Dec. 9, 1969 NG WING YUEN 3,482,954
MANUFACTURE OF SHEET MATERIAL IN RIBBON FORM
Filed June 8, 1966 8 Sheets-Sheet 1

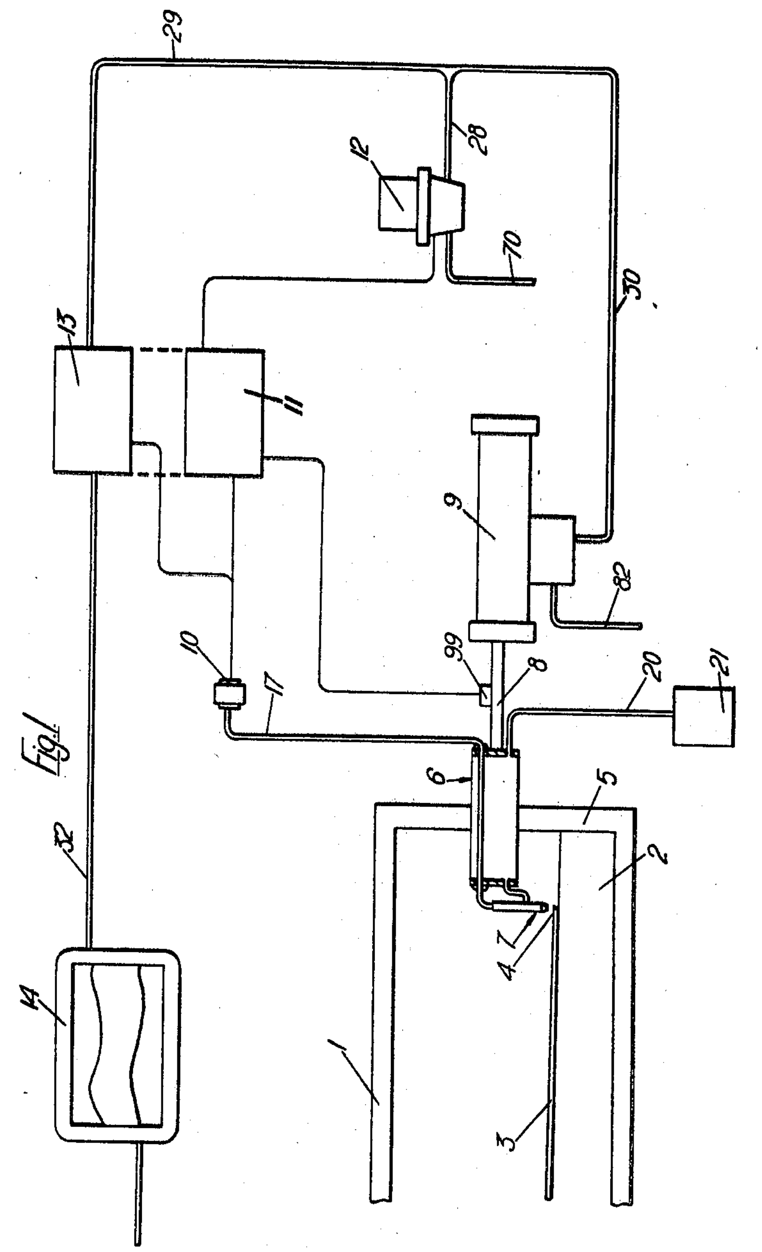

Fig.1

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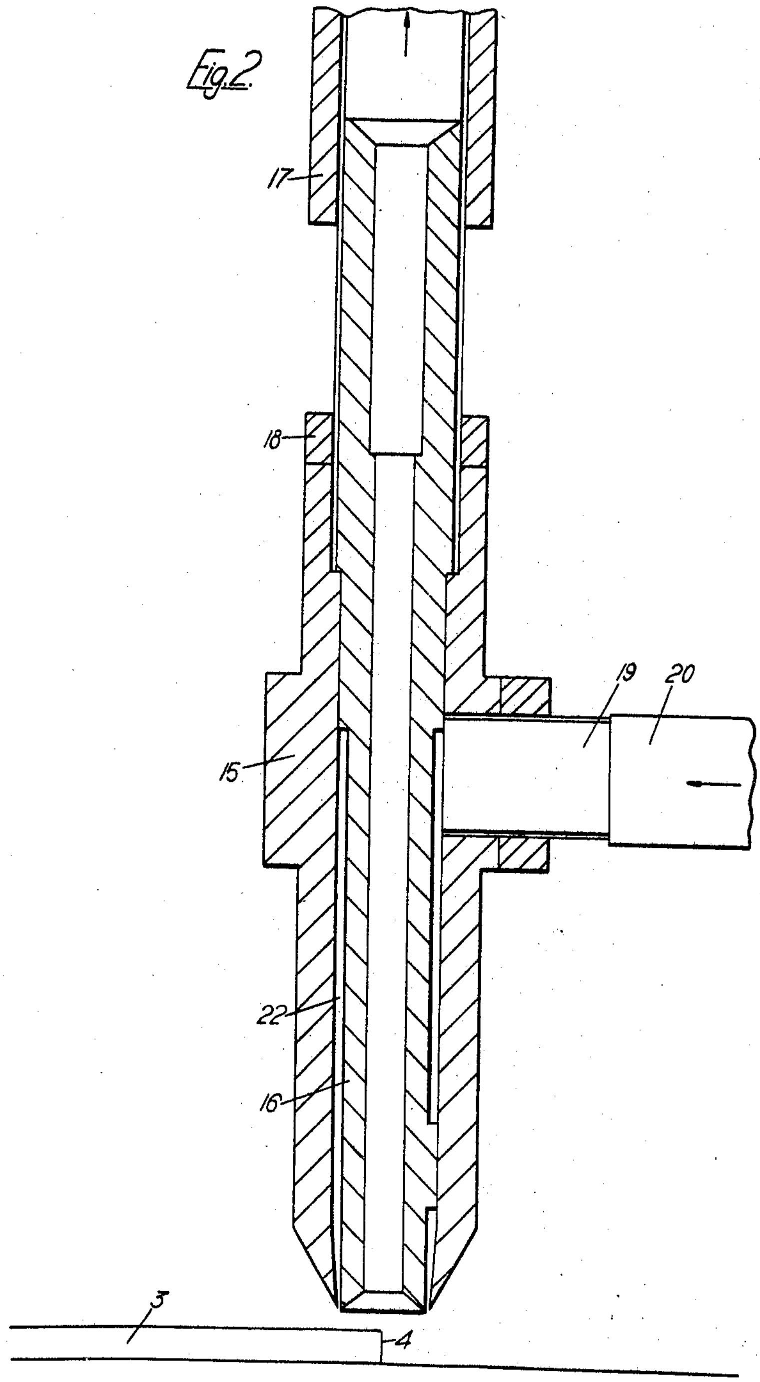
Fig. 2



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MANUFACTURE OF SHEET MATERIAL IN RIBBON FORM

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Fig.3

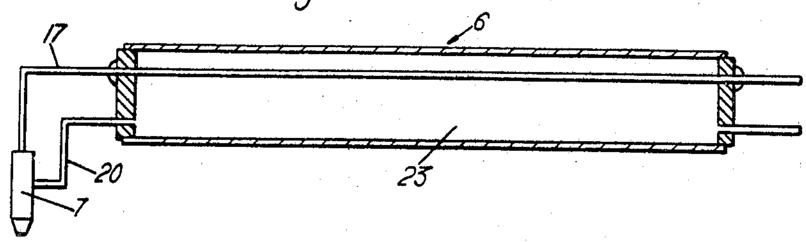


Fig.6

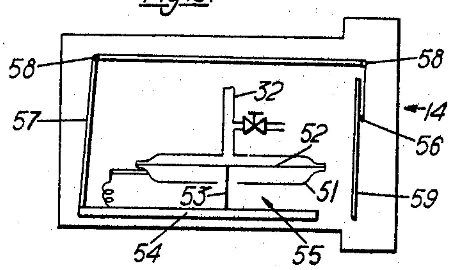
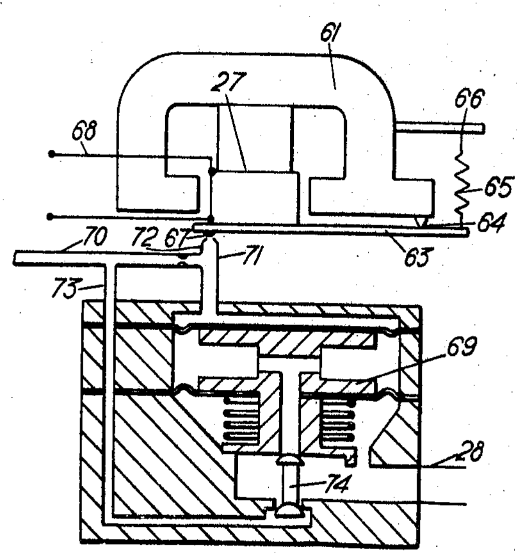


