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Monk

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[54] AUTOMATIC CONTROL FOR ION MILLING MACHINE

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[51] Int. Cl. B23k 15/00

[58] Field of Search... 219/121 R, 121 EB, 121 EM, 219/121 LA, 121 LM; 250/49.5 R, 49.5 A, 49.5 TE, 49.5 P, 49.5 T, 219 TH; 29/57 Z

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[57] ABSTRACT

An ion milling machine having a pair of ion guns for bombarding from opposite sides a sample mounted in a holder in an evacuated chamber. In one embodiment, an ion detector mounted on an apertured blade is periodically shifted into position for receiving the ion beam passing through the sample from one gun while the other gun is turned off. The signal produced by the detector is compared with a reference signal indicating the desired thickness and milling terminated if the detector signal indicates the desired sample thickness has been reached.

13 Claims, 8 Drawing Figures

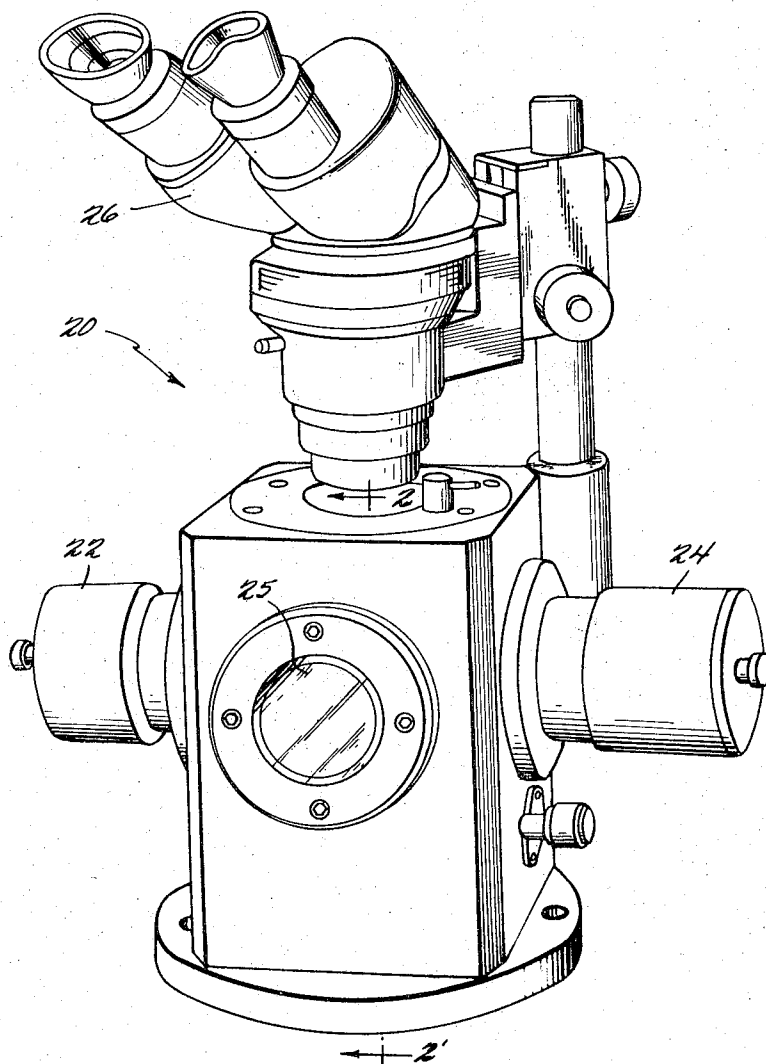


Fig. 1

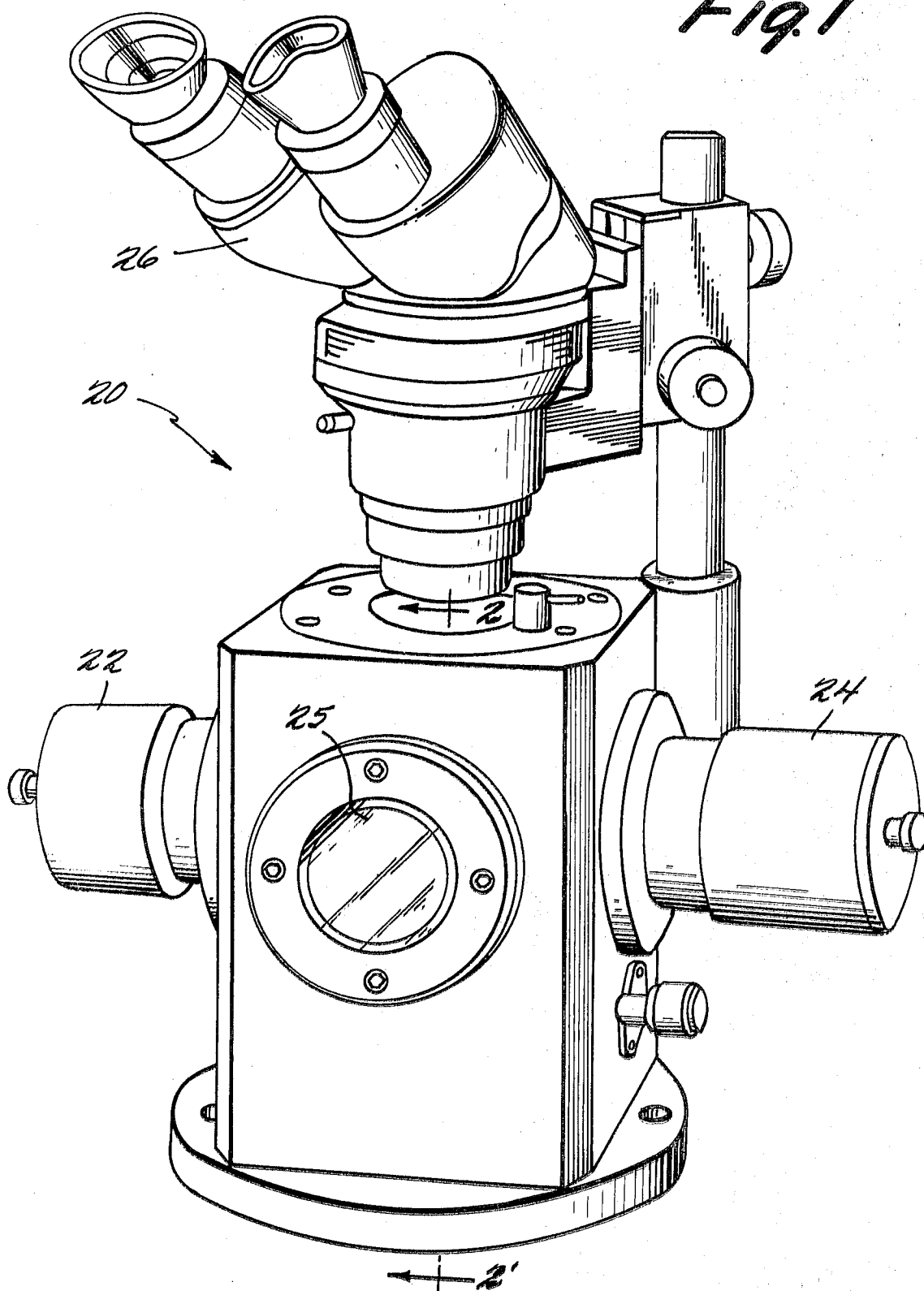
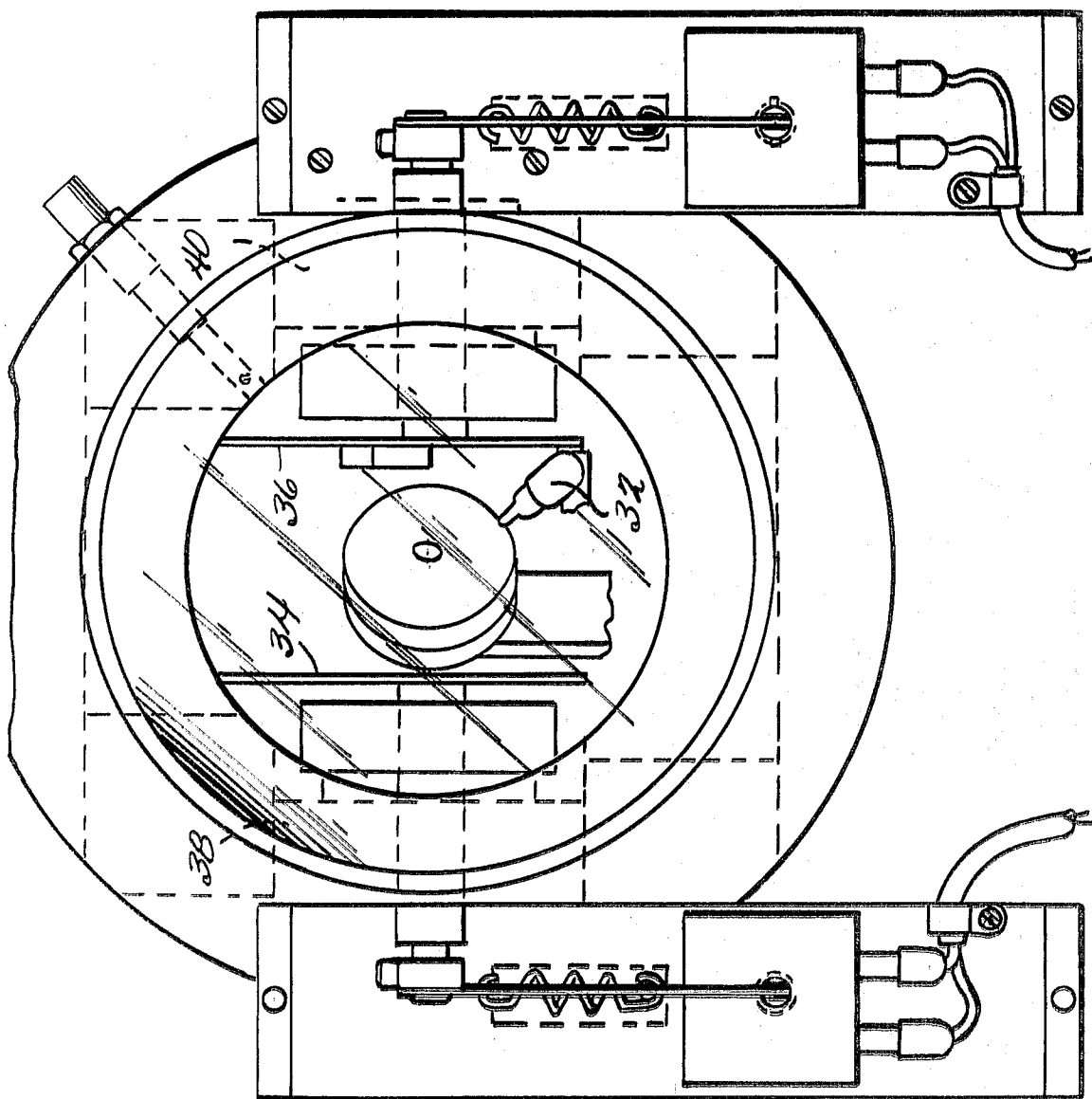


