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Gallucci et al.

[11] **3,752,210**

[45] **Aug. 14, 1973**

[54] **METHOD FOR CONTROLLING FORCES ON A STRAND AS IT SOLIDIFIES**

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

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[52] **U.S. Cl.** **164/82**, 164/282
[51] **Int. Cl.** **B22d 11/12**
[58] **Field of Search** 164/82, 282, 283; 226/189

[56] **References Cited**

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3,542,118	11/1970	Rossi	164/282 X
3,550,674	12/1970	Gallucci	164/282
3,557,865	1/1971	Gallucci et al.	164/282 X
3,566,951	3/1971	Schrewe	164/82

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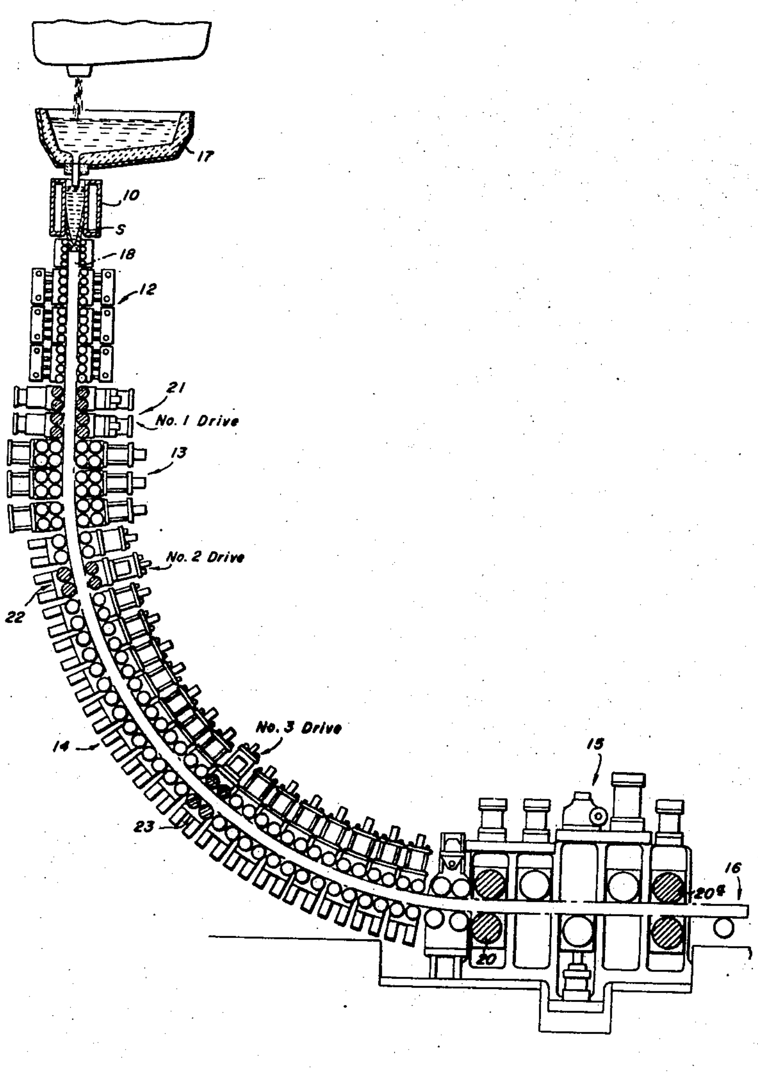
[57] **ABSTRACT**

A method and mechanism for controlling the forces on a partially solidified strand formed in a continuous-casting operation. A speed-regulating tractive force is applied to the strand at a location in the line preceding that where the starter bar is disconnected. In apparatus utilizing a relatively long flexible starter bar, auxiliary tractive forces are applied at preceding locations. In apparatus utilizing a rigid starter bar or a relatively short flexible bar, the auxiliary tractive forces may be applied at locations following the speed-regulating force. The speed-regulating force is maintained at a predetermined maximum, and the auxiliary forces adjusted accordingly to supply the increasing force needed to move the strand, yet avoid excessive tensile or compressive stresses.

5 Claims, 5 Drawing Figures



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3 Sheets-Sheet 1

FIG. 2

FIG. 1

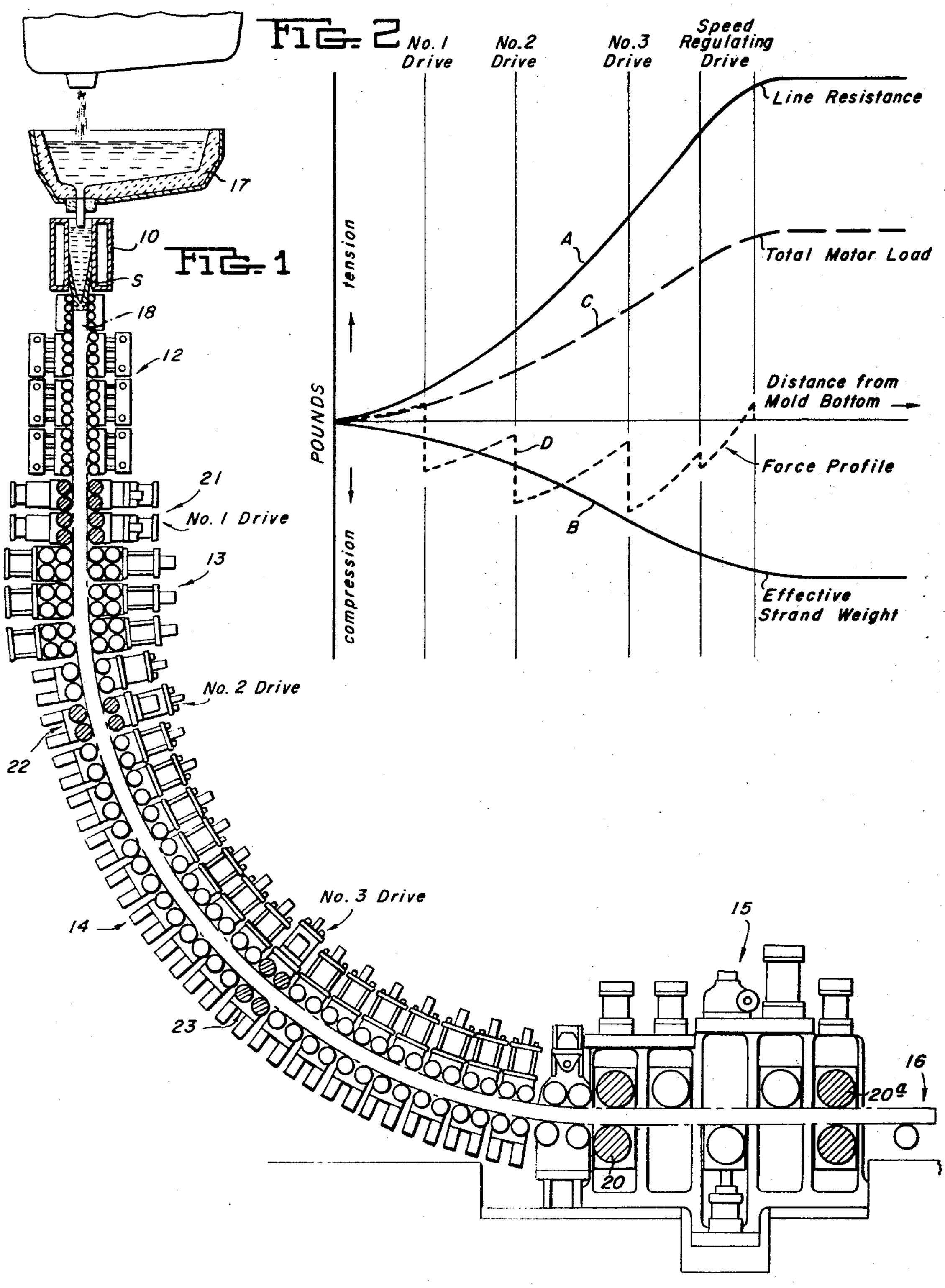

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FIG. 4

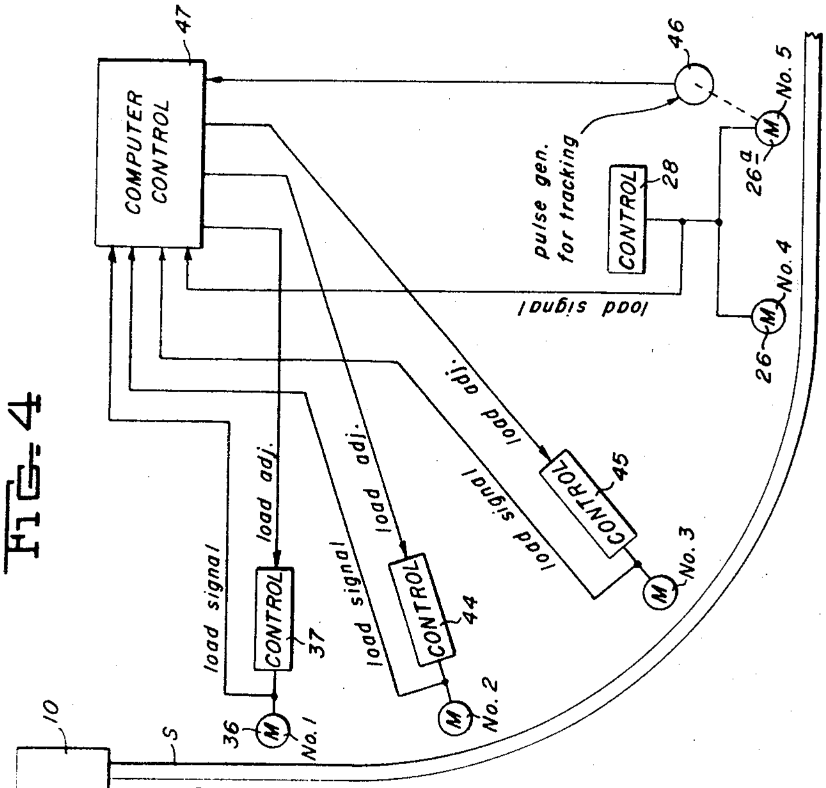

FIG. 3

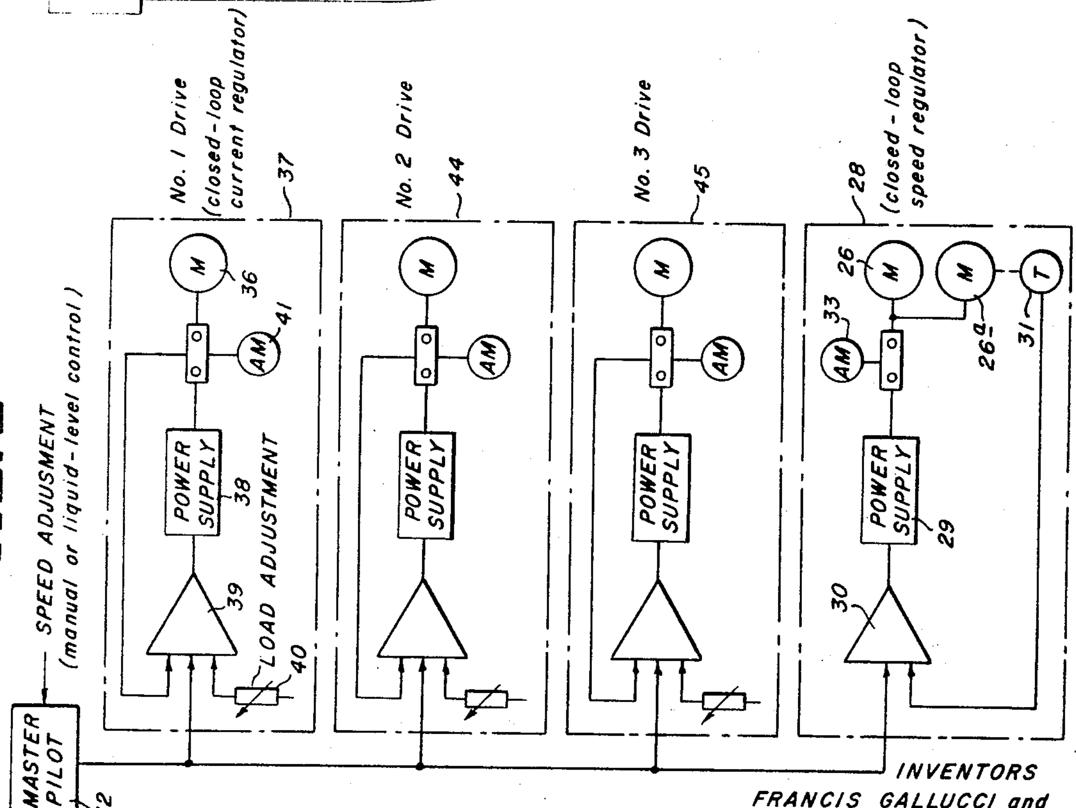

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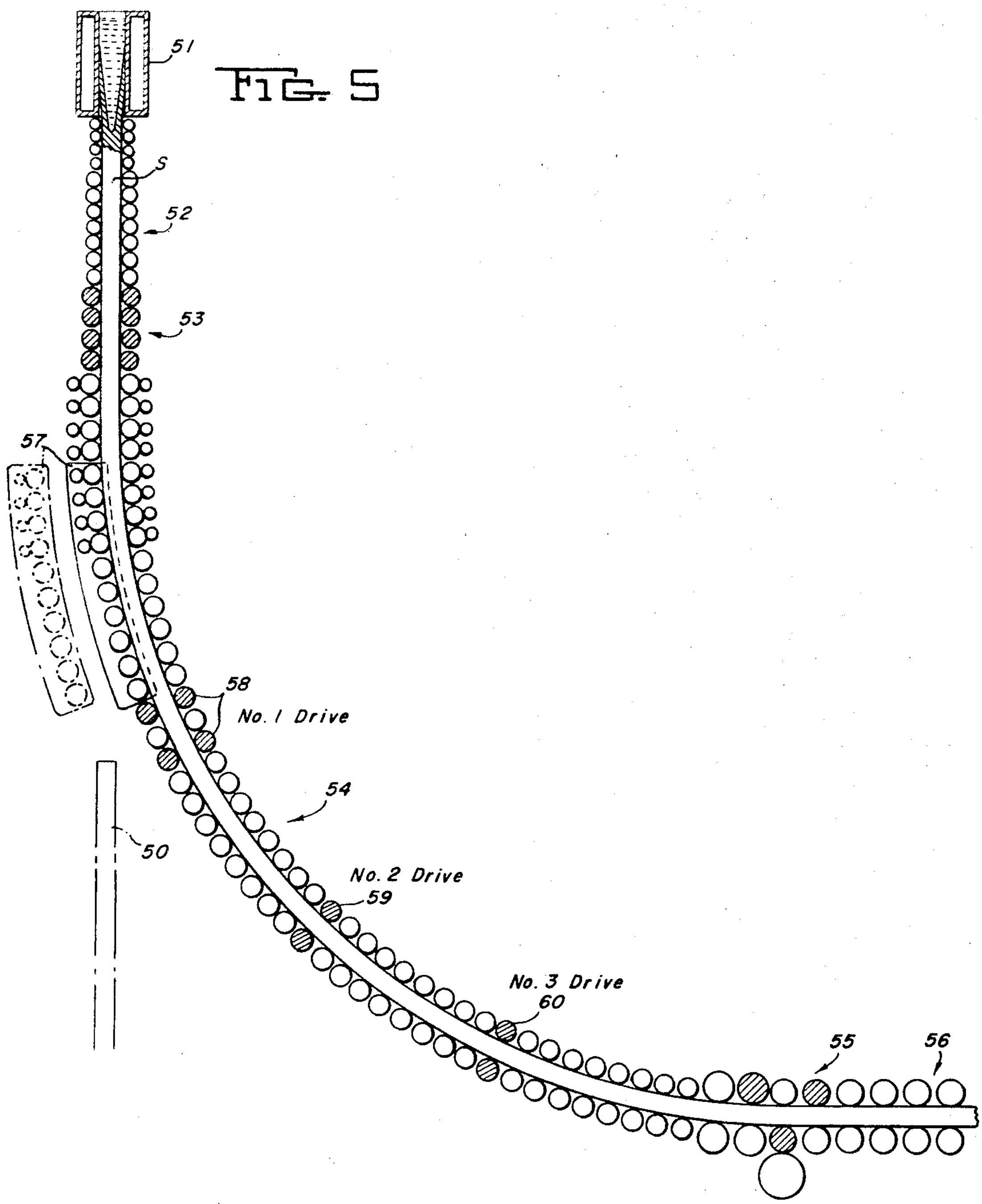
FIG. 5



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METHOD FOR CONTROLLING FORCES ON A STRAND AS IT SOLIDIFIES

This invention relates to an improved method and mechanism for controlling forces on a continuously cast strand as it solidifies.

