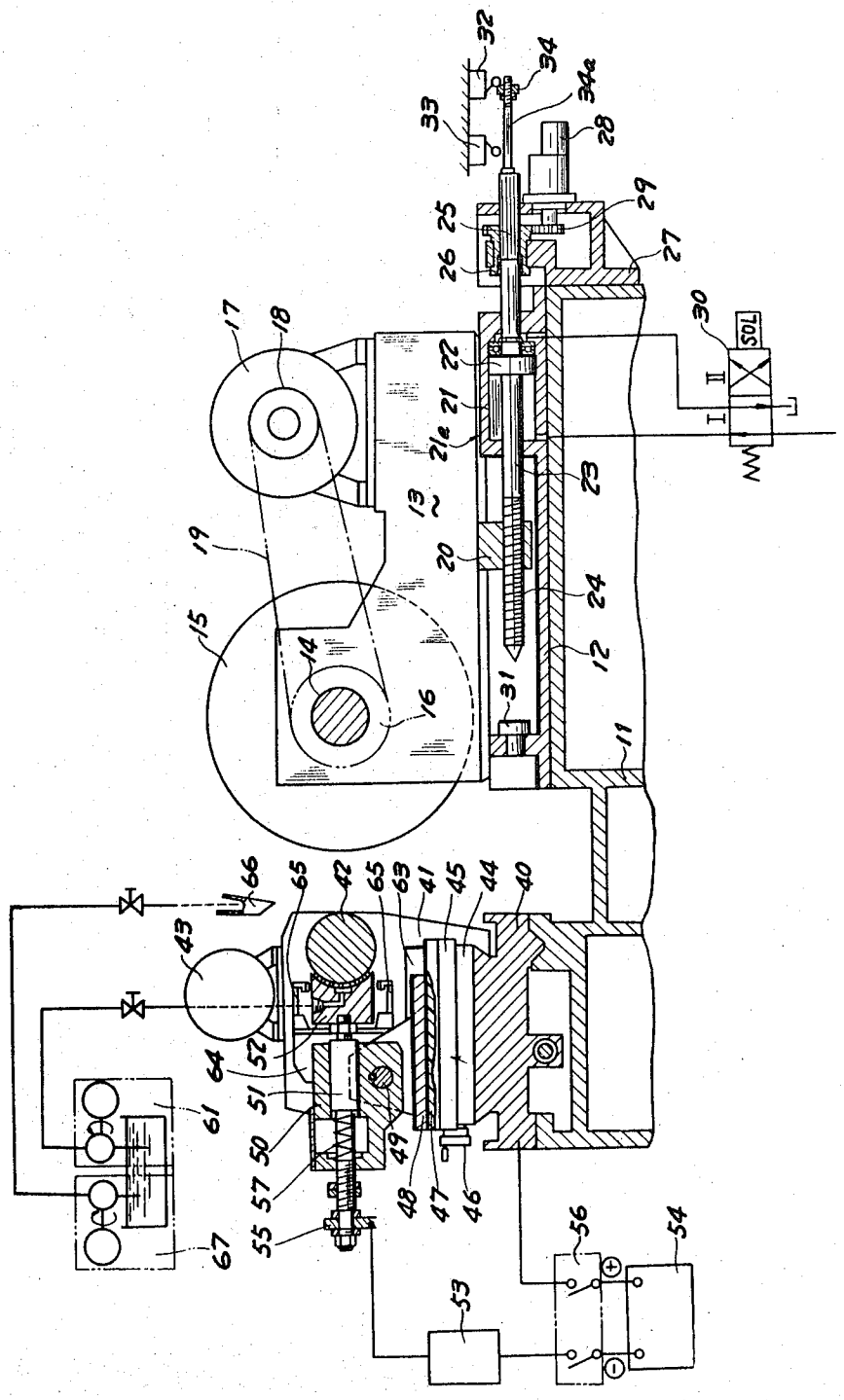
Sept. 26, 1972 KUNIO TAKAHASHI 3,694,340

ELECTROLYTIC GRINDING MACHINE

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Fig.1



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ELECTROLYTIC GRINDING MACHINE

