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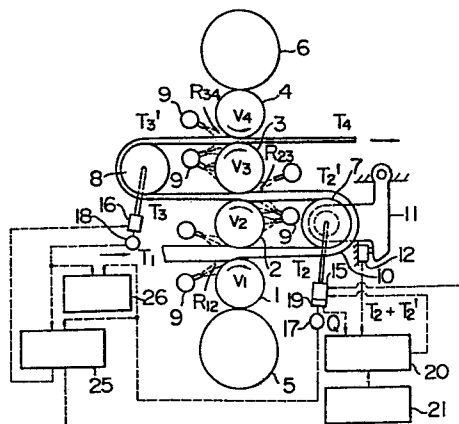
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54 A different circumferential speed rolling mill.

57 A different circumferential speed continuous rolling mill including a plurality of rolls (1,2,3,4;5,6,) including one roll cooperating with other rolls to roll a trip simultaneously at a plurality of rolling points to continuously roll the strip by rotating the one roll at a circumferential speed distinct from the circumferential speed of other rolls, is equipped with a tension difference applying device (7,11,12;8) located in a path of travel of the strip between a first rolling point at which the strip is brought into contact with the one roll and rolled thereby and a second rolling point at which the strip is brought into contact with the one roll again and rolled thereby after clearing the first rolling point, so as to thereby create a difference in the tension applied to the strip between a portion of the strip located at an delivery end of the first rolling point and a portion of the strip located at an delivery end of the second rolling point. The tension difference applying device is operative to increase the tension applied to a portion of the strip located between the first rolling point of the one roll and the tension difference applying device and decrease the tension applied to a portion of the strip located between the tension difference applying device and the second rolling point of the one roll. Thus rolling energy can be fed to the strip not only from the rolls but also from the tension difference applying device to enable continuous rolling with a high degree of efficiency.

FIG. 5



A DIFFERENT CIRCUMFERENTIAL SPEED ROLLING MILL

1 FIELD OF THE INVENTION

This invention relates to different circumferential speed continuous rolling mill capable of increasing the rolling reduction.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a four-high rolling mill of the prior art;

Fig. 2 is a schematic view of a different circumferential speed five-high rolling mill of the prior art;

10 Fig. 3a is a view in explanation of a rolling performed at a constant rolling speed referred to as an NR rolling;

Fig. 3b is a view in explanation of a rolling performed at a different rolling speed referred to as a
15 PV rolling;

Fig. 3c is a view in explanation of a rolling performed at intermediate between those of the NR rolling and PV rolling which is referred to as an NPV rolling;

Fig. 4 is a schematic view of a continuous
20 rolling system of the prior art;

Fig. 5 is a schematic view of an embodiment of the different circumferential speed continuous rolling mill according to the invention;

Fig. 6 is a schematic view of another embodiment

1 of the different circumferential speed continuous rolling
mill according to the invention;

Fig. 7 is a diagrammatic representation of the
relation between the rolling speed and the coefficient of
5 friction with reference to coolant oils;

Fig. 8 is a view in explanation of balancing
of forces exerted in strip material being rolled by the
rolling mill according to the invention;

Fig. 9 is a characteristic view showing allowable
10 maximum rolling reductions in relation to rolling roll
diameters;

Fig. 10 is a schematic view of a further
embodiment of the different circumferential speed continuous
rolling mill according to the invention; and

15 Fig. 11 is a schematic view of a still further
embodiment of the different circumferential speed continuous
rolling mill according to the invention.

DESCRIPTION OF THE PRIOR ART

In recent years, there has been a strong desire
20 to convert production system from that of independent
stands to that of a plurality of stands integrated into a
single production line, to save power and labor. In this
regard, installations have already been realized which
are designed to provide facilities in a single production
25 line for performing cold rolling, cleaning, annealing
and temper rolling. In this case, the speed of the
production line would largely be governed by the speed at

1 which continuous annealing is performed. Generally, the
rolling speed of a cold rolling mill is 3-5 times as high
the speed at which annealing is performed from the point
of view of economy. Thus, integration of cold rolling and
5 annealing into a single line of production would rise
to the problem that the speed at which rolling is effected
would have to be reduced to an economically unacceptable
level. To obviate this problem, it would be necessary
to meet the economic requirement by reducing the number
10 of groups of rolling mills or the number of stands of a
standem mill.

Fig. 1 shows a four-high rolling mill (hereinafter
4H mill) typical of rolling mills of the prior art.

The 4H mill comprises upper and lower working rolls 1 and
15 2 supported by backing-up rolls 4 and 5 respectively to
perform rolling between the upper and lower working rolls
1 and 2. Although not shown, the 4H mill further comprises
other expensive equipment, including a roll stand, a
screw-down device, a roll drive, etc. Thus, if an
20 additional working roll were used with a 4H mill to
enable rolling simultaneously at two rolling points as
shown in Fig. 2, excellent economic effects could be
achieved. However, there is some snag which stands in
the way of realizing benefits from use of an additional
25 roll for the aforesaid purpose. In performing rolling
in a usual manner, the working rolls 1 and 2 or 2 and 3
which form a set have the same circumferential speed which
is substantially equal to the delivery speed of a rolled

1 strip and the entering speed of the roller strip is lower
 than the circumferential speed of the rolls by a magnitude
 substantially corresponding to the rolling reduction
 rate γ . When rolling is performed by the rolling mill
 5 shown in Fig. 2, circumferential speeds v_1 , v_2 and v_3 of
 the upper and lower working rolls 1, 2 and 3 respectively
 are equal to one another. Thus, the following relation
 holds:

$$v_1 = v_2, v_2 = v_3$$

10 Accordingly, $v_1 = v_2 = v_3$, and a strip to be rolled 10 by
 the working rolls 1 and 2 has a speed v_{s2} which has the
 following relation:

$$v_{s2} \approx v_2 = v_3 \approx v_{s3}$$

The rolled strip 10 introduced to between the
 15 working rolls 2 and 3 has a speed v_{s2}' which has the
 following relation:

$$v_{s2} \approx v_{s3} (1 - \gamma) = v_{s2} (1 - \gamma)$$

Thus, $v_{s2}' < v_{s2}$ and the rolled strip 10 will
 have a loop at the delivery end of the working rolls 1 and
 20 2. This makes it necessary to use a loop car 6 for
 accommodating the loop of the rolled strip 10.

Assume that the rolled strip 10 delivered from

1 the working rolls 2 and 3 has a speed $v_{s3} = 500$ m/min,
and a rolling reduction rate γ of the working rolls 2 and
3 is $\gamma = 30\%$. Then, the speed V at which the loop car
6 should move while rolling is being performed can be
5 expressed as follows:

$$\begin{aligned} V &= \frac{v_{s2} - v_{s2}'}{2} = \frac{1}{2} \{v_{s2} - v_{s3} (1 - \gamma)\} \\ &= \frac{1}{2} v_{s3} \{1 - (1 - \gamma)\} = \frac{1}{2} v_{s3} \gamma = \frac{500}{2} \times 0.3 \\ &= 75 \text{ (m/min)} \end{aligned}$$

Thus, the loop car should be moved at the speed of 75 m/min
10 during rolling, making it impossible to use the loop car
6 with a production line for performing continuous rolling.