Fig. 2



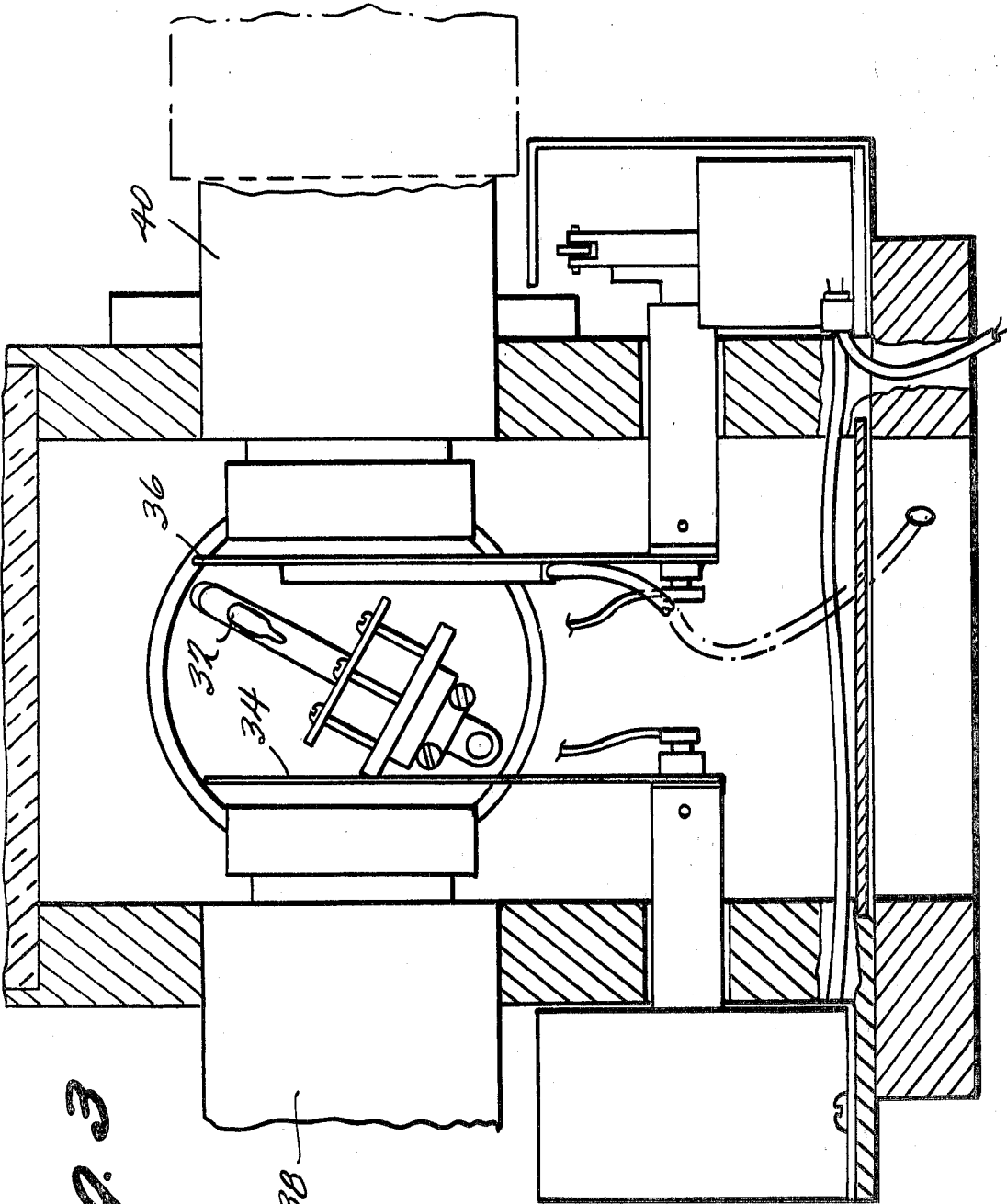


Fig. 3

Fig. 4

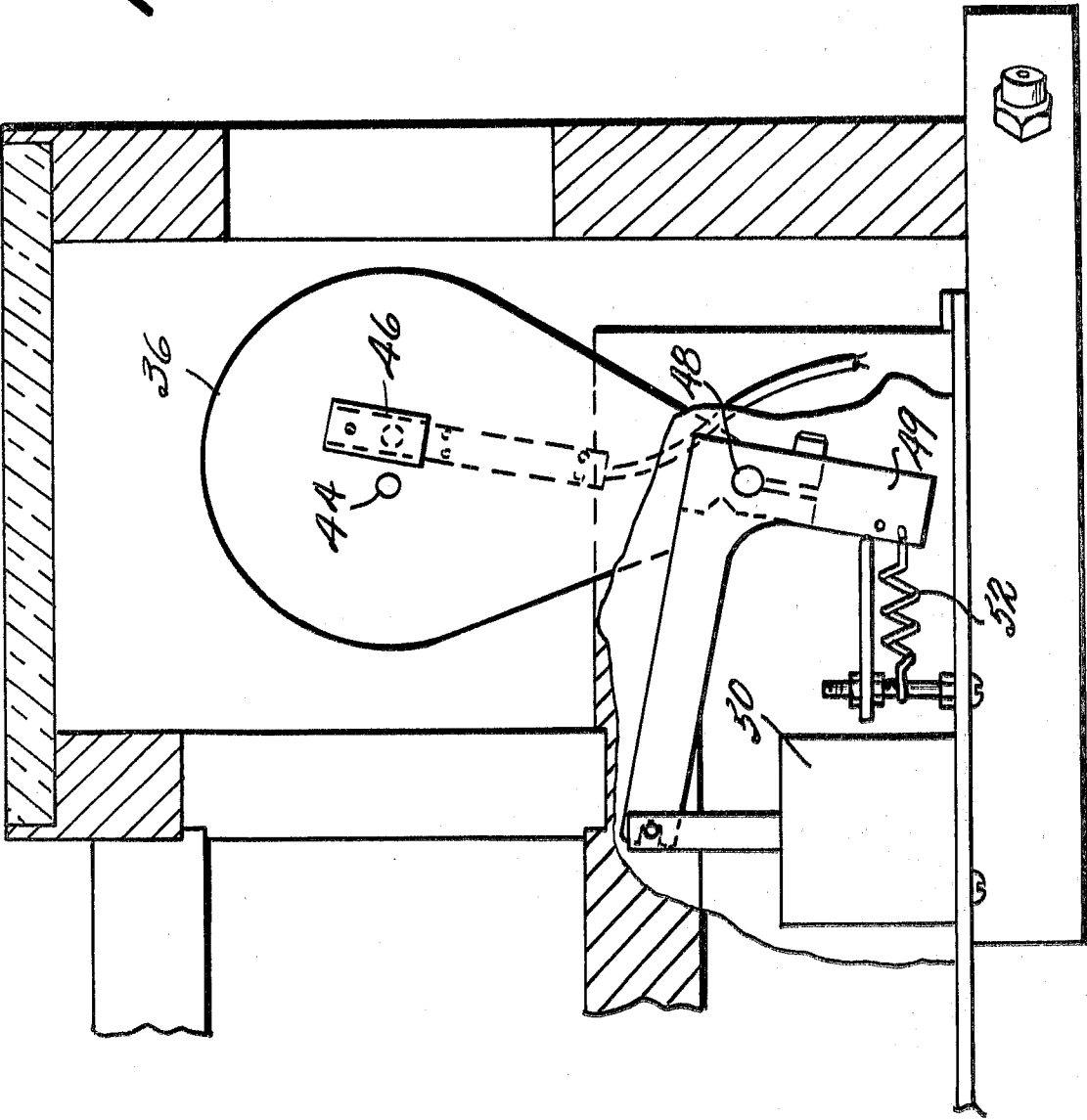


