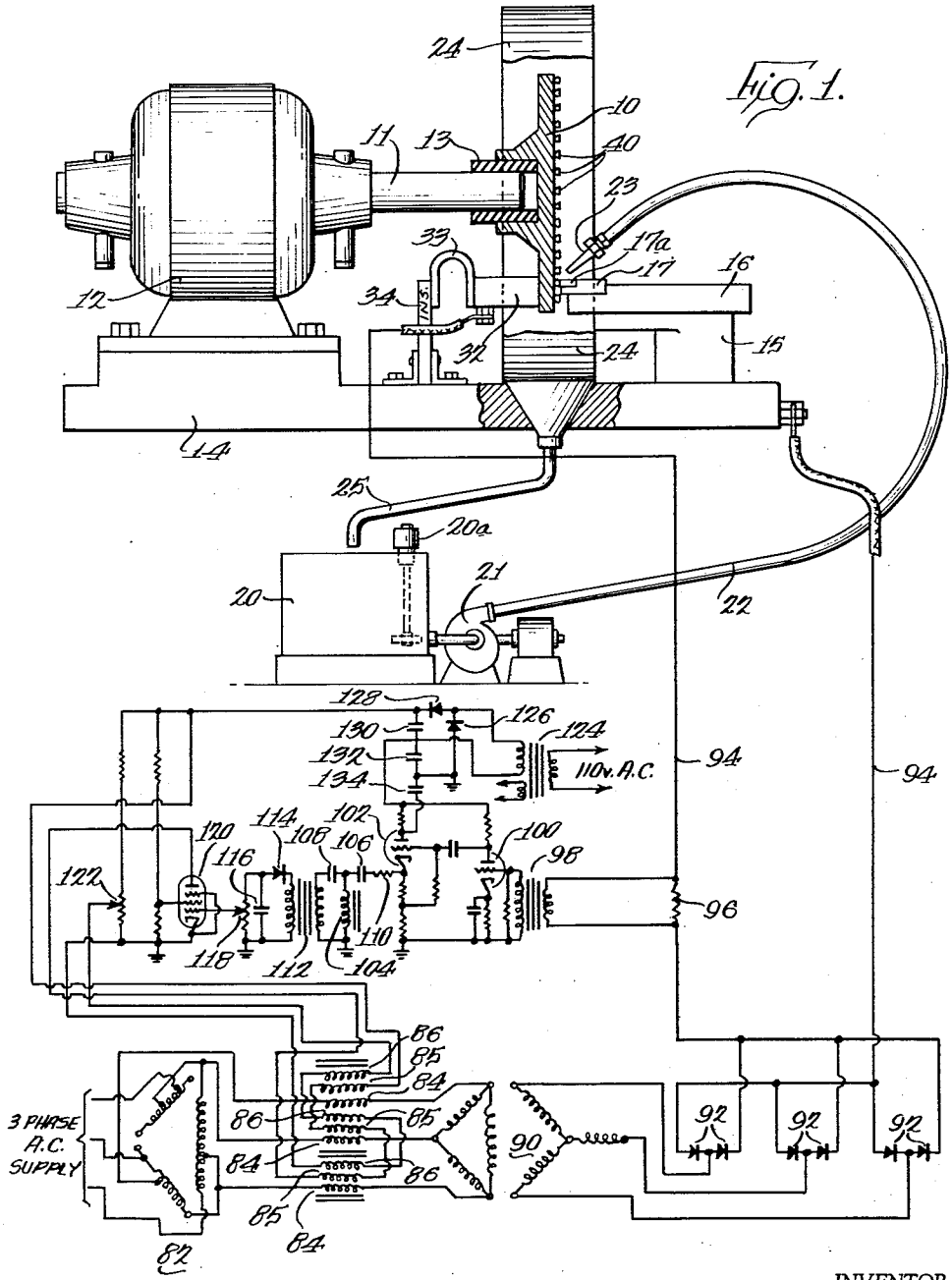
Oct. 17, 1961 G. F. KEELERIC 3,004,910

APPARATUS FOR ELECTROLYTIC CUTTING, SHAPING AND GRINDING

Original Filed Sept. 18, 1952 2 Sheets-Sheet 1

Fig. 1.



