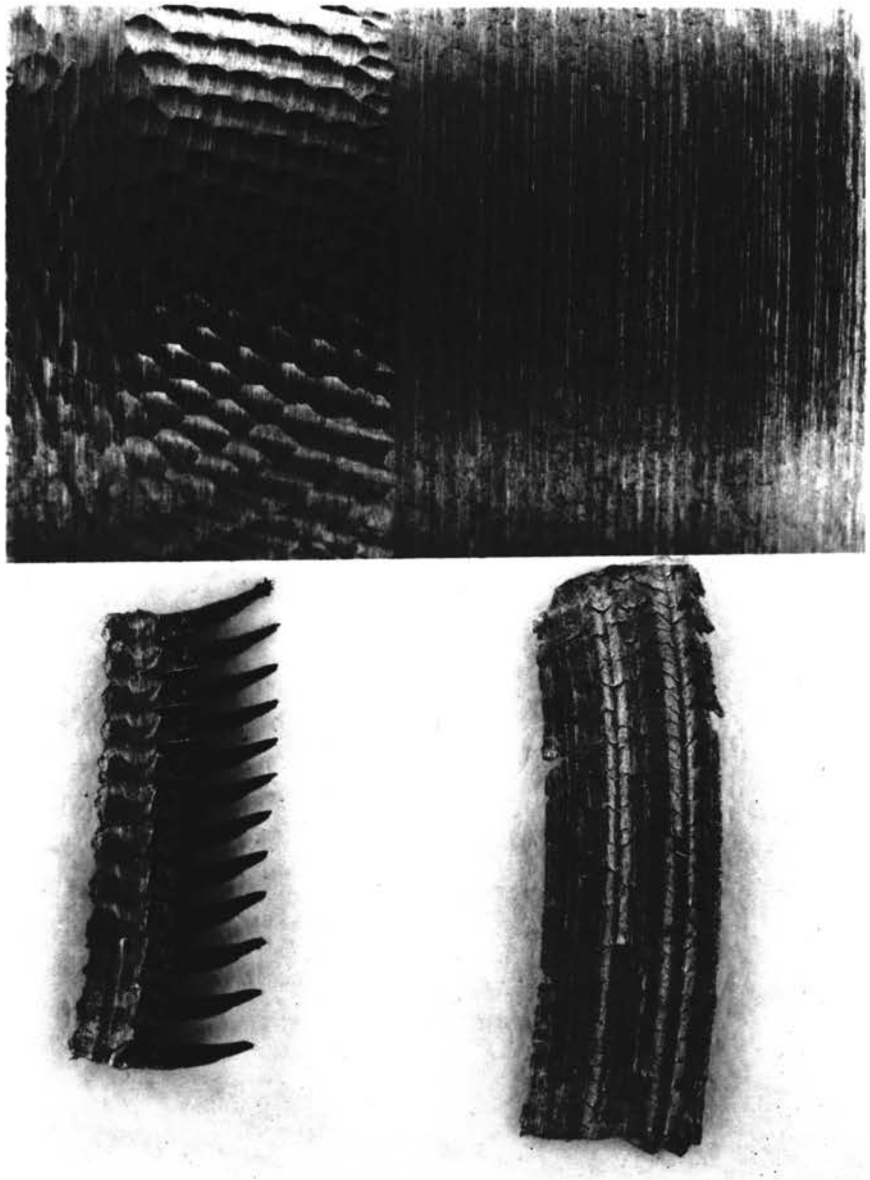


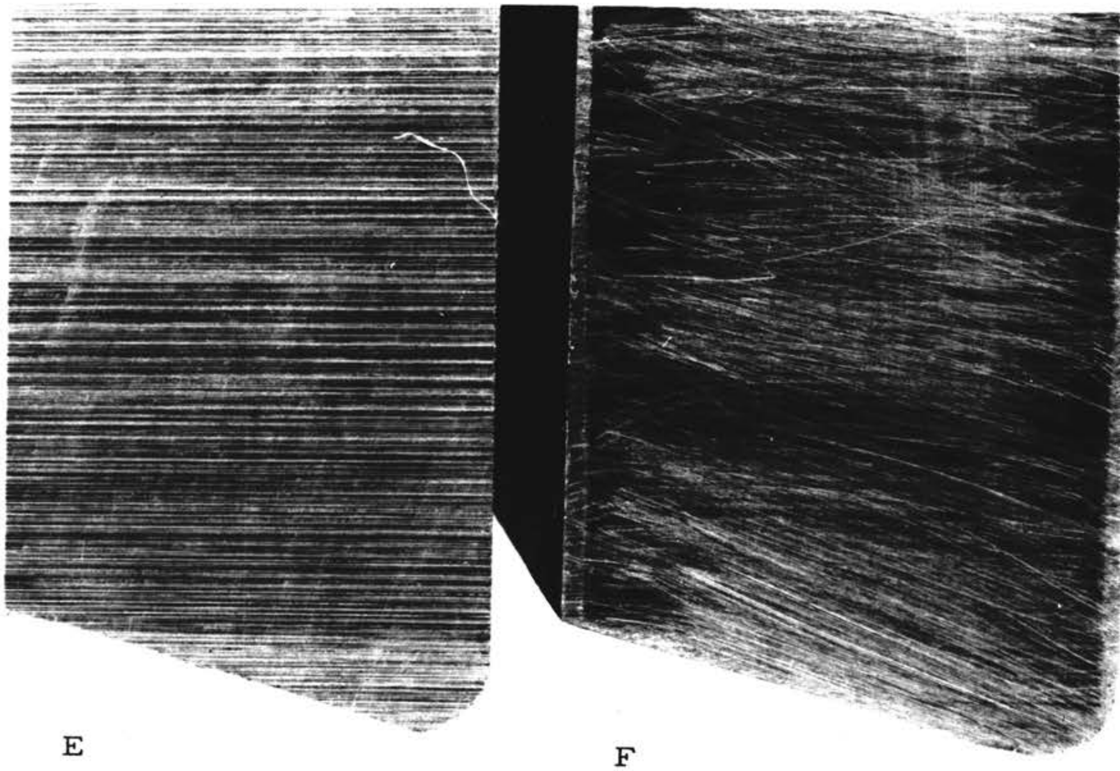
Figure 22

10X PHOTOMACROGRAPH OF EFFECT OF SPEED ON CHATTER
SAE 1020 STEEL

Chatter Conditions
Cutting Speed - - - - - - - - - - - - - - - 180 ft./min.
Depth of Cut - - - - - - - - - - - - - - - 1/16"
Feed - - - - - - - - - - - - - - - - - - - .008"/rev.
Non-Chatter Conditions
Cutting Speed - - - - - - - - - - - - - - - 100 ft./min.
Depth of Cut - - - - - - - - - - - - - - - 1/16"
Feed - - - - - - - - - - - - - - - - - - - .008"/rev.
Cutting Tool
Rough turning tool K, (see Figure 21)

CASE STUDY NUMBER 5

HOLLOW GROUND TURNING TOOLS



E F

Figure 23

10X PHOTOMACROGRAPH, TOP VIEW COMPARISON
OF ROUGH TURNING TOOLS E & F

Grinding the top face of the tool on the periphery of the grinding wheel makes it difficult to hone the radius of the tool properly. As revealed by Tool F, honing a hollow ground surface by hand is not satisfactory.

