United States Patent

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[54] LONG BAND LIFE WHEEL-BAND CASTING MACHINE

9 Claims, 7 Drawing Figs.

[52] U.S. Cl. 164/278
[51] Int. Cl. B22d 11/06
[50] Field of Search 164/82, 87, 89, 278, 281

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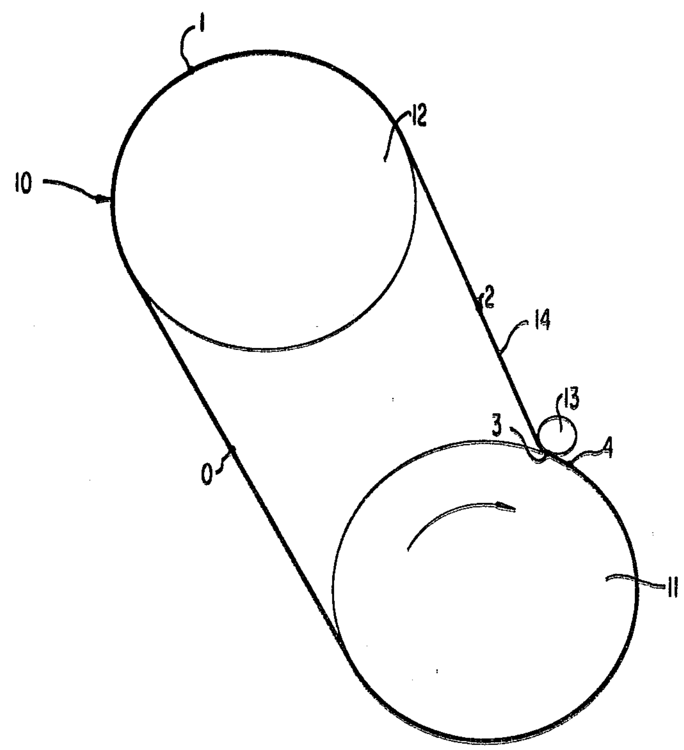
ABSTRACT: A machine for continuously casting metal wherein an endless flexible band is guided into closed relationship with a portion of the peripheral groove of a rotatable casting wheel by a plurality of band guide wheels of substantially the same diameter, and a band positioning wheel of smaller diameter than the band guide wheels is positioned adjacent the periphery of the rotatable casting wheel and is arranged to press the flexible band into positive contact with the casting wheel. The ratio between the thickness of the flexible band and the diameter of the smaller band positioning wheel is such that no more than three times the bending strain is applied by the smaller band positioning wheel to the flexible band than the strain applied by the other band guide wheels.



