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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification: B23Q 35/128 // B23K 37/00 — A1

(11) International Publication Number: WO 79/00004

(43) International Publication Date: 11 January 1979 (11.01.79)

(21) International Application Number: PCT/GB78/00004

(22) International Filing Date: 16 June 1978 (16.06.78)

(31) Priority Application Numbers: 25270/77, 06498/78

(32) Priority Dates: 16 June 1977 (16.06.77), 17 February 1978 (17.02.78)

(33) Priority Country: GB

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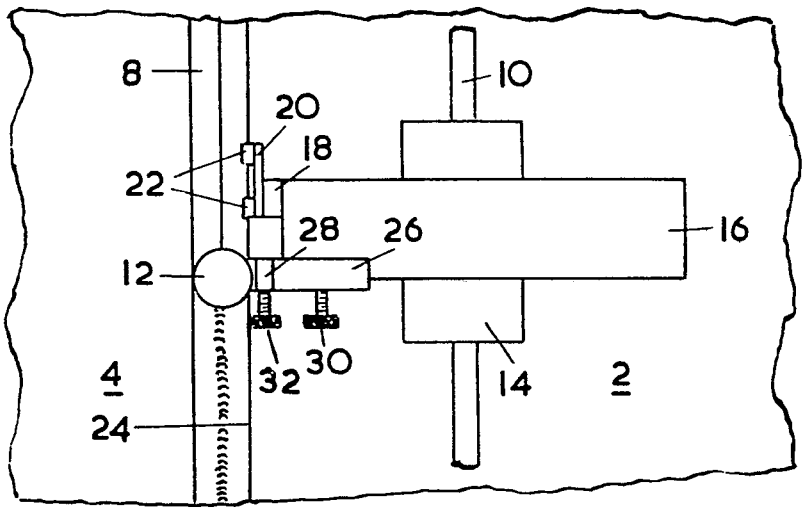
(81) Designated States: DE, GB, US.

Published with:
International search report.

(54) Title: EDGE FOLLOWERS



(57) Abstract

An edge follower for sensing and following a selected edge (24) a workpiece (2) so as to control the path of a metal working tool such as a welding torch (12) includes a light source for illuminating a small area of the workpiece (2) and a photocell for generating a signal corresponding to the amount of light entering the cell after reflection from the workpiece. Means in the forms of a synchronous stepping motor and a carriage (16) is provided to move the light source and photocell incrementally transversely to the edge (24) being followed in accordance with the amplitude of the signal from the photocell to keep the signal at a predetermined level.

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Title: EDGE FOLLOWERS

The present invention relates to edge followers, by which term is meant a device for sensing and following a selected edge of a workpiece so as to control the path of a welding torch or like metal-working tool movable with the edge follower.

By "edge" in this specification is meant the line produced when two surfaces of a single workpiece meet at an angle. When the angle is 90 degrees, two similar workpieces meet to form a butt weld. When the internal angle between the two surfaces is greater than 90 degrees, the abutment of two similar edge-prepared workpieces produces a V-sectioned groove when the two workpieces meet together.

In engineering manufacturing process it is often necessary to ensure that a predetermined position of a tool relative to a workpiece is maintained during the manufacturing process. For example, when seam welding a workpiece, it is known to use an automatic device in which one or more photocells follow a guideline marked on the workpiece at a constant distance from the centre of the intended seam to ensure that the welding torch follows automatically along the centre of the seam. The photocells each form part of a light sensor unit which includes a light source. The light source illuminates a portion of the guideline and the photocells generates a signal corresponding to the amount of light entering the cell after reflection from the guideline. However, drawing the guideline accurately whilst preserving the necessary contrast is both difficult and time consuming.

According to the present invention, an edge follower comprises a light source for illuminating a small area of a workpiece of which an edge is to be followed, a photocell for generating a signal corresponding to the amount of

light entering the cell after reflection from a surface of the workpiece bordering the edge to be followed and means for driving the light source and photocell relative to the edge in a direction extending substantially along the edge, the improvement comprising means for moving the light source and the photocell incrementally transversely to the said direction in accordance with the amplitude of the said signal so as to keep the signal at a predetermined level

The present invention aims at providing an edge follower which is capable of following an edge of a workpiece without any special preparation to the workpiece. Furthermore, the provision of means for moving the light source and the photocell incrementally provides economies when compared to edge followers which use "x" and "y" motors for controlling movement of the light source and photocell.

In a preferred embodiment, the edge follower includes two separate units each unit including a photocell and a light source, the units being spaced apart along the direction of travel with the moving means being responsive to variations in the average signal from both units.

