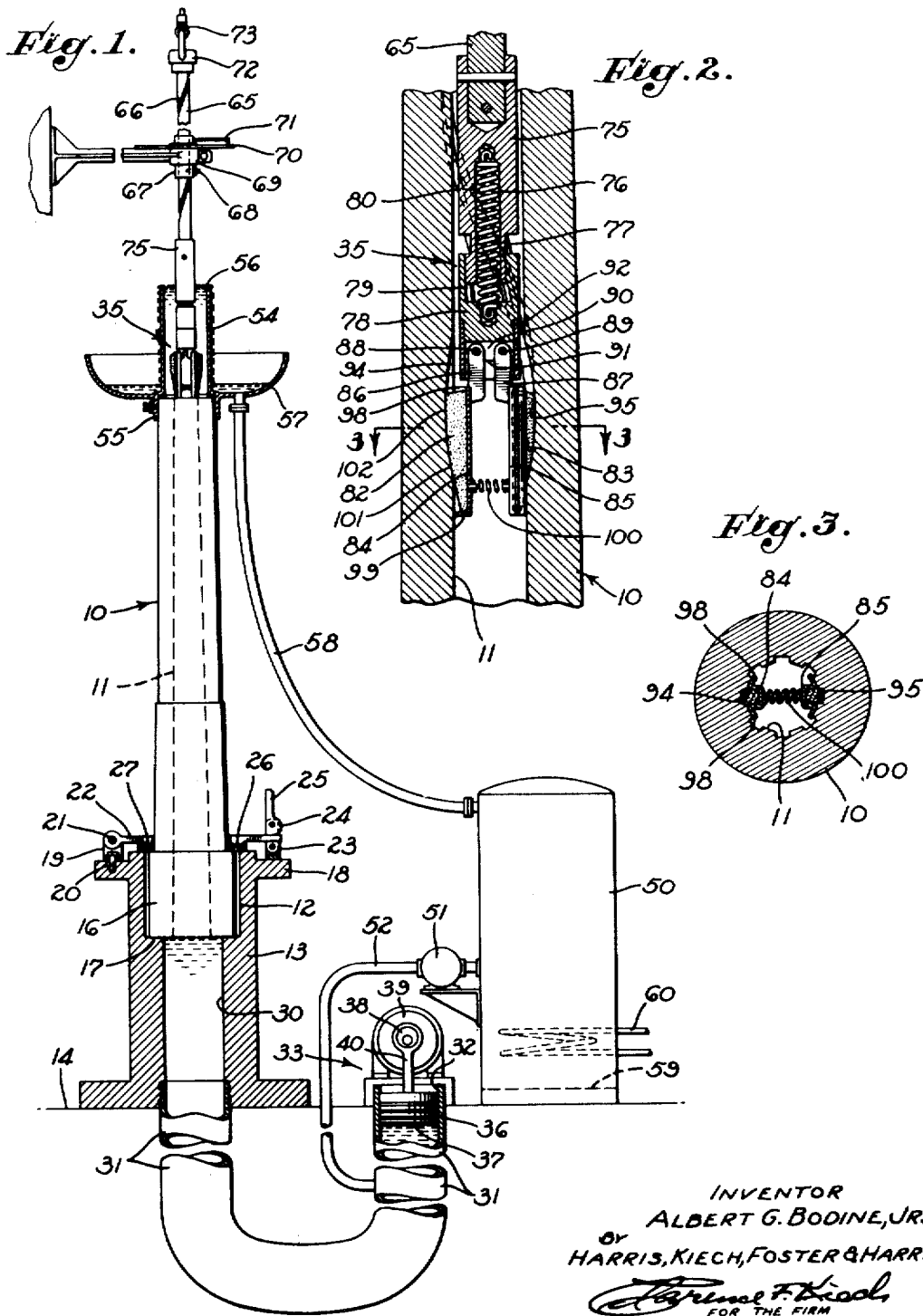


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METHOD AND APPARATUS FOR CUTTING
INTO THE SURFACE OF AN ARTICLE
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METHOD AND APPARATUS FOR CUTTING INTO THE SURFACE OF AN ARTICLE

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1

My invention relates to a novel method and apparatus for cutting in which the cutting member is oscillated by employment of sound waves. The invention will be exemplified with reference to the finishing, cutting, grooving, or rifling of a bore and, more particularly, with reference to the rifling of a tapered gun barrel.

In the art of cutting metals, it is conventional practice to move a cutter relative to the surface, either continuously advancing the cutter to new positions along the surface or by slow reciprocations of the cutter through a relatively long locus of motion. The cutter may be of the blade or point type or of the abrasive type. A block of abrasive material presents a myriad of individual cutting elements and is usually composed of granular material (e.g., silicon carbide, aluminum oxide, etc.) held together by a suitable binder (e.g., fused quartz), the grains presenting relatively sharp cutting tips, a number of which may be in simultaneous abrading contact with the surface of the article. These grains have individual cleavage planes heterogeneously arranged and, being individually friable, they fracture in use to present new cutting tips. The present invention can be employed with blade or point type cutting elements or with cutting elements presented by a block of abrasive material as is conventionally employed either for high-rate removal of stock (as by employment of a high-speed grinding wheel) or for low-rate removal of stock (as in honing processes).

It is an object of the present invention to provide a cutting method and apparatus involving actuation of the cutter through a relatively short locus of motion but with relatively high peak velocities.

In accomplishing such results, the invention comprehends the rapid oscillation of a cutter in response to sound waves. For example, the cutter is disposed in pressure-transferring relationship with an elastic medium, e.g., a fluid column, and sound waves are generated in the column usually at a remote point under such conditions as to oscillate the cutter in response to the wave motion within the elastic medium. The invention is to be distinguished from long-range, slow oscillations by simultaneous bodily movement of all portions of the elastic medium. Rather, the present invention involves wave motion through the elastic medium under conditions in which the molecules in one section of the elastic medium may be moving at a time or rate different from the molecules in another section of the elastic medium.