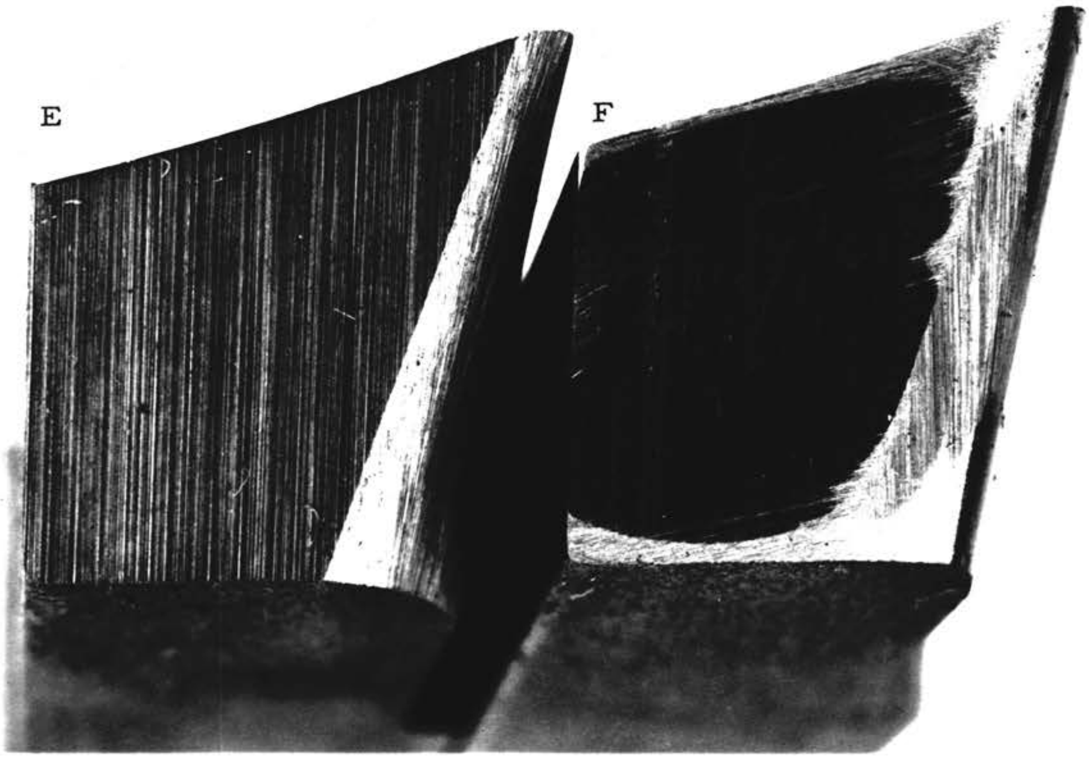


Figure 24

10X PHOTOMACROGRAPH, END VIEW COMPARISON
OF ROUGH TURNING TOOLS E & F

Tool E
Precision ground on the periphery of a 6", 36 grit, aluminum oxide wheel. Nose radius hand ground on an 8", 46 grit aluminum oxide wheel. Tool was not honed.

Tool F
Precision ground on the periphery of a 6", 36 grit, aluminum oxide wheel. Nose radius hand ground on an 8", 46 grit, aluminum oxide wheel. Tool was hand honed with an India Oilstone.

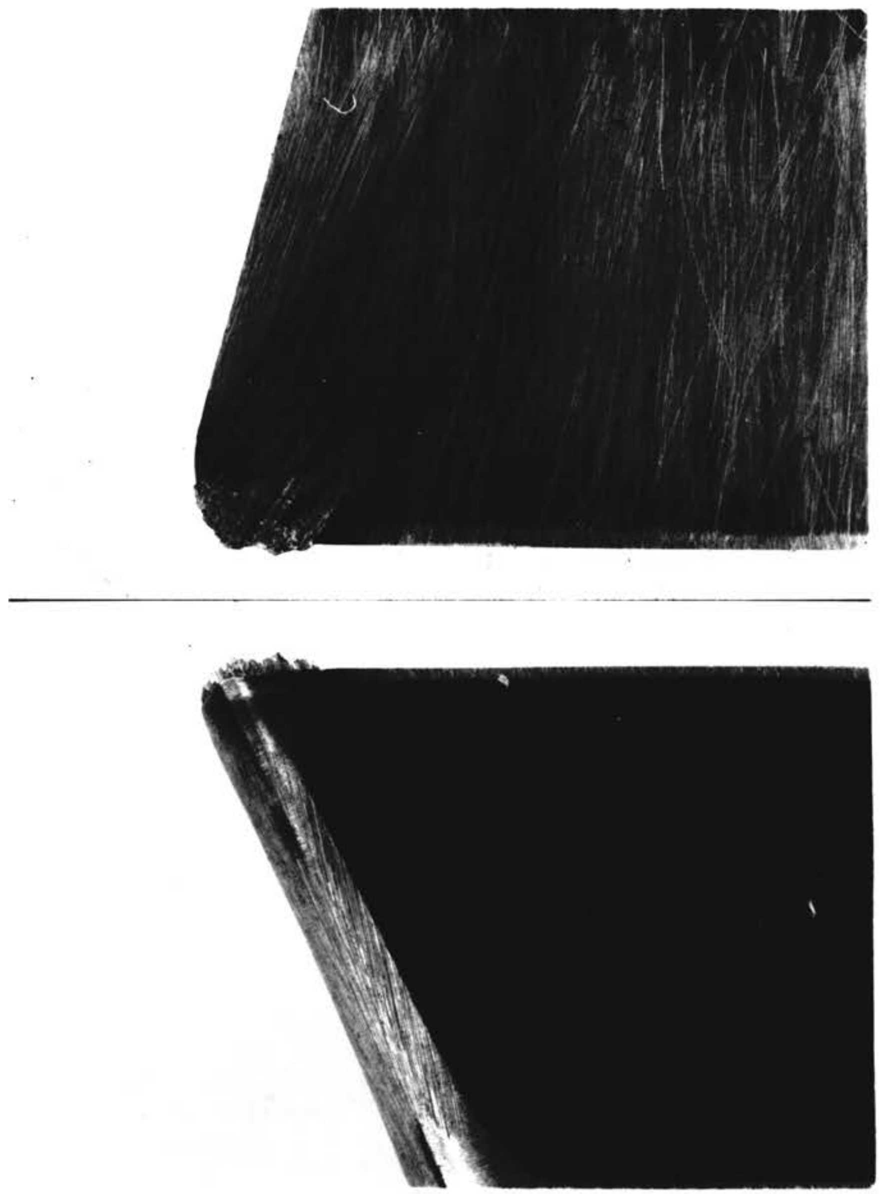


Figure 25

10X PHOTOMACROGRAPH OF BUILT-UP EDGE
ROUGH TURNING TOOL F

The built-up edge indicates the direction of chip flow across face of tool. Profile view of edge reveals the contour of the chip face, (see Figure 31).