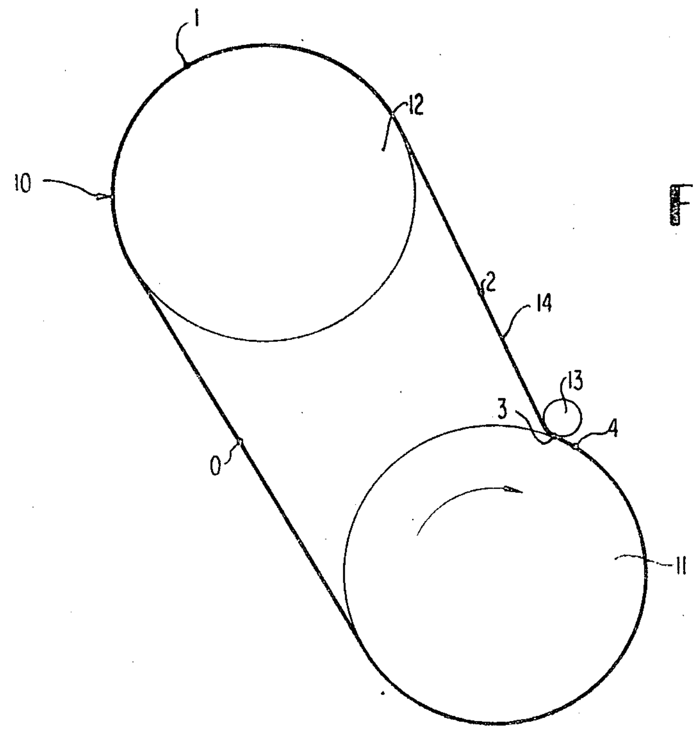
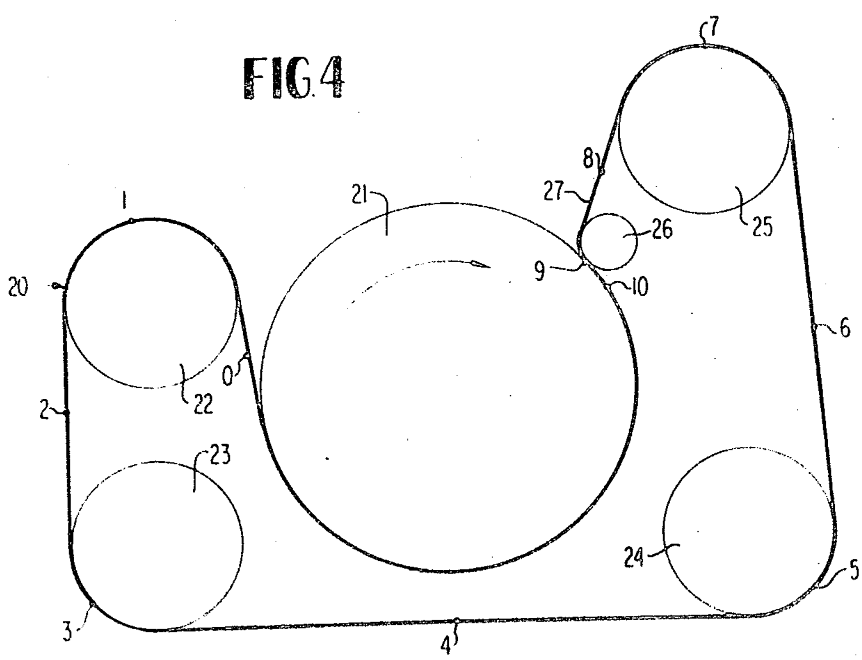


FIG.1

FIG.4



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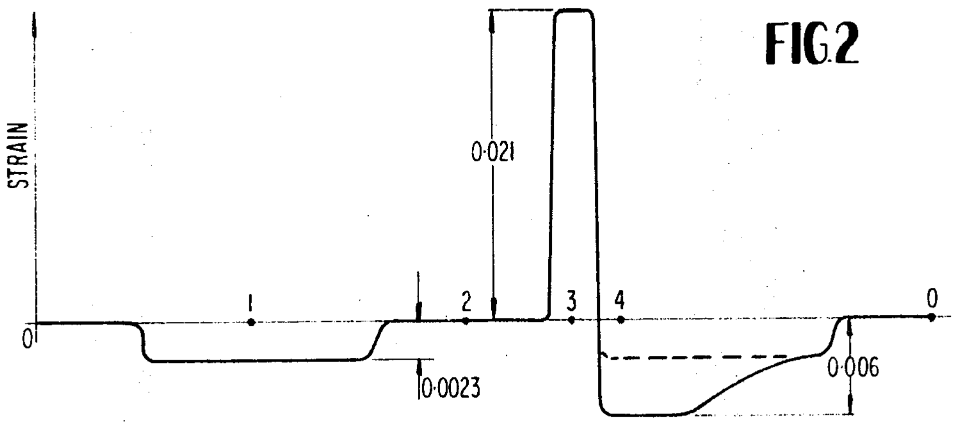
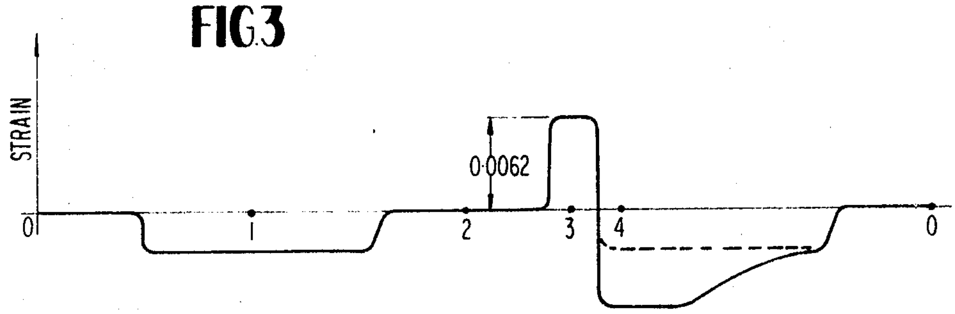