2

By employment of terms such as "sound," "sound waves," "sonics," "sonic energy," "acoustics," or related terms, it should be understood that the frequency relationships involved are not limited to those within the audible range. Rather, such terms have relation to elastic, physical, or mechanical waves, both within and without the audible range of frequency, such waves moving at the speed of sound in the elastic medium employed. Even if within the audible range, actual audibility by the human ear is not necessarily contemplated. The frequencies employed are those at which sonic transmission of energy through an elastic medium can be utilized effectively to move a cutting element. In all instances, they exclude slow reciprocations or oscillations which would cause all sections of the elastic medium to move simultaneously in one direction or the other. Ordinarily, the lowest frequency contemplated by the invention would be at least several cycles per second and usually above fifty cycles per second, the upper limit of frequencies contemplated being many thousands of cycles per second, even to a point beyond the audible range and extending somewhat into the region of supersonics.

It is an object of the present invention to oscillate one or more cutting elements by sound waves transmitted thereto or to a member connected therewith through an elastic medium from a remote point. Other objects of the invention lie in the acoustic actuation of a cutting element in a direction generally parallel to a surface, while exerting on this cutting element a resilient force urging it into contact with the surface.

Particularly desirable results flow from the use of sound waves to oscillate a block of abrasive material. Such advantages involve movement through a relatively short stroke while allowing for relatively low-pressure yet high-velocity motion relative to the surface. The peak velocities of sound waves may be exceedingly high and it is of distinct advantage to oscillate the block of abrasive material at a high peak velocity while at the same time employing a relatively short stroke. The peak velocities may equal, approach, or even exceed instantaneously the surface speed of an abrasive wheel, and the invention permits concentration of abrasive action on a very small area, being similar in this respect to the action of a rotating abrasive wheel. At the same time, a rapid oscillation of a block of abrasive material as effected by sound waves produces a very rapid and satisfactory cutting action, making it ideally suited to high-speed grinding, fast removal of

3

stock, cutting grooves in shafts or bores, etc. It is an object of the present invention to oscillate a block of abrasive material by use of sound waves and while in contact with a surface to obtain such advantages.

The invention finds particular advantages in the rifling of gun barrels. Present rifling methods are open to serious limitations and must be performed by highly skilled labor. Rifling grooves can be produced by employment of a single hook cutter drawn through the bore or, in larger gun barrels, by employment of an adjustable cutter head, which is open to serious space limitations. Other methods involve the employment of a pull-bar broach or a disc broach, the latter method involving drawing through the bore a plurality of progressively larger disc broaches to form the rifling grooves. Such methods, while tedious and involving a high degree of skill, are employed extensively in the rifling of uniform-diameter bores. However, each of these methods is not well suited to the rifling of tapered bores, albeit that recent ballistic investigations show the desirability of employing a rifle bore tapering toward the muzzle, together with semi-deformable shells capable of conforming to the progressively decreasing bore with attendant very substantial increase in muzzle velocity.

The present invention is particularly well adapted to the rifling of gun barrels by employment of one or more blocks of abrasive material oscillated in response to sound waves and being of a width corresponding to the desired groove width. By employment of rapid oscillations of an abrasive material in the formation of rifling grooves, it becomes possible to use metals and alloys much harder and longer wearing than usually employed in gun manufacture, and which cannot be satisfactorily rifled by present methods.

It is an object of the present invention to rifle gun barrels or to groove bores by the sonic oscillation of one or more blocks of abrasive material or cutting stones, regardless of whether the bore is tapered or of uniform size. A low friction polished surface is produced and, if desired, the entire depth of the groove can be produced by a single pass through the bore. Other advantages of my method and apparatus include increasing the speed at which rifling operations can be performed while at the same time permitting employment of relatively unskilled labor, minimizing of spoilage, etc. The invention comprehends also the cutting of rifling grooves of varying rates of pitch, if desired, whether in constant-diameter or tapered bores.

Another object is to provide a novel method and apparatus for cutting a groove in a surface of an article, for example a straight or helical groove, for any purpose by acoustic actuation of a cutting member, for example a block of abrasive material, in a direction generally parallel to the desired groove.

Other objects and advantages of the invention will be evident from the following exemplary showing of the invention.

Referring to the drawing, which illustrates the principles of the invention as applied to the rifling of gun barrels:

Figure 1 is a vertical elevational view, partially in section, showing diagrammatically a system for producing rifling grooves in the barrel of a gun;

Figure 2 is a vertical sectional view showing the cutter means during advancement along the bore; and

4

Figure 3 is a horizontal sectional view, taken on the line 3—3 of Figure 2.

Referring particularly to Figures 1 and 2, the gun barrel to be rifled is indicated by the numeral 10. It is formed in the usual manner with a bore 11, which may be either cylindrical or tapered inwardly toward the muzzle. In the preferred embodiment, this gun barrel is mounted vertically, muzzle upward, in a socket 12 of a base 13 resting on a suitable foundation 14.

I prefer to provide means for detachably connecting the gun barrel 10 to the base 13. Merely by way of example, Figure 1 shows the gun barrel as including a head or flange 16 removably extending into the socket 12 and abutting against a shoulder 17 thereof to effect a substantially fluid-tight seal. The upper end of the base 13 provides a flange 18 to which is pivoted a pair of blocks 19, pivoting about spaced vertical axes defined by bolts 20. Pivoted to each block 19 by a pin 21 is a substantially semi-circular clamping member 22 which can be swung toward and away from the gun barrel by pivoting about its associated bolt 20, and which can be swung vertically by pivoting about its pin 21. The free end of the clamping member 22 is adapted to be pressed against a stop 23 by an eccentric 24 carrying a handle 25. By turning the eccentric 24, the member 22 is brought into clamping relationship with the head 16, a slightly compressible gasket 26 and a washer 27 being compressed therebetween.

The base 13 provides a bore 30 in alignment with the bore 11 and communicating with the interior of a pipe 31, which may be of any suitable configuration but which is shown as being U-shaped, the far end of this pipe providing or communicating with a cylinder 32 of a suitable sound-wave generating means 33. An elastic medium inter-connects the generating means 33 and a rifling unit 35, to be later described, which is disposed to traverse the bore 11. This elastic medium serves as a means for transmitting sound waves from the generating means 33 to the rifling unit 35. While such waves can be transmitted through solid material, such as metal, acting as such an elastic medium and extending between the generating means 33 and the rifling unit 35, many advantages arise from the employment of a fluid column as this elastic medium. In Figure 1, this fluid column comprises a liquid filling the space between the generating means 33 and the rifling unit 35, this space being defined by the pipe 31 and the bores 30 and 11. Such a column of liquid forms a sonic column through which the cutter-actuating sound waves travel to the rifling unit 35.

