MASS-FLOW RATE CONTROL

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FIG. 1

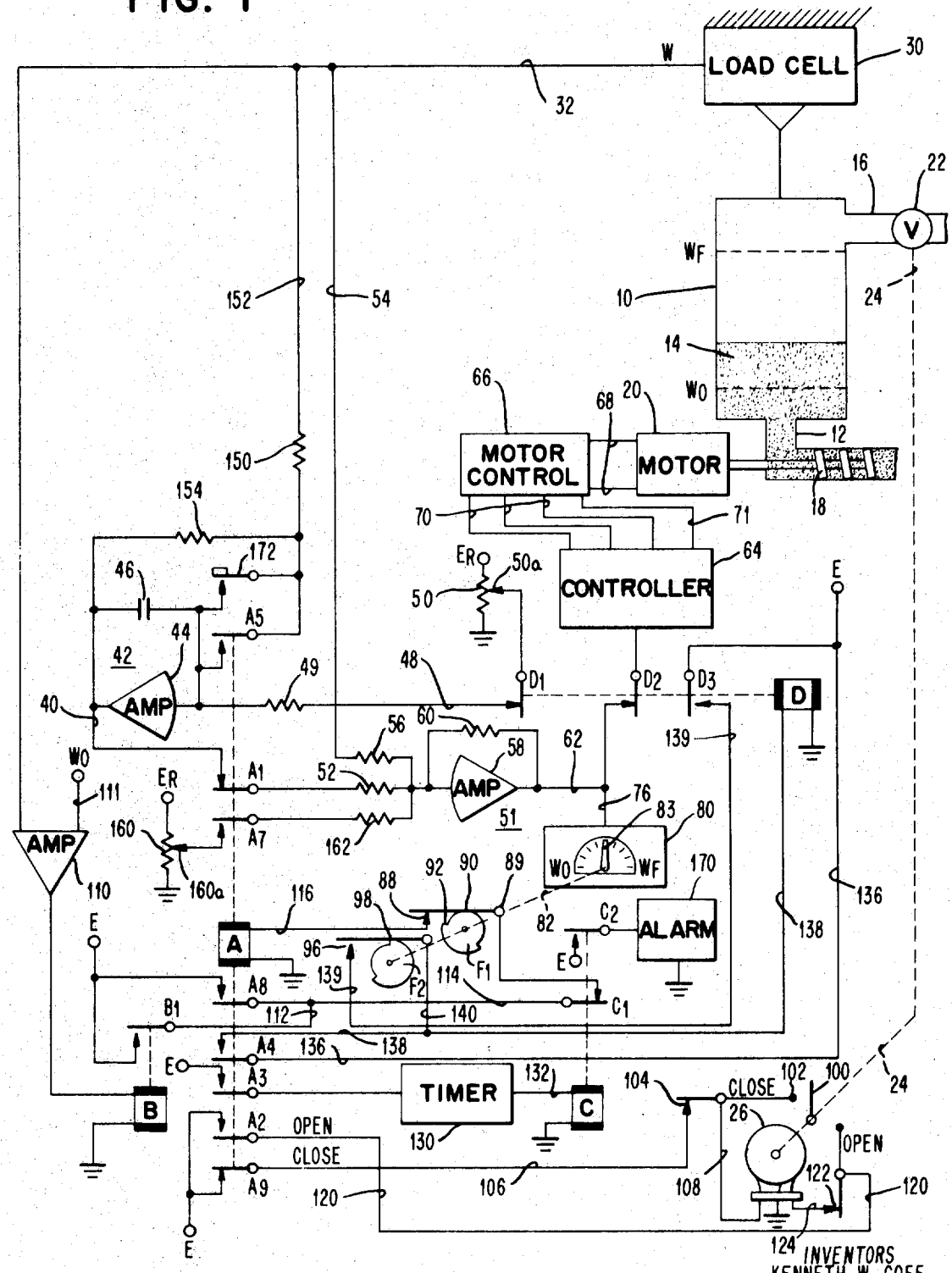

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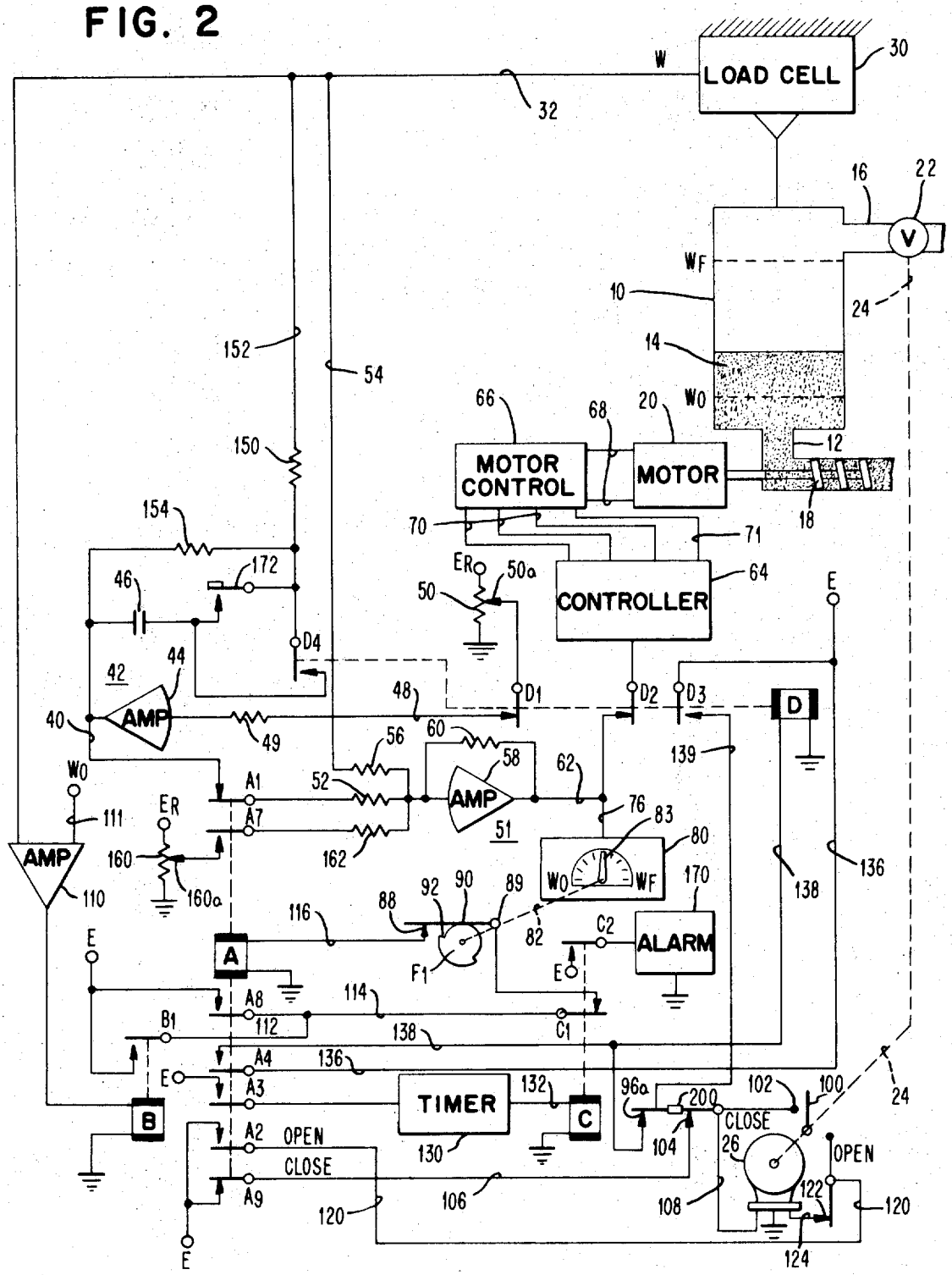
FIG. 2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MOTOR
CONTROLLER
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AMP
AMP
ALARM
TIMER
OPEN
CLOSE
OPEN
CLOSE
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D1
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C1
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F1
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MASS-FLOW RATE CONTROL

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U.S. Cl. 222—58 3 Claims

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

ABSTRACT OF THE DISCLOSURE

A constant decreasing set point for the mass in a container is established by an integrating amplifier having a preset constant input signal. The existing mass in the container is measured by a load cell and the measured value is compared with the changing set point. Any difference resulting from the comparison provides an error signal for controlling the discharge of material from the container so as to maintain the desired constant discharge rate. When the mass in the container is reduced to a minimum, rapid refilling is initiated and the discharge during refill is maintained constant at the value existing before refill was initiated. When refill is completed or after a fixed time sufficient for refill has elapsed, the controlled discharge is resumed without a bump since the capacitor of the integrating amplifier is maintained at a discharge such that no error signal exists during refill.

This invention relates to apparatus for the control of mass-flow rate and particularly to apparatus for controlling the mass-flow rate of a material being discharged from a storage bin or container by controlling the weight of the container to follow a decreasing set point value.

