United States Patent [19]

Slamar

[11] **3,893,502**

[45] **July 8, 1975**

[54] **METHOD AND MECHANISM FOR INDICATING MOLD FRICTION IN A CONTINUOUS-CASTING MACHINE**

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[73] Assignee: **United States Steel Corporation**, Pittsburgh, Pa.

[22] Filed: **May 31, 1974**

[21] Appl. No.: **475,082**

[52] **U.S. Cl.** ..... **164/4**; 73/9; 73/133 R; 164/83; 164/150; 164/260

[51] **Int. Cl.** **G011 5/00**

[58] **Field of Search** ..... 73/9, 133 R; 164/4, 136, 164/150, 154

[56] **References Cited**

UNITED STATES PATENTS

3,358,743	12/1967	Adams	164/154
3,478,572	11/1969	McRae et al.	73/9

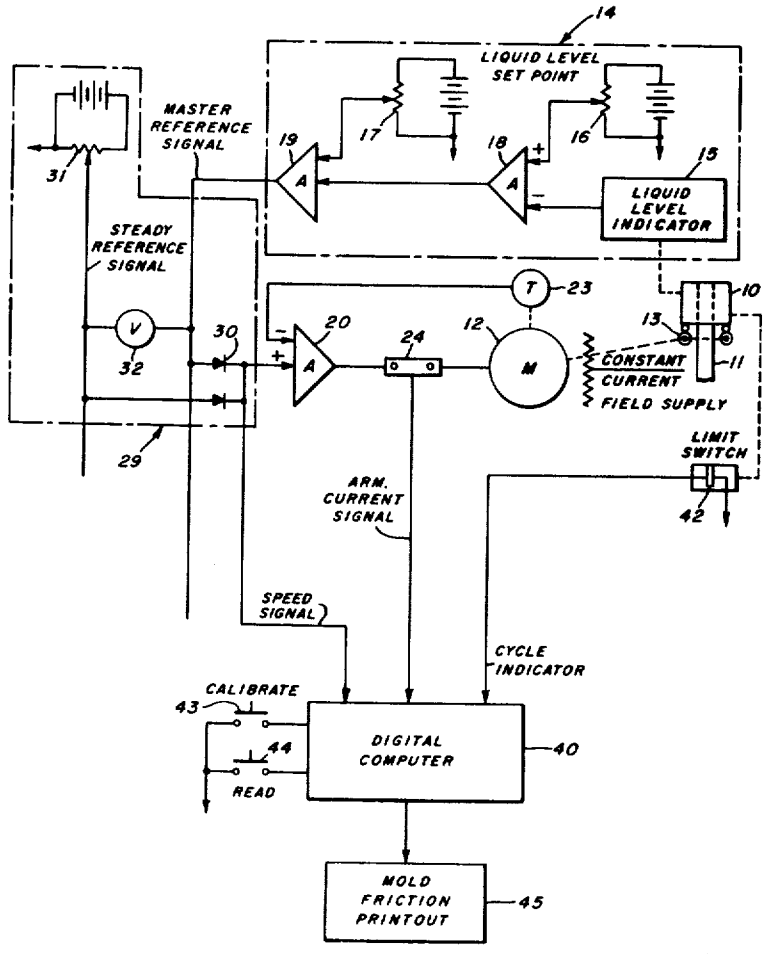
Primary Examiner—Jerry W. Myracle

Attorney, Agent, or Firm—Walter P. Wood

[57] **ABSTRACT**

A method and mechanism for determining frictional forces between the mold of a continuous-casting machine and the casting itself. During a casting operation the mold oscillates up and down, being driven by a motor and cam mechanism. The invention provides a method and means for determining the mold friction by measuring the armature current through the cam drive motor, but compensating for other factors which contribute to the load on the motor, whereby the average magnitude of the armature current through the oscillation cycle is indicative of mold friction only.