Fig.7



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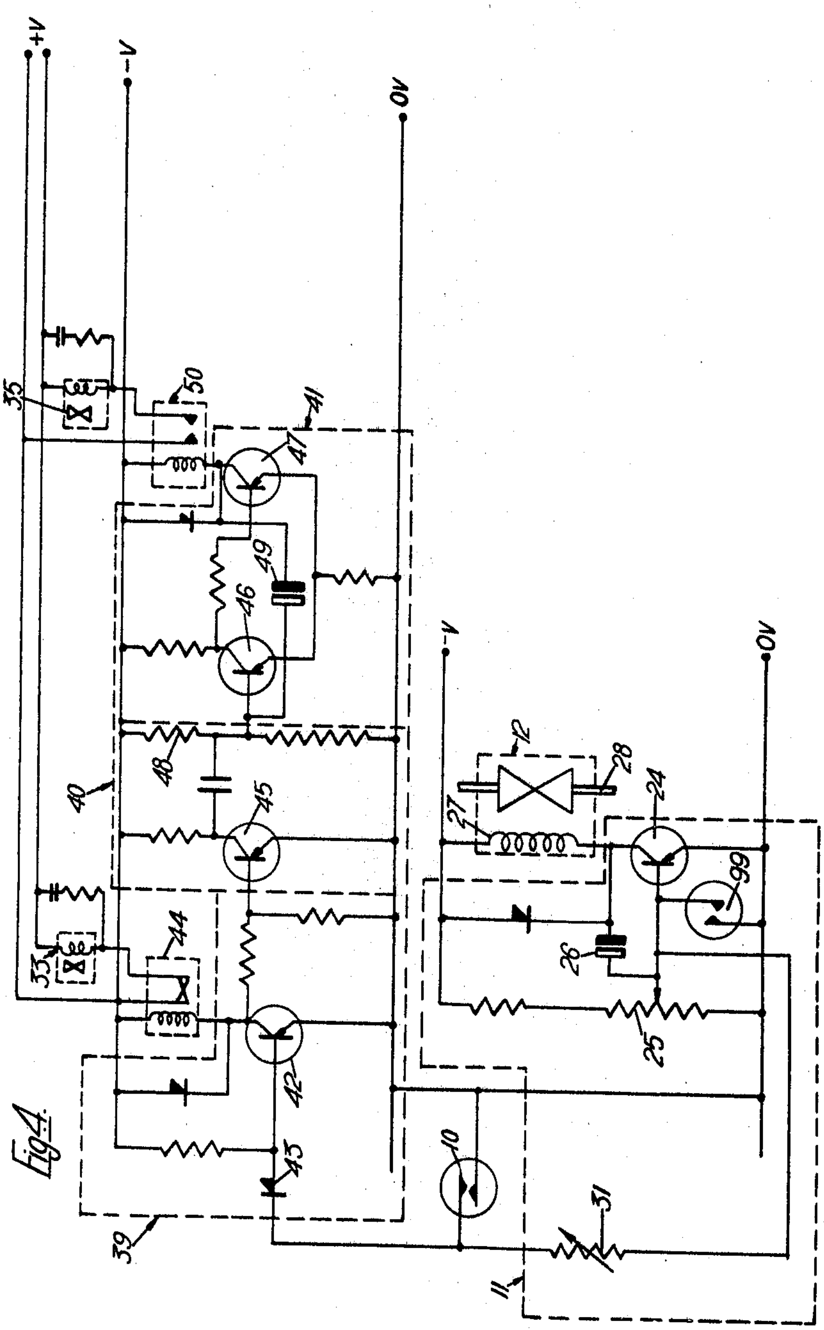

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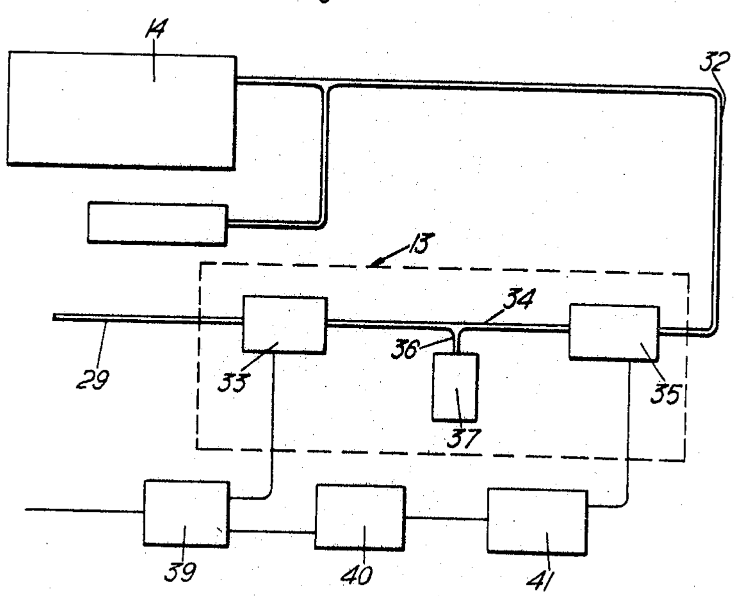
Fig. 5.



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MANUFACTURE OF SHEET MATERIAL IN RIBBON FORM

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Fig. 8

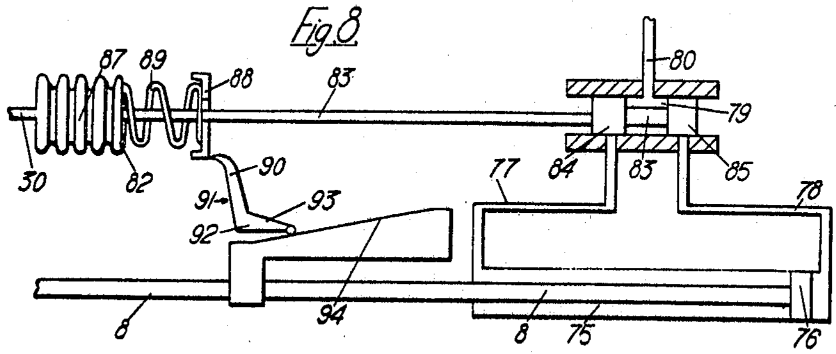


Fig. 9

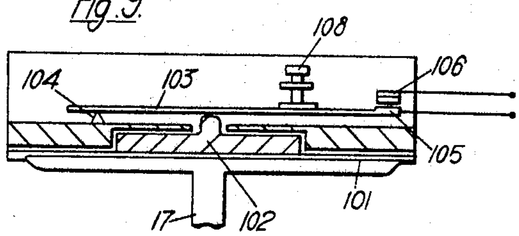
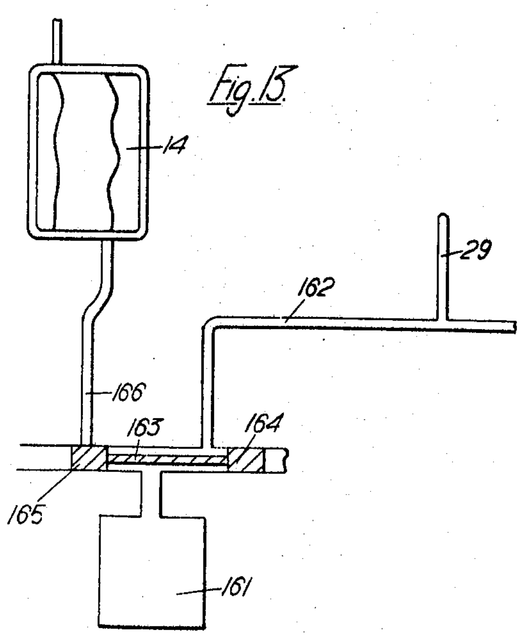


