This invention relates to electrolytic grinding apparatus and to grinding wheels therefor.

One of the objects of this invention is to provide a practical and reliable system and apparatus of the above-mentioned character that will have a high capacity and good efficiency in the removal of stock, as in the machining of hard carbides, by electrolytic grinding action.

Another object is to provide an electrolytic grinding system and apparatus that afford good control against detrimental arcing at the locus of stock removal. Another object is to provide a practical electrolytic grinding method and means and dependable controls thereof, effective throughout the varying requirements and conditions that may be encountered, including control of current distribution and densities whereby to maintain high efficiency of stock removal and long and safe operating life of the grinding wheel. Another object is to provide a practical and dependable grinding wheel, particularly a grinding wheel utilizing diamond abrasive grains such as "bori," having features of construction materially contributing to high efficiency of electrolytic grinding action and to materially increased capacity for stock-removal, and providing, in unique coaction with elements of the apparatus or system and controls, for avoidance of or reliable control against damaging localized current densities or concentrations and for guarding against destructive arcing under the varying conditions of practical use.

Another object is in general to provide improved electrolytic grinding systems and apparatus, including controls and grinding wheels thereof. Other objects will be in part obvious or in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts and in the several steps and relation and order of each of the same to one or more of the others thereof, all as will be illustratively described herein, and the scope of the application of which will be indicated in the following claims.

In the accompanying drawings, in which are shown illustratively the mechanical and electrical features of our invention, and in which similar reference characters refer to similar parts throughout the several views of the drawings,

Figure 1 is a front elevation of the grinding machine; Figure 2 is a side elevation of the grinding machine; Figure 3 is a fragmentary horizontal sectional view on an enlarged scale, showing certain mechanical and electrical features of one form of grinding wheel in relation to a workholder and certain electrical features related to the latter; Figure 4 is a fragmentary horizontal sectional view on an enlarged scale, showing certain mechanical and electrical features of another form of grinding wheel in relation to a workholder and certain electrical features related to the latter; Figure 5 is a fragmentary sectional view of the grinding wheel of Figure 3, showing a modified form of mechanical and electrical assembly; Figure 6 is a transverse sectional view, on a smaller scale, of the grinding wheel as seen along the line 6—6 of Figures 3 and 5; Figure 7 is a side elevation of the grinding wheel of Figure 4 as seen along the line 7—7 of Figure 4; Figure 8 is a fragmentary or detached front elevation of a wheel guard cover and associated electrolyte-distributing parts as related to the grinding wheel of Figure 3 and as seen from the front in Figure 1 and from the left in Figure 3; Figure 9 is a front elevation of the wheel guard cover and associated electrolyte-distributing parts as related to the form of grinding wheel shown in Figure 4 and as seen from the left in Figure 4; Figure 10 is a simplified electrical diagram of circuit connections and controls as related to the multiple conductive ring grinding wheel, such as the grinding wheel of Figure 3 or of Figure 4; Figure 11 is a simplified electrical diagram of a circuit and control related to a single work-wheel interface; and Figure 12 is a diagram of multiple supply circuits and electrical controls interrelated with the multiple interfaces provided between the work-piece and the multiple conductive abrasive elements of the grinding wheel, such as the grinding wheel of Figure 3 or that of Figure 4.

As conducing to a clearer understanding of certain features of my invention, it may at this point be noted that there are many advantages to be gained in stock-removal by electrolytic grinding, especially for machining hard cemented carbides (such as cobalt-bonded tungsten carbide and/or tantalum and/or titanium carbide), wherein stock is removed from the work-piece, such as a cemented carbide tool, by electrolytic decomposition of the work face, materially supplementing the cutting action of the wheel, but that various difficulties can be encountered or the system or apparatus has inherent limitations or there arise phenomena detrimental to or destructive of the grinding wheel. It is desirable to use diamond grinding wheels; these are costly and it is, of course, undesirable to risk destructive action on them or otherwise shorten their useful life. Among the dominant aims of this are: to overcome or materially alleviate such difficulties; to avoid or reduce such limitations; to improve or control the electrolytic action or actions so as to lessen or avoid such risks to the grinding wheel; to achieve better efficiency and higher capacity; to provide a grinding wheel adapted for dependable and effective coaction toward achieving any one or more of these aims or objects.

In electrolytic grinding, a metal bonded abrasive wheel is employed so that the grinding face is effectively conductive, the conductive work-piece is insulatingly supported, and, with a suitable supply of a suitable electrolyte, which also serves as a coolant, at the work-wheel interface, a direct current source supplies a current flow across the interface, the work being the anode. Since the rate of electrolytic decomposition, by which stock-removal from the work is effected, is proportional to current flow, it is desirable to use high current density; but in practice the extent to which current density can be increased in the endeavor to improve stock-removal rate or capacity is severely limited.

For example, visible arcing or sparking sets in in the contact zone, that is, at the work-wheel interface, and that results in high or excessive rates of wheel wear, greatly shortening wheel life. Moreover, even if, within these limitations or handicaps, means are provided for limiting maximum value of, or regulating at substantial constancy, the amperage in the circuit that includes the interface, so that current of allowable and limited or regulated over-all
value is uniformly distributed over the interface, any operating condition that thereafter arises, such as reduction in contact area between wheel and work, to cause the current density to exceed the critical value, brings about destructive arcing. Damage to the grinding wheel results. Illustratively, such a reduction in area at work-wheel interface can take place upon relative traversing movement between the wheel face and the work in excess of that required for complete mutual over-lap of one relative to the other. Moreover, the contact area can be reduced further upon such relative movement of the work-piece completely off the edge of wheel face (or vice versa) or otherwise to effect complete separation between the two. As stated above, such changed conditions bring about destructive arcing in spite of such current-limiting or current-regulating means as mentioned above.

There can be other difficulties. Detrimental arcing may also occur even when the apparent contact area is a large fraction of the maximum possible contact area, if the total current is above what may be termed the critical arcing current for given conditions, again bearing in mind the desirability of increasing the rate of electrolytic decom- position to decrease the rate of stock removal. Parenthetically, small discontinuities in the surface or face tend to cause current concentrations in areas much smaller than the apparent contact area, such concentrations producing local heating and leading to the formation of destructive areas, such as 'hot spots', in the total current, limited in maximum value or regulated for substantial constancy, in effect, tunneled through the small arcing area. Another aim of this invention is to overcome such difficulties as these; more particularly, it is another object of this invention to provide an electrolytic grinding system and apparatus, including wheels thereof, and controls, for preventing the total electrolytic current from concentrating in a small area such as described above and for making it possible to use higher average current values without damaging the wheel.

In carrying out our invention, any suitable mechanism or arrangement may be employed for mounting and driving the grinding wheel of our invention and for mounting and supporting, or even for resting thereon for manual movement (as in so-called "off-hand" grinding), a work-piece, such as a cemented carbide tool or other piece of work, or object to be ground or machined, whereby to obtain relative movements between the grinding wheel and the supported work. For purposes of illustration, and not by way of limitation, we have shown in the drawings a machine having many various relative adjustments and/or movements between grinding wheel spindle and work, and various controls, manual or automatic, therefor. Referring first to Figures 1 and 2, we may utilize a machine having a work table 11 supported on ways 12 and 13 provided on a cross slide 14 mounted on the machine base 15. The ways for the cross slide 14 are not shown but may be conventional and reference may be had to U. S. Patent No. 2,101,787 for many of the constructional features of this illustrative mechanism. A screw shaft 16 passes through a nut 17 which is affixed to the base 15, while the rear end of the screw shaft 16 is journaled in a two-way thrust bearing 18 which is attached to a rearwardly projecting portion 19 of the cross slide 14; rotation of the screw shaft 16 as by means of a hand wheel 20 therefore moves the cross slide 14 forwardly or rearwardly of the machine.

The table 11 can be reciprocated upon the cross slide 14 in any suitable way, manually or otherwise; for example, the manually operated mechanism described in the aforesaid Patent No. 2,101,787 and in Figure 1 I show a piston rod 21 connected to a bracket 22 which is attached to a laterally extending portion 23 of the table 11. The hydraulic mechanism of the aforesaid Patent 2,101,787 need not here be illustrated or described; it is controlled by the table dogs 24 and 25 which alternately engage an interposed reversing lever 26 mounted on the shaft 27 projecting from the front of the cross slide 14. We do illustrate herein, however, manually operated apparatus for moving or reciprocating the table 11 comprising a rack 30 secured to the underside of the table 11 and engaged by a gear 31 which is secured to a larger gear 32 which meshes with a smaller gear 33 secured to a shaft 34 on the front end of which is a hand wheel 35.

The base 15 supports a vertically extending split column 41 (Figure 2) which is provided with a cylindrical bore, not shown, receiving a cylindrical post 43. Adjustedly secured in any desired angular position to the top of the post 43 by means of bolts 44 extending through angular slots, not shown, is a wheel head 45 journaling a grinding wheel spindle 46 which projects both forwardly and rearwardly of the wheel head 45. Affixed to the rear of the spindle 46 is a pulley 47 driven by a belt 48 from a pulley 49 on the armature shaft 50 of a motor 51 which is secured by means of bolts 52 to a table 53 having slots 54 receiving bolts 55 screwed into the wheel head 45; thus the motor 51 is secured in vertically adjustable position to the wheel head 46. The cylindrical post can be raised and lowered by mechanism described in the aforesaid Patent No. 2,101,787 which is operated by a hand wheel 56 (Figure 1, right hand side), and when the desired adjustment is obtained the post 43 can be securely locked by means of a screw 57 extending across the gap in the split column 41.

The front end of the grinding wheel spindle 46 is appropriately constructed to have or is provided with means for mounting a grinding wheel thereon, as by providing it with a tapered portion 63 that is received into the tapered bore of a flanged sleeve 61, with a nut 60, threaded onto the spindle 46, holding the flanged sleeve 61 securely in place; flanged sleeve 61 is suitably constructed to carry and have secured thereto a grinding wheel which, according to our invention, is constructed to provide a plurality of relatively closely spaced abrasive rings that are conductive, thus subdividing the active face that is to take part in electrolytic and grinding action on the work-piece, all for purposes and functions with other parts as later described.

As will become clear from our disclosure of our invention, the grinding wheel may be constructed in various forms or types according to the desired or desirable configuration of operative face, and for purposes of illustration and not by way of limitation, we have shown in Figure 3 a multiple conductive grinding ring wheel construction in which the face that is subdivided is a side face of the grinding wheel, that face falling in a plane at right angles to the axis of the work, and in Figure 4 we have shown a multiple conductive grinding wheel construction in which the face that is subdivided is the cylindrical peripheral surface of the wheel; in each case the surface that is subdivided is a surface of revolution generated by a generatrix line that is rotated about the axis of the wheel and by changing the angle of that generatrix of the axis to an angle other than the 90° angle in Figure 3, or by shifting it out of parallel relation in Figure 4, the operative face becomes frusto-conical. In any such case subdivision electrically and abrasively may be effected, as is illustratively described in connection with Figures 3 and 4.