20 Claims, 3 Drawing Figures



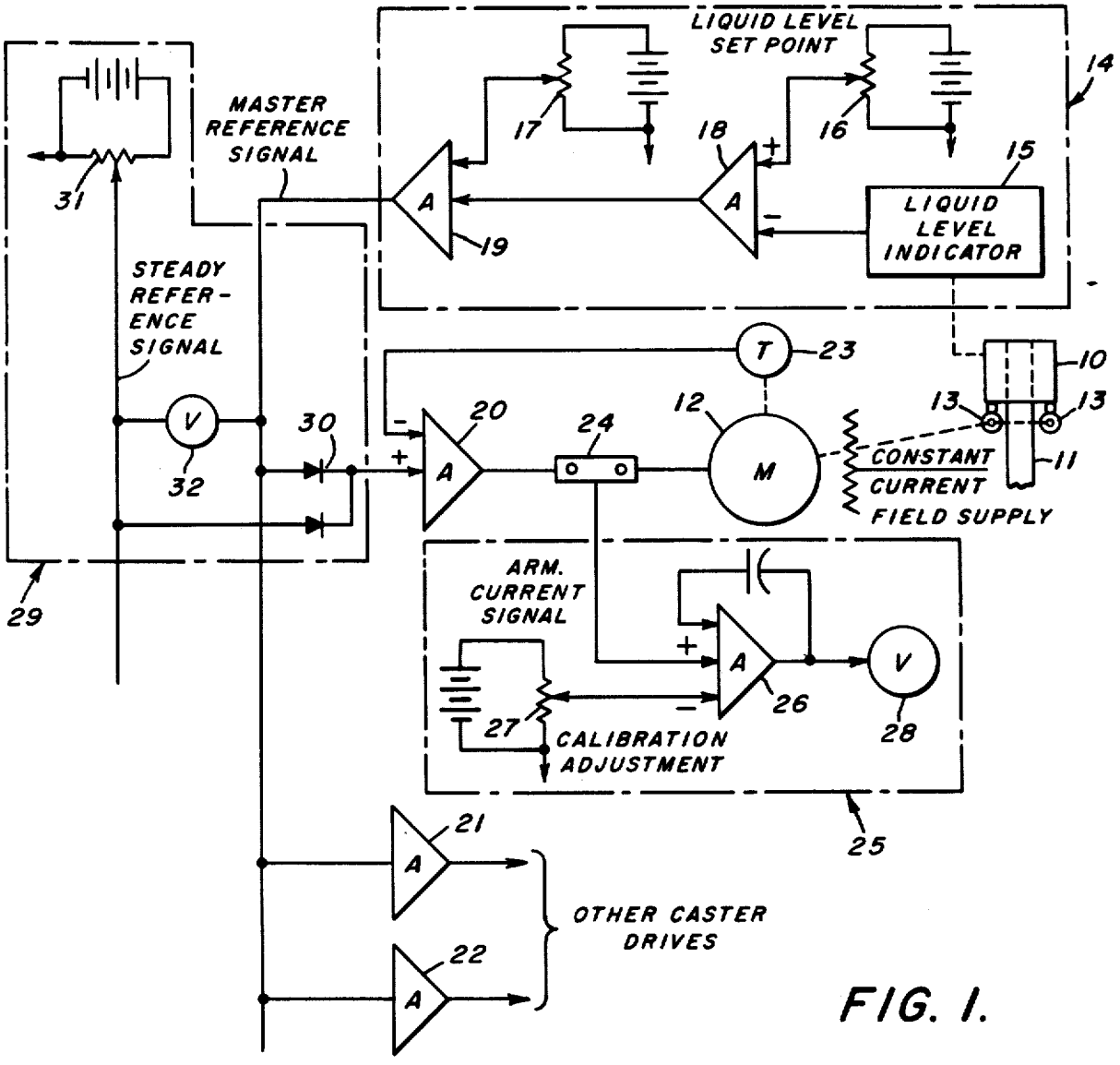

LIQUID LEVEL SET POINT
14
MASTER REFERENCE SIGNAL
17
18
16
15
31
A
19
LIQUID LEVEL INDICATOR
STEADY REFERENCE SIGNAL
T
23
10
V
30
20
24
12
13
13
32
A
M
CONSTANT CURRENT FIELD SUPPLY
11
ARM. CURRENT SIGNAL
29
A
V
26
27
28
CALIBRATION ADJUSTMENT
25
21
A
OTHER CASTER DRIVES
22
A

FIG. 1.

FIG. 2.