The sound-wave generating means 33 may take any one of a number of forms. Its function is to generate sound waves at one end of the fluid column. As is known, such sound waves can be generated by rapid oscillation of a piston 36 within the cylinder 32, this piston providing a face 37 in contact with the liquid and being oscillated by a suitable eccentric or crank 38 driven by a variable-speed motor 39 and operatively connected to the piston 36 by a connecting rod 40. It is desired that the piston face 37 move rapidly in a direction parallel to the longitudinal axis of the fluid column, but it should be understood that various other methods of causing this oscillation can be employed.

In the preferred embodiment of the invention, the fluid column may transmit the cutter-actuating waves, either with no additional sup-

5

ply of fluid to the column or during the time that the fluid in the column is continually or intermittently circulating. The latter system is preferred, particularly where the fluid column comprises a cutting oil as such oil may then surround the cutting elements, and preferably, flow with respect thereto, thus aiding in the cutting, cooling, and cutting-removal operations.

By way of example, Figure 1 shows a tank 50 for the cutting oil and a pump 51 for withdrawing a stream thereof for delivery through pipe 52 to the pipe 31. During the time that the sound-wave generating means 33 is in operation, an additional supply of the cutting oil may thus be delivered to the sonic column, escaping past the rifling unit 35 and discharging from the muzzle end of the gun barrel 10. At this muzzle end is preferably disposed a cylindrical extension 54 providing a depending skirt 55 for detachable connection to the muzzle. The cutting oil rises in this cylindrical extension and overflows a lip 56 thereof to drop into a pan 57 carried by the cylindrical extension 54. From here, the cutting oil flows by gravity through a flexible pipe 58 to the upper end of the tank 50. This circulation, effected by the pump 51, is preferably at such a rate as to carry upward the very fine cuttings produced by the rifling operation, as well as to cool effectively the zone of cutting. The cuttings separate in the tank 50, as suggested by the dotted line 59, and the cutting oil can be used over and over. A supply of cool cutting fluid can be insured by cooling the circulating oil at any portion of the system, as, for example, by use of a cooling coil 60 disposed in the tank 50 and through which a suitable cooling material or refrigerant may be moved.

The function of the rifling unit 35 is to move along the bore 11, cutting one or more rifling grooves therein. Preferably, the rifling unit is started at one end of the bore 11 and advanced completely therethrough to rough out or complete one or more of the desired grooves. I prefer to mount the rifling unit in such way that it is relatively freely movable so that its rate of advancement along the bore is controlled by the rate of cutting. In accomplishing this, it is desirable that there be applied to the rifling unit a resilient force toward the uncut end of the bore, and this can most readily be accomplished by allowing the rifling unit to advance under its own weight by starting it at the top of the bore 11 and permitting it to advance therethrough as cutting progresses.

At the same time, it is desirable to guide the rifling unit 35 in such advancement through the bore to cut one or more rifling grooves of desired pitch. One method of accomplishing this is shown in Figure 1 through employment of a lead screw 65 providing a groove 66 having a pitch corresponding to the desired rifling. A sleeve 67 carries a pin 68 extending into the groove 66, the sleeve being normally stationary so that the rifling unit 35 turns in its longitudinal movement through the bore 11. The sleeve 67 is preferably mounted adjustably in a split collar 69, particularly if more than one pass of the rifling unit is required to produce the desired number of rifling grooves. In this connection, a suitable dividing head may be employed to insure starting of the rifling unit into one end of the bore while in proper angular relationship. Figure 1 shows diagrammatically one type of dividing head, including a plate 70 carried by the collar 69 and a pointer 71 car-

6

ried by the sleeve 67. The plate 70 may carry suitable calibrations by which the angular orientation of the rifling unit with respect to previously-formed grooves can be determined. The upper end of the lead screw 65 carries a swivel 72 having a ball to which may be connected a vertically movable cable 73 serving primarily to retract the rifling unit 35 from its lowermost position, though it may serve also to take a portion of the weight of the rifling unit and its operatively attached lead screw to decrease the downward resilient force during the cutting operation.

To the lower end of the lead screw 65 is connected a movable member 75 which can move substantially parallel to the wall of the bore 11. The lower end of this movable member provides a bore 76 extending upward through a splined neck 77 of reduced diameter. Slidable with respect to this splined neck 77 is a wave-responsive member in the nature of a piston, shown as comprising an oscillation member 78. This member provides a splined opening 79 slidably receiving the splined neck 77. The splines of the movable member 75 and the oscillation member 78 are preferably formed helically, having a pitch substantially corresponding to the desired pitch of the rifling grooves.

A spring 80 is disposed in the bore 76 and resists displacement of the oscillation member 78 with respect to the movable member 75. Desirably, one end of this spring will be connected to the oscillation member 78 and the other end to the movable member 75, in which event the spring may act ultimately both as a tension and compression spring exerting a resilient force on the oscillation member. In other instances, this spring may be supplemented by other resilient means or, if the oscillation member 78 is made integral with the movable member 75, the resiliency of the lead screw 65 may be utilized to permit up and down reciprocation of the oscillation member. However, in a sonic system, it is usually preferable to employ a resilient mount 45 for the oscillation member which is readily compressible and expandable in response to the action of the sound waves, and a separate spring means is usually desirable.

In the preferred embodiment employing the spring 80, the movable member 75 will move progressively along the bore 11 while the oscillation member 78 will move locally at relatively high frequency, determined by the frequency of the sound waves. Its movement will be through a relatively short locus of motion and this movement will be effected in response to sound waves transmitted thereto through the column. It is desirable that the cutter elements of the invention be oscillated with the oscillation member 78, in which event their locus of motion in a direction substantially parallel to the wall of the bore 11 will be determined by the amplitude of the sound waves.