In a conventional continuous-casting operation, liquid metal is poured continuously into a vertically oscillating, water cooled, open-ended mold, which may be either straight or curved. A partially solidified strand of indefinite length emerges from the bottom of the mold and travels between series of rolls which engage opposite faces thereof. In the example of a straight mold, these rolls may include a straight vertical guide-roll rack immediately beneath the mold, power driven pinch rolls and/or bending rolls beneath the guide-roll-rack, a curved roll-rack which changes the direction of travel of the strand from vertical to horizontal, a straightener, optionally in-line work-roll stands, and finally a run-out table on which the strand is severed to appropriate lengths for further processing. Similar parts may be used with curved molds, except that there are no straight guide-roll-rack nor bending rolls, since the strand is cast with a curvature.

As the strand leaves the mold, only a thin outside skin has solidified, and the core remains liquid. The strand is subjected to intense water sprays as it passes the various rolls, referred to as "secondary cooling," whereby it solidifies throughout its cross section by the time it is severed. As long as the core is liquid, forces on the strand must be controlled carefully not to produce defects in the ultimate product. Excessive tensile stresses on a strand may cause it to crack, while excessive compression stresses may cause the strand to bulge. An earlier patent of the present co-inventor Gallucci, U.S. Pat. No. 3,550,674, and Schrewe U.S. Pat. No. 3,566,951 describe some of these problems, but the methods and mechanisms heretofore used for limiting such stresses have not attained precise and positive control we have found desirable.

An object of our invention is to provide a continuous-casting operation and apparatus in which we employ an improved method and mechanism for controlling lengthwise forces on the solidifying strand, thereby avoiding defects in the ultimate product.

A further object is to provide an improved force-controlling method and mechanism in which we apply a speed-regulating tractive force to the strand at a location preceding that where the starter bar is disconnected (e.g., at the straightener), maintain the speed-regulating force at a predetermined maximum, and apply controlled auxiliary tractive forces at other locations to minimize or eliminate stresses in the strand.

A further object, applicable to apparatus utilizing a relatively long flexible starter bar, is to provide a force-controlling method and mechanism in which we subject the strand to a speed-regulating drive at an advanced location in the line, and to a series of adjustable auxiliary tractive forces along its length between the mold and the speed-regulating drive, whereby we maintain lengthwise forces in the strand at any desired value or eliminate tension altogether in favor of a compression stress.

In the drawing:

FIG. 1 is a partly diagrammatic vertical section of a continuous-casting apparatus which utilizes a relatively long flexible starter bar and is equipped with one embodiment of our force-controlling mechanism, the parts being shown in the position they occupy shortly after the start of a casting operation;

FIG. 2 is a graph showing a typical relation of the forces on a strand in an apparatus such as that shown in FIG. 1;

FIG. 3 is a block diagram of an electric circuit suitable for use in the embodiment of our mechanism shown in FIG. 1;

FIG. 4 is a block diagram of a similar circuit, but embodying computer control for automatic operation; and

FIG. 5 is a partly diagrammatic vertical section of a continuous-casting apparatus which utilizes a rigid starter bar and is equipped with a modified embodiment of our force-controlling mechanism, the parts being shown in the position they occupy after the casting operation is underway and the starter bar disconnected.

The continuous-casting apparatus illustrated in FIG. 1 includes from top to bottom a straight mold **10**, a straight vertical guide-roll-rack **12**, a bending roll unit **13**, a curved roll-rack **14**, a straightener **15**, and a run-out table **16**. Liquid metal is introduced to the mold from a tundish **17** supported thereabove. At the beginning of a casting operation, a starter bar **18** is inserted in the lower end of the mold and extends through and beyond the straightener **15**. A partially solidified strand S emerges from the lower end of the mold and descends following the starter bar between the various sets of rolls. After the leading end of th strand S clears the straightener **15**, the starter bar is disconnected and stored in readiness to start the next cast.