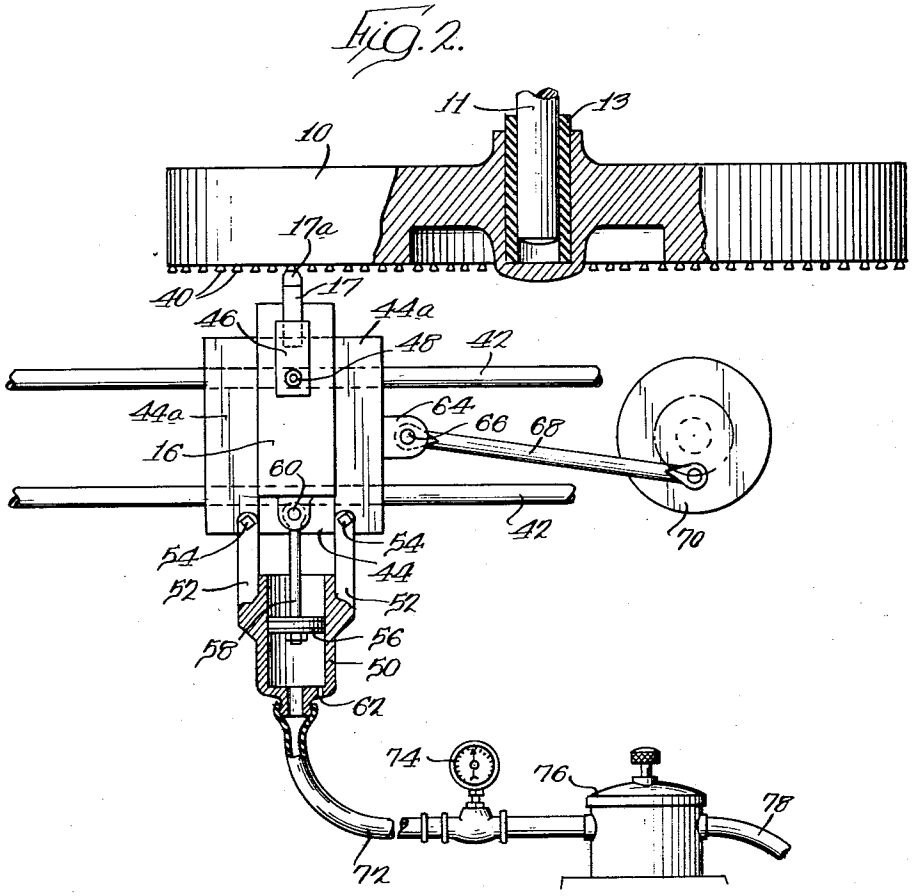
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Fig. 2.



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United States Patent Office 3,004,910 Patented Oct. 17, 1961

3,004,910

APPARATUS FOR ELECTROLYTIC CUTTING, SHAPING AND GRINDING

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Original application Sept. 18, 1952, Ser. No. 310,244. Divided and this application Dec. 3, 1957, Ser. No. 700,493

8 Claims. (Cl. 204—228)

My invention relates to apparatus for electrolytic cutting, shaping, and grinding of very hard materials.

This application is a division of my copending application Serial No. 310,244, filed September 18, 1952, now Pat. No. 2,826,540.

With the increased use of very hard materials in the form of alloys or in the form of sintered carbides like tungsten carbide in the making of tools and dies, turbine buckets, ordnance, etc., the problem of economically cutting, shaping, and grinding such materials is assuming great importance. The common method of performing such operations (which I will refer to generally hereinafter as "shaping") is by the use of diamond abrasive wheels, flat or contoured as may be required. Diamond abrasive wheels are costly and the diamond bort used in their manufacture threatens to become very scarce in the face of its increased usage.

Among the objects of my invention are the following:

To shape hard materials with accurate control of dimensions, fine finishing, freedom from heat stressing or cracks or checks, and with minimum loss through defects;

To carry out such shaping operations at high speed, safely, at low cost, and with a very low rate of wear on grinding wheels or cathodes used in the process;

To provide apparatus which may be readily adaptable to the large quantity of costly grinding equipment already in use;

To achieve the above results, it is my purpose to provide improvements in the electrolytic removal of material which may be augmented by the mechanical removal of insulating oxide films on the material to be shaped which interfere with electrolytic action. Where very high rates of removal are desired I augment electrolytic action by abrasive action.