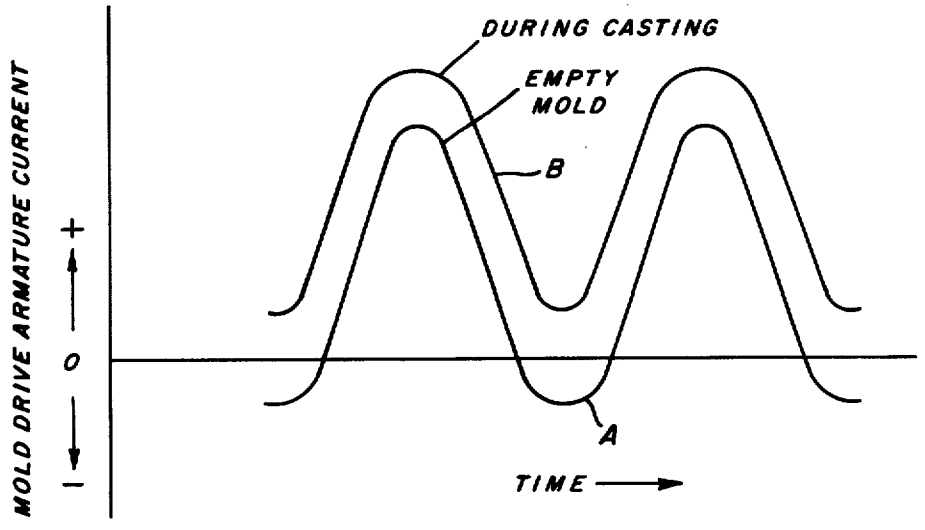
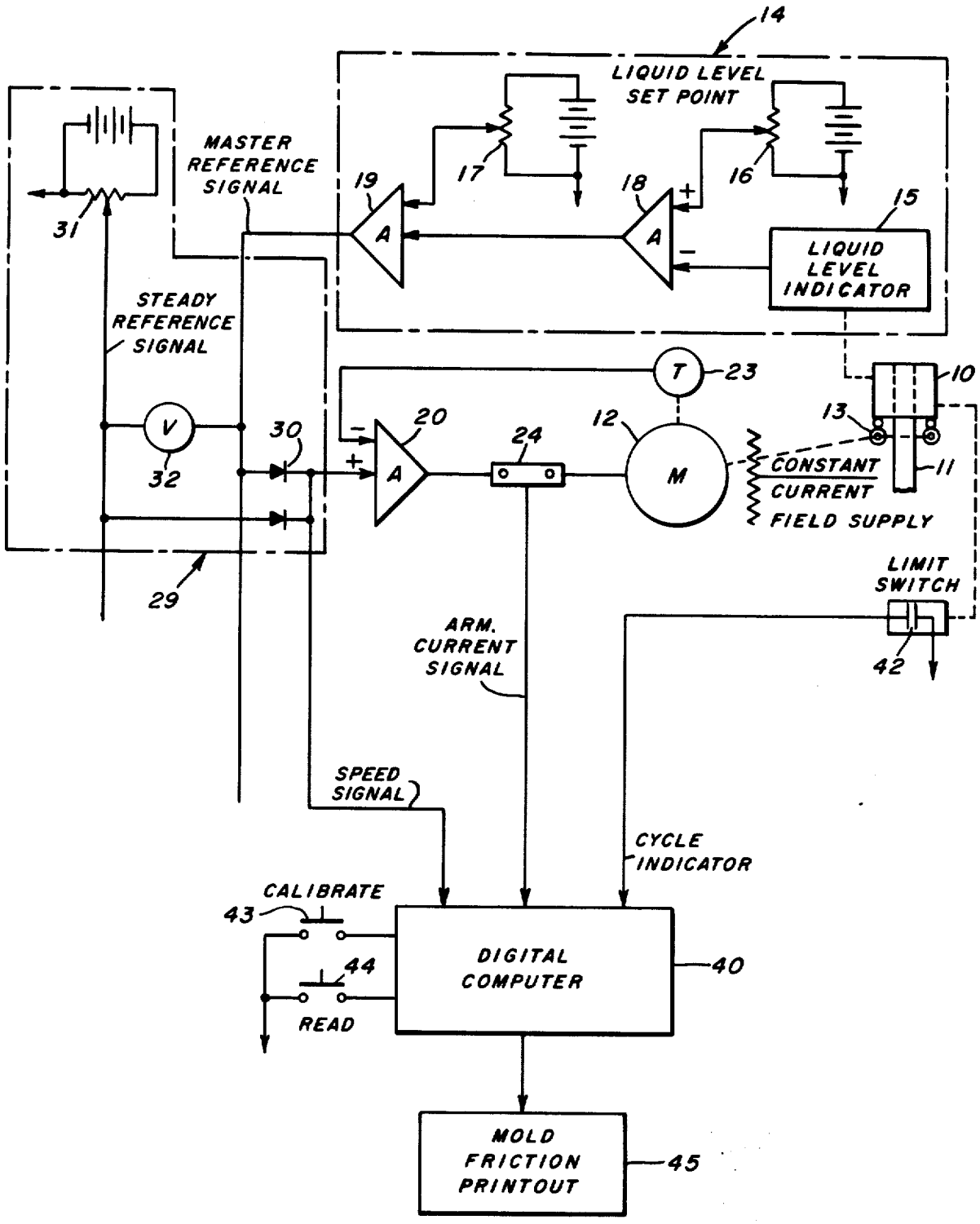

