

- (21) Application No. 10748/77 (22) Filed 14 March 1977 (19)
 (31) Convention Application No. 3540/76 (32) Filed 22 March 1976 in
 (33) Switzerland (CH)
 (44) Complete Specification published 23 July 1980
 (51) INT.CL.³ G05D 7/06 B22D 37/00
 (52) Index at acceptance
 G3R A273 BB
 B3F 1D



(54) AUTOMATICALLY CONTROLLED POURING METHOD AND
 APPARATUS FOR METAL CASTING

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 Corporate, of Fabrikstrasse 300, 3283 Kall-
 nach, (canton of Berne), Switzerland, do here-
 by 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:—
 This invention relates to a method and
 apparatus for automatically controlling the
 pouring of molten metal into a mold. More
 particularly, it relates to a method of the
 type wherein the molten metal flows in a
 stream from a lip-pour or bottom-pour cast-
 ing ladle into a pouring gate at the top
 of a mold; and to apparatus for carrying
 out that method, of the type comprising
 control means for varying at will the flow
 of the molten metal from the ladle and servo
 means controlled by at least one detector
 member and acting upon the control means
 for regulating them.
 Numerous problems are posed by the
 automatic control of casting installations in
 foundries. What is involved is, in principle,
 placing a casting-ladle above a mold, caus-
 ing the molten metal to flow from the ladle
 into the mold, and cutting off the flow
 when the mold is full. The mold is then
 removed and replaced by an empty one
 which is positioned beneath the casting-
 ladle.
 The course of the operation of filling a
 casting mold is subject to imponderable and
 unforeseeable influences of various sorts. In
 manual installations, this operation is con-
 stantly monitored by the founder. For one
 thing, it may be necessary to interrupt the
 flow of metal quickly in the event of an
 abnormal occurrence; for another thing, it
 is likewise necessary to check the rate of
 flow from the ladle in order that the mold
 may fill consistently and the part cast be
 free of pipes, blow-holes, pores, or other
 inner defects.

The present invention is essentially based
 upon the remote determination, by means
 both optical and electronic, of two
 parameters of the casting installation.

1. The level of the free surface of the
 molten metal in the pouring gate.

A sensor device receives the luminous
 and/or infrared radiation emitted by at
 least a delimited portion of the incandescent
 surface. This radiation then varies as a
 function of the contour of the zone of metal
 examined and, consequently, of the level
 thereof if the direction of observation is
 suitable, being dependent upon the geomet-
 rical shape of the pouring gate, the contour
 of that zone being constituted at least in
 part by the edge of the meniscus of the
 liquid metal; the remainder of the contour
 may be delimited by a mask such as will be
 described below in connection with the
 description of the sensor.

2. The flow of the stream of molten
 metal issuing from the ladle.

A sensor similar to that mentioned above
 receives the radiation emitted by at least a
 portion of the stream, this radiation being
 a function of the apparent dimension of the
 stream, hence of its cross-section, and thus
 in turn of the flow of the stream of molten
 metal.

According to one aspect of the present
 invention there is provided a method of
 automatically controlling the pouring of
 molten metal into a series of casting molds,
 wherein said molten metal flows in a stream
 from a lip-pour or bottom-pour casting ladle
 into a pouring gate at the top of said molds,
 the method comprising the steps of:
 separately telemetering during pouring into
 each mold at least one surface portion of
 said molten metal in said pouring gate and
 at least one surface portion of said molten
 metal in said stream by sensing the visible
 light radiation and/or infrared radiation
 emitted by said surface portions, and gener-
 ating a signal which is a function of said

telemetered surface portions and directly or indirectly controlling the rate of flow of said stream by acting upon said ladle so as to maintain the radiation emitted by said surface portion of the molten metal in the pouring gate at a constant value during casting.

According to another aspect of the present invention there is provided apparatus for controlling the pouring of molten metal into a series of casting molds comprising control means for varying at will the flow of a stream of molten metal from a casting ladle, servo means acting upon said control means for regulating them, and first and second photosensitive sensors acting as measuring members for controlling the servo means, the first photosensitive sensor being disposed at a predetermined distance from the ladle and from the mold, oriented in a direction to receive radiation from the free surface portion of molten metal in the pouring gate to a mold, in use of the apparatus, the measure of the radiation from the free surface being a function of the level thereof in the pouring gate, and the second photosensitive sensor being so disposed as to sense the radiation emitted by a surface portion of a predetermined length of the stream of molten metal passing from the ladle to the pouring gate in use of the apparatus, the apparent width of said stream portion being a function of the flow of said stream, means being provided for transmitting the signals from the sensors responsive to the received radiation to the servo means for control thereof whereby the control means is adjusted, in use of the apparatus, to maintain the level of metal in the pouring gate constant.