Another purpose of my invention is to provide control of the degree of sparking or arcing which occurs between the work to be shaped and the shaping electrode.

While the general phenomenon of electrolysis is well known, the principle has not heretofore been found applicable to the shaping of hard materials. Part of the reason for this fact lies in the slow removal rate provided by ordinary electrolytic methods, and part of the reason lies in the difficulty of getting accurate and smooth surface control. These are serious problems, for a practical method of shaping requires removal rates several hundred times greater than those encountered in such processes as electroplating and control of the surface on which removal is carried forward within a fraction of .001 inch.

If the attempt were made to increase the removal rate simply by increasing the voltage applied to the electrolytic circuit, the result would be to cause intolerable heating, gassing, and decomposition of the electrolyte, as well as the wasteful dissipation of a very large amount of electric energy. This would also result in uneven and uncontrolled removal of material so that the remaining surface would be of little use for industrial purposes.

If the attempt is made to increase the removal rate by obtaining higher current through reducing the space between the electrode and the material to be shaped, then two additional problems arise.

The first is that if the gap is narrowed sufficiently to be useful, it is difficult to replenish the electrolyte within the gap at a sufficiently rapid rate. The second is that with a narrow gap there is likelihood of serious sparking or arcing between the electrode and the material through the electrotype. If heavy sparking occurs, it is likely to break over into arcing, and either the heavy sparking or arcing tends to produce a rough finish and damages the surface of the electrode. And in any case, the problem of maintaining adequately close spacing is difficult, particularly in off-hand grinding where the tool is simply supported on a tool rest and moved by hand in order to bring about the desired shaping.

By the means I have devised, I am able to obtain a rate of material removal which is several hundred times the rates encountered in ordinary electrolytic processing. This may be illustrated by the fact that I am able to obtain current densities ranging from 200 amperes per square inch (of the surface of the material) up to more than 1000 amperes per square inch, whereas in ordinary electroplating, current densities will be of the order of 1 or 2 amperes per square inch. The rate of material removal is proportional to the current which is passed. At the same time, I am able to obtain a very smooth, even surface. The way in which I accomplish these results will be understood from the more detailed description of my invention which follows.

In the drawings,

FIG. 1 is a schematic representation of an embodiment of the mechanical apparatus used in my process, and a circuit diagram of the electrical system; and

FIG. 2 is an elevation, partly in section, of an arrangement for indicating and controlling the pressure urging the work piece against the moving electrode.

Referring to FIG. 1, I will explain first the mechanical system used in my invention.

The mechanical apparatus may include a wide variety of commonly used grinding equipment. In the drawings, a moving electrode **10** is mounted to a grinding shaft or spindle **11** through an electrically insulating bushing **13**. The spindle or shaft may be driven by a motor **12**, or in any other conventional manner.

The motor is mounted to a bed **14** which also carries a tool rest pedestal **15**. This is arranged in such a way that a tool to be ground may be rested on its upper surface and then moved by hand to achieve the desired shape. The tool proper frequently consists of a shank **17** to which a hardened tip **17*a*** is attached, for example by brazing. The tip **17*a*** is frequently made of a hard metal carbide, such as tungsten carbide, while the shank **17** is made of steel. One important feature of my invention is that the tip **17*a*** and the shank **17** are shaped together in one operation, and are shaped evenly, so that it is not necessary to work separately on the tip and the shank. The tool consisting of the shank **17** and its attached tip **17*a*** may be mounted in any conventional way to a tool holder **16** which rests against the tool rest pedestal **15**. It should be noted that good electric contact must be maintained between all of these elements—the tool, the tool holder, and the tool rest pedestal. Inasmuch as the electrolyte which is used is conductive and is necessarily splattered somewhat over this area, it is unnecessary to maintain polished surfaces, but the use of paint, etc., is to be avoided.

The arrangement of FIG. 1 for holding a tool in operative relationship to a moving electrode is suitable for off-hand grinding, but where a considerable number of identical tools is to be shaped, it is desirable to provide mechanical means for holding the tool with respect to the electrode. This mechanism is shown in FIG. 2.