DURING CASTING
EMPTY MOLD
B
A
MOLD DRIVE ARMATURE CURRENT
+
0
−
TIME

FIG. 3.


14
LIQUID LEVEL SET POINT
MASTER REFERENCE SIGNAL
STEADY REFERENCE SIGNAL
19
17
18
16
15
31
A
A
LIQUID LEVEL INDICATOR
T
23
10
13
V
32
30
20
24
12
M
CONSTANT CURRENT FIELD SUPPLY
11
LIMIT SWITCH
29
ARM. CURRENT SIGNAL
42
SPEED SIGNAL
CYCLE INDICATOR
CALIBRATE
43
44
READ
DIGITAL COMPUTER
40
MOLD FRICTION PRINTOUT
45

METHOD AND MECHANISM FOR INDICATING MOLD FRICTION IN A CONTINUOUS-CASTING MACHINE

This invention relates to an improved method and mechanism for determining frictional forces between the mold of a continuous-casting machine and the casting itself.

In a conventional continuous-casting operation, liquid metal is introduced continuously to the top of an open-ended, water-cooled, vertically oscillating mold, and a partially solidified casting of indefinite length emerges from the bottom. As the casting travels through the mold, frictional forces oppose its movement. Excessive mold friction may lead to defects in the product, or even may cause break-outs of liquid metal from the solidified shell of the casting. Hence there is a need to monitor the magnitude of the mold friction and to make certain it does not exceed a predetermined limit. Heretofore the magnitude of the mold friction has been determined with load cells placed under the mold, or by measuring the load on the drive motor for the withdrawal rolls which act on the casting below the mold, as shown in Barnard et al U.S. Pat. No. 3,047,915 and in Osborn U.S. Pat. No. 2,824,346 respectively. Both these arrangements have disadvantages. It is costly to install load cells under a mold, and not readily accomplished if the mold support was not designed originally to accommodate them. The second method does not give an accurate determination, since a casting travels through a roll-rack, which absorbs an indeterminate amount of the mold frictional forces. Hence the change in load on the drive motor is proportional only to the frictional forces not absorbed by the roll rack.

Conventional practice is to employ a cam mechanism driven by a variable speed constant-field d-c motor for oscillating the mold, one example of which is shown in Bode Reissue U.S. Pat. No. 27,469 of common ownership. During its downward travel in the oscillation cycle the mold moves at a speed about 10 to 20 percent greater than the casting speed. Usually the casting speed is adjusted so that the level of liquid metal in the mold remains substantially constant. The speed of the cam drive motor commonly is adjusted with adjustments in the casting speed to maintain the speed at which the mold moves downwardly at a predetermined ratio to the casting speed.