FIG.2

FIG.3



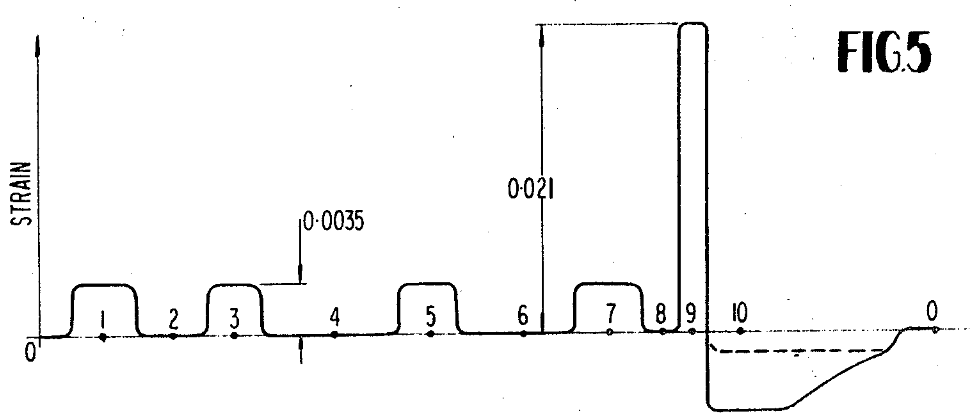


FIG.5

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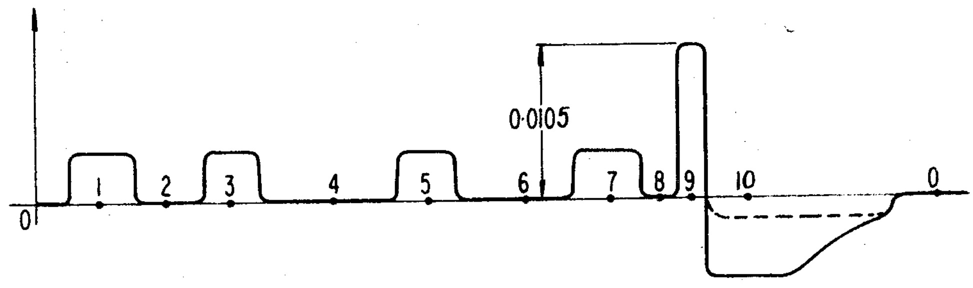
3 Sheets-Sheet 3