SEVEN STUDIES OF CHIPS

ILLUSTRATING SEGMENTATION, CHATTER IN WORK,

SMEAR METAL, HEAT CHECKS, BURNISH, SERRATION,

AND FINISH CHIPS FROM SPECIAL TOOL

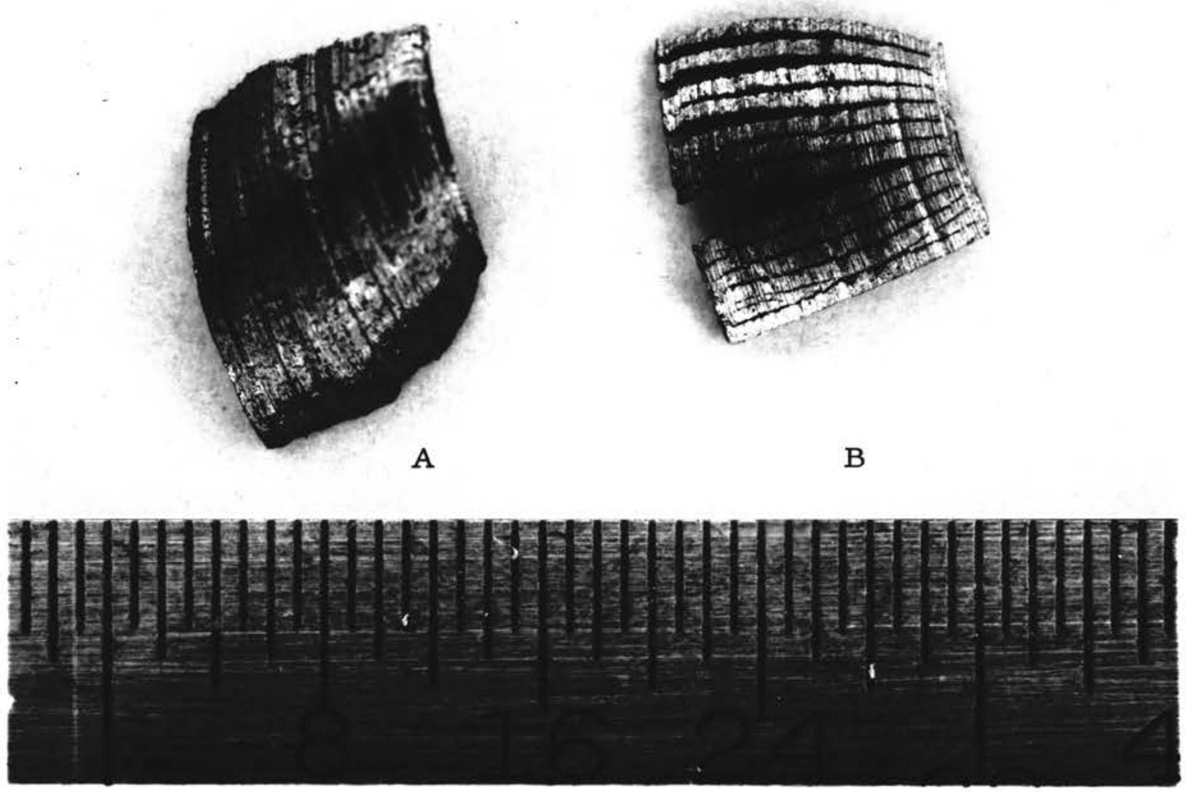


Figure 26 (Scale Graduated in 64ths)

10X PHOTOMACROGRAPH OF TWO PARTING CHIPS
FROM SAE 1020 STEEL

A continuous chip and a segmented chip from the same parting tool plunge-cut. No cutting oil. Evidence of galling and fragmentation in the cut is apparent from chip A.

Cutting Speed, Chip A - - - - - - - - - - - - - 102 ft./min.
Cutting Speed, Chip B - - - - - - - - - - - - - 74 ft./min.
Feed, A & B - - - - - - - - - - - - - - - - - - .002"/rev.
Cutting Tool
Parting, or cutting-off tool, 1/64" corner radii, 5° front clearance, top face hollow ground, no back rake.

Figure 27

10X PHOTOMACROGRAPH OF TWO ROUGH TURNING CHIPS
FROM SAE 1020 STEEL

Illustrating the effect of spring in the work-piece, at the beginning and the end of the cut.
The alternate piling-up of grains on the face of the lower chip indicates the frequency and magnitude of the chatter in the work-piece.

Cutting Speed - - - - - - - - - - - - - - - -	157 ft./min.
Feed -	.008"/rev.
Depth of cut - - - - - - - - - - - - - - - - -	.100 in.

Cutting Tool
Roughing tool, 1/16" nose radius, 10° side clearance, 16° side rake, H.S. Steel Rex AAA, hand ground.