The problem of providing a continuous feed of material to a process is sometimes complicated by the nature of the material. For example, some materials such as powders or rock do not lend themselves to having their rate of flow to the process closely controlled by ordinary flow control apparatus. In such cases, the rate at which the material is fed to the process can be controlled by controlling the weight of the material in an auxiliary storage container to follow a decreasing set point value, usually a constantly decreasing one.

In the past, apparatus of this type has been so constructed as to require manual intervention for the maintenance of control or for the resetting of the controller whenever conditions in the process were of an extraordinary nature. Likewise, the prior art devices were not so constructed as to maintain the control effective for a maximum percentage of the time period in each cycle of operation.

It is therefore an object of this invention to provide an improved control system for controlling the mass-flow rate of material from a storage bin or container.

More particularly, it is an object of this invention to provide a controller for controlling the mass-flow rate of a material from a container so that the weight or mass of the material in the container is varied at a desired rate and so that the feed of material from the container can continue during refilling with a bumpless automatic resumption of control of the feed being effected after full or partial completion of the refilling operation.

It is a further object of this invention to provide a control of the mass-flow rate of a material from a container which is alternately emptied and refilled during a

complete cycle so that the mass-flow rate of the material from the container is controlled during the emptying portion of the cycle and is maintained susbtantially constant during the refilling portion of the cycle.

In accordance with one form of this invention, there is provided a control system for controlling the mass-flow rate of a material from a container which is subject to being alternately emptied and refilling during its cycle of operation so that the mass-flow rate is controlled during the emptying portion and maintained substantially constant during the refilling portion of the cycle. The control includes a means for producing a first signal which is representative of the measured value of the mass or weight of the material in the container from which the mass-rate flow is to be controlled. A second signal which is continuously changing in magnitude during the discharge portion of the cycle is produced by another means. This second signal is representative of a continuously decreasing set point value for the mass of material in the container. There is then provided a means which is responsive to the difference between the first and second signals for controlling the mass-rate flow of the material being discharged from the container so as to tend to maintain the difference between those signals at a zero value. When the mass in the container reaches a predetermined minimum value, the refilling portion of the cycle starts. The refilling continues until the container has a mass or weight which is of a predetermined maximum value. The apparatus also includes a means operable during the refilling cycle for maintaining the mass-flow rate of the material from the container at a substantially constant value. In addition there is included a means operable to maintain the second signal at a value corresponding to the first signal while the container is being refilled. Upon completion of the refilling cycle, resumption of control of the discharge from the container is effected in response to means which are operable upon completion of the refilling cycle. With the resumption of control, the discharge of the material from the container is again controlled by the controller to a value such that the difference between the first and second signals is maintained as nearly as possible to a zero value as the setpoint or second signal is continuously decreased in value.

A better understanding of the present invention may be obtained from the following description in connection with the drawings in which like parts in the several drawings have like reference characters and in which:

FIG. 1 is a circuit diagram showing one form of the invention, and

FIG. 2 is a circuit diagram of a system similar to that in FIG. 1 but with several variations which change slightly the mode of operation.

With reference to FIG. 1, the container **10**, which may be constructed as a large bin, has at the bottom a discharge duct **12** from which the material **14** contained within the container **10** is discharged. The bin or container **10** also has a refill duct **16** through which the material **14** is caused to flow at a rapid rate during the refilling operation.

As shown in FIG. 1, the discharge of the material **14** from the container **10** is effected by a screw-feeding device **18** which is rotated by motor **20**. This type of discharge device or other types such as star feeders may be necessary, for example, where the material **14** is a powdery substance or a rock-like substance. In some applications the material **14** may be other than powder or rock-like substance in which case the discharge device could be any of a number of suitable devices for effecting a discharging of the material from the container **10** in a controllable fashion.

In the refill duct **16** there is shown diagrammatically a alve **22** which for the purposes of this description will be ssumed to be a suitable type of valve which can be pened by the mechanical coupling **24** which is a shaft otated by motor **26** so that the material **14** may be forced nto the container **10** at a rate which is desirably as rapid s can be readily obtained. A fast refill of the container **0** is desirable so that the mass-flow rate from the discharge duct **12** can be maintained under control for a naximum percentage of the total time period of each ycle of operation. For the purposes of this description a ycle of operation includes two portions, namely a discharge portion during which period the material **14** is eing discharged from the container **10** through duct **12** nd a refill portion during which the material **14** is being orced into the container **10** through duct **16**. It will be vident from the following description that the discharge nrough the duct **12** is continued even during the refilling ortion of the cycle since process requirements usually equire that the material **14** be provided at a substanally continuous rate and the processes of the type to hich the present control is applicable are usually not of he type which can be interrupted for the refilling portion f the cycle.

