

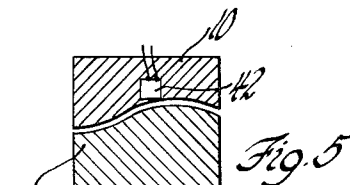
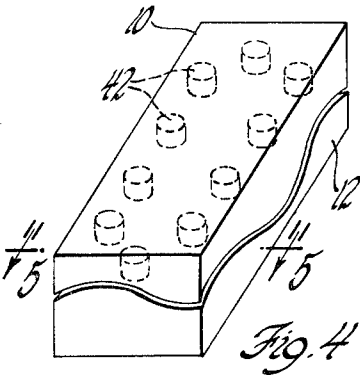
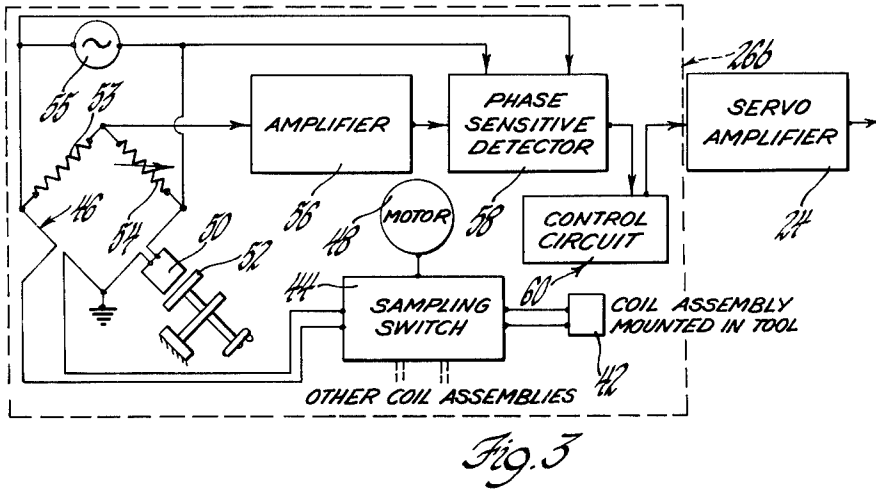
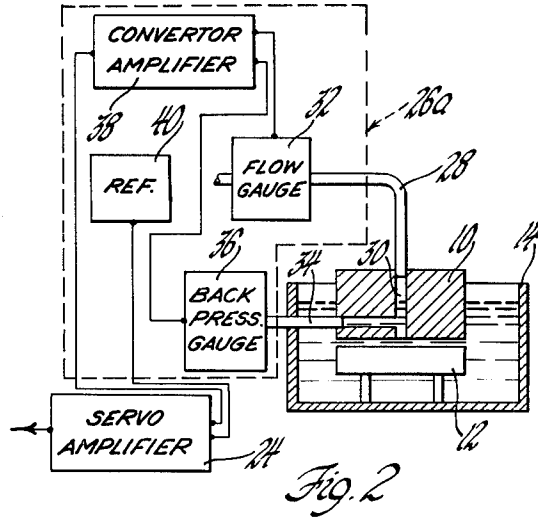
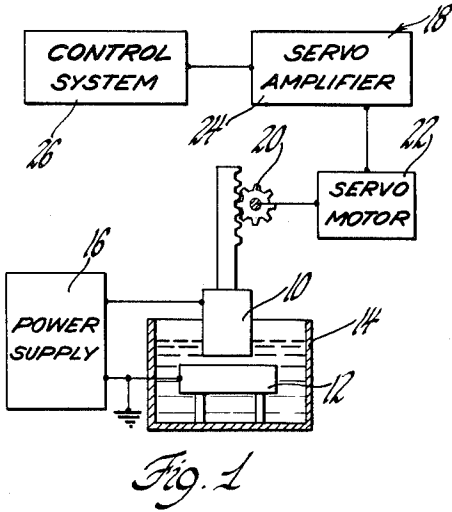
Jan. 11, 1966

G. E. WANTTAJA ETAL  
ELECTROLYTIC PROCESS AND APPARATUS FOR REMOVING  
STOCK FROM A CONDUCTIVE WORKPIECE

3,228,863

Filed Oct. 27, 1960

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

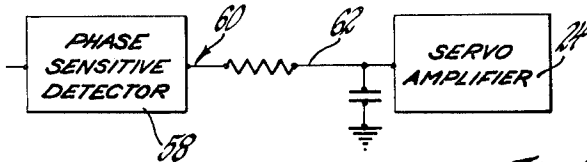


Fig. 6

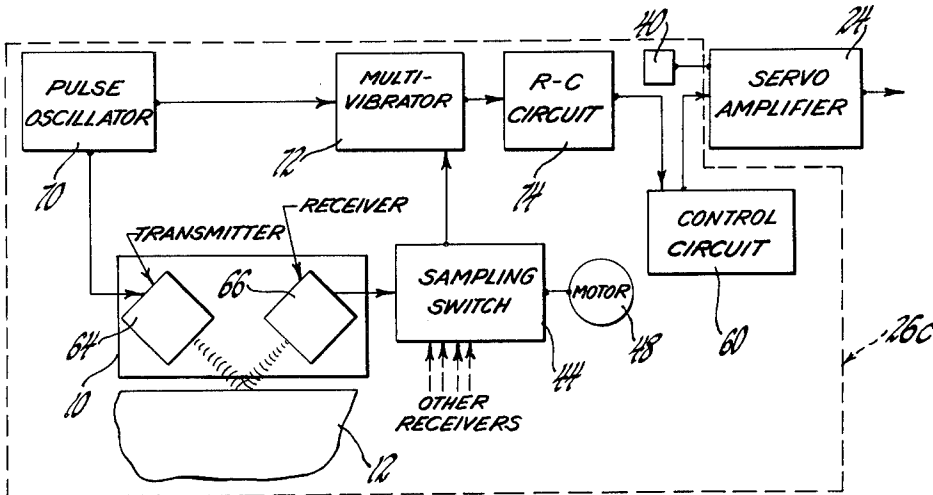


Fig. 7

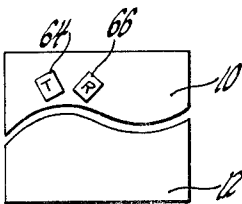


Fig. 8

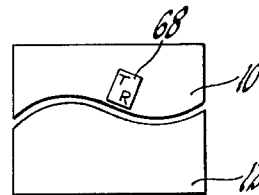


Fig. 9

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3,228,863

## ELECTROLYTIC PROCESS AND APPARATUS FOR REMOVING STOCK FROM A CONDUCTIVE WORKPIECE

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28 Claims. (Cl. 204-143)

This invention relates generally to stock removal apparatus and particularly to control systems adapted for use, although not exclusively, with electrolytic stock removal apparatus.

In the process of electrically removing stock from a conductive workpiece electrode, there is always concern about the attainment of a satisfactory automatic feed of the tool and workpiece electrodes relative to each other. This problem becomes even more complicated when an electrolyte is flowed through the gap between the electrodes, for if a constant feed rate is established, varying conditions including changes in the electrolyte require periodic resetting of the gap. This, of course, demands operator attention and results in "down time" or a non-productive interval. On the other hand, and again when an electrolyte is being employed, the use of gap voltage as an indication of the gap spacing, and therefore offering a mode of automatically adjusting the feed rate with changing conditions, is not a satisfactory solution because when an electrolyte is employed, current density is greatest at the closest point between the electrodes; whereas, a measurement of the gap voltage only produces an average voltage and does not inform the operator of the close proximity of the electrodes at this one point. As a consequence, the presence of this high current density will produce overheating, which in turn can damage the adjacent areas of both the tool and the workpiece electrodes.

With the foregoing problem in mind, the invention contemplates in the electrical stock removal process a unique mode of accurately controlling the feed rate between the electrodes so as to automatically maintain a predetermined gap despite varying influencing conditions and without operator attention. Moreover, by the invention and in a novel fashion, variations in the gap spacing from a predetermined gap are constantly sensed and appropriate corrections are automatically made so as to maintain a predetermined gap between the electrodes at all times.

In carrying out the foregoing, the invention as another aim thereof seeks to provide various ways of measuring the gap spacing including ascertaining the time interval required to transfer energy between the electrodes, determining variations in a magnetic link between the electrodes due to their proximity, measuring differences, again due to the proximity of the electrodes, in the impedance of an energizing circuit carried by one of the electrodes, and determining variations in the pressure of the fluid in the gap areas produced by deviations in the gap spacing from a certain gap.

The foregoing and other objectives and advantages of the invention will become apparent from the following description and from the following drawings in which:

FIGURE 1 demonstrates apparatus utilized in demonstrating the principles of the invention;

FIGURE 2 is a schematic showing of a control system utilizable in the FIGURE 1 apparatus;

FIGURE 3 illustrates in a block diagram form another control system for the FIGURE 1 apparatus;

FIGURE 4 shows a view of tool and workpiece electrodes employed by the FIGURE 3 system;

FIGURE 5 is a sectional view of FIGURE 4 taken along lines 5-5;

FIGURE 6 is a schematic diagram of a control circuit that may be employed in the FIGURE 3 system;

FIGURE 7 is a block diagram of still another control system that may be utilized with the FIGURE 1 apparatus; and

FIGURES 8 and 9 show fragmentary sectional views of the tool and workpiece electrodes and the arrangement thereof used in the FIGURE 7 control system.

Considering the drawings in detail, and initially FIGURE 1, the numerals 10 and 12 designate electrodes for the apparatus and will hereinafter be referred to, respectively, as the tool and the workpiece. The tool 10 is positioned opposite the workpiece 12 so that a predetermined gap is established therebetween. The workpiece 12 is situated in, and insulated from, a tank 14 containing a suitable electrolyte of a quantity adequate to cause the removal of stock from the workpiece 12 by chemical action. This stock removal process is accelerated by connecting a suitable power supply 16 across the gap formed between the tool 10 and the workpiece 12 in a manner such that the tool 10 becomes the cathode and the workpiece 12, the grounded anode. The gap is optimum for existing conditions and the results desired, i.e., workpiece finish and stock removal rates.

As the stock removal takes place by this method, commonly referred to as the electrochemical machining process, it is necessary, because the gap spacing will increase, to maneuver the tool 10 and the workpiece 12 together, if the optimum gap is to be maintained. This is accomplished by a maneuvering provision as the feed mechanism 18. In this instance, the feed mechanism 18 through gearing 20 in turn operated by a servomotor 22 moves the tool 10 up and down relative to the workpiece 12. Of course, if preferred, the workpiece 12 can be moved and instead of gearing 20 and servomotor 22, a piston type motor can be combined directly with the electrode to be maneuvered. Or, both the electrodes can be moved if necessary for effective use of the apparatus. The servomotor 22 in this embodiment receives signals via a servo amplifier 24 from a control system 26, which signals cause the servomotor 22 to increase or decrease the feed rate as required to maintain this predetermined optimum gap.

As has been stated, the feed rate can be constant. However, there are many factors both internal and external that require from time to time that the gap spacing be reset if a constant feed rate is utilized. For this reason, a control system such as that shown in FIGURE 2 and denoted generally by the numeral 26a is preferably utilized. In system 26a, an electrolyte supply conduit 28 is connected to an orifice 30 in the tool 10 and includes therein a flow gage 32 that establishes the rate of flow of the incoming electrolyte. Also associated with the conduit 28 is a branch 34 arranged to interconnect the orifice 30 with a back pressure gage 36. The gages 32 and 36 are of any known construction and develop alternating signals determined by the condition of the electrolyte, i.e., flow and pressure. With this gage arrangement, as the spacing between the tool 10 and workpiece 12 is varied, the resultant back pressure will similarly change and develop a corresponding signal that will be delivered to the input of a converter and amplifier 38. Also supplied to the input of the converter and amplifier 38 is a signal from the flow gage 32, this signal affording a way of correlating flow with the back pressure since increased flow will similarly increase back pressure as will decreased flow decrease back pressure. Of course, if flow is always constant, the flow gage 32 will not be necessary. The variations in the back pressure signal with a certain flow are

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converted to a D.C. control signal and amplified if required prior to being transferred to the servo amplifier 24. If the gages 32 and 36 afford D.C. control signals, of course the converter will not be needed. The servo amplifier 24 has as a part thereof a reference voltage source 40 and is so arranged that the control signal is compared with the reference signal by suitable summing circuitry so as to develop an output or error signal for use by the servomotor 22 indicating both the direction of movement and distance needed to maneuver the tool 10 in order to establish the desired gap spacing. For instance, if the error signal furnished to the servomotor 22 is negative, the servomotor 22 can be caused to increase the feed rate of the tool 10; whereas, if the control signal is positive, the tool 10 can be withdrawn, in each instance until a null error signal is obtained.

Another control system, assigned the numeral 26b, is displayed in FIGURE 3. This system utilizes one or more transducers, such as inductors or coil assemblages 42, each of which is positioned within the tool 10 as demonstrated in FIGURES 4 and 5. The number of these assemblages 42 will depend upon the size and contour of the tool 10 and the workpiece 12. If a number of coil assemblages 42 are required, then a sampling switch as that denoted by the numeral 44 may be employed for sequentially or selectively connecting the individual coil assemblages 42 to a bridge shown at 46. The sampling switch 44 can be operated mechanically and/or electrically, e.g., by a motor 48 so that each coil assemblage is individually connected to the one arm of the bridge 46 for a certain interval. Another arm of the bridge 46 affords a reference and includes a reference coil assemblage 50 that is positioned opposite a reference workpiece 52. The space between the reference coil assemblage 50 and the reference workpiece 52 can be altered as desired so as to establish the gap spacing at which the stock removal process is to be conducted. Also, it should be kept in mind that the reference workpiece 52 should have the same magnetic and conductive characteristics as the workpiece 12. The other arms of the bridge 46 include impedances 53 and 54, impedance 54 being adjustable for calibration purposes.

If the spacing of the coil assemblages 42 relative to the workpiece 12 corresponds to that of the reference coil assemblage 50 and the reference workpiece 52, and further assuming that the input of the bridge 46 is connected to an alternating current source 55, there will be a null output signal since the bridge 46 will be balanced. But, if there is a discrepancy, an unbalanced voltage of a phase determined by the proximity of the tool 10 and the workpiece 12, i.e., whether the gap spacing is less or greater than that predetermined, will be developed, which voltage may be increased by an amplifier 56 if needed and then supplied to the input of a phase sensitive detector 58. At this point, a D.C. error signal will be developed having a polarity and magnitude corresponding to the amount of difference between the actual gap spacing and the desired gap spacing and whether the actual spacing is too close or too far away. Again, it can be assumed if too close the polarity of this error signal will be positive; whereas, if too far apart, a negative error signal will be produced. Also, it should be noted that the operation of the assemblages 42 for gap spacing control purposes is uninfluenced by the conditions of the electrolyte and the machining current and voltage.

The error signal, if only one coil assemblage is employed, may be supplied directly to the servo amplifier 24 and then to the servomotor 22 in FIGURE 1 so as to cause the appropriate correction to be made in the manner explained with respect to the FIGURE 2 control system. But, if there are a series of coil assemblages 42, the sampling switch 44 is utilized along with a control circuit 60, and the average of the error signals from all of the coil assemblages 42 can be integrated to develop an average error signal voltage for supplying to the servo amplifier 24. One way of accomplishing this is shown in FIG-

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URE 6 where an integrating circuit 62 of a proper time constant is displayed for obtaining this average of all the error signals. Preferably, if one of the coil assemblages 42 should indicate that the tool 10 at the checking point is dangerously close to the workpiece 12, the resultant error signal will cause the process to be stopped. This can be accomplished in any appropriate way. For example, the error signal produced when this condition exists can cause interruption of the operation of the integrating circuit 62 as well as cause the power supply 16 to be cut off.

With the FIGURE 3 control system, both magnetic and non-magnetic conductive workpieces can be machined. If the workpiece 12 is magnetic, the spacing between the coil assemblages 42 and the workpiece 12 will vary the magnetic link or coupling therebetween and accordingly change the impedance in the arm of the bridge 46 to which the coil assemblages 42 are connected. In this instance this will be a change in the inductance, which inductance will increase as the tool 10 and the workpiece 12 are moved closer together. On the other hand, if the workpiece 12 is non-magnetic, the alternating current source 55 will, through the coil assemblages 42, induce eddy current activity in the non-magnetic workpiece 12. The eddy current intensity will increase as the spacing between the tool 10 and the workpiece 12 is decreased and again this variation in the eddy current intensity will influence the impedance of the coil assemblages 42 by lowering the apparent resistance thereof when the gap spacing is decreased.

The other control system that may be utilized by the FIGURE 1 apparatus is depicted in FIGURE 7 and is assigned the numeral 26c. In this system, the tool 10 has suitably incorporated therein separate sending and receiving transducers 64 and 66 as viewed in FIGURE 8 or a combined sending and receiving transducer 68 as seen in FIGURE 9. For explanatory purposes only, the transducers 64 and 66 will be described since combined transducer 68 will perform in substantially the same way. Transducers 64 and 66 are arranged as seen in FIGURE 7 so that the sending transducer 64 is connected to the output of a pulse oscillator 70. The same pulse oscillator 70 has another output thereof connected to a flip-flop type multivibrator 72, which functions as a switch. Preferably, the pulse oscillator 70 generates ultrasonic frequencies so that when a pulse signal is produced, it is sent simultaneously to the multivibrator turning it on, and to the sending transducer 64. The sending transducer 64 will emit the pulse signal toward the surface of the workpiece 12 from which it will be reflected due to the arrangement of the transducers and picked up by the receiving transducer 66. The reflected pulse signal then is delivered to the multivibrator 72 via the sampling switch 44, if several sets of these transducers 64 and 66 or the combination transducer 68 are required due to the types of workpiece 12 being machined. The reflected pulse signal will turn the multivibrator 72 off. As is now apparent, if the two pulses generated simultaneously by the oscillator 70 are delivered to the multivibrator simultaneously, the pulse signal turning the multivibrator 72 on will be counteracted by the pulse signal turning it off, and hence, the multivibrator 72 will not generate an output. But, because of the time delay induced due to the distance between the tool 10 and the workpiece 12, the multivibrator 72 will be on for an interval corresponding to the gap spacing and during this interval develop a proportional output control signal. The control signal from the multivibrator 72 is preferably applied to an R.C. circuit 74 so as to obtain an average D.C. control signal and thereafter supplied directly to the servo amplifier 24 if only one set of transducers is employed. If a series is employed, then as with the FIGURE 3 control system 26b, the control circuit 60 may be employed to obtain an average of the control signals from all of the sets of transducers, which average will be supplied to the servo amplifier 24 and compared with the reference voltage source 40 as in the

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FIGURE 2 system. The servo amplifier 24 will supply the corresponding error signal to the servomotor 22 as described in the explanation of the FIGURE 2 system. Also, in the event one set of transducers 64 and 66 indicates that the tool 10 is too close to the workpiece 12 at the area which the set of transducers 64 and 66 controls and as in the FIGURE 3 system, the process can be stopped.

It should be mentioned that the FIGURE 2 system may in the same way as the FIGURE 3 and the FIGURE 7 systems check spacing at a plurality of points between the workpiece 12 and the tool 10. This can be done by employing several orifices 30 and back pressure gages 36 along with a sampling switch 44 and a control circuit 60. As described before, the average of the error signals can be obtained before being supplied to the servo amplifier 24.

From the foregoing, it can be seen that gap spacing can be maintained accurately without resort to the erratic results obtained when relying upon gap voltage. Each of the described systems affords an accurate, uncomplicated mode of determining the actual gap spacing and produce corrections if this actual gap spacing is different from that desired, such representing the optimum spacing for most effective machining.

The invention is to be limited only by the following claims.

We claim:

1. In the electrolytic process of removing stock from a conductive workpiece electrode by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to provide a machining current at a certain voltage for effecting stock removal from the workpiece, measuring variations in the gap spacing from a predetermined gap with a position sensor that is movable with one of the electrodes and arranged so as to be remotely positioned from and out of contact with the other of the electrodes and that is uninfluenced by electrolyte conditions and the machining current and the voltage, and altering the maneuvering of the workpiece and the electrode relative to each other in response to the variations so as to maintain the predetermined gap.

2. In the electrolytic process of removing stock from a conductive workpiece by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece, magnetically linking the workpiece and the electrode, sensing changes in the magnetic field between the workpiece and the electrode due to variations in the gap spacing from a predetermined gap, and altering the maneuvering of the workpiece and the electrode relative to each other in response to the changes sensed so as to maintain the predetermined gap.

3. In the electrolytic process of removing stock from a conductive workpiece by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece, inductively coupling the workpiece and the electrode, sensing changes in the inductive coupling due to variations in the gap spacing from a predetermined gap, and altering the maneuvering of the workpiece and the electrode relative to each other in response to the changes sensed so as to maintain the predetermined gap.

4. In the electrolytic process of removing stock from a conductive workpiece electrode by a conductive tool electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to effect stock removal from

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the workpiece electrode, generating an alternating magnetic field in the workpiece electrode from an energizing circuit carried by one of the electrodes, sensing impedance changes in the energizing circuit due to variations in the gap spacing from a predetermined gap at a plurality of points between the workpiece and the electrode, and altering the maneuvering of the electrodes relative to each other in response to the impedance changes so as to maintain the predetermined gap.

5. In the electrolytic process of removing stock from a conductive workpiece by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece, generating eddy currents in the workpiece, sensing changes in eddy current intensity due to variations in the gap spacing from a predetermined gap at a plurality of points between the workpiece and the electrode, and altering maneuvering of the workpiece and the electrode relative to each other in response to the changes in the eddy current intensity so as to maintain the predetermined gap.

6. In the electrolytic process of removing stock from a conductive workpiece by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form a gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece, radiating wave energy across the gap between the workpiece and the electrode, sensing variations in the time interval required to transfer the wave energy between the workpiece and the electrode due to changes in gap spacing from a predetermined gap, and altering the maneuvering of the workpiece and the electrode relative to each other in response to the variations in the time interval so as to maintain the predetermined gap.

7. In the electrolytic process of removing stock from a conductive workpiece electrode by a conductive tool electrode, the steps including maneuvering the electrodes relative to each other so as to form a gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece electrode, transferring wave energy across the gap between the electrodes, measuring the time interval required to transfer the wave energy between the electrodes, developing a control signal corresponding to the time interval and accordingly gap spacing, comparing the control signal with a reference corresponding to a predetermined gap so as to develop an error signal representing the difference between the actual gap and the predetermined gap, and altering the maneuvering of the electrodes relative to each other in response to the error signal so as to maintain the predetermined gap.

8. In electrical stock removal apparatus, the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween, a source of electrical energy applied across the gap so as to provide a machining current at a certain voltage for effecting stock removal from the workpiece electrode, means maneuvering the electrodes relative to each other, and control means for the maneuvering means, the control means including position sensing means carried by one of the electrodes and arranged so as to be remotely positioned from and out of contact with the other of the electrodes, the position sensing means being uninfluenced by electrolyte conditions and the machining current and the voltage and being operative to measure deviations in the gap spacing from a predetermined gap and cause the maneuvering means to alter the gap spacing in response to the deviations and thereby maintain the predetermined gap.

9. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the

gap so as to provide a machining current at a certain voltage for effecting stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means, the control means including position sensing means movable with one of the electrodes and remotely positioned from and out of contact with the other of the electrodes, the position sensing means being uninfluenced by electrolyte conditions and the machining current and the voltage and being operative to measure variations in gap spacing from a predetermined gap so as to develop corresponding error signals, and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith so as to maintain the predetermined gap.

10. The electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including means inductively coupling the electrodes, means sensing variations in the inductive coupling due to changes in the gap spacing from a predetermined gap so as to develop corresponding error signals, and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

11. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including means magnetically linking the electrodes, means sensing variations in the magnetic field between the electrodes due to changes in the gap spacing from a predetermined gap so as to develop corresponding error signals, and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

12. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including an inductor carried by one of the electrodes, circuit means energizing the inductor with an alternating current and so arranged as to induce an alternating magnetic field in the other electrode and thereby develop an error signal corresponding to variations in the magnetic coupling between the electrodes due to changes in the gap spacing from a predetermined gap and means responsive to the error signal for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

13. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including an inductor carried by one electrode, circuit means energizing the inductor with an alternating current so as to induce an alternating magnetic field in the other electrode, means measuring changes in the magnetic coupling between the electrodes due to changes in the gap spacing from a predetermined gap so as to develop

a corresponding error signal and means responsive to the error signal for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

14. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including an inductor carried by one electrode, circuit means energizing the inductor with an alternating current and so arranged as to induce an alternating magnetic field in the other electrode, means measuring changes in eddy current intensity in said other electrode due to deviations in the gap spacing from a predetermined gap so as to develop a corresponding error signal and means responsive to the error signal for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

15. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including a bridge circuit having an inductor carried by the tool electrode and arranged in one arm thereof and impedance elements in the other arms thereof, and alternating voltage source connected across the input of the bridge circuit, the bridge circuit being balanced at a predetermined gap spacing so that when the workpiece electrode is moved within the magnetic field of the tool electrode, a bridge circuit unbalance voltage is developed corresponding to variations in the gap spacing from the predetermined gap and of a phase determined by whether the gap spacing is greater or less than the predetermined gap, a phase responsive circuit connected across the output of the bridge circuit so as to develop an error signal voltage of a polarity corresponding to the phase of the unbalance voltage, and means responsive to the error signal voltage for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

16. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including a series of transducers carried by one electrode for generating alternating magnetic fields in corresponding portions of the other electrode and so arranged as to develop error signals corresponding to variations in the magnetic coupling therebetween due to changes in the gap spacing from a predetermined gap and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

17. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including a series of transducers carried by one electrode for generating an alternating magnetic field in corresponding portions of the other electrode, means measuring changes in the magnetic coupling between the electrodes due to changes in the gap spacing

in accordance therewith and thereby maintain the predetermined gap.

25. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other and control means for the maneuvering means; the control means including a high frequency pulse source; a series of transducer means carried by one of the electrodes and arranged both for sending pulse signals from the source toward the other electrodes and for receiving the pulse signals reflected by said other electrode, switch means connected to the pulse source and turned on by a pulse signal therefrom and off by a reflected pulse signal from each one of the transducer means so as to develop an output signal corresponding to the time interval required for a pulse signal to traverse the gap between the electrodes, means connecting each of the transducer means to the switch means in accordance with a certain scheme, means comparing the output signal from the switch means with a reference corresponding to a predetermined gap and developing an error signal equivalent to deviations therefrom, and means responsive to the error signal for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

26. In electrical stock removal apparatus, the combination of conductive tool and workpiece electrodes spaced apart so as to provide an electrolyte filled gap therebetween, a source of electrical energy applied across the gap so as to effect stock removal from the workpiece electrode, means maneuvering the electrodes relative to each other and control means for the maneuvering means, the control means including an ultrasonic frequency source, a plurality of sending and receiving transducers carried by one of the electrodes, the sending transducers being so arranged as to emit pulse signals from the source toward the other electrode, the receiving transducers being arranged for reception of the pulse signals reflected by said other electrode, switch means connected to the pulse source and so arranged as to be turned on by a pulse signal from the source and off by a reflected pulse signal from the sending transducer so as to develop an output signal corresponding to the time interval required for a pulse signal to traverse the gap, means connecting each of the plurality of sending and receiving transducers to the switch means in accordance with a certain scheme, means comparing the output signal with a reference corresponding to a predetermined gap and developing an error signal in accordance with variations therefrom, and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

27. In electrical stock removal apparatus; the combination of conductive tool and workpiece electrodes

spaced apart so as to provide an electrolyte filled gap therebetween; a source of electrical energy applied across the gap so as to provide a machining current at a certain voltage for effecting stock removal from the workpiece electrode; means maneuvering the electrodes relative to each other; and control means for the maneuvering means; the control means including a series of transducers carried by one electrode and arranged so as to be remotely positioned from and out of contact with the other of the electrodes, the series of transducers being uninfluenced by electrolyte conditions and the machinery current and the voltage and being operative to determine the gap spacing at a plurality of points between the electrodes and develop error signals corresponding to variations in the gap spacing from a predetermined gap and means responsive to the error signals for causing the maneuvering means to alter the gap spacing in accordance therewith and thereby maintain the predetermined gap.

28. In the electrolytic process of removing stock from a conductive workpiece by a conductive electrode, the steps including maneuvering the workpiece and the electrode relative to each other so as to form an electrolyte filled gap therebetween, applying electrical energy across the gap so as to effect stock removal from the workpiece, magnetically linking the workpiece and the electrode, sensing changes in the magnetic field between the workpiece and the electrode due to variations in gap spacing for a predetermined gap at a plurality of points between the workpiece and the electrode, altering the maneuvering of the workpiece and the electrode relative to each other in response to changes sensed so as to maintain the predetermined gap, and stopping the process when the gap spacing at one of the points sensed is less than some predetermined minimum.

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*Examiners.*

**UNITED STATES PATENT OFFICE**  
**CERTIFICATE OF CORRECTION**

Patent No. 3,228,863

January 11, 1966

Glenn E. Wanttaja et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 73, for "from" read -- form --; column 7, line 16, for "The" read -- In --; column 8, line 37, for "circuit" read -- circuit --; column 12, line 11, for "machinery" read -- machining --.

Signed and sealed this 6th day of December 1966.

**(SEAL)**

**Attest:**

**ERNEST W. SWIDER**

**Attesting Officer**

**EDWARD J. BRENNER**

**Commissioner of Patents**