To eliminate this condition, the requirement
 $v_{s2} = v_{s2}'$ should be met. To this end, it is necessary
that at least the relation $v_3 > v_2$ or $v_2 > v_1$ should hold.
15 This is already known as different circumferential speed
rolling (PV).

To enable the invention to be better understood,
the different circumferential speed rolling will be
outlined. Fig. 3a shows constant circumferential speed
20 rolling (NR) of the prior art in which the circumferential
speed of the roll becomes equal to the speed of the
rolled strip at a neutral angle ϕ in both the upper and
lower working rolls. Let the neutral angles of the upper

1 and lower working rolls be denoted by ϕ_1 and ϕ_2 respectively. Then the following relation holds:

$$\theta > \phi_1 = \phi_2 > 0$$

In this case, a drive torque of the roll gives
 5 a tangential force F to a rolled strip by the friction between the rolls and the rolled strip. The force F is maximized as designated by F_0 when $\phi_1 = \phi_2 = 0$. Assume that, when $\phi_1 = \phi_2 > 0$, a rolling pressure P and a
 10 coefficient of friction μ between the rolls and the rolled strip are approximately constant during the time they are in contact with each other. Then, the following relation holds:

$$\begin{aligned} F &= F_0 \frac{(\theta - \phi_1) - \phi_1 + (\theta - \phi_2) - \phi_2}{2\theta} \\ &= F_0 \frac{\theta - (\phi_1 + \phi_2)}{\theta} \dots\dots\dots (1) \end{aligned}$$

15 If $\phi_1 = \phi_2 = \phi$, then the following relation holds:

$$F = F_0 \frac{\theta - 2\phi}{\theta} = F_0 \left(1 - \frac{2\phi}{\theta}\right) \dots\dots\dots (2)$$

In the PV rolling shown in Fig. 3b, the following equation can be obtained by substituting $\phi_1 = \theta$ and $\phi_2 = 0$

1 equation (1):

$$F = F_0 \frac{\theta - (\theta + 0)}{\theta} = 0 \quad \dots\dots\dots (3)$$

Thus, it is not possible for the upper and lower rolls to conjointly give a tangential force to the rolled strip.

5 That is, the rolls are incapable of supplying energy necessary for effecting rolling to the rolled strip, and instead the difference in the tension of the rolled strip between the entering and delivery ends of the nip of the rolls is utilized. This relation is expressed by the
10 following equation:

$$\sigma_d - \sigma_e = S l_n \frac{1}{1 - \gamma} \quad \dots\dots\dots (4)$$

where σ_d , σ_e : tension (kg/mm^2) of the rolled strip at delivery and entering end.

15 S : means deformation resistance (l g/mm^2) of the rolled strip.

γ : rolling reduction rate

Assume that rolling is performed at a rolling reduction rate of 50% for example. Then, the tension is very high as shown by $\sigma_d - \sigma_e = 0.69S$, so that there is the risk of
20 the rolled strip being ruptured. However, this rolling process offers the advantage that the rolling load is greatly reduced because a shearing force is exerted on the rolled strip in addition to a vertical pressure and a

1 peak of the rolling pressure referred to as a friction
hill usually produced in NR rolling does not appear.

Fig. 3c shows NPV rolling which is intermediate
between the NR rolling and PV rolling and intended to
5 obviate the defects of the PV rolling while sacrificing
its merits to a certain extent.

In this case, the tangential force F can be
expressed, from equation (1), as follows because $\phi_2 \approx 0$:

$$F = F_0 \frac{\theta - \phi_1}{\theta}$$

10 Since $\theta > \phi_1$, $F > 0$.

When this process is used, it is possible to
obtain a reduction in rolling load and perform different
circumferential speed rolling without excessively increas-
ing the tension of the strip.

15 Thus, if it is possible to perform different
circumferential speed rolling, it is possible to perform
continuous rolling in which the same roll simultaneously
performs rolling at two rolling points without the risk
of developing a loop. Fig. 4 shows the manner in which
20 continuous rolling is performed by the NPV rolling process,
in which the strip 10 to be rolled is successively rolled
by the rolls 1, 2, 3 and 4 and, following completion of
rolling, the strip 10 is wound on the rolls 2 and 3 to be
rolled again. In this case, the PV rolling process and
25 NPV rolling process may be used. It is not possible to

1 use the NR process, as aforesaid. Table 1 summarized the characteristics of continuous rolling performed by the PV and NPV rolling processes.

Table 1 Characteristics of Continuous Rolling Process PV

Rolling Point	R_{12}		R_{23}		R_{34}	
Associated Rolling Roll	#1	#2	#2	#3	#3	#4
Rolling Torque	-100	+100	-100	+100	-100	+100
Individual Roll Torque	 -100	 0	 0	 +100		
Total Torque	0					

In the rolling mill shown in Fig. 4 in which the PV continuous rolling process is used, the circumferential speeds v_1 , v_2 , v_3 and v_4 of the rolling rolls and the speeds v_{s1} , v_{s2} , v_{s3} and v_{s4} of the strip have the following relation:

$$v_1 = v_{s1}, v_2 = v_{s2}, v_3 = v_{s3}, v_4 = v_{s4}$$

10 Thus, in Fig. 4, when one considers the rolling torque, it will be seen that the roll 4 designated by #4 roll in Table 1 has a torque of plus 100 and the roll 3 designated by #3 roll in Table 1 has a torque of minus 100 at the rolling point R_{34} and a torque of plus 100 at 15 the rolling point R_{23} with the effects of winding the strip on the roll 3 omitted. The results obtained with

the rolls 2 and 1 are as shown in Table 1 by referring to #2 and #1 rolls respectively. Thus, the total torque of the four rolls becomes zero, and the energy necessary for performing rolling should be obtained by the difference in the tension given to the strip between the entrance and the delivery of the rolling point as shown by equation (4).

In normal rolling of the prior art, the rolling reduction rate is about 30 - 50%. If it is desired to perform three pass rolling simultaneously, then a rolling reduction of 66 - 87% corresponding to three pass rolling performed at the rate of 30 - 50% is desirable. If this rolling reduction is to be achieved only by the difference in tension applied to the strip, then the following relation is obtained from equation (4) and rupture of the strip might result:

$$\begin{aligned}\sigma_d - \sigma_e &= S l_n \frac{1}{1 - \gamma} = S l_n \frac{1}{1 - 0.66} \sim S l_n \frac{1}{1 - 0.87} \\ &= 1.08 \sim 2.5\end{aligned}$$

Also, to keep the tension σ_d at the level of 0.1S $\sim$ 0.38S for normal stable rolling, the rolling reduction should be kept at a low level which would defeat the aforesaid purpose.