The grinding wheel shown in Figure 3 and designated as a whole by the reference character 64 comprises a suitable number, illustratively three, of conductive abrasive rings R1, R2, R3, each presenting a flat annular abrasive face of the same relative dimension in each case concentrically arranged and of such progressively differing diameters that they encircle one another with relatively small annular spaces between successive rings; they are radially held in concentric relation and with their abrasive faces aligned by any suitable insulating means and preferably in such manner that only their aligned annular abrasive faces are exposed, and for this purpose we prefer to envelop or encase them, excepting for their ann.
nular abrasive faces, in a suitable curable plastic or the like, such as Bakelite resin, which can be molded about them and cured, thereby also forming a strong rigid backing or support for the multiple abrasive rings. In Figure 3 the rings are shown as mounted in a strong rigid Bakelite backing B, which, at its center, has molded into it a center hole so that it can be received onto the flanged sleeve 61 and clamped thereon, as by a spanner nut 65 threaded onto the sleeve 61 as shown, which backing B, at its rim-like outer portion, is of greater thickness than the three rings R1, R2, R3 embedded and securely anchored therein with the curable plastic enveloping all of the surfaces thereof excepting the front annular alined abrasive faces, thus also dependably insulating the conductive rings from one another and interposing between adjacent rings solid non-conductive barriers against access thereto of electrolyte, later mentioned.

Any suitable means may be employed to secure the conductive abrasive rings against movement in directions outwardly (to the left in Figure 3) of the annular recesses in the insulating backing B in which they are seated, and an illustrative and convenient means comprises a core 64, as shown in Figure 3, at the back of each ring, as shown in Figure 3, whereby, when the resinous or other plastic is molded and cured about the rings, the latter and the hard, tough cured material of the backing B are securely and rigidly interlocked. These dovetailed projections may be formed integrally with their respective conductive abrasive rings in any suitable manner, as by machining or turning them or molding them integrally and with the same time that the conductive abrasive rings are molded or formed, illustratively in a manner about to be described.

For the grinding of hard cemented carbides, such as those illustratively mentioned above, suitably bonded diamond grains, as of bort, are usually employed because silicon carbide abrasive grains grind the cemented carbides only slightly, and aluminum oxide grains grind them hardly at all, and in the illustrative embodiments of our invention we prefer to use diamond abrasive grains, though, as will later appear more clearly, abrasive grains of other materials, including silicon carbide and aluminum oxide, may be employed; in order that the abrasive rings be conductive, the abrasive grains are metal-bonded and, particularly where diamond grains are employed, it is found that D is preferably formed, at the respective abrasive faces of the rings, in only a relatively small depth in relation to the over-all thickness of the ring itself and, accordingly, as is clear from Figure 3, each ring comprises an outer abrasive portion 66 of small thickness or depth and an inner and usually thicker and heavier portion 67 that need not contain diamond grains and is of metal throughout, serving as a strong rigid support or backing for the thinner diamond-bearing portion 66. Where dovetail elements D are employed, they form part of the metal backing portion 66, as indicated in Figure 3, and are integrally formed or molded therewith.

In making the conductive abrasive rings R1, R2, R3, any suitable or known methods or techniques may be employed and need not be described in detail here. For that matter, the patented art describes how, with the use of powdered metal, to form a unitized conductive abrasive ring or annulus having an outer diamond-bearing abrasive portion and an inner support portion wholly of metal. We might note, however, that a usual method of manufacture comprises placing in a suitably shaped mold, to the desired depth, powdered metal that is to correspond to the non-abrasive backing portion and, after leveling or smoothing off, placing thereover a suitable depth of a mixture of diamond particles and powdered metal, to correspond with the abrasive portion and, after leveling or smoothing off, subjecting the contents of the mold to substantial pressure and then sintering the pressed piece, usually in a protective atmosphere such as hydro-
gen. By appropriately shaping the mold parts the backing portion 67 may be conformed to have a projecting dovetail or ring, such as the dovetails D of Figure 3, or, as above noted, and when the abrasive portion 67 contains no abrasive grains, the dovetail D need not be formed by molding but can be turned or machined to the desired shape after pressing and sintering are completed.

In making the multiple conductive grinding rings, we may use any suitable metal bond appropriate for bonding the abrasive grains and for giving the rings suitable electrical conductivity. In the abrasive-containing portion of each ring, such as the portions 66 of Figure 3, the concentration of abrasive grains should, of course, not be so great as to detrimentally affect electrical conductivity. For finely divided diamond as the abrasive grain, a concentration thereof in the abrasive portion on the order of 25% or less by volume is suitable. Of the many and various metals that are usable for metal-bonding the diamond grains, we prefer to employ a mixture of copper and tin powders in the proportion of about 82% copper and 18% tin, making for both excellent electrical conductivity and good bonding of the grains, and this same mixture of copper and tin is employed in making up the non-abrasive backings, such as the portions 67 of Figure 3, and we set out the just-mentioned mixture of copper and tin as an illustration.

The exposed operative faces of the abrasive portions 66 of the conductive rings R1, R2, R3, the latter being spaced and insulated from each other, as above described, are aligned, or trued to alignment, with each other, and in the embodiment shown in Figure 3, these grinding faces are in a plane at right angles to the axis of the grinding wheel 64 and hence at right angles to the axis of the grinding wheel spindle 46; the head 45, carried at the top of the post 43 (Figures 1 and 2), can be set as above described and locked in position by the bolt 44 so that the just-described plane of the grinding surfaces of the several rings R1, R2, R3, is at right angles to the cross slide 14 of the machine and parallel to the direction in which the work-table 11 is reciprocable (from right to left and vice versa in Figure 1) along the ways 12 and 13 provided on the cross slide 14 so that a work-piece, carried on table 11 in a manner later described, can be moved over or away from the multiple ring-faced grinding wheel 64, as the cross slide 14 is moved rearwardly or forwardly of the machine base or traversed relative thereto as the table 11 reciprocates.

The multi-ring-faced grinding wheel 64 is driven at a suitable speed to give its multiple ring grinding faces suitable surface speeds for appropriate abrasive action, being driven in clockwise direction as viewed in Figure 1; suitable means are provided to electrically connect the rotating conductive abrasive rings into multiple supply and control circuits in which the work-piece, carried by the table 11, as is later described, is also included, adjacent conductive abrasive rings being relatively closely spaced from each other, being separated as above described by the insulating resinous material of the backing B, so that the contiguous and aligned abrasive faces can simultaneously be contacted by the work-piece from which stock is to be removed electrolytically. Such means conveniently slip rings interposed between each other and one for each conductive abrasive ring, and a brush for each slip ring, with the slip rings electrically connected to the respective abrasive rings and mounted to rotate with the grinding wheel spindle 46.

Preferably and in accordance with preferred features of our invention, the slip rings are carried and insulated from each other by the non-conductive back B of the grinding wheel 64, and preferably these slip rings, one for each conductive abrasive ring, and shown in Figure 3 at S1, S2, S3, are mounted concentrically at the back face of the insulating wheel back B, and in juxtaposed relation to their respective conductive rings R1, R2, R3.
that are mounted at the front face of the wheel back B1. These slip rings may be made of any suitable metal, such as copper, and various suitable metals may be employed to secure them in position and to electrically connect them to the abrasive rings which it is to serve.

For example, they may be given a cross-section which, aside from furnishing a good surface for engagement with the brush or brushes, is adapted to interlock with the material of the insulating wheel back B1 and in that case enable them to be molded to the structure of the abrasive rings R1, R2, R3. These slip rings are also interengaged with the insulating material during the process of molding and curing.

For example, the slip rings may be given a trapezoidal cross-section, as indicated in Figure 3, with the base of longer dimension embedded in and interengaged with the cured insulating material of which the back B1 is made, the portions of the latter and the slip rings forming complementary dovetails whereby a secure and dependable mounting of the slip rings results. The exposed conductive parallel faces of the slip rings may be in the same plane and may be flush with the back face of the wheel back B1, as indicated in Figure 3, where they are engaged by their respective stationary brushes, as is later described.

The slip rings S1, S2, S3 are in electrical connection respectively with the conductive abrasive rings R1, R2, R3 and where abrasive rings and slip rings are assembled to the insulating wheel back B1 in the process of molding the latter, it is preferred to electrically interconnect each conductive abrasive ring with its slip ring by a suitable number, substantially equi-angularly spaced about the axial center of the wheel structure, of relatively heavy flexible jumpers J1 between abrasive ring R1 and slip ring S1, and jumpers J2 between abrasive ring R2 and slip ring S2, and jumpers J3 between abrasive ring R3 and slip ring S3. These jumpers are preferably of good flexibility and hence are preferably of stranded copper wire. They are secured at their respective ends to abrasive rings and slip rings by any suitable means or in any suitable manner, illustratively by brazing, making a good mechanical and electrical connection. This is done before the thus-interconnected abrasive rings and slip rings are set into the mold that is to receive the moldable, curable plastic compound, such as the above-mentioned Bakelite resin, and the jumpers are of a length greater than is needed for the ultimate spacing in axial direction between each abrasive ring and its slip ring, by an amount corresponding substantially to the extent to which the unhardened resinous material is subjected, in the molding, to compression in axial direction. During such compression the jumpers J1, being of stranded wires, can give or yield or flex, assuming a somewhat wavy shape as indicated in Figure 3, and though they yield in this manner as the distance between abrasive ring and slip ring is lessened they offer sufficient resistance to shortening up in this manner so as to coact in maintaining the abrasive ring in contact with one plate of the mold and the slip ring in contact with the other plate of the mold. Upon curing by heat, preferably while still under compression, the resinous material is hardened and made rigid and the conductive abrasive rings become securely anchored with their faces in the plane of the cured resinous material at the front face of the grinding wheel, while the slip rings become securely anchored with their exposed faces flush with and in the plane of the rear face of the cured resinous material.

If it is not desired to mount the slip rings in interlocked molded relation with the molded insulating material of the back B1, they may be mounted in position on the back face of the back after the latter has been molded and cured, in the manner shown in Figure 5. Upon completion of the molding and curing operation to interlock the conductive abrasive rings R1, R2, R3 in position, a suitable number of equi-angularly spaced holes, one circular series for each abrasive ring, as indicated at H1, H2, H3, are drilled from the back face of the cured wheel back B1 up to the depth of the abrasive rings, whence these holes are extended but at smaller diameter into the backing part B7, which contains no abrasive grains, of the respective abrasive rings, and the holes in the metal backing portion B7 are tapped to provide them with threads for receiving screws 68, preferably of copper or of a copper-tin alloy, after the screws are passed through suitable countersunk holes in the respective slip rings, thus to clamp the latter securely and concentrically in position at the back face of the wheel back B1, and at the same time forming multiple electrical connections conveying capacity between each slip ring and its conductive abrasive ring.

The screws may be headed, in which case the heads are countersunk into the slip rings, or the screws may be headless, in which case those portions that extend into the countersunk holes in the slip rings may be radially expanded by means of a punch or by a bar or a punch or by a thin file, or by grinding, to be sure that they fall in a plane at right angles to the axis of the grinding wheel and to be sure that the ends of the screws 68 are flush with the faces of their respective slip rings, thus to insure smooth coction with the brushes of the circuits in which the parts are to coast.

In Figure 6 is shown on a smaller scale a transverse section of the grinding wheel 64 as seen along the line 6-6 of Figure 3; it shows the insulating back B1 in transverse section, indicates in broken lines the slip rings S1, S2, S3, and shows cross-sectional the series of equi-angularly spaced connecting jumpers or connecting screws, one circular series for each set of conductive abrasive ring and slip ring. Each series of jumpers or connectors thus provides many parallel paths for current flow between abrasive ring and slip ring, providing an over-all electrical connection between abrasive ring and slip ring that is of low resistance and of substantial current-carrying capacity, and the number and equi-angular spacing thereof in each series coast and achieve minimum, if any, disturbance or variation in circuit resistance as the wheel revolves, to maintain more constant resistance relative to its brush, and to move each abrasive ring relative to the work-piece that is to be operated upon.