FIG 6



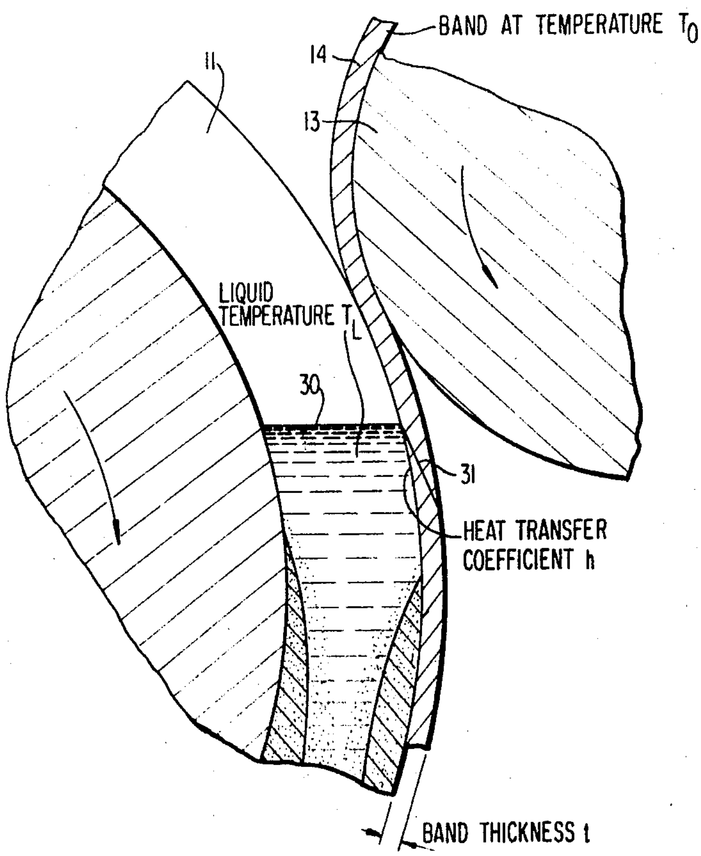


FIG 7

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LONG BAND LIFE WHEEL-BAND CASTING MACHINE

BACKGROUND OF THE INVENTION

In a typical system for continuously casting metal, such as copper, steel or aluminum, an endless flexible metal band is guided about a portion of the peripheral groove of a rotatable casting wheel, and molten metal is poured into the moving mold formed by the band the peripheral groove in the wheel. As the casting wheel rotates, coolant is applied to its external surfaces and to the outside surface of the portion of the band that closes the peripheral groove of the casting wheel to extract the heat from the molten metal at a rapid rate and to prevent the casting wheel and band from overheating. By the time the metal band is removed from the peripheral groove of the casting wheel by the band wheels, the molten metal will have been solidified and can be extracted from the casting wheel and passed on to another stage in the continuous process.

The function of the band guide wheels is to guide the band into engagement with the periphery of the casting wheel to form the arcuate mold, and then to remove the band from the periphery of the casting wheel to open the mold, and guide the band back to its initial mold forming position. One arrangement is to have a single large tensioning wheel spaced above the casting wheel and have the inner surface of the flexible band extend about both the casting wheel and the tensioning wheel. The other typical arrangement is to have the band pass beneath the casting wheel during its return flights, with the band guide wheels engaging the "outer" surface of the band. In both arrangements it is desirable to guide the band away from the area above the casting wheel so that the equipment necessary for pouring the molten metal into the mold and extracting the solidified metal from the mold can be positioned in this space. Thus, the tensioning wheel or band guide wheels must be sized and positioned to guide the band away from the upper portion of the casting wheels; however, in order that the band be guided away from the upper portion of the casting wheel, it has been found necessary to utilize a relatively small band presser wheel or band positioning wheel to position the band adjacent the casting wheel and urge the band into its initial engagement with the periphery of the casting wheel. The band positioning wheel is of small diameter in order to keep the area above the casting wheel relatively free from encumbrance by the band.

In the operation of a continuous casting machine of the types generally set forth above, one of the major maintenance problems is the care and replacement of the band. It is necessary that the band be of relatively small thickness so that it can bend and flex as it passes around the casting wheel and band wheels. Also, a relatively thin band transfers the heat from the molten metal more rapidly than a thicker band and allows the molten metal to solidify more rapidly; however, the relatively thin band is more likely to become overheated from the transfer of heat from the molten metal and deteriorate more rapidly than a relatively thick band. Thus, the endless flexible metal band utilized with a continuous metal casting machine must be fabricated with a thickness to withstand substantial heat deterioration, and yet be thin enough to flex around the band wheels. The continual bending and flexing of the band about the smaller band positioning wheel has the most damaging effect on the band since the band must undergo a curvature of a shorter radius when passing around this band wheel, and the strain felt by the band from the smaller band wheel tends to rapidly deteriorate the band.