From the consideration set forth hereinabove, it will be seen that the PV continuous rolling process has little practical value. Then, let us consider the NPV

1 continuous rolling process. This rolling process enables
the intermediate rolls or #2 roll and #4 roll to supply
positive energy to the rolling mill because these rolls
have a torque of not $+100 - 100 = 0$ but a torque of over
5 unity. It is necessary that a suitable value be selected
for this torque or a circumferential speed in such a manner
that no loop is formed by the strip on the delivery end
of the rolling point or excessive slip of the rolls with
respect to the strip is avoided. Experiments were
10 conducted on single pass different circumferential speed
rolling. The results show that the rolling can be performed
stably when the rolling torque on the low speed side is
up to minus 50 while the rolling torque on the high speed
side is kept at plus 100. Thus, if the torque on the
15 minus side is kept at 50, then it is possible to obtain a
rolling torque distribution shown in Table 2 in which it
will be seen that the total torque is plus 150 and a critical
slip force approximate to that of normal rolling is
obtained in spite of the rolling being performed by varying
20 the roll speed.

Table 2 Characteristics of Continuous Rolling Process NPV

Rolling Point	R_{12}		R_{23}		R_{34}	
Associated Rolling Roll	#1	#2	#2	#3	#3	#4
Rolling Torque	-50	+100	-50	+100	-50	+100
Individual Roll Toruge	 -50	 +50		 +50		 +100
Total Torque	+150					

1 In Fig. 4 is shown a rolling mill in which the NPV continuous rolling process is incorporated. In this rolling mill, the following relation holds:

$$V_{s2} > v_1 > v_{s1}, v_{s3} > v_2 > v_{s2},$$

5 $v_{s4} > v_3 > v_{s3}, v_4 = v_{s4}$

However, the following problem should be obviated to enable the NPV continuous rolling process to be put to practical use and achieved the desired results.

The problem is that, since the rolling is not
 10 performed by the NR rolling process, the rolling energy supplied to the rolls is below that corresponding to one pass of the rolling process of the prior art in spite of the fact that three pass rolling is performed. Thus, it is necessary to provide means for supplying additional
 15 rolling energy to the rolls to enable the desired results to be achieved by the NPV continuous rolling process.

1 Japanese Patent Laid-Open No. 39104/81 and
Japanese Patent Laid-Open No. 111504/81 disclose a
continuous rolling mill of the different circumferential
speed type equipped with tension adjusting means for
5 adjusting the magnitude of tension applied to the strip
to be rolled between the rolling passes, to enable rolling
to be performed at a high rolling reduction rate.

However, some disadvantages are associated with
the tension adjusting means of the prior art. In the
10 tension adjusting means described in the aforesaid
documents, tension is successively given to the strip
between the rolling passes. Thus, the larger the number
of passes, the higher becomes the value of the tension
because it is obtained by integration, thereby causing
15 rupture of the strip. This defect makes it impossible to
carry out continuous rolling of a large number of passes.

SUMMARY OF THE INVENTION

Accordingly, the object of this invention is to
provide a different circumferential speed continuous
20 rolling mill capable of supplying rolling energy of high
magnitude to a strip between rolling passes, to enable
continuous rolling with a high degree of efficiency.

According to the invention, there is provided a
different circumferential speed continuous rolling mill
25 comprising a plurality of rolls including one roll
cooperating with other rolls to roll a strip simultaneously
at a plurality of rolling points so as to continuously

roll the strip by rotating the one roll at a circumferential speed distinct from the circumferential speed of other rolls, and tension difference applying means located in a path of travel of the strip between a first rolling point at which the strip is brought into contact with the one roll and rolled thereby and a second rolling point at which the strip is brought into contact with the one roll again and rolled thereby after clearing the first rolling point, to produce a difference the temperature of the strip between an delivery end of the first rolling point and an entering end of the second rolling point.

In the different circumferential speed continuous rolling mill of the aforesaid construction, it is possible to supply rolling energy to the strip not only from the rolls but also from the tension difference applying means, to enable continuous rolling with a high degree of efficiency.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the different circumferential speed continuous rolling mill in conformity with the invention will be described by referring to the accompanying drawings.

Fig. 5 shows one embodiment in which the different circumferential speed continuous rolling mill comprises working rolls 1, 2, 3 and 4 similar to the #1, #2, #3 and #4 rolls respectively shown in Table 2, backing-up rolls 5 and 6, rollers (which may be bridle rollers)

1 7 and 8 for avoiding winding of a strip 10 on the rolls,
and roll coolant spray means 9 for spraying the rolls with
a coolant to cool and lubricate the rolls. The numeral
11 is a support lever for supporting the bridle roller
5 7 which also supports a load cell 12 for measuring a
tension T_2 of the strip 10. Drives 15 and 16 are provided
to the bridle rollers 7 and 8 respectively for increasing
the tension applied to the strip 10 by actuating the drives
15 and 16, as shown in Table 3. The working rolls 1, 2,
10 3 and 4 have circumferential speeds v_1 , v_2 , v_3 and v_4
respectively which are set at values distinct from one
another. The working rolls 2 and 3 each serves as one
roll cooperating with other working rolls to continuously
perform rolling on the strip 10 at two rolling points at
15 the same time. The function of the bridle rollers 7 and
8 as tension applying means will be described.

Table 3 Characteristics of the Continuous Rolling Process NPV

Rolling Point	R_{12}		R_{23}		R_{34}	
Associated Rolling Roll	#1	#2	#2	#3	#3	#4
Rolling Torque	-50	+100	-50	+100	-50	+100
Individual Roll Torque	 -50 +100		 +50		 +50 +100	
Total Torque	+150					
Equivalent Torque by Tension Applying Means	+100		+100			
Total Equivalent Torque	+350					

1 It will be seen that, when the bridle rollers 7 and 8 serving as tension applying means are used for applying an equivalent torque by +100, it is possible to raise the total equivalent torque to +350, thereby enabling the rolling capacity to be greatly improved.

By increasing the tension applied to the strip 10 by using the bridle rollers 7 and 8, it is possible to increase the tension T_2 which helps the working rolls 1 and 2 (#1 and #2 rolls) and decrease a tension T_2 , which applies the brake to the working rolls 2 and 3 (#2 and #3 rolls). Thus, by increasing the tension applied to a portion of the strip 10 on the entering end of a rolling

1 point and decreasing the tension applied to a portion of
the strip 10 on the delivery end of the rolling point, the
ease with which different circumferential speed rolling
is performed can be increased.

5 The mechanism whereby rolling can be performed
at high rolling reduction with increased efficiency as a
result of application of the difference in tension to the
strip will be discussed.