Fig. 5

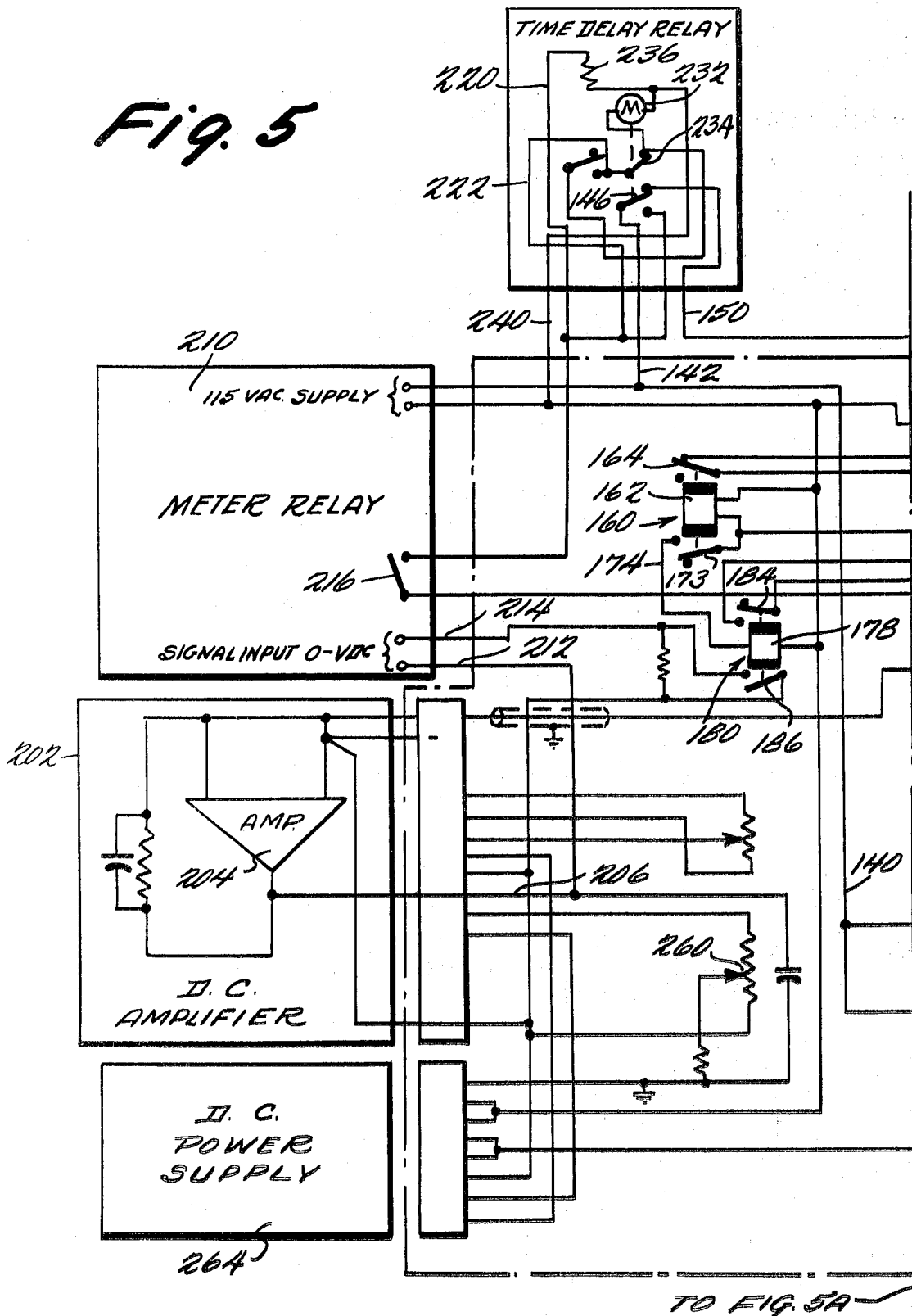
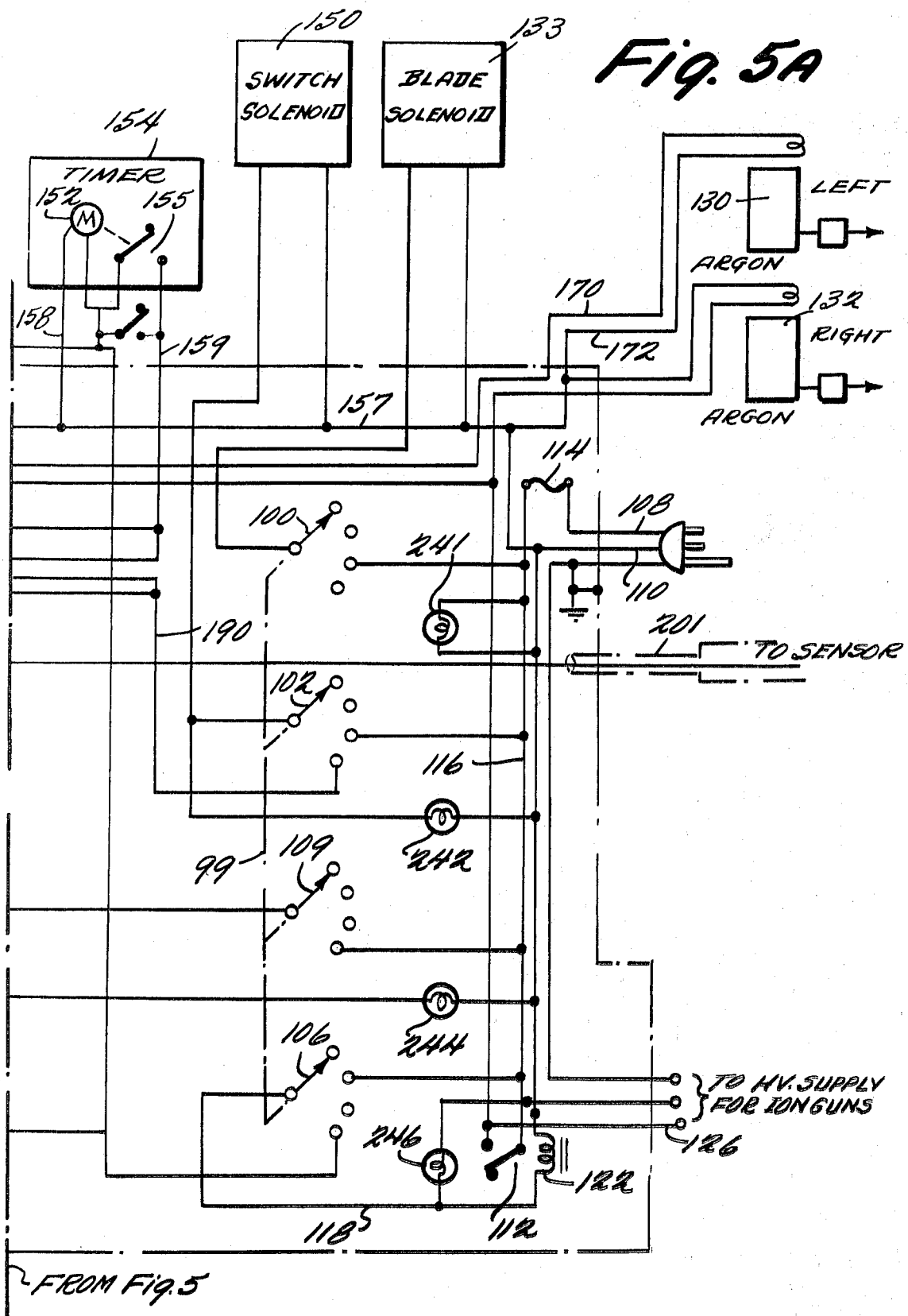
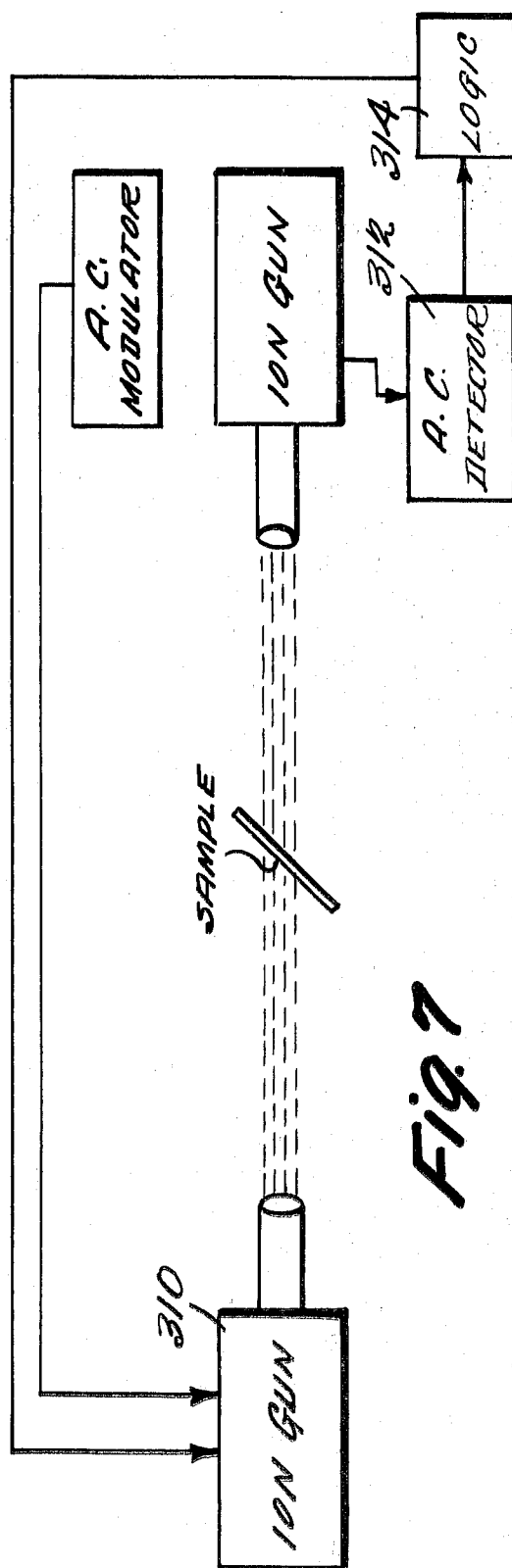
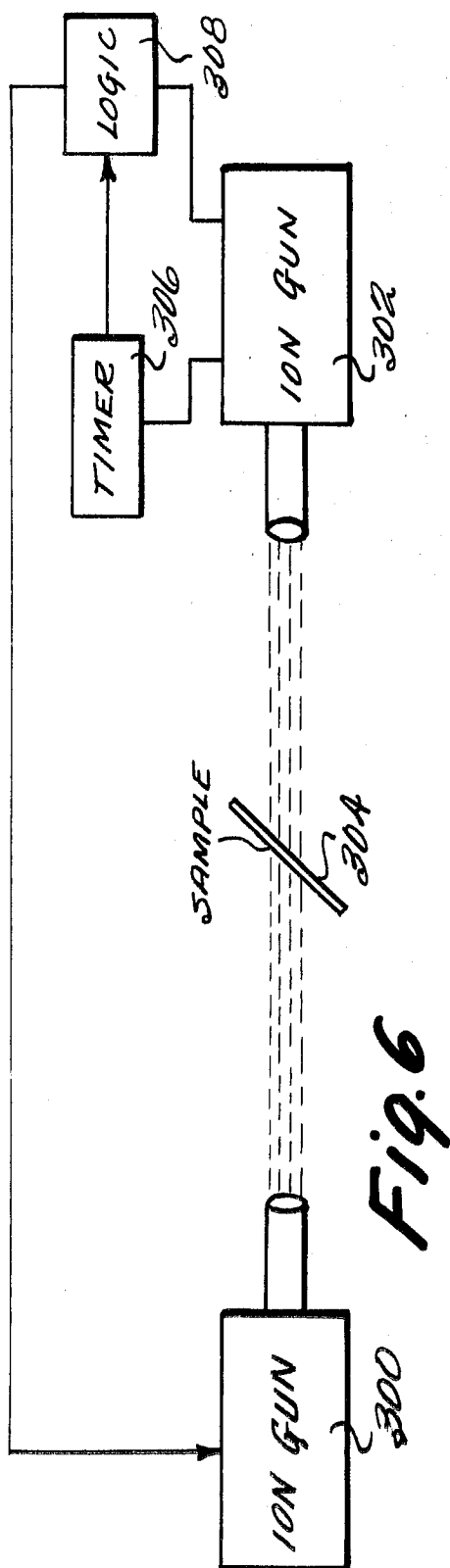


Fig. 5A





AUTOMATIC CONTROL FOR ION MILLING MACHINE

BRIEF DESCRIPTION OF THE PRIOR ART AND SUMMARY OF THE INVENTION

The invention relates to an ion milling machine and more particularly to an improvement whereby the thickness of a sample is periodically or continuously detected by detecting radiation passing through the sample.

Ion milling machines which employ one or more ion guns to focus an ion beam on a sample mounted in an evacuated chamber have been in use for several years. Such devices remove material slowly and uniformly so that the sample can be cleanly milled to any given thickness, and particularly to thicknesses which are thin enough to view with an electron microscope.

One problem in the past has been in determining exactly when the sample has been milled to a given desired thickness. Normally, this has been done by periodically viewing the sample and judging from past experience when milling is completed. Alternately, the sample can be periodically removed and checked to see whether it is at the desired thickness. This is a time-consuming activity involving skilled and expensive laboratory personnel. Further, this approach necessitates nearly constant attention and precludes, for example, letting the machine run unattended at night or the like. Frequently, the technician tending the machine, since he is involved in other chores, forgets to check the thickness and an expensive sample is ruined. In addition, it is frequently desirable to mill a sample to the thickness at which a hole has almost but not yet appeared. This may be difficult to visually determine.

There have been suggestions in the past with respect to automatically detecting the amount of light, for example, which is passing through the sample as an indication of sample thickness. A patent application, Ser. No. 89,430, entitled ION MILLING MACHINE, and filed on Nov. 13, 1970, sets forth an approach of this type, and the disclosure of this co-pending application is explicitly incorporated herein by reference.

The present invention relates to a particularly advantageous technique for automatically determining the thickness of a sample, continuously or preferably from time to time, by detecting the amount of radiation, such as the milling ions, passing through the sample and terminating the milling operation when the sample thickness has reached a desired limit. Thus, the machine can operate unattended and no periodic supervision by a skilled laboratory technician is required, while at the same time great accuracy in choosing a desired thickness can be achieved.

According to one embodiment of the invention, described in detail below, this is accomplished by a structure which includes a sensor blade pivotably mounted within the evacuated milling housing with a detector thereon. The sensor blade can be pivoted by a solenoid or the like from a rest into a detecting position in which the ion or other similar detector receives radiation passing through the sample so that a signal is produced which varies as a function of the received radiation and hence the thickness of the sample. A timer is provided for periodically closing a controlled switch to complete a current path through a first relay which when activated cuts off the supply of gas, for example, to one of

two ion guns. A short time thereafter, a second, time delay, relay, actuated by closing of the controlled timer switch, shifts its switch to operate a solenoid to cause the blade and detector to be shifted into the second position so as to receive ions passing through the sample from the remaining operating ion gun.

Thereafter, the signal from the sensor is applied to a D.C. amplifier and meter relay and compared with a reference voltage or related to desired thickness. Should the sensor voltage exceed the reference voltage by a pre-determined amount indicating that the desired limit for thickness has been reached, the meter relay operates its controlled switch to complete a current path to a conventional time delay relay. After a pre-determined interval, the time delay relay is then actuated to operate switches to prevent further operation of the timer and lock up the circuit.

A mode switch for operating these circuits in any of a plurality of modes is provided and to thereafter operate the device after it has been locked up, the mode switch is simply shifted from an automatic to a manual position. The above operation can thereafter be repeated. In the event that the time delay relay has not operated within a pre-determined time, for example, 10 seconds, the controlled switch of the timer is shifted back to its initial position, causing the turned off ion gun to resume ion production and direction of the ion beam onto the sample, and the sensor solenoid to operate to shift the blade and detector back to its initial position. Requiring that the signal indicating the thickness persist for a given period, for example, 10 seconds, increases the reliability of operation and prevents the turn off as a result of transient or abnormal signals.

According to a further embodiment of the invention, as described below, the ion guns themselves can be used as the detector with one of the ion guns being turned off so that the ion beam from the other gun passes into the gun and is detected. Alternately, both guns can be continuously operated, and continuous detection effected by putting an A.C. component on one of the guns for continuous measuring, and permitting the ion beam to enter one or both of the guns.

Many other objects and purposes of the invention will be clear from the following detailed description of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a perspective view of an ion milling machine with a pair of ion guns.

FIG. 2 shows a top cut-away view of a milling machine, for example, as shown in FIG. 1.

FIG. 3 shows a side cut-away view of a milling machine such as shown in FIGS. 2 and 3.

FIG. 4 shows a front view of the sensor blade and arrangement for shifting it from a rest into a detecting position.

FIG. 5 illustrates a schematic of a circuit for periodically checking the thickness of a sample and preventing further milling after the thickness reaches a pre-determined level.

FIG. 6 shows a schematic of a further embodiment wherein an ion beam penetrating into an ion gun is employed to detect sample thickness and terminate milling when the thickness reaches a pre-determined level.

FIG. 7 shows a further embodiment using an ion gun to detect sample thickness.

DETAILED DESCRIPTION OF THE DRAWINGS

Reference is now made to FIG. 1 which shows an ion milling machine of the type discussed briefly above, and of the type shown further in the above mentioned application, Ser. No. 89,430. Machine 20 includes a pair of conventional ion guns 22 and 24 which are connected to a suitable gas source, for example, argon, for providing an ion source. Gas flow to the individual guns is individually controlled, for example, by means of dual cascade, micro adjusted valves or other valves. These valves are used for shutting off gas flow to one of the guns for thickness detection as described above with regard to the discussion of the schematic of FIG. 5. Gases other than argon, of course, may be used as desired for different applications.

Dual ion guns 22 and 24 bombard a sample which has been loaded into the evacuated chamber within the housing of machine 20 with ions from opposite sides so that the bombarded portions of the sample are gradually thinned, for example, at a rate of roughly 1-5 microns per hour. At least one viewing port 25 and a microscope 26 permit the sample to be viewed during milling.

Reference is now made to FIGS. 2 and 3 which show a cut-away view of an ion milling machine such as shown in perspective in FIG. 1. As indicated above, a sample is mounted on a sample holder 30 within an evacuated chamber. The sample is illuminated by a light 32 for viewing from the top, for example, through microscope 26.

Sample blades 34 and 36 are disposed between the holder and the respective ion guns 22 and 24 for each blocking one ion beam in a first position and permitting that ion beam to impinge on the sample through an aperture in the blade in a second position. Referring to FIG. 4, blade 36 is shaped like a paddle with an aperture 44 through it, so that in the rest position the ion beam passes through aperture 44 onto the sample in holder 30. An ion sensing device 46 of a type which is well known in the art is mounted on blade 36 and produces an electrical signal which varies as a function of the number of ions impinging upon it. Blade 34 is preferably identical to blade 36 except for the absence of detector 46 and a similar arrangement is preferably used for shifting it from a rest to a detecting position.

Both blade 36 and blade 34 are preferably pivotably mounted in the housing about a pin 48 with a lever 49 connecting blade 36 to a conventional solenoid assembly 50. A spring 52 holds lever 49 in the illustrated rest position. When solenoid 50 is actuated, lever 49 is pivoted about pin 48 in a counter-clockwise direction to bring the detector 46 into alignment with the ion beam to detect the beam passing through the sample and hence the sample thickness.

As another feature, a meter 51 can be provided as shown in FIG. 3 to measure continuously the ion current arriving at the sample. A change in detected ion current indicates a change in thickness as more current flows through the hole. Thus, the meter provides a continuous rough monitoring of incident current so that a change in transmitted current indicates a change in hole size. Meter 51 is connected between the sample and ground via a negative bias which minimizes secondary emission effects.

Reference is now made to FIG. 5 which illustrates one schematic for periodically carrying out a check of the thickness of a sample and terminating the milling operation when that thickness reaches a pre-determined level. The circuit illustrated in FIG. 5 includes a ganged mode switch 99 with individual switch arms 100, 102, 104 and 106. As shown in FIG. 5, these switches can be manually shifted to any of four positions numbered 1 through 4. Position 1 is the off position for the unit in which the ion guns are kept turned off and no detection of thickness takes place. In position 2, switch arm 106 connects lines 108 and 110, which in turn connect to a conventional A.C. 120 volt outlet, to a time delay relay 112 via conventional fuse 114, line 116, line 118, and line 120. When current flows through relay coil 122, relay 112, after a short time delay, shifts its controlled switch 124 from the illustrated position into connection with line 126 thus completing a current path to the conventional high voltage supply which causes the two ion guns to operate.

Switch 124 in this position also completes a current path through valves 130 and 132 which supply a gas, such as argon to the ion guns so that the valves are opened to supply the gas. In this second position, no detection of the sample thickness takes place and the device will not automatically terminate upon detection of some given thickness.

In a third "sample" position, blade solenoid 133 is connected to lines 108 and 110 via switch arm 100 so that blade 34 which it controls is shifted from its rest position into a position blocking the ion beam from the gun 38. Switch 102 similarly completes a current path through solenoid 50 which shifts the sensor blade 36 from its normal position permitting the ion beam to flow through aperture 44 into its position blocking the ion beam from gun 24. Switch arm 106 still connects lines 112 to line 116 so that the ion guns remain operative producing an ion beam. The beam current can then be read from a displayed meter reading.

In the fourth "automatic" position, the device operates automatically to periodically check the thickness of a sample and to shut down the machine, preventing further milling, when a pre-determined sample thickness is reached. In this automatic position, switch arm 104 connects line 116 to line 140 which is in turn electrically connected to line 142 which is in turn connected to switch 146 within conventional time delay relay 148. Since switch 146 is normally in the illustrated position, line 142 is normally electrically connected to line 150 via switch 146. Line 150 is in turn attached to one side of conventional timer motor 152 within timer 154. The other side of timer motor 152 is connected via lines 157 and 158 to line 110 so that a complete current path is completed through timer motor 152 via switch 146 when mode switch arms 100, 102, 104 and 106 are in the fourth "automatic" position.

Timer 154 includes a controlled switch 156 which is normally in the illustrated position, and which is periodically closed, for example, by a cam associated with motor 152 of timer 154. The closing of switch 156 electrically connects via switch 146 line 150, which as discussed above is coupled to line 108, to one side of relay coil 160 of relay 162. The other side of relay 162 is connected to line 157 which is in turn connected to line 110 as described above. The shifting of switch 156

from its illustrated position into connection with line 159 thus completes a current path through relay coil 160 which shifts its controlled switch 164 from a closed to open position. Opening switch 164 interrupts the current path to valve 130 via lines 170 and 172. Valve 130 controls the left ion gun 38 so that the left gun is thus effectively shut off, although the high voltage source remains operative. Valve 132, however, remains open in this automatic mode so that argon or other gas still goes to the right gun which continues to produce an ion beam which passes through the sample and impinges on detector 46 after it has been shifted as described below in the detecting position.

The flow of current through coil 160 also causes its other controlled switch 173 to shift from its illustrated position, connecting line 159 to line 174 and completing a current path through coil 178 of time delay relay 180. After a short time delay, for example, ten seconds as determined by relay 180, that relay shifts its controlled switches 184 and 186 from their illustrated positions. The shifting of switch 184 completes a current path between line 159 and line 190 to in turn complete a current path through sensor solenoid 50 via switch 104. Sensor solenoid 50 then, as described above, pivots blade 36 about pin 48 bringing detector 46 into alignment to receive the ions passing through the sample and to produce a signal which varies as a function of the quantity of radiation received which in turn varies as a function of the sample thickness.

Sensor blade 36 is connected to line 201 which in turn is connected as one input to a conventional D.C. amplifier 202. D.C. amplifier 202 includes an internal schematically illustrated amplifier 204 which receives the signal from sensor 200 as one input and receives, as its other input, for example, a suitable reference signal indicative of desired thickness. The output of amplifier 204 on line 206 is applied as one input to a conventional D.C. meter relay 210 at line 212.

The other input to D.C. meter relay 210 on line 214 is ground, connected to line 214 by switch 186, shifted from its illustrated position by coil 178.

Meter relay 210 is the type which compares the two input signals and closes an internal switch 216 when the one input signal exceeds the other input signal by a predetermined amount. Thus, switch 216 is closed whenever the signal produced by sensor 46 reaches a predetermined desired level indicating a pre-determined desired thickness of the sample.

The closing of switch 216 connects line 190 to lines 220 and 222, thus connecting line 108 to lines 220 and 222 via fuse 114, line 116, switch 104, line 140, line 142, switch 146 which still remains in its illustrated position, line 150, timer switch 155, line 159, switch 184 and switch 216. Line 220 is connected to one side of conventional clutch coil 230 and line 220 is connected to one side of the motor coil 232 via switch 234. The other side of clutch coil 230 and motor coil 232 are connected to line 110 via line 156 and line 240.

Thus if switch 216 closes, indicating that the desired thickness had been reached, a current is completed through coils 230 and 232. If that current persists for a pre-determined time as determined by the setting of time delay relay 148, motor coil 232 operates to shift its controlled switches 146 and 234 away from their illustrated position. This time delay insures that transient noise, false signals from arcs, plasma background and

the like will not operate to terminate milling, and that the desired thickness has in fact been reached.

The shifting of switch 146 completes a current path between line 142 and line 220 so that current remains flowing through clutch coil 230. The shifting of switch 234 interrupts the current path through motor coil 232. Clutch 230, however, maintains switches 234 and 146 in their shifted position until the current through coil 230 is interrupted. The switch controlled by clutch coil 230 is not used.

The shifting of switch 234 interrupts the current path through motor 152 so that the timer does not continue operating. Accordingly, the circuit locks in this condition with a current flow through coil 230 until the mode switch arms 100, 102, 104 and 106 are shifted to the off or the position number 2 in which further milling can take place. Shifting mode switch 99 interrupts the current flow through coil 230 so that the controlled switches of relay 148 return to their illustrated positions, and the above steps can be repeated.

If by the end of the time pre-set by timer 154, time delay relay 148 has not shifted its controlled switches indicating that the desired thickness has not been reached, switch 155 is re-opened by motor 152 to interrupt the current flow through relay coils 160 and 178 which return their switches to their illustrated positions, re-completing their current flow through valve 130 so that gas again resumes flowing to the left gun 38 and interrupting the current path through solenoid 50 so that the blade resumes its rest position.

A light bulb 241 labelled "Power" is connected between lines 116 and 110 for indicating that lines 108 and 110 are connected to a source of voltage. Bulb 242 is connected in parallel with the sensor solenoid 50 as shown for being illuminated whenever a sample is being taken. Bulb 244 is connected so as to be illuminated whenever the mode switches 100, 102, 104 and 106 are in the "automatic" position 4. Bulb 244 is connected so as to be illuminated whenever current is flowing through coil 122 to the high voltage supply.

Bias resistor 260 can be manually varied in order to vary the D.C. bias of the input collector from sensor 46 and suppresses noise and background current. Power for D.C. amplifier 202 and meter relay 210 are supplied by a conventional D.C. power source 264 which is connected between lines 156 and 150 as shown via switch 146 so that source 264 is turned off when relay 148 locks up the circuit.

To summarize the operation of the schematic shown in FIG. 5 roughly every fifteen minutes or so while the unit is in the automatic mode, the argon to the left gun is shut off and a short time later, for example, 10 seconds, one of the sensor blades is moved about $\frac{3}{8}$ inch so that the $\frac{1}{8}$ inch diameter collector is directly behind the sample. If the ions passing through the sample from the right gun exceed the setting on the relay meter, the timer will start and if the signal remains higher than the set point for more than a pre-set time, for example, 10 seconds, then high voltage argon flow and other operators are turned off. If the transmitted beam does not exceed the set point for ten seconds, the timers will return to the system to the normal milling condition after about 30 to 45 seconds as provided by timer 154.

Reference is now made to FIGS. 6 and 7 which illustrate schematically two other arrangements for detecting an ion beam and shutting off the system when a pre-determined thickness of sample has been determined.

In the embodiment of FIG. 3, two ion guns 300 and 302 are shown schematically bombarding a sample 304 with ion beams from opposite sides. Periodically, a timer 306 causes ion gun 302 to be shut off but to remain operative to receive the ions from gun 300 which are passing through the sample. As in the embodiment of FIG. 5, if the signal produced by the impingement of ions from gun 300 into gun 302 indicates that the thickness has reached a pre-determined level as determined by logic 308, a signal is produced which shuts off ion gun 300 and terminates the milling operation.

FIG. 7 illustrates a further embodiment in which continuous detection of the thickness can be effected by modulating an A.C. signal onto the transmitting ion gun 310 and detecting the A.C. component by an A.C. detector 312 so that logic 314 shuts off ion gun 310 whenever the desired thickness has been reached. Thus, it is possible to eliminate the blades and use the opposite ion guns themselves as a detector.

It should be noted that other particles can be used for detecting purposes. Instead of the ion beam, an electron beam could be produced and detected. Another possibility is using radio-active particles on one blade with a radioactive detector on the other blade. Soft particles such as beta or alpha particles are believed best for such purposes. Alternately, a light source by photo-detector could be used in this fashion.

Many other changes and modifications in the above described embodiments of the invention can, of course, be made without departing from the scope of the invention. Accordingly, that scope is intended to be limited only by the scope of the appended claims.

What is claimed is:

1. In an ion milling machine of the type having a housing, means in said housing for holding a sample to be milled, and means for directing at least one ion beam onto a sample in said holding means the improvement comprising:

means for receiving radiation from said sample resulting from milling by said ion beam and producing a signal which varies as a function of the quantity of radiation received,

means of mounting said receiving and producing means in said housing so that in a detecting position the radiation is received from said sample and accordingly said signal varies as a function of the thickness of said sample,

means for periodically shifting said mounting means from a rest to said detecting position including timing means for shifting as a function of time a controlled switch means from a first to second electrical condition, and means connected to said controlled switch means for causing said mounting means to move to align said receiving and producing means with the ion beam received from said sample when said controlled switch means shifts from said first to said second electrical condition, and

means connected to said receiving and producing means for preventing said directing means from directing said ion beam onto said sample after said signal indicates a desired thickness has been reached.

2. In a machine as in claim 1, the further improvement wherein said causing means includes a solenoid.

3. In a machine as in claim 2 having at least two ion directing means each directing a beam on an opposite side of a sample the further improvement wherein said shifting means further includes means connected to said controlled switch for causing one of said guns to be rendered inoperative after said controlled switch shifts from said first to second condition.

4. In a machine as in claim 3 the further improvement wherein said means for causing one of said guns to be rendered inoperative includes a first relay operative to shift a controlled switch from a first to second position upon shifting of said controlled switch of said timing means from said first to second condition and said means for causing said mounting means to shift includes solenoid means and a time delay relay connected to said first relay and having a controlled switch connected to said solenoid for causing said solenoid to shift said mounting means into said detecting position a pre-determined time after said first relay shifts its controlled switch from its first to second position.

5. In a machine as in claim 4, the further improvement wherein said means for causing said one of said guns to be rendered inoperative further includes valve means for supplying ion source gas to that gun and connected to said controlled switch of said first relay for closing off said supply when the controlled switch of said first relay shifts from said first to said second position.

6. In a machine as in claim 4, the further improvement wherein said preventing means includes means for producing a variable reference signal indicating desired thickness, means for receiving and comparing said reference signal and said signal which varies as a function of the quantity of radiation received, and for producing a further signal when the comparison indicates the desired thickness has been reached, and means for preventing said two ion directing means from thereafter operating if said further signal persists for a pre-determined time interval.

7. In a machine as in claim 6, the further improvement wherein said reference signal producing means includes a variable resistor receiving and comparing means includes a D.C. amplifier with an input connected to said variable resistor and an input to said radiation receiving and signal producing means for providing an output signal which varies as a function of the difference between the inputs, and meter relay means connected to the output of said D.C. amplifier for receiving said output signal and for shifting a controlled switch, when said output signal reaches a pre-determined value, from a first to second position and wherein said ion directing means preventing means includes a time delay relay connected to said controlled switch of said meter relay and having a controlled switch which is shifted from a closed to an open position if said switch in said meter relay means remains in said second position for more than a given time interval, means electrically connecting said controlled switch of said time delay relay to said ion directing means so that said ion directing means are rendered inoperative when that controlled switch is opened.

8. In a machine as in claim 7, the further improvement includes mode switch means having at least an automatic position electrically connecting a source of voltage to said time delay relay so that said time delay relay maintains its controlled switch in its open position after being shifted and at least a further position for

permitting said controlled switch of said time delay relay to reclose and milling to resume.

9. In a machine as in claim 1 further including mode shifting and preventing means to a source of voltage so as to be rendered operative, and at least a second position disconnecting said shifting and preventing means from said voltage source so as to render both inoperative.

10. In a machine as in claim 1 wherein said machine includes first and second ion guns for directing ion beams onto opposite sides of said sample, the further improvement wherein said mounting means includes a paddle shaped blade having an aperture, means pivotably mounting said blade in said housing between one of said guns and said sample, spring means normally urging said blade to a rest position in which an ion beam passes through said aperture, a solenoid, lever means connecting said solenoid to said blade so that, when activated, said solenoid pivots said blade into a detect position and means for mounting said receiving and signal producing means on said blade so that ions

passing through said sample impinge on said receiving and signal producing means when said blade is in said detect position.

11. In a machine as in claim 10, the further improvement including a second paddle shaped blade having an aperture, means pivotably mounting said second blade in said housing between the other of said guns and said sample, spring means normally urging said second blade to a rest position in which an ion beam passes through said aperture, a second solenoid, lever means connecting said second solenoid to said second blade so that, when activated, said second solenoid pivots said second blade into a detect position.

12. In a machine as in claim 1, further including means for varying a D.C. bias on said receiving and producing means so as to suppress noise and background current.

13. In a machine as in claim 1, further including meter means for measuring ion current arriving at said sample.

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