A characteristic of a d-c motor of the type used for driving the cams is that the magnitude of the armature current is proportional to the load on the motor at any instant. The load of course varies with the varying magnitude of torque which the motor develops through the oscillation cycle. Mold friction is only one of several factors which contribute to the load on the cam drive motor. Other factors include motor losses, mechanical losses in the gearing and other mechanisms, the varying force required to lift and lower the mold through different portions of its oscillation cycle, and accelerating forces brought about by speed changes. Since mold friction is a small factor compared with the others, and the lifting and accelerating forces continually vary through the oscillation cycle, direct measurement of the armature current through the cam drive motor does not itself afford a meaningful determination of mold friction.

An object of my invention is to provide an improved method and mechanism for determining the magnitude of the mold friction, which method and mechanism not only are readily applied to existing continuous-casting machines, but also afford accurate determinations.

A further object is to provide an improved method and mechanism for determining the magnitude of the mold friction in a continuous-casting machine in which I utilize a measurement of the armature current through the cam drive motor, but in which I compensate for the other factors contributing to the load on this motor.

A further object is to provide an improved method and mechanism for accomplishing the foregoing object in which I utilize an integrating amplifier or a digital computer to measure the average armature current to the cam drive motor through a representative number of oscillation cycles, but calibrated to compensate for the effects of factors other than mold friction.

In the drawings:

FIG. **1** is a line diagram of the circuit utilized in one embodiment of my invention utilizing an integrating amplifier;

FIG. **2** is a graph illustrating the manner in which the armature current to the cam drive motor varies through an oscillation cycle with the motor driving an empty mold and during a casting operation; and

FIG. **3** is a view similar to FIG. **1**, but showing a modified embodiment utilizing a digital computer.

CONVENTIONAL OPERATION

FIG. **1** shows schematically a continuous-casting mold **10** from the bottom of which a casting **11** emerges. The mold oscillates vertically, commonly at a rate on the order of about one cycle per second, driven by a variable speed d-c motor **12** acting through a cam mechanism **13.** A master reference signal automatically controls the casting speed so that a substantially constant level of liquid metal is maintained in mold **10.** During normal operation the master reference signal serves also to adjust the speed of motor **12** so that the speed at which mold **10** moves downwardly is maintained at a constant ratio to the casting speed.

MASTER REFERENCE SIGNAL

A conventional arrangement of components for producing a master reference signal is shown schematically within a block **14.** These components include a liquid-level indicator **15,** a liquid-level set-point potentiometer **16,** a speed-adjusting potentiometer **17** and first and second operational amplifiers **18** and **19.** The liquid-level indicator **15** and the set-point potentiometer **16** transmit input voltage signals to the first operational amplifier **18** representative respectively by the actual level in the mold **10** and the desired level. The first operational amplifier transmits an output voltage signal proportional to the algebraic sum of its two input signals. The second operational amplifier **19** receives input voltage signals from the speed-adjusting potentiometer **16** and from the first operational amplifier **18** representative respectively of the desired casting speed and the error in the liquid level. The second operational amplifier transmits the master reference voltage signal, likewise proportional to the algebraic sum of its two input signals. The master reference signal goes to a third operational amplifier **20** used in controlling the speed of motor **12,** and to other operational amplifiers **21, 22,** etc. used in controlling other drives of the continuous-casting machine, not shown since they are not

involved in the present invention. Reference can be made to Milnes U.S. Pat. No. 3,204,460 of common ownership for a more detailed showing of a suitable liquid level indicator and an explanation of how a signal representing the liquid level in a mold may be used in controlling casting speed.

During normal operation the master reference signal is one of the input voltage signals to the third operational amplifier **20.** The other input voltage signal to the latter is a feedback signal from a tachometer **23** which is operatively connected with motor **12.** The output voltage signal from the third operational amplifier passes through a shunt **24** to a control (not shown) for the armature current of motor **12.** The armature current and the load on the motor are directly proportional to the voltage at the shunt **24.**

DETERMINATION OF MOLD FRICTION

The present invention provides means for determining the magnitude of the mold friction through a representative number of oscillation cycles, for example ten to twenty, at any time during a casting operation. This determination is based on a measurement of the voltage at the shunt **24.** The components of this means are shown schematically within a block **25** and include a conventional integrating amplifier **26,** a calibration potentiometer **27,** and a voltmeter **28** calibrated to read mold friction directly. The present invention makes this possible by compensating for the other factors which contribute to the load on motor **12,** as hereinafter explained.