 Generally, when a coefficient of friction μ
10 between a strip to be rolled and rolling rolls is suf-
ficiently high value to perform rolling, the rolling rolls
can exert a sufficiently high tangential force F to the
strip to impart rolling energy sufficiently high. Thus,
the value of F shown in equation (1) is sufficiently
15 even if the value of F is reduced by, for example, making
the value of ϕ_1 large in comparison with the maximum
tangential force F_0 obtained by NR rolling. However, if
the coefficient of friction μ becomes smaller in value,
then a slip occurs between the rolls and the strip, making,
20 it impossible to continue a rolling operation. Generally,
the higher the rolling speed becomes, the lower the
coefficient of friction becomes. This relationship is
shown in Fig. 7, in which curves A and B represent rolling
operations using as a roll coolant a mineral oil base
25 soluble oil and a beef tallow base soluble oil, respec-
tively, which are usually used when a steel strip is
subjected to cold rolling. The curves A and B indicate
that coefficient of friction μ is greatly changed in

1 compliance with the rolling speed. The idea of using a
roll coolant of high coefficient of friction to avoid the
occurrence of a slip might come to mind. However, when
such idea is put into practice, galling would occur
5 between the rolls and the strip and it would be impossible
to continue the rolling operation. To obviate this
problem, the invention imparts rolling energy to a strip
in the form of a difference in tension between one rolling
point and another. In the system of the prior art shown
10 in Fig. 4, the strip to be rolled wound on the rolling
rolls has rolling energy imparted thereto by the frictional
force exerted by the rolling rolls. However, since a
slip occurs in this system, there is a care of causing
the roll marks. Moreover, owing to the rolling rolls,
15 there are the limitations which are to increase the
coefficient of the surface of the rolling rolls and the
angle at which the strip is wound on the rolls. The
invention aims at imparting a difference in tension to the
strip without relying on the rolling rolls as has been
20 the case with the prior art. The end is attained by
increasing tension at the delivery end of one rolling point
and decreasing the tension at the entering end of the
next following rolling point. Operation of the system
of the invention with a marked increase in rolling
25 reduction and a greatly improved efficiency of multiple
pass rolling will now be described.

Fig. 8 shows the balancing of forces. When a
strip is rolled at a constant rolling speed, a force

1 urging the strip to move rearwardly is obtained by

$T_2' - T_3 + 2 \times P \sin \frac{\theta}{2}$ because there is no acceleration.

The force with which the rolling rolls urge the strip to move forwardly is expressed by F shown by equation (1).

5 Thus, the following relation holds because these two forces are equal to each other:

$$F = F_O \frac{\theta - (\phi_1 + \phi_2)}{\theta} = T_2' - T_3 + 2 P \sin \frac{\theta}{2}$$

By definition, F_O is $2\mu P$, and θ is small in value.

Thus,

$$10 \quad 2\mu P \frac{\theta - (\phi_1 + \phi_2)}{\theta} = T_2' - T_3 + P\theta$$

or

$$\theta = 2\mu \left(1 - \frac{\phi_1 + \phi_2}{\theta}\right) + \frac{T_3 - T_2'}{P} \dots\dots\dots (5)$$

In this case, an allowable maximum rolling reduction $\Delta h_{\max}$ can be obtained from the following

15 equation (6) where R is the radius of the rolling rolls:

$$\begin{aligned} \Delta h_{\max} &= h_e - h_d = \theta^2 R \\ &= \left[2\mu \left(1 - \frac{\phi_1 + \phi_2}{\theta}\right) + \frac{T_3 - T_2'}{P} \right]^2 R \end{aligned}$$

Let us consider the case in which $T_3 - T_2' = 0$

1 in equation (6). In this case, the following relation

holds: $\Delta h_{\max} = 4\mu^2 R \left(1 - \frac{\phi + \phi_2}{\theta}\right)^2$. Thus, in the NR
rolling process, $\phi_1 = \phi_2 = 0$ would be possible, and $\Delta h_{\max}$
could be maximized at $4\mu^2 R$. However, in the NPV process,

5 ϕ_2 could be made substantially zero but a loop would be
produced in the strip between the adjacent rolling points
unless ϕ_1 has a large value. Assume that $\phi_2 \approx 0$. Then,
the relation of the following equation (7) holds:

$$\Delta h_{\max} = 4\mu^2 R \left(1 - \frac{\phi_1}{\theta}\right)^2 \dots\dots\dots (7)$$

10 Fig. 9 shows the characteristics of $\Delta h_{\max}$ when the rolling
rolls have a diameter of 500 mm ($R = 250$ mm). It will be
seen that, when the value of μ becomes smaller and the
ratio ϕ_1/θ becomes close to unity, the allowable rolling
reduction becomes extremely small, rendering the rolling
15 process unfit for practical use.

To perform multiple pass simultaneous rolling
of a strip without developing a loop in the strip, it is
necessary that rolling be performed with the ratio ϕ_1/θ
having a value substantially close to unity. This is a
20 decisively important problem, and the invention provides
a solution to this problem by applying a difference in
tension $T_3 - T_2'$ to the strip between the two rolling
points. The effects achieved by the process according to
the invention will be described.

25 In equation (6), when a strip of a thickness of

- 1 2.5 mm is rolled three times at a rolling reduction rate
of 40%, the thickness of the strip will be successively
reduced from 2.5 mm to 1.5 mm, 0.9 mm and 0.54 mm and the
rolling reduction for each pass will be 1.0 mm, 0.6 mm
5 and 0.36 mm respectively.

The second pass will be considered. Let the
value of ϕ_1 be varied by using the values of $\mu = 0.05$
and 0.025, $R = 250$ mm and $\phi_2 \approx 0$ in equation (6). Here,
the tension will be considered per 1 mm of the strip. When
10 the unit tension of the strip is denoted by σ_e , σ_d , the
following relation holds;

$$T_2' = h_e \sigma_e = 1.5 \times 5 = 7.5 \text{ kg/mm}$$

$$T_3 = h_d \sigma_d = 0.9 \times 30 = 27 \text{ kg/mm}$$

The rolling load P is about 800 kg per 1 mm of
15 the width of the strip when the rolling rolls have a
diameter of 500 mm and the strip to be rolled is low-carbon
steel, so that $(T_3 - T_2')/P = 19.5/800 = 0.0244$.

Then, the following relation holds:

$$\Delta h_{\max} = \left\{ 2\mu \left(1 - \frac{\phi_1}{\theta} \right) + 0.0244 \right\}^2 \times 250$$

- 20 The results obtained are shown by broken line curves in
Fig. 9.

From the foregoing, it will be seen that, by
providing a difference in tension to the strip before and

1 after a rolling point, it is possible to greatly increase
the allowable rolling reduction. In Fig. 5, when the
tension T_2 at the delivery end of the first rolling point
is increased, it is possible to increase the allowable
5 rolling reduction at the first rolling point. However,
this will cause an increased in the tension of the strip
at the entering end of the second rolling point and a
reduction in the allowable rolling reduction at the second
rolling point. According to the invention, means is
10 provided for varying the tension applied to the strip so
as to effect a rolling reduction of large magnitude at
each of the first, second and third rolling points as
described hereinabove and perform three pass rolling with a
high degree of efficiency at a single stand rolling mill
15 by increasing the delivery side tension T_2 at the first
rolling point and decreasing the entering side tension T_2'
at the second rolling point.