As is better shown in Figure 3, the wheel head 45 has secured to it, as by cap-screws as shown, a bracket 69, which extends in a radial direction relative to the grinding wheel 64 and which is constructed in any suitable way to insulatingly support brushes 70 which correspond in number to the number of slip rings and which are mounted in suitable conductive sockets insulated from each other and aligned along a radius and spaced from each other to position the operating to fill up the tapered holes in the slip ring, the taper being appropriately portioned to the cold-flow characteristics of the metal of the screw shank to facilitate cold-flow expansion thereof as just mentioned. The faces of the slip rings may then be machined, as by shaving in the manner, or by grinding, to be sure that they fall in a plane at right angles to the axis of the grinding wheel and to be sure that the ends of the screws 68 are flush with the faces of their respective slip rings, thus to insure smooth coction with the brushes of the circuits in which the parts are to coast.
to have the faces of the conductive abrasive rings aligned other than at right angles to the axis of the wheel, as, for example, by locating the conductive abrasive rings about the periphery of the wheel as in Figure 4 while retaining the location of the slip rings at the back face of the wheel and adjacent the wheel head. The contact and coagulation with the brushes and the brush-holding bracket. The wheel head 45, in such a case, is set about the vertical axis of the post 43 (Figures 1 and 2) to give the desired geometric relation of the operative faces of the conductive rings to the work support or work-table, and illustratively, the wheel head 45 may be set as indicated in Figure 4, and locked in position by the bolts 44, so that the axis of the grinding wheel spindle 46 is parallel to the direction in which the work-table 11 is reciprocable (from right to left and vice versa in Figure 1), in which relation the aligned peripheral operative faces of the conductive rings R1, R2, R3 are also parallel to the direction of movement of the reciprocable table 11. It will now also be clear that the wheel head mounting and its adjustable position in the illustrated machine permit setting of the grinding wheel spindle and hence of the aligned operative faces of the conductive rings, which are in contact with the vertical axis of the post 43 as an axis of setting, according to the varying requirements which particular types or shapes of work-pieces might impose.

In Figures 4 and 7 the peripherally operating grinding wheel is designated as a whole by the reference character 71, and it is provided illustratively, as in the wheel construction of Figure 3, with three conductive abrasive rings R1, R2, R3, which are constructed as those described above in connection with Figure 3 excepting that they are of the same diameter, being embedded in B3 and interlocked with the cured resin of the wheel back B4; the back B5 carries on one of its side faces slip rings S1, S2, S3, which may also be embedded in and interlocked with the material of the back B5 as, for example, by giving the slip rings a trapezoidal cross-section as described above in connection with Figure 3. They are concentric and preferably of smaller diameter than those of Figure 3 in order to position them nearer the axis of the wheel and more remote from the periphery at which the conductive abrasive rings are operative. They are engaged respectively by holder 70 in the holder 69, which also is positioned nearer the axis of the grinding wheel spindle 46, being thus compactly accommodated in the space between the grinding wheel 71 and the wheel head 45.

The rings R1, R2, R3 are electrically connected respectively to the slip rings S1, S2, S3 in any suitable manner and by which a suitable number of preferably equally angularly distributed jumpers or connector elements, as indicated at 72, 73, 74 in Figures 4 and 7. These connector elements can be in the form of solid wires of copper or copper-tin alloy or the like, preferably relatively heavy to give them good current-carrying capacity, each set forming a low resistance current-carrying path between its conductive abrasive ring and slip ring. As is clear from Figures 4 and 7, these connector elements extend generally radially inwardly from the conductive ring to the slip ring; each set of conductive abrasive rings and slip rings to hold a metal connector is initially assembled, each as a unit, the ends of the heavy wire connector elements being secured to the rings in any suitable manner, as by brazing, and by shaping the connector elements differently in the different sets, somewhat as shown in Figure 4, they are more easily set in position in the mold along with the uncured plastic or resinous material, the connector elements being sufficiently yieldable or bendable to yield somewhat under the pressure applied in the mold (downwardly as viewed in Figure 4) to permit appropriate relative movement between the abrasive rings and the mold bottom, whence curing of the resinous material proceeds under heat. Upon completion of curing the peripheral face of the resultant structure can be trued to insure that the faces of the abrasive rings and the faces of the hard or rigid resinous material at the periphery all fall in the desired surface of revolution, and also the sides of the wheel can be trued and also to face off the exposed portions of the slip rings for proper coagulations with their respective brushes.

Referring now to Figures 1 and 2, the table 11 which may also be called a carriage supports a swivel table 75 which can be set at various angles on the table 11 and clamped in place, in a manner well known in the grinding machine art. The upper portion of the swivel table 75 is in the form of an elongated dovetail upon which is mounted, for securing in any desired position along the table 75, a dovetailed cut-out bottom of a work-holding fixture 78 which is secured in such a position by means of a screw 79. By means of a bolt and nut combination 80 extending through spaced parallel upright portions 81 of the fixture 78 a vise base 82 is secured in desired angular position (on a horizontal axis of adjustment) to the fixture 78. Referring now to Figure 3, a movable vise jaw 83 and a metal work-holding bar 85 with interposed insulating pieces 86 between them and also under the work-holding bar 85. Referring to Figure 2, the movable vise jaw 83 is operated by the usual screw 87 through a hole in the end of which extends the usual rod type handle 88 which can be screw 87 of course engages a nut on the nut portion, not shown, affixed to or integral with the vise base 82. Thus the metal work-holding bar 85 is held and clamped by the vise but is electrically insulated therefrom while the vise is secured to the swivel table 75 which in turn is secured to the reciprocable work-table 11 and provision is made for all sorts of adjustments, namely, to adjust the position of the work-holding bar 85 along the length of the table 11, to adjust the bar 85 angularly on a vertical axis and angularly on a horizontal axis while the hand wheel 56 can be used to raise and lower the post 43 and the grinding wheel that is carried by it, relative to the work-holding bar 85.

The work-piece is indicated by the reference character W, and for purposes of illustration it is shown, in the drawings, in the form of a block, in the shape of a rectangular parallelepiped; illustratively, it is a piece of cemented carbide of the kind above described. The work-holding bar 85 is provided with any suitable means for solidly supporting and securing the work-piece W, preferably so that it can be easily removed and shifted or replaced; for purposes of explaining the coagulations and features of our invention, it will suffice if the work-holding bar 85 is provided with a suitably shaped hole as shown in Figures 3 and 4, into which the work-piece or block W just about fits, being tightly secured against dislodgement by a screw 89 which can be easily and quickly manipulated by a simple form of wrench. With this arrangement the vise 83—84 need not be operated each time the work-piece W is replaced, and in that manner the above-described arrangement of insulating the work-holder 85, as by the insulating pieces 86, need not be disturbed. As shown in Figures 3 and 4, the work-holding bar 85 is provided with a relatively heavy cap screw 85a at an end thereof remote from its work-holding end, whereby a heavy metal connector may be mechanically and electrically connected to the work-holder bar 85 and thus connect the work-piece W itself into the electrical circuit or circuits, later described.

By the above-described adjustments of swivel table 75 and others, the face or part of the work-piece W and the multi-ring conductive operative surface of the grinding wheel may be set in relation to one another.
and the wide flexibility of relative adjustments makes it possible to meet a wide variety of varying requirements in practical use, mostly dictated by the shape or configuration which the face or part of the work-piece \( W \) has initially or in the rough and the shape or configuration to which it is to be ground. For a reader understanding of the functioning and advantages of our invention, however, it may be assumed that stock is to be removed from the rectangular end face of the work-piece or block \( W \) and that this face is to be at right angles to the longitudinal axis of the block \( W \) itself. Accordingly, the machine parts are set or adjusted as shown in Figure 3 in connection with which those settings are above described, it being noted that, in this simplest illustration, the hole in the work-holder \( 85 \) that receives the work-piece \( W \) is shaped or positioned so that the block \( W \) is held with its longitudinal axis horizontal and at right angles to the plane of the multi-ring abrasive face of the wheel \( 64 \). It will now be apparent that, where the peripherally operative grinding wheel \( 71 \) of Figures 4 and 7 is employed, similar flexibility of adjustment and setting of the various parts may be readily had, and in Figure 4, again to facilitate a reader understanding of our invention, the same work-piece \( W \) is shown with all of the machine parts set as described above in connection with Figure 3 except that the wheel head \( 45 \) is set to bring the four-ring-faced periphery of the grinding wheel \( 71 \) into the desired relation to the work-piece \( W \). The radial dimensions of the abrasive rings \( R_1, R_2, R_3 \), of Figure 3, and the axial spacing of the rings \( R_1, R_2, R_3 \) of Figure 4, being closely spaced as above described, are such, in relation to the face or part of the work-piece to be operated upon, that at least several, if not all, of the rings \( R_1, R_2, R_3 \) are presented to the work-piece; as indicated in both Figures 3 and 4, the face of the work-piece that is juxtaposed to the grinding wheel is of a dimension such that it can bridge two or more of the rings, and preferably all of them; in such case the adjustments provided in the machine readily permit setting of the work-piece in the just-described desired relation.

It will of course be understood that the work-piece may be of substantial dimensions or length, exceeding the over-all width of the multi-ring face of the grinding wheel, and in such case the reciprocable table \( 11 \) may be set in motion, manually or by power, and may also be reciprocated manually or by power to traverse the part of such a long work-piece relative to the grinding wheel. In Figures 3 and 4 the double-headed arrow indicates such movability of the table \( 11 \), the mechanism for effecting such movement having been earlier described generally, and specifically by reference to Patent No. 2,101,787. In such case the line of movement of the table and hence of the long work-piece is parallel to the side face of the grinding wheel \( 64 \) in Figure 3 and is parallel to the multi-ring peripheral grinding face of grinding wheel \( 71 \) of Figure 4, the general path of contact of the work-piece with the wheel being along a horizontal radius of the wheel \( 64 \) of Figure 3, as better appears from Figure 8, and along a line parallel to the axis of the grinding wheel \( 71 \) of Figure 4, and at about the height of that axis, as better appears from Figure 9.

Referring now to Figure 2, for a continuous power feedof the cross slide \( 14 \) to advance the work-piece \( W \) at a steady rate toward the multi-ring face of the grinding wheel, which is again reciprocated by the table \( 11 \), an electric motor \( 90 \) drives a speed-reducing mechanism \( 91 \) which is secured to the rear end of the rearwardly projecting portion \( 19 \), and the speed-reducing mechanism \( 91 \) drives a sprocket pinion \( 92 \) connected by a sprocket chain \( 93 \) to a large sprocket \( 94 \) which is secured to the rear end of the screw shaft \( 16 \). In the practice of the invention this power feed can be used or the work-piece and the grinding wheel can be advanced, one relative to the other, by manually rotating the hand wheel \( 20 \) or any other desired infeed mechanism can be employed, such as the well-known intermittent infeed found on many types of grinders. However, for electrolytic grinding of short work-pieces like the work-piece \( W \), a continuous infeed such as produced by the mechanism just described is preferred, preferably accompanied by reciprocation of work-table \( 11 \) in short strokes suited to the widths of the work-piece face and of the subdivided grinding wheel.

Referring now to Figure 1, we provide a tank \( 95 \) containing liquid \( 96 \) which in accord with this invention is an electrolyte. Ordinary salt water will do very well, that is, a solution of sodium chloride in water. The solution should be reasonably concentrated, which is easily done by dumping a surplus of common salt into the tank \( 90 \) when it is full of pure water, then stirring, as any salt which will not dissolve will simply rest on the bottom. Other salts can be used, but for keeping corrosion at a minimum the very corrosive salts such as calcium chloride, magnesium chloride and zinc chloride will preferably be avoided. Salts such as ammonium chloride can be used. The carbonates such as sodium carbonate and potassium carbonate can be used and in some cases may be preferred as they are somewhat less corrosive than sodium chloride.