Referring to FIG. 2, the electrode **10** has abrasive insulating spacers **40** mounted on its working surface. Elec-

trode **10** is mounted to a rotating shaft **11** through an insulating bushing **13**. On the bed of a grinding machine, I provide ways **42** on which is slidably mounted a shoe **44** having guides **44***a*. Within guides **44***a* a tool holder **16** is slidably mounted.

Tool holder **16** is fitted with a clamp member **46** and a clamping bolt **48** by which the work piece **17** with a hard tip **17***a* is clamped in position.

An air cylinder **50** is fastened by extending lugs **52** and bolts **54** to shoe **44**.

Within the cylinder **50** is mounted piston **56** which is connected through piston rod **58** to tool holder **16** by pin **60**. At the head of the cylinder is a small airbleed hole **62**.

One of the guides **44***a* is provided with a boss **64** which carries a stud **66** to make connection to pitman **68** which is driven by a crank **70** in the conventional manner. The crank **70** may be turned by its own prime mover or may be linked through speed reducing mechanism to motor **12**.

The purpose of the crank mechanism and associated linkage is to give an oscillating motion to the work piece back and forth along the working surface of electrode **10**. In some cases this is desirable in order that any wear of the electrode **10** or insulating spacers **40** may be uniform across the working surface.

A flexible air supply tube **72** is connected to the head of cylinder **50**. The air supply tube **72** is also fitted with a pressure gauge **74** and an adjustable pressure regulator **76** supplied from air supply line **78**.

By setting the pressure regulator at the desired level, the amount of pressure urging the work piece **17** and **17***a* toward electrode **10** against insulating spacers **40** may be carefully adjusted and maintained. Ordinarily, for small work pieces, such as cutting tools, I prefer that the air cylinder be small, having a diameter of approximately one inch. The pressure regulator **76** may then be adjusted so as to supply very slight air pressure to the cylinder, thus putting very light force against the piston **56** so that the work piece makes firm but very light contact with insulating spacers **40**.

It should be understood that the work piece may be movable and the electrode may be fixed. Or, as in rotary grinding where the work piece is circular in section, the work piece may be rotated while the electrode also is rotated. Or the work may be moved back and forth along a stationary electrode as in a honing operation. What is important is that there be relative motion between the work piece and the electrode, and wherever I refer to a moving electrode I mean to include any means for achieving this relative motion.

An important feature of my invention lies in the use of insulating spacers by which very close spacing between the work piece **17** and **17***a* and the rotating or moving electrode **10** may be maintained. The use of insulating spacers in electric removal processes generally (e.g., the electrolytic method, the spark method, and the arc method) is described in greater detail in my application for United States Letters Patent entitled "Improvement in Electric Cutting, Shaping, and Grinding," Serial No. 310,243, and now abandoned.

I prefer to hold a spacing distance under .001 inch and I have obtained good results with a spacing of .0007 inch, but even smaller spacing is permissible down to the point where actual contact between the work piece and the electrode is likely to occur through any irregularities in the system. The spacing is accomplished by interposing insulating spacers **40** between the electrode and the work piece.

While many means of doing this are available, I prefer to mount the spacers **40** more or less permanently on the surface of the electrode **10**. This may be done in several ways. For example, if hard abrasive particles are to be used as insulating spacers, they may be mounted to the electrode in the way described in my United States Letters Patent 2,368,472 for "Method of Making Abrasive Articles," issued January 30, 1945. If insulating spacer particles are used which are less hard, then they may be bonded to the electrode **10** and any irregularities in their protrusion may be eliminated by grinding with a fine abrasive wheel so that all of the particles protrude the desired uniform distance outwardly from the metal electrode **10**.

With whatever arrangement is used, care must be taken that a reasonable space is left between the particles, and this space on the electrode must be electrically conductive. This means either that the bonding material used must itself be conductive, or that the presence of bonding material between the particles either be avoided at the time of application or removed by dissolving or etching, or in some other way, after the particles have been applied. I prefer not to occlude more than three-fourths of the working surface of the metal electrode **10**, thus assuring adequate metal surface to serve as an electrode in the electrolytic process. If the entire surface of the electrode is covered by abrasive, it must be sufficiently pervious to provide channels for electrolyte adequate to carry the desired current.