In the embodiment shown and described herein-
above, when the bridle rollers 7 and 8 are driven by the
20 drives 15 and 16 respectively to increase the tension,
for example, the tensions at the delivery end and the
entering end of the bridle roller 7 are distinct from
each other as designated by T_2 and T_2' . In this case, the
accurate values of the tensions T_2 and T_2' can be obtained
25 by calculation at a calculating unit 20 by sensing the
total value $T = T_2 + T_2'$ by means of the load cell 12 and
obtaining the difference between them by means of a torque
detector 19 attached to the bridle roller 7. More

1 specifically, the torque detector 19 detects a torque Q
which can be expressed as $Q = (T_2' - T_2) R$ where R is
the radius of the roller 7. Thus, by supplying the
detected values of T and Q to the calculating unit 20 and
5 doing calculation on them, it is possible to obtain the
values of T_2 and T_2' . The values of T_2 and T_2' thus
obtained are compared with set values 21 to see whether they
are optimum values, and a command signal is issued based
on the result of comparison and fed into the drive 15 for
10 the bridle roller 7, to positively control the tension of
the strip 10. The speed of the strip 10 can be sensed by
speed sensors 17 and 18 attached to the bridle rollers 7
and 8 respectively. Thus it is possible to control the
speeds of rotation of the drives 15 and 16 by means of a
15 control device 25 based on speed signals produced by the
speed sensors 17 and 18 or to monitor the speed of the
strip 10 by inputting the speed signals into a monitoring
device 26. The embodiment of the invention shown and
described hereinabove can achieve the following effects:

20 (1) Rolling energy of sufficiently high level to
perform rolling of a strip through a plurality of passes on
a single stand rolling mill can be provided to the strip
between the passes, so that different circumferential speed
continuous rolling of the strip can be performed with a
25 high degree of efficiency and a high degree of rolling
reduction.

(2) The tension of the strip between the rolling
points can be sensed with a high degree of precision and

1 the control can be effected to keep the tension of the
strip at an optimum value, thereby eliminating the risk of
the strip being ruptured.

(3) The speed of the strip between the rolling
5 points can be sensed and speeds or torques of the rolls
can be controlled based on the values of the strip speed
between the rolling points, thereby enabling different
circumferential speed continuous rolling to be performed
with a high degree of precision.

10 In the continuous rolling described hereinabove,
the ability to apply tension to the strip can be increased
by increasing the coefficient of friction of the surfaces
of the bridle rollers and increasing the angle at which
the strip is wound on each roller. An increase in the
15 coefficient of friction of the surfaces of the bridle
rollers can be achieved by coarsening the surfaces of the
bridle rollers by applying a shot blast thereto or by
applying to the surfaces of the bridle rollers a material
tending to increase the coefficient of friction. An
20 increase in the strip winding angle may be achieved by using
a plurality of sets of bridle rollers 37, 38 and 39 and
32, 33 and 34 as shown in Fig. 6 which shows another
embodiment of the invention.

In Fig. 6, the numerals 46, 47 and 48 designate
25 guide rollers. However, these are not restrictive and
tension gauges may be used in place of the guide rollers.
Also, a drive may be connected to each of the bridle rollers
32 - 39.

1 In the embodiments shown and described herein-
above, the one rolling roll of the plurality of rolling
rolls cooperating with other rolls to roll a strip
simultaneously at a plurality of rolling points is two
5 in number. However, the invention is not limited to this
specific number of the one rolling roll and the number of
the one rolling roll may be one as shown in Fig. 10 which
shows still another embodiment in which rolling is
performed simultaneously at two rolling points, in this
10 case, the number of the rolling rolls performing rolling
of the strip 10 includes three working rolls 1, 2 and 3.
Thus, tension difference applying means is one in number
which creates a difference in tension in a portion of the
strip 10 disposed between a rolling point at which rolling
15 is effected by the working rolls 1 and 2 of different
circumferential speeds and the other rolling point at which
rolling is effected by the working rolls 2 and 3 of dif-
ferent circumferential speed. It will be seen that the
construction of the different circumferential speed
20 continuous rolling mill shown in Fig. 10 having tension
difference applying means attached to the bridle roller 7
is basically the same as the construction of the different
circumferential speed continuous rolling mill shown in Fig.
5, so that the description of the construction shown in Fig.
25 10 will be omitted.

 In the embodiments shown in Figs. 5, 6 and 10,
the rolling points at which rolling is simultaneously
effected by the one roll in cooperation with other rolling

1 rolls are two in number. However, this is not restrictive
and the invention may have application in a continuous
rolling system in which rolling is performed simultaneously
at three or four rolling points by the one rolling roll
5 cooperating with other rolling rolls.

Fig. 11 shows a further embodiment in which an
internal working roll 40 is surrounded by external working
rolls 50a, 50b and 50c supported by respective backing-up
rolls 60 and rotating at circumferential speeds v_2 , v_3 and
10 v_4 respectively which are distinct from the circumferential
speed v_1 of the internal working roll 40, so that the strip
10 can be rolled simultaneously at three rolling points.
In this embodiment, a bridle roller 70a is located in a
path of travel of the strip 10 between a first rolling
15 point between the internal working roll 40 and first
external working roll 50a and a second rolling point between
the internal working roll 40 and second external working
roll 50b. The bridle roll 70a is provided with a drive
15 and supplies rolling energy to the strip 10. Another
20 bridle roll 70 provided with a drive 16 is located in a
path of travel of the strip 10 between the second rolling
point and a third rolling point between the internal
working roll 40 and third external working roll 50c to
supply rolling energy to the strip 10. By providing the
25 two bridle rolls, it is possible to produce a difference
in the tension applied to the strips 10. The numerals 80
and 9 designate guide rollers for the strip 10 and fluid
spray means for effecting cooling and lubrication of the

1 strip 10, respectively. In the embodiment shown in Fig.
11, rolling energy of sufficiently high magnitude can be
supplied to the strip between the rolling passes to enable
the continuous rolling with a high degree of efficiency
5 in the same way other embodiments of the invention.

From the foregoing description, it will be
appreciated that according to the invention, there is
provided a different circumferential speed continuous
rolling mill capable of supplying rolling energy to the
10 strip between the rolling passes from means other than
the rolling rolls, to thereby enable continuous rolling to
be effected with a high degree of efficiency.

WHAT IS CLAIMED IS:

1. A different circumferential speed continuous rolling mill comprising:

a plurality of rolls (1,2,3,4; 5,6) including one roll cooperating with other rolls to roll a strip simultaneously at a plurality of rolling points to continuously roll the strip by rotating the one roll at a circumferential speed distinct from the circumferential speeds of other rolls; and

tension difference applying means (7,11,12,15; 8,16) located in a path of travel of the strip between a first rolling point at which the strip is brought into contact with the one roll and rolled thereby and a second rolling point at which the strip is brought into contact with the one roll again and rolled thereby after clearing the first rolling point, to produce a difference in the tension of the strip between delivery end of the first rolling point and an entering end of the second rolling point.

2. A different circumferential speed continuous rolling mill as claimed in claim 1, wherein said tension difference applying means is operative to increase the tension of a portion of the strip located between the delivery end of the first rolling point and the tension difference applying means and to decrease the tension of a portion of the strip located between the tension applying means and the second rolling point, to thereby apply a tension difference to the strip.

3. A different circumferential speed continuous

rolling mill as claimed in claim 1, wherein said tension difference applying means comprises a roller (7;8), and a drive (15;16) for driving said roller for rotation.

