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(54) Method and apparatus for the magnetic stirring of molten metals in a twin roll caster.

(57) In a twin-roll caster, stirring magnets (40) are provided, which are positioned within the rolls (20) of the caster so as to effect stirring of a molten metal portion in a nip region of the caster, in a direction of casting.

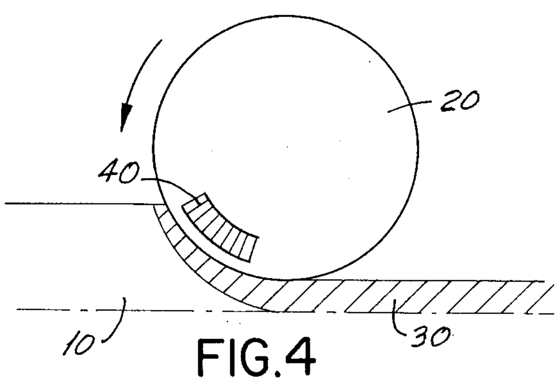

FIG.4

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This invention relates to a method and apparatus for the electromagnetic stirring of molten metals in a twin roll caster for use in continuous sheet casting systems where the casting operation involves relatively thin cross sections.

It is known that electromagnetic stirring can substantially improve the properties of continuously cast steel products, such as billets, blooms and slabs which involve relatively thick cross sections. Electromagnetic stirring is quite extensively practiced in the steel industry for this purpose. Typically the sections stirred are quite large, in the order of at least 100 by 100 mm and frequently much larger, such as 300 by 300 mm blooms or 25 by 2,000 mm slabs. The benefits attributed to stirring are the rapid dissipation of superheat, the promotion of equiaxed as compared to columnar structures and the minimization of segregation in alloyed materials. (See Electromagnetic Stirring During the Continuous Casting of Steel, Literature Search and Installation Survey. February, 1986, The Association of Iron and Steel Engineers. U.S.A.)

The use of electromagnetic stirring in the aluminum industry is much more recent; here again large sections, such as ingots are stirred during casting and the perceived benefits are grain refining as well as a minimization in the extent of microsegregation. (See Vives et al., French Patent No. 8414740.)

In all these applications, relatively large sections (at least 100 mm by 100 mm) are stirred and access to the molten metal by the electromagnetic field is readily accomplished.

More specifically, in the electromagnetic stirring of steel castings, the stirring coils have typically been placed just outside the copper molds, in which case very low frequencies must be employed, so that the field is not intercepted by the highly conductive copper mold. Alternatively, the specimen may be stirred upon exiting the mold ("below the mold stirring"), higher frequencies may be employed and/or the coils may be placed quite close to the billet, slab or bloom.

A common feature of the alternative, more recent technologies employing such casters as wheel casters, roll casters and belt casters is that the solidified product exiting the caster is either a bar, typically 50 by 60 mm or of a comparable dimension, or a plate, of approximately 10-20 mm thick and 100-1,000 mm wide.

The direct casting of bar and plates is being practiced in the aluminum, copper and related industries and these technologies are currently being developed for steel.

Electromagnetic stirring offers many potential attractions for improving the quality of continuously cast products. More specifically, in the roll and plate casting of aluminum, segregation would be avoided, which is particularly critical for the more highly alloyed grades, and grain refining could be accomplished. Similar improvements can be realized for copper, copper alloys and steel.

Up to the present time, the electromagnetic stirring of the molten metal or melt in twin-roll casting operations has not been practiced. One may speculate that among the reasons for this situation are the following factors:

- Until recently there has only been a poor understanding of the mechanism of electromagnetic stirring.
- In order to properly implement the use of electromagnetic stirring in sheet and plate casting a need exists for precise knowledge of the causal relationships between stirring power and liquid motion, in the molten metal.
- In order for electromagnetic stirring to be used effectively, one needs to know precisely the size and shape of the molten portion of the bar, slab or plate.
- Major practical difficulties exist in implementing electromagnetic stirring schemes which require significant modification of the original casting equipment.