SUMMARY OF THE INVENTION

Briefly described, the present invention comprises a casting machine for continuously casting metal which includes a relationship between the band thickness and the diameter of the band wheels that extends the life of the band. The ratio between band thickness and the diameter of the smaller band positioning wheels is maintained at a low level to reduce the strain felt by the band material as it passes around the band positioning wheel during each cycle of the band. While the diameters of the larger band guide wheels are sufficiently large to prevent excessive strain in the band as it passes over these guide wheels, the band positioning wheel next adjacent the casting wheel which urges the band into engagement with the casting wheel at the pouring spout has been enlarged so that the strain experienced at this location is no more than three times the strain experienced at the other band wheels.

Thus, it is an object of this invention to provide a casting machine for continuously casting metal which includes a band and band wheel arrangement that extends the life of the band over the previously known casting machines.

Another object of this invention is to provide a casting machine for continuously casting metal that requires less maintenance than the prior art.

Other objects, features and advantages of the present invention will become apparent upon reading the following specification, when taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic illustration of a casting machine for continuously casting metal wherein the inner surface of the band is passed around the casting wheel and a tension wheel, and the outer surface of the band is engaged by a smaller band positioning wheel.

FIGS. 2 and 3 are graphs which illustrate band strain of the band of the casting machine of FIG. 1; FIG. 2 illustrating band strain with the use of a relatively small band positioning wheel, and FIG. 3 illustrating band strain with the use of a relatively large band positioning wheel.

FIG. 4 is a schematic illustration of a casting machine for continuously casting metal wherein the band is guided with its inner surface engaging the casting wheel and its outer surface passing around the band wheels.

FIGS. 5 and 6 are graphs similar to those of FIGS. 2 and 3 and illustrate band strain of the band of the casting machine of FIG. 4; FIG. 5 showing band strain when a relatively small band positioning wheel is used, and FIG. 6 illustrating band strain when a larger band positioning wheel is used.

FIG. 7 is a schematic detail illustration of the intersection of the band with the casting wheel.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in more detail to the drawing, in which like numerals indicate like parts throughout the several views, FIG. 1 shows a casting machine **10** which includes casting wheel **11**, band tension wheel **12**, and band positioning wheel **13**. Continuous flexible band **14** extends around casting wheel **11** and band tension wheel **12** and forms an arcuate mold with the peripheral groove (not shown) of casting wheel **11**. Band positioning wheel **13** urges band **14** into engagement with the periphery of casting wheel **11**.

The graphs of FIGS. 2 and 3 represent band strain as the continuous flexible band **14** passes through a cycle about casting wheel **11** and band tension wheel **12**. The numbered points along the abscissas of the graphs illustrate the corresponding numbered positions about the casting machine, and the ordinates of the graphs illustrate the amount of strain felt by the band. The difference between FIGS. 2 and 3 is the amount of strain felt by the band at point 3 in the band cycle, where a larger band positioning wheel **13** is used for the cycle of the graph of FIG. 3, and a smaller band positioning wheel **13** was used for the cycle of the graph of FIG. 2.

FIG. 4 shows casting machine **20** which includes casting wheel **21**, band guide wheels **22**, **23**, **24**, and **25**, band positioning wheel **26**, and endless flexible metal band **27**. The inner surface of band **27** extends about casting wheel **21** and defines a mold with the peripheral groove (not shown) of the casting wheel. The outer surface of band **27** extends about band guide wheels **22—25**, and about band positioning wheel **26**.

FIGS. 5 and 6 are graphs of the strain felt by band 27 as it passes through a cycle about casting machine 20. As with FIGS. 2 and 3, the positions indicated along the abscissas of the graphs of FIGS. 5 and 6 indicate the various corresponding positions noted in FIG. 4 in a single band cycle, with the difference in FIGS. 5 and 6 being that a larger band positioning wheel 26 was used for the cycle of the graph of FIG. 6 while a smaller band positioning wheel was used for the cycle of the graph of FIG. 5.