4. A different circumferential speed continuous

5 rolling mill as claimed in claim 1, wherein said tension applying means has a tension sensor means (12) for sensing the tension of the strip, said tension sensor means feeding a signal corresponding to the value of the tension of the strip to the tension difference applying means to control
10 the operation of the tension difference applying means.

5. A different circumferential speed continuous rolling mill as claimed in claim 3, wherein the roller of said tension difference applying means has a speed sensor means for sensing the speed of the strip, said speed
15 sensor means producing a signal based on the value of the speed of the strip to control said roll.

6. A different circumferential speed continuous rolling mill as claimed in claim 1, wherein said one roll and said tension difference applying means are plural in
20 number and said tension difference applying means are each located in a path of travel of the strip between a first rolling point and a second rolling pint of each of said plurality of one rolls.

7. A different circumferential speed continuous
25 rolling mill as claimed in claim 6, wherein each of said tension difference applying means increases the tension applied to a portion of the strip located between the first rolling point of each said plurality of one rolls and the

- 3 -

tension difference applying means and decreases the tension applied to a portion of the strip located between the tension applying means and the second rolling point of each said one rolls, to thereby apply a tension difference to
5 the strip.

8. A different circumferential speed continuous rolling mill as claimed in claim 6, wherein each said tension difference applying means comprises a roller, and a drive for driving said roller for rotation.