As has been previously mentioned, the mass-flow rate f the material **14** from the container **10** is controlled durng the discharge portion of each cycle of operation by naintaining control of the mass of the material **14** in the ontainer **10** so that it follows a constantly decreasing set oint value. To provide such a control, it is necessary nat the mass or weight of the material **14** be constantly neasured. In FIG. 1 this measurement is made by load ell **30** which is so arranged that it produces a signal on ne **32**, signal W, which is continuously related to the nass or weight of the material **14** in the container. Since he weight of the container **10** remains constant, the ignal W can easily be compensated for the weight of he container **10**. The load cell **30** may be any of a number f devices used for producing electrical signals proporonal to the weight of a container. The load cell may, or example, include strain gauges and the necessary asociated circuitry.

For the purposes of illustration, let it be assumed that he level of the material **14** in container **10** is somewhere etween a lower minimum lever representative of the ninimum mass W_o to which the mass in container **10** will e allowed to go before a refilling operation is begun and he maximum value, W_f, to which the container is refilled s quickly as possible after the mass has reached the ninimum value W_o. When the material level in the conainer **10** is somewhere between W_o and W_f, as shown in 'IG. 1, the motor **20** is operated by the control system to otate the screw type discharging device **18** so as to mainain the mass-flow rate through the exit duct **12** at the lesired value.

The desired value or set point for the mass-flow rate s established on line **40** at the output of an operational mplifier **42**. Amplifier **42** includes the high-gain amlifier **44** and a feedback capacitor **46** so as to provide at ts output, which is connected to line **40**, a signal which s the integral of the input from line **48** into the input esistor **49** of amplifier **42**. It will be evident that a contantly decreasing set point value may be established by he output of amplifier **42** on line **40** if a constant signal s maintained on the input line **48**. The constant signal n line **48** is shown as being established by the position f the movable contact **50a** of potentiometer slidewire **50** vhich is connected at one terminal to a reference potenial E_R and at its other terminal to ground. The adjustable ontact **50a** is connected to line **48** through relay contact D_1 which will at this time be closed. A non-linear or a liscontinuous change in the set point value may be estabished by a programmed change in the position of contact 50a as desired.

The set point value represented by the signal on line **40** as established by a fixed position for contact **50a** is fed to operational amplifier **51** by way of the closed relay contact A_1 and input resistor **52** of amplifier **51**. The other input through amplifier **51** which is effective at the same time is input signal W from line **32** which is fed through line **54** and input resistor **56** to amplifier **51**. It will thus be evident that amplifier **51** which includes the high gain amplifier **58** and a feedback resistor **60** is effective to compare the signal W on line **54** with the set point established on line **40** and produce on output line **62** a signal indicative of the difference between the set point and the signal W which is indicative of the mass of material **14** in container **10**.

The signal on line **62** is connected through the normally closed relay contact D_2 to controller **64** which is in turn connected to motor controller **66** so that the motor controller **66** may by virtue of the connecting line **68** control the speed of motor **20** so as to tend to discharge the material **14** at a rate which will maintain the signal on line **62** as close to zero as possible by maintaining W at the set point.

As shown in FIG. 1, the controller **64** is connected for both forward and reverse operation of the motor control **66** by the three lines **70** and the motor control **66** is likewise connected to provide a feedback over line **71** to controller **64**. The controller **64** may be any one of a number of well known types of controllers which are capable of accepting an error signal as an input and providing an output for positioning a motor control which may, for example, include a motor-operated rheostat capable of controlling the speed of motor **20**.

The signal on line **62** is also fed by way of line **76** to an indicator **80** which may be of the circular type as shown in FIG. 1. The indicator **80** of FIG. 1 may have its scale covering a 180° span. Indicator **80** includes on shaft **82**, connected to rotate with the indicating pointer **83**, cams F_1 and F_2. The cam F_1 is so shaped that when the indicating pointer **83** reaches the full scale point, marked W_f, the contacts **88** are opened by virtue of the pivoting of the upper contact about its pivot point **89** when the cam surface **90** rides up on the shoulder **92** of cam F_1. The cam F_1 is so designed that the contacts **88** are maintained closed over the full range of the indicating pointer **83** between W_o and W_f at the upper end and the contacts are separated only when the indicator **83** reaches W_f. The contacts **88** are under no circumstances separated when the indicator **83** is in the lower portion of the scale.

The cam F_2 is so shaped that the contacts **96** are maintained closed when the indicating pointer **83** is in the upper half or right-hand portion of the scale and contacts **96** are open whenever the indicator **83** has dropped to the mid-point on the scale, or below. Contacts **96** are operated by a pivot cam follower **98** in a manner similar to that described for the operation of the contacts **88** by cam F_1. The particular function which is carried out by the contacts **88** and **96** will be described in a subsequent portion of this description.