COMPENSATION FOR VARYING LIFTING AND LOWERING FORCES

FIG. **2** shows the approximate way in which the armature current to motor **12** varies during the oscillation cycle. Curve A is representative of the magnitude of the armature current when the motor is driving an empty mold up and down. Curve B is representative of the magnitude of the armature current during a casting operation. In each instance the magnitude follows approximately sine wave, reaching maximum values as the mold travels downwardly. Curve B lies approximately a uniform distance above curve A and this distance represents the portion of the current utilized in overcoming mold friction. The integrating amplifier **26** automatically averages the measured magnitude of the armature current and thus compensates the reading on the voltmeter **28** for the varying force required to lift and lower the mold through different portions of each oscillation cycle.

COMPENSATION FOR MOTOR LOSSES AND MECHANICAL LOSSES

I compensate the reading on voltmeter **28** for motor losses and mechanical losses in the gearing and other mechanisms by adjusting the calibration potentiometer **27.** I operate the motor **12** through at least a representative number of oscillation cycles with the mold empty at a predetermined speed approximately equal to the speed of the motor during a casting operation. I adjust the potentiometer **27** so that the voltmeter **28** reads zero when the motor operates with the mold empty, whereby subsequent voltmeter readings during a casting operation exclude the portion of the armature current utilized in overcoming the foregoing losses. I have observed these losses vary during a casting operation. When the casting machine is started after several hours of standing idle, the losses are at their maximum. As a casting operation progresses, the losses diminish and ultimately reach a steady magnitude. For this reason I prefer to adjust the calibration potentiometer **27** immediately after completion of a casting operation. The adjustment remains valid for the next casting operation, provided conditions are similar.

COMPENSATION FOR ACCELERATING FORCES

Preferably I also compensate the reading on voltmeter **28** for accelerating forces brought about by speed changes. The voltage of the master reference signal continuously varies to maintain a constant level of liquid metal in the mold. Each change in the master reference signal of course changes the voltage at shunt **24** and the armature current to motor **12.** The change in armature current produces an acceleration or deceleration of the mold. Without compensation, such changes would be read on the voltmeter **28** as erratic variations in the mold friction. I compensate for accelerating forces by utilizing a steady reference signal to control the speed of motor **12** in place of the master reference signal throughout the oscillation cycles during which I determine mold friction. The magnitude of the steady reference signal approximately equals the magnitude of the master reference signal at the beginning of this determination. The casting operation is not appreciably upset if the rate at which the mold oscillates remains constant through a representative number of cycles needed to obtain a determination of mold friction.

The components which produce the steady reference signal are shown schematically within a block **29** and include a blocking rectifier **30,** a potentiometer **31** and a differential voltmeter **32.** The blocking rectifier is connected between the second and third operational amplifiers **19** and **20** and between the potentiometer **31** and the third operational amplifier. The voltmeter **32** has a center zero point and is connected between the lines which are at the master reference voltage and the voltage transmitted by the potentiometer **31** to measure the difference between these voltages. During normal operation of the casting machine, the potentiometer **31** is adjusted so that the master reference voltage exceeds the voltage transmitted by the potentiometer, the voltmeter **32** shows a positive voltage, and the blocking rectifier **30** prevents any voltage from the potentiometer from reaching the third operational amplifier **20.** Whenever I wish to determine mold friction, I adjust the potentiometer **31** so that its voltage slightly exceeds the master reference voltage whereby the potentiometer transmits a steady reference signal which is approximately equal to the master reference signal at the moment. The blocking rectifier now prevents the master reference signal from reaching the third operational amplifier **20,** and the steady reference signal takes over control of the armature current through motor **12.** After I observe mold friction through a representative number of oscillation cycles, I return the potentiometer **31** to its original setting and resume normal operation.

MODIFICATION USING DIGITAL COMPUTER

FIG. **3** shows a modification useful for casting installations in where there is a digital computer available. Some casting installations employ a computer for other purposes, such as controlling the volume of water ap-

plied to the casting to cool it and promote solidification. In such installations the computer conveniently can be used to obtain a print-out of the mold friction in place of the integrating amplifier shown in FIG. 1. If the installation does not already include a digital computer, the simpler embodiment of FIG. 1 of course is preferred. Except as specifically described, the embodiment shown in FIG. 3 is similar to that shown in FIG. 1, and the description is not repeated.