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Fig.2

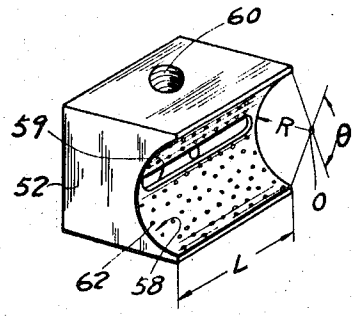
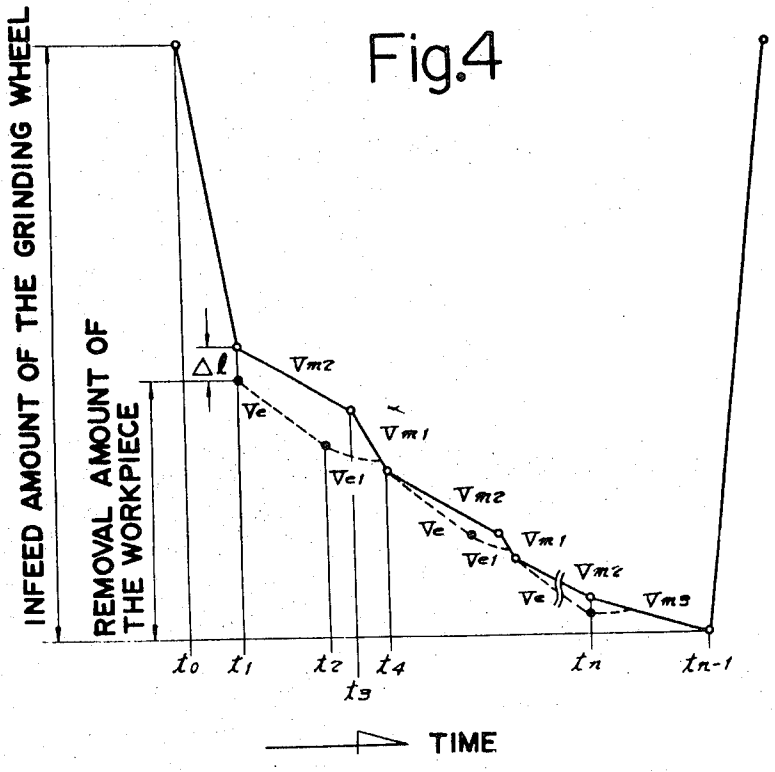


