

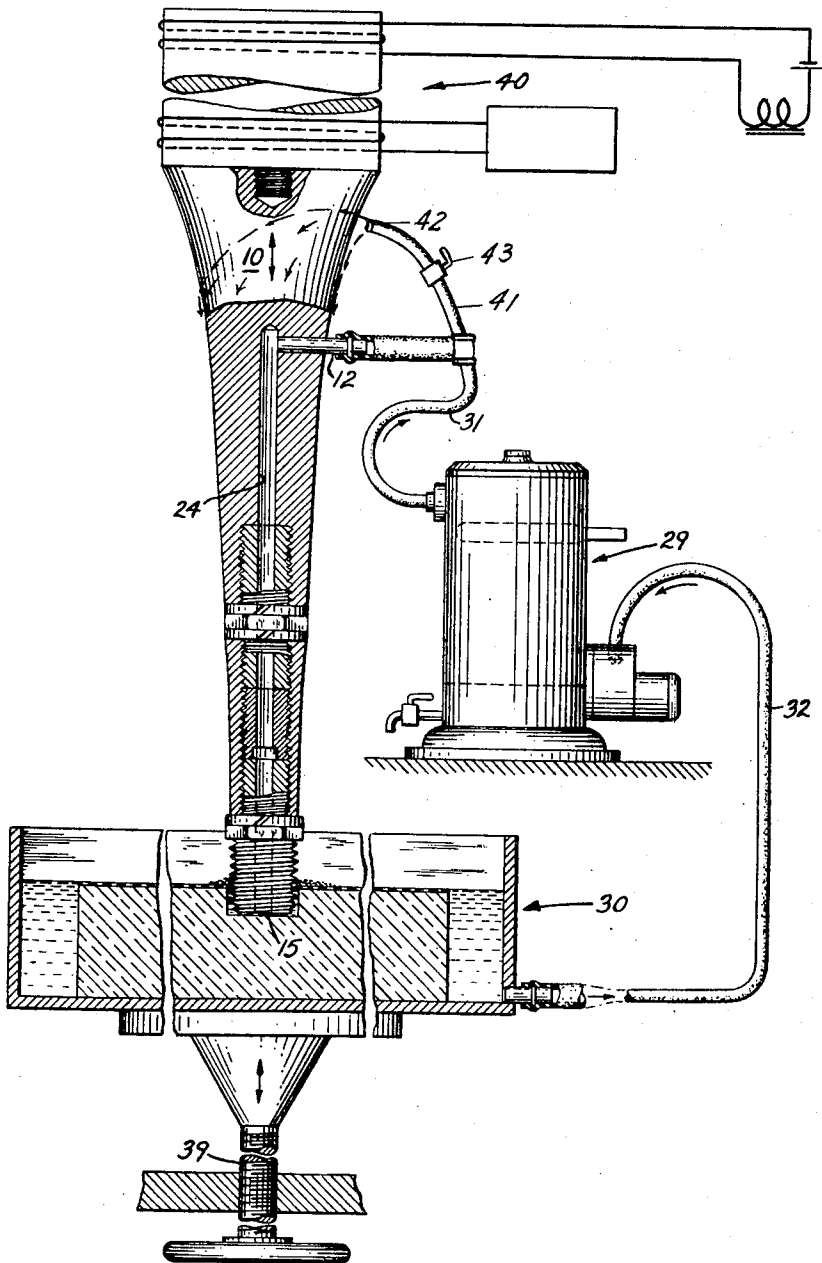
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2,804,724

HIGH SPEED MACHINING BY ULTRASONIC IMPACT ABRASION

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HIGH SPEED MACHINING BY ULTRASONIC IMPACT ABRASION

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7 Claims. (Cl. 51—59)

This invention relates to a novel method and apparatus for shaping of metals, alloys, glass, Carboloy, and other hard substances by the use of high frequency vibratory impact abrasive cutting developed in and/or applied in drilling or in milling machines, lathes, shapers, etc.

This application, consequently, is related to and an improvement on the subject matters of my co-pending applications Serial Numbers 321,579 and 371,408, now issued as U. S. Patents Nos. 2,736,144 and 2,736,148, respectively, and also of my joint co-pending application with Benson Carlin, Serial No. 539,405, now U. S. Patent No. 2,774,193.

It is a particular object of the invention to make it feasible to speed up machining operations of the type hereinbefore specified, to an extent heretofore unattainable and for reasons including cooling of the tool which will hereinafter be explained and amplified.

The invention comprehends the rapid oscillation of comminuted hard abrasives such as aluminum oxide, silicon carbide, or boron carbide, suspended in a film or stratum of a liquid of low viscosity such as water, and accompanied by the rapid flow of such vibrating abrasive suspensions and thorough scavenging of the detritus formed between the surface of the substance to be shaped and a rapidly vibrating, suitably shaped tool; this tool may be blunt, and held with its operative surface constantly adjacent to, but not usually in actual contact with, the surface of the work piece.

The high frequency vibration of the abrasive particles is established by sonic, or preferably ultrasonic, vibration of the tool end which propels or hammers the abrasive particles against the immediately adjacent surface of the work piece, which is thereby subjected to myriads of chipping actions each second; a smooth and rapid cutting of the hardest materials thereby results if the impact abrasive action is not impeded or rendered ineffective.

Cutting by such high-frequency vibratory impact abrasion has been previously used and patented, but has been confined heretofore to the polishing or etching of surfaces or to the drilling of holes or cavities or the surface, or the engraving of very hard metals, gems, glass or the like. Thus the patent to C. H. Griss, No. 2,504,831 for An Apparatus for Engraving Glass, patented April 18, 1950, is an example of such a prior art application of high-frequency vibratory impact abrasive action. There has been no successful attempt known to applicant, other than by the disclosure of his before specified applications and patents, to extend the use of this novel form of abrasion to the rapid removal of relatively large volumes of hard materials, such as is effected in milling machines or by the turning of such materials in lathes. This limitation in the application of the recently developed abrasion phenomena has, in part, been due to an insufficient understanding of the nature of the physical-chemical phenomena involved.

I modify the prior practice of this art by making provision for a rapid and copious flow of thin, liquid abrasive slurry through the narrow locus between the operative face

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of the tool and the work confronting surface; and I further provide means for removal of the detritus of abraded metal particles from the liquid with sufficient rapidity to maintain a return flow of abrasive slurry substantially free of metal detritus, so that its abrasive cutting action in the operative region of the device may be maintained, unimpaired, by any clogging effect of impacted abrasive particles or of extraneous, accumulated, softer metal particles.

In the prior practice of this art it has been customary to employ very thick slurries, as much as one pound or more of comminuted boron carbide suspended in each quart of water. Although slurries of such high concentration have invariably caused the deposition of tenaciously caked deposits of abrasive even upon open, exposed plane surfaces overflowed by rapid currents of the slurry, and despite the fact that any hole or cavity exposed to even rapid flow of a normally thick slurry thereover soon is closed and clogged by coherent plugs of impacted abrasive, it seems to have occurred to no one heretofore that the actual locus of impact abrasive cutting action under the tool end and between it and in the space over the work piece face to be abraded will likewise become encrusted with caked abrasive and/or abraded particles; nor, apparently, has it heretofore been considered necessary to use means or methods to effectually disrupt and to flush out all such impacted accumulations of such particles—or to prevent their accumulation—so as to effectually scavenge the abrasion locus. The consequences of this oversight or neglect, and the failure to use effective corrective measures, has hindered and restricted the use of impact abrasive cutting machines and the general, widespread use of this art. It has been the aim of this applicant to locate and to apply such corrective measures, some of which have heretofore been disclosed in the co-pending applications and patents heretofore herein specified.

It is therefore one of the prime objects of this invention to disclose a method specifying the optimum conditions of use of the improved slurries—those containing additive compounds disclosed in applicant's copending application Serial No. 371,408, now issued as Patent 2,736,148. As described in said last named patent, soluble compounds, such as sodium bicarbonate, carbon dioxide gas, or solid carbon dioxide in the form of Dry Ice, etc., are advantageously added to the abrasive slurries used in impact cutting, to the end that there may be no impoverishment of free gas bubbles to oscillate in the liquid film in the abrasive locus at resonant frequencies, and thus forcibly to impel the otherwise quiescent abrasive particles floating in said liquid at any moment of their transition through the film in the locus. However, suitable tests and observations of the physical and chemical phenomena occurring in the slurry film during passage of the liquid through the abrasion locus have shown that what occurs there during irradiation, is, in fact, much more complex than it seems to have been thought to be—as the level of that thinking is traceable from the subject matters of prior art patents and literature articles about this art. It seems that those who concerned themselves about the modus operandi of impact abrasion and of cutting tools involved therein, superficially considered that everything that occurred in the abrasion locus, could be elucidated by the mere statement that "cavitation" occurred in the transient liquid film, and that impact abrasive cutting is controlled and its optimum use would, and could, be attained by the mere act of ascribing it to cavitation.

Applicant has disclosed and established mathematically in his copending application, Serial No. 371,408 (Patent No. 2,736,148), that resonant bubbles of gas oscillating in the liquid in the abrasion locus can increase the kinetic energy of the liquid film as much as 14,000 times over that attainable in gas-free irradiated aqueous slurries;

and the theoretical computations and deductions of that patent have now been confirmed by suitable comparative tests. However, those tests also made it evident that control and establishment of factors of control, other than the concentration of free and dissolved gas in the liquid, could markedly affect the progress and efficiency of ultrasonic impact cutting. Thus, applicant has discovered, that the thermal conditions and factors, both at the tool tip and in the liquid film beneath and in contact with that tip could and did play an important role in impact abrasive cutting.

Contrary to the generally stated assumption that this operation is one devoid of any heat development it transpires that, in fact, there is a considerable generation of heat, mainly at the very tip or end of the tool, and that unless that heat is adequately dissipated as it is formed, the entire tool and the cone to which it is metallurgically attached becomes quite hot. That such heating should occur seems a rational assumption; but the thermal conditions of the abrasive impact tool during use seems to have been assumed to be static and a matter of no account—except that the reported apparent absence of heat in the high frequency vibrating tool has been acclaimed as one of the virtues of machining methods using such tools, because the deleterious effects of heat upon some materials have thereby been avoided.

But in various machining operations used by applicant recently, the tools became so hot during use that the operation was necessarily discontinued. This was first and most notably observed during use of the hole drilling tools disclosed in applicant's and Benson Carlin's joint application Serial No. 539,405, now United States Patent No. 2,774,193.

In the early use of that tool, the flow of slurry liquid to and from the locus of abrasion was very restricted, due to what were then thought to be necessary features of tool construction; and applicant deduced therefrom the conclusion that a copious stream of cold liquid slurry projected upon and flowing down and over the entire exterior of the tool holder cone, should be used to supplement the diminished cooling of the restricted flow of liquid to and from the abrasion locus.

Applicant, by this invention, accordingly uses two streams of liquid slurry in connection with each tool, instead of one single stream, as heretofore in this art. Applicant's first stream is the one forced through an interior channel which scavenges the detritus from the abrasion locus. Applicant's second stream is a more copious stream of cool slurry or other cooling liquid caused to flow in heat exchanging contact with extended surfaces of the tool holder so as to cool it and the attached tool. These two streams are illustrated in the accompanying drawing, which is a suitably modified copy of Fig. 12 of applicant's copending U. S. application, Serial No. 539,405, now Patent No. 2,774,193.

In the drawing the figure illustrates partly in front elevation and partly in longitudinal section, the coupled transducer 40, tapered tool holder 10, and tool 15, engaged in drilling a hole in a work-piece placed in a trough 30. Extending through the tool holder and tool is a channel 24 through which slurry is forced out of the bottom of the tool 15, which may be of any suitable character depending upon the work to be performed. Slurry is forced through the channel 24 through an inlet tube 12 connected by a pipe 31 with a pump 29. A branch pipe 41 connects with the pipe 31 and carries a nozzle 42 which discharges a stream of cooling slurry or liquid over the outside of the tool holder. The flow of slurry discharged through the nozzle may be regulated by the cock 43. The slurry flows down over the large surface of the tool holder and is collected in the trough 30 and may be recirculated through pipe 32. The tool may be advanced relatively to the work-piece in any suitable manner. As shown, the work-piece may be raised

relatively to the tool by means of the adjusting screw 39 under the trough 30.

But when that expedient was used, the observable exposed portion of the tool holder and tool—those portions not buried in the hole already incised in the work-piece—remained at or near the ambient temperature of the air or that of the slurry. But even then it was observed that the very tip or end of the tool could, under some conditions of use, become quite warm, and elevated in temperature above that of the upper portions of the tool. This was noticed only when the tool was withdrawn quickly from the embedding material of the work and before the highest temperature of heat could be dissipated, either into the contiguous work material or before that occurs, by thermal conduction, into the large mass of metal in the tool holder cone. This restricted heating of the very tip or end of the tool is used now by applicant to good advantage, to heat the slurry film in the abrasion locus to temperatures sufficient to evolve copious gas bubbles from the liquid slurry within any impacted layer of abrasive or abraded particles, thus to disrupt such cakes and permit effective scavenging of them from the abrasion locus.

It was also noted that the temperature of the tool tip depended, after otherwise comparable conditions of use, in large degree upon the coefficient of thermal conductivity of the metal from which the tool cone and tool end itself were constructed. Cones and tool ends priorly used were generally made from Monel, with the tool or tip end usually cold rolled steel, hard soldered to the smaller end of the tool holder cone. Since Monel metal has a relatively high thermal conductivity such tool units remained comparatively and uniformly cool—if the large tool cone surface was kept constantly bathed and cooled by a copious flow of slurry thereover, as by this invention. But tool units constructed by applicant from stainless steel and in one piece showed a higher temperature after otherwise comparable conditions of use and heat absorption into a full stream of slurry, which, it was deduced, arose from the fact that stainless steel is a much poorer heat conductor than Monel metal.

The considerations of the preceding several pages show that by careful and understanding control of the physical and chemical characteristics of the liquid film in the abrasion locus the phenomena of impact abrasive cutting may be in like manner better thereby controlled. And by an application of these considerations, applicant has devised a method to cure the before explained tendency of the abrasive particles of the liquid slurry to settle out to such an extent that all surfaces, even those of the abrasion locus, are encrusted with a tenaciously adhering cake of impacted abrasive particles. The formation of such a "mud" layer over the surface of the work piece desired to be eroded and progressively removed by impact abrasion, naturally would have as a concomitant effect, the cessation of effective attrition of the confronting work surface by impact of any of the abrasive particles which remained movable—from whatever cause. The impacts of minute movable particles—thousands of them per second—which the ultrasonic impact abrasive technique for incisive impact cutting depends upon, will, of course, become non-effective if a relatively soft layer of already impacted abrasive "mud" overlays and shields the brittle, hard surface upon which the impact bombardment is supposed to be directed. Realization of the objectives of this cutting technique consequently predicates the maintenance of an unprotected, bare surface of brittle material at all times at the lower portion of the abrasion locus; and any inception of an intervening cake of deposited and caked "mud" of boron carbide or other similar, newly supplied abraded particles having caking tendencies, will be followed by a progressive building up of further layers of caked particles by the deposition and adherence of movable abrasives which may impinge upon and enter into the initial layer; the result,

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eventually, and in fact, almost immediately, will be building up of an unbroken encrusting "mud" layer, and a total cessation of the desired erosion of the confronting surface of the work-piece.

Consequently the scavenging of freshly abraded particles of the eroding work face from the abrasion locus must extend to include, somehow, a preventive or disrupting effect upon the caking tendency of the abrasive particles which are relied upon to effect the erosion. If removal of the accumulated abrasive and abraded particles does not keep step with the increase of such particles in the locus, then the cutting process becomes throttled, impeded and self-destructive.

This explains why the films, as the slurry passes through the locus of abrasion, should become warm enough to evolve carbon dioxide by dissociation of sodium bicarbonate or of HCO_3 's ion into carbon dioxide bubbles; for liberation thereof within any layer of impacted abrasion or abraded particles, will disrupt such a cake and permit effective scavenging of detritus from the locus of abrasion.

Applicant, in this invention, also uses a method of amplification of the power impulses, sonically generated by the transducer, which is an equivalent means of accomplishing the hydraulic amplification disclosed in Serial No. 321,579 (now Patent No. 2,736,144). This amplifying means can obviously be a tapered tool holding cone such as that described in the U. S. patent to Noyes No. 2,044,807 issued June 23, 1936, or in the U. S. patent to Smith No. 2,407,294 issued September 10, 1946. This kind of amplification is also described in the U. S. patent to Carwile No. 2,651,148 and to Calosi, No. 2,632,858 assigned to Raytheon Mfg. Co. This means of amplification is accordingly well known in the art and requires no further consideration except to state that when used, it is comprehended by the claims of applicant's issued patents and those of his instant application, in combination with other elements therein specified.

Using a transducer and such tapered power amplifying tool holders, vibrations of the tool of amplified amplitude and the high frequency of the transducer, accompanied by movement of the work in a plane divergent to that of the axis of movement of the vibrating tool, produces a rapid cutting of the surface of the work along the line of contact of the tool face and the work; the vibration need only be of the order of a few thousandths of an inch in amplitude, and to have a frequency from four hundred to thirty thousand cycles per second, or even more, or from eight hundred to sixty thousand motions per second, or more, to produce the desired result. It will be understood by those skilled in the art from the foregoing description, that these vibrations may be produced by a number of different means and that they may be imparted to either the tool or to the work, or to both.

It will also be understood that the slurry to be circulated thru the interior of the tube, then underneath the tip of the tool and then upwardly to the surface of the incision, should have a suitable consistency for the nature of the machining to be done; this may be, for example, a suitable thin liquid slurry, such as water containing finely comminuted abrasive, such as one pound of boron carbide in suspension per gallon of water. It has heretofore been the usual practice to use one pound of abrasive in each quart of water, which practice, I find, tends to increase the "caking tendency" and deposition of "mud" and to impede the circulation of the slurry.

By use of the method and means herein disclosed, employing the described departures from prior art practices, applicant has incised and shaped hard brittle work materials at speeds many times higher than those heretofore attainable.

I claim:

1. The method of removing material from a hard substantially non-yielding solid by vibratory impact abrasion, which comprises imparting high frequency oscilla-

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tions to the end of a blunt faced tool held against rotation by a tapered, elongated tool holding member adapted to amplify the acceleration of said vibratory impact, applying said tool end to the work surface of said solid with the cutting face of the tool forming an angle of not less than 45° to the plane of said surface, flowing over the surfaces of the holder and tool and interposing in the locus of abrasion between the tool end and work surface, a film of a thin liquid suspension of a mobile, finely comminuted abrasive containing in solution a substance which dissociates, when said film is irradiated and heated, into pulsating gas bubbles, scavenging mobile and impacted abrasion and abraded particles from said locus while heating said film in said locus by absorption of heat generated in the end surface of said tool during the machine operation, and controlling the temperature of said tool end surface by controlling the rate of flow of said liquid over said tool holder and tool, and advancing the tool into the work as the abrasive progressively removes material from the contact area.

2. The method of removing material from a hard substantially non-yielding solid by vibratory impact abrasion, which comprises imparting high frequency oscillations to the end of a blunt faced tool held against rotation by a tapered, elongated tool holding member adapted to amplify the acceleration of said vibratory impact, applying said tool end to the work surface of said solid with the cutting face of the tool forming an acute angle to the plane of said surface, flowing over the surfaces of the holder and tool and interposing in the locus of abrasion between the tool end and work surface, a film of a thin liquid suspension of a mobile, finely comminuted abrasive containing in solution a substance which dissociates, when said film is irradiated and heated, into pulsating gas bubbles, scavenging mobile and impacted abrasion and abraded particles from said locus while heating said film in said locus by absorption of heat generated in the end surface of said tool during the machine operation, and controlling the temperature of said tool end surface by controlling the rate of flow of said liquid over said tool holder and tool, and advancing the tool into the work as the abrasive progressively removes material from the contact area.

3. The method of removing material from a hard substantially non-yielding solid by vibratory impact abrasion, which comprises imparting high frequency oscillations to the end of a blunt faced tool held against rotation by a tapered, elongated tool holding member adapted to amplify the acceleration of said vibratory impact, applying said tool end to the work surface of said solid with the cutting face of the tool forming an obtuse angle to the plane of said surface, flowing over the surfaces of the holder and tool and interposing in the locus of abrasion between the tool end and work surface, a film of a thin liquid suspension of a mobile, finely comminuted abrasive containing in a solution a substance which dissociates, when said film is irradiated and heated, into pulsating gas bubbles, scavenging mobile and impacted abrasion and abraded particles from said locus while heating said film in said locus by absorption of heat generated in the end surface of said tool during the machine operation, and controlling the temperature of said tool end surface by controlling the rate of flow of said liquid over said tool holder and tool, and advancing the tool into the work as the abrasive progressively removes material from the contact area.

4. The method of removing material from a hard substantially non-yielding solid by vibratory impact abrasion, which comprises imparting high frequency oscillations to the end of a blunt faced tool held against rotation by a tapered, elongated tool holding member adapted to amplify the acceleration of said vibratory impact, applying said tool end to the work surface of said solid with the cutting face of the tool being parallel to said surface, flowing over the surfaces of the holder and

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tool and interposing in the locus of abrasion between the tool end and work surface, a film of a thin liquid suspension of a mobile, finely comminuted abrasive containing in solution a substance which dissociates, when said film is irradiated and heated, into pulsating gas bubbles, scavenging mobile and impacted abrasion and abraded particles from said locus while heating said film in said locus by absorption of heat generated in the end surface of said tool during the machine operation, and controlling the temperature of said tool end surface by controlling the rate of flow of said liquid over said tool holder and tool, and advancing the tool into the work as the abrasive progressively removes material from the contact area.

5. The method of removing material from a hard, substantially non-yielding, solid material, by vibratory impact abrasion, which comprises vibrating at high frequency, positioning and maintaining the end of a hollow, blunt-ended tool in proximity to the confronting surface of the work material which is to be removed, holding said tool against rotation by a tapered, channeled and elongated tool-holding member connected at its larger end to a source of high frequency, low amplitude axial vibrations and, at its smaller end to the non-operative end of said tool, thus to amplify the acceleration of impacts of said tool end upon the locus of abrasion, impelling into and forcing, through the interior of said hollow tool and into and away from said locus and tool end, a stream of a liquid suspension of a comminuted abrasive thus to scavenge abraded detritus from said locus and tool end, and, also, flowing another stream of said liquid suspension over the outer surfaces, of said tool-holding member and its attached tool, thus to control and remove heat of abrasion developed in said tool end and locus.

6. A vibrating device for high speed machining by high frequency impact abrasion, which comprises a source of high frequency mechanical vibrations, means for trans-

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mitting and for increasing the amplitude of said vibrations, comprising an elongated medium attached to said source at one end of said medium, a machining tool attached thereto at its other end, and means forceably to flow a stream of a liquid suspension of a comminuted abrasive to, through and away from the locus of abrasion between said tool end and an adjacent work-piece surface, thus to scavenge the abrasion detritus from said locus and tool end, in combination with means to flow another stream of cooling liquid in contact with said elongated medium, thus to reduce the heat of abrasion developed by said high-speed machining operation.

7. A high-speed ultrasonic machining method for removal of material by impact abrasion, from a hard substantially non-yielding solid, which comprises: vibrating an elongated tool holder connected at one end to a source of high frequency oscillations, connecting a tool to the other end of said tool holder, holding the tool end adjacent to the surface of the solid as it is machined, forceably flowing a stream of a liquid suspension of a comminuted abrasive to, through and away from the locus of abrasion between said tool end and said surface, thus to scavenge detritus of abrasion from said locus, and, also, flowing another stream of cooling liquid in heat exchanging contact with said tool holder, thus to reduce tool heat generated by said high-speed machining.

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