In both FIGS. 1 and 4 the illustrations are schematic and the relative sizes of the elements of the casting machines are not to scale, particularly the sizes of band positioning wheels 13 and 26. Furthermore, it will be apparent from FIGS. 2, 3, 5, and 6 that the sizes of band positioning wheels 13 and 26 are variable for the purpose of illustrating the disclosed invention.

The continuous metal bands 14 and 27 4 where flexible, and as with any material they are subject to failure due to fatigue from continuous flexing as the bands pass around the various band wheels and due to the thermal shock experienced in each cycle of the band from the heat exchange from the molten metal poured into the arcuate mold formed between the band and the casting wheel. When the bands are bent about the casting wheel or one of the guide wheels, the theoretical strain setup in the band surface is

$$e=(t/D)$$

where t is the band thickness and D is the wheel diameter. The strain is in the tension on the outside or convex surface of the band and the compression on the inside or concave surface of the band next to the wheel about which it is passing. Of course, there is also some band strain experienced continuously by the band due to initial tightening of the band about all of the wheels; however, this portion of the band strain is slight and can be ignored for the purposes of this disclosure since a similar strain is present in all casting machines of similar construction.

When the molten metal is poured into the arcuate mold formed between the band and the casting wheel, the bending strain due to the heat gradient across the thickness of the band will depend on the rate of heat transfer through the band, and on the ability of the band to deform. As is shown in FIG. 7, the molten metal 30 initially contacts band 14 when the band is relatively cool and immediately heats band 14 to its highest temperature thus causing a substantial thermal shock. The temperature gradient is illustrated at 31. Of course, the increased temperature causes the band to expand lengthwise, and since the surface of the band in direct contact with the molten metal is hotter than the outer surface of the band, the inner surface will tend to expand more than the outer surface. If the band were not under tension and extended about the casting wheel, it would normally bend away from the casting wheel. Thus, in order to extend the band around the curvature of the casting wheel a substantial bending strain is exerted in the band. The bending strain will be proportional to the difference in band surface temperature and band average temperature. To illustrate the conditions of a band extending about a casting wheel with its inner surface in contact with molten metal and its outer surface having coolant applied to it, the thermal strain can be assumed to be the same as that of a band of twice the thickness of band 14, thermal shocked on both sides and cool in the center. A band under these conditions would not bend and would have the same difference between surface and center temperatures as the inner and outer surface temperatures of band 14.

To determine the bending strain of the band, the maximum thermal stress at the surface is:

$$\frac{1}{\sigma^*\ \mathrm{max}}=1.5+\frac{3.25}{B}$$

where σ^* is a dimensionless stress and is given by:

$$\sigma^*=(\sigma/E\ a\ (T_L-T_0))$$

or:

$$\sigma^*=(e/a(T_L-T_0))$$

where B is the Biot number, E is the modulus of elasticity, a is the thermal expansion coefficient, (T_L-T_0) is the temperature difference between the molten metal and the band, h is the surface heat transfer coefficient, k is the band thermal conductivity, t is the band thickness.

$$B=(h(2t)/k)$$

For an example of a steel band and molten copper:

$$B=\frac{(2000)\frac{1}{(4\times12)}}{25}$$

Therefore:

$$\sigma^*_{max}=0.29$$

Taking a as 6.5×10^{16} in/in. –°F. and (T_L-T_0) as 2000° F., we have:

$$e_{max}=\sigma^*_{max}\ a\ (T_L-T_0)$$

$$e_{max}=0.0038 \text{ in/in.}$$

This is a compressive thermal strain set up in the band surface adjacent the molten copper and is assumed to be approximately the same for all casting machines.