The closest prior art of which the applicants are aware which addresses the problems of stirring in continuous casting devices are the following:

- U.S. Patent No. 2,782,473 to Brennan discloses continuous casting from a crucible through an enclosing die and from a continuous wheel caster, utilizing a high frequency coil to maintain the metal in a molten state.
- U.S. Patent No. 4,372,369 to Flemings et al. teaches a wheel caster with mechanical agitation to produce an agitation zone to prevent formation of an interconnected dendritic network.
- U.S. Patent No. 3,656,537 to Von Starck teaches a method for continuously casting slabs and plates using an open ended mold and a traveling field inductor to induce agitation.
- U.S. Patent No. 3,693,697 to Tzavaras, discloses the continuous casting of ingots involving stirring utilizing a coil energized with a source of alternating current.
- U.S. Patent No. 3,882,923 to Alberny et al. teaches an apparatus for casting a metal slab using an electrical inductor connected to a multiphase current source.
- U.S. Patent 3,981,345 to Alberny et al. teaches the use of induction formed electromagnetic stirring in the casting of slabs, particularly in the steel industry.
- U.S. Patent No. 4,106,546 to Sundberg relates to the continuous casting of steel

strands, involves the use of induced current to stir the molten metal within the cooling strand.

- U.S. Patent No. 4,139,048 to Andersson teaches continuous casting of metal strands involving the use of a magnetic stirrer positioned outside of some of the rollers used therein.
- U.S. Patent No. 4,158,380 to Sasaki et al. involves the continuous casting of steel slabs with the use of agitation induced by magnetic forces.
- U.S. Patent No. 4,429,731 to Delassus, is directed to continuous slab casting using an inductor capable of concentrating the magnetic flux to enable a strong magnetic field to be applied to a relatively thick cross sectioned article being cast.

The prior art which is being practiced using electromagnetic stirring in continuous casting systems may be summarized by stating that electromagnetic stirring is being extensively practiced in the steel industry in the casting of large sections, such as slabs, billets and blooms. Practice has shown that the stirring arrangements used for these different shapes differ significantly, such as the use of linear stirrers for slabs, and circular stirrers in most cases for billets and blooms.

Some of the prior art devices for electromagnetic stirring are of a so-called twin roll caster type. Japanese patent SHO 62-77157 to Masahi Niioka discloses a twin roll caster, in which molten material is fed into a reservoir formed above a pair of water-cooled rolls rotating in opposite directions relative to each other. As the molten metal passes through the gap between the rolls, a thin metallic sheet is formed from the molten metal. The melt in the melt reservoir is stirred in the direction perpendicular to the casting with low frequency range of about 4-6 Hz. The low frequency range utilized in the Niioka arrangement generates, however, a low stirring force, which results in a rather poor stirring effect. Further, the coils and cores are fixed on the fixed shafts and are maintained stationary in the arrangement disclosed in the Niioka reference. The molten metal is stirred using an AC current while a DC current is used to suppress the flow of the molten metal. The stirring effect which normally depends on current frequency and conductivity used is, however, limited in the Niioka twin-roll caster due to excessive penetration and hence very poor gradients in the stirring force.

It is an object of the present invention to significantly improve a stirring effect in a twin-roll caster.

It is a further object of the present invention to provide a twin-roll caster in which stirring is carried out in the direction in which the molten metal pool has the smallest dimension, i.e. to stir in the direction of casting.

According to the present invention stirring may be effected by electromagnetic means or by permanent magnets.

The concept of electromagnetic stirring in twin roll casting operations to produce metal sheets or plates is intrinsically novel and has not heretofore been practiced. Furthermore, the stirring of molten metal having these shapes is inherently much more difficult for the following reasons:

Stirring is caused by the establishment of force field gradients in the melt. In conventional continuous casting the domain to be agitated is large and the extent of the molten regions is well established, so that stirring is quite readily accomplished.

In twin oll casting the molten portion to be agitated is small so that the establishment of significant field gradients requires precise coil design. Furthermore, the small dimensions of the molten portion to be stirred make it quite difficult to establish the desired recirculatory flow pattern.

In realizing agitation in twin roll casting systems yet another group of problems arise regarding the location of the stirring coils. In conventional continuous casting systems these stirring coils either tend to surround the mold, bar, billet, slab or bloom to be cast, or alternatively a linear stirring arrangement is provided, as detailed above. In twin roll casting applications there are major difficulties in arranging the coils or mechanically rotated magnets such that an appropriate field can be produced. The reason for this is that access to the molten regions is severely restricted by the construction of the casting apparatus, be it a wheel casting, roll casting or belt casting arrangement.

None of the aforementioned prior art references teaches the particular combination of features of the present invention which allows one to overcome the aforementioned specific problems.

It is, therefore, yet a further object of the present invention to provide a method and apparatus to achieve electromagnetic stirring in the liquid portion of continuously cast bars, sheet and plates such that the flow of the liquid metal is not impeded, but, at the same time, an adequate stirring velocity, in the range of 0.3 - 1 m/s is imparted to the melt.

In an embodiment a stirring device is provided in a twin-roll caster, which comprises electromagnetic means positioned within at least one of the rolls of the caster so as to effect stirring in a direction of casting of a molten metal portion passed between the rolls, the stirring device being operated at a frequency of from 30 to 3,000 Hz.

The objects of the present invention are also attained by a method of casting a molten metal into bar or sheet shapes having relatively thin cross sections, comprising the steps of feeding the molten metal to a continuous twin-roll caster, positioning magnetic stirring means within at least one roll of the twin-roll caster in the proximity of a molten metal portion located in a nip region between two rolls of the twin-roll caster, and operating said magnetic stirring means to generate a magnetic field of from 300 to 3,000 gauss so as to effect stirring in a direction of casting said metal to thereby minimize segregation and effect grain refining in a cast metal bar or sheet.

The molten metal to be cast may be aluminum, copper, zinc, steel or alloys thereof.

The stirring means are operated so as to create stirring velocities within the molten metal being cast of from 0.3 to 2.0 m/sec.

The electromagnetic stirring means operated at a frequency of from 30 to 3,000 Hz generate electromagnetic forces of from 500 to 5,000 N/m^3.

If the metal being cast is aluminum, the frequency is in the range of 50-1000 Hz. If the metal being cast is steel the frequency range is 30-300 Hz.

The stirring means are positioned within at least one roll of the twin-roll caster so that stirring of molten metal is always effected in the direction of the casting, e.g. in the direction where the metal pool of the caster of the foregoing type has its smallest dimension.

The stirring means may include permanent magnets or electromagnets. The permanent magnets may be rotatable relative to the rolls in which they are located or be fixed thereto.

Where electromagnetic stirring means are employed, the means may comprise electromagnetic coils having multiphase electrical connections.

The rolls of the caster of the present invention may be made of non-magnetic stainless steel.

The stirring means, electromagnetic or permanent magnets, sustain a recirculating motion within the molten metal in the direction of casting.

The electromagnetic stirring means may be AC coils or DC coils.

In an embodiment, the stirring means is a rotating permanent magnet assembly located within at least one of the hollow rolls of the twin-roll caster. The magnet assembly comprises a ring of magnets extending over the full length of the roll and having a diameter of from 0.6-0.9 of the diameter of the roll in which it is located.

In another embodiment, the twin-roll caster having either permanent or electromagnetic stirring means additionally includes edge control magnets positioned near peripheral edge of at least one of the rolls.

The edge control magnets may be DC magnets. In an embodiment, the edge control magnets are Positioned inside the hollow roll of the caster at end faces thereof.

The aforementioned objects, features and advantages of the invention will, in part, become obvious from the following more detailed description of the invention, taken in conjunction with the accompanying drawing, which form an integral part thereof.

Fig. 1 is a schematic representation of a typical conventional twin roll caster arrangement.

Fig. 2 is a schematic representation of a typical twin roll casting arrangement showing the liquid metal flow.

Fig. 3 is a schematic representation of the liquid to solid metal transition in a twin roll casting arrangement.

Fig. 4 is a schematic representation of a twin-roll stirrer of the present invention located inside the rolls of a typical twin roll casting arrangement.

Fig. 5 is a schematic representation of one roll of a twin roll caster with agitation provided by mechanical rotation of a permanent magnet assembly.

Fig. 6 is a schematic representation of a roll of a twin roll caster showing another embodiment of the present invention with agitation provided by rotating a permanent magnetic assembly within the cavity of the roll.

Fig. 7 is a schematic representation of a twin-roll caster according to yet another embodiment of the present invention, in a side view.

Fig. 8 is a schematic top view of the twin-roll caster of Fig. 7.

Fig. 9 is a sectional view of the roll of the twin-roll caster with edge control magnets inserted thereinto.

Fig. 1 of the drawings shows a conventional twin-roll casting arrangement as discussed above.

With reference to Figs. 2 and 3, which schematiccally show a twin roll casting arrangement, which is presently used in the aluminum industry and the use of which is contemplated for steel, it is seen that molten metal (10) is fed horizontally (in some cases it may be fed vertically) between the nips of two rotating rolls (20), which are water cooled, so that solidification (30) takes place between the entry to the rolls and usually before the metal reaches the narrowest distance or nip between the rolls, as represented in Fig. 3, which depicts only one of the two rolls which rotate in opposite directions.

The typical sheet (or plate) thickness cast by this method is 5-10 mm.

In implementing the present invention, the rolls (20) of the twin-roll caster may be constructed of non-magnetic stainless steel and stirrers (40) including A.C. coils are placed inside the both rolls (20), as represented in Fig. 4 showing one of two rolls, for the sake of simplicity. For a typical roll, currently employed in the industry, which is 0.5 to 1 m in diameter, the preferred embodiment of the present invention would be to provide a linear stirrer, extending to the whole length of the roll and having a width (in the direction of the metal flow) of 100-300 mm. The stirrer width may be between 1/2 to 1/3 of the roll radius.

The molten material processed in the twin-roll caster into a cast may be aluminum, copper, zinc, steel or alloys thereof.

Electromagnetic stirrers may be one or more electromagnetic coils having multiphase electrical connections to effect linear stirring within the molten metal being cast.

In the preferred embodiment of this invention a linear stirrer is employed generating a force field in the range of 500-5,000 N/m and a magnetic field in the 300-3,000 gauss range, providing for linear stirring velocities in the 0.3-2 m/s range. The preferred frequency would be 30-300 Hz for steel and 100-1,000 Hz aluminum. The linear stirrer is operated to sustain recirculating motion within the molten metal in the direction of casting.

Fig. 5 illustrates one hollow roll (20) of the typical twin-roll caster showing an arrangement where agitation is provided by rotating a permanent magnet assembly (50), located within the roll cavity. Rotation is preferably provided to the magnet assembly by gearing the shaft of the magnet assembly to that of the roll by any suitable transmission.

Fig. 6 shows another preferred embodiment of the present invention, wherein agitation of the molten metal is also provided by rotating a permanent magnet assembly (50). The assembly (50) is positioned within at least one of the rolls of the twin-roll caster and comprises a ring of magnets (50) extending the full length of the roll and having a diameter of from 0.6-0.9 times that of the diameter of the roll in which the magnet assembly is located. The speed of rotation of the permanent magnet assembly would preferably be in the order of 30-500 revolutions per minute, to provide adequate stirring velocity in the melt. Depending upon specific location of the magnet assembly, a total of from 50 to 200 magnets would be required in the roll. Such roll may be, for example 1-2m long and about 1m in diameter. Preferably a magnetic field of from 500-3,000 gauss would be generated.

The magnets are rotated with a higher speed than the rolls in order to move the molten metal and to stir it with high efficiency. Rotating magnets may either be rotated mechanically as disclosed above or they may be electromagnets. High frequencies of 50-1,000 Hz for aluminum and 30-300 Hz for steel ensure a much better gradient in the driving force than that with conventional twin-roll casters utilizing much lower frequencies.

As also shown in Fig. 6, in addition to stirring by rotating permanent magnet assembly (50), improved edge control is provided by embedding a permanent magnet (90) into the outer edge of the roll (20). A DC magnet may be used for edge control.

With reference to Figs. 7 and 8, it will be seen that in a twin-roll caster two rolls 60 and 70 rotating in opposite directions, similarly to the above-described embodiments have installed therein permanent magnets 72 which can be replaced by electromagnets, such as DC magnets. Each magnet 72 extends the entire length of the respective roll and essentially cover a nip region between the rolls. The magnets 72 are fixed to respective rolls 60, 70. In addition, an electric current is supplied to the pool of the molten material through an electrode contact 74. As seen from Fig. 7, the electric current is introduced centrally of the nip region between two stirring rolls. The electric current is passed through the melt so that agitation is provided by the interaction of a static magnetic field generated by two permanent or DC magnets 72 inserted into the rolls and the current induced into the melt. The magnetic field strength applied to the molten metal is between 500 and 3,000 gauss and the current passing through the metal has 50-500 A/m^2 range. Electrode brushes 76 are used for the current takeoff.

Fig. 9 shows edge control magnets 80 inserted at the edges of roll 82 of the twin-roll caster. Magnets 80 which may be DC magnets or permanent magnets are fixed to the inner face of the roll 80. The rolls of the twin-roll caster are typically hollow.

Claims

1. A method of casting a molten metal into bar or sheet shapes having relatively thin cross sections, comprising the steps of feeding the molten metal to a continuous twin-roll caster, positioning magnetic stirring means (40) within at least one roll (20) of the twin-roll caster in proximity to a molten metal portion located in a nip region between rolls of the twin-roll caster, so as to effect stirring in a direction of casting said metal, and operating said magnetic stirring means to generate a magnetic field of from 300 to 3,000 gauss to thereby minimize segregation and effect grain refining in a cast metal bar or sheet.

2. A method according to claim 1, wherein the molten metal to be cast is aluminum, or copper, or zinc, or steel or alloys thereof.

3. A method according to claim 1, wherein said stirring means is an electromagnetic stirring means operated at a frequency of from 30 to 3,000 Hz and generating electromagnetic forces of from 500 to 5,000 N/m^3.

4. A twin-roll caster including a device for the magnetic stirring of a melt region of the twin-roll caster for continuously casting a molten metal into sheet shapes of substantially thin cross sections, said device comprising stirring means (40) positioned within at least one roll (20) of said caster in the proximity of a molten metal portion located in a nip region between two rolls of said caster for generating a magnetic field of from 300 to 3,000 gauss so as to effect stirring in a direction of casting said molten metal to thereby minimize segregation and to effect grain refining in a cast metal bar or sheet.

5. A twin-roll caster according to claim 4, wherein said stirring means are electromagnetic stirring means operated at a frequency of from 30 to 3,000 Hz.

6. A twin-roll caster according to claim 4, wherein said stirring means include permanent magnets (50).

7. A twin-roll caster according to claim 6, wherein said permanent magnets (50) are rotatable relative to said rolls.

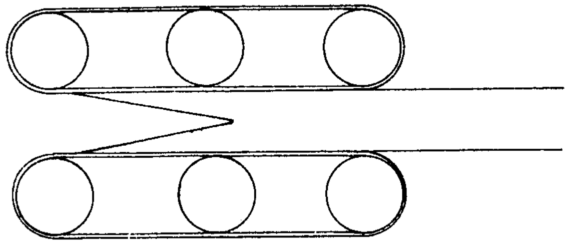
8. A twin-roll caster according to claim 6, wherein said permanent magnets (50) are fixed to said rolls.

9. A twin-roll caster according to claim 5, wherein said electromagnetic stirring means are DC magnets.

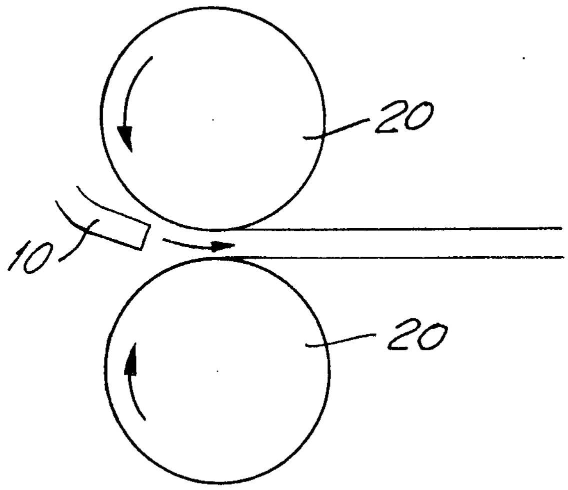
10. A twin-roll caster according to claim 5, wherein the stirring means include a rotating permanent magnet assembly (50) located within at least one of the rolls (20) of the twin-roll caster, said magnet assembly comprising a ring of magnets extending over the full length of the roll and having a diameter of from 0.6-0.9 of the diameter of the roll in which it is located.

11. A twin-roll caster according to claim 4, and further comprising edge control magnets (90) positioned near peripheral edge of at least one of the rolls (20).

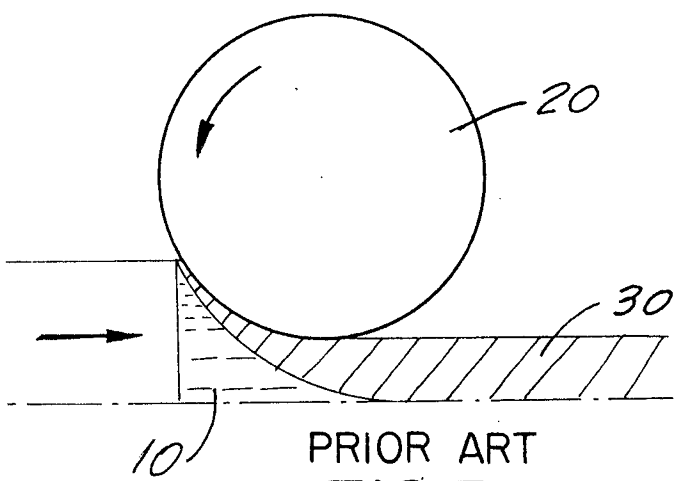
12. A twin-roll caster according to claim 11, wherein said edge control magnets (90) are positioned within said rolls.



PRIOR ART
FIG. 1



PRIOR ART
FIG.2



PRIOR ART
FIG.3

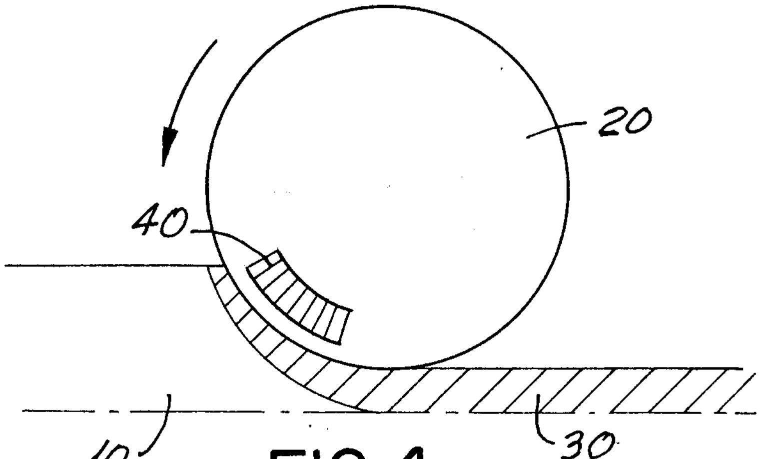


FIG.4

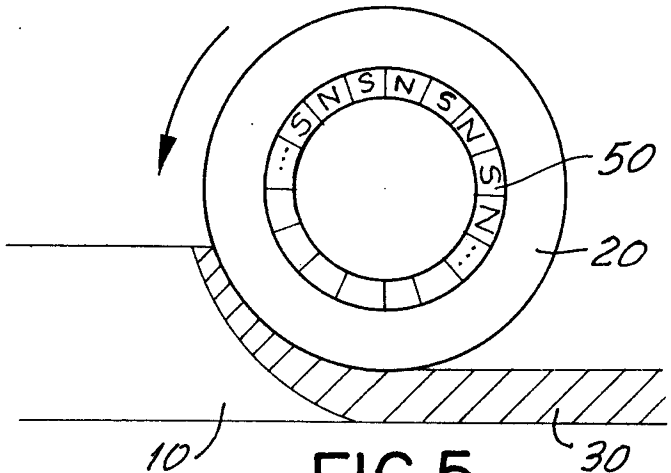


FIG.5

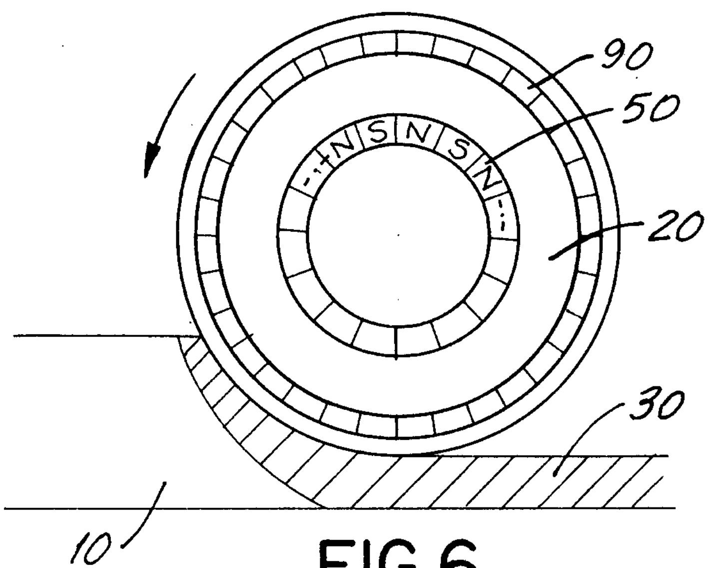


FIG.6

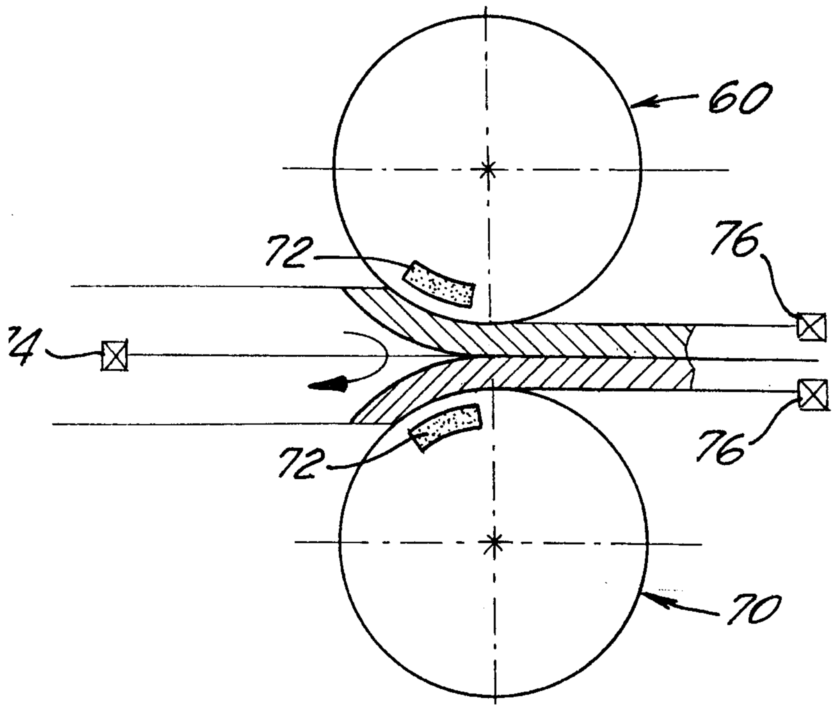


FIG.7

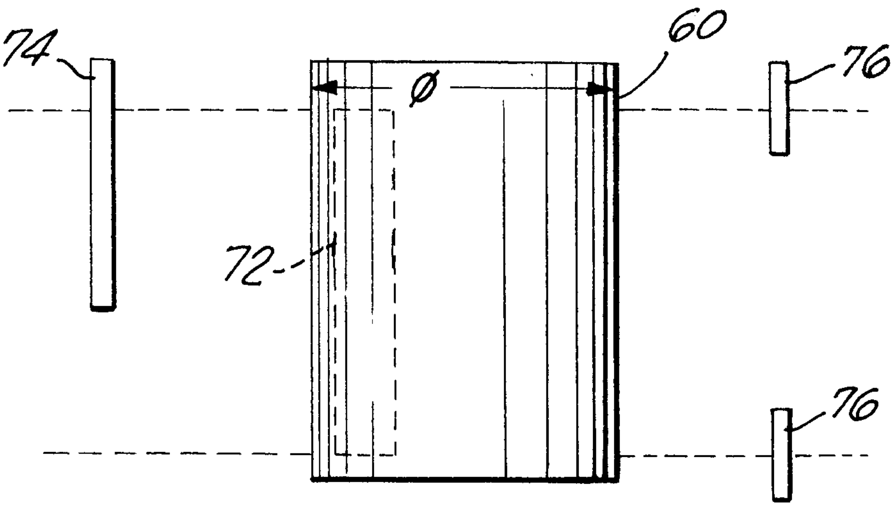


FIG.8

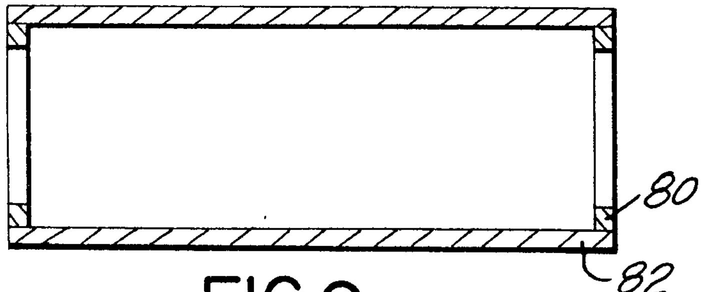


FIG.9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 11 4848

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A D	EP-A-0 053 060 (CEM COMPANIE ELECTRONIC-MECANIQUE) & US-A-4 429 731		B22D11/06 B22D11/10
D,A	US-A-4 106 546 (YNGVE SUNDBERG)		
A D	LU-A-67 753 (IRSID) & US-A-3 882 923		
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 278 (M-623)9 September 1987 & JP-A-62 077 157 (NIPPON STEEL CORP.) 9 April 1987 * abstract *	1,2,4, 6-12	
A	PATENT ABSTRACTS OF JAPAN vol. 14, no. 331 (M-999)(4274) 17 July 1990 & JP-A-21 12 854 (NIPPON STEEL CORP) 25 April 1990 * abstract *		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

B22D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	06 JANUARY 1993	HODIAMONT S.

CATEGORY OF CITED DOCUMENTS

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