Numerous variations in the structure of the casting apparatus of course are possible. The apparatus illustrated in FIG. 1 utilizes a relatively long flexible starter bar, which is not disconnected until it reaches the run-out table, but our invention in modified form can be used with apparatus which utilizes a starter bar (rigid or flexible) disconnected above the bending rolls, as shown in FIG. 5 and hereinafter described. Also it can be used with apparatus which has a curved mold, or which has a varying radius of curvature in the curved roll-rack, or which has in-line work rolls, etc., all of which are well known in the continuous-casting art.

In accordance with the embodiment of our invention illustrated in FIG. 1, the apparatus has sets of driven rolls **20** and **20***a* which engage opposite faces of first the starter bar **18** and later the strand S at an advanced location in the line and which we refer to as our "speed-regulating drive." This embodiment has a first set of auxiliary driven rolls **21**, which engage opposite faces of the strand near the bottom of the mold and which we refer to as our "No. 1 drive." Between our No. 1 drive and out speed-regulating drive, the apparatus has longitudinally spaced sets of auxiliary driven rolls **22** and **23**, which we refer to as our "No. 2 drive" and "No. 3 drive" respectively. All the other rolls shown can be idlers. In the apparatus illustrated, the rolls **20** and **20a** of our speed-regulating drive are located fore and aft of the straightener **15**; our No. 1 drive **21** is located between the guide-roll rack **12** and the bending roll **13**; our No. 2 and 3 drives **22** and **23** are located intermediate the length of the curved roll-rack **14**. Nevertheless it is apparent that the exact location and number of these drives can vary.

At our No. 1 drive **21** the strand S has only a thin skin which is easily ruptured. Hence the pressure which each roll of this drive exerts against the strand must be relatively low. In order to produce the necessary tractive force on the strand, as hereinafter explained, without exerting excessive pressure at any one location thereon, we use a plurality of closely adjacent pairs of rolls at this drive (four pairs in the illustration). At our No. 2 and 3 drives **22** and **23**, the strand still has a liquid core, but its skin is thicker. For the same reason, we prefer to use a plurality of pairs of rolls also at each of these drives, but the number can be smaller (two pairs each in the illustration). Likewise we use two pairs of rolls in the speed-regulating drive, but place them on opposite sides of the straightener, as already described.

At the beginning of a casting operation, when the starter bar **18** extends between the various sets of rolls, our speed-regulating drive **20, 20*a*** acts as a brake to restrain the starter bar from descending under its own weight. Initially we operate our auxiliary drives with their current set points at zero, whereby they act as idlers. As the casting operation proceeds, the leading end of the strand S passes through the guide roll-rack **12,** our No. 1 drive **21** (operating as an idler at this time), and into the bending roll unit **13.** As soon as the strand commences to bend, some tractive force is needed to propel it. At first the speed-regulating drive **20, 20*a*** furnishes this force. The farther the strand progresses, the greater the resistance to its movement and the greater the tractive force or torque needed to propel it at a given speed.

Conveniently the motors for the various drives can be constant-field d-c motors, which have a characteristic that at any speed their torque output is directly proportional to the current valve. When the curent to the speed-regulating drive reaches or commences to exceed a predetermined maximum (for example 10 amperes), we increase the current to our No. 1 drive to supply the increasing tractive force needed to propel the strand, and thereafter we maintain the current to the speed-regulating drive at this maximum. When the leading end of the strand successively passes through our No. 2 and 3 drives **22** and **23**, we increase the current to each of these drives in turn to supply the increasing tractive force, thereafter keeping the current constant to the speed-regulating drive and to No. 1 drive, and subsequently to No. 2 drive after No. 3 drive takes over. After the casting operation is fully underway and the strand extends all the way from the mold **10** to the run-out table **16**, the current to the speed-regulating drive **20, 20*a*** may remain at the exemplary maximum of **10** amperes, and the current to the No. 1, 2 and 3 drives **21, 22** and **23** may be at **20, 15** and **10** amperes respectively.

FIG. **2** is a graph illustrating a typical force profile on the strand when our method is practiced with the casting apparatus shown in FIG. **1.** The abscissae represent distances from the bottom of mold **10.** Positive ordinates represent tensil forces on the strand and negative ordinates compressive forces. Curve A represents the line resistance to movement of the strand through the casting apparatus. Curve B represents the force tending to move the strand through the apparatus under its own weight. Curve C represents the difference between Curves A and B, or the tractive force which must be supplied to move the strand. Curve C also represents the magnitude of tensil stresses in the strand at various points along its length if the speed-regulating drive **20** alone were used to pull the strand through the apparatus. Curve D shows an example of the magnitude of tensil stresses in the strand when our method is followed. From the mold **10** to our No. **1** drive, Curve D is the same as Curve C. At No. **1** drive we apply a tractive force to the strand and thereby place it in compression. Following No. **1** drive Curve D rises parallel with Curve C until it reaches No. **2** drive, where we again apply a tractive force which restores the compression. The same relation takes place between No. **2** drive and No. **3** drive, and again between No. **3** drive and the speed-regulating drive. In this manner the strand remains under slight compression substantially throughout the operation.

FIG. **3** illustrates in block diagram a typical electric circuit we can use for manually controlling the various drive motors. Constant-field d-c motors for the two sets of rolls **20** and **20**a of the speed-regulating drive are indicated at **26** and **26**a respectively. We energize these motors through a closed-loop speed-regulating circuit **28,** which includes a power supply **29,** an amplifier **30** and a tachometer **31.** We control the speed of motors **26** and **26*a*** through a master pilot **32,** which we can adjust either manually or through a liquid-level control mechanism on the mold, as shown for example in Tiskus et al. U.S. Pat. No. 3,300,820. The two motors **26** and **26*a*** run at essentially a constant speed, which we change only to change the strand speed. An ammeter **33** indicates the magnitude of current the motors draw to maintain this speed, which magnitude is a measure of the torque output of the motors.

When a casting operation is getting underway, the magnitude of current which the motors **26** and **26*a*** draw continually increases, since the line resistance to movement of the strand increases, as shown by Curves C and D of FIG. **2.** When this current reaches a predetermined magnitude (for example 10 amperes) as indicated by ammeter **33,** we increase the current to our No. **1** drive **21,** which has a constant-field d-c motor **36** energized through a closed-loop current-regulating circuit **37.** The latter includes a power supply **38,** an amplifier **39,** a manual load adjustment **40** and an ammeter **41.** We connect the master pilot **32** to the amplifier **39,** whereby motor **36** rotates the rolls of No. **1** drive at the same peripheral speed as the rolls of the speed-regulating drive **20, 20*a*.** We gradually increase the current to motor **36** as needed to maintain the current to motors **26** and **26*a*** at the predetermined magnitude as a maximum. Thus No. **1** drive supplies the increasing tractive force needed to move the strand. At this time the leading end of the strand S has passed No. **1** drive and is approaching No. **2** drive **22.**

Our No. **2** snd **3** drives **22** and **23** have closed-loop current-regulating circuits **44** and **45** which are similar to circuit **37** of No. **1** drive. After the leading end of the strand reaches No. **2** drive, we maintain the current to both motors **26** and **26*a*** of the speed-regulating drive and to motor **36** of our No. **1** drive at constant magnitudes and increase the current to No. **2** drive to supply the increasing tractive force needed to move the strand. After the leading end reaches No. **3** drive, we use this drive in the same fashion, keeping the current to No. **2** drive constant.

FIG. **4** illustrates in block diagram the way in which we can make the foregoing adjustments automatically. We connect a pulse generator **46** to motor **26*a*** of our speed-regulating drive to track the leading end of the strand. We connect the pulse generator **46** to a digital computer **47,** which we in turn connect to the control circuits **37**, **44** and **45** for No. **1**, **2** and **3** drives. In this manner the computer automatically adjusts the current to each drive to achieve the same effect as in the manual control already described.

FIG. **5** illustrates a continuous-casting apparatus in which the starter bar **50** is rigid and to which we may apply our invention in modified form. The apparatus includes from top to bottom a straight mold **51**, a straight vertical guide-roll-rack **52**, power-driven pinch rolls **53**, a curved roll-rack **54**, a straightener **55**, and a horizontal roll-rack **56**. The curved roll-rack has at least one switch section **57** in which some of the rolls are journaled. The switch section can open to allow the starter bar **50** to decend vertically after it is disconnected from the leading end of the strand, as shown for example in Foldessy U.S. Pat. No. 3,338,297.