Under some condition, the accuracy of the light sensor unit is affected adversely by ambient natural daylight or artificial light and in the case of a welding operation, the light produced by the welding torch.

Accordingly, the edge follower preferably includes an optical fibre cable comprising an outer and an inner optical fibre, the fibres being arranged coaxially at one end, at least for a part of their length, at the opposite end, the outer and the inner optical fibre are separated, the outer fibre being positioned adjacent to the light source for emitting light onto the surface of the workpiece and the inner fibre being joined to the photocell for permitting light reflected from the surface to travel along the inner fibre to the photocell.

It is believed that because light from the source is emitted from the outer optical fibre as an annulus which surrounds the darker central area immediately opposite the inner optical fibre from which no light exits, then the surrounding annulus of light, in effect, shields from the ambient light, light reflected from the reflective surface into the inner optical fibre.

A rotatable disc may be positioned between the light source and the adjacent end of the outer fibre, the disc being provided with a plurality of equally circumferentually spaced slots thereby permitting pulsed light to be

emitted from the outer optical fibre.

Am embodiment of the invention will now be described, by way of example, reference being made to the Figures of the accompanying diagrammatic drawings in which:-

Figure 1 is a schematic plan view of an edge follower;

Figure 2 is a schematic section through an edge-prepared join between two workpieces, illustrating the position of the light source of the edge follower of Figure 1;

Figure 3 is a schematic view taken at right angles to Figure 2, illustrating the relative positions of the light source and photocell of the edge follower of Figure 1;

Figure 4(a) 4 (b) and 4 (c) are diagrams to illustrate the operation of the edge follower of the Figure 1;

Figure 5 is a plan view of two tack-welded workpieces showing the impingement thereon of the illuminates zones produced by a modification of the edge follower of the present invention using edge sensor units;

Figure 6 is a schematic block diagram of the electronic components of the edge follower of Figure 1

Figure 7 is a diagrammatic sectional view of an alternative method of conducting light to and from the workpiece, and

figure 8 (a), 8 (b) and 8 (c) are diagrama to illustrate the operation of the edge follower with the alternative method of conductor light.

The edge follower shown in Figure 1 is intended to be used to weld together two tubular workieces 2 and 4. Each workpiece has its abutting outer corner chamfered to provide sloping surfaces 6 which cooperate to form a V-sectioned groove 8.

Extending approximately in parallel with the abutting faces of the join is a rail 10. Such a rail would normally be used when the workpieces 2 and 4 are metal plates. If in fact the workpieces are tubular the rail 10 would be omitted and the edge follower of the present invention would be mounted on a gantry near the top dead centre of the abutting pipelines, which would be mounted on driver rollers so that the workpieces would rotate in unison below the edge follower and associated arc-welding torch 12.

Be that as it may, a longitudinal carriage 14 of the edge follower is designed to move along a path relative and parallel to the join to be welded.

Mounted on carriage 14 is a transverse carriage 16 which is movable along its length, and therefore perpendicularly to the axis of rail 10, by means of a synchronous stepping motor (not shown). The gearing between the motor and the carriage 16 is such that each step results in movement of carriage 16 relative to carriage 14 of a small fraction of a millimetre.

Positioned at one end of carriage 16 is a support 18 for a member 20 carrying two sensor units 22. Each sensor unit includes a light source for throwing light onto a small area on the surface which forms the edge being followed, and a photocell or like transducer for receiving light after reflection from the surface, and converting it into an electrical signal. The support 18 is such that the distance between the sensor units 22 and the edge 24 being followed is adjustable.

Also positioned at the same end of carriage 16 is a rack-and-pinion 26 carrying a vertical rack-and-pinion 28 to which the body of torch 12 is secured. Projecting from each of the pinions is a knob 30 or 32. Rotation of knob 30 is sufficient to adjust the horizontal distance between the edge 24 and the weld bead to be laid down by the torch 12, while rotation of knob 32 is sufficient to adjust the height of the torch 12 relatively to the join being welded.

The manner in which each of the sensor unit 22 works will be described with reference to other Figures of the drawings.

Each sensor unit 22 consists of a light source 36 and a photocell unit 38 combined with each other. Positioned in light source 36 is a lamp 40, the light from which is focused by means of a lens 42 so that it illuminates a small area 44 of the work piece. The area 44 is arranged to include within it a small length of the edge 24 being followed.