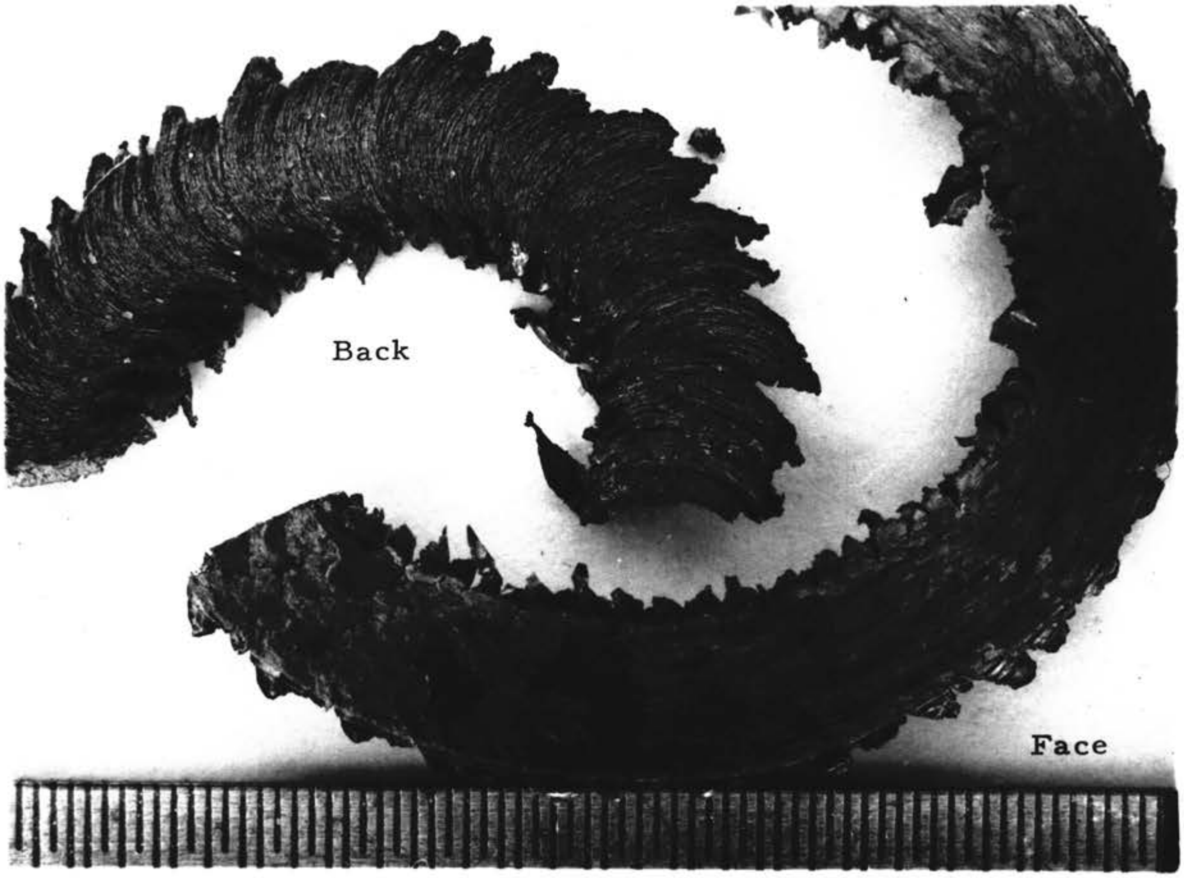


Figure 28

10X PHOTOMACROGRAPH OF FACING CHIP
SAE 1095 STEEL

Face of chip shows areas of smear metal from plastic flow or mushing of grains caused by excessive heat and cutting pressure.
Back of chip clearly shows segmentation process of chip formation. Heavy serrations on chip edges give evidence of resulting rough surface on work.

Cutting Speed - - - - - - - - - - - - - - - - - - -160 ft./min.
Depth of Cut - - - - - - - - - - - - - - - - - - - 1/16"
Cross Feed (center out) - - - - - - - - - - - - - .006" /rev.
Cutting Tool
Roughing tool, 1/16" nose radius, 10° side clearance, 12° side rake, lead angle 70°.

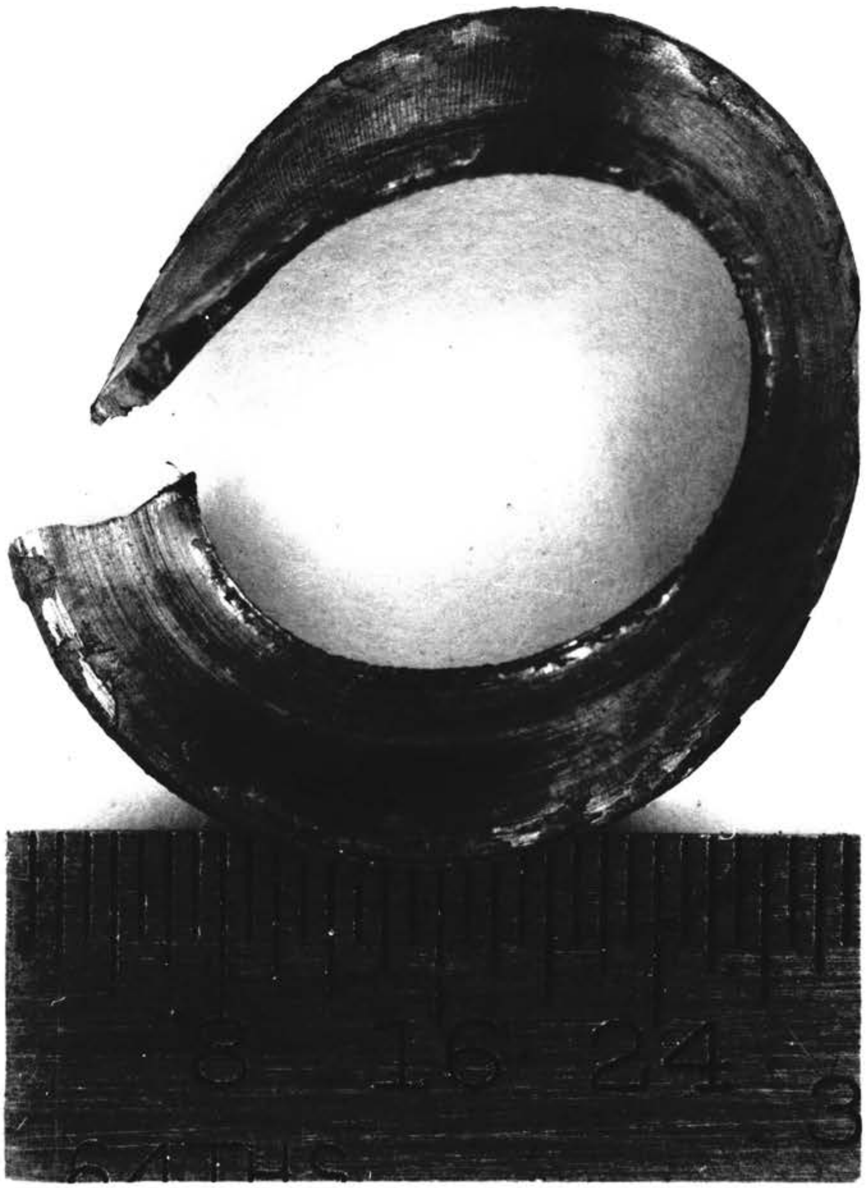


Figure 29

10X PHOTOMACROGRAPH OF CHIP FROM NEGATIVE RAKE TOOL
SAE 1095 STEEL

Chip is dark blue in color, and uniformly covered with smear metal. Negative rake tends to stabilize, but increase, cutting pressure, and reduce vibration. Heat checks reveal extreme work hardening of chip face.

Cutting Speed - 180 ft./min.
Depth of Cut - 1/8"
Feed - .006"/rev.
Cutting Tool
Experimental tool with 20° negative side rake, 0° back rake, 20° side cutting edge angle; lead angle 90° to work.

Face

Back

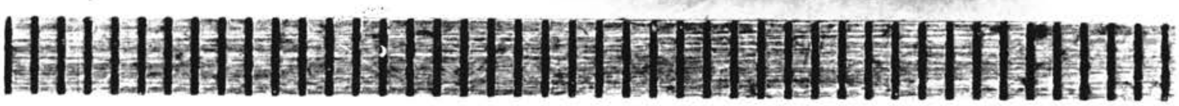


Figure 30

10X PHOTOMACROGRAPH OF BURNISHED CHIP

Cutting Speed - - - - - - - - - - - - - - - - - - 180 ft./min.
Depth of Cut - - - - - - - - - - - - - - - - - 1/16"
Feed - .020"/rev.
Cutting Tool
Rough turning tool A, (see Figure 38).

Chip is dark blue. The combination of speed, feed, and depth of cut exceeded the maximum power of the lathe; the cut stopped the lathe.

