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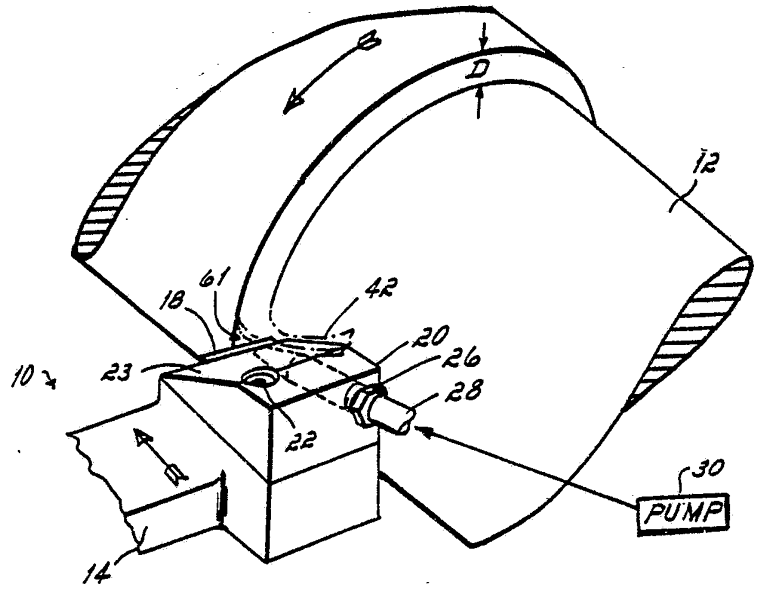

(57) Abstract

A method and apparatus for performing machining operations on a workpiece such as cutting, boring turning and milling is accomplished at reduced power levels with increased tool life and efficiency. The apparatus includes a tool holder (10) formed with at least one release orifice (32) in which a cutting insert (18) is mounted having a surface (17) terminating with a cutting edge (19). The cutting edge (19) of the insert (18) is adapted to engage the workpiece (12) to form chips (42) which overlie the surface (17) of the cutting insert (18) and the release orifice (32) in the holder (10). A coolant delivery system including a pump (30) is adapted to eject a coolant jet (38) from the release orifice (32) at high velocity and high pressure between the surface (17) of the cutting insert (18) and the chips (42), from a location beneath the chips (42).

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CUTTING TOOL COOLANT DELIVERY APPARATUS AND METHOD

Related Applications

This application is a Continuation-In-Part of co-pending U.S. Patent Application Serial No. 470,193, entitled "Cutting Tool Assembly", filed February 28, 1983, which is a Continuation-In-Part of U.S. Patent Application Serial No. 263,305, entitled "Cutting Tool and Insert Therefor", filed May 13, 1981, now abandoned.

Background of the Invention

This invention relates to machining and, more particularly, to an improved method and apparatus for performing metal working operations such as turning, boring, shaping and milling at reduced power levels with increased tool life and efficiency.

A cutting tool generally includes a holder and one or more cutting inserts each having a surface terminating with one or more cutting edges. The holder is formed with a socket to clamp the cutting inserts in a position so that in metal working operations such as turning, boring, shaping and milling, the cutting edges of the inserts engage a workpiece and remove a chip of metal. The chips comprise a plurality of thin sections of metal which slide relative to one another along shear planes when separated from the workpiece. This shearing movement of the thin metal sections forming the chip generates a substantial amount of heat. In fact, the heat generated along the shear planes in the chip may be even greater than the heat generated by abrasion of the cutting edge of the insert as it contacts the workpiece.

The major causes of failure of the cutting inserts of machine tools are abrasion between the cutting insert and workpiece, and a problem known as cratering. Cratering results from the tremendous heat developed in the chip and its engagement with the cutting insert. As the metal forming the chip is sheared from the workpiece, it frictionally engages the top surface of the insert and in some cases the socket portion of the tool holder which secures the insert in place. Many inserts include a chip breaker groove on their upper surface which is adapted to engage the chip and turn it upwardly away from at least a portion of the insert surface and the socket portion of the tool holder. However, even with chip breaker grooves, at least a portion of the upper surface of the insert inwardly from its cutting edge is in frictional engagement with the hottest portion of the chip. Due to this frictional engagement and the tremendous heat generated by the chip, material from the upper surface of the insert is melted and carried away forming grooves or craters in the insert. Once these craters become deep enough, the entire insert is subject to cracking along its cutting edge and along the sides of the insert due to abrasive contact with the workpiece, which quickly leads to failure. Cratering has become a particular problem in recent years due to the development and extensive use of super hard alloys such as titanium.

Prior attempts to achieve cooling and lubrication of the cutting insert-workpiece interface, and between the cutting insert and chip to avoid cratering and abrasion wear, have provided only modest increases in tool life and efficiency. One approach in the prior art has been to form inserts of high strength metals such as carbide steel. Although very hard, carbide inserts are brittle and can be easily chipped which reduces their effectiveness. To improve the lubricity and strength of inserts, such materials as hardened ceramics have been used and a variety of low friction coatings have been developed for coating cutting inserts. In fact, many inserts are currently manufactured with multiple coatings to further increase tool life. While development of improved materials and coatings for cutting inserts has increased tool life to some degree, even the best cutting inserts must be replaced frequently, depending upon the speed and feed rates, particularly in machining titanium and similar hardened materials.

In addition to the improved materials and coatings used in manufacturing cutting inserts, attempts have been made to increase tool life by cooling and lubricating the cutting insert-workpiece interface, and the cutting insert and chip, using a quenching operation in which the tool holder and workpiece are flooded with a low pressure stream of any one of a number of types of coolant. Typically, a nozzle is disposed several inches above the cutting tool and workpiece which directs a low pressure stream of coolant onto the workpiece, tool holder and on top of the chips being produced. This technique, known as flood cooling, effectively cools only the upper surface of the chips, and that portion of the tool holder near the edge of the socket which holds the cutting insert in place. The underside of the chip which makes contact with the cutting insert and the interface between the cutting insert and workpiece, where the extremely high heat is actually produced, remain unaffected by the coolant. This is because the heat produced in the area of the chip and the cutting edge of the insert, at the operating speeds of modern milling or turning machines, vaporizes the coolant well before it can flow near the cutting edge of the insert. In fact, the feed rates and speeds at which modern milling and turning machines can operate far exceed the machining capabilities of existing insert designs and flood coolant techniques.

In some instances, flood cooling can result in thermal failure of the cutting inserts. This occurs because a high temperature gradient is developed between the very hot area immediately surrounding the cutting edge, and the cooler inner portion of the cutting insert held in the socket of the tool holder. The coolant cannot reach the cutting insert area before it is vaporized and thus effectively cools only the area of the insert opposite the cutting edge which is held in the tool holder. This extreme difference in temperature between the cutting edge and the remainder of the cutting insert can result in thermal failure.

One attempt to improve prior art cooling methods is found in U.S. Patent No. 2,653,517 to Pigott. This patent teaches a method and apparatus for applying cooling liquids at a velocity of approximately 260 feet per second to a location between the workpiece and the back or rear edge of the cutting insert beneath the side of the insert where the chip is produced. This approach is also disclosed in German Patent No. 3,004,166. The problem with this method of cooling is that the coolant is not introduced at a location where cratering and high temperatures of the cutting insert occur; that is, between the upper surface of the insert and underneath the chip produced. The introduction of coolant underneath the cutting insert does little or nothing to reduce the frictional engagement between the chip and cutting insert.