Mounted on the cross slide \( 97 \) of the tank \( 95 \) is an electric motor \( 98 \) which drives a pump \( 99 \), the input end of which is connected by means of a pipe \( 100 \) to the inside of the tank \( 95 \), the open end of the pipe \( 100 \) being preferably near the bottom of the tank. The outlet end of the pump \( 99 \) is connected by pipes \( 101, 102 \) and \( 103 \) to a flexible hose \( 104 \) which is connected to a valve \( 105 \) on the end of a pipe \( 106 \) mounted on the wheel guard \( 107 \) (Figure 8) of a wheel guard \( 107 \) secured by brackets \( 108 \) and \( 109 \) to the wheel head \( 45 \). The other end of the pipe \( 106 \) is connected to a broad-mouthed nozzle \( N \) carried by a deformable tube \( 110 \) which can be bent with the hand to give its nozzle end the desired location, and when bent into a particular shape will keep that shape despite the flow of liquid therethrough under moderate pressure. This deformable tube \( 110 \) is set in such shape as to direct the electrolyte discharged from the nozzle \( N \) onto the face of the grinding wheel over and throughout the entire width thereof at the locus where, as above described, the alined multiple grinding surfaces of rings \( R_1, R_2, R_3 \) are contacted or nearly contacted by the work-piece \( W \). Figures 8 and 9 show this setting of the nozzle \( N \); appropriately the nozzle \( N \) is set in the electrolyte discharge onto and throughout the over-all width of the multiple conductive grinding surfaces of the rings.

Referring to Figure 1, the liquid which flows onto the work-piece \( W \) is eventually collected by a large pan \( 113 \) which is built up around the top of the table \( 11 \), as shown in Figure 2, a spout \( 112 \) collects the liquid and allows it to flow into a stationary pan \( 113 \) supported by the column \( 41 \) and extending for the full length of maximum travel of the spout \( 112 \). A return pipe \( 114 \) extends from the pan \( 113 \) to the tank \( 95 \).

In Figure 10 we have shown diagrammatically a simplified circuit arrangement in connection with which the multiple conductive ring grinding wheel, such as those above described, can achieve a number of advantages and improve the action and capacity for stock removal by electrolytic decomposition. We provide a suitable source of current, illustratively a storage battery \( 120 \), one terminal of which, preferably grounded, is connected to the work-piece \( W \), as by utilizing the connector screw \( 85a \) of Figures 3 and 4; its other terminal is connected, by separate conductors, to the conductive abrasive rings, such through a separate control resistance which is preferably variable. In the illustrative embodiments of grinding wheel constructions above described three conductive abrasive rings are employed for purposes of illustration.
and in Figure 10 these three rings R1, R2, R3, together making up the operative grinding face, are diagrammatically shown with the work-piece W juxtaposed thereto and slightly spaced therefrom, and diagrammatically indicated are also their respective slip rings S1, S2, S3, with their respective brushes 70. There are thus formed three current-supplying circuits, one for each conductive abrasive grinding wheel G and conducting directly with its own control resistance, T1, T2, T3 respectively, these circuits having the work-piece W as a common conductive part and, in the illustration, they happen to have in common the same source of electrical energy, though that is by way of simplified illustration and not by way of limitation.

In order better to understand the coactions and advantages of the multiple-ring wheel and associated control circuit arrangement of Figure 10, reference may be had to Figure 11, and consideration may be given to how certain of the difficulties and disadvantages earlier mentioned arise and occur where stock removal is effected from the work-piece W by using a conductive grinding wheel G that presents only a single conductive abrasive surface juxtaposed to the work-piece W, as is diagrammatically indicated in Figure 11. Work-piece W and conductive grinding wheel G are in circuit with a suitable source of energy such as a storage battery 121 and a control resistance T1, usually variable, all arranged in series, with the electrolyte interposed between the juxtaposed faces of the work W and the grinding wheel G also included in the series circuit. The rate of electrolytic depositions of the metal of the work-piece W at the work-wheel interface is proportional to the current flow and hence it is desired to employ high-current density, illustratively on the order of hundreds of amperes per square inch. In practice, however, it is found that much lower current densities have to be employed, thereby materially diminishing the rate of stock removal, and even then disadvantages and difficulties are present, such as arcing, high rate of wheel wear, and the like, even when provision is made to limit maximum permissible current flow, as by the external resistor T in Figure 11.

In such a circuit as in Figure 11 the ohmic value of the resistor T makes several times as great as the normal operating value of the resistance at the work-wheel interface where the electrolytic action takes place, and accordingly, when normal or usual variations take place in the work-wheel resistance they will have little or no appreciable effect upon the current flow at the interface and substantial uniform current density throughout the interface is maintained. The resistor T thus acts to maintain substantial constancy of average value of current flow in the circuit in that the actual value of current may fluctuate through a small range about its average value. For example, if the resistor T has a resistance of one ohm and the work-wheel resistance has a value of 0.2 ohm, a fifty per cent change in the latter resistance causes a change of only about eight per cent in the current flow in the circuit.

In such an arrangement and circuit, if the current is adjusted, by setting the variable resistor T, to a suitable value when its distribution over the work-wheel interface is uniform, and desirably it is sought to set the current value at as high a level as possible, then when any circumstance arises that causes a reduction in the contact area at the juxtaposed work-piece W and conductive grinding wheel G and causes the current density to exceed the critical limit T is made to cause destructive arcing results. The contact area may be reduced and the critical limit of current density exceeded in various ways. For example, a bodily shift of the work-piece W relative to the grinding wheel G, such as a relative traversing movement between the two in a direction parallel to the work-wheel interface, can so diminish the contact area, moreover, such a relative traversing movement can be of an extent to run the work-piece W completely off the conductive face of the grinding wheel G, effecting a constantly increasing diminution of contact area and constantly increasing current density, both being reduced to zero upon complete separation of work-piece from grinding wheel. Destructive arcing results. Arcing may also occur even when the apparent contact area is a large fraction of the maximum possible contact area if the current flow in the circuit and in the work-wheel interface is above that value which is the critical arcing current flow; apparently small discontinuities in the work-piece surface tend to cause current concentrations in areas much smaller than the apparent contact area between work-piece and grinding wheel, and such concentrations produce local heating and lead to the formation of destructive arcs, the total current in effect tunneling through the small arcing area.

It is such undesirable actions and difficulties that can arise with an arrangement and circuit as in Figure 11; by way of illustration it may, in operation, be limited in its stock removal capacity by having to set the resistor T to function to maintain a constant average flow of current on the order of, say, 60 amperes, and still be subject to the hazards of arcing and consequent reduction in wheel life, such as those about described. However, and referring now to Figure 10, by providing separate conductive abrasive rings R1, R2, R3, each in a circuit having its own resistor, the resistors T1, T2, T3 respectively, and setting each of the latter so that each functions in its own circuit to maintain substantially constant average value of current on the order of only one-third of the above assumed critical value of 60 amperes, the above-mentioned hazards are greatly lessened. The total current flow of 60 amperes still occurs, meaning that the same rate of electrolytic decomposition can and does take place, but there is no work-wheel interface at which that total of 60 amperes can be concentrated. If the apparent contact area is reduced, as by relative traversing movement between the work-piece W and the multi-ring grinding wheel, so that only two conductive abrasive rings are juxtaposed to the work-piece, only two of the three circuits remain effective and the maximum possible current flow at the interface is reduced to two-thirds, namely, 40 amperes, and even that remains broken down or subdivided between the two effective circuits at 20 amperes each. If such traverse continues so that only one conductive abrasive ring remains juxtaposed to the work face, the current is reduced to one-third; but it is impossible for the initial total current value of 60 amperes to be effective thereat because that remaining conductive abrasive ring is in its own circuit in which the total current value is only one-third, namely 20 amperes. Nor can discontinuities in the work face cause excessive current concentrations, nor does any such discontinuity finds itself juxtaposed to the face of one or an other of the multiple conductive abrasive rings, and the circuit of that conductive ring is self-regulating at a current value such that insufficient current can flow to bring about destructive arcing or tunneling through a small arcing area.

It will now be understood that by increasing the number of conductive abrasive rings, these coactions and mode of operation bring about corresponding reduction in the permissible current flow in the respective circuits of the conductive abrasive rings, for example, four conductive abrasive rings, each in its own control circuit, would reduce the maximum current flow to 15 amperes in each circuit while maintaining the total current flow at 60 amperes. Accordingly, for any given set of circumstances, the maximum current that can flow in any small area of the work-wheel interface can be reduced to any selected or suitable value by providing the grinding wheel with a sufficient number of individual conductive abrasive elements, in relation to the total current flow, and by appropriately setting the controls, such as the variable resistors of Figure 10.

It is possible, however, with a given number of individual conductive abrasive rings, to materially increase the total current and thus materially increase the stock removal by electrolytic decomposition. For example,
with three abrasive elements R, R2, R3, as in Figure 10, to set the control resistors T1, T2, T3, at values such that the current in each circuit (instead of being 20 amperes, as in the illustration given above, where the total current flow is 60 amperes), is of a much higher value and, as is later described, may substantially equal the critical value itself. For example, the current flow in each circuit may be on the order of only 40 amperes, two-thirds of the assumed critical value of 60 amperes; in such case, the total current flow is 120 amperes, doubling the rate of electrolytic decomposition and yet the maximum possible current flow at any portion of the work-wheel interface never exceed 40 amperes, a value materially less than the critical value of 60 amperes. Thus, stock removal capacity can be increased and risk of damage to the grinding wheel, as by arcing, lessened. And by increasing the number of individual conductive abrasive rings, the stock removal capacity can be further increased. Thus, in the illustration just given, with the provision of four abrasive rings, each with its own control circuit set at 40 amperes maximum current flow, the total current flow is increased to 160 amperes (as against 60 amperes) and lessening of risk of damage to the wheel still achieved. Moreover, if the critical current is, as in the above illustration, 60 amperes, the circuit of each of the several conductive abrasive rings can be set for 60 amperes so that with three abrasive rings, such as rings R1, R2, R3, of Figure 10, the total current flow is increased to 180 amperes, with four conductive abrasive rings it is increased to 240 amperes, and so on, the stock-removing capacity by electrolytic decomposition of the metal of the work-piece W being correspondingly increased, while at the same time, though high values of total current are effective, maximum current flow at any portion of the subdivided work-wheel interface is held at a relatively low value, namely, 60 amperes.

In the just-stated illustrations it is assumed that the relationship of like or uniform conditions exists throughout the several work-wheel interfaces, which are three in number if three conductive abrasive elements are employed, four in number if four such elements are employed, and so on. So long as substantially equal conditions exist at these several interfaces, the voltage drops across these interfaces are substantially equal and the several conductive abrasive elements are of or at substantially the same potential. It is not always feasible, because of various factors, to maintain such equality of contact conditions and hence of voltage drops across the several interfaces; for example, it may be necessary to reciprocate or traverse the work-piece W (as by appropriately moving the table I of Figures 1 and 2, as above described) and thus, for example at one or both ends of reciprocating strokes of the work W, the area of apparent contact of the work-piece W with an end abrasive ring is greatly diminished even though the full contact area is maintained at the next adjacent ring. In such case the voltage drop at the latter remains about the same, while the voltage drop across the reduced area of interface between the end ring and the work is greatly increased because the resistance therebetween increases with decrease in apparent contact area, other factors being equal. Accordingly, the potential of the end ring, in this illustration, is raised above the potential of the next adjacent ring; the resultant difference in potential between such two rings causes a current flow to pass from the one through the electrolyte which bathes both the conductive and non-conductive parts of the operative face of the grinding wheel (see Figure 3 or Figure 4), and electrolytic etching can take place on the conductive abrasive ring. The more positive conductive abrasive ring feeds current through the electrolyte on the workpiece surfaces to its more negative neighboring conductive ring, and the resultant current flow electrolytically etches the more positive abrasive ring. In effect, therefore, electrolytic decomposition takes place, and this of course is undesirable, amounting to excessive or destructive wheel wear. It will now be apparent that such detrimental electrolytic decomposition of one conductive abrasive ring relative to another can be caused by other conditions, such as, for example, inequality of pressures of contact between the work-piece and the respective rings, or inequalities in the spacings between the work face and the respective conductive abrasive rings. It will also be understood that there is always electrolyte at and throughout the work-wheel interfaces and that the stock removal from the work W may or may not be accompanied by abrasive action by the grinding wheel abrasive rings, depending in turn upon various factors, such as rate of inferred of the work W relative to the grinding wheel. At low rate of inferred, for a given total current flow, stock removal can take place by electrolytic decomposition alone, there being substantially no contact between work face and conductive abrasive surfaces, the spacing therebetween being on the order of a thousandth of an inch or a fraction thereof; with somewhat higher rate of inferred stock removal can be made to take place by both electrolytic decomposition and abrasive action, which means that contact between work face and conductive abrasive rings can be maintained as inferred proceeds.

Accordingly, abrasive action by the abrasive grains of the several rings R1, R2, R3, or R4, or does not take place according as there is or is not physical contact between the work W and the conductive abrasive rings at their respective interfaces. But whether there is or is not physical contact at these interfaces, the electrolyte, supplied and distributed thereto by the nozzle N, is always present between these faces and because of its good electrical conductivity ensures maintenance of good and substantially uniform electrolytic surface-contact with work-face and ring-faces through wherein pollution happens to be the area or overlap, which may vary as above noted and as later described, at any particular work-face interface; with electrolyte always immersed at such interface and with the work-ring contact actual, stock removal is effected by both electrolytic decomposition and abrasive action, and when, at the interface, contact is not actual and hence is only "apparent," stock removal takes place by electrolytic decomposition without accompanying abrasive action. In the latter case stock removal or "grinding" proceeds without any wear on the abrasive rings R1, R2, R3, and in the former case the rate of stock removal is due to the combined factors of abrasive action and electrolytic action.

The rotary movement of the faces of the rings R1, R2, R3, being clockwise as viewed in Figure 1, causes to bring electrolyte downwardly (Figures 8 and 9) between the overlapped or juxtaposed work-ring faces whether their contact is actual or apparent, aided also by the downwardly moving electrolyte discharge from the nozzle N (Figures 8 and 9), and the continued downward rotary movement of these ring faces past the work W serves also to sweep the electrolyte downwardly across the face of the work-piece W; these actions are continuous and rapid and, in concert with the current passing through the electrolyte at each of the several interfaces, produce an effect like the abrasive action of a grinding wheel, namely, a good surface on the face of the work-piece W which is substantially the mate for the surface of the multiple-ring wheel.

Thus, removal of stock from the work-piece, where the conductive rings R1, R2, R3 contain abrasive grains, can be variously effected and at the same time as the action on the work-piece is by electrolytic "grinding" action alone or is by both such electrolytic action and abrasive action of the abrasive grains in the conductive rings. Accordingly, for the grinding of hard carbide tools, recourse to the use of diamond abrasive grains need not be had and stock removal from such material can be dependably effected. Moreover, and also for the
grinding of other conductive materials or metals or alloys, less costly and less effective abrasive grains than diamond bort, such as aluminum oxide, silicon carbide or even quartz sand, may be employed where some abrasive action by the conductive rings $R_1$, $R_2$, $R_3$ may be necessary or desired, and high rate of stock removal achieved mainly by the electrolytic "grinding" action. In the illustrative and preferred embodiment of grinding wheel constructions provided for herein disclosed apparatus and system, the slip rings $S_1$, $S_2$, $S_3$, though carried by the grinding wheel back (back B) of Figures 3, 5, 6 and 8, and back B' of Figures 5, 7 and 9, are so located in relation to the faces of the conductive rings $R_1$, $R_2$, $R_3$ as to be out of the range of electrolyte that is supplied to the rapidly rotating ring faces and ultimately cast off them centrifugally (downwardly in both Figure 8 and Figure 9). As appears better from Figure 3, in the there illustrated embodiment, though the slip rings $S_1$, $S_2$, $S_3$ are of substantially the same respective radii as the conductive rings $R_1$, $R_2$, $R_3$, they are on opposite side faces of the back B, and electrolyte supplied to the front face, where the conductive rings $R_1$, $R_2$, $R_3$ are located, is prevented from reaching the slip rings, being centrifugally cast off, including such electrolyte as might even reach the periphery of the wheel 64 of Figure 3. In the illustrative embodiment of Figure 4 the slip rings are all of lesser radius than the radii of the conductive rings so that electrolyte supplied to the wheel at the latter surfaces of greater radii is prevented from reaching the slip rings of lesser radii by the centrifugal forces acting upon them. In the form of Figure 4, the slip rings are thus also out of range of centrifugally thrown electrolyte. Thus, consistently good and uniform electrical contacts, unaffected by the electrolyte or electrolytic action, can be maintained between the slip rings and their respective brushes 70, thus coating with or variation of circuit resistances and coating toward obtaining the intended responses of various electrical control means or devices as those described above in connection with Figure 10 and those about to be described in connection with Figure 12.

Though, as above pointed out, stock removal by electrolytic decomposition at the work face may or may not be accompanied by abrasive action, it is in either case desirable to achieve higher current densities for high rate of stock removal while at the same time preventing detrimental arcing or other action as would damage or destroy the conductive rings or cause detrimental or harmful irregularities or discontinuities in their conductive surfaces; as above noted, conditions can arise where the ring surfaces can be damaged by electrolytic decomposition of one conductive ring serving as an anode to another conductive ring serving as a cathode.

By certain other features of our invention we are enabled to avoid detrimental electrolytic etching or decomposition of the conductive abrasive rings relative to one another, and also to achieve greater stock removal capacity by electrolytic decomposition accompanied by safe and efficient stability of action even though various conditions of insulativity or the like, such as those illustratively above noted, come into being. An illustrative circuit arrangement and controls is diagrammatically shown in Figure 12, where again, for purposes of illustration, the work-piece W and the three rings $R_1$, $R_2$, $R_3$ and the slip rings $S_1$, $S_2$, $S_3$ are shown as in Figure 10, all related to a source of current, such as the storage battery 120, the same as described above in connection with Figure 10. There are individual current supply circuits, one for each conductive abrasive ring, and while they have the work-piece W as a common part of the three circuits, there are, in addition, individual variable control circuits, being indicated in Figure 12 at $T_1$, $T_2$, $T_3$, each arranged serially in the circuit of its associated conductive abrasive ring, the same as in Figure 10.

More specifically, the circuit for the work-wheel interface at ring $R_1$ extends from battery 120, conductor 123, work W, ring $R_1$, slip ring $S_1$, brush 70, conductor 124, and variable resistor $T_1$, and by conductor 126, back to the other side of battery 120.

For the work-wheel interface between work W and ring $R_2$ the circuit extends from battery 120, conductor 133, work W, ring $R_2$, slip ring $S_2$, brush 70, conductor 135, variable resistor $T_3$, and then by way of conductor 136 back to the other side of battery 120.

The circuit for the work-wheel interface between the work W and ring $R_3$ extends from battery 120, conductor 143, work W, ring $R_3$, slip ring $S_3$, brush 70, conductor 145, variable resistor $T_3$, and then by way of conductor 146 back to the other side of the battery 120.

If for any one of these three circuits the remaining ones are momentarily disregarded, it is found that, at the current flow at or below the critical current, for example 40 amperes, the voltage drop from work to wheel ring is approximately six volts, with the ring face and work face juxtaposed for maximum area of contact or of apparent contact, and there is a stable current. Under these circumstances, there is no detrimental arcing and the operation proceeds smoothly. If, however, the current is raised to 70 amperes severe and destructive arcing occurs, greatly reducing wheel life. That this is so can be determined by a single circuit arrangement like that of Figure 11 and has, in fact, been so determined; when operating at the 40 ampere level in such a single circuit as in Figure 11 it has been found that the work to wheel voltage drop very rarely goes materially below the six-volt value above stated, but if the work W is traversed relative to the grinding wheel G in Figure 11, as the end of the stroke and hence the end of the overlap of work W and wheel G are approached, thus progressively diminishing the contact area at the interface, the voltage drop between work W and grinding wheel G may rise to several times the six-volt value. This shows that as the contact area is lessened as the end of overlap is approached the current density increases substantially, since the 40 amperes are distributed throughout a smaller and, in fact, diminishing contact area; accordingly, current density is much higher toward the ends of the stroke of reciprocating traverse of the work W relative to the grinding wheel G than it is at the center of the stroke. This is demonstrated in the just-described arrangement of Figure 11 under typical or illustrative operating conditions in which the work W is a tungsten carbide block presenting a work face measuring 3/8 inch by 3/4 inch to a metal-bonded diamond wheel G having a face width of 3/4 inches, with sodium chloride solution as the electrolyte, and the work-piece pressed against the grinding wheel G at a pressure of 20 pounds.

These considerations will aid toward a reader understanding of the features of our system as illustrated in Figure 12, and give some idea of the magnitude of the voltage-drop changes that can take place between any one of the conductive abrasive rings $R_1$, $R_2$, $R_3$ and the work W, and indicate the order of magnitude of differences of potential that can be created between adjacent or successive ones of the conductive abrasive rings $R_1$, $R_2$, $R_3$.

Referring to Figure 12 we provide a variable resistance, preferably in the form of a carbon pile, shunted across each work-ring gap G. If such gaps are as shown at $P_1$, $P_2$, $P_3$, the piles being conveniently connected across the main current feed lines 123, 125, 133, and 143, and 145 that lead to the respective work-ring gap or interfaces. These piles $P_1$, $P_2$, $P_3$ can be respectively with the variable resistors $T_1$, $T_2$, $T_3$ by controls or control circuits, of which the respective piles and variable resistors form the responsive parts, these control circuits being electrically indicated as a whole, in Figure 12, for each of the three illustrative work-wheel-ring circuits, by the reference char-
2,764,543

actors C1, C2, C3 respectively, and since they are the same it will suffice to describe one of them in detail while, however, pointing out the connections therebetween and their respective modes of operation with respect to the several work-wheel ring gaps or interfaces.

The carbon pile is constructed and arranged, in any suitable manner, for control of its variable resistance by control of the compression of the contacting carbon plates of the pile; for example, one end of the pile may be held stationary or anchored in any suitable way and a variable and controllable pressure applied to its other end, as by a lever 126, pivoted at 127, so that one lever arm operates against the end of the pile while at the other end of the lever is connected the core 128 of a solenoid, the winding of which is indicated at 129, the pull of the solenoid in a direction to increase the pressure on the pile and thus decrease its resistance being opposed in any suitable manner, as by an adjustable spring 130. Accordingly, when the solenoid winding 129 is not energized or is insufficiently energized to overcome the pull of spring 130, the latter holds the lever 126 in a position, as against a stop 131, such that the right end of the lever 126 exerts a minimum or no substantial pressure on the carbon pile and accordingly, the resistance of the latter is at a maximum, preferably high enough so that substantially no current flows through the pile and the current flow from the battery 120 through the resistor T1 passes at substantially full value across the interface between ring R1 and the work W. Illustratively, with the battery 120 having an operating voltage on the order of 46 volts, that current flow, illustratively, is 40 amperes where the resistor T1 is set to have a resistance of one ohm. Should substantial pressure be applied to the carbon pile, the current flow of 40 amperes from the battery through the resistor T1 continues but is now divided, some of the current passing through the interface between ring R1 and work W, and the rest passing through the carbon pile, which thus shunts or bypasses the work-wheel interface or gap, and as will presently be seen it can do so variably.

The solenoid winding 129 is arranged to respond to changes in the voltage drop across the work-ring interface that is shunted by the carbon pile which the winding controls, and an illustrative and convenient arrangement is like that shown in Figure 12, wherein is shown a Wheatstone bridge type of vacuum tube amplifier circuit in which the carbon pile control winding 129 is connected across the output terminals a and c of the bridge, the bridge comprising resistances 132, 137, 138, and a threeclement vacuum tube or triode 139 connected as shown to provide input terminals b and d, to one of which, terminal b, is connected one side of a suitable battery 140, the other side of which is connected as shown to one end of resistance 138 and also through a resistance 141 to the grid of the triode 139, a conductor 142 connecting the grid to the main circuit conductor 125 which leads to the conductive abrasive ring R1. Bridged across the main circuit on the battery side of the variable resistor T1 is a resistance 147 provided with a variable tap 148 which is connected, as shown, to the battery side of the resistance 141, the resistance 147 and variable tap 148 forming a reference voltage control for setting the level of standard of potential response of the grid of the triode 139. Thus point d of the bridge is shiftable along the resistance 138, being in effect a variable tap and thereby providing for tube bias control. The point c of the bridge is shiftable relative to the resistance 137, being in effect a variable tap by which, with the other controls mentioned, the bridge may be balanced according to the portions of the resistance 137 which the selected location of the shiftable point c allocates to the respective arms b-c and c-d.

For each work-abrasive ring interface there is thus provided a control circuit such as that just described above, the control circuit C1 coacting with the interface between the work W and the ring R1, the control circuit C2 coacting with the interface between the work W and the ring R2, and all three coacting to forestall detrimental electrolytic etching or decomposition at the conductive abrasive rings and coacting to prevent destructive arcing at the several interfaces while at the same time permitting a high rate of stock removal from the work-piece throughout very varying and variable conditions, some of which are mentioned above, that can arise during such operations between the work W and the subdivided and electrically separated conductive parts of the operative face of the grinding wheel. With the battery 120 supplying energy at a voltage on the order of 46 volts, let it be assumed, as earlier indicated above, that the variable resistors T1, T3, T7 are set so that each can regulate or control current flow in its circuit to provide a flow of 40 amperes; illustratively, each of these resistors may be set to a resistance value of one ohm. In the absence of abnormal conditions at the several interfaces, where the electrolyte is actively in the several circuits, the voltage drop across each interface as above explained, is six volts, corresponding to an effective resistance at each interface of 0.15 ohms, and that voltage drop of six volts very rarely, if at all, becomes less so long as material variables do not enter to change the condition at one or more of the interfaces, at a continuing current flow of 40 amperes in the circuit of each interface. This condition of a six-volt IR drop at each interface, at 40 amperes in each circuit, can be better understood if it is assumed for the moment, in Figure 12, that the work-piece W is of a length just equal to the over-all width of the exposed faces of the rings R1, R3, R3, for in such case the interface contact areas are identical and equal to each other, and there is the same current density throughout each. But even such a work-piece has to be moved or shifted or traversed or reciprocated relative to the several spaced faces of the conductive abrasive rings, and thus identity of conditions at the three interfaces disappears and a diversity of interface conditions is set up. However, to emphasize the wide diversity of conditions that can be brought about at the several interfaces, the work-piece W is intentionally shown as shorter than the over-all width of the faces of the several rings so that, in whatever position the work-piece W occupies relative to the rings, there cannot be identity of relationships and conditions at the several interfaces. For example, the interface area, with the work-piece W positioned as shown in Figure 12, at the ring R3, is at a maximum, for the work W overlies the entire width of ring R3; at ring R3 the interface area is half of the maximum, possible because the work face overlaps only half the width of the face of ring R3; at ring R1 the interface area is about one-fourth of the maximum value because the work face overlaps only about one-fourth of the width of the face of ring R3.

Accordingly, the resistance at the interface at ring R3 remains about 0.15 ohms, and the voltage drop stays at about six volts. The resistance at the interface at ring R3, with the apparent contact area cut in half, becomes greatly increased, being more or less doubled, and where the same current (40 amperes) to be flowing, the IR drop would be greatly increased, substantially doubled. And at the interface at ring R1, the resistance is increased to still greater extent and where the same current (40 amperes) to flow, current density would be very materially increased and the voltage drop across the interface would also be materially increased. These comparative conditions at the respective interfaces illustrate one way in which the voltage drop across one interface can increase relative to the voltage drop across an adjacent or another interface. Not only could the resultant
voltage differences between conductive abrasive rings affect electrolytic etching or decomposition of one or more of the rings, but also it is possible, as the apparent contact area at only one interface continues to be diminished as upon relative traverse between grinding wheel and work-piece W, to achieve excessive current density at such interface such as to bring about destructive arcing. Such conditions and detrimental effects can be caused also in other ways. For example, and particularly at the commencement of a grinding operation, there may exist some irregularity in the work face to be ground or an unintentional or unavoidable misalignment of the work-piece face relative to the aligned surfaces of the several abrasive rings, and such conditions can also have the effect of material differences in areas of contact at the several interfaces, with resultant different resistances thereacross and hence different voltage drops. Also, where the aligned faces of the several conductive abrasive rings are not flat as in Figure 3, but fall in a curved plane of the peripherally operated grinding wheel of Figure 4 is an illustration, there can be relatively different contact areas at all of the interfaces as the curved operative surface of the grinding wheel grinds itself in, as, for example, upon progressive instead of the work-piece W as well as upon intermittent instead timed with successive stroke of the work-piece as the work-table 11 is reciprocated. This will suffice as illustrations of various ways in which inequalities of working conditions at the several interfaces can arise to cause undesirable or harmful effects such as those noted above.

Referring to Figure 12, it will be seen that the grid of the triode 139 of each of the control circuits C1, C2, C3 has impressed upon it a potential which is the difference between the potential of the abrasive ring with which the control circuit is associated and the potential setting of the reference voltage control represented by the resistance 147 and the shiftable tap 148. The shiftable tap c is set to bring the bridge in balance, that is, to bring the bridge output terminals a and c to the same potential, when the voltage drop across the work-ring interface is six volts. These settings may be effected empirically or by the calibrations associated with the several shiftable controls, such as the bridge balance control resistance 137 and tap c, the bridge control tap d, and the reference voltage control comprising the resistance 147 and shiftable tap 148. In the arm a to d of the Wheatstone bridge the triode 139 is thus made to serve not only as a variable resistance that responds to changes in the voltage drop across the bridge but also as an amplifier whereby to greatly and quickly multiply a potential change into rapid and substantial change in resistance in the arm of the bridge, with the result that the rapid unbalance of the bridge can effect a promptly responsive current flow through the solenoid winding 128 to actuate the carbon pile to decrease its resistance. Preferably, we include in the circuit of each solenoid winding 128, in the output circuit of the bridge, a rectifier 150, the action of which is to permit energization of the solenoid winding 128 only when the voltage drop across the corresponding work-ring interface exceeds the selected value (six volts in the above illustration), that is, the solenoid winding 128 becomes sufficiently energized to decrease the resistance of its carbon pile only when the corresponding conductive abrasive ring becomes more negative than the selected value as distinguished from becoming less negative than that selected value.

Accordingly, were the work-piece W to present to each of the rings R1, R2, R3 the same contact area as would be the case where the work-piece W is of a length greater than the over-all width of the exposed faces of the rings, thus to bring about uniformity of electrolytic working conditions at all of the interfaces, the current flow across each interface, with the resistors T1, T2, T3 set at one ohm, is about 40 amperes and the total 120 amperes; the voltage drop across each interface is just about six volts, and an substantial equality of voltage drop would continue so long as uniform working conditions exist throughout the several interfaces. However, as soon as any circumstance arises to cause any one or more of the voltage drops to rise above the selected six-volt value, which means that the potential of the corresponding abrasive ring or rings becomes more negative than the six-volt value, the grid of the triode of the corresponding control circuit also becomes more negative, and that action effects a multiplying or amplifying change in the resistance of the arm a to d of the bridge, resulting in corresponding energization of the solenoid winding 128 followed by increase in pressure on the carbon pile sufficient to bypass enough of the 40 amperes as will reduce the current flow across the corresponding work-ring interface to restore the voltage drop thereacross to the selected or six-volt value. Excessive current concentrations at the particular interface or interfaces are prevented as is also destructive arcing, while at the same time material potential differences between conductive abrasive rings are precluded from coming into existence as would cause electrolytic decomposition or etching of one ring relative to another.

By way of illustration, consider the relation of the work-piece W in Figure 12 to the three resistors R1, R2, R3 as earlier above described, namely, where the work W overlaps the entire width of ring R3, half of the width of ring R1, and one-fourth of the width of ring R1. In the circuit of ring R1 the current flow remains at 40 amperes, since the voltage drop at that interface, in the assumed illustration, remains at about six volts and accordingly triode 139 of the circuit C2 remains of unchanged resistance and the bridge remains balanced and carbon pile P2 is at maximum resistance or virtually open, and the whole current as determined by the resistor T1 flows across the interface of the work W and ring R3 in a circuit from battery 120, conductor 133, work W, ring R3, conductor 135, resistor T3, and by conductor 136 back to the other side of the battery 120. Carbon pile P3 thus bypasses no material amount of the current.

In the circuit of ring R3, where the interface, in the assumed illustration, is reduced to one-half, an arcing concentration or density of current is prevented from taking place, for as soon as the contact area of the interface R3 becomes less as the full overlap is departed from, as by the traverse stroke of the work relative to the wheel, the voltage drop across that interface commences to exceed the selected value of six volts, the ring R3 becoming more negative than that value, whereupon the triode in the corresponding control circuit C3 promptly responds to unbalance the bridge and to energize the winding 128 of carbon pile P3 to increase the pressure on the pile and decrease its resistance and thereby bypass current from the interface. Though the initial flow of current, at full overlap, is 40 amperes, as determined by the setting of resistor T3, by the time the half-overlap relation of work W to ring R3 is reached, the current flow across the reduced interface is just about halved and brought down to about 20 amperes, the remaining 20 amperes being shunted away from the interface by the carbon pile P3. The interface flow of 20 amperes is in a circuit from battery 120, conductor 123, work W, ring R3, conductor 145, resistor T3 and by conductor 146 back to the battery 120, and the circuit of the 20 amperes bypassed by the pile P3 is from battery 120, conductor 123, conductor 143, carbon pile P4, conductor 145, resistor T3, and then by conductor 146 back to the other side of battery 120. This illustrates how current density is held within safe limits at the reduced area of interface and how the potential of ring R3 is maintained at substantially the same value as that of adjacent ring R3 so that no electrolytic action between the latter two rings can take place.
At ring R1, where in the assumed illustration the area of the work-ring interface is reduced to one-fourth, a circumstance which otherwise would mean an arc-producing current or concentration four times as great as would be present at full overlap, the current flow across the electrolyte between the work W and ring R1 is on the order of 10 amperes in a circuit extending from battery 129, conductor 123, work W, ring R1, conductor 125, resistor T1, and by way of conductor 126 back to the battery 129. Minimizing 30 amperes being shunted away by the carbon pile P1 in a circuit extending from battery 129, conductor 123, pile P1, conductor 125, resistor T1, and by conductor 126 back to the other side of the battery 120. Here again the elements of control circuit C1 have responded progressively as the contact area is diminished by lessening the overlap between work and ring preventing arc-producing current densities and maintaining the potential of ring R1 from such material change relative to ring R2 or R3 as would effect electrolytic decomposition or etching of one ring relative to the other.

Want the contact area between the work W and any of the abrasive rings to be reduced to zero, the increase in resistance at the interface is reflected in the abrasive ring becoming more negative, a condition to which the corresponding control circuit responds, in a manner that will now be clear, to increase the amount of current shunted by the preceding carbon pile to a value ultimately equal to the full 40 amperes for which the corresponding resistor (T1, T2, or T3) is set, so that at the moment of complete breaking of the effective contact condition at the ring there would be either no current flow to interrupt or only so small an amperage of current that destructive arc does not take place.

It will of course be understood that, as any conditions arise make one abrasive ring become more negative than another or more negative than the selected value, in the illustration, of six volts, the solenoid winding 128 that responds thereto not only changes the resistance of its carbon pile to maintain the desired fraction of the current away from the corresponding work-ring interface, but also holds the carbon pile correspondingly compressed at that resistance value; should the particular condition, such as a diminishing contact area, thereafter change so that the current area is increased, thus reducing the resistance at that particular work-ring interface, the voltage drop across the latter begins to decrease and the abrasive ring becomes less negative, with the result that the grid potential of the trolley 129 in the arm of the bridge becomes less negative, unbalancing the bridge in a direction to lessen the current flow through the corresponding resistor (T1, T2, or T3) as the case may be; converted to flow across the work-ring interface, when, on diminishing voltage drop across the work-ring interface, that voltage drop reaches the selected negative value of potential, illustratively six volts. This arrangement and setting have the advantage of avoiding dissipation of electrical energy in the carbon piles so long as conditions at the several work-ring interfaces are substantially equal among current concentrations or densities. The just-described settings are preferred and they are set out as illustrative and not by way of limitation; it will now be apparent that, depending upon various factors usually determined by a particular grinding job or shape or conformation of work-piece to be ground, the various taps and other controls of the several control circuits may be set to other relative values, including such values at which the carbon piles are of high or maximum resistance at ranges of operation when their respective abrasive rings become less negative than the illustrative six-volt value above selected six-volt current and density levels of the work-ring interface.

It will thus be seen that the control system and apparatus of Figure 12 provides dependable safeguards against the occurrence of detrimental actions when conditions at the work-wheel interfaces change. It is possible not only to achieve high rates of electrolytic decomposition at the work face in that high total current values can be employed, but also to controllably vary the respective current values in the several work-ring circuits to provide non-arcing current values and densities at the ends or limits of the stroke of the work-piece relative to the grinding wheel while maintaining higher current values at the middle portions of the stroke of the work, and at no time do potential differences between conductive abrasive rings arise as can cause detrimental electrolytic decomposition or etching of one ring relative to another. In this latter connection the system and controls of Figure 12 provide for maintaining the several component conductive rings of the grinding wheel at substantially the same potential or at such respective potentials, depending upon the particular conditions existing at the respective work-ring interfaces, that at no time does such a potential difference exist between any two of the plurality of rings as could effect detrimental electrolytic decomposition or etching of the rings.

For example, the conditions at one work-ring interface might be such as that indicated in Figure 12 between the work W and the grinding wheel R2, where the full value of current, illustratively 40 amperes, is flowing across that interface, in which case the carbons have at maximum resistance and its bridge control circuit is not called upon to change the pressure on the pile; the voltage drop across that interface, in the above assumed illustration, is 6.0 volts. But at the reduced contact area at the interface between the work W and the ring R2, the current flow across the interface is reduced (as much as the carbon pile P5 is held actuated by the energized bridge control circuit therefore to shunt away enough current to maintain the interface current at the desired safe value, and in such case the voltage drop across that interface is somewhat the solenoid winding 128 so as to induce a pressure on the carbon pile, thereby lessening the amount of current shunted away from the interface and increasing the current across the interface itself, thus virtually maintaining substantial constancy of current density within safe or non-arcing limits. As above noted, it is preferred to so set the various controls, and also to employ the rectifier 150, that the carbon pile need not be actuated in response to the corresponding abrasive ring becoming less negative than the selected value, such as six volts and, accordingly, in the control circuits as specifically illustrated in Figure 12, the carbon pile operating mechanism can be set or adjusted, as by adjusting the spring 130, so that it is of maximum resistance or virtually open-circuited, and the full value of current as determined by the resistor (T1, T2, or T3) is permitted to flow across the work-ring interface, when, on diminishing voltage drop across the work-ring interface, that voltage drop reaches the selected negative value of potential, illustratively six volts. This arrangement and settings have advantage of avoiding dissipation of electrical energy in the carbon piles so long as conditions at the several work-ring interfaces are substantially equal among current concentrations or densities. The just-described settings are preferred and they are set out as illustrative...
of the carbon pile. In this manner potential differences between adjacent abrasive rings can be held within predetermined or selected small values and inter-ring electrolytic destruction prevented from occurring.

It will thus be seen that there has been provided in this invention a grinding apparatus for the safe and efficient stock removal, by electrolytic decomposition, from a work-piece, together with insulated conductive multifaceted grinding wheels and controls therefore, in which the several objects above noted, together with many thoroughly practical advantages, are successfully achieved.

It will be seen that the invention, capable of embodiment in various forms, of which several are illustratively above set forth and described, is well adapted to meet the widely varying conditions and requirements met with in grinding operations and that difficulties, disadvantages and shortcomings of prior practices are dependably and efficiently overcome or their detrimental effects materially alleviated. Moreover, it will be seen that the apparatus, and the grinding wheels and controls thereof, are of wide flexibility of adaptation, or of wide flexibility of control of coatings, and that thereby high rate of stock removal and long life of the grinding wheel are made achievable through the conductive rings and control means.

As many possible embodiments may be made of the mechanical features of the above invention and as the art herein described might be varied in various parts, all without departing from the scope of the invention, it is to be understood that all matter hereinabove set forth, or shown in the accompanying drawings, is to be interpreted as illustrative and not in a limiting sense.

We claim:

1. In apparatus of the character described, in combination, a frame having a rotatable spindle carrying a grinding wheel for rotation thereby, said grinding wheel presenting an operative surface that comprises the aligned conductive faces of a plurality of conductive rings which are relatively closely spaced to each other and are insulated from each other, a work-piece holder, means associated with said frame for mounting said holder to hold a work-piece in operative relation to said operative surface of the grinding wheel for coating with said aligned faces of said conductive rings, means for supplying liquid electrolyte to and between the work-piece and said aligned conductive faces of said rings, a plurality of slip rings, one for each of said conductive rings and in respective electrical connection therewith, means insulatingly supporting said slip rings coaxially of said spindle for rotation therewith, unidirectional current-supply means with a plurality of control and supply circuits, one for each of said conductive rings, all of said circuits having the positive sides thereof electrically connected to said work-piece holder whereby the latter and the work-piece are electrically common to said circuits and having their negative sides in electrical connection respectively with said plurality of slip rings whereby unidirectional current, for electrolytic decomposition of the face of the work-piece presented to said conductive rings faces, may flow from the work-piece to each of said conductive rings, and control means associated with each of said circuits for limiting maximum current flow in each of said circuits to a value not greater than the critical arcing current between the work-piece and the ring face.

2. In claim 1, in which the control means associated with each circuit comprises means responsive to changes in current flow in the circuit as are caused by change in the resistance between the work face and the face of the conductive ring of the circuit.

3. An apparatus as claimed in claim 1, in which the control means of each of said circuits comprises means responsive to changes in the potential of the conductive ring of the circuit relative to the potential of the work-piece.

4. In apparatus of the character described, in combination, a frame having a rotatable spindle carrying a grinding wheel for rotation thereby, said grinding wheel presenting an operative surface that comprises the aligned conductive faces of a plurality of conductive rings which are relatively closely spaced to each other and are insulated from each other, a work-piece holder, means associated with said frame for mounting said holder to hold a work-piece in operative relation to said operative surface of the grinding wheel for coating with said aligned faces of said conductive rings, means for supplying liquid electrolyte to and between the work-piece and said aligned conductive faces of said rings, a plurality of slip rings, one for each of said conductive rings and in respective electrical connection therewith, means insulatingly supporting said slip rings coaxially of said spindle for rotation therewith, unidirectional current-supply means with a plurality of control and supply circuits, one for each of said conductive rings, all of said circuits having the positive sides thereof electrically connected to said work-piece holder whereby the latter and the work-piece are electrically common to said circuits and having their negative sides in electrical connection respectively with said plurality of slip rings whereby unidirectional current, for electrolytic decomposition of the face of the work-piece presented to said conductive rings faces, may flow from the work-piece to each of said conductive rings, and means for preventing detrimental electrolytic decomposition of any one of said conductive rings relative to another, said last-mentioned means comprising control means associated with said control and supply circuits substantially regulating the respective potentials of said conductive rings relative to the potential of the work-piece within relative values insufficient for detrimental electrolytic action between conductive rings.

5. In apparatus of the character described, in combination, a frame having a rotatable spindle carrying a grinding wheel for rotation thereby, said grinding wheel presenting an operative surface that comprises the aligned conductive faces of a plurality of conductive rings which are relatively closely spaced to each other and are insulated from each other, a work-piece holder, means associated with said frame for mounting said holder to hold a work-piece in operative relation to said operative surface of the grinding wheel for coating with said aligned faces of said conductive rings, means for supplying liquid electrolyte to and between the work-piece and said aligned conductive faces of said rings, a plurality of slip rings, one for each of said conductive rings and in respective electrical connection therewith, means insulatingly supporting said slip rings coaxially of said spindle for rotation therewith, unidirectional current-supply means with a plurality of control and supply circuits, one for each of said conductive rings, all of said circuits having the positive sides thereof electrically connected to said work-piece holder whereby the latter and the work-piece are electrically common to said circuits and having their negative sides in electrical connection respectively with said plurality of slip rings whereby unidirectional current, for electrolytic decomposition of the face of the work-piece presented to said conductive rings faces, may flow from the work-piece to each of said conductive rings, and means for preventing detrimental electrolytic decomposition of any one of said conductive rings relative to another, said last-mentioned means comprising control means associated with said control and supply circuits substantially regulating the respective potentials of said conductive rings relative to the potential of the work-piece within relative values insufficient for detrimental electrolytic action between conductive rings.
bedded therein in said closely spaced relation with their said aligned conductive faces aligned with a face of said back whereby surfaces of the rings other than said aligned conductive faces are prevented from taking part in electrolytic action. An electric grinding wheel comprising a back of grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

8. An apparatus as claimed in claim 1, in which said grinding wheel comprises a back of insulating material with said plurality of conductive rings substantially embedded therein in said closely spaced relation with their said aligned conductive faces aligned with a face of said back whereby surfaces of the rings other than said aligned conductive faces are prevented from taking part in electrolytic action. An electric grinding wheel comprising a back of grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

9. An apparatus as claimed in claim 1, in which said grinding wheel comprises a back of insulating material with said plurality of conductive rings substantially embedded therein in said closely spaced relation with their said aligned conductive faces aligned with a face of said back whereby surfaces of the rings other than said aligned conductive faces are prevented from taking part in electrolytic action. An electric grinding wheel comprising a back of grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

10. An apparatus as claimed in claim 1, in which the means insulatingly supporting said slip rings coaxially with said back comprises said grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

11. An apparatus as claimed in claim 1, in which the means insulatingly supporting said slip rings coaxially with said back comprises said grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

12. An apparatus as claimed in claim 1, in which the means insulatingly supporting said slip rings coaxially with said back comprises said grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

13. An apparatus as claimed in claim 1, in which the means insulatingly supporting said slip rings coaxially with said back comprises said grinding wheel which is provided with an insulating back to which said slip rings are coaxially secured.

14. An apparatus as claimed in claim 13, in which the slip rings are of lesser radius than said conductive ring faces and are thereby out of range of centrifugally thrown electrolyte.

15. An apparatus as claimed in claim 13, in which said grinding wheel back of insulating material has a plurality of surfaces of revolution at angles to each other, said plurality of conductive rings being associated with one of said surfaces of revolution and said slip rings being substantially protected from centrifugally thrown electrolyte in that they are associated with another of said surfaces of revolution.

16. An apparatus as claimed in claim 15, in which the surfaces of revolution on which said conductive rings and said slip rings are respectively associated are respectively a side face of the grinding wheel back and a substantially juxtaposed opposite side face thereof, the faces of said conductive rings being annular.

17. An apparatus as claimed in claim 15, in which the surfaces of revolution on which said conductive rings and said slip rings are respectively associated are respectively a peripheral surface and a side surface of the grinding wheel.

18. In electrolytic grinding apparatus, in combination, a work support and a grinding wheel having means for rotatably supporting it to present a conductive operative surface to a work-piece on said work support and having means for supplying liquid electrolyte to and between the work-piece and the operative surface of the grinding wheel for electrolytic decomposition of the work-piece face in response to unidirectional current flow from the latter to the operative surface of the grinding wheel, and means for increasing the rate of electrolytic decomposition at the work-piece and for control against detrimental arcing through the electrolyte comprising unidirectional current-supply means with a plurality of control and supply circuits, all of said circuits having their positive sides thereof electrically connected to said work support whereby the latter and the work-piece are electrically common to said circuits, said grinding wheel comprising a back of insulating material and said grinding wheel operative surface comprising a plurality of conductive rings carried and insulatingly supported on said back and presenting relatively closely spaced aligned conductive faces for coaction with the work-piece on said work support, said conductive rings being recessed into the insulating material of said back whereby surfaces of the rings other than said aligned conductive faces are prevented from taking part in electrolytic action, slip rings, one for each conductive ring and electrically connected respectively thereto, the negative sides of said circuits being in electrical connection respectively with said plurality of slip rings whereby unidirectional current, for electrolytic decomposition of the face of the work-piece presented to said conductive ring faces, may flow from the work-piece to each of said conductive rings, and control means associated with each of said circuits for preventing current flow therein from reaching detrimental arcing density through the electrolyte between the work-piece and the respective conductive ring faces.
latter to the operative surface of the grinding wheel, and means mounting said work support and said grinding wheel for relative movement therebetween to effect progression or recession of electrolytic grinding action on the work-piece face, and means for controlling against detrimental current concentrations as tend to be caused by changes in operating conditions between the work face and the conductive operative surface of said grinding wheel as relative movement therebetween takes place comprising unidirectional current-supply means with a plurality of control and supply circuits, all of said circuits having the positive sides thereof electrically connected to said work support whereby the latter face and the work-piece are electrically common to said circuits, said grinding wheel comprising a back of insulating material and said grinding wheel operative surface comprising a plurality of conductive rings carried and insulated from each other by said back and presenting relatively closely spaced aligned conductive faces for connection with the work-piece on said work support, said conductive rings being recessed into the insulating material of said back whereby surfaces of the rings other than said aligned conductive faces are prevented from taking part in electrolytic action, slip rings, one for each conductive ring and electrically connected respectively thereto, the negative sides of said circuits being in electrical connection respectively with said plurality of slip rings, and control means associated with said circuits adapted to limit maximum current flow in each of said circuits to a value less than that which causes detrimental arcing between the work-piece face and a ring face, said control means including means responsive to changes in the electrical condition between the work-piece face and the ring face to change the standard at which to limit the current flow whereby the current flows in said circuits may be limited at different standards of maximum according as, for example, overlaps or areas or pressures of contact at the respective work-piece face and ring faces differ from each other.

20. An apparatus as claimed in claim 19, in which the last-mentioned responsive means comprises a means, one for each of said circuits, responsive to changes in the potential of the conductive ring of the circuit relative to the potential of the work-piece.

21. An apparatus as claimed in claim 19, in which said last-mentioned responsive means comprises electro-responsive regulating means and electronic means, one for each of said circuits, responsive to the IR drop between the work-piece face and the conductive ring of its associated circuit.

22. A grinding wheel for use in an electrolytic grinding apparatus and adapted to coat with unidirectional current supply and control circuits for increasing the rate of electrolytic decomposition at the work-piece face and for control against detrimental arcing through the electrolyte between the work-piece face and the grinding wheel operative surface, said grinding wheel comprising a back of insulating material supporting a plurality of conductive rings which are relatively closely spaced to each other and present aligned conductive faces to form the operative surface of the grinding wheel for electrolytic grinding action with the work-piece face, and a plurality of slip rings, one for each of said conductive rings, coaxially secured to and insulated from each other by said insulating back at respective locations in the latter out of the range of liquid electrolyte centrifugally cast off said conductive rings, the electrical connections between said slip rings and their respective grinding wheel conductive rings whereby the latter are connectable respectively into said circuits.

23. A grinding wheel as claimed in claim 22, in which the slip rings are of lesser radii than said conductive ring faces and thereby out of range of centrifugally thrown electrolyte.

24. A grinding wheel as claimed in claim 22, in which said grinding wheel back of insulating material has a plurality of surfaces of revolution at angles to each other, said plurality of conductive rings being associated with one of said surfaces and said slip rings being substantially protected from centrifugally thrown electrolyte in that they are associated with another of said surfaces of revolution.

25. A grinding wheel as claimed in claim 24, in which the surfaces of revolution with which said conductive rings and said slip rings are respectively associated are respectively a side face of the grinding wheel back and a substantially juxtaposed opposite side face thereof, the faces of said conductive rings being annular.

26. A grinding wheel as claimed in claim 24, in which the surfaces of revolution with which said conductive rings and said slip rings are respectively associated are respectively a peripheral surface and a side surface of the grinding wheel.

27. A grinding wheel as claimed in claim 22, in which said conductive rings and said slip rings are substantially embedded, except for their respective operative faces, in the insulating material of said back and at opposed side faces of the latter.

28. A grinding wheel as claimed in claim 22, in which said conductive rings and said slip rings are located at respective opposed side faces of the grinding wheel back, the electrical connections respectively therebetween comprising conductive transverse elements that pass through the back and at their respective ends are secured to the conductive rings and the slip rings.

29. A grinding wheel as claimed in claim 22, in which said conductive rings and said slip rings are embedded, except for their respective operative faces, in a peripheral face of the grinding wheel back and in an annular side face thereof.

30. A grinding wheel as claimed in claim 22, in which said plurality of conductive rings are embedded in a peripheral face of the grinding wheel back and said plurality of slip rings are secured to the back at an annular side face thereof.

31. In electrolytic grinding apparatus, in combination, a work support and a grinding wheel having means for rotatably supporting it to present a conductive operative surface to a work-piece on said work support and having means for supplying liquid electrolyte to and between the work-piece and the conductive operative surface of the grinding wheel for electrolytic decomposition of the work-piece face in response to unidirectional current flow from the latter to the operative surface of the grinding wheel, means mounting said work support and said grinding wheel for relative movement therebetween to effect progression or recession of electrolytic grinding action on the work-piece face whereby overlap or pressure or area of contact between the work-piece face and the conductive operative surface of the grinding wheel may change, unidirectional current-supply means with a control and supply circuit having the positive side thereof electrically connected to the work support and having means for maintaining electrical connection of its negative side to said conductive operative surface as the wheel rotates, and control means associated with said circuit for limiting maximum current flow across the electrolyte between the work-piece face and the conductive operative surface of the wheel within a value corresponding to substantially maximum non-arcing current density through the electrolyte and constructed and operating to effect current limitation at maximum values that vary according as the overlap between the grinding wheel conductive surface and the work-piece face or the pressure or area of contact therewith varies, said circuit and said control means comprising regulating means for maintaining substantially constant the current output of said current-supply means, together with means forming a variable shunt across said work-piece and said conductive surface of the wheel and means responsive to an electrical function of electrical
energy dissipated in electrolytic action upon the work-piece face for controlling said variable shunt.

32. An apparatus as claimed in claim 31, in which there is provided electromagnetic means for controlling said variable shunt and said last-mentioned responsive means comprises electronic means having an input circuit connected to respond to potential changes of said conductive surface of the wheel relative to the potential of the work-piece and having an output circuit connected to control the energization of said electromagnetic means.

33. In electrolytic grinding apparatus, in combination, a work support and a grinding wheel having means for rotatably supporting it to present a conductive operative surface to a work-piece on said work support and having means for supplying liquid electrolyte to the interface between the work-piece and the operative surface of the grinding wheel for electrolytic decomposition of the work-piece face in response to unidirectional current flow from the latter to the operative surface of the grinding wheel, and means for increasing the rate of electrolytic decomposition at the work-piece and for control against detrimental arcing through the electrolyte comprising unidirectional current-supply means with a plurality of control and supply circuits, all of said circuits having the positive sides thereof electrically connected to said work support whereby the latter and the work-piece are electrically common to said circuits, said grinding wheel operative surface comprising a plurality of conductive rings insulated from each other and presenting substantially aligned conductive faces for conduction with the work-piece on said work support, slip rings, one for each conductive ring and electrically connected respectively thereto, the negative sides of said supply circuits being in electrical connection respectively with said plurality of slip rings, and control means associated with said circuits for effecting total current flow therein greater than that which, if passed from the work-piece to any one conductive ring, would cause detrimental arcing and for limiting maximum current flow in each of said circuits to a value less than that which causes detrimental arcing between the work-piece and the ring face alone, said control means including means, one for each of said circuits and each responsive to the potential of the conductive ring in its circuit relative to the potential of the work-piece, for maintaining at substantially the same level the potential of all of said conductive rings and thereby prevent substantial electrolytic decomposition between rings.

References Cited in the file of this patent

UNITED STATES PATENTS

977,325 Nichols Nov. 29, 1910
1,017,671 Jenkins Feb. 20, 1912
2,091,249 Bieling Aug. 31, 1937
2,201,410 Sinmonds May 21, 1940
2,431,295 Metzger et al. Oct. 12, 1947
2,526,423 Rudorff Oct. 17, 1950
2,557,047 Geopfert et al. June 12, 1951
2,590,927 Brandt et al. Apr. 1, 1952

FOREIGN PATENTS

257,468 Switzerland Apr. 1, 1949

OTHER REFERENCES

Electrolytic Grinding, Steel, March 17, 1952, pp. 84–86.