Fig. 13



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MANUFACTURE OF SHEET MATERIAL IN RIBBON FORM

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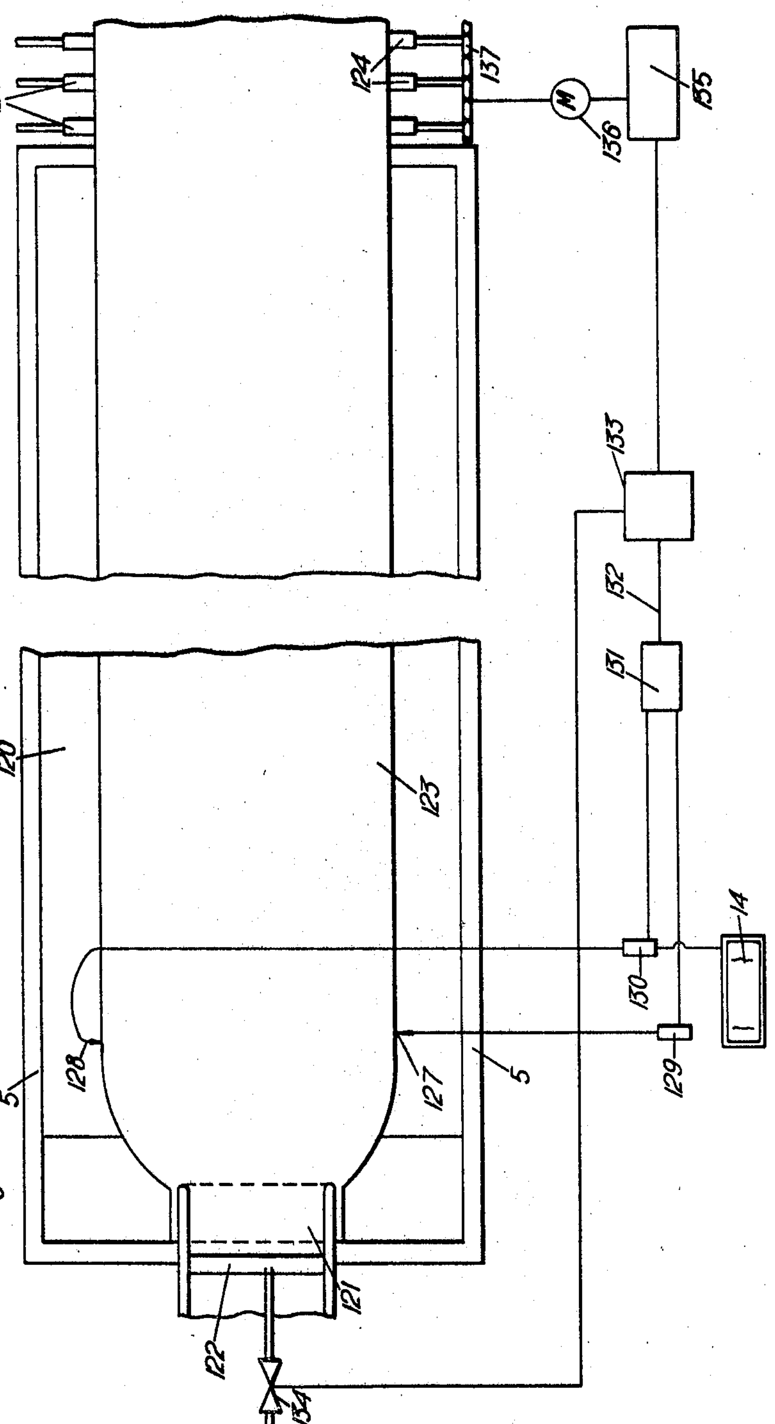

Fig. 10

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Fig.11.

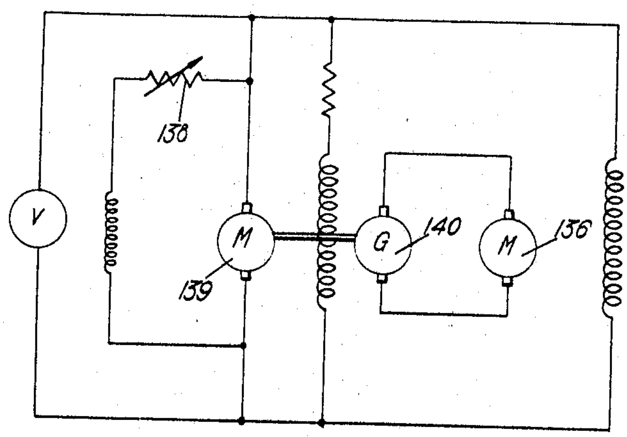
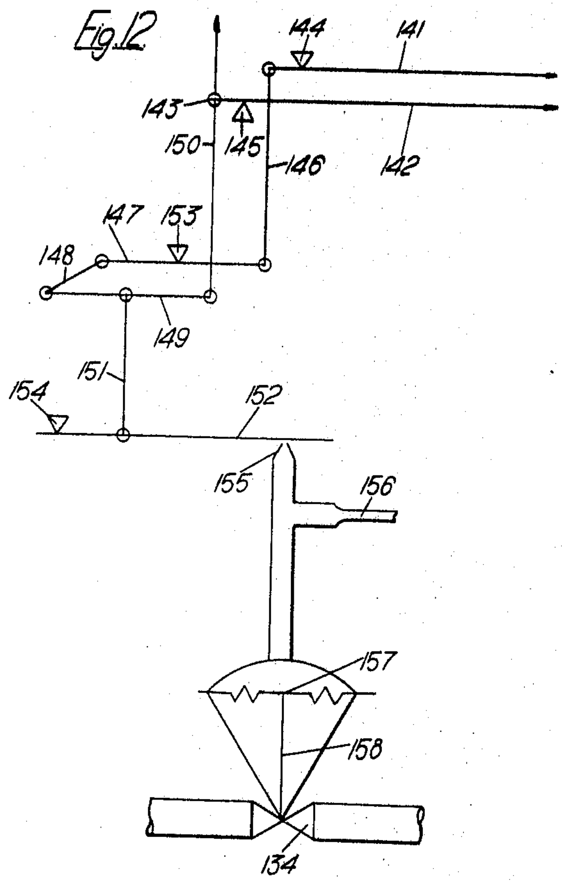


Fig.12.



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MANUFACTURE OF SHEET MATERIAL IN RIBBON FORM

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Int. Cl. C03b *18/02;* G01b *13/04*
U.S. Cl. 65—29 9 Claims

ABSTRACT OF THE DISCLOSURE

The position of an edge of a ribbon of sheet material is continuously sensed by projecting an annular gas stream towards the ribbon edge, sensing the back pressure existing in the zone surrounded by that annular stream, and using the result of the sensing to control the manufacture of sheet material.

This invention relates to the manufacture of sheet material in ribbon form, and more particularly to methods and apparatus for determining the position of an edge of the ribbon as it advanced.

It is a main object of the present invention to provide a method of determining the position of an edge of an advancing ribbon of sheet material which can be applied in methods of manufacture where the ribbon of sheet material is in contact with a surface, and the detecting means can therefore detect the position from one side of the ribbon only.

In accordance with the present invention, there is provided in the manufacture of sheet material in ribbon form, a method of determining the position of an advancing ribbon, comprising the steps of continuously sensing pneumatically in the neighborhood of an edge of the ribbon by determining the back pressure existing in an aperture around which gas is ejected in an annular stream, and deriving from said continuous pneumatic sensing information regarding the position of the edge of the ribbon for use in controlling the manufacture of the sheet material.

Advantageously the pneumatic sensing is performed in a to and fro motion in transverse relation to the advancing ribbon.

According to the broadest aspects of the invention, the method of determining the position of an edge of the advancing ribbon may be employed in any method of manufacture of sheet material in ribbon form. The present invention does, however, have particular application in the manufacture of flat glass during which the glass is advanced in ribbon form in contact with molten metal, and in accordance with this aspect of the invention, the method of determining the position of the advancing ribbon of glass comprises the steps of continuously sensing pneumatically in the neighborhood of the edge of the ribbon by determining the back pressure eixsting in an aperture around which a gas which is substantially inert to the molten metal is ejected in an annular stream, and deriving from said continuous pneumatic sensing information regarding the position of the edge of the glass ribbon for use in controlling the manufacture of the glass.

More particularly, according to this aspect, there is provided in the manufacture of flat glass in ribbon form on a bath of molten metal, the steps of continuously sensing pneumatically in the neighborhood of one or both edges of the glass ribbon by determining the back pressure existing in an aperture around which a gas which is substantially inert to the molten metal is ejected in an annular stream, deriving from said continuous pneumatic sensing information regarding the position of the glass ribbon on the bath of molten metal and utilising the derived information to control either the advancing glass or a subsequent operation performed on the glass ribbon.

As will become evident from the detailed description of one embodiment of the invention, the information regarding the position of the glass ribbon on the bath of molten metal may be utilised in any one of a number of ways, and as one example, the information may be utilised to steer the glass ribbon down a desired path on the surface of the bath of molten metal.

As another example, when the position of both edges of the ribbon is determined by a method in accordance with the invention, information concerning the width of the ribbon may be obtained.

In the particular example of a special method of manufacturing a glass ribbon, there is therefore provided in accordance with this aspect of the present invention in the manufacture of flat glass in ribbon form on a bath of molten metal, wherein a layer of molten glass is permitted to flow freely and a glass ribbon is developed on the surface of the bath of molten metal, a method of determining the width of the glass ribbon formed on the surface of the bath of molten metal comprising the steps of continuously sensing pneumatically in the neighborhood of both edges of the glass ribbon by determining the back pressure existing in respective apertures around each of which a gas which is substantially inert to the molten metal is ejected in an annular stream, deriving from said continuous pneumatic sensing information indicative of the width of the glass ribbon, and, in the event of the sensed width of the glass ribbon differing from a predetermined value, utilising the information indicative of the difference from the said predetermined value for changing the conditions under which the glass ribbon is formed in a manner to correct for the departure from the said predetermined width.

There are a number of ways in which the information indicative of the difference in the width of the glass ribbon from the said predetermined value may be utilised to apply the necessary correction to obtain from the process a glass ribbon of the predetermined width.