To estimate band life on a casting machine, reference is made to FIGS. 1 and 2 of the drawing where a band cycle is plotted. Point 0 is the beginning point of the graph of FIG. 2 and the point on the band after it has left the casting wheel. As the band travels around the machine, it undergoes various bending strain conditions as illustrated at the other point of the figures. At point 1, the strain is given by (t/D), where t=⅛ inches and D=55 inches, and as illustrated on the graph of FIG. 1, is 0.0023 inch per inch. The remaining portion of the graph of FIG. 2 plots the strain experienced by the band as it travels through one band cycle back toward the 0 position. It will be noted that a relatively small strain is felt by the band at position 1, while a relatively large strain is felt at position 3. Positions 1 and 3 are located in the middle of the curvature of the band as it passes about tension wheel 12 and band positioning wheel 13, and a graphic presentation is made of band strain at these positions. Position 4 on the graph indicates strain of the band due to the thermal gradient across the band added to band bending strain due to bending the band around the curvature of the casting wheel; the band strain due to its curvature being illustrated by the dashed line.

Theoretically, each band can pass around the wheels of a casting machine a certain number of times before it fails. This is called band life, and a relationship has been established between the strain felt by a band during each cycle and its life. If n_i represents the number of times a certain strain occurs in a band cycle, and N_i is the life associated with this strain range, we can determine the number of band cycles, N, to failure:

$$\sum_{1}\frac{n_i N}{Ni}=1$$

For example, in casting machine 10 of FIG. 1 the strain of 0.0023 occurs once, the strain of 0.021 occurs once, and the strain of 0.006 occurs once. The band life associated with each of these strains, is respectivelY:

2×10^5 cycles, 7.5×10^2 cycles, 10^4 cycles.

Therefore, the number of band cycles to failure are:

$$4.48\times10^2$$

Since band failure as calculated above is for complete fracture of the material and it is expected that visible cracks in the band will appear long before the band fractures, under normal situations the band will be removed from the casting machine before its fracture.

It is acknowledged that there are various other parameters that should be considered for an absolutely accurate determination of band life. For instance, the temperature of the molten metal will vary, the rate of cooling of the casting wheel and band is determined by coolant volume and temperature and will vary, the tension applied to the band material and the length of the band will vary, the width of the band and the portion of the band that does not come into contact with the molten metal may vary, and there will be variations in the thickness of the band. These and other varying parameters are likely to be present in every casting machine; but for our purposes, we have merely established a relationship between band life and the bending of the band

As illustrated by the data in FIGS. 2 and 3, when band positioning wheel **13** is 6 inches in diameter and the band thickness is one-eighth inches, the coefficient of strain, $e=t/D$ is 0.021 whereas, when band positioning wheel **13** has a diameter of 20 inches, the coefficient of band strain is only 0.0062 when using the same one-eighth inch band. Thus, since the reduction of band strain in each band cycle extends band life, the use of a larger diameter band positioning wheel **13** functions to extend the life of band **14**. Similarly, if the thickness of band **14** was reduced, band life would also be extended. Thus, to extend band life, the ratio between band thickness and wheel diameter must be as low as practical in keeping with heat deterioration problems previously discussed.

A comparison of the graphs of FIGS. **5** and **6** also disclosed that the use of a larger band positioning wheel **26** in casting machine **20** reduces band strain, and increases band life. FIG. **5** illustrates data for a band positioning wheel **26** of a diameter of 6 inches and a band thickness of one-eighth inch. FIG. **6** illustrated data for the same casting machine but with a band positioning wheel **26** having a diameter of 12 inches and a band thickness of one-eighth inch. While the strain at position **9** in the band cycle is 0.021 for the smaller band positioning wheel **26**, the strain is only 0.0104 for the larger band positioning wheel. Obviously, the band life will be prolonged with the use of the larger band positioning wheel **26**.