When the material **14** in container **10** is at a level between W_o and W_f the valve **22** is closed and the limit switch arm **100** rotated by shaft **24** of motor **26** would be positioned against the limit switch operator **102** so as to have opened contacts **104**, disconecting the line **106** from line **108**, so that current can no longer be supplied to motor **26** to move the valve in a "close" direction. When the valve is being moved in a "close" direction, current is normally supplied from a potential source E to normally closed contacts A_9 to line **106** and through the closed contacts **104** to line **108** and the "close" windings of motor **26**.

When the level of the material **14** in container **10** reaches an approximate level indicated as W_o at which the mass in container **10** will have reached a value W_o, the signal on line **32** will be representative of a mass W_o. The signal on line **32** is compared at relay amplifier **110** with the present signal W_o supplied on line **111** and when

the signal on line **32** is equal to that on line **111** or is below that level, it is an indication that the mass of the material in the container **10** has decreased to the minimum point and that a refilling of the container **10** is required.

To begin the refilling operation, the relay amplifier **110** actuates relay B so as to make the normally open relay contact B_1 which connects the potential source E through line **112**, line **114**, the normally closed contact C_1 and the closed contacts **88** to connect relay A for energization. as shown in FIG. 1, the relay A has one terminal connected to line **116** and the other connected to ground.

The energization of relay A causes a number of changes in the control circuit which will now be explained. Contact A_8, for example, will be closed keeping the relay A energized. Contact A_9 will be opened disconnecting the "close" circuit of motor **26** and contact A_2 will be closed to connect the potential source E through line **120** and the closed limit switch contacts **122** to line **124** which in turn connects to the "open" winding of motor **26** causing a clockwise rotation of the shaft **24** and its limit switch actuator **100**. Thus, the closing of contact A_2 causes shaft **24** to open valve **22** to allow for a refilling of container **10**.

The energization of relay A also closes contact A_3 to connect the potential source E to timer **130** which is so designed that upon the expiration of a preset period of time following the energization of timer **130** from potential source E, it will produce an output on line **132** which will energize relay C. Relay C is shown in FIG. 1 as having one of its terminals connected to line **132** and its other terminal connected to ground. The effect of an energization of relay C will be described at a later point in this description.

The energization of relay A also causes a closing of relay contact A_4 so as to connect the potential source E by way of line **136** to line **138** and hence to one terminal of relay D, the other terminal being connected to ground. This will cause an energization of relay D which will in turn cause a closing of the normally open contact D_3 and then opening of the contacts D_1 and D_2. The closing of the contact D_3 completes a holding circuit consisting of the connecting line **139**, contacts **96** and line **140**. Since indicator **80** will be at the middle of its scale during most of the period when container **10** is being discharged if the signal on line **76** is zero, the contacts **96** will be open as shown in FIG. 1 so that the holding circuit including relay contact D_3 will not be completed immediately.

The opening of the relay contact D_2 disconnects the controller **64** from line **62** so that the controller **64** is no longer effective to vary the speed of motor **20**. Instead the speed of motor **20** is maintained at the speed at which it was running when the contact D_2 was disconnected or opened.

Opening of relay contact D_1 disconnects the potential obtained from the movable contact **50a** from the input line **48** of amplifier **42** so that the output of amplifier **42** on line **40** ceases to change in response to the potential on contact **50a**.

The closing of normally open relay contact A_5 connects the feedback capacitor **46** of amplifier **42** to the potential on line **32**, representative of the signal W, by way of resistor **150** and line **152** so that the capacitor **46** is maintained with a charge such that the signal on line **40** corresponds to that on line **32** and is equal to the negative value of the signal W. With the relay contact A_5 closed, the capacitor **46** is shunted by resistor **154**.

The relay contact A_1 will be disconnected upon energization of relay A so as to disconnect the set point signal on line **40** from input resistor **52** so that the set point is no longer provided as an input to amplifier **50**. In place of the set point input, a fixed input is provided by the closing of relay contact A_7 so that a preset potential from movable contact **160a** on potentiometer **160** is coupled through input resistor **162** to amplifier **58**.

The potentiometer **160** is connected at its upper terminal to a reference potential E_R while its lower terminal is connected to ground. The reference potential from movable contact **160a** should be of such a value that the effect on indicator **80** is to convert it from a zero center instrument indicating the deviation of the mass W from its set point to an indicator which will indicate the mass in the container **10** with the left-hand end of the scale indicating a mass of W_o while the right-hand of the csale indicate a mass of W_f. It will be evident that upon energization of relay A the amplifier **50** has as its input the signal on line **54** and the potential from movable contact **160a** so that the signal on line **62** and line **76** is such that indicator **80** will indicate the mass of the material **14** in container **10** as the refilling operation proceeds. At the beginning, the indicator pointer **83** will be opposite W_o.