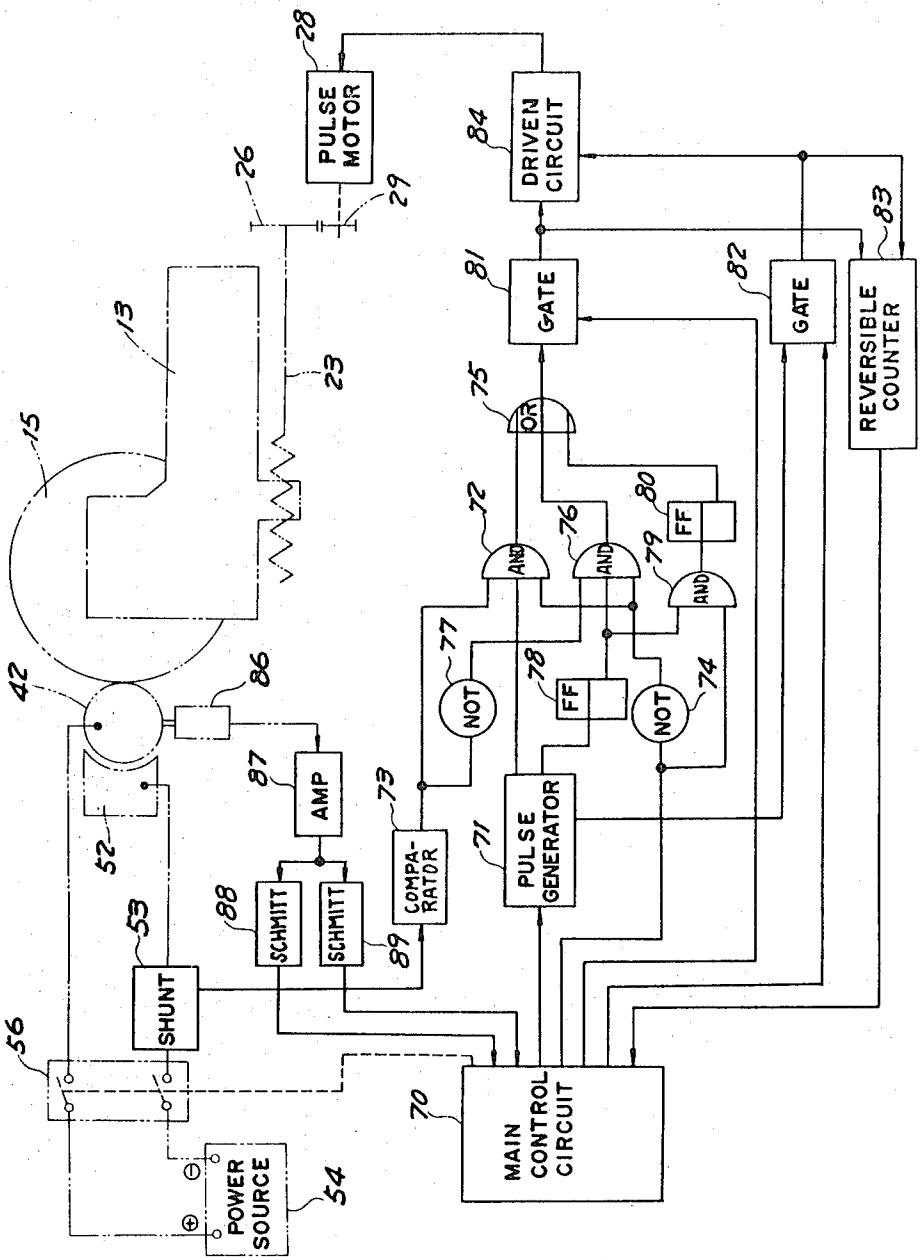
Fig.4



ELECTROLYTIC GRINDING MACHINE

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Fig.3



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ELECTROLYTIC GRINDING MACHINE

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Int. Cl. B23p 1/00
U.S. Cl. 204—224 9 Claims

ABSTRACT OF THE DISCLOSURE

An electrolytic grinding machine having a grinding wheel comprises an electrolytic grinding device, means for detecting the electrolytic grinding current and a control system for controlling the speed at which the grinding wheel head is advanced toward a workpiece. The workpiece is ordinarily ground by the electrolytic grinding device. However, when the electrolytic grinding current becomes smaller than a predetermined current such that the grinding efficiency decreases, a conventional grinding operation by the grinding wheel is automatically applied on the workpiece in response to a command signal provided by the control system.

BACKGROUND OF THE INVENTION

This invention relates generally to electrolytic grinding and more particularly to an improved electrolytic grinding machine wherein a cylindrical workpiece is ground by means of an electrolytic grinding operation and a conventional grinding operation arranged to be automatically performed in a cooperative and efficient manner.

Heretofore, in conventional electrolytic grinding machines having a workpiece and a conductive grinding wheel, the conductive grinding wheel has been maintained in predetermined spaced relation relative to the workpiece by abrasive particles which are bonded on the surface of the grinding wheel, and a direct-current has been applied between the conductive grinding wheel and the workpiece while an electrolyte is simultaneously supplied therebetween. Consequently, while the workpiece and the grinding wheel head of these previous devices are being rotated in a conventional manner, the grinding wheel head is advanced toward the workpiece at an appropriate preselected speed, whereby the electrolytic grinding process is started. When the workpiece has been ground to a predetermined size, the direct-current supplied between the workpiece and the conductive grinding wheel is shut off, and afterward the workpiece is conventionally fine finished by the grinding wheel only.

However, since both the workpiece and the grinding wheel are generally constructed in cylindrical configurations, the opposing area therebetween, namely the actual area available for electrolytic grinding, is extremely small, so that a large amount of direct-current cannot be applied between the workpiece and the grinding wheel, and the electrolytic grinding efficiency suffers because of it.

Furthermore, as the feeding speed of the grinding wheel head and the electrolytic grinding speed are not suitably controlled, if the feeding speed of the grinding wheel head becomes greater than the electrolytic grinding speed, or in other words, if the grinding wheel is advanced toward the workpiece at a greater speed than that at which the electrolytic grinding process is being performed, then the workpiece will be ground by the grinding wheel rather than by electrolytic grinding. In this case, it is highly likely that the grinding wheel and/or the abrasive particles bonded thereon will suffer extensive wear and damage. Therefore, the beneficial aspects of the combination of electrolytic grinding and conventional wheel grinding

are not fully realized by the electrolytic grinding machines presently available.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an improved electrolytic grinding machine which avoids the aforementioned disadvantages of previously known electrolytic grinding machines.

