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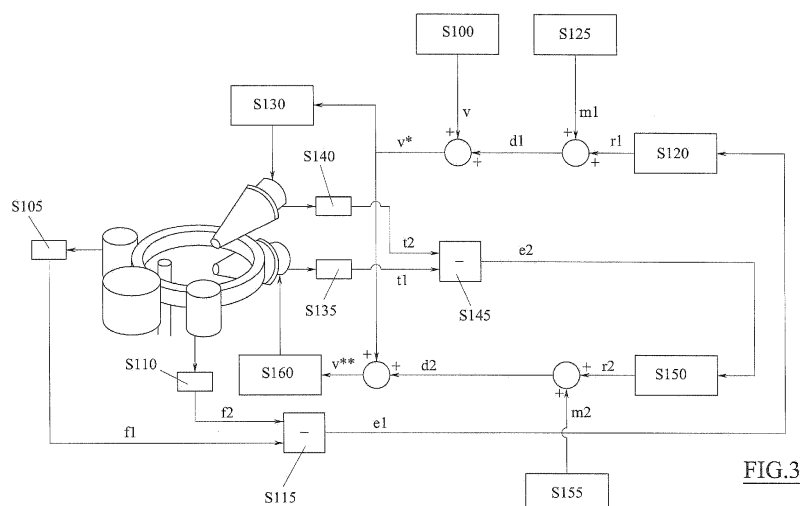
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(54) **METHOD FOR CONTROLLING A RADIAL-AXIAL ROLLING MILL FOR RINGS AND RADIAL-AXIAL ROLLING MILL FOR RINGS**

(57) A method for controlling a radial-axial rolling mill (100) for rings (200) is described, wherein the radial-axial rolling mill (100) comprises: a main roller (105), a contrast roller (110), a pair of guide rollers (115), and a pair of tapered rollers (130, 135), wherein the control method provides for adjusting the rotation speed of each tapered roller (130, 135) by the steps of: establishing a reference value ( $v$ ) of the rotation speed of the tapered roller (130, 135), applying to said reference value ( $v$ ) a correction ( $d1, d2$ ) to obtain a correct value ( $v^*, v^{**}$ ) of the rotation speed of the tapered roller (130, 135), and actuating the tapered roller (130, 135) at a rotation speed having the correct value ( $v^*, v^{**}$ ), and wherein the control method is executable in a learning mode and in a subsequent operating mode; in the learning mode, the control method provides for recording, for each tapered roller, the cor-

rection ( $d1, d2$ ) which is applied to the reference value ( $v$ ) of the rotation speed of the tapered roller (130, 135), measuring the diameter of said first ring (200), and using the recorded values of the correction ( $d1, d2$ ) and the measured values of the diameter of the first ring (200) to create a correlation map ( $M1, M2$ ); in the operating mode, the control method providing for measuring, for each tapered roller, the diameter of at least a second ring (200) being processed, obtaining from the correlation map ( $M1, M2$ ) the correction value ( $d1^*, d2^*$ ) corresponding to the measured diameter, and applying the value ( $d1^*, d2^*$ ) obtained and the correction ( $d1, d2$ ) to the reference value ( $v$ ) of the rotation speed of the tapered roller (130, 135).

The invention also relates to a radial-axial rolling mill for rings.



**Description**Technical Field

5     **[0001]** The present invention relates to a method for controlling a radial-axial rolling mill of the type used for hot-rolling metal rings, e.g. made of steel or other particular metals, among which copper, aluminium, titanium or super alloys.

State of the art

10    **[0002]** The hot rolling of metal rings is a versatile metalworking process that makes it possible to manufacture rings with precise dimensions and an accurate degree of roundness.

**[0003]** The hot-rolling process starts from a "donut"-shaped semi-finished (or blank) product made of a high-temperature metal, e.g. between 900°C and 1000°C in the case of steels or even much lower, e.g. between 250°C and 300°C in the case of copper or aluminium.

15    **[0004]** This semi-finished product is then rolled in a radial and axial direction until a ring of the desired dimensions is obtained.

**[0005]** The rolling process is carried out by a machine called a radial-axial rolling mill, which essentially consists of a plurality of rollers that support and shape the ring being processed.

20    **[0006]** Specifically, the radial-axial rolling mill generally comprises a main roller, which is adapted to stay in contact with an outer perimeter surface of the ring being processed, and a contrast roller, commonly called a mandrel, which is adapted to stay in contact with the inner perimeter surface and compress the ring in a radial direction against the main roller.

**[0007]** The radial-axial rolling mill may also comprise a pair of guide or centring rollers, which are adapted to stay in contact with the outer perimeter surface of the ring being processed at points that are mutually symmetrical with respect to the plane of symmetry containing the axes of rotation of the main roller and mandrel.

25    **[0008]** These guide rollers are carried by respective support arms, commonly referred to as centring arms, each of which is adapted to oscillate about an oscillation axis parallel to the rotation axis of the main roller and is arranged symmetrically to the oscillation axis of the other support arm with respect to the aforementioned plane of symmetry.

**[0009]** The guide rollers can thereby move following the variation in diameter of the ring being processed, while ensuring that this ring maintains its roundness and remains in a suitable position on the rolling mill.

30    **[0010]** The radial-axial rolling mill also comprises a pair of tapered rollers adapted to stay respectively in contact of the opposite axial ends of the ring being processed, so as to compress it axially.

**[0011]** These tapered rollers are both motor-driven and are generally actuated at a reference rotation speed such that the peripheral speed thereof is equal to the peripheral speed of the ring being processed at all points of mutual contact.

35    **[0012]** This condition may be effectively achieved and maintained as long as the vertices (at least the ideal ones) of the tapered rollers are perfectly aligned with the centre of the ring being processed.

**[0013]** However, as the diameter of the ring being machined increases, the tapered rollers must be gradually moved away radially from the main roller, so that, beyond certain limits, it is not possible to keep the tapered roller vertices at the centre of the ring being machined.

40    **[0014]** Under these conditions, it is possible to determine a reference rotation speed for which the peripheral speed of the tapered rollers is equal to that of the ring being machined at only one point of mutual contact, while at all other points a difference between the peripheral speeds will occur.

**[0015]** This difference in peripheral speed causes a "material creep" which tends to move the ring being processed to one side or the other, making it to lose the correct centring.

45    **[0016]** To overcome this drawback, it is known to adjust the rotation speed of tapered rollers by adding a suitable correction to the reference rotation speed, which is generally obtained from the sum of one or more corrective contributions.

**[0017]** Some of these corrective contributions are automatically established by the rolling mill electronic system through appropriate feedback controllers, which aim to equalise the thrust force exerted by the ring being processed on the guide rollers in order to keep the ring centred on the rolling mill, as well as to equalise the torque applied to the tapered rollers.

50    **[0018]** Other corrective contributions are of the manual type, i.e. they are provided directly and discretely by an operator by actuating special manual controls, such as knobs or handwheels, for instance to correct possible growth defects or affect the behaviour of the mill in particular cases.

55    **[0019]** However, feedback corrective contributions are generally rather slow in compensating for possible imbalances in the dynamic system, while manual contributions introduce a degree of discretion which, especially for large mass productions, may result in rings that are not perfectly equal to each other.

Disclosure of the invention

**[0020]** In the light of the foregoing, an object of the present invention is to solve or at least mitigate the aforementioned drawbacks of the prior art, in the context of a simple, rational and relatively cost-effective solution.

**[0021]** These and other objects are achieved thanks to the features of the invention as set forth in the independent claims. The dependent claims outline preferred and/or particularly advantageous aspects of the invention but not strictly necessary for implementing it.

**[0022]** In particular, one embodiment of the invention makes available a method for controlling a radial-axial ring rolling mill,

wherein the radial-axial rolling mill comprises:

- a main roller adapted to stay in contact with an outer perimeter surface of the ring being processed,
- a contrast roller having a rotation axis coplanar to the rotation axis of the main roller and adapted to stay in contact with an inner perimeter surface of the ring being processed,
- a pair of guide rollers having rotation axes parallel to the rotation axis of the main roller and adapted to stay in contact with the outer perimeter surface of the ring being processed, each guide roller being carried by a support arm oscillating about an oscillation axis arranged symmetrically to the oscillation axis of the other support arm with respect to a plane of symmetry containing the rotation axis of the main roller and the rotation axis of the contrast roller, and
- a pair of tapered rollers having rotation axes coplanar on said plane of symmetry, which are respectively adapted to stay in contact with the opposite axial ends of the ring being processed,

wherein the control method provides for adjusting the rotation speed of each tapered roller by means of the steps of:

- establishing a reference value of the rotation speed of the tapered roller,
- applying (e.g. adding) a correction to said reference value in order to obtain a correct value of the rotation speed of the tapered roller,
- actuating the tapered roller at a rotation speed having the correct value, and

wherein the correction is obtained as a function (e.g. from the sum) of a feedback contribution and/or a manual contribution.

**[0023]** According to the invention, the control method may be performed in a learning mode and in a subsequent operating mode.

**[0024]** In the learning mode, the control method provides, for each tapered roller, for:

- recording the correction that is applied (e.g. added) to the reference value of the rotation speed of the tapered roller in a plurality of successive instants during the processing of at least a first ring,
- measuring the diameter of said first ring at each instant in which the correction is recorded, and
- using the recorded values of the correction and the measured values of the diameter of the first ring to create a correlation map which, for each value of the ring diameter, correlates a corresponding value of the correlation.

**[0025]** In the operating mode, the control method provides, for each tapered roller, for:

- measuring the diameter of at least a second ring being processed,
- obtaining from the correlation map of the tapered roller the correction value corresponding to the measured diameter,
- applying (i.e. adding) the value obtained from the correlation map and the correction to the reference value of the rotation speed of the tapered roller.

**[0026]** Thanks to this solution, corrections to the rotation speed of the tapered rollers that are recorded in the learning mode are advantageously used to prior correct the speed of rotation of the tapered rollers in the operating mode, by actually adding a feed-forward contribution to the retracting and manual contributions.

**[0027]** Thereby, especially in the hypothesis of having to make a large number of rings identical to the one tested in the learning mode, the intervention of the control system on the adjustment of the rotation speed of the tapered rollers will be much quicker and more repetitive, leading to rings that are more similar to each other.

**[0028]** In particular, all the manual corrections that were recorded while processing the ring in the learning mode will also be applied to the rings processed in the operating mode, without the need for the operator to intervene and by increasing the standardisation of the process.

**[0029]** According to one aspect of the invention, the feedback contribution of at least one of the tapered rollers (e.g. of a first of said tapered rollers) may be obtained by the steps of:

- measuring the force applied by the ring being processed on each guide roller,
- calculating a difference between the measured forces,
- using said difference as input of a controller, preferably a PID or PI controller, which outputs said feedback contribution.

**[0030]** Thanks to this solution, the control method automatically tends to adjust the rotation speed of the tapered rollers so as to equalise the forces applied by the ring being processed on the guide rollers and thus keep it centred on the rolling mill.

**[0031]** According to another aspect of the invention, the feedback contribution of at least one of the tapered rollers (e.g. of a second one of said tapered rollers) can be achieved by the steps of:

- measuring the torque applied to each tapered roller,
- calculating a difference between the measured torques,
- using said difference as input of a controller, preferably a PID or PI controller, which outputs said feedback contribution.

**[0032]** Thanks to this solution, the control method automatically tends to adjust the rotation speed of the tapered rollers so as to equalise the torque applied to them, thereby preventing the ring, being processed, from being warped or inclined.

**[0033]** Another aspect of the invention provides that the reference speed of each tapered roller can be established on the basis of at least the following parameters: rotation speed of the main roller, diameter of the main roller and rotation speed of the ring being processed.

**[0034]** By means of these parameters, it is in fact possible to establish a reference speed which, at least theoretically, guarantees that the peripheral speeds of the tapered rollers are equal to the peripheral speed of the ring being processed, at least at a point of mutual contact.

**[0035]** Another embodiment of the invention makes available a radial-axial ring rolling mill, comprising:

- a main roller adapted to stay in contact with an outer perimeter surface of a ring being processed,
- a contrast roller having a rotation axis coplanar to the rotation axis of the main roller and adapted to stay in contact with an inner perimeter surface of the ring being processed,
- a pair of guide rollers having rotation axes parallel to the rotation axis of the main roller and adapted to stay in contact with the outer perimeter surface of the ring being processed, each guide roller being carried by a support arm oscillating about an oscillation axis arranged symmetrically to the oscillation axis of the other support arm with respect to a plane of symmetry containing the rotation axis of the main roller and the rotation axis of the contrast roller,
- a pair of tapered rollers having rotation axes coplanar on said plane of symmetry, which are respectively adapted to stay in contact with the opposite axial ends of the ring being processed, and
- an electronic processing unit configured to perform the control method outlined above.

**[0036]** Finally, the invention also makes available a software comprising a computer code which, when executed by a computer, enables the computer to perform the control method described above.

**[0037]** These embodiments of the invention substantially achieve the same advantages as mentioned above, in particular that of making the speed regulation of the tapered rollers faster and more repetitive, improving the standardisation of the rolling process, especially for mass production of rings having the same characteristics.

#### Brief description of the drawings

**[0038]** Further features and advantages of the invention will be more apparent after reading the following description provided by way of non-limiting example, with the aid of the figures illustrated in the accompanying drawings.

Figure 1 is a perspective view of the essential mechanical components of a radial-axial rolling mill.

Figure 2 is a plan view of the radial-axial rolling mill of Figure 1, with the arms for supporting the guide rollers and the associated actuators being added.

Figure 3 is a block diagram of a method for controlling the radial-axial rolling mill of Figures 1 and 2.

Figure 4 is a block diagram of the control method the Figure 3 in a learning mode.

Figure 5 is a block diagram of the control method of Figure 3 in an operating mode.

#### Detailed description

**[0039]** A radial-axial rolling mill 100 for hot-rolling metal rings, such as made of steel or other special metals, including

copper, aluminium, titanium or super alloys is schematically shown in Figures 1 and 2.

**[0040]** The rolling mill 100 comprises a main roller 105, which is adapted to rotate on itself about its central axis A.

**[0041]** The main roller 105 may have a cylindrical shape or possibly a shaped profile to allow the production of rings with circular, flanged, spherical or variously shaped profiles. Preferably, the rotation axis A of the main roller 105 is oriented vertically, but it is not excluded that, in other embodiments, it may be oriented horizontally.

**[0042]** The main roller 105 is preferably motor-driven, i.e. it is connected to at least one motor adapted to rotate it.

**[0043]** The rolling mill 100 also includes a contrast roller 110, usually called a mandrel or pin, which is adapted to rotate about its central axis B.

**[0044]** Similarly to the main roller 105, the counter roller can also have a cylinder shape (e.g. smaller in diameter than the main roller 105) or have a shaped profile to allow the production of rings with circular, flanged, spherical or variously shaped profiles.

**[0045]** The rotation axis B of the contrast roller 110 is coplanar and substantially parallel to the rotation axis A of the main roller 105, so that the two rollers are mutually placed side by side.

**[0046]** The term "substantially" means that the rotation axis B of the contrast roller 110 may not only be perfectly parallel to the rotation axis A of the main roller 105, but may also be inclined by a few degrees with respect to the latter (e.g. between 0° and 5° in both directions).

**[0047]** Often, such inclination is adjustable and settable by means of suitable actuators, e.g. electric or hydraulic, which are managed by the control system of the rolling mill 100. The contrast roller 110 is preferably an idler roller, i.e. it is free to rotate about its own rotation axis B without being associated with any actuating motor.

**[0048]** The contrast roller 110 may be combined with actuator members (not shown) adapted to make it translate in a direction orthogonal and coplanar to both rotation axes A and B, so that the mutual distance between the contrast roller 110 and the main roller 105 can be varied.

**[0049]** The rolling mill 100 also comprises a pair of guide rollers 115, preferably having a cylindrical shape, each of which is adapted to rotate on itself about its central axis C which is parallel to the rotation axis A of the main roller 105.

**[0050]** However, it is not excluded that, in some particular cases, also the guide rollers 115 may be shaped.

**[0051]** The guide rollers 115 preferably have the same diameter and are arranged on opposite sides with respect to an (ideal/imaginary) plane of symmetry S on which the rotation axes A and B of the main roller 105 and the contrast roller 110 lie (see Fig. 2).

**[0052]** Preferably, the guide rollers 115 are idler rollers, i.e. they are adapted to rotate freely about their own rotation axis C without being connected to any actuating motor.

**[0053]** Each guide roller 115 is carried by (and pivotally mounted on) a respective oscillating support arm 120, which is adapted to oscillate by rotating about an oscillation axis D that is parallel to and spaced from the rotation axis C of the respective guide roller 115. The oscillation axes D of the two oscillating support arms 120 are preferably arranged symmetrically with respect to the aforementioned plane of symmetry S, and the distance separating the oscillation axis D from the rotation axis C of the respective guide roller 115 is preferably the same for both oscillating support arms 120.

**[0054]** Each oscillating support arm 120 may be actuated to oscillate about its own oscillation axis D by a respective actuator 125, e.g. by a hydraulic piston cylinder assembly via a suitable leverage.

**[0055]** One function of these actuator members 125 is to hold the rotation axes C of the guide rollers 115 in a desired/programmed position.

**[0056]** In some cases, this position may be the one (illustrated in the figures) wherein the rotation axes C of the guide rollers 115 are mutually symmetrical with respect to the plane of symmetry S.

**[0057]** In other cases, however, the oscillating support arms 120 may be controlled so that the position of the rotation axes C of the guide rollers 115 is deliberately asymmetrical.

**[0058]** The rolling mill 100 also comprises a pair of tapered rollers, respectively referred to as 130 and 135, each of which has a respective central axis of symmetry E.

**[0059]** A tapered roller is of course also understood to be a truncated cone roller, i.e. any roller with an axialsymmetrical side surface whose generatrices all converge at a point (vertex) on the central axis of symmetry E.

**[0060]** Preferably, the central axes of symmetry E of the two tapered rollers 130 and 135 lie coplanar on the plane of symmetry S.

**[0061]** Furthermore, the vertices V of the two tapered rollers 130 and 135, i.e. the vertices (also ideal) of the respective tapered side surfaces, are preferably aligned with each other along an (ideal/imaginary) axis Q that is parallel to the rotation axis of the main roller 105.

**[0062]** This axis Q is preferably interposed between the tapered rollers 130 and 135 and the main roller 105.

**[0063]** The two tapered rollers 130 and 135 (i.e. the respective tapered surfaces) are finally facing and oriented so that the mutually closest generatrices of one and the other tapered roller 130 and 135 are parallel to each other and perpendicular to the rotation axis A of the main roller.

**[0064]** For example, the tapered rollers 130 and 135 (i.e. their tapered side surfaces) may have the same angle at the vertex and their axes of central symmetry E may be mutually inclined by an angle equal to the angle at the vertex of

each of them.

**[0065]** The angle at the vertex is generally understood to be the angle formed at the vertex by any pair of tapered surface generatrices lying coplanar to each other in a plane that also contains the central axis of symmetry E.

**[0066]** In the example shown, wherein the rotation axis A of main roller 105 is oriented vertically, the tapered rollers 130 and 135 are essentially superimposed, with the tapered roller 130 which is arranged below the tapered roller 135.

**[0067]** In the embodiments wherein the rotation axis A of the main roller 105 was horizontal, the tapered rollers 130 and 135 would be oriented vertically and placed mutually side-by-side.

**[0068]** In any case, each one of the tapered rollers 130 and 135 is adapted to rotate on itself about its own central axis E.

**[0069]** In particular, each tapered roller 130 and 135 is preferably motor-driven, i.e. connected to at least one motor adapted to rotate it.

**[0070]** The motors actuating the two tapered rollers 130 and 135 are preferably independent of each other, so that the rotation speed of such rollers may be adjusted equally independently.

**[0071]** The tapered rollers 130 and 135 may also be combined with first handling members (not shown) adapted to move them relative to each other in a direction parallel to the rotation axis A of the main roller 105.

**[0072]** For example, the first handling members can move the (upper) tapered roller 135 closer to/ away from the (lower) tapered roller 130, which remains stationary, or vice versa, or move both.

**[0073]** Finally, the tapered rollers 130 and 135 may be associated with second handling members (not illustrated) adapted to move them both (and simultaneously) closer to and away from the main roller 105, along a direction perpendicular to the rotation axis A and lying in the plane of symmetry S.

**[0074]** The operation of the rolling mill 100 described above starts with "donut" shaped semi-finished (or blank) product 200 made of a high-temperature metal, e.g. between 900°C and 1000°C in the case of steels or even much lower, such as between 250°C and 300°C in the case of copper or aluminium.

**[0075]** In particular, this semi-finished product 200 may comprise an annular wall, e.g. cylindrically shaped, which develops about a central axis and has an outer perimeter surface 205, an inner perimeter surface 210 and two opposite axial ends 215 and 220.

**[0076]** The semi-finished product 200 is placed in the rolling mill 100 so that its axis is parallel to the axis of the main roller 105 and its annular wall is interposed between the latter and the contrast roller 110.

**[0077]** In particular, the semi-finished product 200 may be arranged so that the main roller 105 is positioned outside and the contrast roller 110 is positioned inside the annular wall.

**[0078]** At this point, by moving the contrast roller 110 closer to the main roller 105, the wall of the semi-finished product 200 is clamped between these two rollers, with the main roller 105 staying in contact with the outer perimeter surface 205 and the contrast roller 110 staying in contact with the inner perimeter surface 210.

**[0079]** By thereby rotating the main roller 105 about the rotation axis A, the semi-finished product 200 is also rotated about its own axis.

**[0080]** In order to stabilise this rotation, the guide rollers 115 are also brought into contact with the outer perimeter surface 205 and, by oscillating their respective support arms 120, they are placed in a desired/prefixed position.

**[0081]** As mentioned above, this position may be chosen so that the axis of the semi-finished product 200 is coplanar with the rotation axes A and B of the main roller 105 and the contrast roller 110, i.e. lying on the plane of symmetry S.

**[0082]** In other words, the position assumed by the guide rollers 115 may be such that their points of contact with the outer perimeter surface 205 of the semi-finished product 200 are mutually symmetrical with respect to the plane of symmetry S.

**[0083]** However, some rolling techniques may provide that, during certain rolling steps, the position of the guide rollers 115 is actively modified in order to "move" the ring 200 being processed with respect to the centreline of the rolling mill 100 (off-centre rolling), normally by a few degrees, and then "return it to the centre" at the end of rolling.

**[0084]** At the same time, the tapered rollers 130 and 135 are arranged on axially opposite sides of the semi-finished product 200, preferably so that the axis Q, along which the vertices V of the respective tapered surfaces are aligned, coincides with the axis of the semi-finished product 200 itself.

**[0085]** The tapered rollers 130 and 135 are then moved closer together in the axial direction, so that the tapered roller 130 stays in contact with the axial end 215 of the semi-finished product 200 while the tapered roller 135 stays in contact with the opposite axial end 220.

**[0086]** As the semi-finished product 200 continues to rotate about its own axis, the contrast roller 110 is progressively moved closer to the main roller 105 (in a direction perpendicular to the rotation axis A), while the tapered rollers 130 and 135 are progressively moved closer together (in a direction parallel to the rotation axis A).

**[0087]** The wall of the semi-finished product 200 thereby undergoes axial crushing and radial crushing, which simultaneously also cause an increase in diameter, until obtaining a ring with the desired height, thickness and diameter.

**[0088]** As the diameter of the semi-finished product 200 increases, the guide rollers 115 gradually spread apart, while continuing (by appropriate control of the actuators 125) to perform their positioning function, e.g. to maintain the axis of the semi-finished product 200 in the plane of symmetry S of the rolling mill 100 or to maintain the axis of the semi-finished

product 200 in a desired/programmed "off-centre" position.

**[0089]** For this purpose, the support arms 120 carrying the guide rollers 115 may be controlled in pure position, force-limited position or more rarely in pure force.

**[0090]** At the same time, as the increase in diameter also involves a movement of the axis of the semi-finished product 200 away from the main roller 105, the tapered rollers 130 and 135 are progressively moved in the same direction, so that the vertices V of their tapered surfaces remain aligned along the axis of the semi-finished product 200.

**[0091]** As long as the latter condition can be maintained, it is possible to rotate each tapered roller 130 and 135 about its respective rotation axis E at a reference speed such that the tangential speed of said tapered roller 130 or 135 is equal to the tangential speed of the semi-finished product 200 at all points of mutual contact.

**[0092]** In particular, this reference speed, which essentially depends on the geometry and rotation speed of the semi-finished product 200, can be calculated and set on the tapered roller 130 via an appropriate control supplied to the respective motor.

**[0093]** In this way, no material creep in the semi-finished product 200 is produced.

**[0094]** However, when the diameter of the semi-finished product 200 increases beyond a certain value, it is no longer possible to keep the vertices V of the tapered rolls 130 and 135 perfectly aligned with the axis of the semi-finished product 200 itself.

**[0095]** In this condition, it is possible to rotate each tapered roller 130 and 135 about its respective rotation axis E at a reference speed such that the tangential speed of such tapered roller 130 or 135 is equal to the tangential speed of the semi-finished product 200 at a single point of mutual contact, e.g. at a midpoint between the inner perimeter surface 210 and the outer perimeter surface 205.

**[0096]** At all the other points of mutual contact, however, there will be a tangential speed difference between each tapered roller 130 and 135 and the semi-finished product 200, such that material creep may occur.

**[0097]** This material creep tends to move the semi-finished product 200 to one side or the other, causing it to lose its correct position or leading to defects.

**[0098]** To overcome this drawback, the rotation speed of each tapered roller 130 and 135 is then adjusted to try to equalise the thrust force exerted by the semi-finished product 200 on the two guide rollers 115 and to equalise the torque applied to the tapered rollers 130 and 135.

**[0099]** For this purpose, the rotation speed of the tapered rollers 130 and 135 may be adjusted by the control method shown in Figure 3.

**[0100]** This control method firstly provides for establishing (block S100) the aforementioned reference value v of the rotation speed of each tapered roller 130 and 135.

**[0101]** This value v may, for example, be calculated as a function of one or more parameters selected from the group consisting of: rotation speed of the main roller 105, diameter of the main roller 105, geometry of the tapered rollers 130 and 135, rotation speed of the semi-finished product 200, position of the semi-finished product 200 between the tapered rollers 130 and 135.

**[0102]** Alternatively, the reference value v may be retrieved from a correlation map that receives as input one or more of the above parameters and outputs the corresponding reference value v of the rotation speed of the tapered rollers 130 and 135.

**[0103]** A correction d1 is then applied to this reference value v in order to obtain a first correct value v\*.

**[0104]** The correction d1 is a numerical value (of positive or negative sign depending on the case) which is preferably added to the reference value v of the rotation speed. However, it is not excluded that, in other embodiments, the correction d1 may be a multiplicative factor or another type of factor.

**[0105]** In any case, the correction d1 depends in turn on at least a first retracting contribution r1 and at least on a first manual contribution m1.

**[0106]** These contributions r1 and m1 are also numerical values (of positive or negative sign depending on the case) which are preferably added together to obtain the correction d1. However, it is not excluded that, in other embodiments, the correction d1 may be calculated, still as a function of the contributions r1 and m1, however using a different mathematical relation.

**[0107]** Regardless of these considerations, the feedback contribution r1 may be the one that performs the function of equalising the thrust force exerted by the semi-finished product 200 on the two guide rollers 115.

**[0108]** For this purpose, the feedback contribution r1 may be obtained by first measuring the thrust force f1 that is exerted by the semi-finished product 200 on a guide roller 115 (block S105) and the thrust force f2 that is exerted by the same semi-finished product 200 on the other guide roller 115 (block S110).

**[0109]** These two thrust forces f1 and f2 may be measured by means of suitable force (or torque) sensors installed for instance on the oscillating support arms 120 and/or in the respective actuating members 125.

**[0110]** The thrust forces f1 and f2 may then be subtracted from each other (block S115) so as to calculate a difference e1 (or error).

**[0111]** This difference e1 may then be provided as input to a controller S120, e.g. a PI or PID controller, which outputs

the value of the feedback contribution r1.

**[0112]** For example, in the case of a PID, the value of the feedback contribution r1 output by the controller S120 can be expressed by the following relation in the time domain t:

$$r1(t) = K_p e1(t) + K_i \int_{t_0}^t e1(\tau) d\tau + K_d \frac{de1(t)}{dt}$$

where e1 is the difference calculated between the thrust forces f1 and f2,  $K_p$  is a parameter named as proportional gain,  $K_i$  is a parameter that is called integrative gain, and  $K_d$  is a parameter that is called derivative gain; or equivalently from the following relation:

$$r1(t) = K_p \left( e1(t) + \frac{1}{T_i} \int_{t_0}^t e1(\tau) d\tau + T_d \frac{de1(t)}{dt} \right)$$

where  $T_i (=K_p/K_i)$  is a parameter named integration time while  $T_d (=K_d/K_p)$  is a parameter named derivation time.

**[0113]** Each of the above-mentioned parameters may have a constant value that is pre-set when setting up the controller S120.

**[0114]** In case the S120 controller is a PI controller, the value of the feedback contribution r1 will be expressed by the same relations excluding the derivative contribution, i.e. considering a derivative gain  $K_d$  equal to zero.

**[0115]** The manual contribution m1 is instead selected and adjusted as desired by an operator supervising the operation of the rolling mill 100 (block S125), e.g. through the manual operation of a handwheel or any other member for controlling or interfacing with the machine.

**[0116]** The first correct value  $v^*$  obtained in this way is used to control the rotation speed of the tapered rollers 135 and 130.

**[0117]** In particular, the first correct value  $v^*$  may be directly transmitted to a driver S130 that actuates the motor of the tapered roller 135, so that the latter is commanded to rotate at a speed exactly corresponding to the first correct value  $v^*$ .

**[0118]** At the same time, the first correct value  $v^*$  may also be used to actuate the tapered roller 130, preferably after being further corrected by means of a second correction d2.

**[0119]** In this context, the first correct value  $v^*$  may therefore be considered as a new reference value for controlling the rotation speed of the tapered roller 130.

**[0120]** In this case also, the correction d2 is a numerical value (of positive or negative sign depending on the case) which is added to the first correct value  $v^*$  of the rotation speed. However, it is not excluded that, in other embodiments, the correction d2 may be a multiplicative factor or another type of factor.

**[0121]** The correction d2 may also depend in turn on at least a second feedback contribution r2 and on at least a second manual contribution m2.

**[0122]** These contributions r2 and m2 are numerical values (of positive or negative sign depending on the case) which are preferably added together to obtain the correction d2. However, it is not excluded that, in other embodiments, the correction d2 may be calculated, still as a function of the contributions r2 and m2, however using a different mathematical relation.

**[0123]** The feedback contribution r2 may be the one that performs the function of equalising the torque applied to the tapered rollers 130 and 135.

**[0124]** For this purpose, the feedback contribution r2 may be obtained by first measuring the torque t1 that is applied to the tapered roller 130 (block S135) and the torque t2 that is applied to the other tapered roller 135 (block S140).

**[0125]** These torques t1 and t2 may be measured by means of suitable torque sensors associated with the motors actuating the tapered rollers 130 and 135.

**[0126]** The torques t1 and t2 may then be subtracted from each other (block S145) in order to calculate a difference e2 (or error).

**[0127]** This difference e2 may then be supplied as an input to a controller S150, such as a controller of the PI or PID type, which outputs the value of the second feedback contribution r2.

**[0128]** For example, in the case of a PID, the value of the feedback contribution r2 output by the controller S150 can be expressed by the following relation in the time domain t:

$$r2(t) = K_p e2(t) + K_i \int_{t_0}^t e2(\tau) d\tau + K_d \frac{de2(t)}{dt}$$

where  $e2$  is the difference calculated between the thrust forces,  $K_p$  is the proportional gain,  $K_i$  is the integrative gain, and  $K_d$  is the derivative gain; or equivalently by the following relation:

$$r1(t) = K_p \left( e1(t) + \frac{1}{T_i} \int_{t_0}^t e1(\tau) d\tau + T_d \frac{de1(t)}{dt} \right)$$

where  $T_i (=K_p/K_i)$  is the integration time and  $T_d (=K_d/K_p)$  is the derivation time.

**[0129]** Even in this case, each of the above-mentioned parameters may have a constant value that is pre-set when setting up the controller S150.

**[0130]** In case the S150 controller is a PI controller, the value of the feedback contribution  $r2$  will be expressed by the same relations excluding the derivative contribution, i.e. considering a derivative gain  $K_d$  equal to zero.

**[0131]** Of course, the  $K_p$ ,  $K_i$ ,  $K_d$ ,  $T_i$  and/or  $T_d$  parameters of the controller S150 may be different from the same coefficients of the controller S120.

**[0132]** The manual contribution  $m2$  is instead selected and adjusted as desired by an operator supervising the operation of the rolling mill 100 (block S155), e.g. through the manual operation of a handwheel or any other member for controlling or interfacing with the machine.

**[0133]** Correcting the first correct value  $v^*$  with the correction  $d2$  provides for a second correct value  $v^{**}$  of the rotation speed, which can be directly transmitted to a driver S160 commanding the motor of the tapered roller 130, so that the latter is commanded to rotate at a speed exactly corresponding to the second correct value  $v^{**}$ .

**[0134]** In order to improve the efficiency and repeatability of the control method described above, especially in the context of mass production, the latter can be performed in two different modes, a learning mode and an actual operating mode.

**[0135]** The learning mode may be performed when rolling a sample or test semi-finished product 200, while the operating mode may be performed when subsequently rolling one or more semi-finished products 200 having the same geometrical characteristics as the sample product, to obtain finished rings of the same dimensions.

**[0136]** As illustrated in Figure 4, in the learning mode, in addition to the steps already described above, the control method involves recording in real time (block S165) the correction  $d1$  (including the relative contributions  $r1$  and  $m1$ ) which is applied to the reference value  $v$  of the rotation speed of the tapered rollers 130 and 135, in a plurality of successive instants during the processing of the semi-finished product 200.

**[0137]** At the same time, the control method may provide for recording in real time (block S170) the correction  $d2$  (including the associated contributions  $r2$  and  $m2$ ) that is applied to the first correct value  $v^*$  of the rotation speed, in a plurality of successive instants during the processing of semi-finished product 200, e.g. at the same instants in which the correction value  $d1$  is also measured.

**[0138]** At the same time, the control method may provide for measuring and then preferably recording (block S175) the diameter assumed by the semi-finished product 200 at each instant when the correction  $d1$  and/or correction  $d2$  is recorded.

**[0139]** The diameter of semi-finished product 200 may be measured with any fit-for-purpose sensor.

**[0140]** To be precise, the diameter of the semi-finished product 200 is preferably measured by means of a laser gauge (usually of the triangulation type) or by means of a mechanical touch probe made by means of an idler wheel held in thrust on the outer perimeter surface 205 of the semi-finished product 200 by an air cylinder "acting as a spring" and connected to a linear measuring system (optical scale or other-type transducer).

**[0141]** These devices may be located between the two tapered rollers 130 and 135 (in the case of the mechanical touch probe) or in a position behind them (in the case of the laser gauge), so that the linear measurement taken is always on the centreline of the rolling mill 100, i.e. along a direction lying in the plane of symmetry S.

**[0142]** At the end of the rolling process performed in the learning step, the recorded values of the correction  $d1$  and the measured values of the diameter of the semi-finished product 200 may be advantageously used to create a correlation map M1 which correlates, to each value of the diameter of the semi-finished product 200, a corresponding value (i.e. the one recorded at the same instant) of the correction  $d1$ .

**[0143]** This correlation map M1 may be defined by a mathematical function or curve, possibly obtained as an interpolation of the measured/recorded "points", or it may simply be a table or matrix in which the values of the correction  $d1$  corresponding to the various diameters of the semi-finished product 200 are stored.

**[0144]** Similarly, the recorded values of the correction d2 and the measured values of the diameter of the semi-finished product 200 may advantageously be used to create a correlation map M2 which correlates, to each value of the diameter of the sampled semi-finished product 200, a corresponding value (i.e. the one recorded at the same time) of the correction d2.