Another approach is taught in U.S. Patent No. 4,302,135 to Lillie. The rotary cutting tool in Lillie comprises a body formed with a shank portion and a cutting portion through which a longitudinal bore extends including an inlet in the shank portion and an outlet in the cutting portion. Formed in the bottom surface of the cutting portion and extending radially outwardly from the outlet are spaced channels which terminate at sockets adapted to mount cutting inserts. The channels align with grooves formed in the cutting inserts which lead to the cutting edge of the inserts. Coolant is pumped through the central passageway, directed radially outwardly through the channels and is then radially deflected by the tool body along the coolant flow channels in the cutting inserts.

An attempt is made with the Lillie rotary tool to direct a high velocity, high pressure coolant flow to the area of the cutting insert-workpiece interface. Unfortunately, the structure provided in the Lillie patent does not permit the coolant to reach the cutting edge - workpiece interface, or the chips in that immediate area, due to the intense heat developed by the cutting operation. Flow of the coolant from the central passageway in Lillie to the cutting inserts is essentially unconfined. Once the coolant is ejected from the outlet in the central passageway, its pressure and velocity drop by an order of magnitude. This is because the cross-sectional area of the base of the cutting portion of the Lillie tool is relatively large compared to that of the central bore, and the coolant flow is exposed to the atmosphere as each insert rotates to the area already cut by the tool. With its pressure and velocity substantially reduced, the coolant stream provided in Lillie simply vaporizes before it can reach the immediate area of the cutting edge-workpiece interface where the intense heat is produced. Therefore the Lillie invention is essentially a flood cooling system in which any cooling achieved is confined to an area of the cutting insert immediately adjacent the end of the radial channels in the cutting portion of the body, and/or to the chips flowing outwardly from the cutting edge-workpiece interface when they reach that location.

In machining low, medium or hard alloy metals using the prior art cutting insert designs and the cooling and lubricating methods mentioned above, or any other known methods, the machining rates which can be achieved are much less than the capacity of the machine tools. For example, commercially available tooling used to machine the types of alloy steels used in jet aircraft engines are operable to machine at rates of 20 to 200 surface feet per minute at a chip load in the range of .001 to .005 inches per revolution to remove up to 10 cubic inches per minute. These machining rates are typical of those recommended for currently available tooling, and operation outside of such recommended rates can invite catastrophic failure due to high loads beyond the strength of the cutting inserts and high deterioration. While such machining rates are considered to be reasonable using existing cutting inserts and flood cooling techniques, improvements are desirable to match more closely the capabilities of existing machine tools and to avoid more costly methods of machining such as electrochemical etching or grinding.

Another pervasive problem in the cutting tool industry involves the removal of chips from the area of the cutting insert and holder. Preferably, chips should be broken into segments of two inches or less when sheared from the workpiece. If they are not broken but form in a continuous length, the chips tend to wrap around the cutting insert, tool holder and/or the workpiece which can lead to tool failure or at least require periodic interruption of the machining operation to clear the area of impacted or bundled chips.

Current attempts to solve the chip removal problem are limited to various designs of cutting inserts having a chip breaker groove, which is a groove formed in the top surface of the cutting insert immediately adjacent the cutting edge. Chip breaker grooves engage the chips as they shear from the workpiece and turn them upwardly from the surface of the cutting insert so that the chips tend to fracture. While acceptable performance has been achieved with some chip breaker groove designs in some applications, variables in machining operations such as differing materials, types of machines, depths of cuts, feed rates and speeds make it virtually impossible for one chip breaker groove design to be effective in all applications. This is evidenced by the multitude of chip breaker designs now available which are intended to accommodate the widely varying machining conditions which can occur in industry. Selection of a suitable cutting insert for a particular application, if one exists at all, can be an expensive and difficult problem.

Summary of the Invention

In a broad aspect of this invention, a method and apparatus is provided for performing a machining operation such as cutting, boring, turning, milling, grooving, threading or drilling in which a coolant is directed at high velocity between the upper surface of a cutting insert, and the bottom surface of the chips it produces, from a location beneath the chips.

In a more specific aspect of this invention, a method and apparatus is provided for machining a workpiece in which the chips produced in the machining operation are effectively cooled, and fractured from the workpiece in relatively small lengths, while the surface of the cutting insert performing the machining operation is lubricated and cooled. The apparatus comprises a tool holder having a leading end formed with at least one release orifice. The tool holder includes a socket in which a cutting insert is mounted having a surface terminating with a cutting edge. The cutting insert is adapted to engage a rotating workpiece to form chips which overlie the surface of the cutting insert and the release orifice. Means are provided for ejecting the coolant from the release orifice at high velocity along the top surface of the cutting insert and beneath the chips.

In more specific aspects of the apparatus of this invention, the cutting operation is performed at a predetermined feed rate and depth of cut. As is well known, the feed rate represents the distance moved by the tool holder for each revolution of the workpiece. Preferably, the cutting insert is mounted within the holder so that the release orifice formed in the holder is spaced a distance in the range of about 6 to 10 times the feed rate from the cutting edge, or about 6 to 10 times the distance moved by the holder in each revolution of the workpiece. The release orifice may be either circular or noncircular in cross section. If circular, the release orifice is formed with a diameter preferably approximately equal to the depth of the cut taken by the cutting insert. A noncircular orifice is formed with a cross section having a smaller and larger transverse dimension. Preferably, the larger transverse dimension of the noncircular release orifice is approximately equal to the depth of cut taken by the cutting insert.

In a further aspect of this invention, the apparatus is provided with means for conveying coolant to the tool holder and means for conveying the coolant through the tool holder and ejecting it from the release orifice at high velocity. The coolant is conveyed to the tool holder by a delivery line connected at one end to the holder and at the other end to a high pressure pump. Preferably, the pump and delivery line are sized to convey the coolant to the tool holder at a velocity in the range of about 20 to 40 feet per second. The coolant is conveyed within the tool holder by a main passageway communicating at one end with the delivery line, and a transition passageway disposed between the main passageway and the release orifice. Preferably, the walls of the transition passageway taper from the main passageway to the release orifice so that it is frusto-conical in shape. The angle formed by the walls of the transition passageway at the release orifice is preferably less than about 20 degrees. Assuming the release orifice is circular in cross section, the length of the transition passageway is preferably about 20 times the diameter of the release orifice. In addition, the walls of the transition passageway are highly polished in any one of a variety of known methods. The dimensions, frusto-conical shape and polished walls of the transition passageway permit acceleration of the coolant between the main passageway and the release orifice to a velocity on the order of 10 times that within the main passageway and delivery line, depending on the particular machining conditions, as discussed in detail below.

In a further broad aspect of this invention, a method of machining is disclosed in which a high velocity, high pressure coolant jet is directed between the upper surface of a cutting insert and the underside of a chip sheared from a workpiece by the insert, from a location beneath and covered by the chip. The release orifice formed in the tool holder herein is positioned relative to the cutting edge of the cutting insert so that the chips produced in the machining operation overlie the release orifice. In effect, an enclosure or cavity is produced surrounding the release orifice which is formed by the workpiece, the upper surface of the cutting insert, the underside of the chip and the tool holder. The coolant jet ejected at high pressure and high velocity from the release orifice is confined within this cavity and undergoes minimal energy losses until the chip is broken away from the workpiece.

Several advantages over prior art machine tools and cooling techniques are provided by the process of machining according to this invention wherein a high velocity, high pressure coolant jet is ejected in a confined area or cavity directly beneath the chips being formed from the workpiece. It has been found that by maintaining high pressure and velocity at a location directly beneath the chips being formed, the coolant jet can pierce the heat barrier produced by abrasion at the cutting insert-workpiece interface and by the shearing motion within the chips being formed. Due to the large surface area presented by the underside of the chips, and the extreme temperature differential of the chips and coolant, rapid heat transfer occurs between the chips and coolant. It is believed that the chip temperature is lowered so rapidly, on the order of 0.1 seconds or less, that its semi-plastic lattice structure is actually solidified in a disrupted molecular configuration. This results in the formation of very brittle chips which are much easier to break from the workpiece than chips having a normal lattice structure. In the process of conducting the heat from the insert-workpiece interface, and the chips, a portion of the coolant becomes vaporized. Since the coolant jet is ejected into an essentially closed cavity, a substantial vapor pressure is developed by the vaporized coolant beneath the chip in addition to the pressure applied by new coolant continuously being ejected from the relaease orifice. The combined pressure of the vaporized coolant and line pressure builds within the closed cavity beneath the chip which fractures the chips from the workpiece and removes them from the cutting area.

It has been found that at least some of the coolant jet is not vaporized but flows at high velocity within the enclosed cavity as a thin film along the upper surface of the cutting insert. This thin film of coolant performs two functions. First, at least some of the coolant film reaches the cutting edge-workpiece interface and flows between the microscopic interstitial surface irregularities of both the cutting edge and workpiece. This provides at least some lubrication and removes some of the heat produced thereat. Secondly, the thin coolant film on the upper surface of the cutting insert exerts a hydrodynamic fluid force against the chips being formed which tends to urge them upwardly out of contact with the insert. This reduces abrasive wear of the cutting insert and cratering formed by engagement of the chips with the insert.

The method and apparatus of this invention achieves a true coolant assisted machining operation in contrast to prior art flood cooling techniques. A high velocity, high pressure coolant jet is introduced at a location beneath the chips being formed where it is confined in an essentially sealed or closed cavity so that its pressure and velocity are maintained with only minimal losses. The introduction of a high velocity, high pressure coolant jet beneath the chip and immediately adjacent the cutting edge-workpiece interface permits the coolant jet to pierce the vapor or heat barrier produced in the area of the cut so that effective cooling is provided at the cutting edge-workpiece interface and in the chips where extremely high heat is produced. Flood cooling systems are incapable of piercing this vapor barrier and therefore cannot achieve cooling of the cutting edge-workpiece interface or the immediately adjacent area of the chip.

Description of the Drawings

The structure, operation and advantages of this invention will become further apparent upon consideration of the following description taken in conjunction with the accompanying drawings wherein:

Figure 1 is a partial isometric view, which is greatly exaggerated for purposes of illustration, showing a turning holder in accordance with this invention in the process of taking a cut on a cylindrical piece of stock;

Figure 2 is a partial isometric view of the turning holder shown in Figure 1;

Figure 3 is an enlarged side view of Figure 1 in the area of the cut;

Figure 3a is and enlarged side view of Figure 1 at the beginning of a cut to form a chip;

Figure 3b is a side view as shown in Figure 3a in which the chip being produced contacts the leading edge of the tool holder;

Figure 3c is a side view as shown in Figure 3a in which the chip being produced moves further along the upper surface of the tool holder; and

Figure 4 is a side view, similar to Figure 3 of a prior art flood cooling system.

Detailed Description of the Invention

Referring now to the drawings, a tool holder 10 is illustrated for machining a workpiece 12 in accordance with the method of this invention. The workpiece 12 is mounted in a chuck (not shown) which is adapted to rotate the workpiece 12 in the direction indicated in Figure 1. Tool holder 10 is a turning holder for performing a turning operation, but it should be understood that the method of machining according to this invention is applicable to other machining operations such as milling, boring, cutting, grooving, threading and drilling, and the tool holder 10 is shown herein for purposes of illustration. Tool holder 10 comprises a support bar 14 formed with a cutout 16 adapted to receive a cutting insert 18 having an upper surface 17 terminating with a cutting edge 19. The cutting insert 18 is secured within the cutout 16 by a clamp 20 which extends along the edge of the support bar 14 to a point spaced from the cutting edge 19 of insert 18. The clamp 20 is removably secured to the support bar 14 by a screw 22 or other suitable means.

A port 24 is formed in the end of clamp 20 opposite the cutting insert 18, which receives a fitting 26 connected to one end of a coolant delivery line 28. The opposite end of the coolant delivery line 28 connects to a high pressure pump 30 (shown schematically) having a flow and pressure capacity discussed in detail below. A release orifice 32 is formed in the leading end 21 of clamp 20 opposite the coolant delivery line 28. Although a single release orifice 32 is shown in the drawings, it is contemplated that two or more release orifices 32 may be formed in clamp 20 depending on the cut to be made. Coolant is conveyed through the clamp 20 from the coolant delivery line 28 to the release orifice 32 by a main passageway 34 connected at one end to the coolant delivery line 28, and a transition passageway 36 formed between the main passageway 34 and the release orifice 32. Preferably, the interior wall 37 of transition passageway 36 is highly polished by first buffing it with a diamond paste and then depositing a substance such as silica glass using a known vapor deposition process. The finish of the interior wall 37 of transition passageway 36 should exhibit surface irregularities no larger than about 10 microns.

The pump 30, coolant delivery line 28, and passageways 34, 36 comprise a coolant delivery system for producing a high speed, high pressure coolant jet 38 which is ejected from the release orifice 32. Depending on such factors as the type of material forming workpiece 12, the speed at which the workpiece 12 is rotated and the feed rate of the tool holder 10, a pump 30 having a particular pressure and flow capacity is chosen. An example of how a pump 30 is chosen for a particular application is described in detail below. Preferably, the coolant delivery line 28 is sized according to the flow capacity of pump 30 to produce a coolant flow from the pump 30 to the port 24 in clamp 20 having a velocity of about 20 to 40 fps (feet per second). It has been found that at this velocity the coolant travels along the coolant delivery line 28 with minimum turbulence and insignificant losses due to drag. In a preferred embodiment of this invention, the diameter of the main passageway 34 formed in clamp 20 is approximately equal to the diameter of the coolant delivery line 28. This ensures that the coolant will maintain a velocity of about 20-40 fps within the main passageway 36 of the tool holder 10 to avoid turbulence. Although it is not necessary to form the delivery line 28 or main passageway 34 with circular cross sections, a circular cross section is preferred to simplify machining of the tool holder 10 and because of the availability of standard lines or hoses.

The coolant entering transition passageway 36 accelerates from a velocity of 20-40 fps at the main passageway 34 to a velocity typically greater than 400 fps, forming a coolant jet 38 which is ejected from the release orifice 32. Preferably, the transition passageway 36 is frusto-conical in shape so that its interior wall 37 tapers uniformly from the main passageway 34 to the release orifice 32. As shown in the Figures, the main passageway 34 and transition passageway 34 are colinear. This allows the coolant to flow in a straight path from the port 24 where it enters holder 10 to the release orifice 32 where it is ejected. The linear fluid path provided by passageways 34, 36 minimizes turbulence and drag which otherwise would slow the coolant stream and prevent the production of the desired velocity at the release orifice 32. The acute angle formed by the wall 37 of the transition passageway at the release orifice 32 is preferably less than about 20 degrees to produce a gradual taper along the length of transition passageway 36 which further aids in the prevention of turbulence as the coolant is accelerated to the release orifice 32. In order to ensure sufficient acceleration of the coolant, the transition passageway 36 is preferably formed with a length approximately equal to 20 times the diameter of the release orifice 32. If the release orifice 32 is not circular in cross section, its area is first calculated and the length of transition passageway 36 is then made to be approximately 20 times the diameter of a circular cross section having the same area. The diameter or largest transverse dimension of the release orifice 32 is preferably approximately equal to the depth D of the cut taken in workpiece 12, as exaggerated in Figure 1 for purposes of illustration. The total cross sectional area of the release orifice 32 is dependent on the energy of the coolant jet 38 required for a particular cutting operation, and an example is provided below in which the size of a release orifice is calculated for a particular application.

The leading end 21 of clamp 20, and the release orifice 32, are spaced from the cutting edge 19 of insert 18 a space 40 which is dependent on the feed rate at which workpiece 12 is machined. As is well known, the feed rate in a turning operation such as illustrated in the Figures is the distance the tool 10 is advanced along the longitudinal axis of the workpiece 12 for every revolution of the workpiece 12. In a preferred embodiment of this invention, the distance 40 between the cutting edge 19 and release orifice 32 is in the range of about 6 to 10 times the feed rate, or 6 to 10 times the distance the tool holder 10 or insert 18 advances axially along the workpiece 12 for every revolution of the workpiece 12.

Before discussing the operation of tool holder 10 in accordance with the method of this invention, it is important to note the aspects of a typical machining operation and the problems created. As is well known, engagement of the cutting edge 19 of insert 18 with the workpiece 12 removes metal in the form of a chip 42. The chip 42 has a width equal to the depth D of the cut taken in the workpiece 12, and the thickness of the chip 42 is equal to the distance the tool holder 10 is moved laterally along the workpiece 12 for every revolution of the workpiece 12. As best shown in Figures 3b, 3c, the chip 42 is actually formed by shearing the metal on the surface of the workpiece 12 along well-defined shear planes 44. The chip 42 comprises a plurality of individual, thin sections 46 of metal which slide relative to one another along the shear planes 44 as the workpiece 12 rotates while in engagement with the cutting edge 19 of insert 18. It should be understood that the position of the thin sections 46 of chip 42 relative to one another is exaggerated in the drawings for purposes of illustration, and actually appear as an essentially smooth surface.

There are many sources of heat generated in the cutting area 48 immediately surrounding the cutting edge 19 and the underside of chip 42. Heat is generated by the abrasive, frictional contact of the cutting edge 19 with the workpiece 12, by contact of the chip 42 with the upper surface 17 of the insert 18 and also as a result of the friction produced by adjacent sections 46 of chip 42 as they slide relative to one another along the shear planes 44. The temperature at the cutting edge 19-workpiece 12 interface may be on the order of 1500° F., or higher, and the temperature of the chip 42 as it is sheared from the workpiece 12, induced by the movement of sections 46 forming chip 42 along their shear planes 44, may be even higher.

Referring to Fig. 4, a cutting operation performed with a typical prior art tool design using flood type cooling is illustrated. Using this prior art design, the intense heat developed in the chips 50 can cause cratering of the cutting insert 51 leading to failure. As the chips 50 are sheared from the outer surface of the workpiece 52 they move along the upper surface of the cutting insert 51. The heat produced by the chips 50, as well as their frictional engagement with the upper surface of cutting insert 51, melts and carries away a portion of the metal from the cutting insert 51 creating depressions or craters 53. These craters or pockets of removed metal eventually become sizable enough to induce failure of the cutting insert 51, in combination with the abrasive contact between the cutting insert 51 and workpiece 52.

Recognizing these aspects of a cutting operation, it is among the primary objects of this invention to remove as much heat as possible from the cutting area 48 and to resist contact of the chip 42 with the upper surface 17 of cutting insert 18. The manner in which these objects are accomplished by the apparatus and method of machining provided herein is best described with reference to a cutting operation.

Referring now to Figure 3 - 3c, a cutting operation according to the method of this invention proceeds as follows. With the pump 30 operating and a coolant jet 38 being ejected from release orifice 32, the cutting edge 19 of insert 18 initially contacts the workpiece 12 and moves inwardly a predetermined depth D. The tool holder 10 is then advanced axially along the longitudinal axis of the workpiece 12 at a predetermined feed rate or axial distance for each revolution of the workpiece 12. The metal on the surface of workpiece 12 is sheared by the cutting edge

19 and a chip 42 begins to move along the upper surface 17 of insert 18 (see Figure 3a). At this point in time, the chip 42 contacts the upper surface of insert 18 and the coolant jet 38 ejected from release orifice 32 strikes the front the chip 42, its top surface and the workpiece 12.

The machining operation proceeds as shown in Figure 3b. The chip 42 continues its advance along the upper surface 17 of cutting insert 18 until it contacts the leading end 21 of clamp 20. As best shown in Figure 2, the leading end 21 of clamp 20 is tapered and clamped directly on the surface 17 of insert 18. As soon as contact is made with the leading end 21 of the clamp 20, the chip 42 is turned upwardly onto the angled surface 23 of the clamp 20 and overlies the release orifice 32. With the chip 42 in engagement with the angled surface 23 of clamp 20, as in Figures 3b, 3c, a substantially sealed enclosure or cavity 60 having six sides or walls is formed around the release orifice 32. Cavity 60 is formed by the workpiece 12, the angled surface 23 of clamp 20, the underside 41 of chip 42 and the upper surface 17 of insert 18. As viewed in Figures 3 - 3c, the workpiece 12 forms a wall opposite release orifice 32 and behind the chip 42, the top and bottom walls of the cavity 60 are formed by the underside 41 of chip 42 and the top surface 17 of insert 18, respectively, and the angled surface 23 of clamp 20 forms the wall of cavity 60 opposite the cut in the workpiece 12. The edge of chip 42 extending outwardly from the workpiece 12 forms an open area 61 in cavity 60 once the chip 42 contacts clamp 20 and bends upwardly from the surface 17 of insert 18 (see Figure 1). It has been found, however, that the chip 42 tends to twist in the direction of open area 61 toward the upper surface 17 of insert 18, and minimizes the loss of coolant through the open area 61. The chip 42 continues moving along the angled surface 21 of clamp 20 until its end 43, still attached to workpiece 12, is fractured to completely separate the chip 42 from the workpiece 12, as discussed below.

It has been found that in order to effectively remove heat from the underside 41 of chip 42 and the cutting edge 19-workpiece 12 interface within the cutting area 48, a high velocity, high pressure coolant jet 38 must actually reach the cutting area 48 without first becoming completely vaporized. Improved lubrication of the cutting edge 19-workpiece 12 interface and resistance to contact between the upper surface 17 of insert 18 and the chip 42, are also dependent on the successful introduction of the high velocity coolant jet 38 into the cutting area 48.

In the initial phase of the cutting operation, shown in Figure 3a, the pressure of the coolant jet 38 is substantially reduced, immediately upon exit from the release orifice 32. This is because the coolant jet 38 is not confined within an enclosure but exposed to atmospheric pressure. At this stage, the coolant jet 38 flows primarily along the top of the chip 42. However, when the chip 42 advances into contact with the leading end 21 of clamp 20 as shown in Figures 3b, 3c, it overlies the release orifice 32 and seals or encloses it within cavity 60. Although some loss of coolant velocity and pressure is created by the outwardly facing side of cavity 60, or open area 61, the coolant jet 38 ejected from the release orifice 32 is confined within a substantially sealed or closed cavity 60. The cavity 60, in effect, forms an extension of the closed transition passageway 36 within clamp 20 so as to maintain the velocity and pressure developed in the coolant jet 38 at a location beneath the chip 42 in the cutting area 48.

It has been found that the distance 40 between the release orifice 32 and the cutting edge 19 of insert 18 is important to the proper operation of tool holder 10 as described above. Preferably, the space 40 between the release orifice 32 and cutting edge 19 is in the range of about 6 to 10 times the feed rate of the machining operation or 6 to 10 times the axial distance moved by tool holder 10 for each revolution of workpiece 12. Experiments have shown that if the release orifice 32 is placed too close to the cutting edge 19, the coolant jet 38 cannot be forced beneath the chip 42. The chip 42 and workpiece 12 form a barrier which deflects the coolant jet 38 creating turbulence instead of a flow beneath the chip 42. Placement of the release orifice 32 too far away from the cutting edge 19 does not permit the chip 42 to properly seal against the angled surface 23 of clamp 20, which is necessary to form cavity 60. It has been found that the coolant jet 38 at least partially cools the top of chip 42 as it is initially formed. This creates a temperature differential between the top surface and underside 41 of chip 42 which tends to bend the chip 42 upwardly. If the clamp 20 is positioned too far from the cutting edge 19 of insert 18, the chip 42 is turned upwardly away from the insert 18 before it can contact the angled surface 23 of clamp 20. It has been found that the preferred positioning of the release orifice 32 relative to the cutting edge 19, specified above, prevents the chip 42 from being turned upwardly from the surface 17 of insert 18 without contacting with the angled surface 23 of clamp 20.

Several advantages are realized by the introduction of a high velocity, high pressure coolant jet 38 between the upper surface 17 of cutting insert 18 and the underside 41 of chip 42 from the confined location of release orifice 32 beneath the chip 42. It has been found that under these conditions, the high velocity coolant jet 38 produced is capable of piercing the vapor barrier developed in the cutting area 48 by the heat generated from the formation of chips 42 and the contact between the cutting edge 19 and workpiece 12. One advantage in reducing the heat produced at the underside of chip 42 is that melting of the insert 18 is substantially reduced, and problems of cratering and cutting edge abrasion are thus lessened which increases insert life.

The second benefit obtained by the conduction of heat away from the chip 42 within cutting area 48 relates to chip removal. Since the coolant jet 38 is confined within the cavity 60, there is an efficient heat transfer between the very hot chip 42 and insert 18, and the ambient temperature coolant jet 38. Due to the large surface area presented by the underside 41 of chip 42 within the cavity 60, it has been found that a substantial reduction in the heat of the chip 42 is achieved in a very short period of time. It is believed that the coolant jet 38 actually penetrates a short distance into the chip 42 along the shear planes 44 formed between the individual thin sections 46. This rapid cooling of chip 42, believed to be accomplished in .1 second or less, disrupts the lattice structure of the chip 42. It is believed that the chip 42 is heated during the machining operation to such an extent that its lattice structure becomes semi-plastic, and when cooled by the coolant jet 38 so quickly, the semi-plastic lattice structure is solidified in a disrupted molecular configuration. Solidification of the chips 42 in a disrupted molecular configuration, at least within the cutting area 48, creates a brittle structure of substantially reduced ductility and bending strength. With the chips 42 in a brittle state, much less force is required to fracture the end 43 of chip 42 attached to workpiece 12 and remove the chip 42 from cutting area 48.

The chip 42 is fractured from workpiece 12 and removed by the high pressure developed within the cavity 60. A portion of the coolant jet 38 is vaporized by the heat developed in the cutting area 48. Since the cavity 60 provides a substantially sealed enclosure, high pressure is developed by the vaporized coolant jet 38 within the cavity 60 which is applied directly to the chip 42. In addition, pressure is exerted by the new coolant continuously exiting the release orifice 32 within the sealed cavity 60. The combined line pressure and vapor pressure of the coolant jet 38 is more than sufficient to snap or fracture the end 43 of chip 42 from the workpiece 12 and remove the entire chip 42 from the cutting area 48. In most applications, fracture of the chip 42 is achieved as it moves between the positions shown at Figures 3b, 3c. As a result, relatively short chips 42 are produced and they are forced under pressure away from the cutting area 48.

This feature of the invention provides an important advantage over existing machining systems in which chips are not typically fractured in small lengths but tend to form in long sections which wrap around the tool holder and cause problems of jamming.

An additional advantage is provided by the introduction of a coolant jet 38 from the release orifice 32 positioned within an essentially closed cavity 60 beneath the chip 42. It has been found that at least a small portion of the coolant jet travels along the upper surface 17 of cutting insert 18 once the leading end of the chip 42 is lifted above the insert surface 17 as in Figure 3c. This stream or film layer 62 of coolant jet 38 forms a hydrodynamic fluid support which resists contact of the chip 42 with the upper surface 17 of insert 18. The hydrodynamic fluid support provided by the film layer 62 urges the chip 42 upwardly from the upper surface 17 of insert 18 to avoid or at least reduce frictional contact therebetween which can lead to cratering and damaging abrasive contact. The coolant film layer 62 continues along the upper surface 17 of insert 18 and flows through microscopic surface irregularities in the cutting edge 19 of insert 18 and in the workpiece 12, which provides some lubrication to reduce the frictional contact therebetween during the cutting operation. The reduction of friction provided by the film layer 62, and in particular its creation of a hydrodynamic lift force, reduces the power requirements for making the cut. As is well known, the power required to make a cut includes not only the force required to shear the chips from the workpiece but also the force required to push the chips along the insert and away from the cut. The method and apparatus of this invention greatly reduces the power required to remove the chips 42 because of the great reduction in friction between the upper surface 17 of insert 19 and the chips 42.

As mentioned above, several design aspects of the tool holder 10 according to this invention are dependent on a variety of variables in any particular application including the speed and feed rates, type of material to be machined, horsepower rating of the machine and other factors. An example is provided below to illustrate how such factors are considered in the design of an appropriate tool holder 10 for a given application.

It is assumed in this example that it is desired to machine a cylinder of SAE 1020 steel having a diamater of 2 feet and a shear strength of 50,000 psi, at a feed rate of 0.010 inches per revolution (IPR), at a speed of 500 surface-feet per minute (SFM) and at a depth of cut of 0.200 inches.

The first step in the design procedure is to determine the horesepower required to make the cut.

$$Hp_{cut} = V_{mr}\ Hp_{unit} \qquad (1)$$

Where:

Hp_{unit} = horsepower required to machine one cubic inch of SAE 1020 steel

V_{mr} = volume of metal removed

According to the "Machinability Data Handbook", published by Metcut Laboratories, Cincinnati, Ohio, the horsepower required to machine one cubic inch of SAE 1020 steel, Hp_{unit}, is 1 Hp per cubic inch. To determine the volume of metal removed from workpiece 12 in each revolution, V_{mr}, the following relationship is used:

$$V_{mr} = DFS \qquad (2)$$

Where:

D = depth of cut (0.200 inch)

F = feed rate (.010 IPR)

S = speed (500 SFM)

Substituting the value determined for V_{mr} in equation (2), and the value for Hp_{unit} from the "Machinability Data Handbook", equation (1) is solved to obtain:

$$Hp_{cut} = 12\ Hp$$

It has been determined experimentally that in order for sufficient velocity to be developed in the coolant jet 38 exiting release orifice 32, the horsepower of the jet 38 must be greater than the horsepower required to cut the material. To provide a factor of safety, the horsepower of the coolant jet 38 at the release orifice 32 is chosen to be 14 Hp.

Orifice Cross Sectional Area

Having determined that the horsepower of the coolant jet 38 at the release orifice 32 should be about 14 Hp, the cross sectional area of the release orifice may be determined. Initially, the flow rate of the pump, Q_p, is determined using the following relationship:

$$Q_p = \frac{(Hp_{jet})\ (1714)}{P\ \ ME_{pump}} \qquad (3)$$

Where:

Hp_{jet} = jet horsepower (14 Hp)
P = pump pressure (psi)
ME_{pump} = mechanical efficiency of the pump 30

At this point, an assumption is made as to the pressure provided by the pump 30. It has been found experimentally that a pump 30 with a rating of 1500 psi is appropriate for many applications and is used here for this example. In addition, it is assumed that the pump 30 has a mechanical efficiency of about 85%. Solving equation (3), the result is as follows:

$$Q_p = 13.6 \text{ gal./min.}$$

In order to determine the area of release orifice 32, A_o, a relationship has been derived relating A_o to the flow rate of the pump 30, Q_p, and the pump pressure, P, assuming negligible drag losses at the orifice 32:

$$A_o = \frac{0.0263\ Q_p}{P} \qquad (4)$$

Solving equation (4) with the values of Q_p and P found above yields:

$$A_o = 0092 \text{ sq. inches}$$

As mentioned above, the width of orifice 32 is preferably approximately equal to the depth of the cut to be machined in the workpiece 12. Since the depth of cut is assumed here to be 0.200 inch, the width of the orifice 32 is about 0.200 inch and therefore its length is about 0.046 inch. Of course, this solution assumes a rectangular shaped orifice 32. It should be understood that orifices of other cross sections could be utilized as long as one transverse dimension is about equal to the depth of cut, and the total area is 0.0092 square inches.

Coolant Delivery Line

Having determined the flow rate of pump 30, Q_p, to be 13.6 gal./min., the cross-sectional area of coolant delivery line 28 may be calculated from the following relationship:

$$A_L = \rho \frac{Q_p}{V_c} \qquad (5)$$

Where:

A_L = area of coolant delivery line 28
V_c = velocity of coolant within line 28
ρ = density of a standard water-oil coolant

As mentioned above, in order to reduce turbulence and drag within delivery line 28, the velocity of the coolant therethrough should be in the range of about 20- 40 fps. For purposes of this example, a velocity, V_c, of 30 fps. is assumed herein. Solving equation (5):

A_L = 0.145 sq. in.

The nominal size of delivery line 28, making it somewhat greater in cross sectional area to accommodate standard sizes, is therefore chosen to be 1/2 inch.

The type of material, speed and feed rates and the depth of cut chosen in the above example represent a typical application. Tool holders with known cutting inserts and flood coolant systems are capable of running at such speeds. The advantage of the method and apparatus of this invention over such systems is that productivity can be drastically increased. It has been found that if the tool holder 10 is run at the speed and feed rates of the example, the life of the cutting insert is increased 2 to 5 times and the horsepower requirements are reduced compared to known tool holder and insert designs. This means that due to the reduction in friction and removal of heat provided by this invention, as described above, the horsepower needed to make the cut as calculated above is actually less than 14 Hp. Therefore, in addition to reducing horsepower requirements and extending cutting life, productivity may be increased using this invention by matching the horsepower available in the machine tool with the horsepower required to make the cut. This is done by setting up the system as described above, running it initially at the speed (500 sfm) chosen, noting the horsepower usage and then increasing the speed of the cut until the rated horsepower of the machine tool is reached. In this manner, more of the machine's capability is utilized and productivity is substantially increased. Although insert life decreases with increased speeds, the amount of material cut increases substantially.

While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

(1) A method of machining a workpiece with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder, comprising the steps of:

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert; and

directing a coolant at high velocity between said surface of said cutting insert and said chips from a location beneath said chips.

(2) A method of machining a workpiece with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder formed with at least one release orifice, comprising the steps of:

positioning said cutting insert within said holder so that said release orifice is disposed at said surface of said cutting insert;

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert and said release orifice of said holder; and

ejecting a coolant jet at high velocity from said release orifice between said surface of said cutting insert and said chip.

(3) A method of machining a workpiece with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder formed with at least one release orifice, comprising the steps of:

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert and said release orifice, said engagement with said workpiece and the formation of said chips producing substantial heat;

ejecting coolant from said release orifice at high velocity between said surface of said cutting insert and underneath said chip, said coolant being confined within a cavity formed by said workpiece, cutting insert, chip and holder.

(4) The method of claim 3 further including the step of:

transferring said heat developed by said engagement of said cutting insert and workpiece and by said formation of said chips to said coolant for rapid cooling of said chips.

(5) The method of claim 3 further comprising the steps of:

pressuring said coolant beneath said chip due to the confinement of said coolant within said cavity formed by said workpiece, cutting insert chip and holder; and

breaking an end of said chip from said workpiece under said pressure applied by said coolant beneath said chip.

(6) The method of claim 3 further comprising the steps of:

directing at least a portion of said coolant along said surface of said cutting insert; and

creating a hydrodynamic fluid support with said coolant for resisting contact of said chip with said surface of said cutting insert.

(7) The method of claim 3 further comprising the steps of:

cooling said chip to about the ambient temperature of said coolant in at least about 0.1 seconds by ejecting said coolant underneath said chip; and

creating embrittlement of said chip due to rapid cooling wherein the molecules of said chip are solidified in a disrupted state.

(8) A method of machining a workpiece at a predetermined feed rate with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder formed with at least one release orifice, comprising the steps of:

positioning said cutting insert within said workpiece so that said release orifice is disposed a distance in the range of about 6 to 10 times said feed rate from said cutting edge;

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert and said release orifice of said holder; and

ejecting a coolant jet at high velocity from said release orifice between said surface of said cutting insert and said chip.

(9) A method of breaking chips formed in machining a workpiece with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder formed with at least one release orifice, comprising the steps of:

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert and said release orifice, said engagement with said workpiece and the formation of said chips producing substantial heat;

ejecting coolant from said release orifice at high velocity between said surface of said cutting insert and underneath said chips, said coolant being confined within a cavity formed by said workpiece, cutting insert, chip and holder;

vaporizing at least a portion of said coolant within said cavity with said substantial heat;

pressurizing said coolant and vaporized coolant beneath said chip due to said confinement of said coolant within said cavity; and

breaking an end of said chip from said workpiece under said pressure applied by said coolant and vaporized coolant beneath said chips.

(10) A method of forming a hydrodynamic fluid support beneath the chips formed in machining a workpiece with a cutting insert having a surface terminating with a cutting edge and being mounted within a holder formed with at least one release orifice, comprising the steps of:

engaging said workpiece with said cutting edge to form chips overlying said surface of said cutting insert and said release orifice;

ejecting coolant from said release orifice at high velocity between said surface of said cutting insert and underneath said chip;

directing at least a portion of said coolant along said surface of said cutting insert to form a thin film of coolant therealong; and

creating a hydrodynamic fluid support with said thin coolant film beneath said chips for resisting contact of said chips with said surface of said cutting insert.

(11) Apparatus for machining a workpiece comprising:

a holder having at least one release orifice;

a cutting insert having a surface terminating with a cutting edge, said cutting insert being mounted within said holder, said cutting insert being adapted to engage said workpiece to form chips overlying said surface of said cutting insert and said release orifice;

means for ejecting coolant from said release orifice at high velocity along said surface of said cutting insert and beneath said chips.

(12) Apparatus as in claim 11 in which said cutting edge is adapted to machine said workpiece at a predetermined feed rate, said cutting insert being mounted within said holder so that said release orifice is disposed a distance of about 6 to 10 times the feed rate from said cutting edge.

(13) Apparatus as in claim 11 in which said cutting edge is adapted to machine said workpiece at a predetermined depth of cut, said release orifice having a diameter approximately equal to said depth of cut.

(14) Apparatus as in claim 11 in which said cutting edge is adapted to machine said workpiece at a predetermined depth of cut, said release orifice having a non-circular cross section with a smaller and larger transverse dimension, said larger transverse dimension being approximately equal to said depth of cut.

(15) Apparatus as in claim 11 in which a predetermined horsepower is required to form said chips, said means for ejecting said coolant at high velocity from said release orifice being adapted to develop greater horsepower in said coolant than said predetermined horsepower required to form such chips.

(16) Apparatus for machining a workpiece comprising:

a holder having at least one release orifice;

a cutting insert having a surface terminating with a cutting edge, said cutting insert being mounted within said holder, said cutting insert being adapted to engage said workpiece to form chips overlying said surface of said cutting insert and said release orifice;

means for conveying coolant to said holder;

means for conveying said coolant through said holder and ejecting said coolant from said release orifice at high velocity along said surface of said cutting insert beneath said chips.

(17) Apparatus as in claim 16 in which said means for conveying coolant to said holder comprises a pump and a delivery line, said pump and delivery line being adapted to convey said coolant to said holder at a velocity in the range of about 20 to 40 feet per second.

(18) Apparatus as in claim 16 in which said means for conveying said coolant through said holder to said release orifice comprises a main passageway, and a transition passageway disposed between said main passageway and said release orifice.

(19) Apparatus as in claim 18 in which said main passageway has a larger diameter than any portion of said transition passageway.

(20) Apparatus as in claim 18 in which said transition passageway is formed with a uniformly tapering wall from said main passageway to said release orifice.

(21) Apparatus as in claim 18 in which said transition passageway is frusto-conical in shape.

(22) Apparatus as in claim 18 in which said transition passageway is formed with a highly polished wall.

(23) Apparatus as in claim 18 in which said transition passageway is formed with uniformly tapering walls from said main passageway to said release orifice, the angle formed by said walls at said release orifice being less than about 20°.

(24) Apparatus as in claim 18 in which said release orifice is circular in cross section, the length of said transition passageway between said release orifice and said main passageway being about 20 times the diameter of said release orifice.

(25) Apparatus as in claim 18 in which said release orifice is non-circular in cross section, the length of said transition passageway between said release orifice and said main passageway being about 20 times the diameter of an orifice of circular cross section having the same cross sectional area as said release orifice of non-circular cross section.

(26) Apparatus for machining a workpiece comprising:

a holder having at least one release orifice;

a cutting insert mounted within said holder, said cutting insert having a surface terminating with a cutting edge adapted to engage said workpiece to form chips overlying said surface of said cutting insert and said release orifice, the engagement of said workpiece and formation of said chips producing a high temperature vapor barrier;

said chips contacting said holder to form a substantially closed cavity having walls enclosing said release orifice, said walls of said cavity being formed by said chips, said surface of said cutting insert, said holder and said workpiece;

means for ejecting coolant from said release orifice at high velocity within said cavity and beneath said chips, said coolant being adapted to:

> pierce said vapor barrier and remove said heat produced in the engagement of said workpiece and formation of said chips;
>
> create a hydrodynamic fluid support along said surface of said cutting insert to resist contact between said surface and said chip; and

vaporize and develop pressure within said cavity and beneath said chip to separate said chip from said workpiece.

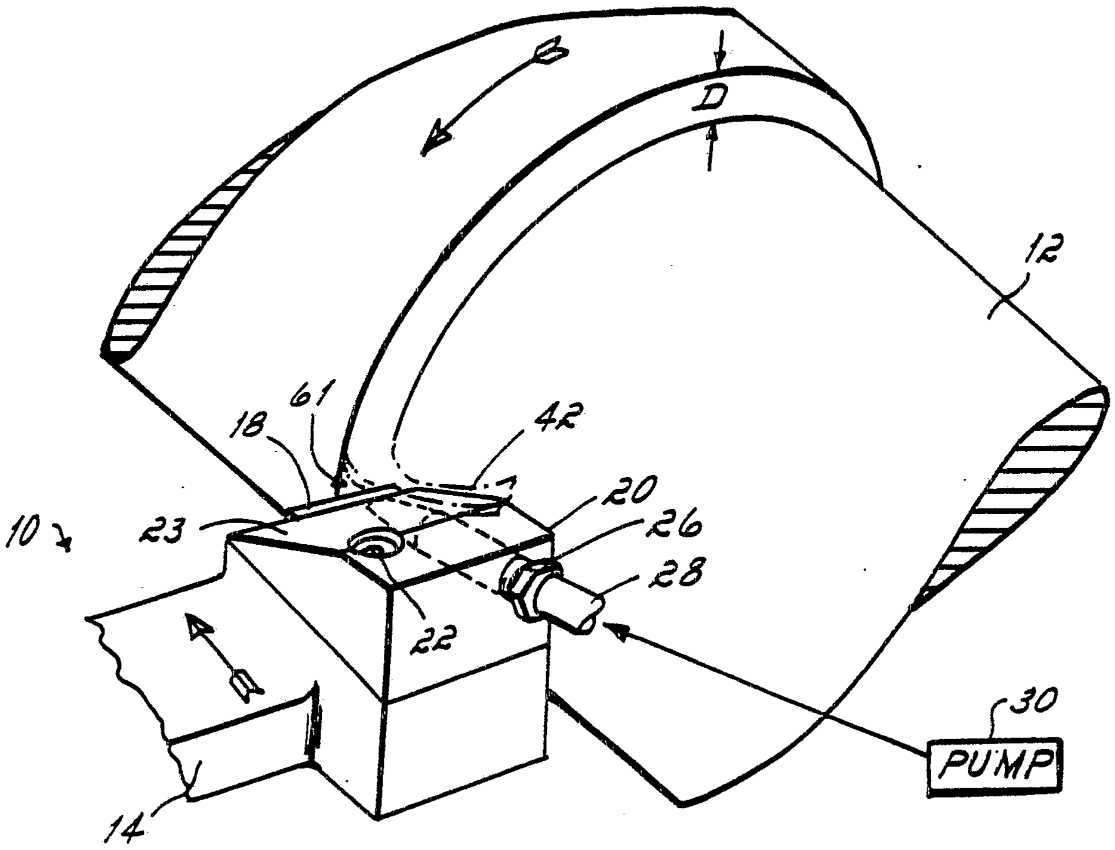
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FIG. 1

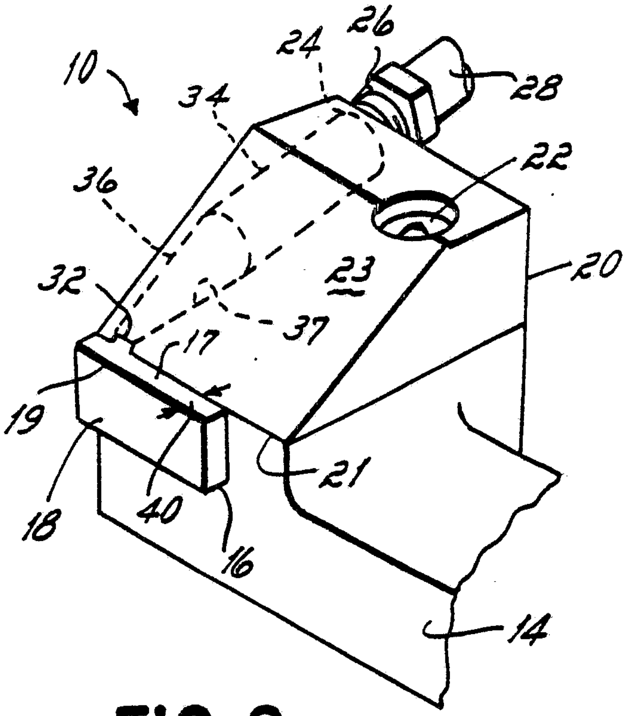
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FIG. 2

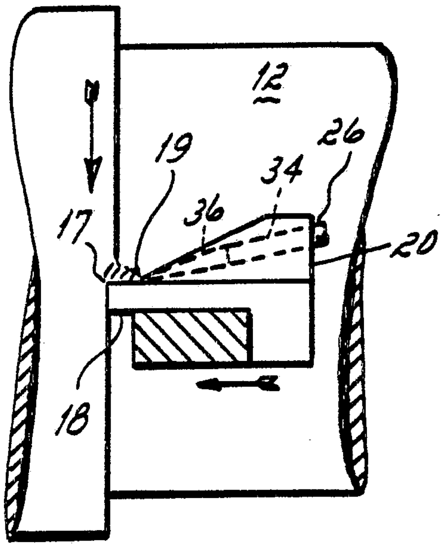


FIG. 3

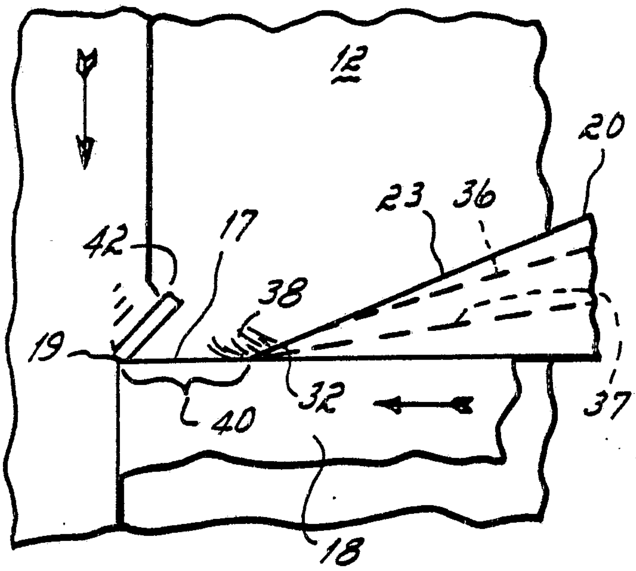


FIG. 3a

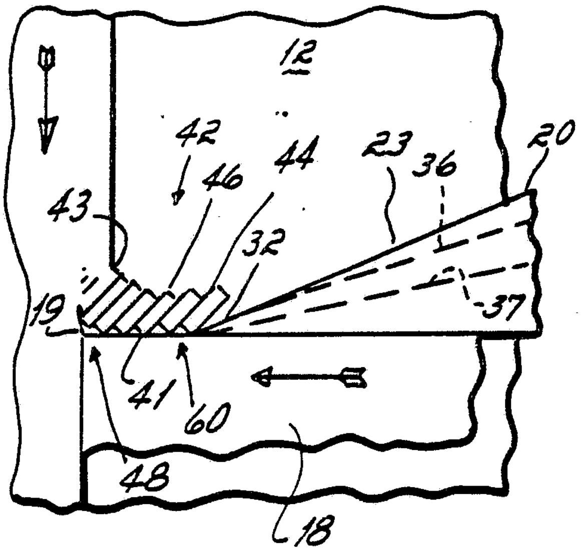


FIG. 3b

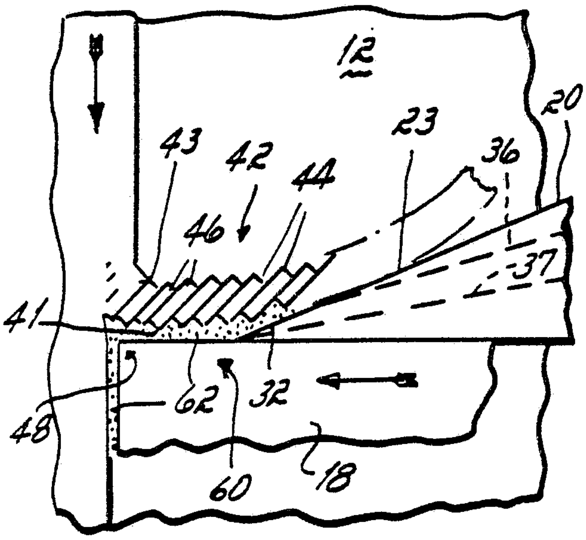
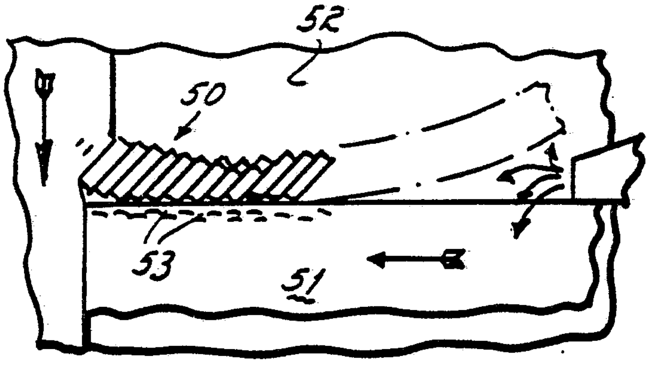


FIG. 3c



PRIOR ART
FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/US84/00289

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^3 B23 B27/10
USA 407/11 408/59 60

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
USA	407/11 408/56 57 59 60 61

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US,A, 160,161 (Clay) 23 February 1875	1-26
A	US,A, 354 498 (Kerchove) 14 December 1886	
X	US,A, 522,588 (Chouteau) 10 July 1894	1-26
A	US,A, 1,119 660 (Wigness) 1 December 1914	
X	US,A, 1,695 955 (Frayer) 18 December 1928	1-26
X	US,A, 2 653,517 (Piggott) 29 September 1953	1-26
Y	US,A, 2,848 790 (McMann) 26 August 1958	1-26

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2] 11 April 1984	Date of Mailing of this International Search Report [2] 17 APR 1984
International Searching Authority [1] ISA/US	Signature of Authorized Officer [20] Jerry Kearns

International Application No. PCT/US84/00289

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

X	US,A, 3,002,410 (Lee) 3 October 1961	1-26
Y	US,A, 3,176,330 (Jennings) 6 April 1965	1-26
A	US,A, 3,323,195 (Vanderjagt)	1-26
Y	US,A, 3,808,656 (Lindskog) 7 May 1974	1-26
Y	US,A, 4,302,135 (Lillie) 24 November 1981	1-26
Y	DT, A, 3,004,166 21 August 1980	1-26

V.☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers , because they relate to subject matter [12] not required to be searched by this Authority, namely:

2.☐ Claim numbers....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI.☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.