Yet another object of the present invention is to provide an electrode shoe adapted to be disposed against the workpiece on the opposite side of the grinding wheel and which is formed to match the contour of the workpiece with a predetermined space being maintained therebetween, whereby an electrolytic grinding area of increased proportions and a corresponding relatively large amount of electrolytic current may be provided between the workpiece and the electrode shoe.

A still further object of the present invention is to provide means for detecting electrolytic grinding current and a control system for controlling the feeding speed of the grinding wheel head of an electrolytic grinding machine, whereby whenever the current becomes smaller than a predetermined current, the control system will be effective to initiate grinding of the workpiece by the grinding wheel.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and various other objects of the present invention will be more fully appreciated as the same becomes better understood from the following detailed description of a preferred embodiment when considered in connection with the accompanying drawings wherein like numerals designate like or corresponding parts throughout the several figures and in which:

FIG. 1 is a sectional view showing a preferred embodiment of the present invention;

FIG. 2 is a perspective view of an electrode shoe forming part of the invention and constructed according to the teachings thereof;

FIG. 3 is a block diagram of a control system applied to the electrolytic grinding machine constructed according to the present invention; and

FIG. 4 is a diagram illustrating an ordinary cycle of a grinding operation performed by the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Now, referring to FIG. 1, there is secured on a machine bed **11** of an electrolytic grinding machine a stationary base **12** having a grinding wheel head **13** slidably mounted thereon. A grinding wheel spindle **14** is rotatably journalled in the grinding wheel head **13**, and has a conventional grinding wheel **15** positioned at one end thereof and a pulley **16** at the other end. A motor **17** for driving the grinding wheel **15** is mounted on the rear end of the grinding wheel head **13**. The pulley **16** on the spindle **14** and another pulley **18** keyed to the drive shaft of the motor **17** are operably connected by a V-belt **19**, whereby the motor **17** drives the grinding wheel **15** through the pulleys **16** and **18** and the V-belt **19**.

A rapidly feeding hydraulic actuator generally indicated by the numeral **21***a* is mounted on the rear end of the stationary base **12** and comprises a cylinder **21** and a piston **22** slidably mounted therewithin. The piston **22** is integrally formed on the intermediate portion of an elongate feed shaft **23** having a threaded portion **24** at one end thereof and a splined portion **25** at the other end. The threaded portion **24** is engaged with a threaded block **20** secured to the lower side of the grinding wheel head **13**. On the other hand, the splined portion **25** is engaged with the splined portion of a gear **26**, which is rotatably mounted in a bracket **27** secured to the rear

side of the machine bed **11**, with axial movement of the gear **26** being restricted by conventional means. The gear **26** engages another gear **29** which is keyed to the output shaft of an electro-hydraulic pulse motor **28** secured to the rear side of the bracket **27**.

When fluid under pressure is supplied to a directional control valve **30** from a fluid pressure source, not shown, and a solenoid of the valve **30** is energized to change the valve **30** to a position indicated at II, fluid under pressure is supplied to the right chamber of the cylinder **21**, whereby the grinding wheel head **13** is rapidly advanced toward a workpiece **42** by the piston **22** until the top end of the threaded portion **24** engages a stop plate **31** fixed to the stationary base **12**, whereupon the grinding wheel head **13** is then further advanced at a rough grinding feed speed or a fine grinding feed speed by operation of the pulse motor **28** through the threaded block **20**, shaft **23** and gear **29**.

Reference numerals **32** and **33** designate limit switches fixedly positioned for actuation by a dog plate **34** carried on a shaft **34***a* extending from the splined end portion **25** of the elongate feed shaft **23**. The limit switch **32** confirms the starting position of the grinding wheel head **13** and the switch **33** the final position in the path of movement thereof toward the workpiece negotiated by the piston **22**.

On the bed **11**, there is also slidably mounted a table **40** on which a head stock **41** and a tail stock, not shown, are mounted for rotatably supporting the workpiece **42**. A motor **43** is mounted on the head stock **41** for rotating the workpiece **42** through turning gear mechanism, not shown, provided in the head stock **41**.

Between the head stock **41** and the tail stock, the slidable table **40** is provided with a supporting base **44** for supporting the electrolytic grinding device. A movable base **45** is slidably mounted on the supporting base **44** for advancement and retraction relative to the workpiece **42** by a hand wheel **46** mounted on the front side of the supporting base **44**. A holding bracket **48** is secured on the movable base **45** through an insulator **47**, and has a pivot pin **49** thereon to which support **50** is keyed for thereby pivotably mounting the same on the holding bracket **48**. The shaft **49** is usually restricted from the relative pivotable movement in a conventional manner.

A conductive holding member **51** is slidably mounted in the support **50** and restricted from rotational movement therein by any conventional means, such as, for example, by a key relation to the slot within the support, being in the form of a rectangular cross section. A conductive electrode shoe **52** is screwed to the top end of the holding member **51** and disposed opposite the grinding wheel **15**, thereby placing the workpiece **42** therebetween. The holding member **51** has a terminal **55** at the rear end thereof, which is connected to the negative pole of a direct current power source **54** through a shunt **53** and a switch **56**, and on the other hand, the positive pole of the power source **54** is connected to the slidable table **40** and the workpiece **42** through the head stock **41**, the tail stock and other sections of the device. A compression spring **57** is installed between the support **50** and the holding member **51** for biasing the electrode shoe **52** against the workpiece **42**.

The electrode shoe **52**, as shown in FIG. 2, preferably has an arcuate convex surface **58** thereon, of which the inner radius R is substantially the same radius as that of the workpiece **42**, the angle θ of the circular arc between the end edges of the arcuate surface **58** is properly decided by the electrolytic grinding condition, and the transverse length L thereof is approximately equal to the length of the workpiece **42**. An axially extending slot **59** providing a delivery port for electrolyte is formed on the intermediate portion of the arcuate convex surface **58**, and is connected to an electrolyte supply port **60** disposed on the upper surface of the electrode shoe **52**. Therefore, pressurized electrolyte supplied from an electrolyte source **61** may be delivered through the supply port **60** and the delivery port **59** in the electrode shoe **52** onto the workpiece **42**. The electrode shoe **52** further has insulating particles **62**, such as diamond, uniformly spaced in adhering relation on the whole arcuate surface **58** for spacing the arcuate surface a predetermined distance from the periphery of the workpiece **42** being received in the shoe **52**.

A table **63** for slidably supporting a sizing device **64** is fixedly mounted on the slidable table **40** between the head stock **41** and the supporting base **44**. The sizing device **64** can be reciprocated relative to the workpiece **42** by means of a piston-cylinder mechanism, not shown, also mounted in the table **63**. Moreover, the sizing device **64** is provided with a pair of opposed feelers **65** to engage the workpiece **42** for measuring the diameter thereof. The lower feeler **65** is mechanically interlocked with the core of a differential transformed **86** mounted in the sizing device **64**. The output signal from the differential transformer **86** is sent to a main control circuit **70**, as shown in FIG. 3, through an amplifier **87** and a pair of Schmitt triggering circuits **88** and **89**, presently to be described. Reference numeral **66** designates a coolant supply nozzle for supplying coolant fluid from a coolant fluid source **67** onto the areas of contact between the grinding wheel **15** and the workpiece **42**. In this embodiment, the electrolyte serves as the coolant being delivered to the workpiece **42**, so the electrolyte and coolant may be supplied from a common fluid source.

Next, referring to FIG. 3, the feed control system for the grinding wheel head **13** will be described. Reference numeral **70** designates the aforementioned main control circuit for controlling the whole mechanical movement of the electrolytic grinding machine by means of signals being sent from various electrical sensing means, such as the limit switches **32** and **33**, the sizing device **64**, and the like. Reference numeral **71** designates a pulse generator for providing pulse signals in response to the receipt of a signal from the main control circuit **70**. Reference numerals **72**, **76** and **79** designate AND gates. The AND gate **72** will provide a pulse signal to an input of an OR gate **75** upon the simultaneous receipt of a signal from the pulse generator **71**, the comparator **73** and a NOT gate **74**. The AND gate **76** will provide a pulse to another input of the OR gate **75** in response to the simultaneous receipt of a signal from the pulse generator **71**, after being divided in half by a Flip-Flop gate **78**, an inhibit signal from a NOT gate **77** and an inhibit signal from the NOT gate **74**. In the above, it should be noted that the inhibit signal at the output of the NOT gate **74** is in response to a fine grinding operation and the output of the NOT gate **77** is in response to an ordinary grinding operation, namely a grinding operation by the grinding wheel **15**. The AND gate **79** will provide a pulse to the OR gate **75**, after being divided in half by a Flip-Flop **80**, in response to the simultaneous receipt of a pulse from the output of the Flip-Flop **78** and a signal representing a fine grinding operation from the main control circuit **70**. The reference numeral **81** designates a gate circuit for enabling a forward rotation of the pulse motor **28** and hence an advancement of the grinding wheel head **13** in response to a signal from the OR gate **75**. Reference numeral **82** designates a gate circuit for enabling a reverse rotation of the pulse motor **28**, and hence a retraction of the grinding wheel head **13** in response to a signal from the main control circuit **70**. A reversible counter **83** is provided and the same will add any pulses received from the gate circuit **81** and will subtract any pulses received from the gate circuit **82**. When the number in the counter registers a zero count, a signal will be emitted therefrom and applied to the main control circuit **70** for stopping the grinding wheel head **13** and indicating that the same should be returned to its starting position. Reference numeral **84** designates a driving circuit for respectively driving the electro-hydraulic pulse motor **28** in either a forward or reverse direction depending upon whether pulse signals are received from either the gate circuit **81** or the gate circuit **82**.

In addition, it should be understood that the aftoremen-tioned shunt **53** is connected between the electrode shoe **52** and the power source **54** for enabling the electrolytic

grinding current, which is inversely proportional to electrolytic grinding resistance between the electrode shoe **52** and the workpiece **42**, to be detected. It should further be understood that the shunt **53** will provide a voltage control signal to the comparator **73** with an amplitude which is proportional to the electrolytic grinding current in the power source **54**. In the comparator **73**, when the signal from the shunt **53** exceeds a predetermined reference value, a signal will be applied to the input of the AND gate **72** and the NOT gate **77**. The predetermined value of the reference voltage applied to the comparator **73** may be varied in a conventional manner so as to select any desired value. The differential transformer **86** is connected to the pair of Schmitt trigger circuits **88** and **89** through the amplifier **87** and interlocked to the sizing device **64**, as hereinbefore indicated. When a signal representative of the diameter of the workpiece **42** is obtained from the differential transformer **86** then a signal for enabling a fine grinding operation is applied from the Schmitt trigger circuit **88** to the main control circuit **70** and a sizing signal is applied from the Schmitt trigger **89** to the main control circuit **70**.

Now, hereinbelow explained is the operation of the above described embodiment of the present invention with particular reference to FIGS. 1, 3, and 4. FIG. 4 diagrams the cycle of the grinding operation in which the solid lines show the infeed amount of the grinding wheel head **13** respective to time and the broken lines show the removal amount of the workpiece **42** by means of the electrolytic grinding operation respective to time. When the main control circuit **70** receives a starting signal in a conventional manner, such as by operation of a push button, the solenoid in the directional control valve **30** is energized by a signal from the main control circuit **70** to change the valve **30** to a position indicated at II, whereby fluid under pressure from the fluid power source, not shown, is accordingly supplied to the right chamber of the cylinder **21** to thereby advance the grinding wheel head **13** at a rapid feeding speed toward the workpiece **42**. The limit switch **32** is deactuated by the movement away therefrom of the dog plate **34** with the advancing grinding wheel head **13**, to thereby cause operation of the motor **43** for rotating the workpiece **42** and to actuate the coolant supply source **67** for supplying coolant on the contacting surface area of the workpiece **42** and the grinding wheel **15** from the supply nozzle **66**. When the forward end of the shaft **23** engages the stop plate **31**, the limit switch **33** is actuated by the dog plate **34**, whereupon the advancement of the grinding wheel head **13** is stopped at that point, at the time indicated at t_1 in FIG. 4. In this case, as shown in FIG. 4, the grinding wheel is spaced a predetermined distance Δl from the workpiece **42**. Actuation of the limit switch **33** causes the switch **56** to be closed and the electrolyte supply source **61** to be actuated, and further the sizing device **64** to be advanced toward the workpiece **42** for measuring the diameter thereof. Consequently, an electrolytic current is impressed between the workpiece **42** and the electrode shoe **52** from the power source **54**, and the electrolytic grinding operation is initiated at the electrolytic grinding speed Ve, which designates the removal amount of the workpiece **42** per unit time, from the time t_1. As above described, as the grinding wheel **13** is spaced from the workpiece **42** by a distance Δl, the workpiece **42** is not being ground by the grinding wheel **15**. Moreover, a command signal is provided by the main control circuit **70** for causing the pulse generator **71** to emit pulse signals and a gate opening signal is sent to the gate circuit **82**. However, before oxide, graphite or the like are formed on the outer surface of the workpiece **42** and while electrolytic resistance between the electrode shoe **52** and the workpiece **42** is still small enough that a large amount of current is flowing in the power circuit, no signal is generated by the comparator **73**. Of course, in this instance, a command signal for a fine grinding operation is not emitted from the main control circuit **70**. Accordingly, the inhibit signals for the actuation of the comparator **73** and for the fine grinding operation are derived from the NOT gates **77** and **74**, respectively, and then sent to the AND gate **76**. Therefore, a pulse signal from the pulse generator **71** is sent to the OR gate **75** through the Flip-Flop gate **78** in which the pulse numbers are divided in half, and the AND gate **76**, and continuously to the pulse motor **28** through the gate circuit **81** and the driving circuit **84**. Thus, the pulse motor **28** is rotated with a rotational speed proportional to the pulses passing through the gate circuit **81** for advancing the grinding wheel head **13** at a slow feed speed Vm_2 from the time t_1. These pulses are added in the reversible counter **83**. The electrolytic grinding speed Ve is set up slightly faster than the slow feeding speed Vm_2, for maintaining electrolytic grinding until the electrolytic current falls below the predetermined value. The relationship set up between the speeds Vm_2 and Ve may be varied by changing the output current of the power source **54** or changing the numbers of pulses being generated by the pulse generator **71**.

In the meantime, during the electrolytic grinding operatioin, as infusible oxides are formed on the surface of the workpiece **42**, or graphites are precipitated from the workpiece **42**, electrolytic resistance between the workpiece **42** and the electrode shoe **52** gradually increases, thereby causing the current in the power source **54** to decrease. Consequently, when the electrolytic current falls below the predetermined value, the electrolytic grinding speed Ve slows to the speed Ve_1 from the time t_2. Thus, from the time t_8, after a little while at t_2, the comparator **73** is actuated, and the signal from the NOT gate **77** ceases. Therefore, the pulse signal from the pulse generator **71** is directly sent to the AND gate **72**, and through the OR gate **75** and the gate circuit **81** to the driving circuit **84** for driving the pulse motor **28** proportional to the pulse frequency of the pulse generator **71**. In consequence, from the time t_3, the grinding wheel head **13** is advanced at a fast feeding speed Vm_1, which of course is twice as fast as the slow feeding speed Vm_2. Thus, the grinding wheel **15** serves to remove the oxide, graphite and the like on the workpiece **42** by a conventional grinding operation, and the electrolytic grinding operation continues to actually grind the workpiece **42**. When the electrolytic resistance between the workpiece **42** and the electrode shoe **52** again decreases, whereupon the electrolytic current in the power circuit is increased, the comparator **73** is again disactuated from the time t_4. Accordingly, the pulse signal from the pulse generator **71** is sent to the AND gate **76** through the Flip-Flop gate **78** for reducing the pluse frequency by half, and the reduced pulse signal frequency is sent to the pulse motor **28** through the OR gate **75**, the gate circuit **81**, and the driving circuit **85**. Thus, the grinding wheel head **13** is again advanced at the slow feeding speed Vm_2.

As above described, the workpiece **42** is ground by means of the electrolytic grinding process and the conventional wheel grinding operation, and when the operation is progressed to the time tn, wherein the dimension of the workpiece **42** is at the desired point, a command signal for the fine grinding operation is sent from the Schmitt circuit **88** to the main control circit **70**, thereby opening the switch **56** and stopping the flow from the electrolyte supply source **61**, thus signaling the completion of the electrolytic grinding operation. At this time, the command signal for fine grinding operation is sent from the main control circuit **70** to the AND gate **79** and the NOT gate **74**, respectively, so that the reduced pulse signal from the Flip-Flop gate **78** is sent to the OR gate **75** through the AND gate **79** and the Flip-Flop **80** in which the pulses are further divided in half, and then sent to the pulse motor **28** through the gate circuit **81** and the driving circuit **84** for advancing the grinding wheel head **13** at a fine grinding speed Vm_3. When, at the time

t_{n-1}, the workpiece **42** is finished to the final dimension, the final sizing signal is sent from the Schmitt circuit **89** to the main control circuit **70**. Then, the gate closing signal is sent to the gate circuit **81** from the main control circuit **70**, thus stopping the grinding wheel head **13**. At the same time or a little while deriving the sizing signal, an opening signal for gate **82**, namely a reversing pulse motor **28** signal, is sent to the gate circuit **82**, and a de-energizing signal is sent from the main control circuit **70** to the solenoid of the directional control valve **30** for changing the position to I. Accordingly, the grinding wheel head **13** is retracted at the composite speed of the rapid feeding speed by the piston **22** and the speed of the pulse motor **28**. Then, upon appropriate retraction of the grinding wheel head, the limit switch **33** is deactuated for retracting the sizing device **64** to its initial position. The pulses applied to the pulse motor **28** are subtracted from the reversible counter **83** during reversing rotation of the pulse motor **28**. When the number in the counter **83** reaches zero, a stopping signal is sent from the counter **83** to the main control circuit **70** for indicating that the grinding wheel head **13** has been retracted to its starting position. Furthermore, a command signal for stopping the generation of pulse signals and for closing the gate **82** are sent to the pulse generator **71** and the gate circuit **82**, respectively. Thus, the grinding cycle is completed, and the workpiece **42** is ground to a final predetermined size.

As above described, in the electrolytic grinding machine formed according to the present invention, a workpiece is ground initially by means only of an electrolytic grinding process until the electrolytic grinding current, namely the electrolytic grinding speed, falls below a predetermined value, whereupon conventional grinding by a grinding wheel is applied to the workpiece for removing the graphite and oxide precipitated theeron. Thereafter, electrolytic grinding current again increases. Thus, it is expected to increase the electrolytic grinding efficiency and to minimize the wear and the damage of the grinding wheel.

While the present invention has been described by means of a specific embodiment, various modifications and variations are possible in light of the teachings of the invention. It should be understood, therefore, that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In an electrolytic grinding machine having a grinding wheel rotatably mounted on a grinding wheel head, and a head stock and a tail stock for rotatably supporting a workpiece in operative relationship therewith, the improvement comprising:

an electrolytic grinding device also in operative relationship with said workpiece;

a feed mechanism for reciprocably moving said grinding wheel head toward and away from said workpiece;

a sizing device for measuring the size of said workpiece;

means for detecting the electrolytic grinding current; and

a control system connected to said detecting means for controlling the speed of said grinding wheel head feed mechanism responsive to said electrolytic grinding current.

2. An electrolytic grinding machine as set forth in claim **1**, wherein said electrolytic grinding device comprises an electrode shoe having a supply port, a workpiece receiving surface, an electrolyte delivery port in said surface, and insulating particles secured on said surface for spacing the workpiece a predetermined distance from said receiving surface, said shoe supply port being connected to a source of electrolyte, and a power source connected to said shoe and said workpiece.

3. An electrolytic grinding machine as set forth in claim **2**, wherein said workpiece-receiving surface of electrode shoe is an arcuate convex surface.

4. An electrolytic grinding machine as set forth in claim **2**, wherein said electrolytic power source is a direct-current power source.

5. An electrolytic grinding machine as set forth in claim **1**, wherein said detecting means comprises a shunt.

6. An electrolytic grinding machine as set forth in claim **1**, wherein said feed mechanism comprises:

a rapidly feeding hydraulic actuator mounted on a machine bed and connected to said grinding wheel head for moving said grinding wheel head through a predetermined linear path whereby said grinding wheel is positioned in predetermined spaced relation with respect to said workpiece; and

a fast, slow and fine finish feeding device for said grinding wheel head for further advancing the same toward said workpiece.

7. An electrolytic grinding machine as set forth in claim **6**, wherein said fast, slow and fine feeding device comprises a pulse motor actuable by a signal from said control system.

8. An electrolytic grinding machine as set forth in claim **7**, wherein said pulse motor is an electro-hydraulic pulse motor.

9. An electrolytic grinding machine as set forth in claim **8**, wherein said control system comprises:

a pulse generator for supplying pulse signals to said pulse motor;

a comparator connected to said electrolytic current detecting means;

first, second, and third control gates for controlling said grinding wheel head feeding speed provided between said pulse generator and said pulse motor;

said first control gate for operating said feeding device at said slow speed responsive to a normal electrolytic grinding speed;

said second control gate for controlling said fast feeding speed being responsive to a signal from said comparator upon a predetermined decrease in said electrolytic grinding speed; and

said third control gate for said fine finish feeding speed being responsive to a signal from said sizing device.

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