The remaining relay contact A_8 which is closed upon energization of relay A is effective to connect the potential source E through line **114**, closed contact C_1, closed contacts **88** and line **116** to provide a holding circuit to maintain relay A in an energized state. It is desirable that relay A be maintained in an energized state until the container **10** is filled at least to a level such that the mass in the container equals W_f. When the mass of material **14** in the container has reached the level such that it is equal to W_f, the indicator **83** will be at the right hand limit of its scale and the contacts **88** will open so as to release the holding circuit and cause relay A to de-energize. If the material available for refilling the vessel **10** is not sufficient to bring the mass in container **10** to the point where it equals W_f, then the relay A would not be de-energized until contact C_1 is opened by the energization of relay C at the end of the time period set for the timer **130**. Thus, the refilling operation can be discontinued automatically under either of two alternative conditions, namely when the mass of material **14** has reached a value equal to W_f or when the particular time period set in timer **130** has expired after the initial energization of the timer **130** by the closing of contact A_3. The refilling operation could, of course, be discontinued manually by an operator at any time.

If the filling operation has successfully brought the mass of material to a value equal to W_f so as to cause the de-energization of the relay A, the contact A_9 will again be closed so that the motor **26** will be operated in a "close" direction until the limit switch contacts **104** are opened, as previously explained. If the motor **26** operates at a speed such that valve **22** will close with sufficient rapidity so that over filling of the container **10** is not experienced, then upon a disconnection of the relay contact A_7, the connection of contact A_1 and the disconnection of contact A_5. The set point signal on line **40** will be at a value corresponding with W_f, the signal on line **54** will correspond with W_f and hence the output of amplifier **50** will be at a zero level. Since the disconnection of contact A_7 causes the indicator **80** to then be a zero center instrument, the pointer **83** will be at the center point on the scale and the contacts **96** will be maintained open so that relay contact D_3 will not be effective to act as a holding circuit for the relay D. The D relay will then be de-energized, thus reconnecting the controller **64** by making relay contact D_2 and reconnecting the movable contact **50a** to line **48** by the making of contact D_1.

By virtue of the fact that during the filling operation the capacitor **46** has been maintained charged to a potential such that the signal on line **40** is maintained equal to the signal on line **54**, there is then provided upon a re-establishment of control a bumpless transfer to a controlled operation of motor **20** so that the discharge portion of the cycle is again begun and the set point on line **40** will be constantly decreased by virtue of the integrating

fect of amplifier **42** which receives an input signal on line from the variable contact **50**a.

Having explained above a complete cycle of operation, will now be explained how the system of FIG. 1 can commodate various deviations from the normal expected peration of the system. For example, if the motor **26** ould close the valve **22** at such a rate that the container is overfilled, the signal on line **32** will then be above e value W_f and hence when the de-energization of relay makes the indicator **80** a zero center instrument, the dicating pointer **83** will be to the right of the center oint and the cam follower **98** will be off the shoulder f the cam and the contacts **96** will be closed so as to mplete with the closed contact D_3 a holding circuit for lay D. This holding circuit includes the contact D_3, ne **139**, contacts **96** and line **140**, as well as line **138**. The lay D will then be maintained in an energized state in ite of the de-energization of relay A and the relay con- cts D_1, D_2 will be maintained in an open condition, thus aintaining the controller **64** disconnected from line **62** nd maintaining a disconnection of the variable contact a from the line **48**. The result of the maintenance of energization of relay D will be to delay the reestablish- ent of control over the discharge of material from con- iner **10** until the time when the constant discharge which as maintained during the refilling operation is such as to ring the mass of the material **14** down to a level where is equal to W_f. At that time, the contacts **96** will open nce the pointer **83** will have reached the center point of e scale and the cam follower **98** will have reached the oulder of cam F_2 so that the contacts **96** will be opened ith the resulting release of the holding circuit for relay and the consequent de-energization of that relay so as reestablish control by the closing of contacts D_1 and D_2.

The situation may arise in which the availability of aterial for refilling the container **10** is insufficient to ring the mass of the material **14** up to a value equal to W_f. In that case, the timer **130** will be effective to cause e de-energization of relay A by disconnecting relay con- ct C_1. At the same time, normally open contact C_2 will e made so as to connect the source of potential E with an larm circuit **170** which will cause the alarm to be actuated nd bring the attention of the operator to the situation. he operator may then take the necessary steps to correct e situation. Meanwhile, however, control is not stopped. nstead the circuit of FIG. 1 is so arranged that control ill be resumed and the discharge rate, that is the mass- ow rate of material **14** from the container **10** will be con- olled in accordance with a decreasing set point value as stablished on line **40**. Thus, even though the material vailable is insufficient to fill the container **10**, there will be transfer back to control and it will be bumpless by virtue f the closing of the contact A_5 during the refilling opera- on.

The manually operated contact **172** is provided so that e control system may be started up without causing a apid change or a bump in the control system. The anually operated contact **172** serves the same function s contact A_5 of relay A in that it connects line **152** to apacitor **46** by way of resistor **150** so that the signal on ne **40** will be maintained at a value equal to that on line **4** when the contact **172** is closed. Thus it will be seen at the effect of closing the contact **172** would be to ring the signal on line **62** to zero as is desirable when tarting up the control system or under certain other con- itions.

The control system of FIG. 1 may be modified as shown n FIG. 2. This modification includes the omission of the am F_2 and its associated contacts **96** and the substitution or the contacts **96** of the limit operated contacts **96**a hich serve the same purpose as the contacts **96** of FIG. and which are opened when motor **26** has caused the alve **22** to reach its closed limit. Thus the relay D in FIG. is de-energized whenever the filling portion of the cycle s completed as indicated by the full closing of the valve **22**. In order that the control may be properly effected upon de-energization of relay D, a normally open contact D_4 is substituted for the contact A_5 of FIG. 1 so that instead of the set point value represented by the signal on line **40** in FIG. 1 being maintained at a value W_f in FIG. 2 the signal on line **40** will be equal to whatever mass is contained in the container **10** at the time that the valve **22** is completely closed and relay D is de-energized. In the case of an over-filling of the container **10**, as may occur when the valve **22** is slow in closing, the signal on line **40** will then be above the value W_f but it will nevertheless be equal to the value W so that a bumpless reestablishment of control may be effected. In the circuit of FIG. 2, the control is reestablished before the over-filled container **10** is emptied to the point where the mass is equal to W_f and hence the control will be effective for a greater percentage of the time than would be the case with the arrangement of FIG. 1.

In FIG. 2, the contacts **104** are isolated from the contacts **96**a by an insulating segment **200** which is interposed between the contacts **104** and **96**a on the pivoted member **102**.

It will be evident to those skilled in the art that other variations of the control apparatus herein described may be advantageously utilized for the maintenance of a desired mass-flow rate of material from a container. For example, the control may be carried out by a mechanical system or by a completely digital apparatus while still utilizing the novel features of the invention. It is likewise apparent that the mass-flow rate of the material may as previously mentioned be made non-linear during the emptying portion of the cycle if such an arrangement should be desirable for the particular process to which the apparatus is being applied.

In addition, it will be evident that under some circumstances it may be desirable to completely discontinue the discharge of material from the container during the refilling portion of its cycle and indeed such a mode of operation may be desirable in some processes. While the system here described tends to maintain a substantially constant discharge during the refilling portion of the cycle based upon a desired mass-flow rate which is predetermined, the predetermined rate may under some conditions be desirably of zero magnitude. Under still other circumstances the discharge rate during refilling could be in accordance with any desired program, depending upon the process with which the control is associated.

What is claimed is:

1. A control system for controlling the mass-flow rate of material from a container which is subject to being emptied by the discharge of said material during one portion of a cycle and refilled during another portion comprising

a first means for producing a first signal representative of a measured value of the mass of said material in said container,

a second means for producing a second signal continuously changing during said discharge portion of said cycle, said second signal being representative of a continuously decreasing set point value for the mass in said container,

a third means responsive to the difference between said first and said second signal for controlling the mass-flow rate of the material being discharged from said container so as to tend to maintain said difference at zero,

a fourth means operable when said mass in said container reaches a predetermined minimum value to start said refilling portion of said cycle to refill said container until it contains a predetermined maximum mass,

a fifth means operable during said refilling portion of said cycle for maintaining said third means unresponsive to the said difference so that the mass-flow rate of said material from said container is maintained at

a substantially constant value during said refilling portion of said cycle,

a sixth means operable to maintain said second signal at a value corresponding with said first signal while said container is being refilled,

a seventh means operable after completion of said refilling portion of said cycle to cause resumption of the control of said discharge by said third means, and

an eighth means operable a predetermined time period after the beginning of said refilling portion of said cycle to cause resumption of the control of said discharge if said refilling portion has not already been completed.

2. A control system as set forth in claim 1 in which said eighth means includes a timer producing a signal after a predetermined period following the beginning of said refilling portion, said signal being operative to effect a resumption of control.