Preferred embodiments of both the method and the apparatus according to the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic view, partially in perspective, of a casting installation equipped with the control apparatus;

Figures 2 and 3 are diagrammatic sections showing two possible forms of the pouring gate of the mold;

Figure 4 is a longitudinal section through an electro-optical sensor; and

Figure 5 is a block diagram of the control apparatus.

The main elements of the casting installation are illustrated diagrammatically in Figure 1, which shows a casting ladle 1 having a lip 2 and borne by a mobile rig 3 pivotable about an axis 4. The position of the ladle 1 is determined by a motor 5 driving a winch 6 upon which a cable 7, from which the mobile rig 3 is suspended, is wound. An angular position sensor 8 is

likewise driven by the motor 5 and provides data concerning the position of the ladle 1 to a circuit 9.

When the ladle 1 is full of molten metal, it is brought into a predetermined position above the path followed by the casting molds. The latter either run on rails or are disposed on a turntable and successively come into the casting position. A mold 10 comprises a pouring gate 11 and two risers, in the openings 12 of which the molten metal appears when the mold is full.

For carrying out the casting operation, the installation comprises a control device including the regulating circuit 9 and the position sensor 8, as well as a number of optical sensors A, B, C, D, E, and F, which will be described in detail further on. These optical sensors are disposed at fixed locations around the mold 10 and the ladle 1 at distances on the order of about 0.5—2 m. from the points to be monitored. Each sensor monitors one particular point of the installation.

The sensor A is aimed towards the free surface of the molten metal contained in the ladle 1 near the lip 2; it acts as a checking and correction element, responding as a function of the temperature of the metal, as will be seen further on.

The sensor B is aimed at the tip of the lip 2, its function being to monitor the presence of molten metal at that location in order automatically to start operation of the control and servo device when casting begins.

The sensor C is aimed at the stream of molten metal flowing from the ladle 1 into the pouring gate 11. Its function is to measure the width of the stream and, consequently, its flow.

As for the sensor D, its function is to provide height data by monitoring the free surface of the metal in the pouring gate 11. This operation will be described in more detail in connection with Figures 2 and 3.

Auxiliary sensors E and F are intended to control the cut-off of the casting operation: the sensors E, aimed towards the openings 12, control the righting of the ladle 1 when the casting operation is finished and the molten metal appears in the openings 12, whereas the sensors F are safety sensors causing casting to be interrupted if they detect molten metal at an abnormal location as a result of overflowing, of misdirection of the stream, or of some other incident pertaining to the mold, for example. The sensors F may be aimed at zones of the mold adjacent to the casting openings or at any other surrounding zone over which molten metal is liable to run by mistake.

The sensors C and D are of primary significance in carrying out the casting operation. In order for the latter to proceed

normally, it can be important to maintain the surface of the liquid metal in the pouring gate 11 at a substantially constant level. In order to achieve this, the sensor D may be disposed either as shown in Figure 2 or as shown in Figure 3.

In Figure 2, the mold comprises a runner having a cylindrical pouring gate 11, towards which the sensor D is aimed obliquely. When the free level of molten metal is relatively low, e.g., at a (Figure 2), only the surface portion a_1 radiates towards the sensor D since the remainder of the surface a is concealed by the upper edge of the pouring gate 11. If, on the other hand, the level of liquid metal attains the height b , it will be seen that the whole surface b_1 radiates towards the sensor D, so that the beam of light and/or infrared rays sensed will be appreciably wider. Thus the sensor can transmit an electrical signal corresponding to the extent of the surface portions which it "sees" and, consequently, to the level of the free surface of the metal.

Figure 3 shows how the sensor D may be disposed in the case of a pouring gate 11 of conical shape. When the free metal surface reaches the level a , the area thereof has the value a_1 , whereas if the free surface reaches the level b , the area will have the value b_1 . Whatever the level, the entire free surface is visible to the sensor D. In this case, the monitoring direction may even be vertical.

In practice, measurement is facilitated even more by the use of a mask delimiting the monitored surface portion to the only zone which is truly of interest, situated on the left-hand part of the pouring gate, as viewed in Figure 2 or Figure 3. In particular, this eliminates the disturbance factor caused by any possible disintegration of the edge of the pouring gate situated to the right in the case of the configuration shown in Figure 2.

Figures 2 and 3 also illustrate how the sensor C can measure the flow of the stream of molten metal. The dot-dash circle C_1 appearing in each of these figures shows diagrammatically the field of vision perceived by the sensor C. This field of vision covers a fixed length of the stream, and the radiation sensed will obviously depend upon the width of the stream and, consequently, upon the flow thereof. In practice, care will be taken to aim the sensor C towards a portion of the stream which is substantially cylindrical in shape, and the monitoring field will be delimited by means of a generally rectangular mask.

Figure 4 shows the design of the sensors A to F. The field of vision is localized by appropriate positioning of a cylindrical sheath 13 constituting the body of the sensor. The sheath 13 carries a lens support 14

screwed within the body and precisely adjustable in its axial position by rotation, using a tubular pin-wrench engaging a slot 16. A gasket 15 maintains accurate positioning by friction.

The support 14 bears a lens 17 of an appropriate focal length which forms, at the rearward end of the sheath 13, a real image of the field of vision of the sensor. A rear endpiece 18 bears a photosensitive member 19, e.g., a photosensitive resistor or any other photoelectric element of suitable performance capable of acting upon an electric circuit as a function of the radiation received by the element. In a simplified version, the lens 17 may be replaced by a simple disc having a small hole or window in it, which would act in an equivalent manner although having a lower luminous output, thus requiring much more sensitive photoelectric elements. The photosensitive member 19 is connected to the electronic circuit 9, as may be seen in Figure 1, by a cable 20.

The photosensitive member 19 itself is housed within a capsule 21 secured to the endpiece 18 and comprising a translucent screen 22 held in place at the entrance of the capsule 21 by springs 23 and by a locking ring 24. This arrangement enables rapid dismantling of the capsule 21 for adjustment of the sensors. It will be obvious, however, that other types of assembly may also be used. For example, the photosensitive element may be situated on the same side of the screen as the lens, the screen then operating by reflection rather than by transparency.

Each sensor is adjusted by forming an appropriate mask 25 and mounting it in front of the screen 22. First of all, the lens 17 must be placed at the desired location so that the real image of the field of vision is formed on the screen 22 when the endpiece 18 is in place. From this real image, those elements which are supposed to act upon the photosensitive member 19 are then selected. This selection is carried out by making the mask 25 of an appropriate shape so that only the radiation emanating from the liquid metal surface portion chosen to act upon the member 19 reaches the translucent screen 22. Thus there is formed upon the screen 22 a light spot which irradiates the cell 19. In the case of the sensor C, the mask 25 will be cut out in such a way as to eliminate the liquid metal surface portions which might be visible at the sides of the portion of the stream which it is desired to sense; while in the case of the sensor D, the mask 25 will eliminate the influence of the surface of the stream and will be cut out in such a way that only the radiation emanating from a part of the free surface situated at the periphery of the pouring gate reaches the cell 19. If need be, the screen might be

the sensitive surface of the photoelectric element itself.

In practice, the sensors are adjusted by means of an accessory tool (not shown), comprising a graduated frosted screen and an eyepiece, which is temporarily mounted in place of the endpiece 18 and the capsule 21, the focal plane of the frosted glass being identical to that of the screen 22 for which it is substituted.

If so desired, it is possible to use photosensitive cells 19 having a more or less selective chromatic sensitivity characteristic. In the event that photosensitive resistors are used, these elements are known to be sensitive to the visible and infrared spectra. Thus they are particularly suitable for detecting radiation emitted by a molten metal such as cast iron or steel, the temperature of which is of the order of 1300—1700°C.

The sensors described supply an analog-type signal. In the case of a photosensitive resistor, the current passing through the conductors of the cable 20 is a measure of the extent of the metal surface seen by the sensor. However, it would also be possible to provide sensors equipped with a highly magnifying optical system and to place upon the screen a cell matrix enabling a determination of the radiant surface by the digital measurement of its extent, or the detection of the position of the free surface of the molten metal against the wall of the pouring gate by logical scanning circuits of the combination or sequential-scanning type.

The same effect might even be achieved by arranging a group of elementary sensors, each detecting a particular level or a particular width of the stream.

It should be noted, however, that these last two solutions provide only a relatively rough estimate of the parameters to be determined if it is desired to limit the matrix to a reasonable degree of complexity; moreover, they do not lend themselves well to the use (as describe below) of derived data, the latter being discontinuous.

Figure 5 shows the main part of the control circuit 9, which comprises two overlapping servo loops.

The first loop is composed of the sensor D, a level-regulating circuit 26 and a level reference element 27, while the second loop comprises the sensor C and a flow-regulating circuit 28. The circuit 28 is acted upon by the regulating signal transmitted by the level-regulating 26, and its output is amplified in an amplifier 29 which controls the motor 5 regulating the position of the ladle 1.

Before reaching the regulating circuit 26 or 28, the signals transmitted by the sensors C and D are corrected in compensating circuits 30 and 31 by the data emanating from a control circuit 32, which is in turn acted upon by the sensor A. Thus the signals

supplied to the circuits 26 and 28 undergo an appropriate correction according to the actual temperature of the molten metal.

The sensor A, the entire field of vision of which is constantly occupied by a portion of the free surface of the molten metal, transmits a signal, the strength of which is a measure of the temperature; this information may even be stored, if deemed necessary, taking into account the shape of the pouring opening and of the disturbances to which it is prone.

The sensor E is not included in Figure 5. Its task is to enable the circuit 9 to control the position of the ladle 1 when casting begins; for when the mold 10 has been brought into place opposite the ladle 1, or vice versa, a contact automatically takes place which starts up the motor 5 so as to control the tilting of the ladle 1. The control is interrupted as soon as the sensor B detects the presence of molten metal at the end of the lip 2 so that, from then on, the motor 5 may be connected into the control circuit and may respond directly to the orders emanating from the circuit 28.

The connection between the position sensor 8 and the circuit 9 is also not shown in Figure 5. The sensor 8 supplies information concerning the position of the winch 6, i.e., of the ladle 1. This information is compared with the stored information corresponding to the end of the preceding casting operation. Taking into account the signal transmitted by the sensor B, it is thus possible to detect the existence of any abnormality, such as a dangerous slag barrier obstructing the lip 2, in which case the casting operation must be stopped without delay by returning the ladle 1 to its resting position and setting off an alarm.

The signals transmitted by the sensors E and F are used, after amplification, to control the rapid return of the ladle to its resting position at the end of casting (E) or in the event that the presence of liquid metal is detected outside the mold 10 (F). It is obvious that any untimely flow of metal at an undesired location must be stopped immediately and an alarm given in view of the risk of damage and the danger which this may represent.

The control circuit described by way of example is designed so as to have the greatest possible efficiency and stability. The first servo loop responds to the free liquid metal surface portion perceived by the sensor D in the pouring gate. The signal transmitted by this sensor is a function of the extent of this surface and, consequently, of its level. It is compared to a reference signal representing a predetermined desired level of that surface, and the result of this comparison is a regulating signal for the desired flow, which is supplied to the second servo

loop. In the latter, the control circuit 28 compares the desired-flow signal with the signal coming from the sensor C, i.e., with the actual flow of the stream of molten metal. The result of the comparison between the actual flow and the desired flow is an order transmitted by the amplifier 29, which actuates the motor 5. Hence there is provided apparatus which responds very rapidly and ensures stability of control.

Moreover, whenever the level in the pouring gate 11 or 11¹ abruptly exceeds the desired level by a certain value upon complete filling of the mold, the signal from the sensor D may also be used to cause the rapid return of the ladle 1 into its resting position, especially in the case of casting in molds not provided with risers 12.

Depending upon the particular circumstances, other control circuits may be used. Thus it may happen that it suffices to detect the thickness of the stream and to control the motor regulating the position of the ladle as a function of that information alone; whereas in other cases, where maintenance of a constant level in the pouring gate is of prime importance, but where irregularities in flow need not be feared, it may suffice to use only the sensor D, dispensing with the sensor C.

On the other hand, the control circuit is likewise designed to be able to utilize not only the instantaneous value of the signals transmitted by the sensors, but also the rate of their variation and their stored total, in order to obtain a PID-type control (proportional plus reset plus rate action). This mode of operation is naturally facilitated by the use of analog-output sensors.

The apparatus described may also be used with a bottom-pour ladle. In this case, the motor 5 simply controls the proportional opening of the stopper.

In conclusion, some of the main advantages of the system described above may be summed up as follows:

—The optical sensors allow continuous measurement of the casting parameters, supplying preferably analog data usable as both instantaneous and derived values owing to the very low time constant inherent in the electro-optical elements employed.

—The high focusing of the optical systems forming the image of the zones monitored makes it possible to mount the sensors a good distance away from the critical zones represented by the lip of the ladle and the pouring gate of the mold thus facilitating maintenance work on the ladle and its lip, which remain easily accessible. Furthermore, this remoteness contributes towards limiting the risk of accidents involving the detector members as a result of spattering molten metal or glowing gases.

—Finally, the sensors used are completely

static members, therefore having no moving parts subject to wear and tear.

WHAT WE CLAIM IS:—

1. A method of automatically controlling the pouring of molten metal into a series of casting molds, wherein said molten metal flows in a stream from a lip-pour or bottom-pour casting ladle into a pouring gate at the top of said molds, the method comprising the steps of: separately telemetering during pouring into each mold at least one surface portion of said molten metal in said pouring gate and at least one surface portion of said molten metal in said stream by sensing the visible light radiation and/or infrared radiation emitted by said surface portions, and generating a signal which is a function of said telemetered surface portions and directly or indirectly controlling the rate of flow of said stream by acting upon said ladle so as to maintain the radiation emitted by said surface portion of the molten metal in the pouring gate at a constant value during casting.

2. A method in accordance with claim 1, wherein the surface portion of the molten metal in the pouring gate corresponds to the apparent area of said surface and varies as a function of the level of the surface, said control of rate of flow being effected so as to maintain said level substantially constant during casting.

3. A method in accordance with claim 1 or 2, wherein the light radiation emitted by a portion of said stream of a predetermined length is sensed with the control of rate of flow being so effected that the width of said stream portion and hence the flow of said stream are constantly maintained at a reference value determined by a signal as a function of said free surface level in said pouring gate.

4. A method in accordance with claim 1, 2 or 3, wherein said signal is further utilized for controlling the interruption of casting when said signal exceeds a predetermined limiting value.

5. Apparatus for controlling the pouring of molten metal into a series of casting molds comprising control means for varying at will the flow of a stream of molten metal from a casting ladle, servo means acting upon said control means for regulating them, and first and second photosensitive sensors acting as measuring members for controlling the servo means, the first photosensitive sensor being disposed at a predetermined distance from the ladle and from the mold, oriented in a direction to receive radiation from the free surface portion of molten metal in the pouring gate to a mold in use of the apparatus, the measure of the radiation from the free surface being a function of the level thereof in the pouring gate, and

the second photosensitive sensor being so disposed as to sense the radiation emitted by a surface portion of a predetermined length of the stream of molten metal passing from the ladle to the pouring gate in use of the apparatus, the apparent width of said stream portion being a function of the flow of said stream, means being provided for transmitting the signals from the sensors responsive to the received radiation to the servo means for control thereof whereby the control means is adjusted, in use of the apparatus, to maintain the level of metal in the pouring gate constant.

6. Apparatus in accordance with claim 5, wherein said servo means comprise a first servo loop controlled by said signal transmitted by said first sensor and supplying a reference signal, and a second servo loop overlapping said first servo loop and controlled by said reference signal, said second loop acting upon said control means for conforming a signal transmitted by said second sensor to said reference signal.

7. Apparatus in accordance with claim 5 or 6, further comprising rapid driving means controlled by said servo means for returning said ladle to its resting position when the servo means receives a signal which exceeds a predetermined limiting value.

8. Apparatus according to claim 5, 6 or 7, further comprising a compensating light sensitive sensor for sensing the radiation emitted by a constant and predetermined surface portion of the metal and for emitting a compensating signal which is a function of the temperature of the metal, said compensating sensor being connected to a control circuit which corrects the signals received from the first and second sensors.

9. Apparatus according to claim 5, 6, 7

or 8, wherein the light sensitive sensors each comprise a screen, an optic system, arranged to form a real image on said screen, means for selecting on said screen a predetermined portion of said image and at least one light sensitive element placed to receive light transmitted by said image portion on said screen, and to emit said signal.

10. Apparatus according to claim 5, 6, 7 or 8, wherein the said servo-means comprise acting elements able to act on said control means proportionally to a control signal received from said first and second sensors and acting elements able additionally to act on said control means proportionally to the speed of variation of such received signal.

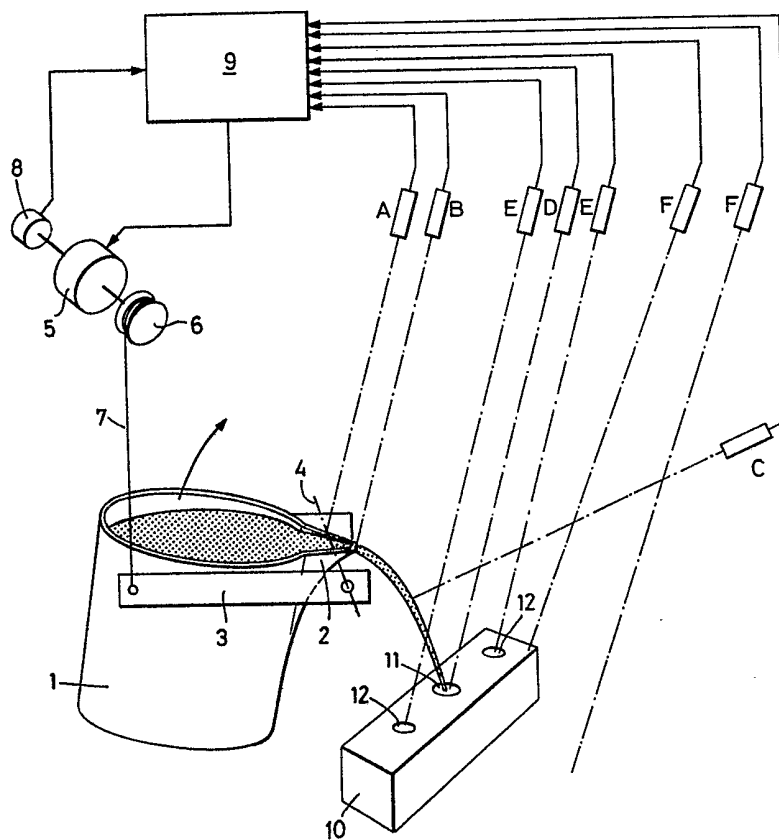
11. Apparatus according to any one of claims 5 to 10, wherein said servo means further comprise detecting means able to sense the position of the control means and means for stopping pouring of the metal in the mold when the position of said control means irregularly varies between two pouring operations.

12. A method of automatically controlling the pouring of molten metal into a series of casting molds substantially as hereinbefore described with reference to the accompanying drawings.

13. Apparatus for controlling the pouring of molten metal into a series of casting molds constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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FIG. 1



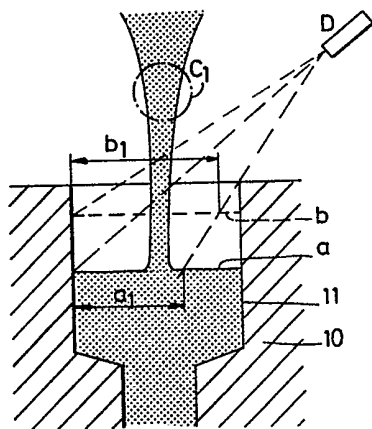


FIG. 2

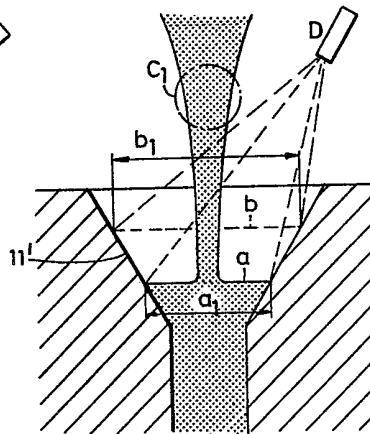


FIG. 3

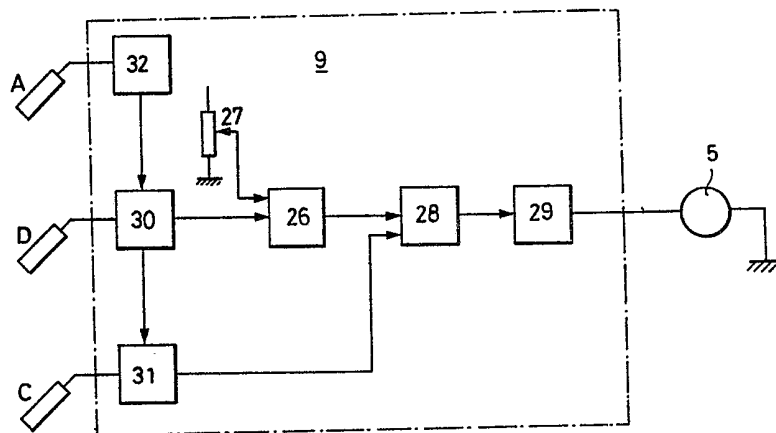


FIG. 5

FIG. 4