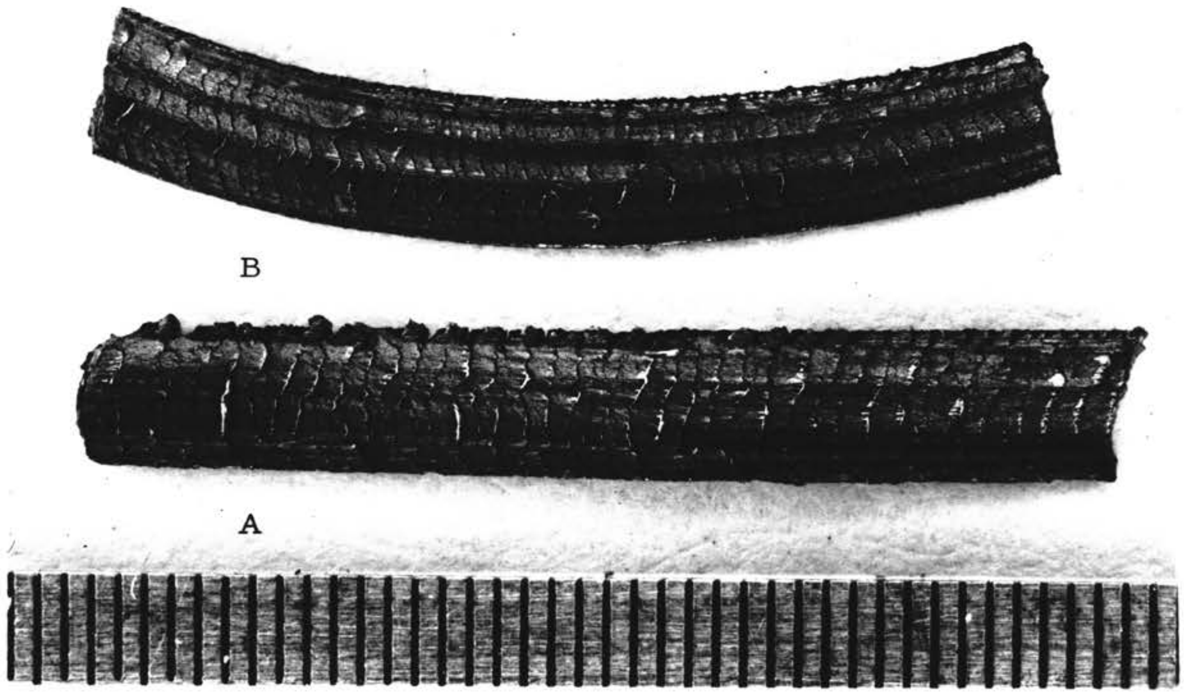


Figure 31 (Scale Graduated in 64ths)

10X PHOTOMACROGRAPH OF CHIPS FORMED BY TOOL F
SAE 1020 STEEL

Chip A	
Cutting Speed - - - - - - - - - - - - - - -	92 ft./min.
Depth of Cut - - - - - - - - - - - - - - -	1/16"
Feed - - - - - - - - - - - - - - - - - - -	.008"/rev.
Chip B	
Cutting Speed - - - - - - - - - - - - - - -	127 ft./min.
Depth of Cut - - - - - - - - - - - - - - -	1/16"
Feed - - - - - - - - - - - - - - - - - - -	.008"/rev.

Serrations on the edge of chip A indicate vibration in the cut. With increase in cutting speed, this vibration decreased both in magnitude and frequency, as can be seen in chip B.

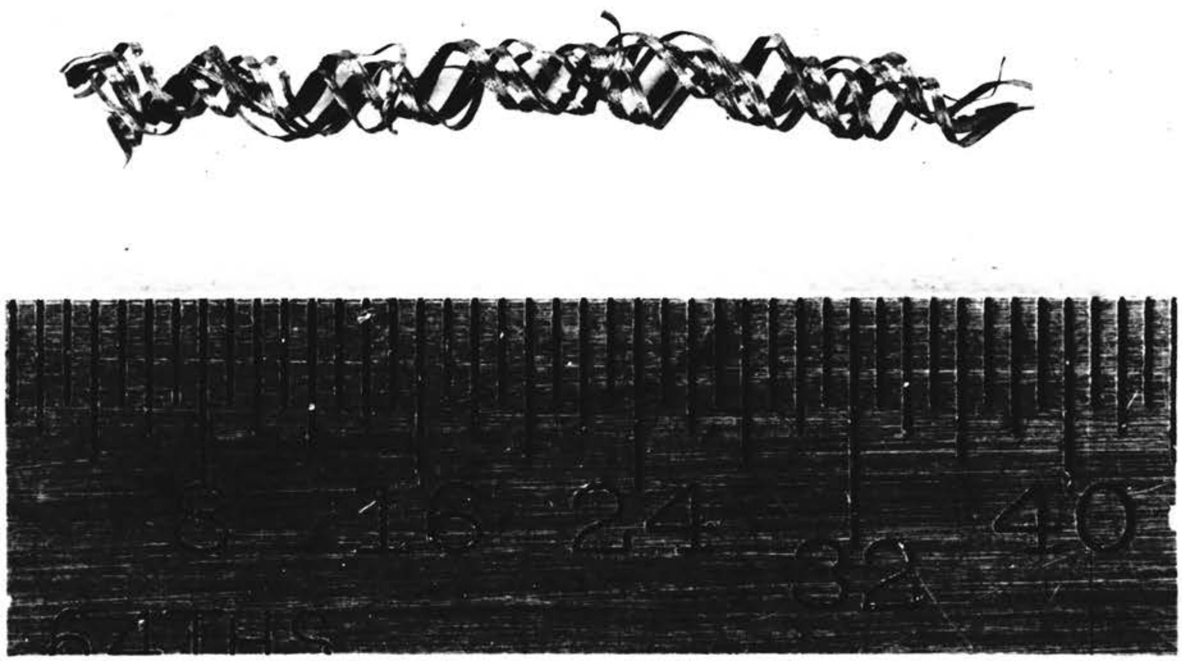


Figure 32

10X PHOTOMACROGRAPH OF FINISH TURNING CHIPS
FORMED BY TOOL D

Cutting Speed - - - - - - - - - - - - - - - -	235 ft./min.
Depth of Cut - - - - - - - - - - - - - - - -	.003"
Feed -	.008"/rev.

Multiple chips indicate that tool contact was not continuous with work. Finish surface obtained was free from scuffing.

SIX COMPARATIVE STUDIES OF

TURNING TOOLS

ILLUSTRATING METHODS OF GRINDING AND HONING

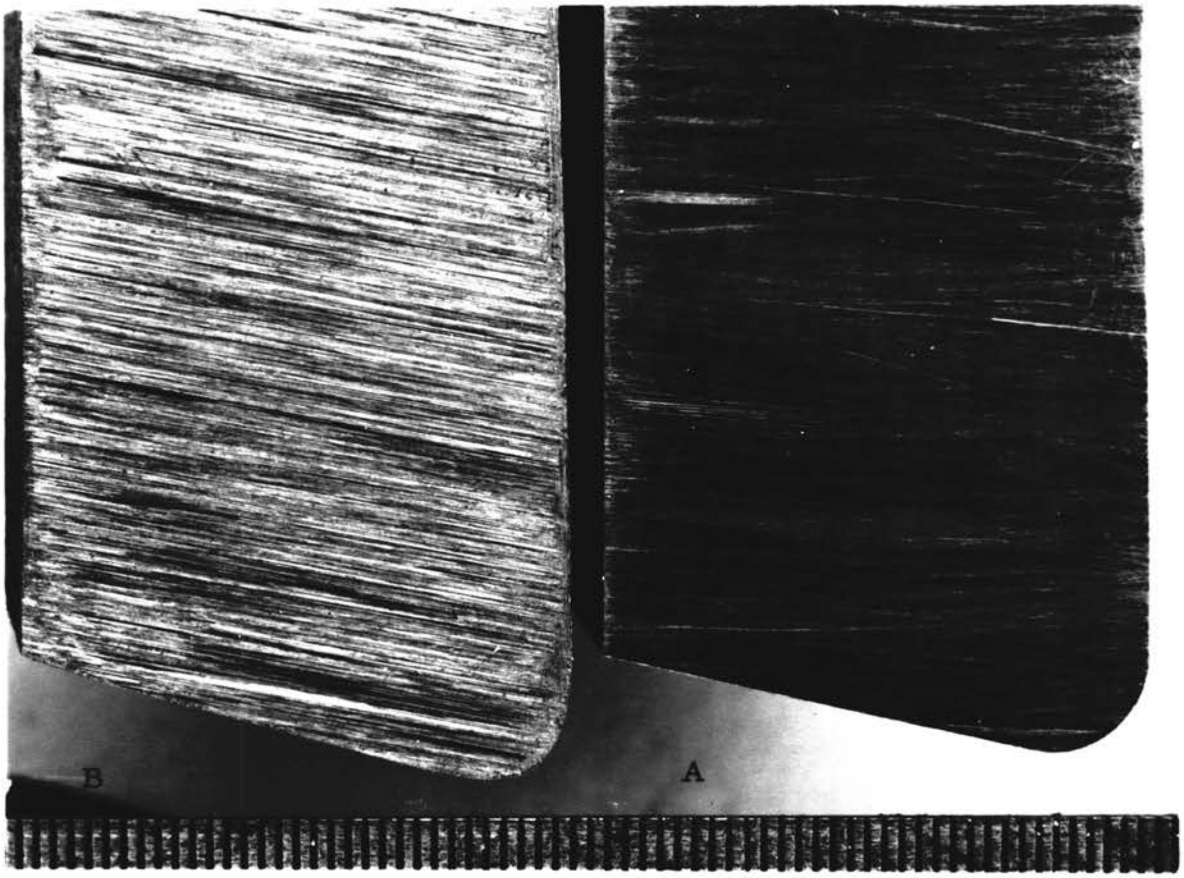


Figure 33 (Scale Graduated in 64ths)

10X PHOTOMACROGRAPH, TOP VIEW COMPARISON,
TWO ROUGH TURNING TOOLS
REX AAA H.S. STEEL

Tool A - Precision ground on Norton 36 grit, Aluminum Oxide, cup-wheel. Hand honed with India Oilstone.
Tool B - Hand ground on periphery of 46 grit Carborundum wheel, 8" diameter. Hand honed with India Oilstone.

Tool Angles	Tool A	Tool B
Nose Radius	1/16"	3/64"
End Cutting Edge Angle	8°	8°
Front Clearance	8°	8°
Side Clearance	8°	10°
Side Rake	16°	16°
Back Rake (in toolholder)	16°	16°

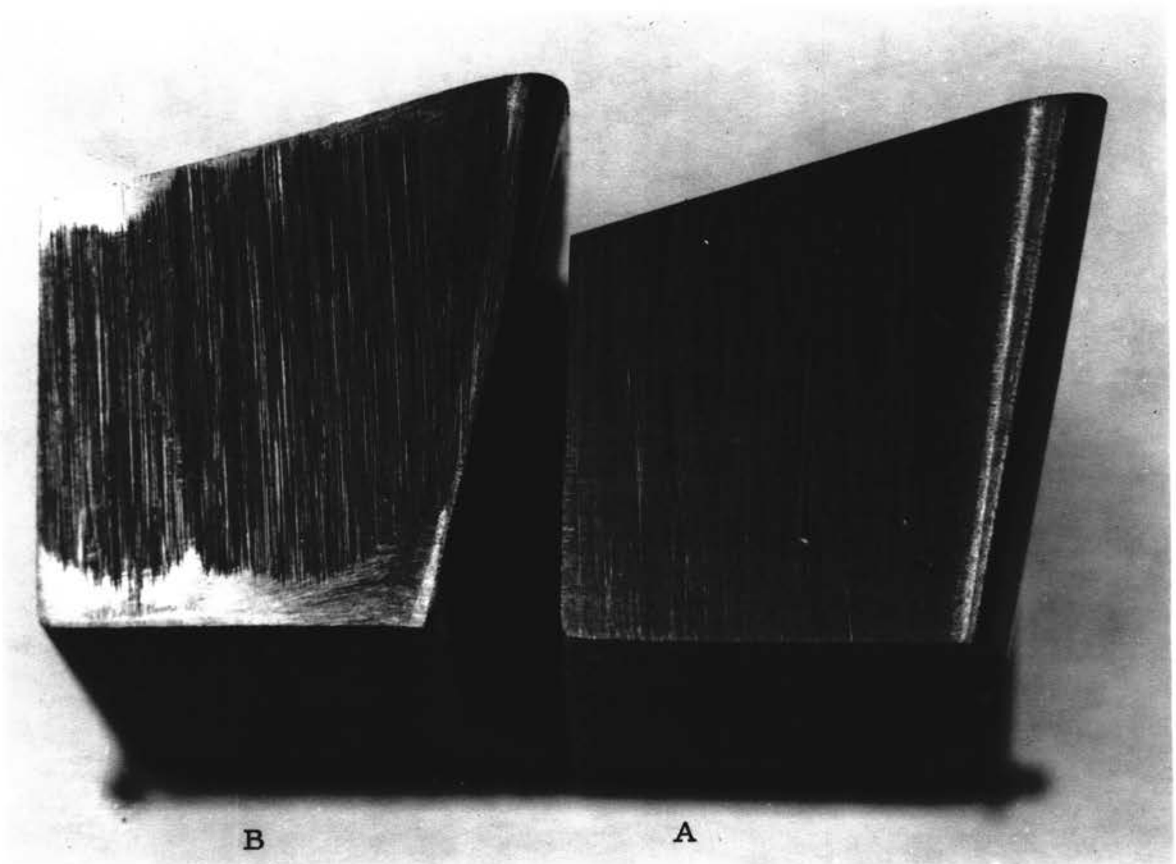


Figure 34

10 X PHOTOMACROGRAPH, END VIEW COMPARISON
ROUGH TURNING TOOLS A & B

Radius of precision ground tool A was formed with a Kaoli radius grinding attachment.

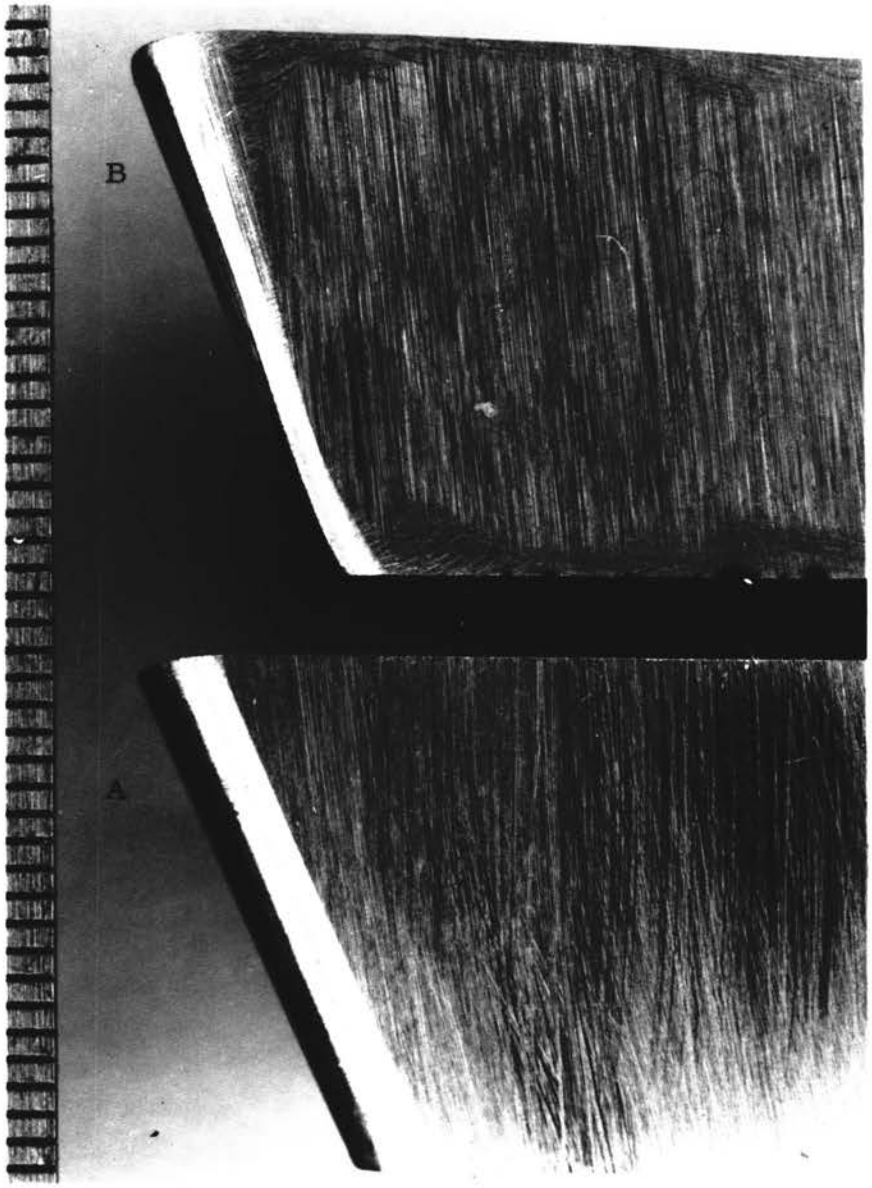


Figure 35 (Scale Graduated in 64ths)

10X PHOTOMACROGRAPH, SIDE VIEW COMPARISON
ROUGH TURNING TOOLS A & B

The radius of cutting edge on tool A is keener than the radius of cutting edge on tool B.

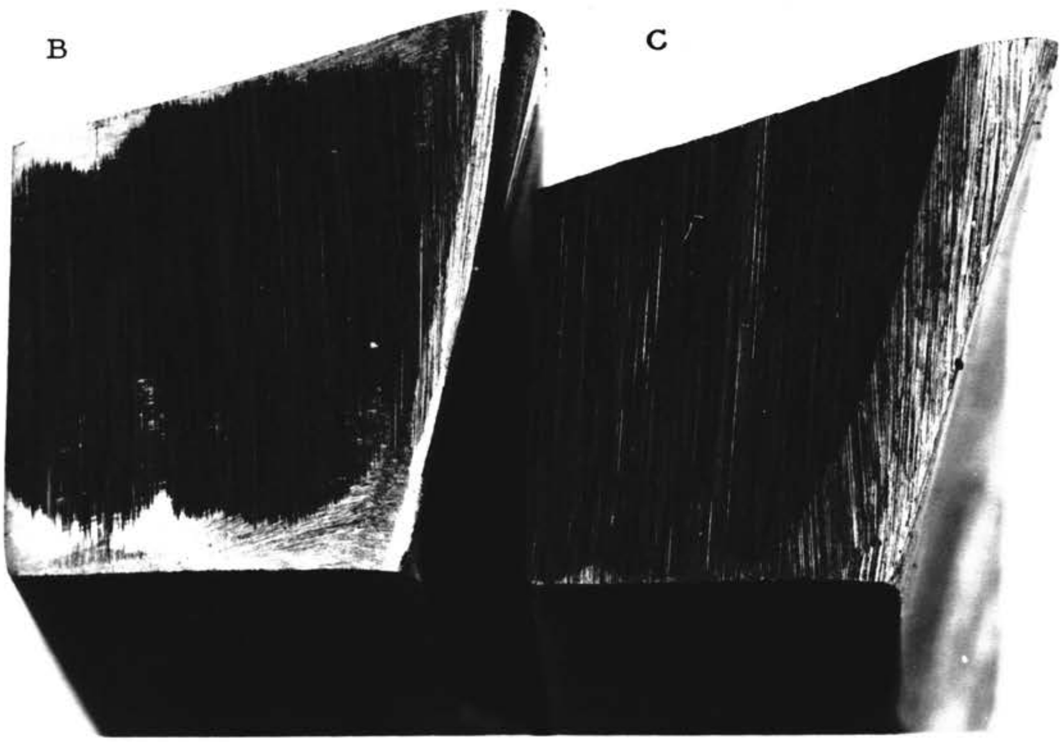


Figure 36

10X PHOTOMACROGRAPH, END VIEW COMPARISON
ROUGH TURNING TOOLS B & C

These tools were ground by a fairly skilled tool grinder, yet differences are apparent. Careful hand honing practically doubles tool life, in addition to greatly improving surface finish.

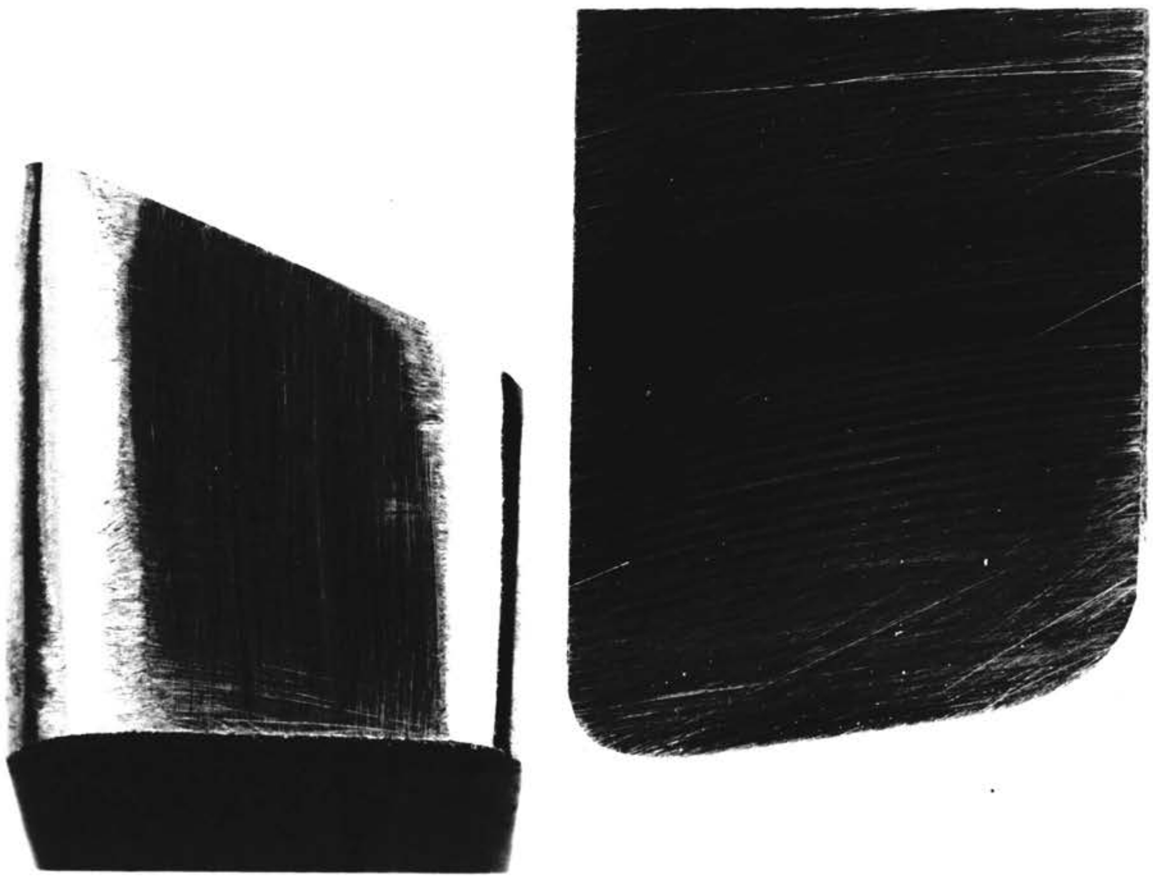


Figure 37

10X PHOTOMACROGRAPH OF SPECIAL FINISHING TOOL D
REX AAA H.S. STEEL

Precision ground and hand honed, same as tool A. Side rake combined with front clearance give an effective end cutting edge angle of about 4° even though tool was precision ground at 0°.

Tool Angles

Nose Radius -	1/8"
End Cutting Edge Angle - - - - - - - - - - - - - - - -	0°
Front Clearance -	8°
Side Rake -	20°
Back Rake (in toolholder) - - - - - - - - - - - - - - -	16°

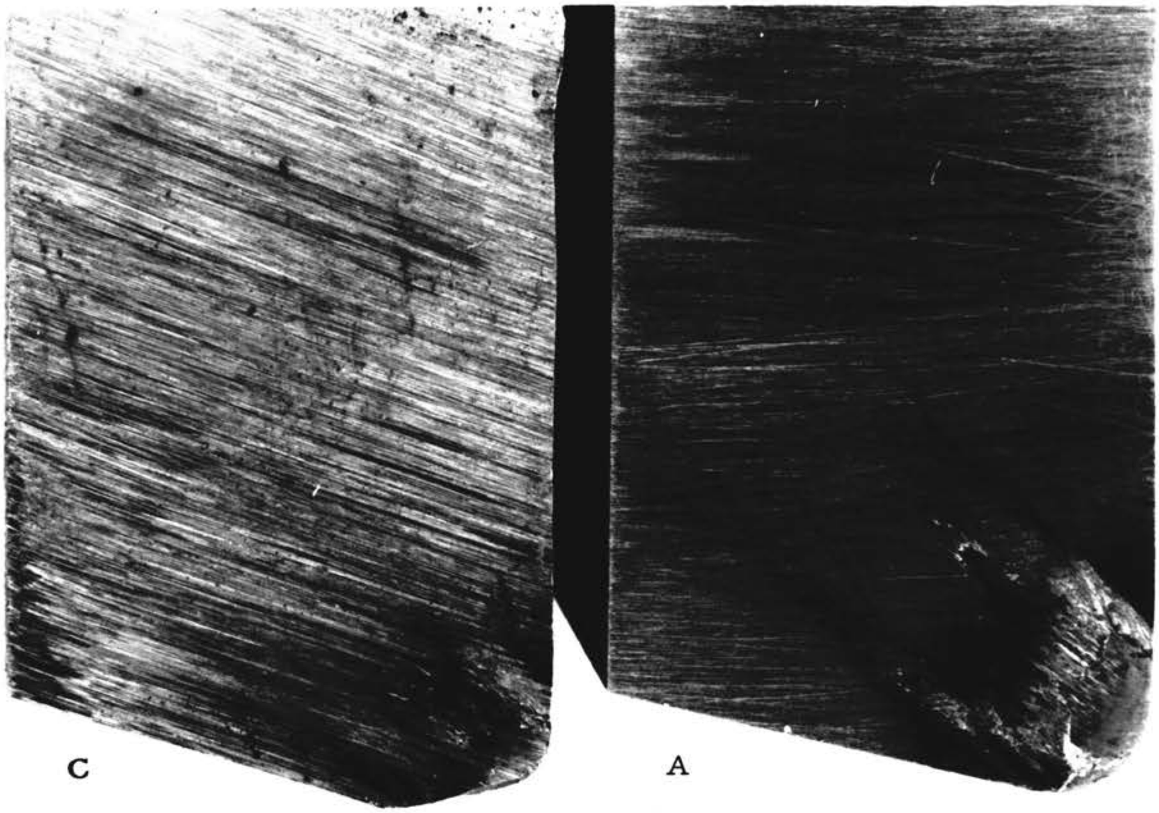


Figure 38

10X PHOTOMACROGRAPH OF TOOLS A & C

Both tools were stopped in their respective cuts which were made under identical conditions of cutting speed, depth of cut, and feed. Tool C was stopped in cut shown in Figure 19. Tool A produced chips shown in Figure 30.

Virginia Lee Davis

Typist