There are numerous ways in which cutters or blocks of abrasive material can be operatively connected to the oscillation member 78 while being retained in cutting relationship with the wall of the bore 11. Figure 2 shows a simplified construction employing two stones or blocks of abrasive material 82 and 83 secured in mounts 84 and 85 for cutting two diametrically opposite rifling grooves during a single pass of the rifling unit 35 through the bore 11. The mounts 84 and 85 respectively provide arms 86 and 87 journaled on axes provided by pins 88 and 89, these

axes being inclined from the horizontal at a small angle so that the arms 86 and 87 extend in the general direction of the rifling groove. The pins 88 and 89 traverse a groove 90 formed in the lower surface of the oscillation member 78, this lower surface forming a wave-reflecting surface and being indicated by the numeral 91. The groove 90 may be formed to aid the pins 88 and 89 in maintaining the stones and their mounts pointed in the direction of the rifling grooves.

A skirt 92 depends from the oscillation member 78 around the arms 86 and 87 and serves as a stop means determining the outermost relative position of the stones 82 and 83. If desired, this stop means may be employed to determine the maximum depth of rifling grooves 94 and 95 being cut, but I prefer to employ other stop means, to be described, to limit groove-depth and to use the skirt 92 only to limit outward movement of the mounts 84 and 85 when the rifling unit 35 is withdrawn from the bore. The skirt 92 also serves to guide the flow of cutting oil and its suspended cuttings away from the zone of relative movement of the arms 86, 87 and the oscillation member 78 to reduce wear.

The mount 84 serves to retain the stone 82 and provides, in effect, a cavity in which the stone is cemented or otherwise retained. The shape of this cavity is best shown in Figure 3. The mount 84 preferably provides curved extensions 98 on opposite sides thereof which serve as a stop means limiting the maximum depth of the rifling groove 94 when they come into sliding contact with the surface of the bore 11 on opposite sides of the groove 94 or with the surfaces of the adjacent lands formed by previous rifling. The lowermost end of the mount 84 provides a wall 99 and the extensions 98 preferably extend throughout the length of the stone 82 and to this wall so that the lowermost portions of these extensions serve as a guide or stop means when the rifling unit 35 is in the position shown in Figure 1, where it is just entering the gun barrel. The mount 85 is identically constructed.

The rifling unit 35 is, in effect, self-centering and this feature is, in part, made possible by employment of a suitable spring means 100 resiliently urging the stones 82 and 83 outward. In Figures 2 and 3, this spring means is shown as being a small compression spring, though it should be clear that any other form of spring means can be employed. One important function performed by such a spring means is to urge the stones 82 and 83 outward into resilient cutting engagement with the gun barrel.

The stones 82 and 83 preferably have a configuration as best shown in Figures 2 and 3. They are of a width substantially corresponding to the width of the rifling groove to be cut thereby. In the illustrated embodiment, they are relatively long and provide a curved surface 101 which accomplishes most of the cutting action. This curved surface may extend to the rear of the stone, though it is preferable to make the rear portion of the stone, indicated by the numeral 102, substantially straight and substantially tangential to the curved surface 101. As the stone is used, it may wear away the curved surface 101, progressively renewing this curved surface toward the rear of the stone. At the same time, this rear portion of the stone determines the maximum depth of the groove and is subjected to very little wear because the major portion of the groove is cut by the curved surface 101.

As the stone 82 is being oscillated up and down, the curved surface 101 forms a substantially correspondingly curved surface on the gun barrel. The mechanism is such that the curved surfaces of the stone and of the barrel are largely in surface engagement during the cutting. For example, Figure 2 shows the oscillation member 78 near the upper portion of its oscillatory motion, the extensions 98 engaging the surfaces of the bore 11 adjacent the groove 94. As the oscillation member moves downward, the curved surface 101 of the stone 82 advances along the previously formed curved surface of the gun barrel in abrading relationship. At the same time, the curved surfaces on the stones 82 and 83 move the mounts 84 and 85 closer together to compress the spring 100. The extensions 98 at this time separate from the gun barrel. Upon later upward movement of the oscillation member 78, the curved surface 101 of the stones move in an opposite direction along the corresponding curved surfaces of the gun barrel, while the spring 100 urges these stones away from each other and into resilient cutting contact with the curved surfaces of this barrel. Correspondingly, cutting is accomplished by the up and down motion of the stones, during which motion they are alternately pinched together and expanded by the action of the spring 100.

It should be observed also that, as soon as the extensions 98 come into contact with the wall of the bore 11 adjacent the rifling groove, further penetration of the related stone is prevented. Oscillatory motion of these extensions while in contact with such adjacent walls produces a desirable burnishing action on these walls whereby the lands intervening the grooves can be burnished or smoothed in a very desirable manner.

When employing stones 82 and 83, which are relatively long as compared with their width, it is desirable that the splines interconnecting the movable member 75 and the oscillation member 78 be disposed helically so as to guide the stones along the desired path to be grooved or rifled. If, however, the ratio of stone length to stone width is decreased, such helical splining becomes less important, and if the ratio approaches unity, the splines may be parallel to the axis of the bore. Thus, for example, if the cutting or outward-extending portion of each stone is of a circular or oval configuration in vertical cross section, vertical or non-helical splines can be employed. The distance across such extensions in a vertical plane can be less than the desired groove width, the width of the groove being determined by the magnitude of vertical oscillation. On the other hand, such stones which are not substantially longer than they are wide can, of course, be employed with the preferred helical splining of the members 75 and 78, if desired, in which event the width of the groove will be determined by the shape of the outward-extending portion of the stone.

The mode of operation of the sonic portion of the system by which the oscillation member 78 is moved up and down is as follows. As the piston 36 is advanced downward, a pressure pulse is created in the liquid which travels through the liquid column as a wave of condensation. This wave travels at the speed of sound in the cutting oil and moves upward in that portion of the fluid column within the gun barrel to impinge upon, and be reflected by, the rifling unit 35. Reflection is primarily from the wave-reflecting surface 91. Reflection of such a wave of condensation causes a momentary upward thrust on the oscil-

lation member 78, causing movement thereof against the action of the spring 80. Such a wave, when reflected, re-traverses the fluid column in a reverse direction and would, of course, be again reflected by the face 37 of the piston 36 even if this piston had retained its advanced position. On the other hand, if the piston 36 has, in the meantime, moved to a retracted position and is again advancing at the time the reflected wave reaches the face 37, the wave will be not only reflected but reinforced and a condition of substantial resonance will exist in the fluid column.