When we apply our invention to an apparatus constructed as shown in FIG. **5**, the pinch rolls **53** become the speed-regulating drive. We use a plurality of closely adjacent pairs of pinch rolls to spread the force along the strand, similar to the No. **1** drive of FIG. **1**. At the beginning of a casting operation, the pinch rolls **53** engage the starter bar and act as a brake to restrain it from descending under its own weight. After the starter bar is disconnected and the switch section **57** closed, the strand S enters the curved roll-rack **54** and requires an increasing tractive force to propel it. At spaced locations along the curved roll-rack, we provide auxiliary pairs of driven rolls **58**, **59** and **60** which we again refer to as our No. **1**, **2** and **3** drives. The rolls in the straightener **55** are driven, but all the other rolls can be idlers.

At the beginning we operate the auxiliary drives **58**, **59** and **60** as idlers, the same as in the apparatus shown in FIG. **1**. When the leading end of the strand passes through No. **1** drive **58**, we increase the current to this drive to supply the increasing tractive force needed to propel the strand, and thereafter maintain the current to the speed-regulating drive (pinch rolls **53**) constant. When the leading end of the strand successively passes through our No. **2** and **3** drives **59** and **60** and finally the straightener **55**, we increase the current to each, the same as in FIG. **1**, keeping the current to the preceding drives constant.

From the foregoing description, it is seen that our invention assures that a solidifying continuously-cast strand is relieved of any excessive longitudinal stresses as it solidifies. Preferably we maintain a small compressive stress during most of the operation, as Curve D of FIG. **2** indicates. In the apparatus shown in FIG. **1**, the speed-regulating drive pulls the strand, and our auxiliary drives act to relieve excessive compressive stresses which tend to bulge the strand, as well as excessive tensile stresses. In this manner our invention avoids defects in the strand caused by lengthwise stresses, and permits a higher casting speed for crack-sensitive steel grades.

We claim:

1. In a continuous-casting operation in which a par-

tially solidified strand of indefinite length descends from the bottom of a mold and travels between series of rolls which engage opposite faces thereof;

at least some of said rolls defining a curved path in which the strand bends, whereby its direction of travel becomes substantially horizontal; and

a starter bar is connected to the leading end of said strand as the leading end emerges from the mold, but is disconnected therefrom at a location spaced below the mold;

an improved method of controlling forces on said strand comprising:

initially applying, through selected rolls of said series at a location preceding the location at which the starter bar is disconnected, a force restraining descent of said starter bar and said strand;

subsequently using said selected rolls to apply a speed-regulating tractive force to said strand as the leading end thereof advances through said curved path and a tractive force is required to propel the strand;

initially operating other selected rolls of said series substantially as idlers, which other selected rolls have the capability of being driven and of applying auxiliary tractive forces to said strand;

energizing the drive to the first of said other selected rolls nearest the mold when said speed-regulating tractive force reaches a predetermined maximum;

sequentially energizing the drives to the succeeding other selected rolls as the leading end of said strand advances farther along said curved path and the force on the immediately preceding other selected rolls in turn reaches a predetermined maximum;

whereby lengthwise stresses in said strand are minimized through the operation.

2. A method as defined in claim **1** in which the speed-regulating force is applied to the strand at an advanced location in the line and pulls the strand through the line, and said auxiliary forces are applied at locations preceding said speed-regulating force and act to relieve tensile stresses in the strand.

3. A method as defined in claim **1** in which the line includes a straightener following said curved path, said speed-regulating force being applied at said straightener.

4. A method as defined in claim **3** in which the first of said auxiliary forces is applied at a location near said mold, and the others of auxiliary forces are applied at locations between the first auxiliary force and said speed-regulating force.

5. A method as defined in claim **1** in which the speed-regulating force is applied to the strand at a location near the mold and pushes the strand through the line, and said auxiliary forces are applied at locations following said speed-regulating force and act to relieve excessive compressive stresses in the strand.

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