FIG. 3 shows a digital computer 40 to which are transmitted a speed signal, an armature current signal, and a cycle indicator signal. The speed signal is either the master reference signal or the steady reference signal, either of which is obtained as already described. The armature current signal again is the voltage at shunt 24. A limit switch 42 is operatively associated with the mold to be opened and closed with each oscillation of the mold. I set the computer to determine the average magnitude of the armature current during a representative member of mold oscillation cycles. Operation of the limit switch signals the computer as to the number of cycles which take place. When the selected number of oscillations have taken place, I terminate the observation. I operate the motor 12 with the mold empty as already described for calibration purposes, thus enabling the computer to subtract the portion of the armature current signal utilized in overcoming motor losses and mechanical losses. The computer has a calibration switch 43, a read switch 44, and a mold friction print out 45.

OPERATION

In both embodiments of the invention, the voltage at the shunt 24 is representative of the load on the motor 10. The factors which contribute to this load include the varying forces to lift and lower the mold during different portions of its oscillation cycle, motor losses, mechanical losses in the gearing and other mechanisms, and accelerating forces, beside mold frictions. I measure the voltage at the shunt 24, but I obtain a direct reading of mold friction in this measurement since I compensate for these other factors. I compensate for the varying lifting force by averaging the voltage through a representative number of cycles, either with an integrating amplifier as shown in FIG. 1 or with a digital computer as shown in FIG. 3. I compensate for motor losses and mechanical losses by calibrating the voltmeter 28 while driving the mold 10 up and down empty. I compensate for the accelerating forces by temporarily utilizing a steady reference signal to control the speed of motor 12 in place of the varying master reference signal.

From the foregoing description, it is seen that my invention affords a simple method and mechanism for determining the magnitude of mold friction, and can be applied readily to existing casting machines without disturbing their structure, as is necessary if load cells are placed under a mold. The determination is accurate, since compensation is made for all other factors which would produce an erroneous determination. The mold friction in force units is readily determined from the motor load measurements when a proportionality factor is determined from motor characteristics, gear ratios, and cam designs.

I claim:

1. In a continuous-casting operation in which liquid metal is introduced continuously to the top of an open-ended mold, a partially solidified casting of indefinite length emerges from the bottom of the mold, and the mold is oscillated vertically, the movement of said casting through said mold being opposed by friction, and in which the drive means for oscillating the mold includes a motor operatively connected therewith, the magnitude of the armature current to said motor being proportional to the load on the motor, an improved method of determining the magnitude of the mold friction, said method comprising measuring the magnitude of the armature current to said motor with the motor oscillating the mold through a representative number of cycles during a casting operation, and compensating for factors which contribute to the load on the motor other than mold friction.

2. A method as defined in claim 1 in which the factors for which compensation is made include the varying force required to lift and lower the mold through different portions of its oscillation cycle, motor losses, and mechanical losses in the gearing and other mechanisms.

3. A method as defined in claim 2 in which the varying force required to lift and lower the mold is compensated for by averaging the current measurement through said cycles.

4. A method as defined in claim 2 in which the mold losses and mechanical losses are compensated for by running said motor with the mold empty and calibrating the measuring means to read zero with the motor driving the empty mold.

5. A method as defined in claim 2 in which an additional factor for which compensation is made is the accelerating force on the motor brought about by changes in the speed of mold oscillation, and the accelerating force is compensated for by operating the motor at a constant speed during said cycles.

6. In a continuous-casting operation in which liquid metal is introduced continuously to the top of an open-ended mold, a partially solidified casting of indefinite length emerges from the bottom of the mold, and the mold is oscillated vertically, the movement of said casting through said mold being opposed by friction and in which the drive means for oscillating the mold includes a variable speed d-c motor operatively connected therewith, and means for producing a master reference signal for controlling the casting speed and maintaining the speed at which the mold oscillates at a predetermined ratio to the casting speed, the magnitude of the armature current being proportional to the load on the motor, an improved method of determining the magnitude of the mold friction, said method comprising measuring the average magnitude of the armature current to said motor with the motor oscillating the mold through a representative number of cycles during a casting operation, calibrating the measuring means to compensate for motor losses and mechanical losses by running said motor with the mold empty and setting the measuring means to zero, and replacing said master reference signal with a steady reference signal while the mold friction determination is made to compensate for accelerating forces.