Some of the light incident on the upper surface 46 of one of the workpieces is reflected towards photocell 38, which is connected to an amplifier 48 so as to produce a signal indicative of the amount of light reflected from surface 46. The light incident upon the sloping surface 6 is either absorbed by the surface or reflected either randomly or in a direction which leads to an insignificant proportion of such light being received by photocell 38. It has been found that with an edge follower of the present invention, even when the workpieces to be welded together are butt-jointed, the inevitable initial gap between the workpieces leads to light being lost. One can view the edge follower of the present invention as being designed to so move the carriage 16 carrying at least one sensor 22 so that the size of the area 44 seen by photocell 38

is kept substantially constant at a finite value which is significantly less than the full size of area 44. This control is effected by operating on the output signal from amplifier 48.

Referring now to Figures 4a, 4b and 4c, in Figure 4 (a) is shown a diagrammatic view of a nonlinea groove 8 between two workpieces, with an edge 24 thereof having an area 44 illuminated. When the area 44 is effectively bisected by edge 24, this gives rise to the optimum signal from amplifier 48, which may be called the 'grey'signal. However, should the edge follower ever become spaced by such a distance from groove 8 that the area 44 lies wholly within the surface 46, then the amplifier 48 produces a maximum signal, which may be referred to as a 'white'signal. The effect of receipt of this 'white' signal by the motor controlling the position of carriage 16 is to drive the carriage in a direction indicated by the arrow in Figure 4 (b), so that it moves towards the edge 24 being followed. This transverse movement continues until the optimum position shown in Figure 4 (a) is reached.

Should the area 44 ever reach a position such as is shown in Figure 4 (c) then virtually none of the light emitted by light source 36 is received by photocell 38, which leads to a minimum level, or 'black', signal from amplifier 48. The effect of this signal is opposite to that caused by the 'white' signal, so that the carriage 16 is driven in the direction shown by the arrow in Figure 4 (c) until it reaches the desired, optimum position shown in Figure 4 (a).

As shown in Figures 1 and 5, in a preferred form of edge follower, there are two light sensor units 22. These are provided primarily to allow for the follower to operate successfully even when the workpieces to be welded together are tack-welded. When this hapens, the 'tack' 50 indicated diagrammatically in Figure 5 would, when intercepted by the illuminated area 44, give rise to a 'white' signal. This could cause an undesired movement of carriage 16 such that the edge follower at the least makes a significant diversion from the line of the edge being followed, even if it does not lose the edge altogether. To guard against this, the second sensor unit 22 is provided, and in the associated electronic circuity an average of the two signals from the sensor units 22 is provided. In the associated electronic circuity an average of the two signals from the sensor units 22 is used as the' gray' signal. When the front sensor unit passes over a tack 50, the resultant 'white' signal from this front sensor unit causes the sensor unit to become inoperative, so that the edge follower continues moving along the line dictated by the rear sensor unit. As soon as the front sensor unit has passed overthe tack, the resultant decrease in

in the signal level from the front sensor unit is used to cause the operating conditions to be restored to their normal ones. This continues for a short time until the rear sensor unit traverses the tack 50. The reverse then happens, with the rear sensor unit being effectively disabled, leaving only the front sensor unit to follow the edge until the rear sensor has passed over the tack 50.

Should the tacks be spaced apart by the same spacing as the two sensor units or should the workpiece ever become flooded with light, so that both sensor unit generate' white' signals concurrently, the edge follower is designed to fail safe'. After both signals have remained at the 'white' level for a short time, the follower and torch are de-energised to stop the torch from damaging either of the workpieces.

With an edge follower using such a pair of sensor units, if the line being followed is virtually linear the orientation of the two cells can be fixed relatively to each other and to the general direction of the edge being followed. However, when the edge to be followed can be expected to depart significantly from being linear, the two cells may be mounted on a rotary support driven by a motor controlled by signals derived from the two sensor units. This motor can be used to ensure that the 'grey'signals from both sensors are about equal to each other. When a significant inequality arises, the motor is energised so as to rotate the sensor units so as to bring the line between them more or less in parallel with the general direction of that portion of the edge being followed at any time. In order to retain the desired insensitivity of the edge follower to the presence of tack welds, the time constants of the circuit can be chosen so that the speed of rotation of the two sensor units is so slow that the rear cell is still able to control the edge follower sufficiently accurately while the front sensor unit is passing over the tack weld, and conversely.

It is a feature of the present invention that the surface 46 needs no special preparation other than to ensure that that portion of the surface which cooperates with surface 6 to form edge 24 is cleaned, as with a wire brush to ensure that the reflectivity of the surface is both uniform and sufficient to establish the desired 'grey' signal level. Such wire-brushing of the workpiece is conventional before a welding operation, and so the use of the edge follower of the present invention adds nothing to the preparation costs.

The electronic circuitry is shown diagrammatically in Figure 6. In this Figure the sensor units 22 are connected electrically to amplifier 48 having independent push buttons 52 and 54 by means of which the sensor units 22 can

be indepently switched on and off. The gain of amplifier 48 is controlled by a device 56. The output of amplifier 48 is fed to a 'window generator' 58. This in effect controls the 'greyness' of the optimum signal. An upper level control 60 puts a maximum brightness on the 'grey' signal, while a corresponding control 62 puts a minimum brightness on this signal, whereas the control 64 varies the effective difference between these maximum and minimum signals, so as to increase the sensitivity of the edge follower to the output signals from the sensor units.

From the window generator the signals pass to a control unit 66 having a fast control 68, a slow control 70, a 'move to the right' control 72, and a 'move to the left'control 74. Normally the longitudinal carriage 14 can be driven at two speeds relatively to the workpiece, or in fact the speed can be adjustable over a range. The controls 72 and 74 dictate the direction in which the transverse carriage 16 is driven when a grey signal is either increased to the white level or decreased to the black level. Thus, referring back to Figure 4 (a), 4(b) and 4 (c) one ensures that when the area 44 fails to intercept the edge 24 for any reason, it is always moved in the correct direction back towards the edge, rather than away from it.

Should the driving motor ever ceased to operate with the stepping motor energised, the latter would drive the or each sensor unit back towards the edge (if initially displaced from it) until the desired 'grey' signals is produced, whereafter the stepper motor would remain stationary until the driving motor was re-energised.

The output from control unit 66 passes to a drive unit 76 for the stepping motor 78 effecting the desired incremental transverse movement of carriage 16.

Although the circuitry has been indicated only diagrammatically, this is because it is believed that it is within the competence of control engineers to devise particular circuits which would have the intended result, when give suitable parameters without requiring the exercise of inventive ingenuity.

In Figure 7 is shown an alternative system for illuminating the area 44 and for conveying light back to the photocell 38. The illustrated system includes an optical fibre cable 100.The cable 100 comprises an outer optical fibre 200 and an inner optical fibre 400, the fibres 200, 400 being arranged coaxially at one end for a part of their length. The fibres 200,400 at the opposite end are separated. The outer fibre 200 is positioned adjacent to the light source, 36, for example, a tungsten halogen lamp which produces white light. The inner optical fibre 400 is joined to the photocell 38.

At said one end, the coaxial optical fibres 200,400 are contained within a ferrule 140 having external screw threads 160. A lens holder 180 containing a lens 42 is releasably attached to the ferrule 140 by means of cooperating screw threads.

The cable 100 is positioned over the workpiece 2 on the carriage 16 by means of a clamp 220. The carriage 16 also supports the welding torch (not shown) so that movement of the welding torch is concomitant with movement of the cable 100.

In use, the cable 100 is so positioned that with the welding torch in its required position, the annulus of light emitted by the optical fibre 200 is bisected by one edge of a tape 110 (positioned immediately adjacent to the edge 24 as shown in Figure 8(a). Light from the light source enters the end face of the outer optical fibre 200 and owing to the optical properties of the material forming the optical fibre 200 once light has entered the end face it travels along the length of the fibre virtually unattenuated. The light is emitted from the optical fibre 2 and is focussed by the lens 42 to form an annular pool of light. The inner optical fibre 400 picks up light reflected from the tape 110 which transmits it to the photocell 38.

Electrical output from the photocell 38 is connected to an amplifier so as to produce a signal indicative of the amount of light reflected from the tape 110 as previously explained.

When the pool of emitted light is effectively bisected by the edge of the tape 10 this will give rise to an optimum "grey" signal. However, should the cable 100 ever become displaced so that the pool of light lies substantially completely over the tape 110 then the signal to the amplifier produces a "white signal". The effect of receipt of this white signal by the circuitry controlling the movement of the carriage 16 is to drive the device in a direction indicated by the arrow in Figure 8 (b). Should the emitted light ever reach the position shown in Figure 8 (c), that is, with virtually none of the light being reflected by the tape 110, then a "black" signal is received by the electronic circuitry the effect of which is to cause to carriage to move in the direction of the arrow shown in Figure 8 (c).

It is thought that because the central area immediately opposite the inner optical fibre 40 is wholly surrounded by the emitted light, the cable 100 becomes insensitive to the level of ambient light caused by natural daylight or

artificial light or the light, for example, from a welding torch.

In a modification, to avoid DC drift, caused for example, by a variation in output from the photocell due to fluctuations in ambient temperature, an AC system can be adopted. As shown, this can be achieved by a pulsed light source. Light from the source 36 before entering the end of the outer optical fibre 200 is passed through circumferentially spaced slots 25 formed in a rotating disc 27 to give a constant frequency of light pulses. Only reflected light at the correct frequency is permitted, by means of an electronic filter, to effect the control circuitry operating the carriage 16.

