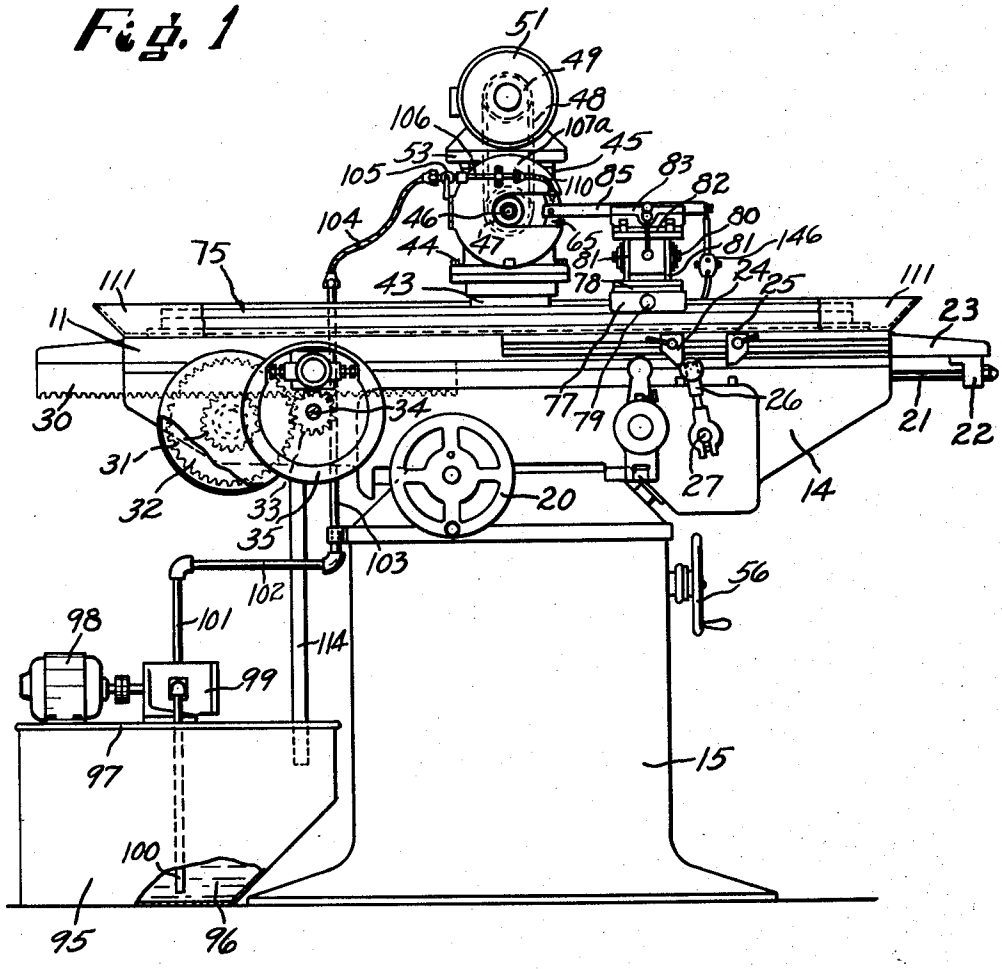
Jan. 5, 1960 S. S. KISTLER 2,920,026

GRINDING MACHINE

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Fig. 1



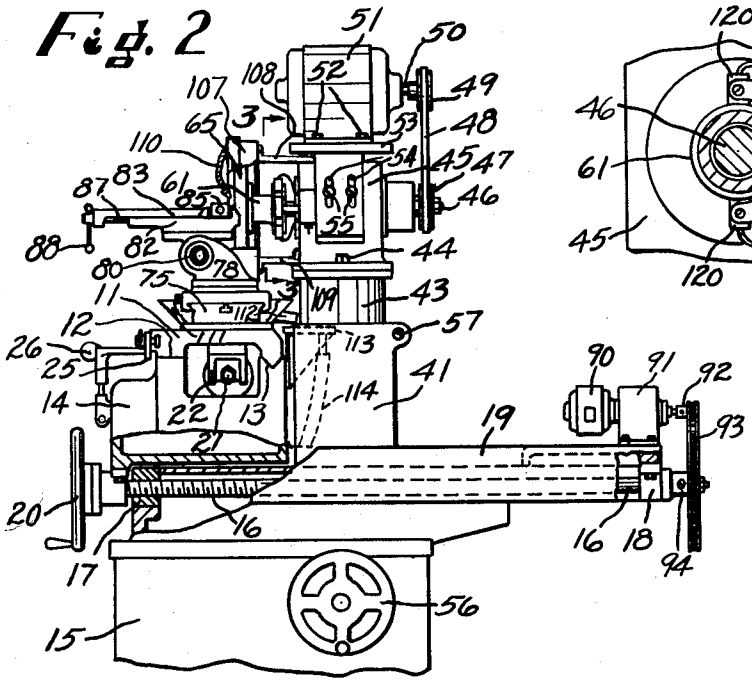
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GRINDING MACHINE

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Fig. 2



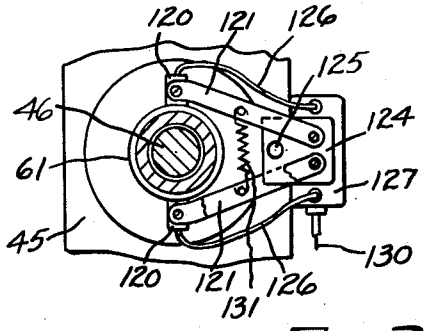


Fig. 3

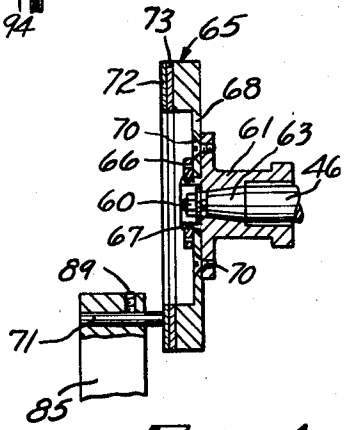


Fig. 4

Fig. 6

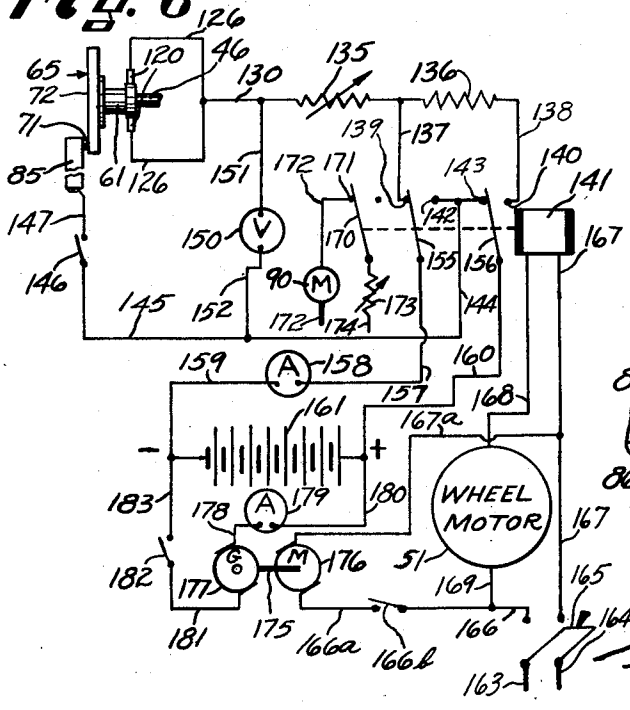
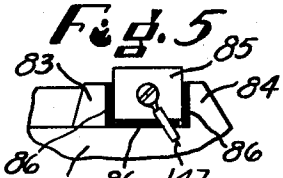


Fig. 5



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GRINDING MACHINE

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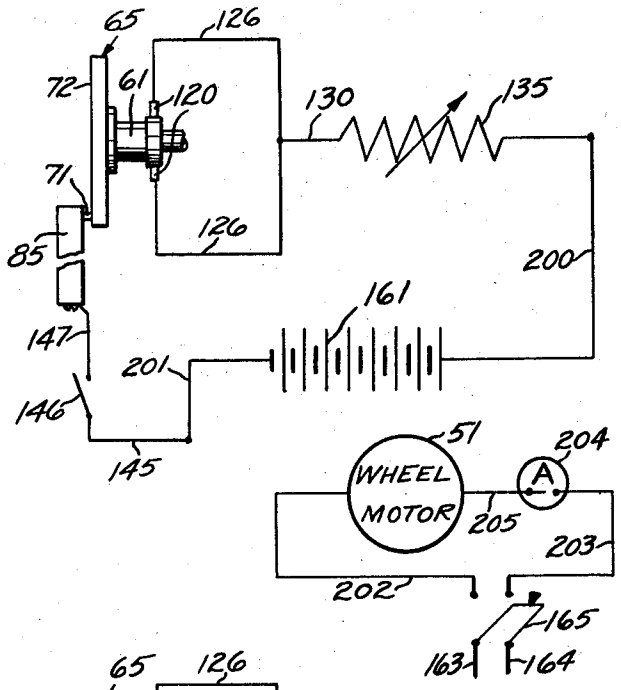


Fig. 7

Fig. 8

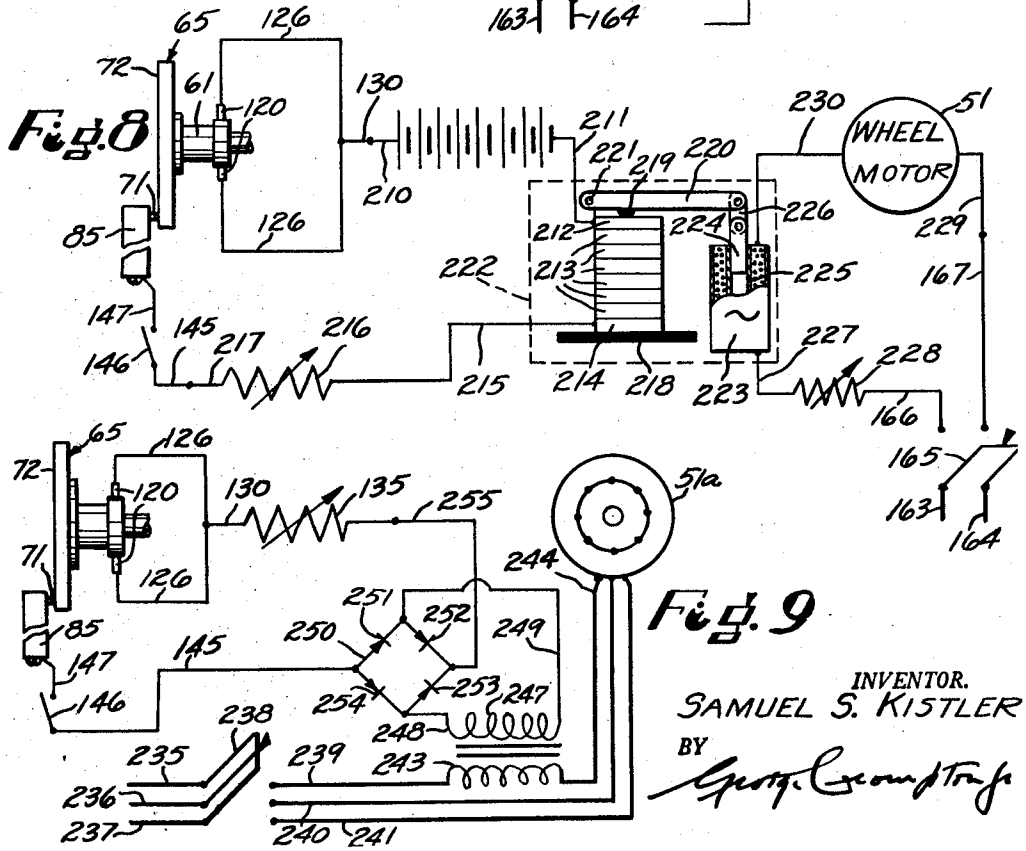


Fig. 9

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GRINDING MACHINE

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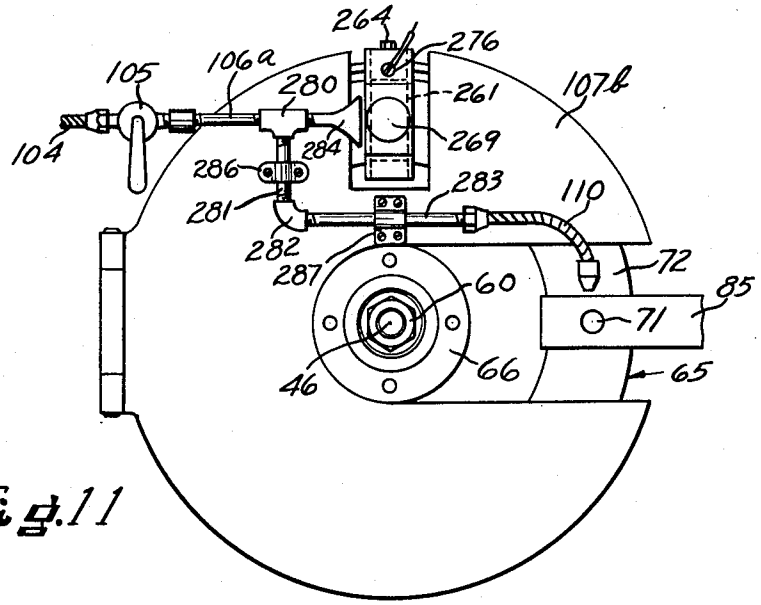


Fig. 11

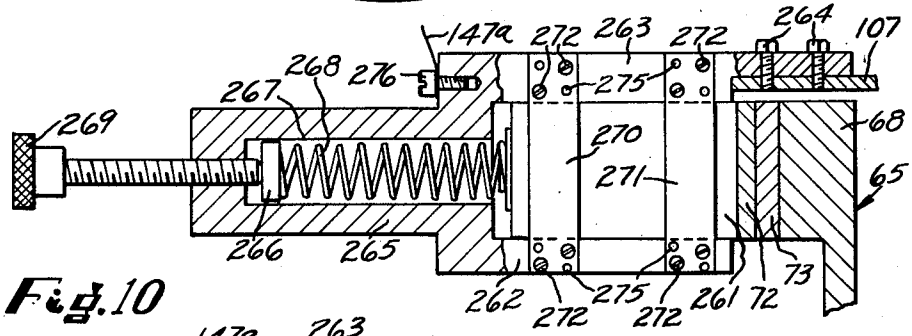


Fig. 10

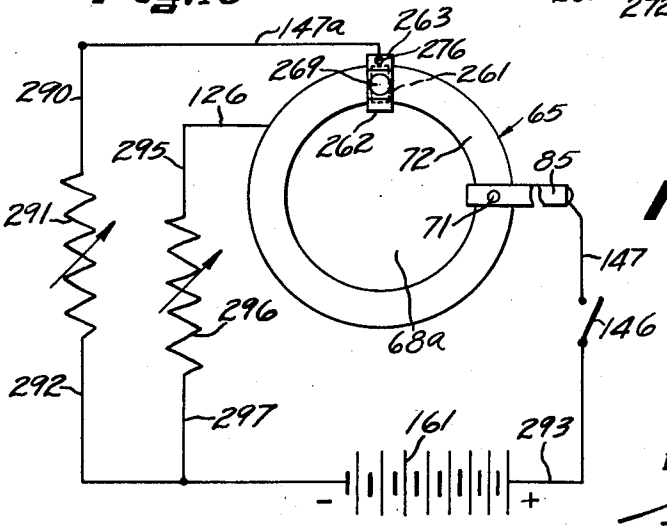


Fig. 12

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United States Patent Office 2,920,026 Patented Jan. 5, 1960

2,920,026

GRINDING MACHINE

Samuel S. Kistler, West Boylston, Mass., assignor to Norton Company, Worcester, Mass., a corporation of Massachusetts

Application May 1, 1952, Serial No. 285,377

8 Claims. (Cl. 204—218)

The invention relates to grinding machines.

One object of the invention is to provide means for dressing the grinding wheel without the use of a corporeal tool. Another object is to provide means for dressing grinding wheels, especially diamond grinding wheels, without fracturing any abrasive granules which, especially when diamond grinding wheels are involved, saves valuable abrasive material. Another object is to provide an automatic machine, especially for machining the hard carbides, which can remove stock by electrolytic action as well as by grinding and in which the grinding wheel is automatically dressed whenever it needs dressing. Another object is to provide means for dressing a grinding wheel by electrolytic action.

Another object of the invention is to provide means for dressing a wheel without the use of a corporeal tool in direct contact with the wheel and which means also keeps the face of the wheel true. Another object is to provide a grinding machine for high speed removal of very hard stock with efficient means for dressing and truing the grinding wheel from time to time. Another object of the invention is to provide means for intermittently or continuously removing the load or glaze from the wheel face of a grinding wheel. Another object of the invention is to provide a grinder in which the work piece is eaten away by electrolytic action as it is being reduced by grinding and in which the grinding wheel is never allowed to load because as fast as it loads the load is removed electrolytically and in which the grinding wheel is kept free cutting by slow electrolytic removal of the wheel bond.

Other objects will be in part obvious or in part pointed out hereinafter.

In the accompanying drawings illustrating several embodiments and modifications of the invention,

Figure 1 is a front elevation of the grinding machine,

Figure 2 is a side elevation of the grinding machine,

Figure 3 is a sectional view on an enlarged scale taken on the line 3—3 of Figure 2,

Figure 4 is a fragmentary horizontal sectional view on an enlarged scale of the grinding wheel and work piece holder,

Figure 5 is a fragmentary side elevation on an enlarged scale illustrating the work holder clamp,

Figure 6 is a wiring diagram,

Figures 7, 8 and 9 are wiring diagrams illustrating further embodiments of the invention,

Figure 10 is a fragmentary view partly in side elevation and partly in section illustrating a modification of the invention,

Figure 11 is a front elevation of the wheel guard cover and associated parts and further to illustrate the modification of Figure 10,

Figure 12 is a wiring diagram illustrating another embodiment of the invention.

Referring first to Figures 1 and 2, the machine has 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 embodiment of the invention. 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 journalled 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** by the fluid pressure 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**. I need not illustrate or describe the hydraulic mechanism of the aforesaid Patent 2,101,787 which is controlled by the table dogs **24** and **25** which alternately engage an interposed reversing lever **26** mounted on a shaft **27** projecting from the front of the cross slide **14**. I 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** which is provided with a cylindrical bore, not shown, receiving a cylindrical post **43**. Adjustably 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** journalling 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**.

Referring now to Figure 4 as well as to Figure 2, on the front of the spindle **46** is a nut **60** which holds a flanged sleeve **61** having a tapered bore on the front end of the spindle **46** which has a conical portion **63** engaging the tapered bore of the sleeve **61**. A so-called cup shaped grinding wheel **65** is secured to the flanged sleeve **61** by means of a spanner nut **66** which engages an exteriorly threaded hollow cylindrical portion **67** integral with and extending forwardly from the sleeve **61**, the usual hole in the center of the back **68** of the grinding wheel **65** being of a size nicely to fit the portion **67** thus to center the grinding wheel **65** on the spindle **46** while the nut **66** clamps the back **68** against the flange of the sleeve **61**. In order to apply the torque of the spindle **46** to the grinding wheel **45** screws **70** extend through holes in the back **68** and into threaded holes in the flange portion of the sleeve **61**.

In accordance with the present invention the grinding wheel **65** is electrically conductive meaning that it is a good conductor of electricity. For the grinding of the hard cemented carbides (e.g. cobalt bonded tungsten carbide and/or tantalum and/or titanium carbide) as represented by a work piece **71**, diamond grinding wheels are normally used insomuch as silicon carbide grinds the cemented carbides only slightly and aluminum oxide

grinds them hardly at all. Because of the high cost of diamonds such diamond grinding wheels usually have only a thin rim or (in this case) a thin annular face **72** constituting the diamond bearing portion of the wheel. In the manufacture of diamond grinding wheels, the diamond bearing portions have been bonded with phenolic resin or vitrified bond or sintered metal bond; because in accordance with the present invention the abrasive portion of the wheel must be electrically conductive I utilize in the present invention metal bonded diamond wheels that is to say at least the abrasive bearing thin annular face **72** or the equivalent comprises abrasive bonded with metal. For manufacturing reasons, the diamond bearing portion is usually integral with a molded metallic portion such as the annular portion **73** which is made of metal but contains no diamonds. If convenient I prefer that the back **68** be also made of metal thus to connect the abrasive face **72** in the electrical circuit but any other manner of so doing such as by means of brushes engaging the annular portion **73** may be used.

I will not give any long description of the manufacture of metal bonded diamond wheels since they are fully described in the patent literature but merely note that they are usually manufactured by mixing the diamond particles with powdered metal placing the mixture in a mold and thereafter sintering the pressed pieces usually in a protective atmosphere such as hydrogen. Also some wheels are made by electroplating operations. I may use any metal bond which reasonably well conducts electricity and practically all metals do conduct electricity at least those which are capable of being sintered do so and the only precaution is to avoid the use of such a high volume of diamonds or abrasive fillers as to interrupt the conductive path. However, currently the concentration of diamonds in metal bonded diamond wheels in the diamond bearing portion does not exceed 25% by volume the rest being substantially all metal and I can readily use wheels of such character or having lesser concentration of diamonds. Merely as an illustrative embodiment I find that a mixture of copper and tin powders in the proportion of about 82% copper and 18% tin makes an excellent bond for diamond grinding wheels usable in this invention.

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 all 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 desired 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 fixtures **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 5, a movable vise jaw **83** and a fixed vise jaw **84** cooperate to hold 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** and the screw **87** of course engages a nut or 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 or carriage **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 grinding wheel **65** relative to the work holding bar **85**. Referring to Figure 4, the work piece **71** is held by the bar **85**, as it extends through a hole therein and is secured in place by means of a screw **89**.

Referring now to Figure 2, for a continuous power infeed of the cross slide **14** to advance the work piece **71** at a steady rate toward the annular face **72** of the grinding wheel **65** 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 gear **94** which is secured to the rear end of the screw shaft **16**. In the practice of the invention this power infeed 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 conservation of the grinding wheel **65** a continuous infeed such as produced by the mechanism just described is preferred.

Referring now to Figure 1, I provide a tank **95** containing liquid **96** which in accordance with this invention is an electrolyte. Ordinary salt water will do very well and clean ocean water can be used. However, it is probably more convenient in most places to use 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 salammoniac (ammonium chloride) can be used. The carbonates such as sodum 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 cover plate **97** on 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 output 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 cover **107***a* of a wheel guard **107** secured by brackets **108** and **109** to the wheel head **45**. The other end of the pipe **106** that is secured to the wheel guard cover **107***a* is connected to a deformable nozzle **110** which can be bent with the hand to give it the desired curve and when bent into a particular shape will keep that shape despite the flow of liquid therethrough under moderate pressure. This deformable nozzle **110** will be set in such shape as to direct the liquid onto the face **72** of the grinding wheel **65** over the entire locus where it will be contacted or nearly contacted by the work piece **71**.

Referring to Figure 1, the liquid which flows onto the work piece **71** is eventually collected by a large pan **111** which is built 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**.

Referring now to Figure 3, I provide a pair of brushes **120** in contact with the flanged sleeve **61**, and these brushes are held in such contact by means of arms **121** articulated to an insulated block **124** secured by a pin **125** to the wheel head **45**. Electric wires **126** connect the brushes **120** with a connection box **127** in which the wires **126** are connected to a lead in wire **130**. The articulated arms **121** are connected by a spring **131** thus serving to keep the brushes **120** in firm contact with the flanged

sleeve 61. The connection box 127 is secured to the block 124.

Referring now to Figure 6 wherein the wires 126 and 130 are identified, the latter is connected to a variable resistance 135 which is connected to a resistance 136 and to a wire 137, the resistance 136 is connected to a wire 138 and the wires 137 and 138 are connected to contact terminals 139 and 140 of a relay switch 141 having also contact terminals 142 and 143. The contact terminals 142 and 143 are connected by a wire 144 to a wire 145 to a hand switch 146 to a wire 147 which is shown in Figure 5 as connected to the work holding bar 85. Across the line between the wires 130 and 145 is a volt meter 150 connected to these lines by wires 151 and 152.

Switch arms 155 and 156 of the relay switch 141 are connected by wire 157, ammeter 158 and wire 159 in the former case and by wire 160 in the latter case to a storage battery 161. I have had excellent results using an Edison type storage battery.

When the relay switch 141 is in the position shown, the positive side of the battery 161 is connected through wire 160, switch arm 156, terminal 143, wire 144, wire 145, hand switch 146, wire 147 to the work holding bar 85 and thus the work piece 71 becomes positive. The negative side of the battery is connected through wire 159, ammeter 158, wire 157, switch arm 155, terminal 139, wire 137, resistance 135, wire 130, wires 126, brushes 120 to the flanged sleeve 61 which is in direct electrical connection with the back 68 which is in direct electrical connection with the annular portion 73 which is in direct electrical connection with the thin annular face 72 and therefore this grinding face of the grinding wheel 65 becomes negatively charged. With the liquid electrolyte 96 flowing between the work piece 71 and the grinding wheel 65, assuming now the hand switch 146 is closed, electric current flows in the above described circuit and removes stock from the work piece 71. It has been found that, with the continuous infeed represented by the motor 90 and associated mechanism set for a low rate of infeed stock is steadily removed from the work piece 71 without any actual contact between it and the face 72. Thus grinding proceeds without any wear on the "grinding" wheel 65 but if the infeed is increased actual grinding contact will be made and the wheel 65 will grind in the normal fashion but stock will still be removed electrolytically from the work piece 71 so therefore the rate of stock removal is due to the combined factors of grinding and electrolytic action and removal of stock can be at a higher rate than by any purely grinding operation with all the grinding variables the same.

Thus in the machine herein illustrated, removal of stock can take place at various rates and if desired all wear of the grinding wheel 65 can be eliminated. This is significant since the demand for diamond grinding wheels now exceeds the production rate of such grinding wheels from all sources in the country. Furthermore stock of hard carbide tools can be removed in a machine of this character with a metal bonded grinding wheel in which the abrasive is aluminum oxide or silicon carbide or indeed it might be quartz sand. Furthermore it appears that the wheel 65 might be a plain metal wheel with no abrasive whatsoever, for example a copper or brass wheel since for a low rate of infeed there will be no contact between work piece 71 and the wheel 65 although they will approach within a thousandth of an inch or a fraction thereof.

It is still important, however, to use a rotating wheel because the electrolyte must be swept away from the work piece 71 in order to produce an effect like grinding namely to produce a good surface which is the mate for the surface of the wheel 65. The electrolytic action is therefore analogous to grinding and so much like it that the wheel 65 appears to be grinding even if there is no actual contact. When the wheel 65 does contact the work piece 71 that fact can be ascertained by the presence of the customary grinding sparks.

I have found that when a high rate of infeed in produced and assuming now the grinding wheel 65 is a metal bonded diamond wheel, the face 72 of the wheel 65 will gradually load up and glaze. This manifests itself in overloading of the wheel motor 51. In accordance with my invention I dress the face 72 of the wheel 65 from time to time by electrolytic action and this I will now explain by reference again to Figure 6.

Main power lines 163 and 164 represent a source of current, for example, single phase 60 cycle current at 220 volts can be used. The power line 163 is shown in Figure 6 as connected through a knife switch 165 to a wire 166. The power line 164 is connected through the knife switch 165 to a wire 167 which is connected to the solenoid of the relay 141 which is connected by a wire 168 to the motor 51 the other terminal of which is connected by a wire 169 to the wire 166. Loading and glazing of the grinding wheel 65 by excessive infeed continued for too long results in overloading the motor 51 which results in a rise in the line current through the solenoid of the relay 141. This overloading, when it reaches a critical figure, swings the switch arms 155 and 156 to the right connecting the former to the terminal 142 and the latter to the terminal 140. When this happens, as a glance at the circuit of Figure 6 will quickly show, the grinding wheel 65 becomes positive and the work piece 71 becomes negative. Consequently the electrolytic action now removes some metal bond from the abrasive face 72 at the surface thereof including any metal loading on this face. In fact the loading metal is first removed. After a short time the current passing through the motor 51 and solenoid of the relay 141 drops to a lower amperage value and then the switch arms 155 and 156 return to the position shown in Figure 6 and grinding is resumed.

With the stopping of the electrolytic removal of stock from the workpiece a continuation of the infeed at the same rate would soon stall the machine and would further load and glaze the face of the grinding wheel 65, so I provide for automatically cutting out the infeed electric motor 90 whenever the current is reversed to dress the grinding wheel 65 in the manner described. Accordingly in Figure 6 I have shown an additional switch arm 170 which is part of the relay switch 141 and this is normally in contact with a terminal 171 connected by a wire 172 to the motor 90 the other side of which is connected to a power line 172. The switch arm 170 is connected through a variable resistance 173 to a power line 174. The power lines 172 and 174 may represent a relatively low voltage source of electric energy, for example 110 volts single phase A.C. but preferably a 6 or 12 volt battery and the motor 90 may be a direct current motor the speed of which can very well be controlled with a simple variable resistance 173 such as an ordinary rheostat. With low voltage in this line a circuit breaker will not be necessary and of course the motor 90 can be a low power motor since it is merely turning the feed screw 16 through reduction gearing and needs only little more than the power required to overcome the friction of the reduction gearing. It will now be seen that whenever the current is reversed to make the grinding wheel positive the motor 90 is cut out so that grinding is discontinued. This makes it possible for the electrolytic action to dress and true the wheel, eliminating load therefrom, and this action is not interfered with by any infeed of the workpiece at this time.

I provide a converter 175 the motor 176 of which is connected to the wires 166 and 167 via wires 166*a* and 167*a* and switch 166*b* and the generator 177 of which is connected at one side by a wire 178 to an ammeter 179 and by a wire 180 to the positive terminal of the battery 161. The other side of the generator 177, which is a direct current generator, is connected by a wire 181 to a hand switch 182 to a wire 183 which is connected to the

negative terminal of the battery 161. This converter 175, therefore, keeps the battery 161 charged. I have found that the output of the battery 161 can be kept at 38 volts plus or minus two volts. This I find to be sufficient electromotive force for practical electrolytic grinding and for dressing of the wheel 65 by electrolytic action in accordance with the invention. The switches 166*b* and 182 are normally kept closed but of course may be opened from time to time whenever a very steady current is wanted because the battery 161 alone gives, over a considerable interval of time, a current of quite constant electromotive force. I have found, however, that a fluctuation of two volts on a standard voltage of 38 is not detrimental to the electrolytic grinding and dressing. The dressing action is also a truing action as not only is the load removed from the wheel face and the wheel sharpened but its surface is kept trued.

In the modification shown in Figure 7, the variable resistance 135 is directly connected to the positive terminal of the storage battery 161 by means of a wire 200 and the wire 145 is directly connected to the negative terminal of the battery 161 by means of a wire 201. The power line 163 is connected to the wheel motor 51 (through the switch 165) by means of a wire 202 and the power line 164 is connected (also through the switch 165) by a wire 203 to an ammeter 204 which is connected by a wire 205 to the wheel motor 51. In this embodiment of the invention the grinding wheel 65 is positive, that is to say it is the anode whenever the switch 146 is closed. The operator can watch the ammeter 204 and whenever the current is excessive he can close the switch 146 or, in case the switch 146 is closed all the time, he can adjust the variable resistance 135 to increase the flow of current in the circuit therethrough. Thus, in this form of the invention, the wheel 65 is dressed from time to time or if desired continuously at a rate controlled by the operator, and the work piece 71 is reduced in size entirely by grinding. Metal from the wheel 65 will not plate upon the work piece 71 as it is carried away by the fast moving electrolytic fluid issuing from the nozzle 110. Thus, if desired, dressing of the wheel can be continuous and in any event more stock can be removed than was heretofore possible due to the fact that the wheel 65 is kept free cutting. Furthermore no time is lost for dressing of the wheel. As fast as the face 72 of the wheel 65 loads up the metal load from the work piece 71 is removed electrolytically and also some of the metal bond is removed to a sufficient extent to keep the wheel 65 free cutting. The other parts and connections shown in Figure 7 are those already identified in connection with the previous description and the previously used numerals are applied thereto.

Referring now to Figure 8, in this embodiment of the invention the operator does not have to watch an ammeter. The wire 130 is connected by a wire 210 to the positive terminal of the battery 161 while the negative terminal of the battery 161 is connected by a wire 211 to a copper disc 212 of a carbon pile having carbon discs 213 while another copper disc 214 is connected by a wire 215 to a variable resistance 216 which is connected by a wire 217 to the wire 145. The discs 213 between the discs 212 and 214 act as a carbon pile regulator. The copper disc 214 is supported by an insulating support 218 while the disc 212 is contacted by an insulating presser 219 on a lever 220 pivoted on a pin 221 projecting from a suitable frame 222 indicated only by dash lines in Figure 8 and to this frame 222 the insulating support 218 is also attached. Secured to this frame 222 is a solenoid coil 223 which is wound for alternating current, for example 60 cycle alternating current. The iron solenoid core 224 has a sliding fit in a brass sleeve 225 in the solenoid coil 223 and is connected by a link 226 to the lever 220. One end of the solenoid coil 223 is connected by a wire 227 to a variable resistance 228 the other end of which is connected to the wire 166. The wire 167 is connected by a wire 229 to the wheel motor 51 and the other terminal of the wheel motor 51 is connected by a wire 230 to the solenoid coil 223. It will now be seen that when the current through the wheel motor 51 rises as when the grinding pressure on the work piece 71 increases, the core 224 will be drawn into the solenoid coil 223 increasing the pressure on the carbon pile which will cause more current to flow through the circuit including the grinding wheel 65 and the work piece 71. In this case also the grinding wheel 65 is the anode and the metal load on, and from time to time some of the metal bond of, the face 72 of the wheel 65 is removed at a rate commensurate with very high speed grinding of the work piece and the dressing operation is automatically regulated by the carbon pile regulator and the circuits as described. Here again parts and portions of the circuit not mentioned in this description are identified by the numerals previously used and the previous description.

Figure 9 shows still another embodiment of the invention in which a wheel motor 51*a* just for example is indicated as a three phase induction squirrel cage motor although it could be a single phase motor without changing the circuit. Three phase power lines 235, 236 and 237 are connected by a hand switch 238 to wires 239, 240 and 241. The wire 239 is connected to the primary 243 of a transformer and the other end of the primary 243 is connected by a wire 244 to one terminal of the motor 51*a*. The wires 240 and 241 are respectively connected to the other terminals of the motor 51*a*. The secondary coil 247 of the transformer is connected by wires 248 and 249 to opposite corners of a bridge rectifier 250 having selenium rectifying units 251, 252, 253 and 254 arranged as indicated wherein the arrows indicate the direction of permissible current flow, and by current I mean current as conventionally understood (opposite to flow of electrons). The other two corners of the bridge rectifier 250 are respectively connected to the wire 145 and to a wire 255 which is connected to the variable resistance 135, all as clearly shown. In this embodiment of the invention the current through the primary 243 induces current through the circuit including the wheel 65 and the work piece 71 and again the wheel 65 is the anode. Whenever the load on the motor 51*a* rises the current through the wheel 65 and work piece 71 increases and thus the load on the wheel face 72 is removed as fast as it is formed. As in the other embodiments of the invention the adjustable resistance 135 can be used to obtain optimum conditions. Here again parts and connections of the circuit not mentioned herein are those previously identified using the same numerals.

Referring now to Figures 10 and 11, in this modification of the invention the cathode is a block of metal 261 which can be a piece of commercial tungsten carbide so-called, which is carbide bonded with cobalt and sometimes the carbide is tungsten carbide or it may be a mixture of carbides including tungsten carbide and titanium carbide or tantalum carbide or both. This block 261 can be a rectangular parallelepiped which is one of the simplest shapes to form. It is supported by a frame which can be made of steel comprising a lower plate 262 on which the block 261 is slidable, an upper plate 263 secured by bolts 264 to the wheel guard 107 and an integral connecting portion 265 having a boss 266 with a bore 267 receiving a spring 268 which urges the block 261 toward the wheel face 72. The spring 268 can be a spring of light tension, adjustable by means of a thumb screw 269, so that the block 261 presses very lightly against the wheel face 72. The frame is strengthened by bars 270 and 271 secured to the lower plate 262 by screws 272 and to the upper plate 263 by screws 273 and pins 274 and 275 may be used accurately to align the parts. The bars 270 and 271 hold the block 261 with a sliding fit thus to keep it in alignment with the wheel face 72.

This modification can be used in combination with any of the foregoing embodiments of Figures 6, 7, 8 and 9 by

connecting the switch **146** to the plate **263** by the wire **147** and a binding post **276**. Thus, in accordance with this modification, the work piece **71** need not be conductive as the grinding wheel can be dressed electrolytically in accordance with any one of the circuits of Figures 6 to 9 inclusive with the block **261** substituting for the work piece **71** in the circuit.

I further provide means to deliver liquid electrolyte **96** to the block **261** and between it and the face **72** as illustrated in Figure 11. In that figure the valve **105** is identified and the pipe **106***a* of Figure 11 is like the pipe **106** of Figure 1 only the pipe **106***a* leads to a T-union **280** nected to a pipe **283** to which the deformable nozzle **110** is attached. But the T-union **280** also has a nozzle **284** connected thereto delivering liquid all over the face **72** where it is running under the block **261**. The electrolyte supply pipes and connections can be secured to the cover **107***b* of the wheel guard **107** as by brackets **286** and **287** securing the pipes **281** and **283** to the cover **107***b* as shown in Figure 11.

A further embodiment of the invention shown in Figure 12 is based upon the modification of Figures 10 and 11 in which the binding post **276** is connected by a wire **147***a* to a wire **290** which is connected to an adjustable resistance **291** which is connected by a wire **292** to the negative terminal of the battery **161** while the positive terminal of the battery **161** is connected by a wire **293** to the switch **146** which is connected by the wire **147** to the work holding bar **85**. Thus current from the battery **161** goes by way of wire **293** and switch **146** to the wire **147** to the bar **85** to the work piece **71** to the electrically conducting face **72** of the grinding wheel to the block of metal **261** through the lower plate **262** and/or the bars **270** and **271** to the plate **263** to the wire **147***a* to the wire **290** to the resistance **291** to the wire **292** to the negative terminal of the battery **161**. Thus the electric current is continuously removing metal from the work piece **71** (in this case the work piece is assumed to be conductive) while any load which builds up upon the face **72** is removed by current flowing out of said face and into the block **261** and grinding can be at a very high rate; indeed metal is removed by electrolytic action as well as by grinding and coincidentally the wheel is kept free from load. As it will readily be seen the circuit of Figure 12 is very simple. Of course the converter **175** can be connected as illustrated in Figure 6 to charge the battery **161** in this embodiment of Figure 12.

The rate of removal of metal electrolytically is such that, with the circuit so far described in this embodiment of Figure 12, the resistance **291** would have to be set at a high value in order to prevent too rapid removal of metal bond from the face **72** of the grinding wheel **65**, and setting the resistance **291** at a high value would reduce the amount of electrolytic stock removal of the work piece **71**. Therefore I preferably provide a shunt line in the embodiment of Figure 12 involving a wire **295** connected to one of the wires **126** (identified in connection with the other embodiments) the wire **295** being connected to a variable resistance **296** which is connected by a wire **297** to the wire **292**. Thus a part of the current entering the wheel **65** will shunt through the variable resistance **296** and a part of the current will pass from the wheel face **72** into the block **261**, and by adjusting the resistances **291** and **296** the operator can select the amount of current to go through each part of the circuit. However, the operator is interested in removing stock from the work piece and in keeping the face **72** of the wheel free cutting and he doesn't have to know how many amperes are passing through the resistance **291** and how many amperes are passing through the resistance **296**; he merely adjusts these two resistances until he obtains the utmost stock removal in a given time because all features of the invention add up to the achieving of greater production in the removal of stock from the work piece. In this connection the variable resistances **291** and **296** can be adjusted until those current values in the several circuits are achieved which result in the greatest removal of stock in a given time and it will be noted that in this embodiment of Figure 12 there is no interruption for dressing and truing but on the contrary stock removal and dressing of the wheel are continuous.

In the embodiment of Figure 6 when the wheel **65** is being dressed, and in the embodiments of Figures 7, 8, 9 and 12 when the switch **146** is closed, the grinding wheel **65** is the anode of the electric circuit and the electric circuit includes a cathode, with the electrolyte between the anode and the cathode. In the embodiments of Figures 6, 7, 8 and 9 as first described, this cathode is the work piece **71**. However in the modification illustrated in Figures 10 and 11, the cathode is the block **261**. However it should further be noted that in the embodiment of Figure 12 which uses the modification of Figures 10 and 11 the wheel face **72** is partly a cathode being a cathode where it contacts or nearly contacts the work piece **71** and being an anode where it contacts or nearly contacts the block **261**. In this connection it should be pointed out that true electrolytic action is achieved even when there is actual contact between the grinding face **72** and the work piece **71** and/or the block **261** because the diamond or other abrasive creates a slight gap between the metal load or bond and the work piece **71** and between the metal load or bond and the block **261**. Even when the metal load on the wheel face **72** projects beyond the abrasive points there is a slight film of salt water or other electrolyte between the parts to support the electrolytic action.

It should be understood that the invention in any of the embodiments can be applied to a grinder in which the infeed is intermittent as it is in the case of most cylindrical grinders. Furthermore the invention is of utility not only for machines equipped with metal bonded diamond grinding wheels but also for the grinding of steel with grinding wheels made of fused alumina bonded with metal and for the grinding of cast iron and nonferrous metals with grinding wheels made of silicon carbide bonded with metal.

It will thus be seen that there has been provided by this invention a grinding machine in which the various objects hereinbefore set forth together with many thoroughly practical advantages are successfully achieved. As many possible embodiments may be made of the above invention and as many changes might be made in the embodiments above set forth, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. Apparatus for dressing an abrasive face of an electrically conductive grinding wheel comprising a grinding wheel spindle, bearings for said spindle, means to rotate said spindle, means to hold a metal cathode piece in close proximity to the abrasive face, a first means for supplying direct current electric energy, a variable resistance regulator including electromagnetic means and a variable resistance connected thereto whereby increase of current in the electromagnetic means decreases the resistance of the variable resistance, a wheel spindle motor connected to the wheel spindle, a second means for supplying electric energy, a circuit connecting the second means to the electromagnetic means and to the motor, and a second circuit connecting the variable resistance the first means the grinding wheel and the means to hold the cathode piece so that the grinding wheel is positive and the means to hold the cathode piece is negative, whereby when the current through the motor increases, the current from the grinding wheel to the cathode piece increases also.

2. Apparatus for dressing an abrasive face of an electrically conductive grinding wheel comprising a grinding

wheel motor, an electric circuit connected to energize said motor, a transformer, the primary of said transformer being connected to said electric circuit means to hold a metal cathode piece in close proximity to said abrasive face, a rectifier, and a circuit connecting the rectifier, the grinding wheel, the means to hold the cathode piece and the secondary of the transformer whereby the grinding wheel is positive and the cathode negative and increase in the current energizing the motor increases the current through the grinding wheel and passing out into the metal cathode piece.

3. A grinding machine comprising a grinding wheel spindle, an electric motor to rotate said wheel spindle, an electric conductor to conduct electricity to a conductive grinding wheel mounted on said spindle, a workpiece holder adjacent said spindle, infeed mechanism to feed said workpiece holder relative to said spindle for grinding of a workpiece held by said holder, an electric conductor to conduct electricity to a workpiece held by said holder, means for flooding the gap or area between the workpiece and the grinding wheel with liquid electrolyte, a circuit and switches to make the workpiece positive and the grinding wheel negative and alternatively to make the grinding wheel positive and the workpiece negative, and a relay and circuit connecting the wheel motor thereto and said relay operating said switches with connections so arranged that overloading of the wheel spindle motor operates the relay to make the grinding wheel positive and the workpiece negative but when the wheel spindle motor is not overloaded the switches set the circuit to make the workpiece positive and the grinding wheel negative.

4. A grinding machine according to claim 3 having an electric motor to operate the infeed mechanism, and a further switch operated by the relay and so connected as to connect the infeed motor to power to operate the infeed when the wheel spindle motor is not overloaded and to break the circuit to the infeed motor when the wheel spindle motor is overloaded.

5. Apparatus for dressing an abrasive face of an electrically conductive grinding wheel comprising a grinding wheel spindle, an electrically conductive grinding wheel on said spindle, bearings for said spindle, means to rotate said spindle, means to hold a metal cathode piece against the abrasive face of said grinding wheel, separate means to hold a workpiece in close proximity to said abrasive face, electric power means for supplying direct current electric energy, an electrical connection from the source on the positive side to the means to hold the workpiece, an electrical connection having a variable resistance therein from the source on the negative side to the means to hold the metal cathode piece to make it negative, and a shunt circuit with a variable resistance therein connecting the grinding wheel to the negative side of the source whereby to select from the total current entering the wheel how much is to pass out through the cathode piece.

6. In a grinding machine, an electrically conductive grinding wheel including abrasive material on its face, a wheel spindle for said wheel, means journalling said spindle for rotation, power means to rotate said spindle and said wheel thereon, a workpiece holder positioned to hold a workpiece against said wheel holding said workpiece stationary with regard to rotation, an electrically conductive cathode piece, means to hold said cathode piece against said wheel holding said piece stationary with regard to rotation, means to flood said wheel with electrolyte especially at the locus of contact between the wheel and the workpiece and at the locus of contact between the wheel and the cathode the cathode piece covering at least the same locus of area of the wheel as does the work piece supported by the work piece holder, electric power means for supplying direct current electric energy, an electric conductor connecting the positive side of said electric power means to the workpiece holder, an electric conductor connecting the negative side of said electric power means to said cathode piece, a shunt conductor connecting the negative side of said electric power means to said wheel, and a variable control for said shunt conductor to adjust and to regulate the amount of electric current passing through it, whereby efficiently to erode a workpiece by electrolytic action and coincidentally to keep the grinding wheel free of metal load but by said means for controlling and varying the current through the shunt conductor controlling the amount of material removed from the grinding wheel to prevent undesired loss of abrasive material.

7. In a grinding machine as claimed in claim 6, the combination with the parts and features therein specified, of a variable control for the electric conductor connecting the negative side to the cathode piece to adjust and to regulate the amount of eletcric current going into the cathode piece.

8. Apparatus for dressing an abrasive face of an electrically conductive grinding wheel comprising a grinding wheel spindle, an electrically conductive grinding wheel including abrasive material on its face on said spindle, a metal cathode piece, means to hold said metal cathode piece against the abrasive face of said wheel holding said cathode piece stationary with regard to rotation, means to hold a work piece in close proximity to said abrasive face, means for supplying direct current electric energy and electrical connections making the means to hold the work piece positive and making the metal cathode piece negative, and means for supplying electrolyte to the cathode piece where it is contacted by the grinding wheel the cathode piece covering at least the same locus of area of the wheel as does a work piece supported by said means to hold it whereby to remove material from the grinding wheel by electrolytic action.

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