FIG. 1
PRIOR ART

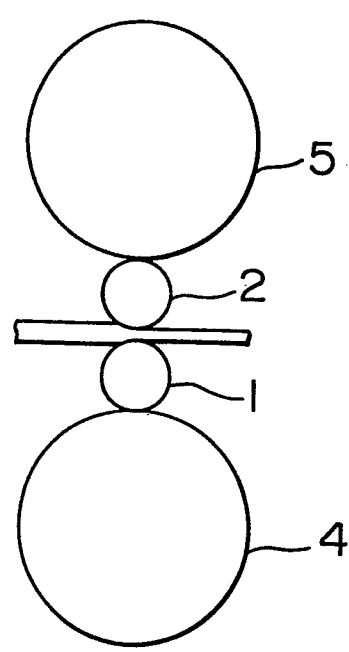


FIG. 2
PRIOR ART

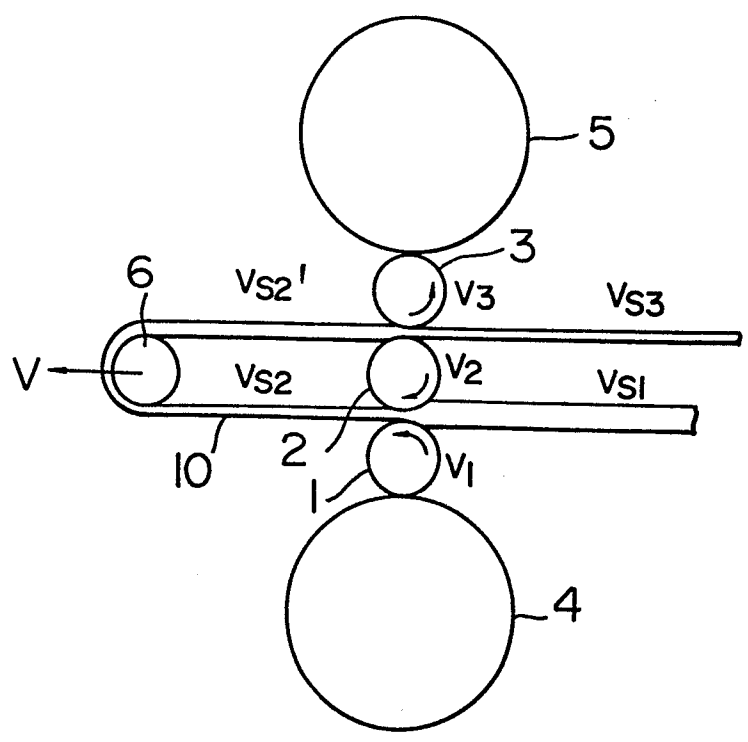


FIG. 3a
PRIOR ART

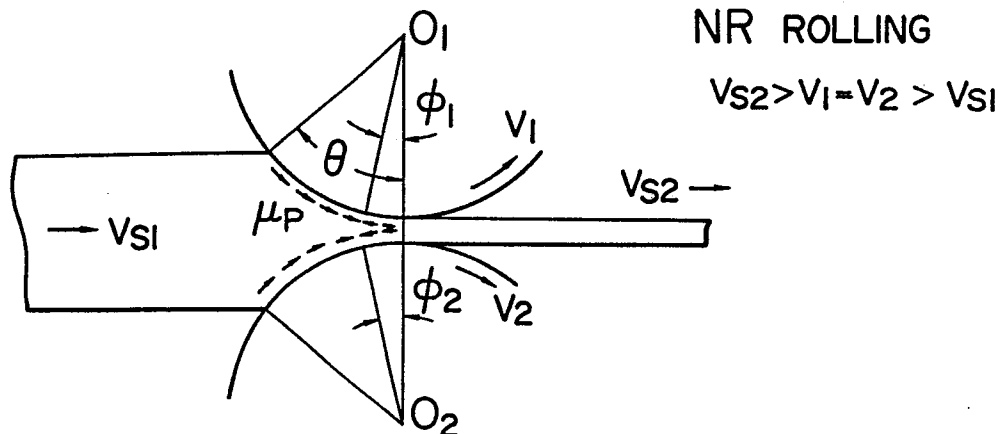


FIG. 3b
PRIOR ART

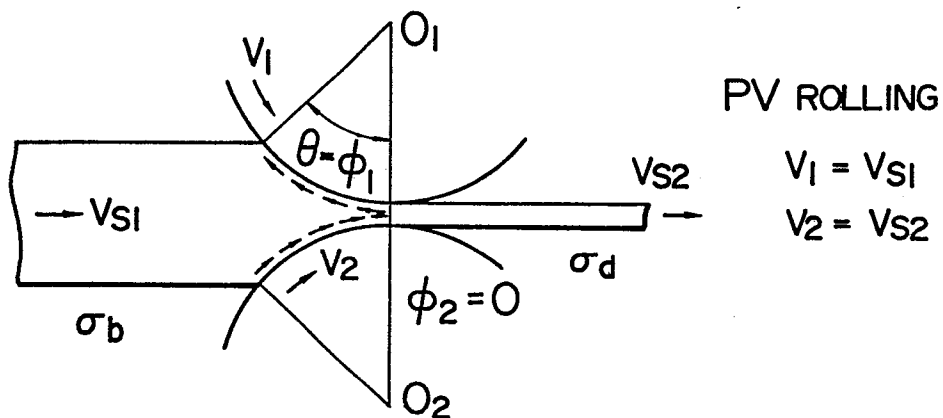


FIG. 3c
PRIOR ART

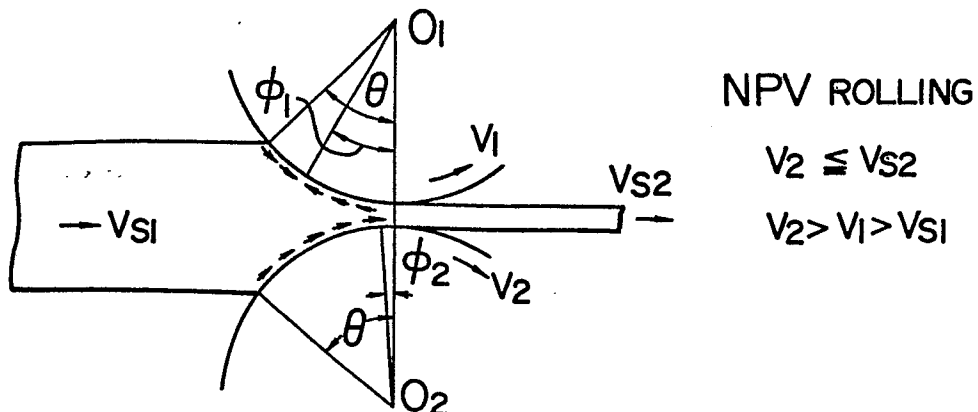


FIG. 4
PRIOR ART

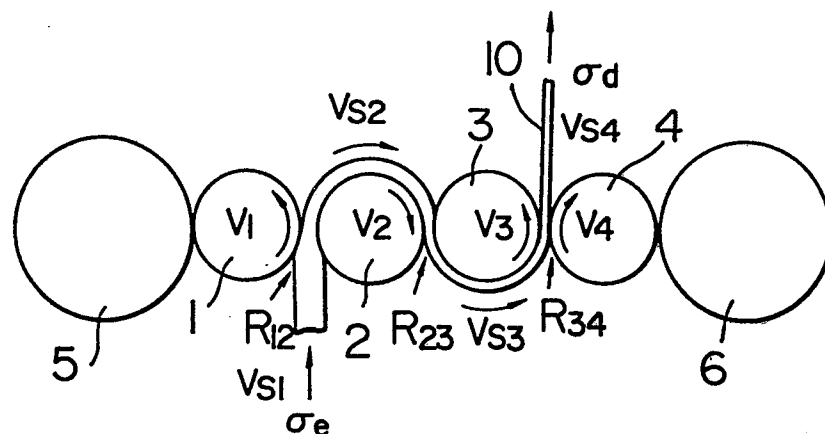


FIG. 5

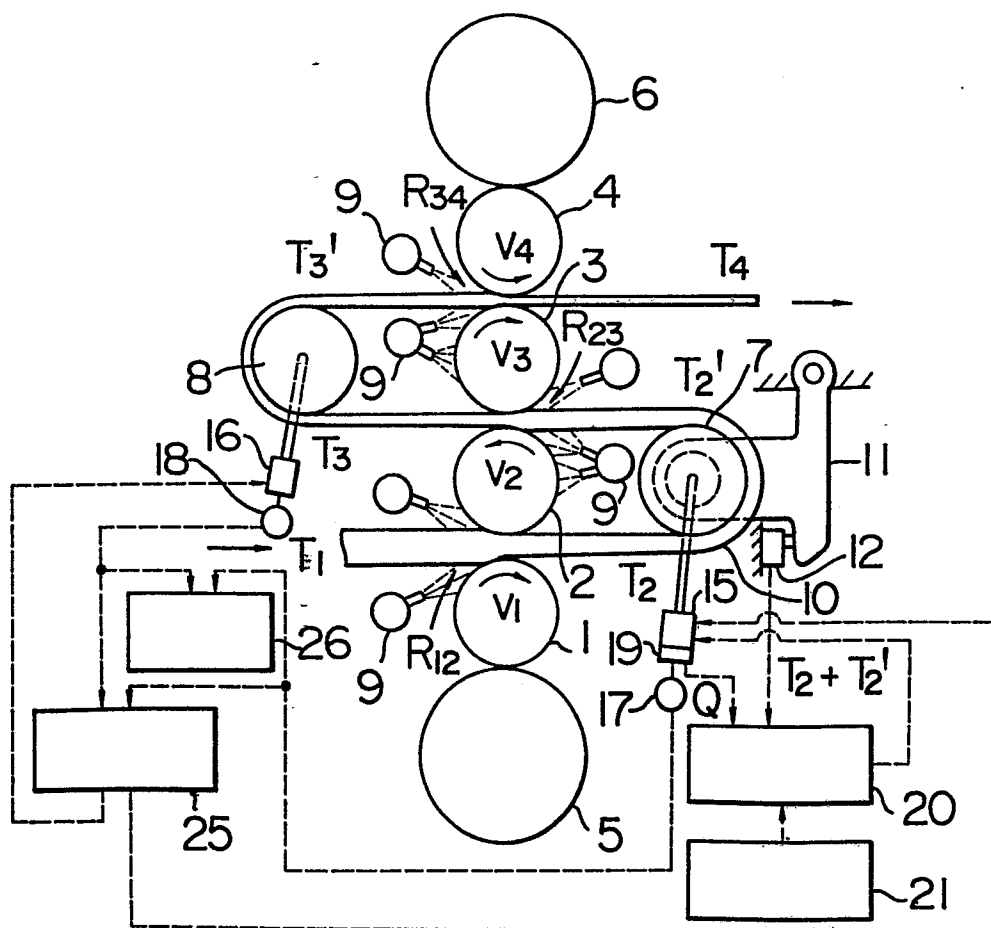


FIG. 6

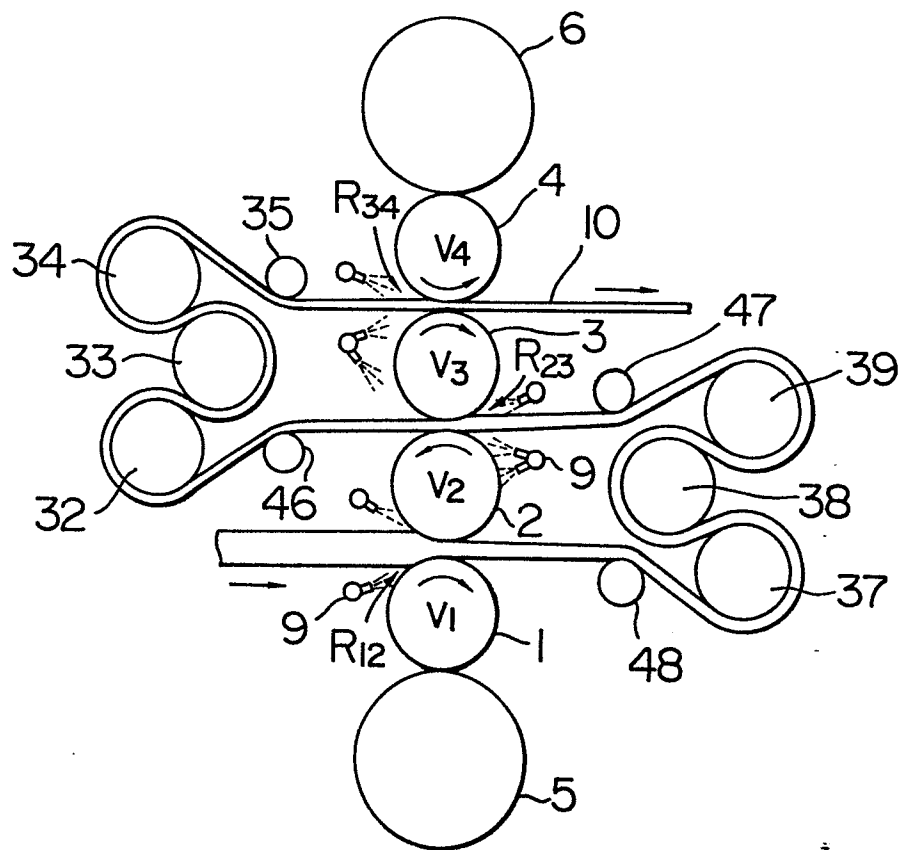
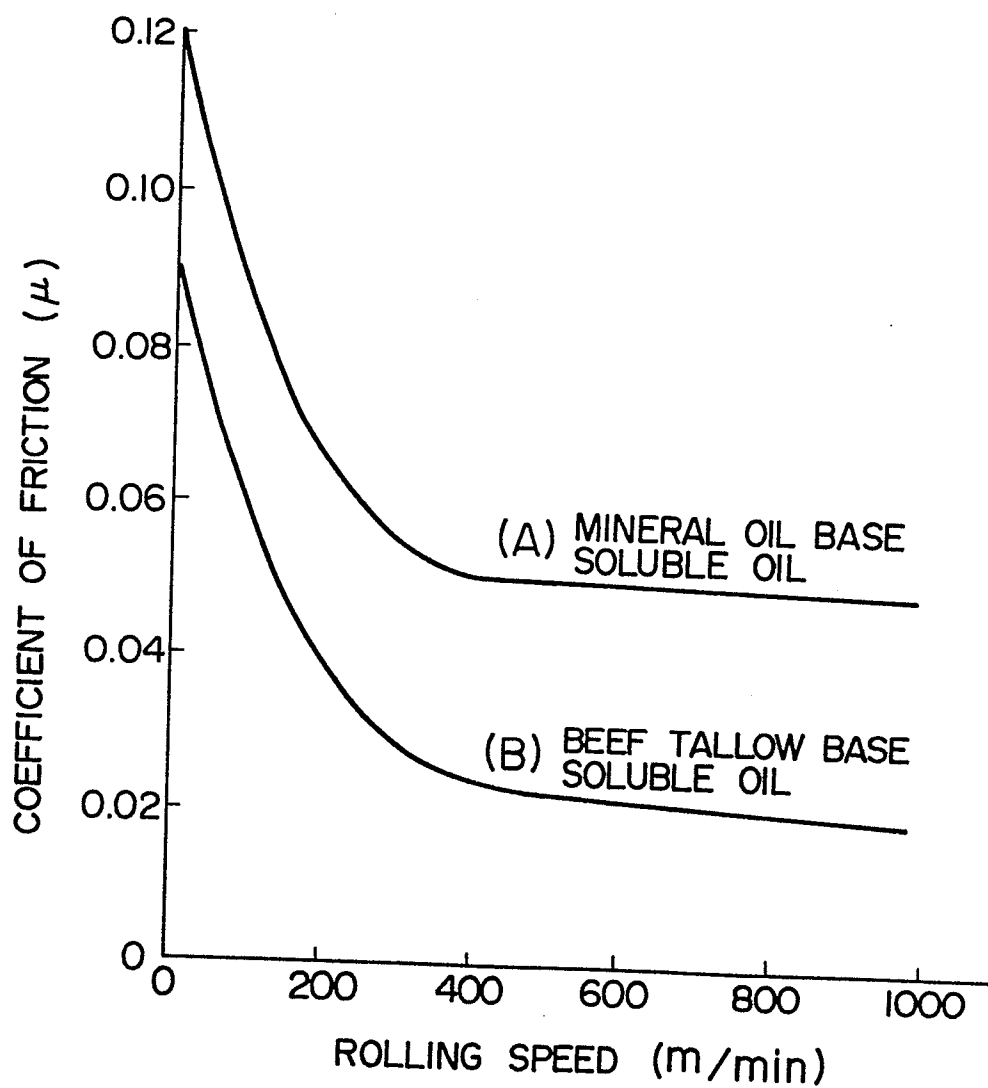


FIG.7



The diagram illustrates a curved beam of thickness h_2 and central axis length $D/2$. A point load P is applied at the top surface, at a distance $D/2$ from the center. The beam is supported at both ends by forces T_2' and T_3 . The diagram shows the internal stress distribution with angles θ , ϕ_1 , ϕ_2 , and $\theta/2$. A small deflection h_d is shown at the right end.

The graph plots Allowable Maximum Rolling Reduction (mm) on the y-axis (0 to 2.0) against ϕ_1/θ on the x-axis (0 to 1.0). Four curves are shown:

- Solid line: $\mu=0.05$, $T_3 = T_2'$
- Dashed line: $\mu=0.05$, $(\frac{T_3 - T_2'}{P} = 0.0244)$
- Dashed line: $\mu=0.025$, $(\frac{T_3 - T_2'}{P} = 0.0244)$
- Solid line: $\mu=0.025$, $T_3 = T_2'$

The curves show that allowable reduction decreases as ϕ_1/θ increases. Higher friction coefficients (μ) and higher temperature differences ($T_3 - T_2'$) generally result in higher allowable reductions for a given ϕ_1/θ .