Although reference has been made to a reflective tape 110 this is is not necessary if a surface is provided on the workpiece which will reflect light.

Normally when welding two workpieces together by means of a so-called 'V-edge preparation', it is necessary to use a succession of passes with the welding torch in order to complete the weld. The first pass deposits the so-called root weld in the base of the groove 8. Thereaftersuccessive weld beads are laid down on top of earlier weld beads and/or the surface of one of the workpieces until the groove 8 is completely filled with weld metal. To enable this to happen by means of the edge follower of the present invention, the horizontal distance between the edge 24 being followed and the root of groove 8 has to be known. Once this is know, the control knob 30 can be adjusted so as to position the welding torch 12 over the centre of the root, for the first welding pass. After the first pass has been completed, the knob 30 is moved to alter the horizontal spacing between edge 24 and the torch so that a second weld bead is laid down partly overlapping the root bead. As already mentioned this process continues until the groove 8 is completely filled. The edge follower of the present invention can be used for the whole of this operation by following the same edge in successive passes. All that needs to be done is to ensure that the last weld bead to be laid down is the one which covers that part of surface 6 which cooperates with surface 46 to form the edge 24. It has been found that only a small part of this surface 6 needs to be visible for sufficient light to be reflected from it to permit the follower to operate as described above.

As the welding process continues and the groove 8 becomes filled up, it will be necessary to alter the height of the torch relative to the previously deposited weld bead. This can be done by adjusting control 32 in a known manner.

Although manual control of the height of both torch 12 and support 20 for

the two sensor units 22 is envisaged, it is within the purview of the present invention to use an automatic height sensor. Such devices are known in themselves, and can be used to keep the sensor units 22 at such a height above the edge being followed that the area 44 stays of constant size, or that the height of the welding torch 12 above the workpiece is always at the optimum value for the particular selected welding conditions, or both.

CLAIMS

1. An edge follower comprising a light source for illuminating a small area of a workpiece of which an edge is to be followed, a photocell for generating a signal corresponding to the amount of light entering the cell after reflection from a surface of the workpiece bordering the edge to be followed and means for driving the light source and photocell relative to the edge in a direction extending substantially along the edge, the improvement comprising means for moving the light source and the photocell incrementally transversely to the said direction in accordance with the amplitude of the said signal so as to keep the signal at a predetermined level.

2. An edge follower as claimed in claim 1, characterised by an optical fibre cable comprising an outer and an inner optical fibre, the fibres being arranged coaxially at one end, at least for a part of their length, at the opposite end, the outer and the inner optical fibre are separated, the outer optical fibre being positioned adjacent to the light source for emitting light on to the surface of the workpiece and the inner fibre being joined to the photocell for permitting light reflected from the surface to travel along the inner fibre to the photocell.

3. An edge follower as claimed in claim 2, characterised by the coaxial optical fibres at their said one end, being contained in a ferrule to which is releasably attached a lens holder containing a lens.

4. An edge follower as claimed in claim 2 or 3, characterised by the provision of a rotatable disc positioned between the light source and the adjacent end of the outer fibre, the disc having a pluralty of equally circumferential spaced slots thereby permitting pulsed light to be emitted from the outer optical fibre.

5. An edge follower as claimed in claim 1, characterised by two separate units, each unit including a photocell and a light source, the units being spaced apart along the direction of travel with the moving means being responsive to variations in the average signal from both units.

6. An edge follower as claimed in claim 5, characterised by an optical fibre cable associated with each unit, each optical fibre cable comprising an outer and an inner optical fibre, the fibres beig arranged coaxially at one end, at least for a part of their length, at the opposite end, the outer and the inner optical fibres are separated, the outer optical fibre being positioned adjacent

to the light source for emitting light on to the surface of the workpiece and the inner fibre being joined to the photocell for permitting light reflected from the surface to travel along the inner fibre to the photocell.

7. An edge follower as claimed in claim 6, characterised by the coaxial optical fibres of each cable at their said one end, being contained in a ferrule to which is releasably attached a lens holder containing a lens.

8. An edge follower constructed, arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in the Figures of the accompanying drawings.

1/4

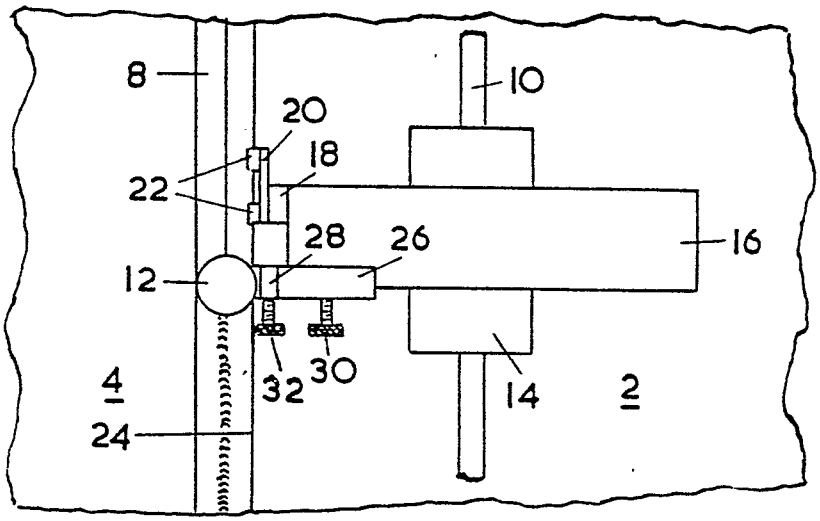

FIG.1

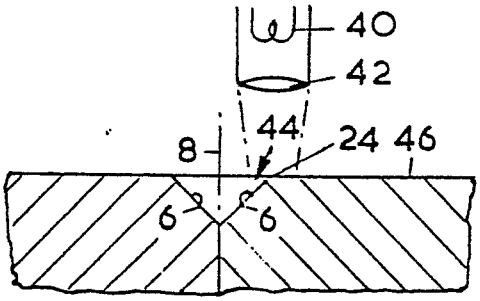

FIG.2

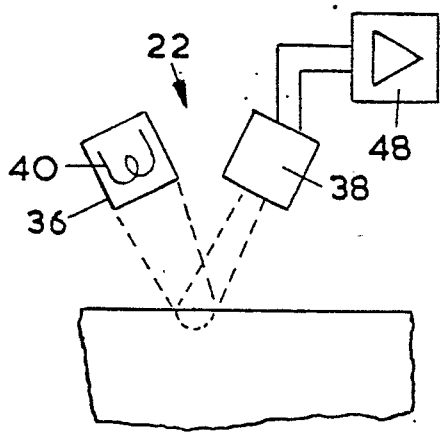

FIG.3

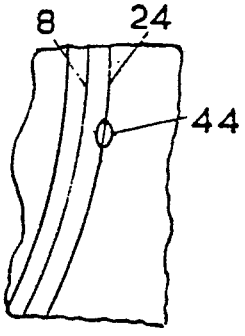

FIG.4a

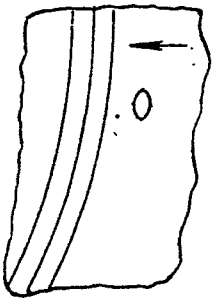

FIG.4b

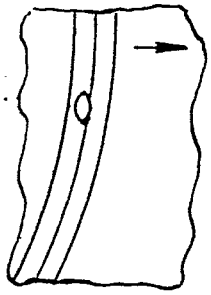

FIG.4c

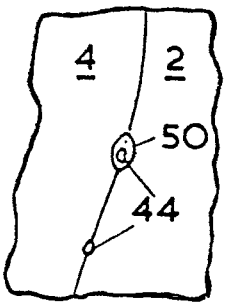

FIG.5

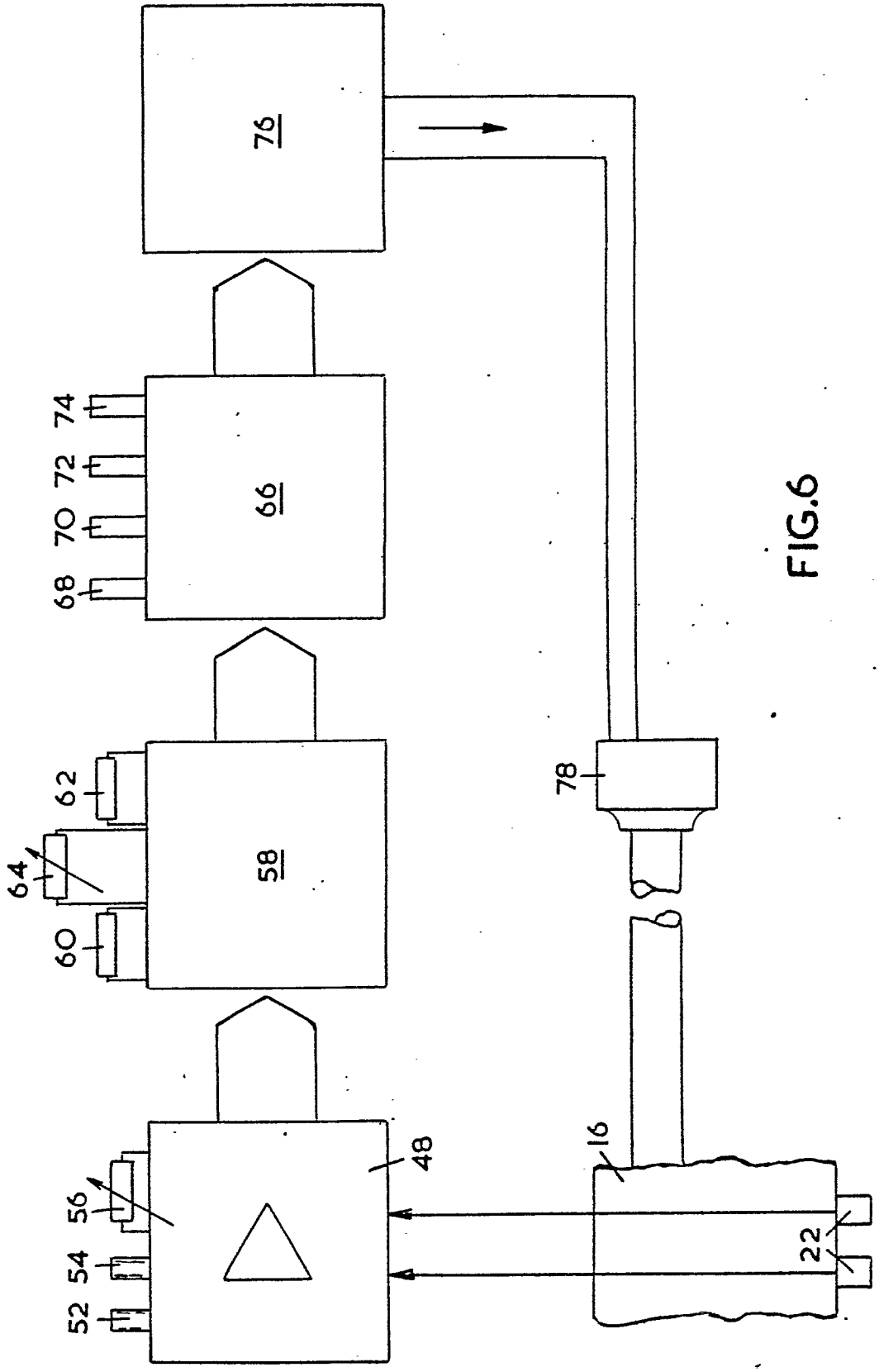

FIG.6

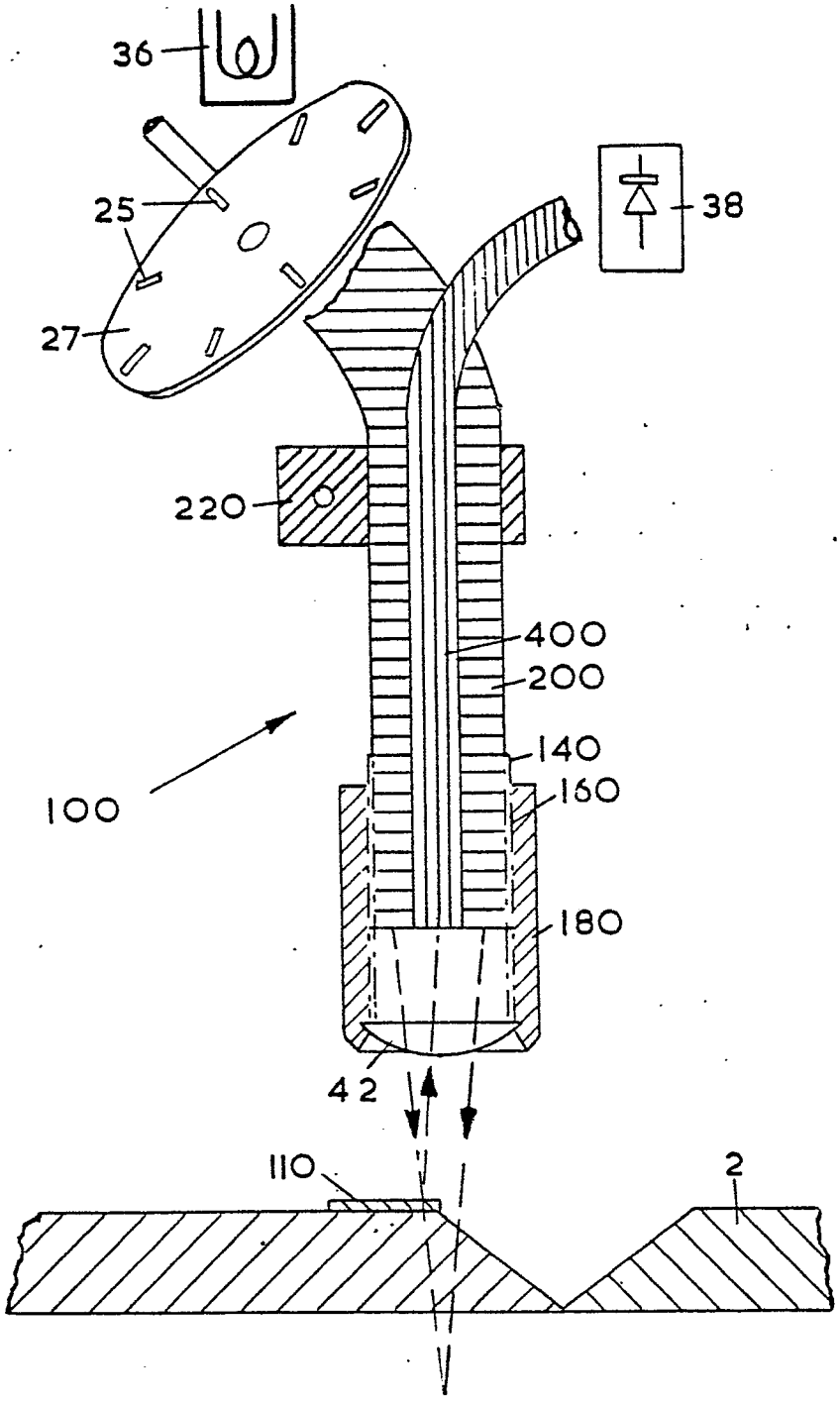

FIG.7

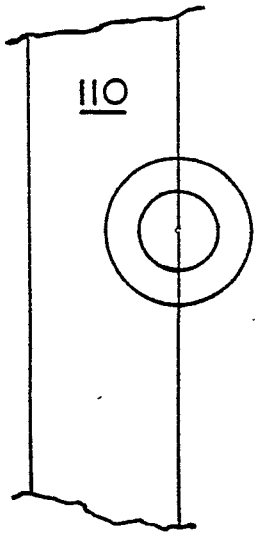

FIG.8a

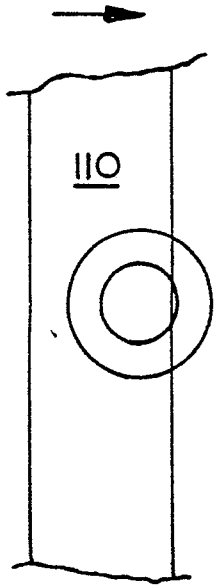

FIG.8b

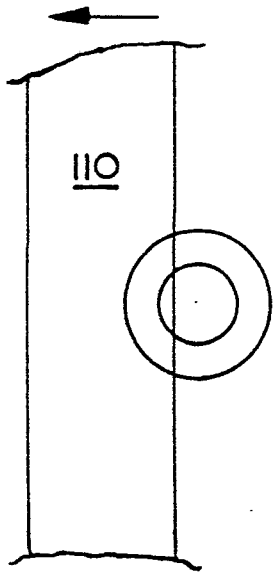

FIG.8c

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 78/00004

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

B 23 Q 35/128 // B 23 K 37/00

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
Int.Cl.[2]	B 23 Q 35/128; B 23 K 37/00; G 06 K 11/02; B 23 Q 35/40

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
	GB, A, 1353919, published 1974, May 22, see page 10, lines 96-122 (OPTOGRAMS)	1,8
	DE, A, 2311656, published 1973, September 20, see page 9 (HIRSCHMANN)	1,3,8
	FR, A, 2093021, published 1972, January 28, see: figures 5 and 6; page 7, lines 19-24; page 10, lines 18-19; figure 4 (MALENGE)	2,3,6
	US, A, 3855446, published 1974, December 17, see: abstract; column 11, line 53 to column 12, line 63 (KOTAVA)	5
	DE, A, 2023727, published 1970, November 19, see page 11, lines 11-15 (COMMISSARIAT)	4

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"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
05-09-1978	18-09-1978
International Searching Authority [1]	**Signature of Authorized Officer [20]**
European Patent Office	

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

	GB, A, 901203, published 1962, July 18, see page 1, lines 62-86 (HIRSCHMANN)	1
	FR, A, 1381839, published 1964, December 11, see page 2, left-hand column, lines 3-17 (LEITZ)	4
A	FR, A, 1465710, published 1967, January 13, see page 5, right-hand column, lines 30-34 (COMPAGNIE D'ETUDES)	1

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ....., because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.