Likewise, when the piston 36 is being retracted, there will be created in the liquid a rarefaction which will travel through the column as a wave of rarefaction to impinge upon and be reflected, as a rarefaction, from the rifling unit 35 to re-traverse the fluid column and be again reinforced by a subsequent rarefaction created by a later retraction of the piston 36. Correspondingly, the wave pattern in the fluid column plotted against time will show successive pressure pulses separated by one wave length with intervening rarefaction pulses and can be represented substantially as a sinusoidal wave. Employment of the eccentric 38 will impart substantially simple harmonic motion to the piston 36 conducive to formation of such a sinusoidal wave but, even if the motion of the piston 36 is not simple harmonic, the wave pattern in the fluid column will tend to assume sinusoidal characteristics.

Alternate reflection of condensation and rarefaction waves from the wave-reflecting surface 91 will cause the oscillation member 78 to reciprocate at a frequency determined by the frequency of the generating means 33. The movement of this oscillation member will be substantially sinusoidal in nature, acceleration being a maximum at the start of each stroke and the velocity being relatively high at the midportion of the stroke, after which deceleration occurs substantially in accordance with the characteristics of simple harmonic motion. The amplitude of motion of the oscillation member 78 will be determined by the amount of sonic energy imparted to the fluid column and can be varied either by changing the stroke of the piston 36 of the generating means 33 or by departure from existing sonic conditions to a condition closer to or more removed from exact resonance. The substantially sinusoidal motion of the oscillation member 78 is very desirable as it does not subject the stones to excessive shock, while still permitting extremely high peak velocities, if desired.

The sound waves reaching the rifling unit 35 in actuating relationship serve primarily to reciprocate the oscillation member 78. At the same time, they can be made to assist the action of the spring 100. Thus, a wave of condensation tending to move the oscillation member 78 upward serves also to exert a pressure on the mounts 84 and 85, tending to separate them and move the corresponding stones 82 and 83 resiliently outward. By the same token, a wave of rarefaction tending to draw the oscillation member 78 downward will tend to draw the mounts 84 and 85 toward each other. The spring 100 should be designed keeping in mind this acoustic spreading and contraction of the mounts 84 and 85. It should be noted that the spreading action assists the spring 100 in increasing the cutting pressure while the acoustic contraction is in opposition to the action of this spring. If the acoustic retraction is made sufficiently large with reference to the spreading action of the spring 100, it is

possible to lower the oscillation member 78 with decreased or no pressure between the stones and the gun barrel, thus making it possible to produce most of the cutting action on the upstroke of the oscillation member and thus separating the stone from the gun barrel to permit ingress of cutting oil therebetween. Usually, however, I prefer to design the system so that cutting takes place both during the upward and downward movement of the oscillation member 78.

As the stones 82 and 83 may spread from each other during advancement along the bore 11, it becomes possible to rifle a tapered bore with substantially the same ease as a cylindrical bore. In rifling a tapered bore, the rifling unit 35 may be started either at the larger end or the smaller end, though the latter is usually preferable. It is only necessary to form a bore of the desired taper and then insert the rifling unit. The extensions 98 will form uniform-depth grooves along the bore.

The wave pattern in the fluid column under conditions of resonance will represent substantially what is known as a standing wave. Considerable energy will be stored in the column and this energy will change from kinetic to potential at different positions along the column. For example, the column may have one or more zones of maximum velocity variation separated by one or more zones of maximum pressure variation. In the zones of maximum velocity variation, the molecules of the liquid move to and fro longitudinally of the column at maximum amplitude. At a zone of maximum pressure variation, there is substantially no movement of the molecules in a direction longitudinal of the column, the energy being primarily pressure or potential energy. Correspondingly, the energy is changed from potential to kinetic to potential to kinetic, etc., the total number of zones of maximum pressure or maximum velocity variation depending, of course, upon the relationship between the length of the fluid column and the frequency developed by the generating means 33.

The fluid column between the generating means and the rifling unit 35 is, in effect, confined at both ends and, to resonate such a system, this length of the column should be a multiple of one half wave length. The zones immediately adjacent the face 37 of the piston 36 and the wave-reflecting surface 91 of the rifling unit 35 represent substantially zones of maximum pressure variation, though they are not pure zones of this character in view of the small oscillatory motion, both of the piston and of the oscillation member 78. At a distance along the fluid column, which is substantially one quarter wave length either from the piston or from the oscillation member, there will be a zone of maximum velocity variation. Depending upon the length of the fluid column, there may be several other zones of maximum pressure variation and maximum velocity variation if the system is being resonated. Usually, however, entirely satisfactory results will be obtained by employment of a relatively short fluid column, equal in length, for example, to substantially one half wave length.

If the system is being used under substantially resonant conditions, it is desirable to correlate the length of the pipe 52 (between the pump 51 and the pipe 31) with reference to the wave length. The most desirable relationship is to have the length of the pipe 52 equal to one quarter wave length or odd multiple thereof. In this instance, the pipe 52 should communicate with

11

the fluid column at a position near the piston 36. The liquid in the pipe 52 will resonate with the liquid in the main fluid column and the pump 51 will be substantially at a zone of maximum velocity variation so that its discharge is not subjected to high pressure variations. As the rifling unit 35 moves downward in the bore 11, the effective length of the fluid column is reduced. If the total length of the gun barrel is small as compared to the total length of the fluid column between the generating means and the rifling unit, the system can still be operated in substantial resonance, even without change in speed of the generating means. However, if exact resonance is desired, the speed of the generating means can be changed as the effective length of the fluid column changes.

It should be understood, however, that the invention does not rely for operativeness upon the establishment of resonant conditions in the fluid column. By operating the system at or near resonance, it is possible to store a very large amount of energy in the column and to reciprocate the oscillation member 78 at greater amplitudes. However, even under non-resonant conditions, the successive waves of condensation and rarefaction reaching the oscillation member 78 will effect vertical movement thereof. In all instances, the stroke or locus of motion of the oscillation member 78 can be adjusted by changing the stroke of the piston 36. In this way, it is possible to adjust the stroke of the stones in any manner desired, making this stroke very short or extending it to a matter of an inch or so, if this is desired.

It is not essential that the oscillation member 78 be tight-fitting with respect to the bore 11 as the system can be successfully operated even though some of the sonic energy is dissipated into the cutting oil above the rifling unit 35. A relatively complete closure is, however, desirable, particularly if previous rifling grooves have been cut in the bore 11, and it is within the contemplation of the invention to employ an oscillation member 78 which forms a closure which extends into previously-formed rifling grooves, if this is desired. This expedient can also be employed as a guide means for guiding the stones 82 and 83 in a helical path, as determined by the pitch of the previously-formed rifling grooves or the previously-formed section of the particular groove being formed by the cutting operation.

I have found that the acoustic relationship of the system are not negated by continual or periodic ingress and egress of cutting oil to the fluid column. The wave pattern will be substantially unaltered, while at the same time the supplementary circulation is very effective in supplying cutting oil to the stones and in removing heat and cuttings from the gun barrel.

While the system exemplified in the drawing shows only two cutting stones, it is within the contemplation of the invention to increase the number of cutting stones to correspond to the total number of rifling grooves to be formed. In this instance, a single pass of the rifling unit will produce the desired number of grooves.

The principles of the invention are applicable to the rapid oscillation of various types of cutter elements, whether they are of the blade type, point type, or abrasive-material type, and it should be understood that the description of the invention with reference to the rifling of gun barrels is merely exemplary, though this use is an important one. In any of these instances, the

12

invention can be employed where it is desired to move a cutting element through a relatively small locus of motion, usually, a small fraction of an inch, while at the same time obtaining relatively high peak velocities. The cutting action is quite rapid and is adaptable to many uses falling within the scope of the appended claims.

This application is a continuation-in-part of my copending application, Serial No. 397,252, now Patent No. 2,304,793.

I claim as my invention:

1. A method of cutting into the surface of an article by use of an abrasion member adjacent said surface and yieldingly mounted to move in a direction along said surface, which method includes the steps of: generating sound waves in an elastic medium; and transmitting these sound waves through the elastic medium into pressure-transferring relationship with said abrasion member in a manner to oscillate same against the action of said yielding mounting in cutting relationship with said surface and in a manner to vary the pressural contact between said abrasion member and said surface.

2. A method of cutting into the surface of an article, which method includes the steps of: yieldingly urging an abrasive cutter toward and into engagement with said surface; yieldingly restraining motion of said cutter in a direction longitudinally of said surface and substantially perpendicular to the direction in which said cutter is yieldingly urged toward said surface; and generating sound waves in an elastic medium in pressure-transferring relationship with said cutter and transmitting said sound waves to said cutter in a direction generally parallel to said surface to oscillate said cutter longitudinally of said surface against the yielding restraint of said cutter and during the time that said cutter is yieldingly urged toward said surface.

3. A method of cutting into a surface by use of a cutting element connected to an elastic medium, which method includes the steps of: applying to said cutting element in a direction toward said surface a yielding force tending to hold said cutting element in contact with said surface; and generating sound waves in said elastic medium of a frequency to resonate same and generate oscillatory forces causing said cutting element to vibrate substantially transverse to the yielding force and in cutting relationship with said surface.

4. A method of grooving a generally cylindrical and previously ungrooved surface of an article by employment of a cutting element, which method includes the steps of: relatively moving said cutting element and said surface while guiding said cutting element from a position spaced from said cylindrical surface and independently of any guiding of said cutting element by contact with the article to move relative to said surface in a substantially helical path; and rapidly oscillating said cutting element with substantially simple harmonic motion during such relative movement to impart thereto a to-and-fro motion generally parallel to said substantially helical path.

5. A method for abrading a surface by employment of a block of abrasive material, which method includes the steps of: contacting said surface and said block of abrasive material; relatively slowly advancing said block of abrasive material relative to said surface along the path to be abraded with an exclusively longitudinal relative motion as distinct from a rotary relative

13

motion; and, during said advancement, rapidly oscillating said block of abrasive material in a direction substantially parallel to said path by wave energy transmitted thereto through a resonating elastic medium to effect abrasion of said surface along said path.

6. A method for abrading a surface by employment of a block of abrasive material carried in a member, which method includes the steps of: contacting said surface and said block of abrasive material; contacting said member and said block of abrasive material with a column of fluid; and establishing sound waves in said column of fluid to move therethrough to said member in a manner to oscillate said block of abrasive material rapidly in abrading relationship with said surface while the fluid of said column communicates with the zone of contact between said block of abrasive material and said surface.

7. A method for abrading a surface by employment of a block of abrasive material, which method includes the steps of: contacting said surface and said block of abrasive material; advancing a stream of fluid toward said block of abrasive material to contact same and continue its movement therebeyond to form a sound-transmitting fluid column extending to said block; and establishing sound waves in said column of fluid to move therethrough to said block of abrasive material in a manner to oscillate said block of abrasive material rapidly in abrading relationship with said surface.

8. A method of forming rifling grooves in the surface of a bore, which method includes the steps of: positioning a cutting element in contact with said surface of said bore; generating sound waves in an elastic medium extending into said bore; and transmitting said sound waves through said elastic medium to said cutting element to oscillate same in the general direction of the desired rifling groove and while said cutting element is in pressural engagement with the surface of said bore.

9. In an apparatus for cutting into the surface of an article, the combination of: a movable member bodily movable in a direction substantially parallel to said surface; an oscillation member; resilient means for mounting said oscillation member for local high-frequency motion with respect to said movable member and in a direction substantially parallel to said surface; an elastic sound-wave-transmitting medium operatively associated with said oscillation member; means for sending sound waves along said elastic medium from a point remote from said oscillation member to said oscillation member to oscillate said oscillation member relative to said movable member; and cutter means carried by said oscillation member to oscillate in contact with said surface.

10. In an apparatus for cutting into the surface of an article, the combination of: a movable member bodily movable in a direction substantially parallel to said surface; an oscillation member; resilient means for mounting said oscillation member for local high-frequency motion with respect to said movable member and in a direction substantially parallel to said surface; a column of fluid in pressure-transferring relationship with said oscillation member; means for sending sound waves along said column of fluid to oscillate said oscillation member relative to said movable member against the action of said resilient means; and cutter means carried by

14

said oscillation member to oscillate in contact with said surface.

11. In a device for processing an article providing a passage bounded by a wall, the combination of: a sonically movable abrasive member within said passage and movable longitudinally therein in contact with said wall of said passage; means for mounting said abrasive member to oscillate to and fro in said passage; a column of fluid in said passage and in operative relationship with said abrasive member; and means for sending sound waves through said fluid to oscillate said abrasive member.

12. In a device for processing an article providing a bore bounded by a wall, the combination of: a sonically movable abrasive member within said bore; means for guiding said abrasive member to move relative to said article in a direction to traverse said bore along a predetermined path and to contact the wall of said bore during such movement; elastic means for mounting said abrasive element to oscillate relative to said guiding means and in the direction of said path; an elastic sound-wave-transmitting medium operatively associated with said abrasive member; and means for sending sound waves through said elastic medium to oscillate said abrasive member relative to said wall of said bore.

13. In an apparatus for grooving a bore, the combination of: an abrasion member within said bore; means for guiding said abrasion member to move in said bore in contact with the wall thereof; a column of fluid in the uncut portion of said bore and in pressure-transferring relationship with said abrasion member; and means for rapidly oscillating said fluid in said bore to impart to said abrasion member a to-and-fro motion to abrade said wall of said bore.

14. A combination as defined in claim 13, including means for advancing the fluid of said column with respect to said abrasion member during said oscillation of said fluid.

15. In an apparatus for grooving a vertically disposed bore, the combination of: a cutting element within said bore and tending to move downward therein by gravity; means for resiliently urging said cutting element into contact with the wall of said bore; a column of fluid in said bore in pressure-transferring relationship with said cutting element; and means for generating sound waves in said column of fluid to oscillate said cutting element in cutting relationship with the wall of said bore and in a manner alternately to raise said cutting element against the action of gravity and lower same while aided by the action of gravity.

16. In a cutting apparatus, the combination of: a cutting element in contact with a surface to be cut; an oscillation member; means for movably mounting said oscillation member to move in a direction substantially parallel with respect to said surface to be cut; means for operatively connecting said oscillation member and said cutting element to move said element in cutting relationship with said surface upon oscillation of said oscillation member; a column of fluid in pressure-transferring relationship with said oscillation member; means for generating sound waves in said column of fluid to oscillate said cutting element in cutting relationship with said surface; means for delivering additional fluid to one portion of said fluid column during oscillation of said cutting element in response to said sound waves; and means for removing from said fluid column at another position an amount of

said fluid substantially corresponding to the amount of said additional fluid supplied to said column at said one position.

17. A combination as defined in claim 16, in which said second position is adjacent said cutting element whereby fluid is discharged from said fluid column adjacent said cutting element to cool same and remove cuttings.

18. In an apparatus for cutting, the combination of: a wave-operable cutting unit including a cutting element in contact with a surface to be cut; walls defining a space extending to said cutting unit and to a position therebeyond; means for advancing a column of fluid along said space in leaving relationship with said cutting element; and sound-wave generating means for generating sound waves in said column of fluid to oscillate said cutting element in cutting relationship with said surface by wave energy transmitted through said column of fluid from said sound-wave generating means to said sonically-operable cutting element.

19. In an apparatus for rifling a gun barrel, the combination of: an oscillation member within said barrel; guide means extending into said barrel for guiding said oscillation member for advancing movement substantially parallel to the axis of said gun barrel and for turning about said axis during such advancing movement; cutting means carried by said oscillation member for cutting rifling grooves in said gun barrel; an elastic sound-wave-transmitting medium in pressure-transferring relationship with said oscillation member; and means for sending sound waves through said elastic medium to oscillate said oscillation member and said cutting means with respect to said gun barrel.

20. In an apparatus for rifling a smooth bore gun barrel, the combination of: a cutting element in engagement with the wall of said gun barrel and adapted to cut a groove therein as it advances therealong; guide means spaced from said gun barrel for guiding said cutting element in a helical path as it advances along said gun barrel; means for mounting said cutting element for local oscillation during its advancement along said gun barrel; an elastic medium in said gun barrel and operatively associated with said cutting element; and means for generating sound waves in said elastic medium for transmission to said cutting element to oscillate same locally while advancing in cutting relationship with said gun barrel to cut a rifling groove in the smooth-bore barrel.

21. In an apparatus for cutting a groove in a previously ungrooved surface of an article, the combination of: a cutting element; means for mounting said cutting element to cut into said surface when oscillated; means for limiting the depth to which said cutting element may penetrate said surface, said means preventing said cutting element from moving completely through said article and comprising an extension on said mounting means slidable along said surface when the groove is of the desired depth; means for relatively advancing said cutting element and said surface along the path of the groove to be cut; and means for rapidly oscillating said cutting element to move same to and fro with respect to said surface in a direction generally parallel to the direction of the desired groove.

22. In an apparatus for cutting a groove in the surface of an article, the combination of: a cutting element comprising a block of abrasive material substantially corresponding in cross-

sectional configuration to the cross-sectional configuration of the groove to be cut; a mount for said block of abrasive material comprising an extension engageable with said surface to limit the penetration of said block of abrasive material and thus the depth of the groove being cut thereby; means for advancing said cutting element in the direction of the desired groove while said cutting element is in contact with said surface; and means for rapidly oscillating said cutting element during such advancement and in a direction generally parallel to the direction of the desired groove.

23. In combination in an abrading apparatus: an oscillation member; a sound-wave generator remote from said oscillation member; an elastic medium operatively connecting said sound-wave generator and said oscillation member for transmission of wave energy from said generator to said oscillation member to reciprocate same, the length of said elastic medium being substantially a multiple of one half wave length of the waves in the elastic medium to establish substantially a resonant condition in said elastic medium; and a block of abrasive material operatively connected to said oscillation member to be reciprocated thereby and adapted to engage a surface of an article in abrading relationship.

24. In a cutting apparatus, the combination of: an oscillation member movable in response to sound waves transmitted thereto; a fluid column in operative contact with said oscillation member; means for establishing sound waves in said column of fluid at a position remote from said oscillation member to move through said fluid column and create pressure variations adjacent said oscillation member to rapidly reciprocate said oscillation member; and a cutting element in contact with the surface to be cut and operatively connected to said oscillation member to be reciprocated thereby in a direction substantially along said surface, said cutting element being disposed in pressure-transferring relationship with said fluid column whereby the pressure variations in said fluid column will vary the pressure of contact between said cutting element and said surface during the oscillation of said cutting element by said sound waves.

25. In a cutting apparatus for surfacing the interior of an article, the combination of: an oscillation member disposed in said interior; a column of fluid within said interior and in pressure-transferring relationship with said oscillation member; means for delivering pressure pulses to said fluid column to be transmitted therealong to said oscillation member for oscillating same; a cutting element within the interior of said article and in pressure-transferring relationship with a portion of said fluid column; and means for operatively connecting said cutting element to said oscillation member to oscillate therewith and to move toward and away from said surface whereby the pressure contact between said cutting element and said surface is varied by said pressure pulses during oscillation of said cutting element by said oscillation member.

26. In combination in an apparatus for surfacing an open-ended bore of an article: a sonically-operable cutting unit movable within said bore, said bore being substantially filled from end to end with a fluid whereby said cutting unit is surrounded by said fluid; conduit means communicating with one end of said bore and containing fluid, the fluid in said conduit means and

17

in said bore to a position adjacent said cutting unit comprising a column of fluid; means for oscillating said cutting unit in response to sound waves transmitted thereto through said column of fluid, said means including a sonic generator associated with said column of fluid to establish waves of condensation and rarefaction therein which are transmitted along said fluid column to said cutting unit to oscillate same in cutting relationship with said bore, said cutting unit being sufficiently smaller in size than said bore to permit passage of fluid past said cutting unit to the other end of said bore; and means for delivering additional fluid to said fluid column during wave transmission therein and in amount substantially corresponding to the amount of fluid moving past said cutting unit and from said other end of said bore.

27. In an apparatus for cutting a surface, the combination of: a sonically-movable cutting unit; a column of fluid in pressure-transferring relationship with said cutting unit; means for continuously delivering additional fluid to said column of fluid to discharge a corresponding portion of said fluid from said column adjacent said cutting unit to remove material cut from said surface by said cutting unit; sonic generator means associated with said column of fluid at a position removed from said cutting unit for oscillating said cutting unit in cutting relationship with said surface in response to wave energy transmitted from said sonic generator means to said cutting unit through said column; and means for returning to said fluid column the fluid discharging adjacent said cutting unit.

28. In combination in a cutting apparatus: a sonically-operable cutting means providing a wave-receptive surface; means for resiliently mounting said cutting means to oscillate in resilient contact with the surface to be cut and in a direction substantially along such surface; means for continuously circulating a confined stream of fluid in contact with said wave-receptive surface; and means for establishing sound waves in said stream of fluid of sufficient magnitude to oscillate said cutting means in contact with said surface to be cut.

29. In an apparatus for cutting the surface of an article, the combination of: a movable member bodily movable in a direction substantially parallel to said surface; an oscillation member; resilient means for mounting said oscillation member for local high-frequency motion with respect to said movable member and in a direction substantially parallel to said surface; a column of liquid in pressure-transferring relationship with said oscillation member; means for sending sound waves along said column of liquid to oscillate said oscillation member relative to said movable member; and cutter means carried by said oscillation member to oscillate in contact with said surface, said cutter means being disposed in said liquid.

30. In an apparatus for cutting the surface of an article, the combination of: a movable member bodily movable in a direction substantially parallel to said surface; an oscillation member; resilient means for mounting said oscillation member for local high-frequency motion with respect to said movable member and in a direction substantially parallel to said surface; a column of fluid in pressure-transferring relationship with said oscillation member; means for sending sound waves along said column of fluid to oscillate said oscillation member relative to

18

said movable member; cutter means carried by said oscillation member to oscillate in contact with said surface; and means for advancing the fluid of said fluid column past said cutter means during oscillation thereof to carry material cut from said surface by said cutter means.

31. In an apparatus for cutting a groove of a desired depth in a surface, the combination of: a block of abrasive material disposed in cutting relationship with said surface and of a width substantially equal to the width of the groove to be cut, said block of abrasive material having a curved cutting surface facing the surface to be cut for cutting thereinto to produce a correspondingly-curved surface with one end terminating in the bottom wall of the groove being cut and another end terminating at the surface to be cut; a mount for said block of abrasive material and means for movably mounting same to move toward and away from said surface to be cut as said curved surface of said abrasive material slides along said correspondingly-curved surface being cut; stop means for limiting the motion of said mount toward said surface to determine the depth of the groove; means for rapidly oscillating said block of abrasive material in a direction longitudinally of its curved surface to cut said groove; and means for advancing said block of abrasive material along said surface to be cut at such rate that said stop means limits the movement of said mount and said block of abrasive material in a direction toward such surface during a portion of each oscillation.

32. In an apparatus for abrading the surface of an article, the combination of: an abrasion member movable relative to said surface in abrading relationship therewith in a first direction substantially parallel to said surface; means for mounting said abrasion member for movement in a second direction toward and away from said surface; and sound-wave-transmission means for transmitting wave energy to said abrasion member to oscillate same in said direction toward and away from said surface during relative abrasion-producing movement between said abrasion member and said surface while in contact with each other to change cyclically the pressure of contact between said abrasion member and said surface during said abrasion-producing movement.

33. In an apparatus for abrading the surface of an article, the combination of: an abrasion member; means for mounting said abrasion member for movement along said surface in a first direction and for moving said abrasion member in said first direction in abrading relationship with said article; means for mounting said abrasion member for movement in a second direction toward and away from said surface; means for applying a resilient force to said abrasion member to urge same toward and into contact with said surface; and a sound-wave-transmission means for transmitting wave energy to said abrasion member to move same in said second direction toward and away from said surface during relative abrasion-producing movement between said abrasion member and said surface in said first direction and against the resilient force urging said abrasion member toward said surface to vary the pressure of contact between said abrasion member and said surface during said abrasion-producing movement and in step with the wave energy.

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19

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Number	Country	Date
553,176	Great Britain -----	May 11, 1943

Certificate of Correction

Patent No. 2,445,934.

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ALBERT G. BODINE, JR.

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Column 15, line 15, claim 18, for the word "leaving" read *laving*; column 16, lines 10 and 11, claim 22, for "cuttnng" read *cutting*; column 20, line 6, list of references cited, for "Gaumgold" read *Baumgold*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 9th day of November, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

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