The schematic diagram illustrates a three-stage gas turbine engine. It features three compressor stages labeled \$V_1\$, \$V_2\$, and \$V_3\$ from bottom to top. Each stage includes a rotor assembly with a central shaft (labeled 7) and a set of blades (labeled 9). The inlet air flow is indicated by arrows and labels \$T_1\$, \$T_2\$, and \$T_3\$. The outlet air flow from each stage is labeled \$R_{12}\$, \$R_{23}\$, and \$R_{34}\$. A fuel injection system (labeled 10) is shown injecting fuel into the combustion chamber (labeled 11). The combustion products expand through a turbine (labeled 12) which drives the compressors. The exhaust gases exit through a nozzle (labeled 13). The overall pressure ratio across the engine is denoted as \$P_1/P_2\$. The temperature at the inlet of the first stage is \$T_1\$, and the temperature at the inlet of the second stage is \$T_2\$. The temperature at the inlet of the third stage is \$T_3\$. The temperature at the outlet of the third stage is \$T_2 + T_2\$. The temperature at the inlet of the first stage is also labeled \$T_1\$. The temperature at the inlet of the second stage is also labeled \$T_2\$. The temperature at the inlet of the third stage is also labeled \$T_3\$. The temperature at the outlet of the third stage is also labeled \$T_2 + T_2\$. The temperature at the inlet of the first stage is also labeled \$T_1\$. The temperature at the inlet of the second stage is also labeled \$T_2\$. The temperature at the inlet of the third stage is also labeled \$T_3\$. The temperature at the outlet of the third stage is also labeled \$T_2 + T_2\$.