3. A control system for controlling the mass-flow rate of material from a container which is subject to a continuous discharge and a relatively rapid refill comprising

means for producing a first electrical signal corresponding with the measured value of the existing mass of material in said container;

means for producing a second electrical signal to provide a changing set point for said measured value during a controlled period of said discharge;

means responsive to the deviation of said first and second signals to control the discharge of said material from said container so as to tend to maintain said deviation at zero;

means for detecting the decrease of the mass in said container below a preset minimum value, said detecting means being operable to

(a) disconnect said control means so as to maintain the mass-flow rate of discharge from said container at a substantially constant value corresponding with that existing at the time said minimum was reached,

(b) initiate a refilling of said container, and

(c) connect said first signal to said means for producing said second signal in manner to maintain said second signal at a value corresponding with that of said first signal during said refilling;

means for detecting the increase of the mass in said container to a preset maximum value, said increase detecting means being operable to

(a) disconnect said first signal from said second signal producing means to prevent said second signal from continuing to follow said first signal,

(b) initiate a cessation of the refilling operation, and

(c) detect the change of said first signal to equality with said second signal for reconnecting said control means for reestablishing said changing set point so as to again control the discharge from said container to obtain the desired mass-flow rate.

[4. A control system for controlling the mass-flow rate of material from a container which is subject to being emptied by the controlled discharge of said material during one portion of its cycle and refilled during another portion of its cycle while the discharge is maintained substantially constant comprising

a load cell for producing a first electrical signal representative of a measured value of the mass of said material in said container,

an integrating circuit including an integrating amplifier and having a reference potential as an input thereto for producing a second signal continuously changing so as to produce during the controlled discharge portion of said cycle a second signal representative of a

continuously decreasing set point value for the mass in said container,

an operational amplifier having as its inputs said first and said second signals so as to produce at its output a signal indicative of the difference between said first and said second signals, said operational amplifier being coupled during the controlled discharge portion of the said cycle to a controller which is in turn coupled to operate a motor control for varying the discharge rate of material from the said container so as to tend to maintain the output of said operational amplifier at zero,

a relay amplifier responsive to said first signal and a signal indicative of a predetermined minimum value and operable upon said first signal reaching a value indicative of said predetermined minimum value to start the refilling portion of said cycle,

relay means operable during said refilling portion of said cycle for disconnecting said controller and for maintaining the mass-flow rate of said material at a value substantially equal to that existing at the time said controller was disconnected,

relay contact means operable during said refilling portion of said cycle for connecting said first signal to said integrating amplifier so that the output of said integrating amplifier is maintained at a value corresponding with said first signal during said refilling portion of said cycle, and

means responsive to said first signal reaching said maximum value for the mass in said container for effecting a resumption of the control of said discharge by reconnecting said controller so as to tend to maintain the said difference between said first and said second signal at zero while said second signal is continuously being decreased in value.]

[5. A control system for controlling the mass-flow rate of material from a container which is alternately emptied and refilled comprising

means for producing a first electrical signal indicative of a measured value of the mass of material in said container,

means including an integrating amplifier having a feedback capacitor for producing from a reference electrical signal a programmed second electrical signal indicative of the set point for said measured value of said mass,

means responsive to the difference between said first and said second electrical signal for controlling the discharge of material from said container so as to maintain said first signal equal to said second signal during the period when said container is being emptied, and

means operable when said container is being refilled to maintain a desired discharge rate therefrom and to maintain the charge on said feedback capacitor at a value such that said second signal is maintained equal to said first signal so that reestablishment of control of said discharge can be carried out without a bump.]

[6. A method for controlling the mass-flow rate of material from a container which is subject to being alternately emptied and refilled during its cycles of operation so that the rate of discharge of material is controlled during said emptying portion of the cycles and is maintained at a predetermined value during the refilling portion comprising the steps of

producing a signal indicative of the measured value of the mass of material in said container,

producing during said emptying portion of each of said cycles a changing signal indicative of the set point for said measured value required to maintain a desired program for the mass-flow rate of said material from said container,

controlling the discharge rate of said material from said container during said emptying portion of said

cycles to tend to minimize the deviation of said measured value signal from said set point signal,

establishing the discharge during said refilling portion of said cycle at a rate which will maintain the mass-flow rate from said container substantially at the value existing at the end of said emptying portion of said cycle,

maintaining the value of said set point signal at the existing measured value signal during said refilling portion of each of said cycles, and

reestablishing control of the discharge rate after a predetermined period of time if said container is not refilled during that period to begin the emptying

portion of next cycle with said set point signal equal to said measured value signal.]

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