In general, the glass ribbon formed on the surface of the bath of molten metal is taken up from the bath and advanced by rollers which are driven at an appropriate speed and which apply a tractive force to the glass ribbon as it is formed on the bath of molten metal. In one example, the information indicative of the difference of the width of the glass ribbon from the said predetermined value is used to change the speed at which the said rollers are driven, and thereby to correct for the departure of the width of the glass ribbon from the said predetermined value.

Alternatively, the information indicative of the difference of the width of the glass ribbon formed on the bath of molten metal from the predetermined value is used to alter the temperature of the molten glass from which the ribbon of glass is formed on the bath to correct for the departure of the width of the glass ribbon from the said predetermined value.

A third possible alternative is that the information indicative of the difference in width of the glass ribbon formed on the bath of molten metal from the said predetermined value is used to regulate the rate of flow of molten glass to the bath of molten metal and thereby to correct for the departure of the width of the glass ribbon from the said predetermined width.

The present invention also comprehends apparatus for determining the position of an edge of an advancing ribbon, the apparatus comprising pneumatic sensing means including an inner tube located co-axially with an outer tube to define an annular nozzle, gas delivery means for supplying gas under pressure to the space between said inner and outer tubes whereby a jet of gas is discharged therefrom, and a pressure sensitive switch responsive to the back pressure set up in the said inner tube, driving means for moving the pneumatic sensing means laterally with respect to the advancing ribbon, control means arranged to control the said driving means and to produce a signal indicative of the position of the pneumatic sensing means as the pneumatic sensing means is moved by the said driving means, and sampling means controlled by said pressure sensitive switch for sampling the signal produced by said control means at the instant that said pneumatic sensing means experiences a change in the back pressure in the said inner tube consequent upon the movement of the said pneumatic sensing means over the edge of the said ribbon.

More particularly, according to this aspect of the present invention, there is provided apparatus for determining the position of an edge of an advancing ribbon of sheet material, the apparatus comprising pneumatic sensing means including an inner tube located co-axially with an outer tube to define an annular nozzle, gas delivery means for supplying gas under pressure to the space between said inner and outer tubes whereby a jet of gas is discharged therefrom, and a pressure sensitive switch responsive to the back pressure set up in the said inner tube, pneumatic driving means arranged to move the pneumatic sensing means laterally with respect to the advancing ribbon, electro-pneumatic control means arranged to produce a pneumatic signal which controls the said driving means and which is indicative of the position of the pneumatic sensing means as the pneumatic sensing means is moved by the said pneumatic driving means, electrically operated sampling means controlled by said pressure sensitive switch for sampling the pneumatic signal produced by said electro-pneumatic control means at the instant that said pneumatic sensing means experiences a change in the back pressure in the said inner tube consequent upon the movement of the said pneumatic sensing means over the edge of the said ribbon, and detector means for analysing, indicating or recording the signal passed by said sampling means and indicating the position of the edge of the advancing ribbon.

Advantageously the said pressure sensitive switch is arranged to control the electronic current generator which in turn operates to change the condition of the said electro-pneumatic control means, whereby the pneumatic driving means is reversed to move the pneumatic signal means in the opposite direction in relation to the edge of the advancing ribbon.

More particularly, apparatus in accordance with the present invention is apparatus for determining the width of a glass ribbon manufactured on the surface of a bath of molten metal. The apparatus for determining the width of a glass ribbon will include duplicate apparatus for determining the position of an edge of an advancing ribbon as set forth above and will additionally include comparator means for comparing the distance between the indications of the respective edges of the advancing ribbon with a predetermined value for the width of the advancing ribbon and a pneumatic recorder controller dependent upon the output of the said comparator means for changing one condition under which the glass ribbon is formed in a manner to correct for the departure from the said predetermined width.

As has been indicated already, there are a number of ways in which the correction to the width of the glass ribbon may be applied. The pneumatic recorder controller is arranged to change the rate at which the glass ribbon is withdrawn from the bath of molten metal.

As an alternative, the pneumatic recorder controller may be arranged to control the rate of delivery of glass to the bath of molten metal.

As a third alternative, the pneumatic recorder controller

is arranged to vary the temperature of the glass supplied to the bath.

In order that the invention may be more clearly understood, a preferred embodiment thereof will now be described by way of example, with reference to the accompanying diagrammatic drawings of an embodiment of the invention in which the position of the edges of the glass ribbon advanced along the surface of a bath of molten metal is determined, and in which:

FIGURE 1 is a flow diagram of a pneumatic servo-mechanism for reciprocating a probe over an edge of a ribbon of glass and indicating means for recording signals produced by the probe,

FIGURE 2 is an elevation in section of the nozzle for a probe for use in the apparatus of FIGURE 1,

FIGURE 3 is an elevation, partly in section of the probe,

FIGURE 4 shows the electrical circuit details of the apparatus of FIGURE 1,

FIGURE 5 shows in a simplified block diagrammatic form the sampling apparatus, the electrical detail of which is shown in FIGURE 4,

FIGURE 6 shows one form of recorder for recording the pneumatic signals passed from the sampling apparatus of FIGURE 5,

FIGURE 7 shows an electro-pneumatic relay for use in the apparatus of FIGURE 1,

FIGURE 8 shows the driving means for moving the probe over the ribbon of glass,

FIGURE 9 shows a pressure switch for use in the apparatus of FIGURE 1,

FIGURE 10 shows a plan view of apparatus for manufacturing a ribbon of glass of desired width on a bath of molten metal and including apparatus according to the invention,

FIGURES 11 and 12 show details of apparatus included in FIGURE 10, and

FIGURE 13 shows an alternative form of sampling apparatus.

In the drawings like reference numerals designate the same or similar parts.

Referring to the drawings, there is shown in FIGURE 1 a block diagram of the detecting apparatus used to determine and record the position of one edge of a ribbon of glass advancing along the surface of a bath of molten metal.

In FIGURE 1, there is indicated diagrammatically a part of a structure **1** containing a bath **2** of molten metal, preferably molten tin, on the surface of which a ribbon of glass **3** is continuously advanced. A protective atmosphere based on nitrogen which is chemically inert to the molten metal of the bath is maintained within the structure **1** in the headspace over the bath. For simplicity, there is shown in FIGURE 1 only one lateral edge **4** of the advancing glass ribbon **3**, and the detecting apparatus of FIGURE 1 is designed to determine and record the position of this edge **4** of the glass ribbon **3**.

The structure **1** includes a side wall **5** in relation to which the position of the edge **4** of the glass ribbon is to be determined and through a gas seal in the side wall **5** of the structure **1** there extends a probe **6** consisting of a nozzle **7** carried at the end of an arm **8**. The arm **8** is arranged to be operated by a pneumatic driving means **9** so that the nozzle **7** is moved either progressively towards or away from the side wall **5** of the structure. The pneumatic driving means **9** is itself controlled in a manner to be described by a pressure-operated electrical switch **10**, an electronic current generator **11** and an electro-pneumatic relay **12**.

The pressure-operated electrical switch **10**, in addition to controlling the direction of movement of the probe **6**, also controls a sampling apparatus **13** which permits the transmission of signals indicative of the position of the edge **4** of the glass ribbon to a pneumatic recording apparatus **14** where the signals are recorded.

The nozzle **7** will now be described with reference to FIGURE 2, which is an enlarged cross-sectional view and which shows the nozzle **7** comprising an outer casing **15** coaxial with an inner tube **16**.

The inner tube **16** is connected directly to the pressure-operated electrical switch **10** by a gas line **17** so that the pneumatic signal constituted by a gas pressure within the inner tube **16** is communicated immediately to the pressure-operated electrical switch **10**.

The pressure-operated electrical switch **10** is arranged such that its contacts are open when there is a sub-atmospheric pressure within the inner tube **16**, and its contacts are closed when the pressure in the inner tube **16** is greater than atmospheric pressure. In the ensuing description, a gas pressure greater than atmospheric pressure in the inner tube **16** will be referred to as a positive signal, and a gas pressure less than atmospheric in the inner tube **16** will be referred to as a negative signal.

The outer casing **15** of the nozzle **7** is sealed about the inner tube **16** by appropriate locking means **18** and a conduit **19** connected to a gas line **20** opens into the outer casing **15** as shown in FIGURE 2. The gas line **20** is connected to a source of gas which is inert to the molten metal of the bath **2** at the temperature of the molten metal bath and conveniently there is used a source **21** of gas similar in composition to the protective atmosphere maintained in the headspace over the bath. The gas from the source **21** is arranged to flow through the gas line **20** and conduit **19** and so out of the nozzle **7** comprised by the annular space **22** between the inner tube **16** and the outer casing **15**.

It will be appreciated that, when gas is flowing through the gas line **20**, the conduit **19** and the annular space **22**, an annular jet is continuously emitted from the nozzle **7**. Provided that the gas in the annular jet can escape freely, that is to say there is no object immediately in the path of the emitted gas, the flow of gas from the nozzle **7** will draw gas from the inner tube **16**, thus decreasing the pressure in the inner tube and setting up a negative signal. On the other hand, if there is an object closely in front of the nozzle **7** and obstructing the path of the gas flowing from the nozzle, the escape of this gas is prevented so that there is a build-up of pressure in front of the nozzle **7** and gas is deflected from the object back into the inner tube **16** so that a pressure greater than atmospheric pressure is created in the inner tube **16** and this constitutes a positive signal communicated from the interior of the inner tube **16** to the gas line **17**.

Consequently, if the nozzle **7** is suitably positioned in relation to the surface of the molten metal bath **2** and the glass ribbon **3** on the surface of the molten metal bath **2**, a change from a negative signal to a positive signal may be obtained as the nozzle **7** is traversed across the edge **4** of the glass ribbon **3** in a direction away from the side wall **5** of the structure **1**.

FIGURE 3 shows a preferred arrangement of the probe **6** in which the arm **8** includes a gas reservoir **23** interposed in the gas line **20**. The reservoir **23** damps small variations in the pressure of the gas supplied from the gas source **21** so that a substantially even flow of gas is fed to the nozzle **7** through the conduit **19**.

The probe **6** is sealed into the side wall **5** of the structure **1** (FIGURE 1) so that ingress of air into the structure **1** is prevented. The probe **6** including the gas reservoir **23** is arranged for axial reciprocation by the arm **8** of the pneumatic driving means **9**, the reciprocation taking place in the sealing means in the side wall without ingress of air into the structure **1**.

The operation of the apparatus will now be described commencing from the rest position in which the probe **6** is at the side of the bath near to the wall **5**.

Assuming that the bath atmosphere supply from the source **21** is already applied to the probe **6** and to the gas seal in side wall **5** of the structure **1** and that air is already supplied to the other pneumatic parts of the apparatus, the detecting apparatus is then put into operation by switching on the electrical power. The points at which the air is supplied to the other pneumatic parts of the apparatus will be mentioned in the course of the description.

In the rest position of the apparatus with the nozzle **7** and the probe **6** away from the glass ribbon **3**, there will be a negative signal passed from the inner tube **16** to the line **17** and consequently the contacts of the pressure-operated electrical switch **10** will be open.

The way in which the pressure-operated electrical switch **10** acts in the electrical part of the apparatus is illustrated in FIGURE 4 of the accompanying drawings.

With the contacts of the switch **10** open, the operating conditions of the transistor **24** are determined by the base current drawn out of transistor **24** by the setting of a potentiometer **25**.

The transistor **24** is connected to operate as a miller integrator so that, in the conditions shown in FIGURE 8 with the switch **10** open and electrical power applied, the current flowing through transistor **24** increases linearly.

The linearly increasing current passing through transistor **24** also passes through a coil **27** of the electro-pneumatic relay **12** and the electro-pneumatic relay **12** responds to this increase in current to give a continually increasing air pressure in the output line **28** (FIGURES 1 and 4). A detailed description of the electro-pneumatic relay **12** will be made with reference to FIGURE 7 of the accompanying drawings.

Referring again to FIGURE 1, the output line **28** feeds air pressure to further lines **29** and **30**. Line **29** supplies this increasing air pressure to the sampling apparatus **13** whose operation will be described later.

The linearly increasing pressure in the line **30** operates the driving means **9** to move the arm **8** continually towards the left as seen in FIGURE 1, in a manner which will be described in detail with reference to FIGURE 8 of the accompanying drawings. The continual movement of the arm **8** to the left as seen in FIGURE 1 causes the nozzle **7** of the probe **6** to be moved inwards from the side wall **5** of the structure **1** towards the central part of the bath **2** of molten metal.

During this inward movement of the nozzle **7** it passes over the edge **4** of the glass ribbon **3** with the result that there is a change from a negative signal to a positive signal in the line **17**, and the contacts of the pressure-operated electrical switch **10** close.

The closing of the contacts of the switch **10** connect the base of the transistor **24** (FIGURE 4) to the common line through a potentiometer **31** with the result that the potential applied to the base of the transistor **24** is changed to a lower value which is dependent upon the setting of the potentiometer **31**. This change in the value of the potential applied to the base of the transistor **24**, which is acting as a Miller integrator, causes the current through the transistor **24** to commence to fall at a uniform rate.

The current flowing through the transistor **24** flows also through the coil **27** of the electropneumatic relay with the result that the closing of the contacts of the pressure-operated electrical switch **10** as a result of a change from negative signal to positive signal in the gas line **17** causes a continually decreasing air pressure to be applied to the output line **28** and thence to the line **30** which is connected to the driving means **9**. The change in the air pressure applied to the driving means **9** causes the arm **8** to commence to move to the right in FIGURE 1 (as will be hereinafter described with reference to FIGURE 8) so that the nozzle **7** is moved in a direction away from the centre of the bath **2** towards the side wall **5** of the structure **1**. The movement of the nozzle **7** towards the side wall **5** in FIGURE 1 takes place at a controlled rate determined by the preset value of potentiometer **31** and the setting of potentiometer **25**.

Accordingly the nozzle **7** moves from over the glass ribbon **3** across the edge **4** thereof until it is over the molten metal bath **2**, whereupon there is a change from a positive signal to a negative signal communicated through the gas line **17** to the pressure-operated electrical switch **10**. The contacts of the switch **10** therefore open and, as already described, the nozzle **7** is caused to move back to the left again, Consequently a to and fro motion of the nozzle **7** about the position of the edge **4** of the glass ribbon **3** takes place.

During this to and fro motion of the nozzle **7**, the air pressure in the line **28** oscillates up and down in consequence of the repeated changing over of the contacts of the switch **10**, and the pressure in the line **28** is indicative of the position of the nozzle **7** at any particular time.

In order to record the position of the edge **4** of the glass ribbon **3**, the action of the change-over of the position of the contacts of the switch **10** is utilised to sample the air pressure in the line **28** through the line **29**, the sampling apparatus **13** and an air line **32** in a manner which will now be described.

This description will be made with reference to FIGURES 4 and 5 of the accompanying drawings. FIGURE 5 shows diagrammatically the apparatus used, while FIGURE 4 sets out the electrical circuitry employed in that apparatus.

Referring then to FIGURE 5, the sampling apparatus **13** comprises a first solenoid-operated valve **33** which is supplied with air direct from the line **29**, a line **34** joining the valve **33** to a second solenoid-operated valve **35**, a branch gas line **36** leading off the line **34** and a reservoir **37** at the end of the line **36**. The second solenoid-operated valve **35** controls the output of air to an air-line **32** which leads to the recorder **14**.

The principle upon which the sampling apparatus **13** operates is that the solenoid-operated valve **33** is opened while the second solenoid-operated valve **35** is kept closed. The reservoir **37** is thus charged to the pressure existing in signal line **29**. In practice, the volume of the reservoir **37** is small so that this reservoir may be charged quickly to a pressure precisely the same as the pressure in the signal line **29** in the comparatively short time interval that it takes the nozzle **7** to cross the edge **4** of the glass ribbon **3**. The reservoir **37** therefore becomes charged to the same pressure as exists in the line **29** and, when the first solenoid-operated valve **33** is closed, the pressure in the signal line **29** at that time, which is the time that the nozzle **7** crosses the edge **4** of the glass ribbon, is retained in the reservoir **37**.

The pressure to which the reservoir **37** has been charged is then communicated to the recorder **14** by opening the second solenoid-operated valve **35**. The time for which the second solenoid-operated valve **35** is open is not confined to short limits because the first solenoid-operated valve **33** is closed at this time and will be open again only when the nozzle **7** traverses the actual edge **4** of the glass ribbon **3** in the reverse direction.

Basically the electrical circuit which controls the sampling apparatus **13** comprises a switching circuit **39**, an inverter **40** and a univibrator **41** connected in series, with an output from the switching circuit **39** to the first solenoid-operated valve **33** and an output from the univibrator **41** to the second solenoid-operated valve **35**.

Referring again to FIGURE 4, the parts of the circuit corresponding to the switching circuit **39**, the inverter **40** and the univibrator **41** are indicated thereon.

The operation of this electrical circuit is that, immediately the contacts of the pressure-operated electrical switch **10** close, the transistor **42** has its base connected to the common line via diode **43** so that the current through the transistor **42** is cut off, de-energising the electro-magnetic relay **44** and thus de-energising the first solenoid-operated valve **33**. Since solenoid-operated valve **33** is held open when energised, closing the contacts of the pressure-operated electrical switch **10** will close off solenoid-operated valve **33**.

Switching off transistor **45** produces a current step at the base of the transistor **45** and an inversion of this step at the collector of transistor **45**. This current step is differentiated to produce a positive going pulse which is fed to the base of transistor **46** and triggers the "flip-flop" or univibrator action of the combination of transistors **46** and **47**. Thus transistor **46** which is normally conducting, is switched off at contact closure of pressure operated electrical switch **10**, and transistor **47** switched on for a period dependent on the resistor **48** and capacitor **49**.