7. A method as defined in claim 6 in which said steady reference signal approximately equals the magnitude of said master reference signal at the beginning of the determination.

8. A method as defined in claim 6 in which the average magnitude of the armature current is obtained by

applying said steady reference signal to an integrating amplifier.

9. A method as defined in claim 6 in which the average magnitude of the armature current is obtained by applying said steady reference signal to a digital computer through a predetermined number of oscillation cycles.

10. A method as defined in claim 6 in which the mechanical losses are at a maximum at the beginning of a casting operation, but diminish and reach a steady magnitude as casting progresses, and said calibrating step is conducted immediately after the completion of a casting operation.

11. In a continuous-casting machine which comprises an open-ended mold for receiving liquid metal and from the bottom of which a partially solidified casting emerges, a motor operatively connected with said mold for oscillating it vertically, the magnitude of the armature current to said motor being proportional to the load on the motor, one of the factors contributing to said load being the frictional force between the mold and the casting, the combination therewith of a mechanism for determining the magnitude of the mold friction, said mechanism comprising; means for measuring the armature current, and means for compensating for other factors contributing to said load, whereby the armature current measurement affords a direct determination of mold friction.

12. A continuous-casting machine as defined in claim 11 in which another factor contributing to said load is the varying force required to lift and lower the mold through different portions of its oscillation cycle, and the means for compensating for variations in the lifting and lowering force includes means for averaging the armature current through a representative number of oscillation cycles.

13. A machine as defined in claim 12 in which said averaging means is a digital computer.

14. A machine as defined in claim 11 in which said averaging means is an integrating amplifier.

15. A continuous-casting machine as defined in claim 11 in which other factors contributing to said load are motor losses and mechanical losses, and the means for compensating for said losses include calibration means which are set to show a zero with said motor driving an empty mold.

16. A continuous-casting machine as defined in claim 11 in which another factor contributing to said load is acceleration force brought about by changes in the speed at which said mold oscillates, and the means for compensating for acceleration force includes means for producing a steady reference signal for controlling the armature current.

17. In a continuous-casting machine which comprises an open-ended mold for receiving liquid metal and from the bottom of which a partially solidified casting emerges, a motor operatively connected with said mold for oscillating it vertically, and means for producing a varying master reference signal which controls the speed of said motor, the magnitude of the armature current to said motor being proportional to the load on said motor, the factors contributing to said load including mold friction, the varying force required to lift and lower the mold through different portions of its oscillation cycle, motor losses, mechanical losses, and accelerating forces brought about by speed changes, the combination therewith of a mechanism for determining the magnitude of the mold friction, said mechanism comprising means for measuring the armature current averaged over a representative number of oscillation cycles to compensate for the varying force required to lift and lower the mold, means connected with said measuring means for compensating for the effect of said losses, and means for replacing said master reference signal with a steady reference signal while the mold friction determination is made to compensate for said accelerating forces.

18. A mechanism as defined in claim 17 in which the means for measurng the armature current includes a voltmeter and an integrating amplifier operatively connected with said voltmeter and receiving said steady reference signal.

19. A mechanism as defined in claim 17 in which the means for measuring the armature current includes a digital computer and a print-out operatively connected with said computer, said computer receiving said steady reference signal.

20. A mechanism as defined in claim 17 in which the means for replacing said master signal with a steady reference signal includes a blocking rectifier and a potentiometer connected to the circuit which carries said signals, said blocking rectifier normally permitting said master reference signal to pass, but permitting said steady reference signal to pass when its magnitude is greater than said master reference signal.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,893,502 Dated July 8, 1975

Inventor(s) Frank Slamar

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 51, after "voltage" insert a comma.

Column 5, line 29, "read" should read -- "read" --.

Column 7, line 45, after "zero" insert -- reading --.

Signed and Sealed this

sixteenth Day of *September 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks