Aug. 16, 1966 J. H. GREENING 3,267,018

ELECTROLYTIC HONING DEVICE

Filed Oct. 29, 1962 4 Sheets-Sheet 1

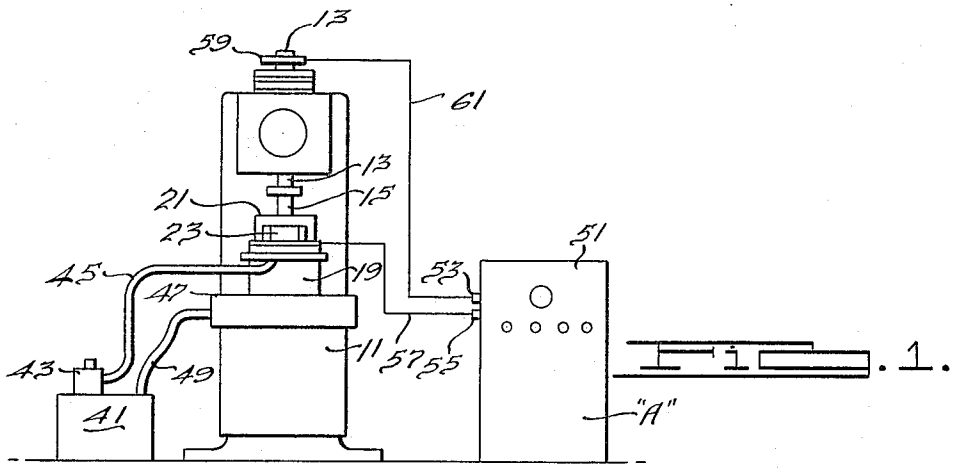


Fig. 1.

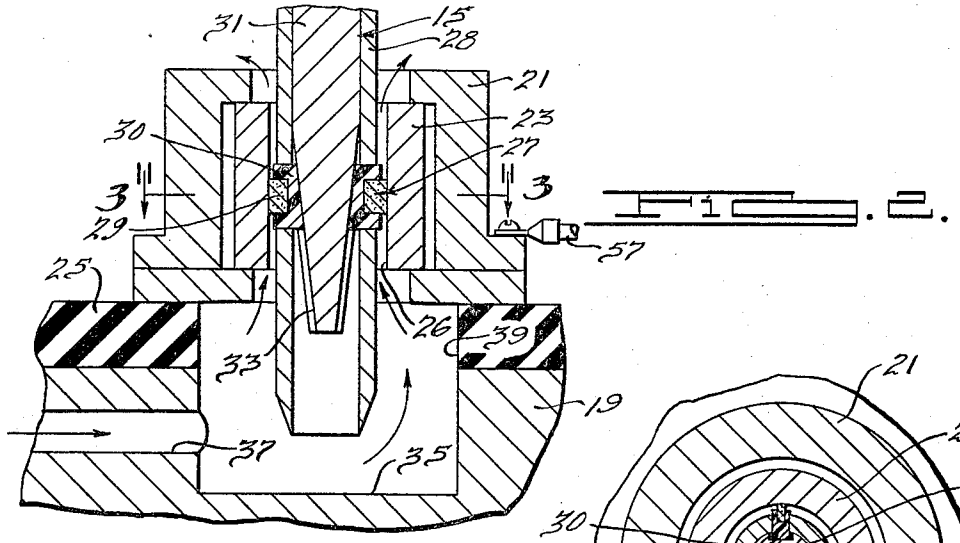


Fig. 2.

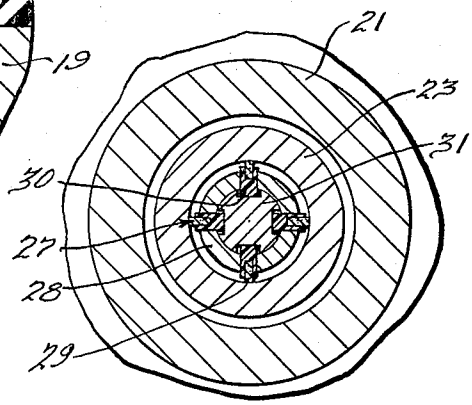


Fig. 3.

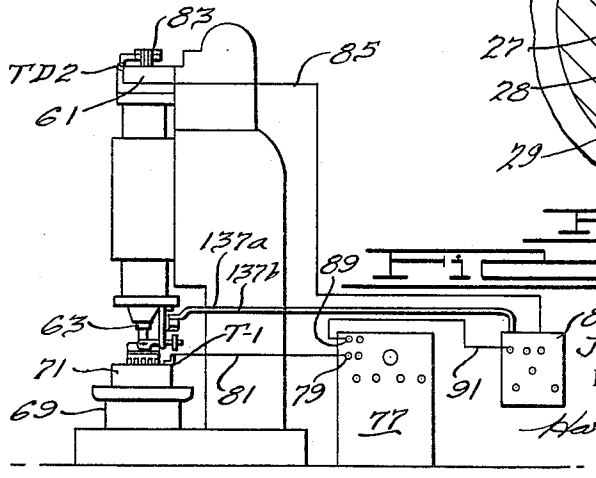


Fig. 4.

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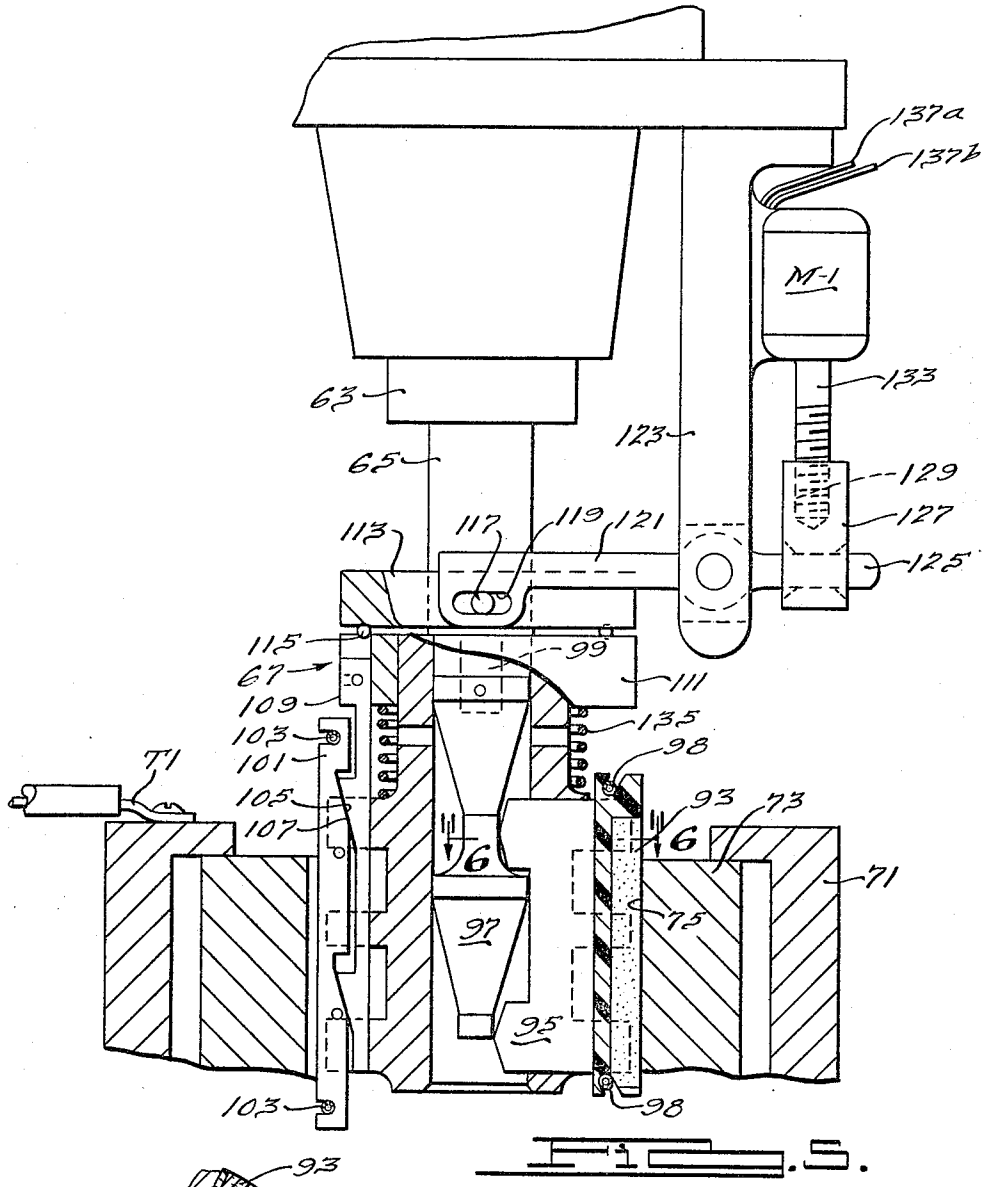


FIG. 5.

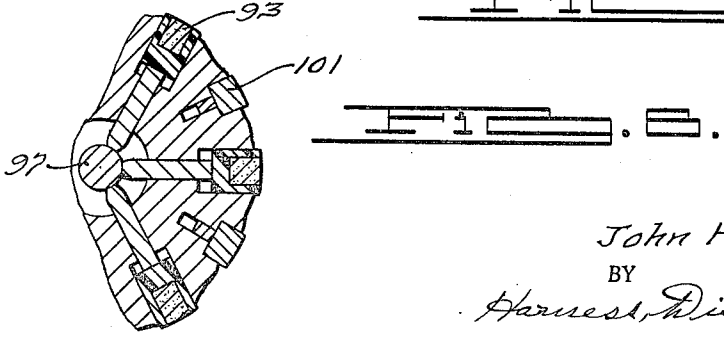


FIG. 6.

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ELECTROLYTIC HONING DEVICE

Filed Oct. 29, 1962 4 Sheets-Sheet 3

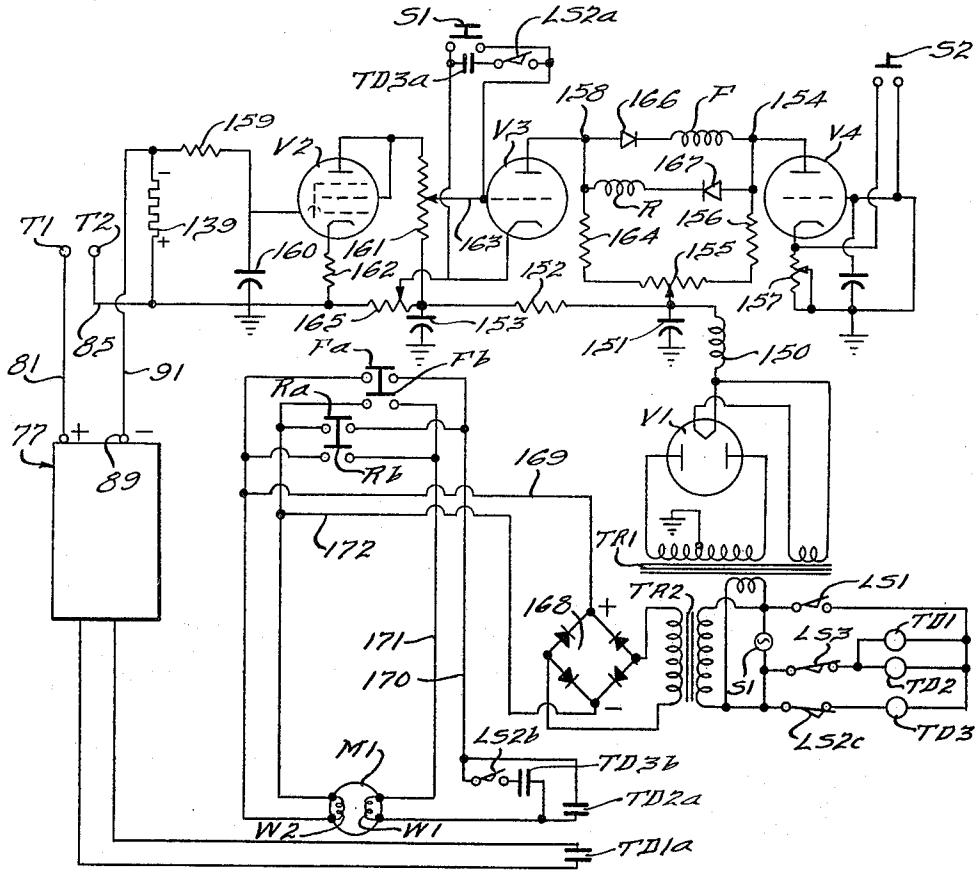


Fig. 7.

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ELECTROLYTIC HONING DEVICE

Filed Oct. 29, 1962 4 Sheets-Sheet 4

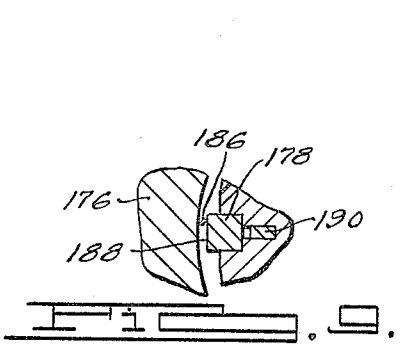


FIG. 9.

FIG. 8.

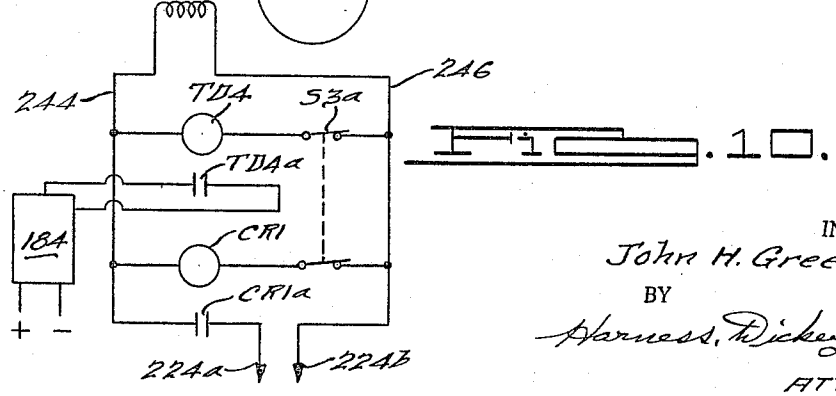


FIG. 10.

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United States Patent Office 3,267,018 Patented August 16, 1966

3,267,018

ELECTROLYTIC HONING DEVICE

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Filed Oct. 29, 1962, Ser. No. 233,772
12 Claims. (Cl. 204—224)

This application is a continuation-in-part of my prior copending application Serial No. 811,914, filed May 8, 1959, now abandoned.

This invention relates to the honing art and particularly to a honing device and method in which material is removed from a work surface by the combined action of abrasive stones and a deplating electrolytic current.

It is an object of the present invention to provide an abrading machine and tool in which the speed, efficiency and quality of the abrasive process are enhanced by an electrolytic current flowing from the workpiece to a cathode member to etch the surface of the workpiece and thereby render more efficient the action of the honing stones.

It is another object of the present invention to provide an abrading device of the above character in which a large amount of electrolytic coolant may be passed between the cathode member and the work surface thereby permitting the usage of large currents without "boiling out" the electroyltic coolant.

It is still another object of the present invention to provide an abrading device of the above character in which the abrasives may be continuously advanced during the abrading operation to compensate for the abrasive material worn away without thereby altering the spacing between the cathode member and the work surface or producing a consequent substantial change in the level of the current flow.

It is another object of the present invention to provide a honing device of the above character by means of which the honing of very hard metals is greatly facilitated and which permits the honing of many metals which heretofore could not be honed in an economically feasible manner.

It is another object of the present invention to provide a device of the above character and a method of honing in which the rate of stock removal is substantially increased and in which the life of the honing stones is lengthened.

It is another object of the present invention to provide a honing device of the above character having means to maintain a constant level of current through the electrolyte as the diameter of a cylindrical work surface is changed during the honing operation.

It is a still further object of the present invention to provide a device of the above character which is efficient in operation, reliable in performance and inexpensive to manufacture.

These and other objects of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic view of a honing machine embodying the principles of the present invention;

FIG. 2 is a longitudinal sectional view of a portion of the structure illustrated in FIG. 1;

FIG. 3 is a cross-sectional view of the structure illustrated in FIG. 2, taken along the line 3—3 thereof;

FIG. 4 is a schematic view of a honing machine illustrating another form of the present invention;

FIG. 5 is a view partly in section and partly in elevation of a portion of the structure illustrated in FIG. 4;

FIG. 6 is a fragmentary sectional view of the structure illustrated in FIG. 5 taken along the line 6—6 thereof;

FIG. 7 is a schematic representation of a portion of the control circuitry for the structure illustrated in FIG. 4;

FIG. 8 is a longitudinal sectional view of structure illustrating a still further form of the present invention;

FIG. 9 is a fragmentary sectional view of the structure illustrated in FIG. 8 taken along the line 9—9 thereof; and

FIG. 10 is a schematic representation of a portion of the control circuitry for the structure illustrated in FIG. 8.

The invention is illustrated herein in the form of honing apparatus for abrading cylinder bores. FIGURE 1 illustrates a honing machine **11** having a rotating and reciprocating spindle **13** to which a honing tool **15** is drivably connected. A rising fixture quill **19** is mounted beneath the tool and supports a work holding fixture **21** holding a workpiece **23** in alignment with the spindle **13**. An insulating pad **25** of electrically nonconductive material is interposed between the quill **19** and fixture **21** to electrically isolate the fixture **21** and workpiece **23** from the rest of the machine **11**. The workpiece **23**, which is illustrated in the forming of a bushing, is positioned to have its internal cylindrical surface **26** finished by the honing tool **15**, which is reciprocated and rotated with respect to the bushing **23**. The honing tool **15** includes a plurality of abrasive members or honing stones **27** arranged circumferentially around a hollow cylindrical honing tool body **28** and including a bonded abrasive stick **29** and a nonabrasive shell or casing **30**. Each shell **30** is integrally molded around its stick **29** and covers all sides of the stick except its working face. The shell **30** is desirably made from a plastic material that wears away evenly with the stick **29** as the member **27** is consumed. The stick **29** may be made from a vitreous bonded electrically nonconductive material. It is also possible to use a metal bonded stick **29**, inasmuch as the plastic shell **30**, which is electrically nonconductive, insulates the stick **29** from the tool body **28**. In either case, the abrasive stick **29** is in electrically nonconductive relation to the tool body **28**, which forms the cathode member in the electrolytic action, as will be more fully explained. An actuating rod **31** is axially feedable within the honing tool body **28** and includes a conical lower portion **33** engageable with the abrasive members **27** to radially expand them. During the course of the honing operation, the actuating rod **31** is continuously fed in an axial direction, expanding the abrasive members **27** to compensate for the material abraded therefrom and to enlarge the work surface being honed.

The quill **19** is provided with a well **35** positioned immediately beneath the workpiece and has a port **37** communicating with the well **35** for the delivery of liquid into it. During the honing operation an electrolyte or electrolytic coolant is pumped by a pump **43** from a reservoir **41** through a conduit **45** leading to the port **37** and, thus, to the well **35**. The insulating pad **25** has an enlarged aperture **39** located above the well **35** and the fixture **21** is of such construction as to permit the upward flow of electrolyte from the well **35** into the workpiece **23** through the annular passageway between the honing tool body **28** and the inner surface **26** of the workpiece. While this annular channel is blocked at places by the honing stones **27**, there is more than ample room for the electrolyte to flow upwardly in the spaces between the honing stones. The electrolyte then flows out over the top of the fixture **21** and into a collecting trough **47** formed around the quill **19**. From the trough **47**, the electrolyte flows by gravity back to the reservoir **41** through conduit **49**. While the electrolyte is electrically conductive and serves in the deplating process hereinafter described, it also functions as a coolant to dissipate heat from the workpiece.

An electrolytic power supply unit **51** is provided adjacent the honing machine proper **11** and has negative and positive output terminals **53** and **55**, respectively. The power supply unit **51** functions to supply direct electrical current of a selected magnitude to the work. The positive output terminal **53** is connected by a conductor **57** to the fixture **21**. The fixture **21**, which is made of steel or other electrically conductive material, permits the flow of current through to the workpiece **23**. From the workpiece **23** the current flows through the electrolyte to the body **28** of the honing tool, which is also of steel or other electrically conductive material. The abrasive members **27**, which are electrically nonconductive with respect to the body **28**, serve to center the hone body within the workpiece and prevent it from touching the workpiece. From the honing tool body the current flows up through the spindle **13** to a brush take-off unit **59**, by means of which electric current is transmitted from the rotating spindle to a conductor **61** leading to the negative power supply terminal **53**.

The action of the current flow is to deplate or etch material from the inner cylindrical workpiece surface **26** in contact with the electrolyte, an action which is substantially the reverse of electrolytic plating. Standard electrolytes may be used which are preferably salts of certain metals, such as sodium nitrate or potassium chloride, dissolved in water. In addition, rust inhibitors, such as sodium nitrite, may be added to the solution. It will be seen that the workpiece serves as the anode of the electrolytic cell, to which the anions of the solution are attracted. Thus, if a potassium chloride electrolytic agent is used, ferric chloride will be produced by the electrolytic process which will flow out of the workpiece with the normal flow of electrolyte and will precipitate out of the solution in the reservoir **41**. The honing tool body **28** is made of steel and is such as to prevent plating of the material onto it. As the honing tool **15** rotates and reciprocates within the workpiece, the abrasive members **27** are in constant abrading engagement with the work surface **26**, keeping the same clean of the film produced by the electrolytic action and thereby accelerating the electrolytic action. The electrolytic action, in turn, deplates or etches metal from the work surface in irregular channels, thereby presenting a roughened surface which is more easily abraded away by the honing stones. In addition, the roughened work surface tends to aid the gradual breakdown of the working surface of the honing stones and prevents the embedding of metallic particles from the workpiece thereon. This function is referred to as keeping the stones dressed. During the honing operation the sodium nitrite (which is the rust-inhibiting element) is acted upon by the electrolytic current to produce ammonium hydroxide, which keeps the electrolyte solution basic with a pH of between 9 and 11.

The electric current which is used in the electrolytic process is relatively low in voltage and high in amperage. For example, a current of 200 amperes at 20 volts has been found satisfactory for most honing operations. For a power supply of a given voltage, the magnitude of the current passing through the electrolyte will vary with the resistance encountered. Thus, a larger gap between the hone body **28** and workpiece **23** will produce a larger resistance, decreasing the current flow. In small diameter bores in which less than ten-thousandths of an inch of material in diameter is removed, the change in amperage will not exceed the limits for efficient operation of the machine. Thus, it has been found that using five-thousandths of an inch clearance from rough bore size to the tool body and with a current of 200 amperes at 20 volts, a total of ten-thousandths of an inch of hard-bearing steel can be removed in ten seconds.

In the honing of large diameter bores where a greater amount of stock is removed from the work surface, it is possible that the change in gap between a stationary hone

body and the constantly increasing work surface can produce an undesirable drop in current flow. To overcome this disadvantage, the form of the invention illustrated in FIGS. 4, 5 and 6 provides means for expanding the hone body to maintain a substantially constant gap with the work surface. FIG. 4 schematically illustrates a honing machine **61** having a rotating and reciprocating spindle **63** to which the drive shaft **65** of a honing tool **67** is drivably connected. The machine is provided with a rising quill **69** on which a work holding fixture **71** is supported so as to hold a workpiece **73** in alignment with the tool **67** for finishing of its internal cylindrical work surface **75**. An electrolyte is pumped between the tool **67** and work surface **65** in a manner similar to that described in the prior embodiment. In addition, an electrolytic power supply unit **77** has its positive outlet terminal **79** connected to terminal **T1** on the work holding fixture **71** by means of a conduit **81**. The fixture **71** is in direct physical contact with the workpiece **73** and, therefore, current is free to flow to the workpiece **73** and then through the electrolyte to the honing tool **67**. From the honing tool **67** the current flows up the drive shaft **65** to the machine spindle **63**. The upper end of the spindle **63** is provided with a brush take-off unit **83** through which the current flows to conduit **85**, which is in turn connected to a servo-amplifier unit **87**. From the servo-amplifier unit **87** the current flows to the negative outlet terminal **89** of the power supply unit **77** by means of a conduit **91**. The servo-amplifier **87** serves to control the expansion and contraction of the honing tool **67** in response to changes in amperage of the current flowing through the circuit from the power supply unit **77**.

The honing tool body includes a plurality of abrasive stones **93** spaced about its periphery which are in abutting engagement with inwardly extending cam shoes **95**. The stones **93** are radially expandable by a double cone element **97** against the bias of a pair of garter springs **98**. During the honing operation an actuating rod **99** connected to the double cone element **97** is progressively fed downwardly to radially expand the stones **93**, thereby compensating for the material abraded from the surface of the stones and continuously enlarging the work surface being honed. Spaced about the periphery of the honing tool between the honing stones **93** are a plurality of cathode shoes **101** which are biased radially inwardly by garter springs **103**. Each cathode shoe has a pair of inclined surfaces **105** which are engageable by similarly inclined cam surfaces **107** on cathode expansion members **109**. A collar **111** surrounds the upper end of the tool body and has an abutting relationship to the upper ends of the cathode expansion members **109**. Disposed above the collar **111** is a nonrotatable ring **113** connected to collar **111** by ball elements **115**. A pair of pins **117** project oppositely outwardly from the ring **113** and are received in elongated slots **119** formed in opposite sides of a fork lever **121**. The lever **121** is pivotally connected to a bracket **123** secured to a reciprocating but nonrotating portion of the honing machine. The rear end **125** of the arm **121** supports a block **127** having an internally threaded bore **129** formed in the upper end thereof. An electric servo motor **M–1** also supported on the bracket **123** drives a screw element **133** threadably engaged in the block **127**. Rotation of the screw element **133** in opposite directions by means of the motor **M–1** thereby raises and lowers the block **127** in order to move the forward fork end of the lever **121** in the opposite vertical direction. Downward movement of the forward end of the lever **121** transmits downward pressure to the nonrotatable collar **113**, which transmits similar downward pressure through ball elements **115** to the collar **111**. Collar **111**, in turn, forces the cathode expander elements **109** downwardly to cause radial expansion of the cathode shoes **105**. Raising of the forward end of the arm **121** relieves the pressure of the cathode expansion members **109** on the cathode shoes **105** and permits their collapse

under the bias of the garter springs **103**. This collapsing action is further aided by a coil spring **135** biasing the collar **111** upwardly. The motor M–1 is wired to the servo-amplifier system by conductors **137A** and **137B** and its operation is controlled thereby in response to the current flowing through the electrolyte from the electrolytic power supply unit **77**. For a power supply of any voltage, the magnitude or amperage of the current passing through the system is dependent upon the resistance present in the circuit. As material is removed from the surface of the workpiece **73**, the gap between the cathode shoes **105** and the work surface **75** will increase and, thus, the current has a longer distance to travel through the electrolyte. Thus, the resistance offered by the electrolyte is increased and this increased resistance causes a consequent drop in the magnitude of the current in the circuit. The servo-amplifier **87** serves to compare this current to a preselected value in order to expand or contract the cathode shoes **105** by driving of the motor M–1 in the appropriate direction.

The control circuitry for the machine of FIGS. 4 through 6 is illustrated in FIG. 7 and includes limit switch LS1, limit switch LS3 and limit switches LS2*a*, LS2*b* and LS2*c*. Limit switch LS1 is normally open and is closed when the honing tool reaches its lower position and is disposed within the workpiece in preparation for the honing operation. Limit switch LS1 may also initiate operation of the spindle motor to produce rotation of the honing tool. Limit switch LS3 is controlled by suitable gauging mechanism such as is shown in my prior application, Serial No. 672,740, now Patent No. 3,010,259 issued November 28, 1961, entitled "Bore Gauging Device." Limit switch LS3 is closed at all times except when the gauging mechanism of the honing machine indicates that the workpiece has reached proper size. Limit switches LS2*a*, LS2*b* and LS2*c* are controlled by the honing tool, limit switches LS2*a* and LS2*b* being opened at all times except when the tool is fully raised and limit switch LS2*c* being closed at all times except when the tool is fully raised. Limit switches LS2*a*, LS2*b* and LS2*c* are tripped at the same instant and may in fact be plural contacts of a single limit switch mechanism if desired.

The operational cycle is initiated with the tool **67** fully raised and with the stones **93** fully retracted. As a result, limit switch LS1 is open, limit switch LS3 is closed, limit switches LS2*a* and LS2*b* are closed and limit switch LS2*c* is open. As the tool starts down into the workpiece, limit switches LS2*a* and LS2*b* are opened and limit switch LS2*c* is closed. The opening of limit switches LS2*a* and LS2*b* disables certain circuits to be described and the closure of limit switch LS2*c* prepares an energizing circuit to be described. When the tool reaches its fully down position, limit switch LS1 is closed. As a result, energizing circuits for time delay relays TD1 and TD2 are completed from source S1 through limit switches LS1 and LS3. Time delay relay TD1 is provided with a pair of normally open contacts TD1*a* which close a timed interval after the energization of relay TD1, such as, for example, a few seconds. The closure of relay contacts TD1*a* energizes the electrolytic power supply **77** which produces a direct voltage between conductors **81** and **91**. Relay TD2 is provided with a pair of normally open contacts TD2*a* which are closed a timed interval after the energization of the winding of relay TD2, this timed interval desirably being slightly greater than the delay period of relay TD1. The closure of contacts TD2*a* prepares an energizing circuit for the armature winding W1 of D.C. servo motor M1.

Concurrently with the energization of relays TD1 and TD2, the honing tool begins to rotate and the conventional feed mechanism (not shown) begins to move the actuating rod **99** downwardly to expand the honing stones **93**. At the same time, the electrolyte flows between the work surface **75** and the cathode shoes **105**, acting as a coolant for the honing stones **93**. The energization of the power supply unit **77** and the preparation of the energizing circuit for motor M1 desirably occurs after a few seconds of the honing cycle have elapsed.

The voltage between conductors **81** and **91** developed by the power supply **77** produces a conventional current flow from conductor **81**, terminal T1, through the fixture **71** (FIG. 5), through the workpiece **73**, through the electrolyte to the cathode shoes **105**, through the honing tool **67**, drive shaft **65**, spindle **63**, brush take-off **83**, terminal T2, conductor **85** (which is grounded), current sensing resistor **139** (having a value of, for example, 0.005 ohm), and to the return conductor **91**. The voltage drop appearing across resistor **139** varies in accordance with the current therethrough and hence in accordance with the current through the electrolyte. The function of the servo system is to compare this voltage to a reference voltage and to continuously adjust the workpiece-to-cathode-shoe-spacing so as to maintain the voltage across resistor **139** in a preselected relationship with the reference voltage.

The servo amplifier includes vacuum tubes V2, V3 and V4 which are supplied with plate voltage by means of a power supply including power transformer TR1 (energized from source S1), full wave rectifier V1, choke input filter including inductor **150** and capacitor **151** and a further isolating and filtering network including resistor **152** and capacitor **153**.

The magnitude of the reference potential at point **154** is established by means including vacuum tube V4, the anode of which is supplied with plate voltage through potentiometer **155** and plate load resistor **156** and the cathode of which is grounded through cathode resistor **157**. The control grid of tube V4 is grounded. The magnitude of the current flow through tube V4 and hence the magnitude of the potential at point **154** is selected by varying the bias of resistor **157**. Since the spacing between the workpiece and the cathode shoes is continuously adjusted to maintain the current through the electrolyte at a value determined by the potential at point **154**, it will be seen that adjustable resistor **157** can be employed to set or select that spacing.

Vacuum tubes V2 and V3 serve as elements of a means for producing a potential at point **158** having a magnitude determined by the magnitude of the current flow through the electrolyte. Thus, the voltage developed across sensing resistor **139** is applied to the control grid of vacuum tube V2 through resistor **159**, capacitor **160** serving to by-pass transients. Tube V2 is supplied with plate voltage through potentiometer **161**, the resistive element of which serves as a plate load resistor, and the cathode of tube V2 is connected to ground through self-biasing resistor **162**. The signal voltage developed across resistor **139** and applied to the control grid of tube V2 is negative in polarity and varies in magnitude in direct proportion to the magnitude of the current flow through the electrolyte. As a result, the magnitude of the current through tube V2 varies inversely with that electrolyte current and the value of the voltage applied to conductor **163** varies directly with the magnitude of the electrolyte current. The signal voltage on conductor **163** is applied to the control grid of vacuum tube V3, the anode of which is supplied with plate voltage through the left-hand portion of potentiometer **155** and through plate load resistor **164** and the cathode of which is maintained at a positive value relative to the control grid voltage by means of potentiometer **165**.

The magnitude of the current through tube V3 varies directly with the magnitude of the current through the electrolyte and hence the potential at point **158** varies inversely with the magnitude of that electrolyte current. The signal voltage at point **158** is positive relative to ground but may be positive or negative relative to the potential at point **154** in accordance with whether the magnitude of the current through the electrolyte is less than or greater than it should be under the instant setting

of potentiometer 157. If the potential at point 158 is positive relative to the potential at point 154, conventional current will flow through rectifier or unidirectional current conducting device 166 and the winding of relay F to energize that relay. Conversely, if the potential at point 158 is less than negative relative to the potential at point 154, conventional current will flow through rectifier 167 and the winding of relay R to energize relay R.

Relays F and R control the energization of winding W1 of motor M1 from a direct voltage source including transformer TR2 and the full wave rectifying bridge 168. If the "forward" relay F is energized, contacts F*a* and F*b* are closed. The closure of those contacts completes a circuit from the positive terminal of bridge 168, conductor 169, contact F*a*, conductor 170, now-closed contact TD2*a*, winding W1, conductor 171, contact F*b*, and conductor 172 to the negative terminal of bridge 168. Since winding W2 is continuously connected across the bridge 168, motor M1 is energized and will rotate in a direction to move the cathode shoes toward the workpiece. When this occurs, the magnitude of the electrolyte current will increase and the potential at point 158 will be reduced. When it is reduced sufficiently toward or to the value of the potential at point 154, relay F releases, contacts F*a* and F*b* open and the forward movement of the motor terminates. Conversely, if the spacing between the cathode shoes and the workpiece becomes too small, the potential at point 158 will become negative relative to the potential at point 154 and relay R will operate, closing contacts R*a* and R*b*. The closure of contacts R*a* and R*b* serves to connect winding W1 of motor M1 to bridge rectifier 168 in an opposite polarity to that previously described and accordingly motor M1 will operate in a reverse direction to move the cathode shoes further from the workpiece. When that distance has increased to the point at which the electrolyte current is reduced to a value to bring the potential at point 158 to or substantially to the value of the potential at point 154, relay R releases and energization of the motor M1 is terminated.

The equipment continues to operate in this manner, continuously maintaining the cathode shoes at a preselected spacing from the workpiece, until the size control device signals that the honing cycle is about to be terminated. At that time, down feed of the actuating rod 99 and cone element 97 is terminated in order to cause the stones 93 to run out against the workpiece in a manner well known in the art and the same condition causes the limit switch LS3 to be opened to deenergize time delay relays TD1 and TD2. These relays immediately open their contacts TD1*a* and TD2*a*, respectively, to deenergize the power supply 77 and to open the circuit of winding W1 of motor M1 to prevent further operation of that motor at this time.

When the run-out cycle is completed, the honing tool 67 is withdrawn from the workpiece and moved upwardly. When the tool is completely withdrawn, limit switches LS2*a*, LS2*b* and LS2*c* are tripped. The opening of limit switch LS2*c* terminates the energization of relay TD3. Relay TD3, however, maintains its contacts TD3*a* and TD3*b* closed for a preselected period. Consequently, the closure of limit switch LS2*a* completes a connection from the cathode of tube V3, closed contacts TD3*a*, limit switch LS2*a* and to the control grid of tube V3. This places tube V3 in a condition of zero bias, reducing the potential at point 158 to a low value relative to the potential at point 154 and causing relay R to be operated. Additionally, the closure of limit switch LS2*b* completes a connection also including contacts TD3*b* in shunt of the now-open contacts TD2*a* to enable the energizing circuit for winding W1 of motor M1 even though contacts TD2*a* are at this time open. As a result, winding W1 is energized in a direction to cause the motor M1 to reverse to contact the cathode shoes sufficiently to insure free insertion into the next workpiece. The duration of the reverse motion of the motor M1 is controlled by the delay period of relay TD3. At the end of that period, contacts TD3*a* open to terminate the interconnection of the control grid and cathode of tube V3 and contacts TD3*b* open to disable the energizing circuit for motor M1. The apparatus is now in condition to receive a new workpiece.

For test and setup purposes, a manually operable switch S1 may be provided to interconnect the control grid and cathode of tube V3 for contracting the cathode shoes and a manually operable switch S2 may be provided to interconnect the control grid and cathode of tube V4 to cause the cathode shoes to be expanded.

FIGS. 8, 9 and 10 illustrate another form of the subject invention by means of which a predetermined gap may be maintained between a workpiece 176 and a plurality of cathode shoes 178 arranged circumferentially about a honing tool body 180. As in the previous embodiments, the workpiece is held by an electrically conductive fixture 182, which is connected to an electrolytic power supply unit 184 for the passage of a direct electric current from the work through an electrolyte to the cathode shoes 178 and thence back to the power supply unit in a manner similar to that shown in the first embodiment. Each of the cathode shoes 178 is provided with an electrically nonconductive insulator or tab 186 bonded or otherwise secured along one margin of its outer face 188 and which is adapted to engage the work surface being honed during the operation of the machine. The shoes are radially expanded or advanced in and out by axial movement of cathode expansion members 190; and the shoes 178 are held in abutment with the expansion members 190 by a pair of garter springs 192. The lower ends of the expansion members 190 are secured to an actuating plate 194 by any suitable means, such as screws 196. A depending stud 198 is secured to the plate 194 by a pair of nuts 200, and is integrally joined at its lower terminus to a piston 202. The piston 202 reciprocates within a cup or cylinder 204 having a cylindrical inner wall surface 206. The cylinder 204 is carried by a supporting member 208 fixedly suspended from the honing tool body 180 by suitable fastening means, such as screws 210 and sleeves 212. The cathode expansion members 190 are normally biased upwardly by a spring 214 seated within the cylinder 204 and bear against the underside of the piston 202. The piston is adapted to be moved downwardly against the spring 214 under the influence of compressed air which is supplied to the upper portion of the cylinder 204 by a flexible air supply hose 216 which passes through the honing tool body 180 and is fitted at its upper end in an inner rotatable ring 218. The ring 218 is sealed with respect to a nonrotatable outer ring 220 and, together with the ring 220, forms a chamber 222 to which compressed air is supplied from a solenoid actuated air valve 224. A pressure regulator 226 and gauge 228 may be interposed between the solenoid valve and the chamber 222 for regulating the pressure with which the cathode shoes 178 will be expanded against the work and for providing visual means to check the magnitude of this pressure.

The honing tool illustrated in FIG. 8 is provided with the usual abrasive stones 230, which are adapted to be radially advanced by downward axial movement of an actuating rod 232 which effects downward movement of a double expansion cone element 234 engaging cam elements 236 in abutment with the abrasive stones 230. As the honing tool is rotated and reciprocated within the workpiece, the rod 232 is fed downwardly to compensate for the material abraded away from the face of the honing stones 230 and to increase the diameter of the cylindrical surface being honed. In addition, compressed air under a regulated pressure is supplied to the cylinder 204 to maintain the insulating tabs 186 of the cathode shoes 178 in engagement with the surface being honed but under a lesser pressure than that applied to the abrasive stones. The radial thickness of the insulating tabs 186 determines the gap between the outer face 188 and the work surface, which gap is filled with an electrolytic cool-

ant by means such as that illustrated in the prior embodiments. Suitable nylon or ceramic materials can be used for the tabs **186** which will wear extremely well if the pressure with which they are held against the bore wall is not too great. The thickness of the tabs **186** determines the distance through which the electric current will flow in passing from the workpiece to the cathode shoes **178**.

In the operation of the honing tool of this embodiment, the tool body **180** and its associated structure is moved into the workpiece with the abrasive stones **230** and cathode shoes **178** in a compressed or retracted position. At the bottom of the first stroke, downward axial movement of the actuating rod **232** is commenced to advance the honing stones **230** and rotation of the honing tool is also begun. FIG. 10 illustrates suitable circuitry for controlling the operation of the device at this point. A spindle motor **240**, by which the honing tool is rotated, is supplied with three-phase current from leads L1, L2 and L3. A step-down transformer **242** has its primary winding connected to the leads L1 and L2 and its secondary winding serves to produce an alternating current between leads **244** and **246**. At the beginning of the feed of the rod **232**, a feed switch S3 is actuated by any suitable means and its contacts S3*a* and S3*b* are thereby closed to energize the windings of relays TD4 and CR1. The energization of relay CR1 produces closure of its contacts CR1*a* to energize the solenoid valve **224** through terminals **224***a* and **224***b*. The energization of relay TD4 will, after a time delay of several seconds, cause closure of its contacts TD4*a* to turn on the electrolytic power supply unit **184** and thereby initiate the flow of current from the workpiece **176** to the cathode shoes **178** through the electrolyte, which is now flowing through the gap between said members. The operation continues in this manner until the completion of the honing operation, at which time the switch S3 is actuated to open its contacts S3*a* and S3*b*, thus deenergizing the relays TD4 and CR1 and causing contacts TD4*a* and CR1*a* to open. By this means, the solenoid valve **224** is deenergized and the cathode shoes **178** will be retracted under the influence of the spring **214** and garter springs **192**. In addition, the power unit **184** will be shut off to terminate the flow of current from the workpiece to the cathode shoes.

It will be seen that the form of the invention in FIGS. 4–7 and the form of the invention illustrated in FIGS. 8–10 both provide means for maintaining a constant gap between the work surface being honed and the nearest electrically conductive portions of the tool, despite the constantly changing size of the work surface. It has been found that when the cathode shoes or other electrically conductive portion of the tool body is maintained too close to the work surface, sparking and other undesirable effects are produced. If the gap is too large, insufficient etching of the work surface will result. It has therefore been found that the maintenance of a predetermined gap between the work surface and the honing tool will produce the most desirable results, particularly in the honing of a work surface in which the change in the size of the work surface from the unfinished to the finished state will exceed a certain amount.

While the embodiments of the invention illustrated herein are intended for use in finishing interior cylindrical surfaces, it should be appreciated that the invention is equally applicable to honing devices intended for the finishing of exterior surfaces and in which the honing stones are advanced in a radially inward direction to contact the work surface.

While it will be apparent that the preferred embodiments herein illustrated are well calculated to fulfill the objects above stated, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the proper scope or fair meaning of the subjoined claims.

What is claimed is:

1. An abrading device for finishing metallic surfaces comprising:
- (a) a tool body,
- (b) at least one electrically conductive cathode shoe carried by said body in confronting spaced relation to a portion of an anode work surface,
- (c) means for flowing an electrolyte between the work surface and said cathode shoe,
- (d) means for passing an electric current from said work surface to said cathode shoe through said electrolyte,
- (e) means for maintaining said conductive cathode shoe in fixed relation to the work surface as material is removed from said work surface,
- (f) abrasive means carried by said body in electrically non-conductive relation to said cathode shoe and engageable with a portion of said work surface other than that confronted by said body at any one time,
- (g) means for moving said abrasive means over the work surface to abrade the work surface,
- (h) means for moving said cathode shoe relative to said tool body, and
- (i) means for moving said abrasive means toward the work surface independently of said cathode shoe and relative to said tool body.

2. An abrading device for finishing metallic work surfaces as defined in claim **1**, wherein:
- (a) said maintaining means includes a substantially non-wearing insulating element carried by said cathode shoe.

3. An abrading device for finishing metallic work surfaces as defined in claim **2**, wherein:
- (a) said tool includes a honing tool having a body portion carrying a plurality of angularly spaced radially extending abrasive members,
- (b) means for radially expanding and contracting said abrasive members,
- (c) means for applying a radial force to said cathode shoe to maintain said insulating element in engagement with the work surface, and
- (d) means for radially expanding and contracting said abrasive members and said cathode shoe.

4. An abrading device for finishing metallic work surfaces as defined in claim **3**, wherein:
- (a) said means for radially expanding and contracting said abrasive elements includes a cam means operable to radially expand said abrasive elements against the work surface,
- (b) said means for applying a radial force to said cathode shoe includes a cam means operable to radially expand said cathode shoe against the work surface, and including,
  - (1) means for axially moving said last-named cam means, and
  - (2) means for limiting movement of said last-named means to maintain said cathode shoe in a predetermined spaced relation with an anode work surface.

5. An abrading device for finishing metallic work surfaces as defined in claim **1**, wherein:
- (a) said cathode moving means includes a means biasing said cathode shoe toward an anode work surface to maintain engagement with the work surface whereby a spacing is established between said cathode shoe and said work surface.

6. An abrading device for finishing metallic work surfaces as defined in claim **5**, wherein:
- (a) said means biasing said cathode shoe includes a means independent of movement of said abrasive means for radially adjusting said cathode shoe to maintain said cathode shoe in a substantially constant preselected spacing with the work surface.

7. An abrading device for finishing metallic work surfaces as defined in claim 6, wherein:

(a) said means biasing said cathode shoe includes a means responsive to the magnitude of said current for controlling said cathode shoe advancing means, whereby said cathode shoe is adapted to be in a constant preselected spatial relation with the work surface.

8. An abrading device for finishing metallic work surfaces as defined in claim 7, wherein:

(a) said means responsive to the magnitude of said current includes a sensing means for sensing said current, and including,

(1) means for producing a signal whenever said current differs from a pre-selected value, and

(2) means responsive to said signal for radially advancing said cathode shoe.

9. An abrading device for finishing metallic work surfaces as defined in claim 7, wherein:

(a) said means including said sensing means for producing a voltage signal whenever said current differs from a preselected value and having a polarity determined by the direction of the difference, and

(b) means responsive to said signal for moving said cathode shoe radially and in a direction determined by the polarity of said signal.

10. An abrading device for finishing metallic work surfaces as defined in claim 1, wherein:

(a) said abrasive means includes a plurality of angularly spaced electrically non-conductive abrasive members carried by said tool body and projecting from said tool body toward said work surface.

11. An abrading device for finishing metallic work surfaces as defined in claim 1, wherein:

(a) said tool includes an electrically conductive hollow cathode body,

(b) a plurality of angularly spaced abrasive members comprising bonded abrasive particles carried by said body and extending radially outwardly therefrom, said abrasive members being in electrically non-conductive relation to said body,

(c) means for radially outwardly advancing said abrasive member,

(d) means for passing an electrolytic coolant between said body and a workpiece surface forming an anode, and

(e) means for passing a direct electric current from the surface of the workpiece to said body through said electrolytic coolant in locations intermediate said abrasive members.

12. An abrading device for finishing metallic work surfaces as in claim 11, wherein:

(a) said hollow cathode body having a substantially cylindrical outer contour and provided with circumferentially spaced recesses in the outer surface thereof,

(b) a plurality of angularly spaced abrasive members carried by said honing tool in said recesses, said abrasive members being in electrically non-conductive relation to said body portion, and

(c) means for advancing said abrasive members radially outwardly of said recesses and with respect to said body portion.

References Cited by the Examiner

UNITED STATES PATENTS

2,191,256	2/1940	Dunbar et al.	51—342
2,343,500	3/1944	Fairbairn et al.	51—343
2,746,917	5/1956	Comstock	204—143
2,757,488	8/1956	Greenberg	51—340
2,764,540	9/1956	Farin et al.	204—224
2,805,197	9/1957	Thibault et al.	204—143
2,826,540	3/1958	Keeleric	204—143
3,022,232	2/1962	Bailey et al.	204—26
3,061,529	10/1962	Crompton	204—143

OTHER REFERENCES

Webster's New International Dictionary, second edition, G. & C. Merriam Co., publ., Springfield, Mass., 1958, page 1195 relied upon.

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