The insulating spacers permit very close spacing, which is important not only in order to get requisite current densities, but also in controlling the dimensions and surface finish of the work. For example, if the space between the work piece and the moving electrode is opened up to as much as .005 inch, the surface generated on the work piece will be rough and uneven in contour, sometimes concave, sometimes convex. While this may not be troublesome for some kinds of operations, it is highly undesirable in making the final finish on dies and tools where the surfaces must be smooth and must follow the contour of the electrode. Here it should be understood that while I have shown an electrode having a flat surface, there will be many applications in which the electrode surface will be contoured to produce the desired shape on the work piece.

In the grinding of certain metals and metal carbides, such as tungsten carbide, the abrasive insulating spacers **40**, however applied, perform an additional important function which is the removal of an insulating oxide film which forms rapidly under electrolytic action. Since the film is soft, it may be removed easily and even the lightest direct contact between the work piece and the insulating spacers will bring about this result. But it must be removed if the electrolytic process is to go forward effectively.

If the insulating spacers are made of hard material, for example diamond particles, then it is possible to accelerate the rate of material removal by pressing the work piece against the diamond particles with pressures used for ordinary diamond grinding. Under these conditions the electrolytic removal of material is augmented by abrasive action, with the result that material is removed at a rate approximately 300 percent of the removal rate achieved by diamond grinding alone. Ordinarily, this augmentation will not be attempted with specialized contouring electrodes, for normal grinding pressures produce wear on the diamond particle surface (and removal of diamond particles through chipping, breakage, etc.) so that with time the desired contoured shape is lost and the electrode must be replaced. If grinding pressures are avoided, and only the very light pressure needed for film removal is used, then the electrode and the insulating spacers will have very long life.

Turning now to the electrolyte system, I use the system usually provided with grinding machines for supplying coolant to the work area. Thus, as shown in FIG. 1, I provide a sump or supply tank **20**, which may be provided with mechanical agitators **20***a*, a pump **21**, a tube or conduit **22**, and a nozzle **23** adjacent the work area. Around the moving electrode I place a shroud **24** which collects the electrolyte and returns it to the sump or

supply tank **20** through conduit **25**. The conduits, of course, should be made of material not readily corroded by the kind of electrolyte used.

As electrolyte, I have used both acid and alkali solutions, but these present some problems because the operator, particularly when doing off-hand grinding, will necessarily be splattered by the electrolyte. On this account salt solutions which are neutral or nearly so, are of some advantage. I have used with considerable success a solution made in the proportion of three ounces sodium nitrate and one and one-half ounces sodium acetate to one gallon of water. While a large variety of conductive electrolyte solutions can be used, I have found that the addition of a salt of the formic acid series, such as sodium acetate, sodium citrate, sodium tartrate, etc., is very helpful in preventing loading up of the electrode in the spaces between the insulating spacers when these are mounted permanently on the electrode.

The flow of electrolyte to the work area itself is aided by the relative motion between the electrode and the material, and by the use of insulating spacers which provide a labyrinth of openings in which electrolyte is entrained and carried into and out of the work area, at the same time being violently agitated. The flow of electrolyte for shaping of ordinary industrial cutting tools should be at the rate of about one liter per minute. In any case, the general flow rate should be adjusted upward until no further increase in current is occasioned by a greater rate of flow. The relative motion between the electrode and the material is not critical when insulating spacers are used, for the insulating spacers are so helpful in carrying electrolyte through the work area that it is not necessary to use extremely high motion. For example, I have varied the speed of rotation of a six inch diameter wheel electrode from 900 r.p.m. to 2400 r.p.m., which speeds are obtainable with the commonly used grinding equipment previously mentioned.

The electrical system represents another important aspect of my invention, for it makes it possible to supply current for the electrolytic process at the maximum level which may be used without causing excessive sparking or arcing through the electrolyte. It is possible, of course, to remove material by sparking or arcing, and some systems have been proposed which depend either entirely or in large part upon sparks or arcs for material removal. I prefer, however, to rely in large measure upon electrolytic action, but if the rate of material removal is to be satisfactory, it is desirable to use the maximum current which can be carried without breaking over into a degree of sparking or arcing which will be deleterious. The current may, of course, be controlled by a rheostat which is adjusted manually for with the uniform spacing brought about by the use of insulating spacers, the resistance of the electrolytic circuit will not change very rapidly when a work piece of given size is being shaped. However, one work piece will be different in area from others. Moreover, the resistance path will change as shaping proceeds, and may change very rapidly in the case of off-hand grinding where the work piece is placed in different positions with respect to the electrode. Under these circumstances, manual adjustment for maximum current becomes difficult, and accordingly the tendency is to reduce the current below the maximum that might otherwise be used, thus slowing down the rate of material removal.

The electrical system which I use, when combined with the uniform spacing achieved by use of insulating spacers, gives excellent results, although it may also be of value without the insulating spacers.

The general principle of operation is the use of any alternating current component which arises in the electrolytic circuit as the result of sparking or arcing to provide a signal for control apparatus which will reduce the supply voltage under these conditions.

While I have used a rectifier system, the same principle of operation may be applied to a motor generator system or to other supply means. If a motor generator system is used, I control the field of the motor generator, reducing the field strength in order to cut down the current supply when serious sparking occurs.

Referring to FIG. 1, I provide a tapped line transformer **82** to accommodate a varietly of available line voltages without the need for a variety of internal circuit components. As shown here, a three-phase system is employed, but it will readily be seen that the same system may be applied to a single phase or a two-phase system by adaptations which will be readily understood.

In the supply lines leading from line transformer **82**, I provide saturable iron core reactance coils **84**. The main windings have low resistance, and when their iron cores are saturated, pass the line voltage with little loss. The cores are saturated to greater or less degree by bias windings **86**, the bias level being adjustable by potentiometer **122**. The current is then passed through voltage reducing transformer **90** and through the rectifier system comprising rectifier elements **92** to the electrolytic circuit proper which consists of supply lines **94**, brush **32**, movable electrode **10**, the electrolyte, the work piece **17** and **17***a*, and the tool holder **16**. The brush **32** is held by spring **33** against the movable electrode **10**. The spring **33** may be mounted on any suitable insulating holder **34**. If desired, a plurality of brushes may be used.

In one of the supply lines **94** a shunt resistor **96** is provided across which the control signal is generated.

This control signal is fed to transformer **98** and then amplified by triode **100**.

The output of triode **100** is connected through a cathode follower tube **102** to a high pass filter comprising inductance **104**, condensers **106** and **108**, and resistor **110**. The components of this filter are designed to provide sharp attenuation below 1500 cycles per second and minimum attenuation above this frequency. This is done in order that alternating current supply ripple in the electrolytic circuit will not have effect on the control apparatus.

The filtered signal is then passed through transformer **112**, germanium rectifier **114**, and is partially integrated by condenser **116** and fed from potentiometer **118** to the control grid of pentode **120**. Potentiometer **118** adjusts the gain or sensitivity of the control system. Ordinarily, it is set so as to cause supply voltage attenuation when the slightest incipient sparking is observed between electrode **10** and the work piece **17** and **17***a*. At this level the sparks appear as fine hair-like strands and contribute little to current conduction or to the removal of material. However, adjustment may be made so as to produce somewhat heavier sparking with some increase in rate of material removal which, however, tends to produce a rough finish on the work piece and causes erosion of the electrode. It may be desired, nevertheless, to operate at this level for rough shaping and then to adjust to a lower level for finishing.

When adjusted at the minimum sparking level, the finish achieved may be as fine, when measured by a Brush analyzer, as five micro inches R.M.S.

The output of pentode **120** is connected to control windings **85** which augment the flux produced by bias windings **86**. Normally the output of pentode **120** is sufficient to energize control windings **85** to such an extent that a substantial degree of saturation of the iron cores of reactance coils **84** exists. In response to signal, the output of pentode **120** is reduced, thereby reducing the degree of saturation of the iron cores of reactance coils **84**. Under these conditions the effective inductance increases and the current passed is reduced. The level to which the current falls may be set by the adjustment of potentiometer **122** which controls current supply to bias windings **86**. The lower the current supplied to bias windings **86**, the lower will be the minimum saturation of iron cores of reactance coils **84**, and accordingly, the lower the current

will be dropped in response to signal generated by oscillations caused by sparking or arcing.

The electric supply system for the control elements just described is a conventional half-wave rectifier system with a voltage doubler circuit for B supply for pentode **120**. It consists of transformer **124**, rectifiers **126** and **128**, and condensers **130**, **132**, and **134**.

With space between the electrode and the work piece of the order of .001 inch, a current density of several hundred amperes per square inch is achieved at voltages between two and thirty volts, which is well within the range of usability without requiring special insulation to protect personnel from seriou electrical shock.

When seen in normal operation, a slight amount of sparking can usually be observed at the trailing edge of the work piece. The color of the spark will be a pale blue, or may be of reddish cast, or some other cast, depending perhaps upon the electrolyte and the material being worked. This is to be distinguished from arcing, in which a brilliant white-blue light is clearly visible. Frequently the arc is accompanied with a considerable amount of popping and hissing noise, while such sparking can not be heard above the noise of the machinery and surrounding equipment in a machine shop environment. While arcing under these conditions tends to be somewhat irregular and intermittent, nevertheless the arc is characterized by steadier oscillation as seen in an oscilloscope than that produced by sparking. I find that I get best results by adjusting the current supply with relation to the size of insulating spacers used and the size of the work piece, so that some amount of sparking may be seen, but no arcing. For fine finish, but with somewhat slower removal rate, I set the adjustments so that sparking is just barely visible at infrequent intervals. Or the current supply may be limited below the level at which any sparking occurs to give a very fine finish.

The electrolytic action is concentrated almost entirely on the surface of the work piece facing the electrode, but a very slight amount of material removal also may occur on the surfaces adjoining the surface being shaped for a distance of as much as 1/16 inch back from the surface presented to the electrode. Under some circumstances this is undesirable, and where this is the case I insulate the work piece, for example by lacquer, so that it it electrically insulated on all of the surfaces except that toward the electrode. In this way I can obtain very sharp edges.

In operation, I have been able to remove material from hard substances, such as tungsten carbide, at a rate comparable with the removal rate obtained with the best diamond abrasive practice. The life of the electrodes is very great as neither the electrode nor the insulating spacers need be worn away by substantial grinding pressures. I have also provided a means of using substances other than diamonds as insulating spacers, thus making it possible to produce lower cost grinding wheels. The surface finish on work pieces ground by my apparatus may be made even better than that ordinarily obtained in commercial diamond abrasive practice.

The entire apparatus is safe and easy for operators of normal skill to use. The whole system and apparatus may be adapted to existing grinding equipment by providing an electrode of the kind here described and attaching it through an insulating member to an existing grinding spindle, by substituting an electrolyte for the ordinary coolant, and by providing the necessary electrical apparatus in one or more convenient packages.

While a preferred embodiment of the apparatus for cutting, shaping, and grinding constituting this invention has been shown and described, it will be apparent that numerous modifications and variations thereof may be made without departing from underlying principles of the invention. It is therefore desired, by the following claims, to include within the scope of the invention all such variations and modifications by which substantially the results of this invention may be obtained through the use of substantially the same or equivalent means.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. Apparatus for supplying and controlling electric current for electrolytic grinding comprising in combination pick-up means responsive to a signal of high-frequency components arising in the electrolytic circuit of electrolytic-grinding equipment, filter means for rejecting low-frequency components in said signal, means for amplifying said signal, a power source of alternating current, means for rectifying said alternating current to provide a direct-current power source for the electrolytic circuit of the electrolytic-grinding equipment, control means interposed between said power source of alternating current and said rectifier, and circuit connections from said amplifier to said control means for activating said control means to reduce the flow of current in response to said signal.

2. Apparatus for supplying direct current for electrolytic-grinding equipment comprising in combination a power source of alternating current, a rectifier for converting said alternating current to direct current, current-control means interposed between said power source and said rectifier, means for activating said current-control means including pick-up means responsive to sparking or arcing in the electrolytic circuit of the electrolytic-grinding equipment, means for amplifying a signal received by said pick-up means, filter means for rejecting ripple frequency components in said signal, and means for feeding the amplified, filtered signal to said current-control means whereby the flow of current is reduced in response to the signal.

3. A control system for a rectifier supply of direct current to electrolytic-grinding equipment having an electrolytic circuit, said control system comprising means for receiving a high-frequency signal resulting from sparking or arcing in the electrolytic circuit, means for amplifying and filtering said signal, means for rectifying said signal, and means responsive to said amplified, filtered and rectified signal to reduce direct-current supply voltage in response thereto.

4. In apparatus of the type in which a workpiece of hard, electrically conductive material is moved into engagement with a movable electrode having a conductive work face and abrasive elements projecting from the work face a distance not substantially greater than .005", in which an electrolyte is passed at a rapid flow rate between the workpiece and electrode, and in which an alternating current supply is rectified to apply a direct current potential across the workpiece and electrode for removal of material from the workpiece by abrasion and electrolysis, the combination with the supply of an amplifier in the supply controlling the intensity of the potential applied across the workpiece and electrode, circuit means coupled to the supply selectively responsive to high frequency signals produced by arcing and sparking between the electrode and workpiece to produce a variable intensity control signal as a function of the intensity of the high frequency signals, and means applying the control signal to the amplifier to control the applied potential as an inverse function of the high frequency signal intensity.

5. In apparatus of the type in which a workpiece of hard, electrically conductive material is moved into engagement with a movable electrode having a conductive work face and abrasive elements projecting from the workface a distance not substantially greater than .005", in which an electrolyte is passed at a rapid flow rate between the workpiece and electrode, and in which an alternating current supply is rectified to apply a direct current potential across the workpiece and electrode for removal of material from the workpiece by abrasion and electrolysis, the combination with the supply of a valve in the supply controlling the intensity of the potential applied across the workpiece and electrode, circuit means

coupled to the supply selectively responsive to high frequency signals produced by arcing and sparking between the electrode and workpiece to produce a variable intensity control signal as a function of the intensity of the high frequency signals, and means applying the control signal to the amplifier to control the applied potential as an inverse function of the high frequency signal intensity.

6. In apparatus of the type in which a workpiece of hard, electrically conductive material is moved into engagement with a movable electrode having a conductive work face and abrasive elements projecting from the work face a distance not substantially greater than .005", in which an electrolyte is passed at a rapid flow rate between the workpiece and electrode, and in which an alternating current supply is rectified to apply a direct current potential across the workpiece and electrode for removal of material from the workpiece by abrasion and electrolysis, the combination with the supply of an amplifier in the supply controlling the intensity of the potential applied across the workpiece and electrode, circuit means coupled to the supply including high pass filter, amplifying, and integrating sections responsive to the high frequency signals produced by arcing and sparking between the electrode and workpiece to produce a unidirectional control signal the strength of which varies as a function of the intensity of the high frequency signals, and means applying the control signal to the amplifier to control the applied potential as an inverse function of the high frequency signal strength.

7. In equipment of the type in which a workpiece of hard, electrically conductive material is moved closely adjacent a movable electrode, in which an electrolyte is passed between the workpiece and electrode, and in which a supply circuit applies a direct current potential across the workpiece and electrode for removal of material from the workpiece by electrolysis, the combination with the supply circuit of signal responsive apparatus controlling the intensity of the applied potential, circuit means responsive to high frequency signals produced by arcing and sparking between the electrode and workpiece to produce a variable intensity control signal as a function of the intensity of the high frequency signals, and means applying the control signal to the apparatus in a manner inhibiting arcing and sparking.

8. In equipment of the type in which a workpiece of hard, electrically conductive material is moved into engagement with a movable electrode having a conductive work face and insulating elements projecting from the work face a short distance, in which an electrolyte is passed between the workpiece and electrode, and in which a supply circuit applies a direct current potential across the workpiece and electrode for removal of material from the workpiece by electrolysis, the combination with the supply circuit of signal responsive apparatus controlling the intensity of the applied potential, circuit means responsive to high frequency signals produced by arcing and sparking between the electrode and workpiece to produce a variable intensity control signal as a function of the intensity of the high frequency signals, and means applying the control signal to the apparatus in a manner inhibiting arcing and sparking.

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