To extend band life, it would be desirable to form band positioning wheels **13** and **26** with diameters as large as the band tensioning wheel **12** or band guide wheels **22—25**; however, the space requirements above casting wheels **11** and **21** require that smaller diameter band positioning wheels be utilized. Thus, while the strain encountered in the bands at positions **3** (FIG. **1**) and **9** (FIG. **4**), must necessarily be in excess of the strains in the band as the band passes around band guide wheels **22—25** and band tensioning wheel **12**, it is desirable to hold the strain encountered in the band to a level no greater than the strain in the band as the band contacts the molten metal, so the band thickness and materials can be selected and gauged for only the highest necessary strain in a single cycle of the band. Since band stain virtually cannot be reduced through a level below that encountered in positions 4 (FIG. 1) and **10** (FIG. **4**), it is unnecessary to enlarge the diameters of band positioning wheels **13** and **26** to hold the strain below the necessarily high strain level since further enlargement of the band positioning wheels would cause the wheel to occupy an excessive amount of space above the casting wheel.

This band strain limits for the band positioning wheels for the examples shown are calculated:

$$e=(t/D)<(1/90).$$

The band thicknesses are between approximately 0.0747 inch and 0.125 inch, and the band positioning wheels are 12 inches and larger for casting machines of the type illustrated in FIG. 4 and 20 inches and larger for the casting machines of the type illustrated in FIG. **1**. The diameter of the guide wheels of the FIG. **4** casting machines were 36 inches and the diameter of the tensioning wheel of the FIG. **1** casting machine was 60 inches. Thus, the ratio between positioning wheel diameter and guide wheel diameter and guide wheel or tensioning wheel diameter is maintained at one to three. This ratio is suitable since approximately three times the amount of band strain is experienced when the band first encounters the molten metal as is experienced when extending about a guide wheel.

While this invention has been described in detail with particular reference to preferred embodiments thereof, it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described hereinbefore and as defined in the appended claims.

I claim:

1. In a machine for continuously casting metal wherein an endless flexible band is guided into closed relationship with a portion of the peripheral groove of a rotatable casting wheel, guided away from the peripheral groove, and returned on the same side of the casting wheel to the peripheral groove by a plurality of band guide wheels of substantially the same diameter and a band positioning wheel of smaller diameter than the band guide wheels is positioned adjacent the periphery of the rotatable casting wheel and arranged to press the flexible band into positive contact with the casting wheel, the improvement therein of the ratio between the thickness of the flexible band and the diameter of the band positioning wheel being lower than one to 90.

2. The invention of claim **1** and wherein the thickness of the flexible band is in the range of from 0.0747 inch to 0.125 inch, and the diameter of the band positioning wheel is greater than 12 inches.

3. The invention of claim **1** wherein the diameter of band positioning wheel is at least one-third as large as the diameter of the band guide wheels.

4. The invention of claim **1** wherein the diameter of the band positioning wheel is sized to impart no more than three times the bending strain to the flexible band than the band guide wheels.

5. The invention of claim **1** wherein the diameter of the band positioning wheel is sized to impart no more bending strain to the flexible band than the strain felt by the band as it passes about the casting wheel and is in direct contact with molten metal.

6. In a machine for continuously casting metal wherein the inner surface of an endless flexible band partially about the peripheral groove of a casting wheel and about a tensioning wheel spaced from the casting wheel and a band positioning wheel is placed adjacent the casting wheel and engages the outer surface of the band urges the inner surface of the band into engagement with the casting wheel, the improvement therein of the ratio of band thickness to band positioning wheel diameter being smaller than one to 90.

7. The invention of claim **6** wherein the band tensioning wheel diameter is greater than three times the positioning wheel diameter.

8. The invention of claim **6** wherein the band positioning wheel is sized and arranged to impart no more than three times the bending strain to the flexible band than the tensioning wheel.

9. The invention of claim **6** wherein the diameter of the and positioning wheel is sized to impart no more strain to the flexible band than the strain felt by the band as it passes about the casting wheel and is in direct contact with molten metal.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,596,705 Dated August 3, 1971

Inventor(s) John H. Murphy

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

Claim 6, line 2 (column 6, line numbered 41), after "flexible band" insert -- extends --;

Claim 6, line 6 (column 6, line numbered 45), after "band" insert --and--;

Claim 9, line 1 (column 6, line numbered 56), change "and" to --band--.

Signed and sealed this 8th day of February 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents