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(54) MICROTOME

(71) We, KABUSHIKI KAISHA AKASHI SEISAKUSHO, of No. 2-3, 3-Chome, Marunouchi, Chiyoda-Ku, Tokyo, Japan, a Japanese company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

5 This invention relates to a microtome for continuously cutting thin sections of specimens for examination by electron-microscope. More particularly, it relates to a microtome employing electromagnetic means for the control of specimen cutting. 5

10 In one known microtome, a specimen holder is carried at one end of an arm which is supported, intermediate its ends, from a cord connected with a pulley. In this known microtome, a knife is mounted, adjacent the specimen holder, on an inching stand by means of which the knife can be moved progressively nearer to the specimen holder as successive thin sections are cut by the knife from a specimen mounted in the specimen holder. The thin sections are cut from the specimen by swinging the arm up and down so that the specimen holder is displaced up and down in directions transverse to the edge of the knife, the up and down movement of the arm being effected by means of a cord connected with the arm and with a pulley arranged to be reciprocated about its rotary axis through a predetermined angle. 15

20 In continuous cutting, the second and each subsequent thin section of the specimen held in the specimen holder is obtained, after the cutting stroke of the arm which has produced the previous section, raising the arm by operating the pulley, to a position in readiness for the next cutting stroke, and operating the pulley to effect the next cutting stroke after sliding the inching stand a little towards the specimen or after thermally expanding the arm, to move the specimen holder a little towards the knife, by energizing an electric heater disposed around the arm. 25

30 In such known microtome, only the apparent cutting speed is controlled by externally regulating the motion of the arm by its own weight. Therefore, it is difficult to control accurately the speed with which the specimen is cut. Furthermore, external vibrations add significantly to the motion of the arm because only one end thereof is cantilevered by the hinge. It has consequently been difficult to obtain uniform continuously cut thin sections of the specimen using such a known microtome. 30

It is an object of the present invention to provide an improved microtome in which the above noted disadvantages are avoided or mitigated.

35 According to one aspect of the invention there is provided a microtome comprising a knife holder, a lever having at one end thereof a specimen holder disposed adjacent said knife holder, the lever being mounted for pivotal movement relative to said knife about an axis about which the lever is dynamically balanced, and an electrically operable drive mechanism including means operable to produce oscillatory movement of said lever about said axis and thereby cause said specimen holder to make translational oscillatory movements relative to said knife holder. 40

45 According to another aspect of this invention there is provided a microtome comprising: a table; a lever having a front end and an opposite end and fitted to the table so as to swing around a horizontal axis in a dynamically balanced state; a knife; a specimen holder attached to the first end of the lever opposite to the knife; an electrically operated drive mechanism, disposed at the opposite end of the lever, for effecting the swinging of the lever 45

so that a specimen held by the specimen holder is cut by the knife, the drive mechanism comprising a fixed magnet having a coil space, and a coil fitted to and movable with the opposite end of the lever and disposed in the coil space of the fixed magnet; and a compensating circuit for energizing the coil, relative to the magnet, the circuit having a power supply, being interposed between the power supply and the coil, and being effective to reduce the voltage drop of the coil based on its resistance.

The construction and operation of a preferred embodiment of the invention, and various advantages thereof over the prior art, will be evident from the following description with reference to the accompanying drawings in which:

Figure 1 is a schematic view in side elevation of a known microtome,

Figure 2 is a side view, partly in elevation and partly in section, of a microtome embodying the invention.

Figure 3 is a timing chart showing the operation of specimen cutting control means, and

Figure 4 shows a compensating circuit incorporated in said specimen cutting control means.

In the known microtome illustrated in *Figure 1*, one end *4a* of an arm 4 is connected via a hinge 3 to a support 2 on a base 1. To the other end *4b* of the arm 4 is attached a specimen holder 7 which holds a specimen *7a* adjacent to a knife 6 mounted on an inching stand 5 also mounted on base 1. The specimen *7a* can be sectioned by moving the arm 4 up and down by means of a cord 9 connected to a pulley 8 adapted to be reciprocatingly turned through a desired angle as indicated by the arrow.

In operation of the microtome of *Figure 1*, the arm 4 is moved up and down by means of the cord 9 and pulley 8, so that the specimen 7 as successive thin sections are cut from the specimen *7a* makes cutting and return strokes relative to the knife 6, the blade 6 being moved closer to the specimen *7a*, by means of the inching stand 5 or alternatively the specimen holder being moved progressively closer to the blade 6 by heating the arm 4, by passing electrical current through a heating element 10 wound round the arm, to expand the arm thermally. With this known microtome, it is difficult to control accurately the speed with which the specimen is cut and to prevent vibrations arising externally of the microtome from having an adverse effect on the operation thereof.

Referring to *Figure 2*, the microtome shown therein includes a movable table 14 which is supported on a base 11, via supporting springs 12 and 13, so as to be resiliently displaceable to a limited extent horizontally, from left to right and vice versa in the drawings, but so as to be substantially non-displaceable relative to the base in the vertical direction or in the direction normal to the plane of the drawing.

A lever 16 is pivotally mounted on the movable table 14, via a pivot shaft 15 so as to be pivotable about a horizontal axis normal to the plane of the drawing. As an alternative, the lever 16 may be connected with the table 14 via a spring acting as pivotal connection, i.e. allowing only swinging movement of the lever in the plane of the drawings substantially about the axis of shaft 15 while substantially preventing other movement. A specimen holder 19 is attached to one end *16a* of the lever 16, the specimen holder allowing a specimen 18 to be held adjacent a knife 17 at a desired angle. The other end *16b* of the lever 16 carries a counterweight 20 so contrived that the lever 16 is in dynamic balance for swinging movements about the axis of pivot shaft 15. The counterweight 20 carries, on its underside, a solenoid or coil *21b* which extends into an annular air gap provided between the appropriately shaped poles of a permanent magnet *21a* fixed on the base 11. The magnet *21a* and coil *21b* together constitute electromagnetic means 21 for producing oscillatory pivotal movement of the lever 16 about the axis of shaft 15.

The axis of the coil *21b* and the axis of the annular air gap of the magnet *21a* are both substantially vertical and are substantially coincident, the coil *21b* extending into the air gap without contacting the fixed magnet *21a*.

An electromagnetic attracting mechanism 22, which is operable to attract the movable table 14 away from the knife 17 against the force of the springs 12 and 13, is interposed between the movable table 14 and the base 11.

This electromagnetic attracting mechanism 22 comprises a ferro-magnetic member *22a* attached to the movable table 14 and an electromagnet *22b* attached to the base 11 opposite to said ferro-magnetic member *22a*.

Furthermore, an adjustable resilient spacer 25 comprising a compression spring 23, a spring shoe 26 and an adjusting screw 24 is interposed between the movable table 14 and the base 11.

The adjusting screw 24 of the adjustable elastic spacer 25 is engaged in an internal thread *26a* extending centrally through the spring shoe 26, and one end of screw 24 thereof is coupled to a motor 27 mounted on the base 11. The compression spring 23 of the adjustable elastic spacer 25 has one end inserted in a recess *14a* in the movable table 14, with the other end of the spring 23 being engaged by the spring shoe 26.

Accordingly, the spring shoe 26 can be moved horizontally, from left to right and vice versa in the drawing, by turning the adjusting screw 24 to a desired extent and in the appropriate sense by means of the motor 27. This changes the degree of compression of the compression spring 23 and thus the force exerted thereby on the movable table 14, thereby permitting a slight horizontal displacement of the de-energised equilibrium position of the movable table 14, i.e. the position of equilibrium of the table 14 when the electro-magnet 22b is not energised.

Electrical current is supplied to the moving coil 21b, the electromagnet 22b and the motor 27 via respective electrical conductors not shown. It will be appreciated that provided the inertia of the table 14 or of the arm 16 is not thereby made too great, the permanent magnet 21a may be carried by the arm 16 and the coil 21b by the base 11 instead of vice versa, or the ferro-magnetic member 22a carried by the base 11 and the electromagnet 22b carried by the table 14 instead of vice-versa.

The moving coil 21 may also be attached directly to the lower side of the end 16b of the lever 16, instead of to the counterweight 20.

A frame 28, mounted on the base 11 surrounds the lever 16 adjacent the end 16a thereof, so as to limit movement of the lever 16.

The frame 28 serves as a stopper to define the upper and lower limits of the motion of the lever 16 but the frame 28 also carries or is formed as a sensor which is capable of detecting the position of the lever 16 between said upper and lower limits without making physical contact with the lever 16.

The knife 17 is mounted on an inching stand 30 via a knife holder 29 which permits adjustment of the specimen cutting angle of the knife. The inching stand 30 is mounted on the base 11 so that its position, relative to the base 11, along a horizontal path extending from left to right in the drawing may be finely adjusted.

To cut a specimen 18 into thin sections using the microtome described with reference to Figure 2, the following procedure is adopted:-

Initially a direct-current is passed through the coil 21b by applying a d.c. voltage across the coil during the period o-o' as indicated on the timing chart (I) of Figure 3. As a result the end 16a of the lever 16 is moved upwards to engage the frame 28, and in this position of the lever the specimen 18 is fitted in the specimen holder 19 and the knife holder 29 and inching stand 30 are adjusted to set the knife 17 in a suitable position relative to the specimen 18.

Next, a relatively large control voltage is applied across the moving coil 21b, during the period o'-a in Figure 3-(I), and as a result the end 16a of the lever begins to swing downwards towards the knife. The sensor incorporated in or formed by frame 28, for detecting the lever position, detects when the specimen 18 has come to a position immediately above the knife 17 (this occurring at point a in Figure 3). Thereafter a smaller control voltage is applied across the coil 21b during the period a-b in Figure 3-(I), during which the knife 17 cuts from the specimen 18 a thin section which then lies on the knife. The control voltage applied across the coil 21b during the period a-b controls the cutting speed and is selected to suit the specimen being sectioned.

Thus, if e = the control voltage applied across the moving coil 21b during the period a-b, i = the current passing through the moving coil 21b, R = resistance of the moving coil 21b, l = the length of the conductor forming the moving coil 21b, v = the speed of movement of the moving coil 21b during the period a-b, and B = the magnetic flux density in the air gap of the fixed magnet 21a, then the following equation is obtained:

$$e = Ri + Blv \quad (1)$$

If the term Ri can be ignored, for example if $Ri \ll Blv$, the control voltage e is expressed as follows:

$$e \doteq Blv \quad (2)$$

Since the speed of movement v' of the specimen 18 is proportional to the speed of movement of the coil 21b, the factor of proportionality being determined by the relative distances of the coil 21b and specimen 18 from the shaft 15, the speed v' can be controlled by the control voltage e alone.

When the cutting of the specimen 18 has been completed (point b in Figure 3-(I)), the polarity of the control voltage e applied to the moving coil 21b is reversed, during the period b-a, in order to return the end 16a of the lever to its raised position. In the range b-a of Figure 3-(II), a voltage is also applied across the coil of the electromagnet 22b to move the movable table 14 away from the knife 17.

As a consequence, the specimen 18 can be raised clear of the knife 17, which is thus freed

from the risk of damage.

While the specimen is in its raised position, during the period a-a in Figure 3, a voltage is applied to the motor 27 to turn the adjusting screw 24 to a desired extent, as shown in Figure 3-(III). This withdraws the spring shoe 26 slightly, whereby the force of the compression spring 23 on the movable table 14 is reduced and the movable table 14 moves slightly to the left in Figure 2 until a new de-energised equilibrium position is reached, the amount of movement of the table from the previous to the new de-energised equilibrium position defining the thickness of the next thin section to be cut from the specimen 18.

By repeating the above-described cycle a-b, b-a, a-a, as shown in Figure 3, the specimen 18 can be continuously cut into a desired number of thin sections.

The control voltages e applied to the moving coil 21*b*, electromagnet 22*b* and motor 27 may be controlled by relays or other known means by detecting the respective positions of the lever 16 by means of the frame 28. Otherwise, they may be process-controlled by programming their application procedures.

The term Ri in the equation (1) can be eliminated by a circuit shown in Figure 4.

Referring to Figure 4, a differential amplifier 31 has a non-inverting input 31*a* and an inverting input 31*b*. The input 31*a* is connected with a reference voltage source not shown, which maintains a control voltage e_1 at the input 31*a*. An output terminal 31*c* of amplifier 1 is connected to the junction between resistors R_1 and R_2 , which are respectively connected to the inputs of inverting amplifiers 32 and 33. The inverting amplifier 32 has the moving coil 21*b* connected between its output 32*a* and its input, while the inverting amplifier 33 has a resistor R_3 connected between its output 33*a* and its input.

Output terminals 32*a* and 33*a* of the inverting amplifiers 32 and 33 are also connected with respective inputs of a subtraction circuit 34, which in turn has its output connected to the inverting input 31*b* of the differential amplifier 31.

The output voltage e_3 of the differential amplifier 31 in the circuit of Figure 4 is given by the expression:

$$e_3 = (e_1 - e_2)A, \quad (3)$$

where A is the gain of amplifier 31.

Assuming that the inverting amplifiers 32 and 33 have high open-loop gains and high input resistances, currents i_1 and i_2 passing through the resistors R_1 and R_2 become:

$$i_1 = e_3/R_1 \quad (4)$$

$$i_2 = e_3/R_2 \quad (5)$$

Then, output voltages e_4 and e_5 of the inversion amplifiers 32 and 33 are:

$$\begin{aligned} e_4 &= -(Ri_1 + Blv) \\ &= -(e_3R/R_1 + Blv) \end{aligned} \quad (6)$$

$$e_5 = -R_3i_2 = -e_3R_3/R_2 \quad (7)$$

By adjusting to make $RR_2 = R_1R_3$, the output voltage e_2 of the subtraction circuit 34 becomes:

$$e_2 = e_5 - e_4 = Blv \quad (8)$$

From equations (3) and (8),

$$e_1 = e_3/A + Blv \quad (9)$$

From equations (4) and (9),

$$e_1 = R_1i_1/A + Blv \quad (10)$$

By making the resistance of the resistor R_1 equal to the resistance R of the moving coil 21*b*, equation (10) becomes:

$$e_1 = Ri_1/A + Blv \quad (11)$$

Thus, the term Ri of equation (1) is reduced to $1/A$, and becomes negligible when A is large enough. Accordingly, the voltage e_1 becomes as follows:

$$e_1 \doteq Blv \quad (12)$$

Thus, if e_1 , rather than the voltage actually applied across the coil $21b$, is selected to correspond with the desired velocity v' of the specimen, the actual velocity v' of the specimen can be controlled to within close limits by the voltage e_1 alone, even if Ri_1 is not itself negligible compared with Blv .

That is, the effect of the resistance R of the moving coil $21b$ can be eliminated by actuating the moving coil $21b$ by the differential voltage e_3 from the differential amplifier 31 and performing negative feedback of the voltage e_2 proportional to the moving speed v of the moving coil $21b$ to the differential amplifier 31.

In the circuit of Figure 4, the single moving coil $21b$ serves both for speed detection and for power generation, but it is also possible to use one coil such as the coil $21b$ for providing the electromagnetic forces for moving the lever 16 and another coil, for example co-axial with and wound on the first coil and thus extending into the same air gap, for speed detection. If desired with respective resistance eliminating circuits may be provided for one or both such coils.

The same circuit as described above which permits speed control by controlling only one voltage can be used even if the position of the speed detecting sensor on the lever 16 is changed. It is also possible to eliminate the resistance R of the moving coil $21b$ by feeding back output voltage to the differential amplifier 31 and making the resulting output impedance a negative resistance.

The microtome described with reference to Figures 2 and 4 is less susceptible to the influence of external vibrations since the lever 16 is kept in a dynamically balanced state by the counterweight 20 or other means. This insures the satisfactory cutting of the specimen 18 irrespective of the microtome posture.

This microtome is nevertheless simple in construction, yet allows of accurate control of specimen cutting speed irrespective of posture and uniform supply of continuously cut thin specimen sections uninfluenced by external vibrations.

Also, the microtome described with reference to Figures 2 and 4 lends itself readily to the automation of the specimen cutting cycle since the various mechanisms are all electrically operated.

WHAT WE CLAIM IS:

1. A microtome comprising a knife holder, a lever having at one end thereof a specimen holder disposed adjacent said knife holder, the lever being mounted for pivotal movement relative to said knife, about an axis about which the lever is dynamically balanced, and an electrically operable drive mechanism including means operable to produce oscillatory movement of said lever about said axis and thereby cause said specimen holder to make translational oscillatory movements relative to said knife holder.

2. A microtome according to claim 1 wherein said means operable to produce oscillatory movement of said lever about said axis includes a magnet carried by a member relative to which said lever moves during such oscillatory movement about said axis, said magnet creating a magnetic field in air, a coil formed by an electrical conductor and carried by said lever, said coil being located within said magnetic field and means for passing an electric current through said coil to produce said oscillatory movement of the lever electromagnetically.

3. A microtome according to claim 2 wherein said means for passing an electric current through said coil includes means for maintaining a predetermined e.m.f., corresponding to that due to movement of said coil in said magnetic field, at a level corresponding to a predetermined velocity of the specimen holder and a compensating circuit for eliminating from the measured e.m.f. across said coil, that portion of the e.m.f. arising from the current through the coil in conjunction with the ohmic resistance thereof.

4. A microtome according to any preceding claim wherein said lever is mounted on a table for pivoting about said axis relative to said table, the table in turn being resiliently supported on a base, on which said knife holder is mounted, for reciprocating movement along a path extending transversely to said axis, such that during such movement the specimen holder is moved towards and away from said knife holder, said electrically operable drive mechanism including electromagnetic means for displacing said table relative to said base along said path so as to move said specimen holder towards and away from said knife holder.

5. A microtome according to claim 4 wherein said table is supported on said base, for movement along said path, by supporting springs and wherein a resilient spacer is provided urging said table in one direction along said path, said resilient spacer being counteracted

by said supporting springs, when the electromagnetic means for displacing the table relative to the base is not energised, to determine a de-energised equilibrium position of the table relative to the base along said path, the resilient spacer being adjustable to vary the force exerted thereby on the table and thereby to vary said de-energised equilibrium position of the table.

5 6. A microtome according to claim 5 wherein said adjustable resilient spacer includes a compression spring acting between the table and the base, and an adjusting screw whereby the compression of the compression spring can be adjusted. 5

10 7. A microtome comprising: a table: a lever having a front end and an opposite end and fitted to the table so as to swing around a horizontal axis in a dynamically balanced state; a knife; a specimen holder attached to the first end of the lever opposite to the knife; an electrically operated drive mechanism, disposed at the opposite end of the lever, for effecting the swinging of the lever so that a specimen held by the specimen holder is cut by the knife, the drive mechanism comprising a fixed magnet having a coil space, and a coil fitted to and movable with the opposite end of the lever and disposed in the coil space of the fixed magnet; and a compensating circuit for energizing the coil, relative to the magnet, the circuit having a power supply, being interposed between the power supply and the coil, and being effective to reduce the voltage drop of the coil based on its resistance. 10

15 8. A microtome in accordance with claim 7 including a base; springs for supporting the table from the base; and an electromagnetic attracting mechanism, interposed between the table and base for attracting the table away from the knife against the force of the springs. 15

20 9. A microtome in accordance with claim 8 including an adjustable elastic spacer comprising a compression spring and an adjusting screw disposed in series therewith, interposed between the table and the base to keep the table in a position suited for cutting the specimen held in the specimen holder, subject to returning of the table by the spring on release of the electromagnetic attracting mechanism. 20

25 10. A microtome substantially as herein described with reference to and as shown in Figures 2 and 4 of the accompanying drawings. 25

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35 40

FIG. 1

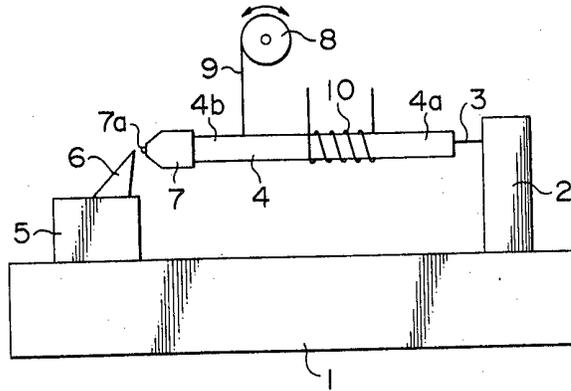


FIG. 2

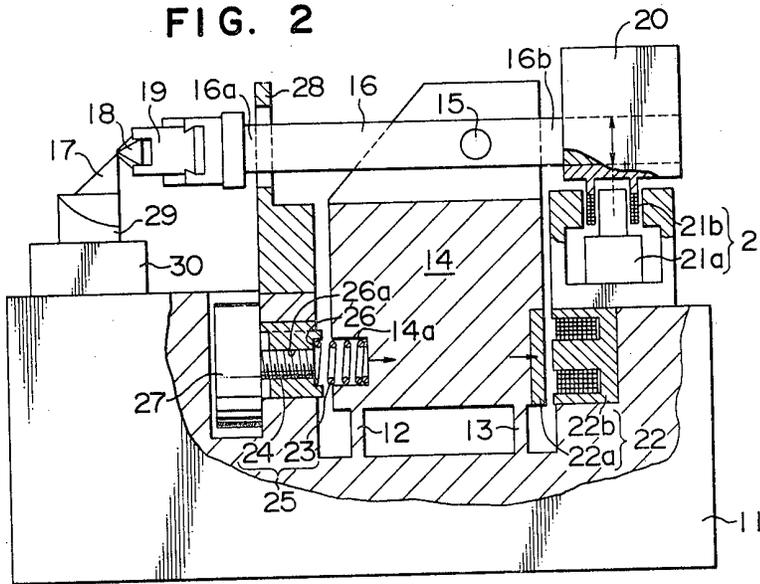


FIG. 3

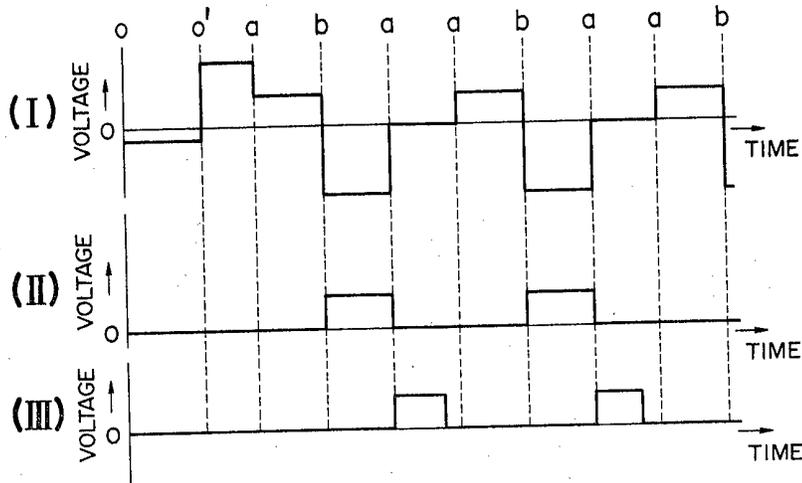


FIG. 4