Current will then flow through transistor **47**, energising electro-magnetic relay **50**, and hence energising solenoid-operated valve **35** to open for the period set by resistor **48** and capacitor **49**, allowing the air stored in the reservoir **37** to be transmitted to the pneumatic recorder **14**. At the end of this period, transistor **47** reverts to the switched off condition thus closing solenoid-operated valve **35**. It only remains for the opening of the contacts of the pressure-operated electrical switch **10** to leave the circuit ready to be triggered again the next time the contacts of the pressure-operated electrical switch **10** close.

The recorder **14** will now be described with reference to FIGURE 6 of the accompanying drawings. The line **32** is connected to a capsule **51** within which a diaphragm **52** is mounted so that the air pressure in the line **37** is applied to move the diaphragm **52**. The diaphragm **52** is connected by an arm **53** to a beam **54** pivoted at **55** and the movement of the arm **53** is transmitted to a pen **56** by connecting rods **57** pivoted to one another at **58**.

Movement of the diaphragm **52** by a pressure signal impinging thereon from the supply line **32** is transmitted to the pen **56** so that the pen traces on a chart **59**, which is continually rotated on the drum on which it is mounted, a line indicative of the position of the edge **4** of the glass ribbon **3** in relation to the side wall **5** of the structure **1** containing the bath **2** of molten metal.

In use there will be similar probes **6**, each carrying a nozzle **7** acting to determine the position of each edge **4** of the glass ribbon **3**, and there will be similar apparatus connecting each of the probes to the recorder **14** which has two pens each recording the position of one edge of the glass ribbon.

The electro-pneumatic relay **12**, the pneumatic driving means **9** and the pressure-operated electrical switch **10** are based on well-known items of equipment which may be obtained readily on the market. However, for the sake of completeness, a preferred form of each of these items of equipment is illustrated respectively in FIGURES 7, 8 and 9 of the accompanying drawings.

As will be understood from the previous description, the electro-pneumatic relay **12**, which is shown in more detail in FIGURE 7 is a device for converting an electrical current signal into a proportional output air pressure signal and comprises a permanent magnet **61**, a coil **27** mounted on a beam **63** pivoted at **64**, one end of the beam **63** carrying an extension spring **65** having its other end fixed at **66**, and the other end carrying a baffle **67**. An electric current fed to the coil **27** through a connection **68** from the transistor **24** will cause the beam **63** to pivot about the pivot **64** by interaction of the field produced by the current in the coil **27** with the field of the permanent magnet **61**.

The electro-pneumatic relay **12** further comprises a diaphragm assembly **69** on which air delivered to the relay from an appropriate air source through a conduit **70** and a T-junction **71** will impinge. One arm **72** of the T-junction is formed as an outlet through which air supplied through conduit **70** may exhaust, but which may be closed by the baffle **67** carried by the beam **63** when the latter pivots about the pivot **64**. A junction **73** in the conduit **70** also causes air from the air supply to pass to a poppet valve **74**, movement of which by the diaphragm assembly **69** controls the amount of air delivered from the relay **12** through the output signal line **28**.

An increase in the input electrical current to the coil **27** suspended in the magnetic field of the permanent magnet **61** moves the beam **63** in the direction of the air outlet **72** allowing less input air from the air line **70** to bleed through it and thus causing more air to contact the diaphragm assembly **69** and, by the pressure on the diaphragm assembly **69**, to open the poppet valve **74**. The opening of the poppet valve **74** allows air to be delivered through the junction conduit **73** to the air line **28**. A balance will be reached when the force on the beam produced by the input current to the coil **27** is balanced by the force on the beam produced by the air issuing from the jet **72**.

As already described, the pressure of air in the air line **28** is fed to the sampling apparatus **13** through an air line **29** and to the pneumatic driving means **9** through the air line **30**.

The pneumatic driving means **9** is illustrated in FIGURE 8.

The pneumatic driving means **9** comprises a power cylinder **75** in which the end of the arm **8** is mounted in a piston head **76**. The power cylinder **75** is connected to a source of air supply (not shown) through air lines **77** and **78**, which enter at opposite ends of the power cylinder **75**, via a pilot valve **79** and air line **80** to which the source of air is connected.

The operating part of the pilot valve **79** consists of a conecting rod **83** carrying two slipper blocks **84** and **85** so arranged that, as the connecting rod **83** is reciprocated, the slipper blocks **84** and **85** will cause air pressure to be applied selectively from the air line **80** either to the air line **78** or to the air line **77**.

The connecting rod **83** is mounted in the actuating face or end wall **82** of a bellows **87**. The bellows **87** is arranged to be supplied with air pressure from the air line **30**. Freely mounted on the flexible connecting rod **83** is a transverse member **88** which is an annular disc and is effectively an end cap arranged to bear against one end of a compression spring **89**, the other end of which bears against the actuating face or end wall **82** of the bellows **87**. Part of the transverse member **88** also acts on one arm **90** of a crank **91** which is pivoted at **92**, and the second arm **93** of which acts as a cam follower bearing against a cam surface **94**. The cam surface **94** is mounted on the arm **8** and accordingly moves with the arm **8**.

The spring **89** is treated in a discussion of the operation of the pneumatic driving means **9** as a substantially rigid member, the spring being provided to take up play between the arm **90** of the crank **91** and the actuating face or end wall **82** of the bellows **87** and to be compressed slightly as the forces acting increase. Consequently, the system which forms the pneumatic driving means **9** is essentially a two force system, the forces being the pneumatic signal from the air line **30** and the balancing force from the crank **91**, both forces being applied to the actuating face or end wall **82** of the bellows **87**.

In the rest position of the apparatus when no electrical energy is applied to the system there is no air signal applied to the air line **30**. In practice a small air pressure in the air line **30**, and consequently in the bellows **87**, is equivalent to no signal.

This low signal or air pressure applied to the bellows **87** is balanced by a low force applied by the arm **90** of the crank **91** when the cam follower arm **93** is at a low position on the cam surface **94**. With these two forces in balance, the connecting rod **83** is in an equilibrium position in which the slipper blocks **84** and **85** prevent air pressure being supplied from the air line **80** to the respective air lines **77** and **78**. The piston head **76** therefore remains in its rest position near the right hand of the power cylinder **75** as shown in FIGURE 8.

As soon as the apparatus is put into operation and electrical energy is applied to the system, the increasing signal (i.e. the gradually increasing air pressure) is applied to the bellows **87**. The connecting rod **83** is therefore displaced to the right so that air pressure from the supply line **80** is connected, when the pilot valve **79** is opened, to the air line **78** by reason of the movement of the slipper block **85** to open the inlet to the air line **78**. The force thus applied to the piston head **76** causes this to move to the left, as shown in FIGURE 8, so that the whole arm **8** tends to move in the same direction and the probe **6** moves away from the side wall of the tank structure to seek the edge **4** of the glass ribbon.

The movement of the arm **8** to the left means that the cam face **94** is also moved to the left with the result that the cam follower arm **93** rides up the cam face **94** and the crank **91** is caused to turn about its pivot **92** in an anticlockwise direction, and the pressure exerted by the arm **90** on the transverse member **88** and hence on the actuating face or end wall **82** of the bellows **87** is increased.

If the air pressure applied to the bellows **87** from the air line **30** were not continually increasing, the force applied to the actuating face or end wall **82** of the bellows **87** as a result of movement of the cam face **94** would become equal to the increased air pressure in the bellows **87**, so that equilibrium would be restored with the return of the actuating face or end wall **82** of the bellows **87** to its neutral position, thus closing the pilot valve **79**, and preventing further movement of the piston head **76** in the power cylinder **75**.

In practice, however, the input signal from the air line **30** to the bellows **87** is continually increasing until either the probe reaches its fullest extent (i.e. the piston head **76** is moved fully to the left in the power cylinder **75** as seen in FIGURE 8), or until the nozzle **7** of the probe **6** passes over the edge **4** of the glass ribbon. Consequently, the actuating face or end wall **82** of the bellows **87** remains displaced to the right until either of these conditions is reached. When the nozzle **7** passes over the edge **4** of the glass ribbon the input signal to the air line **30** is changed, as already described, with the result that the actuating face or end wall **82** of the bellows **87** is moved to the left, as seen in FIGURE 8, and the piston head **76** is caused to start movement to the right so that the probe **6** and the nozzle **7** are withdrawn from over the glass ribbon.

This movement takes the nozzle **7** clear of the glass ribbon, when the action repeats and an oscillating movement of the nozzle **7** continues, due to the inertia of the system. With a low inertia system the nozzle **7** can be made to "lock" onto the edge of the glass ribbon, the pilot valve **79** remaining closed. An advantage of keeping the nozzle oscillating is that the continual movement prevents the nozzle from sticking.

Referring now to FIGURE 9 of the accompanying diagrammatic drawings, the pressure switch **10** comprises a limp diaphragm **101** on which a pneumatic signal delivered through the gas line **17** will impinge, a plunger **102** mounted on the diaphragm **101** and abutting, at about its centre, a switching beam **103** pivoted near one end at **104**, the other end carrying an electrical contact **105**. A second electrical contact **106** is mounted above and close to the electrical contact **105** and is arranged so that, as the diaphragm **101** is deflected upwardly under the pressure from a gas signal, the contacts **105** and **106** close and complete an electrical circuit. The contacts **105** and **106** therefore comprise the contacts **10** shown in FIGURE 4.

An adjuster spring **108** is included in the pressure switch **10** to predetermine the strength of the gas signal required to close the electrical contacts **105** and **106**.

Referring to FIGURES 1 and 4, there is shown a nozzle guard switch **99** which is provided to prevent damage arising from large lumps of glass present near the edge of the glass ribbon, or, alternatively, moving down the bath separately from the glass ribbon. When such a lump of glass impinges against the nozzle **7** of the probe **6**, the whole probe **6** rotates and in rotating it actuates the nozzle guard switch **99** which connects the base of the transistor **24** directly to the common line, so that current through the transistor **24** reduces linearly and the probe **6** is caused to retract. When the probe **6** is clear of the glass, the nozzle **7** and the probe will rotate under the action of a return system (not shown), for example a spring, back to their vertical position. The contacts **99** will then open again so that the transistor **24** will again provide a linearly increasing current and the probe **6** will be advanced towards the edge of the glass ribbon in a direction away from the side of the tank structure.

In the embodiment of the invention so far described, the apparatus is employed to obtain a record of the position of the edge of the glass ribbon in the form of a permanent record on paper. In addition or alternatively, a temporary visual indication of the position of the edge **4** of the glass ribbon **3** can be obtained, and this indication can be used by an operator to effect a change in the conditions of operation of the process in order to restore the edge of the glass ribbon to a desired position.

Alternatively the arrangement according to the invention can be employed in a fully automatic system so that any departure of the edge **4** of the glass ribbon from its desired position, a given distance from the side wall of the tank structure, will initiate a correction to restore the edge **4** of the glass ribbon to the desired position. In this case the sampling apparatus **13** is arranged to give an output to control a steering device, for example a carbon fender, which acts to push the glass ribbon towards the centre of the bath when the edge of the glass ribbon moves too near to the side wall of the tank structure. Alternatively the steering correction could be effected by a restrictor tile fitted with a heating control.

More particularly according to this aspect, the invention provides a method of correcting when the glass ribbon departs from a desired width. The embodiment of the invention which will now be described with reference to FIGURE 10 includes a means for obtaining, from the sensing of the two edges of the glass ribbon, an indication of the width and then using any departure of this indication from the desired width to alter one or more of the conditions under which the glass ribbon is formed to make the necessary correction.

Referring then to FIGURE 10, there is shown a plan view of the apparatus for manufacturing a ribbon of glass by delivering molten glass to a bath of molten metal, for example tin or an alloy of tin having a specific gravity greater than that of glass. The molten glass is delivered to a bath **120** of molten metal from a spout **121** and the rate of flow of the molten glass down the spout **121** is controlled by a tweel **122**. The molten glass is allowed to flow freely on the bath of molten metal to form a ribbon **123** of glass, and the ribbon **123** of glass is withdrawn by taking it up from the surface of the bath **120** of molten metal by appropriate rollers **124** which lead to the lehr in which the ribbon of glass is annealed.

The rollers **124** along which the ribbon of glass is advanced after it has been removed from the bath **120** of molten metal apply a tractive force to the ribbon of glass as this is formed on the bath of molten metal, and an alteration in the speed of the rollers **124** is a convenient method of changing the width of the ribbon **123** of glass formed on the bath.

Indicated diagrammatically in FIGURE 10 by the arrows **127** and **128** are probes which are similar to the probe **6**, and each of which tests for the position in relation to the side wall **5** of one edge of the glass ribbon **123** at a position on the bath **120** where the ribbon is being formed from the layer of molten glass developed on the bath after delivery from the spout **121**. The block diagrams **129** and **130** indicate the apparatus in accordance with the invention and comprise all the apparatus shown in FIGURE 1 and external to the tank structure containing the bath of molten metal, with the exception of the recorder **14**. Two outputs are taken from each of the apparatus **129** and **130**, the first output from each being fed to a recorder **14** similar to that already described.

The second output from each of the apparatus **129** and **130** is fed to a respective input of an averaging relay **131**. The averaging relay is of a known type, for example it may be of a diaphragm type such as a Kent air-operated controlling unit.

Conveniently the arrangement including the averaging relay **131** works on the system that, when the respective edges of the glass ribbon are in positions equivalent to the desired width of the glass ribbon, equal outputs are applied from the apparatus **129** and **130** to the respective inputs of the averaging relay, and no output is obtained therefrom. However, when one of the edges of the glass ribbon departs from its desired position and the other edge does not make a similar departure, the respective inputs to the averaging relay **131** are no longer equal. The averaging relay **131** then gives an output indicative of the departure from the desired width of the glass ribbon, this output appearing in output line **132**.

The output indicative of the departure of the ribbon width from a desired value is fed along the output line **132** to a pneumatic recorder controller **133** (a brief description of one form of pneumatic recorder controller will be made with reference to FIGURE 12 of the accompanying drawings).

Any input signal from the line **132** results in the pneumatic recorder controller **133** giving a mechanical correction signal which is fed to a valve **134**, conveniently a hydraulic valve, which controls the position of the tweel **122**.

If the width of the glass ribbon being formed is too small, then the correction signal applied by the pneumatic recorder controller **133** to the valve **134** will cause the tweel **122** to be raised to permit a greater mass of glass to flow to the bath **120** of molten metal. The delivery of a greater mass of molten glass to the bath causes the width of the glass ribbon formed to be increased. Conversely, if the width of the glass ribbon **123** formed on the bath **120** of molten metal is found to be too great, then the pneumatic recorder controller **133** will give a mechanical correction signal to the valve **134** to cause the mass of molten glass delivered to the bath of molten metal to be decreased.

An alteration in the control of the mass of molten glass delivered to the bath can itself impart any correction necessary in order to obtain from the bath **120** a ribbon of glass of desired width, but alternatively other alterations in the conditions under which the ribbon is formed may be used for the same purpose, and preferably more than one variable is altered in order to ensure that a ribbon of glass taken from the bath has a desired width and a desired thickness.

In FIGURE 10 of the accompanying drawings, the correction signal given by the pneumatic recorder controller **133** is shown also to be applied to a speed controller **135** which adjusts the speed of a motor **136** (conveniently a D.C. motor) which drives the rollers **124** through an appropriate gearing **137**.

In general when the width of the glass ribbon formed on the bath is less than the predetermined value, the correction signal applied to the speed controller **135** by the pneumatic recorder controller **133** acts to reduce the speed of the motor **136** so that the rollers **124** rotate more slowly to advance the glass ribbon at a slower speed. The tractive force applied during the formation of the glass ribbon **123** is therefore reduced and the width of the glass ribbon formed is allowed to increase.

Alternatively when the width of the glass ribbon is found to be too great, the output given by the pneumatic recorder controller **133** acts to make the speed controller **135** increase the speed of the motor **136** so that the rollers **124** advance the glass ribbon more quickly and apply a greater tractive force to reduce the width of the glass ribbon at the time of its formation on the bath **120** of molten metal.

The controlling action just described for the speed of the rollers **124** is the control which would be applied to obtain a desired width of glass ribbon if a variation in the rollers **124** was used alone to alter the width of the glass ribbon. In practice, however, the thickness of the glass ribbon is generally of the primary importance and a desired width for the glass ribbon is a matter of manufacturing convenience rather than an essential pre-requisite for the product. As the speed of the rollers **124** and the tractive force exerted by them has a particular controlling influence on the thickness of the glass ribbon as well as on its width, in general, some other control, for example the position of the tweel **122**, has to be used in conjunction with an alteration in the speed of the rollers **124** in order to obtain a glass ribbon of desired thickness and width.

Additionally, apparatus in accordance with the present invention may be used to alter the temperature of the molten glass supplied to the bath in order to provide a correction when the width departs from a desired value. Such a control of the temperature of the molten glass delivered to the bath may be used on its own as a control, or in conjunction with one or more other variables, such as the two variables already described with reference to FIGURE 10.

Desirably the speed controller **135** is a Ward-Leonard arrangement (see FIGURE 11) associated with a D.C. motor **136** and the control of the speed of the motor is effected by causing the mechanical correction signal to change the setting of a variable resistor **138** in a motor generator set feeding the armature current of the motor **136**, the field windings of which are fed from a constant current supply V. The motor generator set comprises a shunt motor **139** mechanically coupled to a drive dynamo **140**, and the change in the setting of the variable resistor **138**, by altering the armature current of the motor **136**, effects a correcting adjustment in the speed of the motor **136**.

Referring now to FIGURE 12 there is shown schematically a suitable apparatus for use as the pneumatic recorder controller **133**. In FIGURE 12, there is shown a mechanical arrangement comprising pointers **141** and **142**, the first of which is preset and the second of which varies according to the pneumatic output signal applied at **143** from the line **132** leading from the averaging relay **131**. The pointers **141** and **142** are respectively pivoted at **144** and **145** and are connected to a linkage comprising members **146, 147, 148, 149, 150, 151** and **152**. This linkage is also pivoted at **153** and **154**, the member **152** which is pivoted at **154** being a flapper for controlling the rate at which air is emitted from a nozzle **155** to which air is supplied from an air line **156**, as its position in relation to the nozzle **155** alters in accordance with the pneumatic force applied at **143**.

When a predetermined force is applied at **143** in the direction of the arrow shown acting at that point, the apparatus remains in its normal balanced or rest position, and the quantity of air permitted to escape from the nozzle **155** is such that the pressure applied to a diaphragm **157** acts through a member **158** to control the valve **134** at a predetermined setting.

However, when the force applied at **143** in the direction of the arrow increases, the pointer **142** is caused to move downwards and the linkage comprising members **150** and **149** moves up, as seen in FIGURE 12, with the result that the mid-point of member **149** moves up, the member **151** is also moved in the same direction, and the flapper **152** is moved about its pivot **154** in a direction away from the nozzle **155**. Consequently more air is able to escape from the nozzle **155** and the pressure applied to diaphragm **157** decreases so that the member **158**, controlled by the diaphragm **157**, alters the setting of the valve **134**.

The mechanism will move in the reverse direction when there is a decrease in the force applied at **143** or if the force applied at that point is a force in the opposite direction to the arrow shown in FIGURE 12, with the result that a greater pressure is exerted on the diaphragm **157** and the setting of the valve **134** is altered in the reverse direction through the action of member **158**.

In the earlier description, the sampling apparatus has been described in FIGURES 4 and 5 as an electro-pneumatic sampling apparatus. Alternatively the sampling apparatus could be a mechanical/pneumatic component enabling the univibrator **41** and solenoid-operated valves **33** and **35** to be omitted. A simplified form of this alternative mechanical/pneumatic component is shown in FIGURE 13.

In FIG. 13 the signal which is an air pressure indicative of the position of the probe in relation to the side wall **5** of the tank structure is shown applied from the air line **29** to a reservoir **161** via a line **162**. This position obtains so long as a member **163** carrying the slipper blocks **164** and **165** remains in the position shown in FIGURE 13 where the line **162** is permitted to be connected directly to the reservoir **161**.

At the instant that the contacts **10** close, the member **163** is moved to the left so that the reservoir **161** is connected to the line **166** instead of to the line **162**. In FIGURE 13, the line **166** is shown as being connected directly to a recorder **14** but equally it could be connected to one input of an averaging relay **131**.

The mechanism under control of the contacts **10** and causing the movement of the member **163** may be solenoid operated or mechanically operated.

In the embodiments of the invention which have been described, the method and apparatus according to the present invention are used in determining the position of an edge of a glass ribbon advancing along a bath of molten metal and in controlling the position of the edge or alternatively controlling the width of the glass ribbon on the bath of molten metal. Alternatively, however, the information of the position of the edge of the glass ribbon may be used to control the positioning of apparatus for performing some later operation of the glass ribbon, for example in cutting the edge of the glass ribbon or for cutting of the glass ribbon into sheets. The information may further be used for controlling a polishing action on the surface of the glass ribbon if such polishing action is desired to be undertaken.

Instead of determining the position of the glass ribbon on a bath of molten metal, the apparatus may be employed for determining the position of the edge of a glass ribbon as the ribbon is advanced through an annealing lehr, and similarly the information may be used for controlling a subsequent operation on the glass ribbon.

The application of the invention, however, is not limited to the manufacture of glass in ribbon form and may be applied in any industry in which sheet material is manufactured in ribbon form and it is desired to determine the position of the ribbon obtained or the width of the ribbon obtained.

I claim:

1. Apparatus for determining the position of an edge of advancing ribbon, the apparatus comprising pneumatic edge sensing means including an inner tube located co-axially with an outer tube to define an annular nozzle, said nozzle being disposed at a position which is substantially aligned with the edge of the advancing ribbon, gas delivery means for supplying gas under pressure to the space between said inner and outer tubes whereby an annular stream of gas is discharged therefrom, and a pressure sensitive switch responsive to the state of the back pressure set up in the said inner tube, driving means for moving the pneumatic sensing means laterally with respect to the advancing ribbon, control means connected to said drive means and arranged to control the operation of said driving means and to produce a signal indicative

of the position of the pneumatic sensing means in relation to the edge of the advancing ribbon as the pneumatic sensing means is moved by the said driving means laterally of the advancing ribbon, and sampling means connected to said pressure sensitive switch for sampling the signal produced by said control means at the instant that said pneumatic sensing means experiences a change in the state of the back pressure in the said inner tube consequent upon the movement of the said pneumatic sensing means over the edge of the said advancing ribbon.

2. Apparatus for determining the position of an edge of an advancing ribbon of sheet material, the apparatus comprising pneumatic edge sensing means including an inner tube located co-axially with an outer tube to define an annular nozzle, said nozzle being disposed at a position which is substantially aligned with the edge of the advancing ribbon, gas delivery means for supplying gas under pressure to the space between said inner and outer tubes whereby an annular stream of gas is discharged therefrom, and a pressure sensitive switch responsive to the state of the back pressure set up in the said inner tube, pneumatic driving means arranged to move the pneumatic sensing means laterally with respect to the advancing ribbon, electro-pneumatic control means connected to said drive means and arranged to produce a pneumatic signal which controls the operation of said driving means and which is indicative of the position of the pneumatic sensing means in relation to the edge of the advancing ribbon as the pneumatic sensing means is moved by the said pneumatic driving means laterally of the advancing ribbon, electrically operated sampling means in electrical connection with said pressure sensitive switch and in pneumatic connection with said electro-pneumatic control means for sampling the pneumatic signal produced by said electro-pneumatic control means at the instant that said pneumatic sensing means experiences a change in the state of the back pressure in the said inner tube consequent upon the movement of the said pneumatic sensing means over the edge of the said advancing ribbon, and detector means pneumatically connected to said sampling means for analysing, indicating or recording the pneumatic signal passed thereto by said sampling means and indicating the position of the edge of the advancing ribbon.

3. An apparatus according to claim **2** wherein the said pressure sensitive switch is arranged to control the electronic current generator which in turn operates to change the condition of the said electro-pneumatic control means, whereby the pneumatic driving means is reversed to move the pneumatic sensing means in the opposite direction in relation to the edge of the advancing ribbon.

4. Apparatus for determining the width of a glass ribbon manufactured on the surface of a bath of molten metal, the apparatus comprising duplicate apparatus according to claim **2** for determining the position of respective edges of the advancing ribbon, comparator means connected to the output of each said apparatus for comparing the distance between the indications of the respective edges of the advancing ribbon with a predetermined value for the width of the advancing ribbon and a pneumatic recorder controller dependent upon the output of the said comparator means for changing one condition under which the glass ribbon is formed in a manner to correct for the departure from the said predetermined width.

5. Apparatus according to claim **4** wherein the pneumatic recorder controller is arranged to change the rate at which the glass ribbon is withdrawn from the bath of molten metal.

6. Apparatus according to claim **4** wherein the pneumatic recorder controller is arranged to control the rate of delivery of glass to the bath of molten metal.

7. Apparatus according to claim **4** wherein the pneumatic recorder controller is arranged to vary the temperature of the glass supplied to the bath.

8. A method of manufacturing flat glass in ribbon form on a bath of molten metal, comprising delivering glass at a controlled rate to the bath, advancing the glass in ribbon form along the bath, projecting an annular stream of gas towards one edge of the advancing ribbon of glass, sensing the state of the back pressure existing in the zone surrounded by the annular stream, simultaneously moving said annular stream laterally with respect to the advancing ribbon across said one edge of the ribbon, producing a signal which controls the lateral movement of the annular stream and which is indicative of the position of said stream in relation to the edge of the advancing ribbon as the annular stream is moved laterally of the ribbon, and controlling the manufacture of the advancing glass ribbon in response to that signal at the instant that there occurs a change in the state of the back pressure in said zone surrounded by the annular stream consequent upon movement of the annular stream over the edge of the advancing ribbon to correct for any departure in said edge from a predetermined position.

9. A method of manufacturing flat glass in ribbon form on a bath of molten metal, comprising delivering glass at a controlled rate to the bath, advancing the glass in ribbon form along the bath, projecting respective annular streams of a gas inert to the molten metal downwardly towards the edges of the advancing ribbon of glass, sensing the state of the back pressure existing in the zones surrounded by those annular streams, simultaneously moving each said annular stream laterally with respect to the advancing ribbon across the respective edge of the ribbon, producing two signals which control the lateral movement of the annular streams and which are indicative of the positions of said streams in relation to the edges of the advancing ribbon as the annular streams are moved laterally of the ribbon and thereby indicative of the width of the ribbon of glass, and controlling the formation of the ribbon on the bath in response to those signals at the instant that there occurs a change in the state of the back pressure in the said zones surrounded by the annular streams consequent upon movement of the annular streams over the respective edges of the advancing ribbon so as to correct for any departure of the width of the advancing ribbon from a predetermined width.

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