**[0145]** This correlation map M2 may also be defined by a mathematical function or curve, possibly obtained as an interpolation of the measured/recorded "points", or it may simply be a table or matrix in which the values of the correction d2 corresponding to the various diameters of the semi-finished product 200 are stored.

**[0146]** The correlation map M1 and/or the correlation map M2 may then be advantageously used by the control method in the subsequent operating mode, i.e. when rolling a semi-finished product 200 having the same characteristics as the sampling one, in order to obtain a finished ring having the same dimensions as the one obtained in the learning step.

**[0147]** In particular, as illustrated in figure 5, in the operating mode, in addition to the general steps already described with reference to figure 3, the control method of the rolling mill 100 provides for measuring in real time (block 180) the diameter assumed by the semi-finished product 200, at a plurality of successive instants during the rolling process, for example at each instant when the feedback calculation of the contributions r1 and/or r2 is repeated.

**[0148]** Of course, the measurement of the diameter may be done in the same way as for the learning mode.

**[0149]** The control method thus provides for obtaining from the first correlation map M1, for each measured value of the diameter, the corresponding correction value d1 (block S185), which will be hereinafter referred to as d1\* for clarity's sake.

**[0150]** The correction d1\* retrieved from the M1 correlation map is then applied to the reference value v of the rotation speed, together with the correction d1 obtained from the contributions r1 and m1.

**[0151]** In particular, the correction d1\* may simply be added to the correction d1, to be added together with the latter to the reference value v of the rotation speed.

**[0152]** However, it is not excluded that, in other embodiments, the correction d1\* may be a multiplicative factor or another type of factor.

**[0153]** Similarly and at the same time, the control method may provide for obtaining from the second correlation map M2, for each measured value of the diameter of the semi-finished product 200, the corresponding value of the correction d2 (block S190), which will be hereinafter referred to as d2\* for clarity's sake.

**[0154]** The correction d2\* retrieved from the second correlation map M2 is then applied to the first target value v\* of the rotation speed, together with the correction d2 obtained from the contributions r2 and m2.

**[0155]** In particular, the correction d2\* may simply be added to the correction d2, to be added together with the latter to the first corrected value v\* of the rotation speed.

**[0156]** However, it is not excluded that, in other embodiments, the correction d2\* may be a multiplicative factor or another type of factor.

**[0157]** Thanks to this approach, the reference value v of the rotation speed is corrected not only on the basis of the feedback contributions r1 and r2 and on the manual contributions m1 and m2, but also on the basis of a contribution d1\* and d2\* that is essentially feed-forward and determined by the previous experience, i.e. during the learning step. Thereby, especially in the hypothesis of having to produce a large number of rings identical to the one obtained in the learning mode, the intervention of the control system on the adjustment of the rotation speed of the tapered rollers 130 and 135 is much quicker and more repetitive, leading to the production of rings more similar to each other.

**[0158]** The control method outlined above with reference to figures 3 to 5 may be advantageously performed automatically by an electronic processing unit (not shown) of the rolling mill 100, which is connected to the various actuator member and sensors and is configured/programmed to perform the above-described operations.

**[0159]** Obviously, a person skilled in the art may make several technical-applicative modifications to what described above, without departing from the scope of the invention as hereinafter claimed.

## Claims

1. A method for controlling a radial-axial rolling mill (100) for rings (200),

wherein the radial-axial rolling mill (100) comprises:

- a main roller (105) adapted to stay in contact with an outer perimeter surface (205) of the ring (200) being processed,
- a contrast roller (110) having a rotation axis (B) coplanar to the rotation axis (A) of the main roller (105) and adapted to stay in contact with an inner perimeter surface (210) of the ring (200) being processed,
- a pair of guide rollers (115) having rotation axes (C) parallel to the rotation axis (A) of the main roller (105) and adapted to stay in contact with the outer perimeter surface (205) of the ring (200) being processed,

each guide roller (115) being carried by a support arm (120) oscillating about an oscillation axis (D) arranged symmetrically to the oscillation axis (D) of the other support arm (120) with respect to a plane of symmetry (S) containing the rotation axis (A) of the main roller (105) and the rotation axis (B) of the contrast roller (110), and

- a pair of tapered rollers (130, 135) having rotation axes (E) coplanar on said plane of symmetry (S), which are respectively adapted to stay in contact with the opposite axial ends (215, 220) of the ring (200) being processed,

wherein the control method provides for adjusting the rotation speed of each tapered roller (130, 135) by means of the steps of:

- establishing a reference value (v) of the rotation speed of the tapered roller (130, 135),
- applying a correction (d1, d2) to said reference value (v) to obtain a correct value (v\*, v\*\*) of the rotation speed of the tapered roller (130, 135),
- actuating the tapered roller (130, 135) at a rotation speed having the correct value (v\*, v\*\*), and

wherein the correction (d1, d2) is obtained as a function of a feedback contribution (r1, r2) and/or a manual contribution (m1, m2),

**characterized in that** the control method is executable in a learning mode and in a subsequent operating mode, wherein, in the learning mode, the control method provides, for each tapered roller, for:

- recording the correction (d1, d2) which is applied to the reference value (v) of the rotation speed of the tapered roller (130, 135) in a plurality of successive instants during the processing of at least a first ring (200),
- measuring the diameter of said first ring (200) at each instant in which the correction is recorded (d1, d2), and
- using the recorded values of the correction (d1, d2) and the measured values of the diameter of the first ring (200) to create a correlation map (M1, M2) which, for each value of the ring diameter, correlates a corresponding value of the correction, and

wherein, in the operating mode, the control method provides, for each tapered roller, for:

- measuring the diameter of at least a second ring (200) being processed,
- obtaining, from the correlation map (M1, M2) of the tapered roller (130, 135), the correction value (d1\*, d2\*) corresponding to the measured diameter,
- applying the value (d1\*, d2\*) obtained from the correlation map (M1, M2) and the correction (d1, d2) to the reference value (v) of the rotation speed of the tapered roller (130, 135).

**2.** A method according to claim 1, wherein the feedback contribution (r1) of at least one of the tapered rollers (135) is obtained by means of the steps of:

- measuring the force (f1, f2) applied by the ring (200) being processed on each guide roller (115),
- calculating a difference (e1) between the measured forces,
- using said difference (e1) as an input of a controller (S120) which outputs said feedback contribution (r1).

**3.** A method according to claim 2, wherein said controller (S120) is a PID or PI controller.

**4.** A method according to any one of the preceding claims, wherein the feedback contribution (r2) of at least one of the tapered rollers (130) is obtained by means of the steps of:

- measuring the torque (c1, c2) applied to each tapered roller (130, 135),
- calculating a difference (e2) between the measured torques (c1, c2),
- using said difference (e2) as an input of a controller (S150) which outputs said feedback contribution (r2).

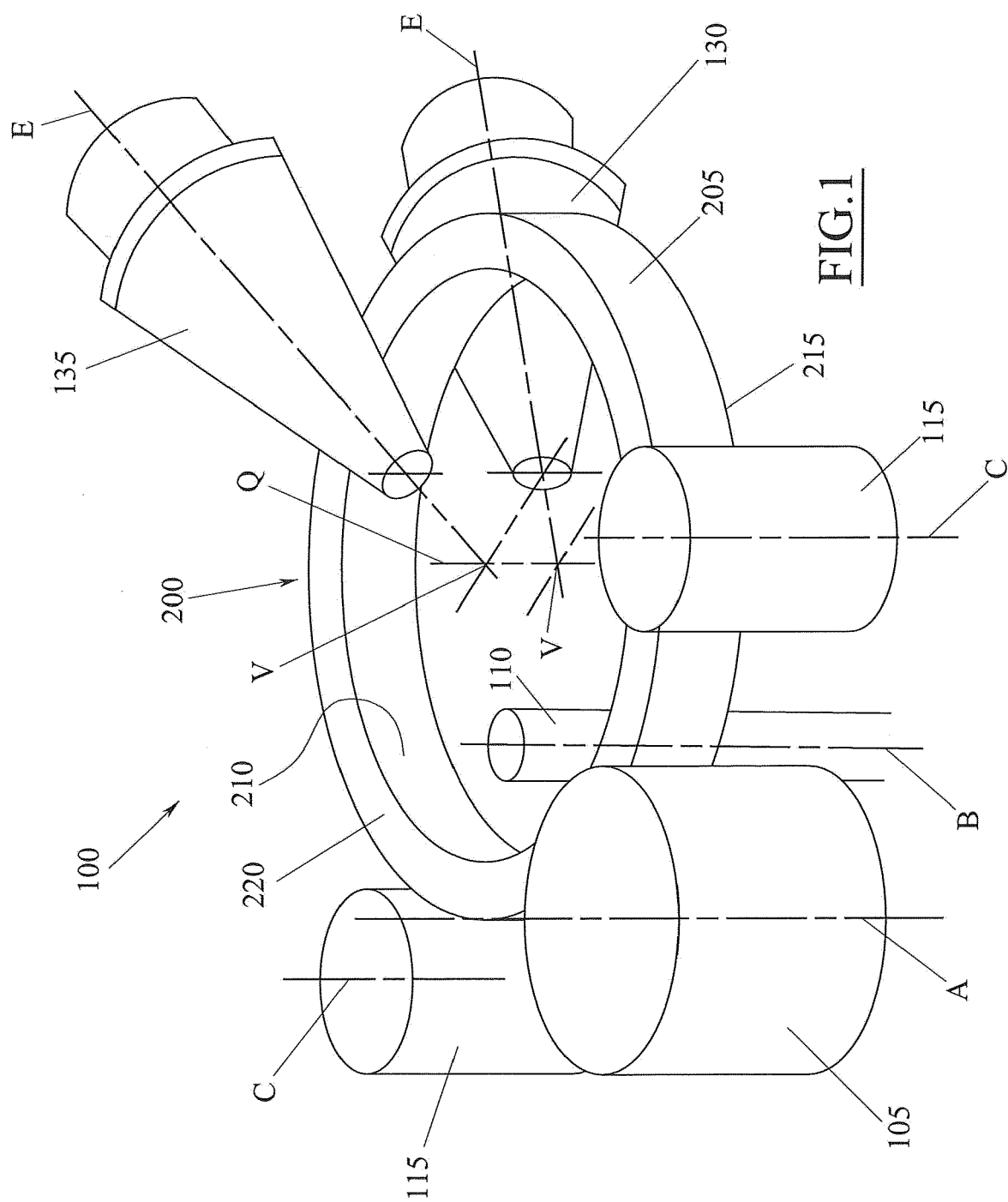
**5.** A method according to claim 4, wherein said second controller (S150) is a PID or PI controller.

**6.** A method according to any one of the preceding claims, wherein the reference speed (v) of each tapered roller (130, 135) is established based on at least the following parameters: main roller rotation speed, main roller diameter, and rotation speed of the ring being processed.

7. A radial-axial rolling mill (100) for rings (200), comprising:

- a main roller (105) adapted to stay in contact with an outer perimeter surface (205) of a ring (200) being processed,
- a contrast roller (110) having a rotation axis (B) coplanar to the rotation axis (A) of the main roller (105) and adapted to stay in contact with an inner perimeter surface (210) of the ring (200) being processed,
- a pair of guide rollers (115) having rotation axes (C) parallel to the rotation axis (A) of the main roller (105) and adapted to stay in contact with the outer perimeter surface (205) of the ring (200) being processed, each guide roller (115) being carried by a support arm (120) oscillating about an oscillation axis (D) arranged symmetrically to the oscillation axis (D) of the other support arm (120) with respect to a plane of symmetry (S) containing the rotation axis (A) of the main roller (105) and the rotation axis (B) of the contrast roller (110),
- a pair of tapered rollers (130, 135) having rotation axes (E) coplanar on said plane of symmetry (S), which are respectively adapted to stay in contact with the opposite axial ends (215, 220) of the ring (200) being processed, and
- an electronic processing unit configured to perform the control method outlined above.

8. A software comprising a computer code which, when executed by an electronic processor, enables the electronic processor to execute the method of any one of claims 1 to 6.



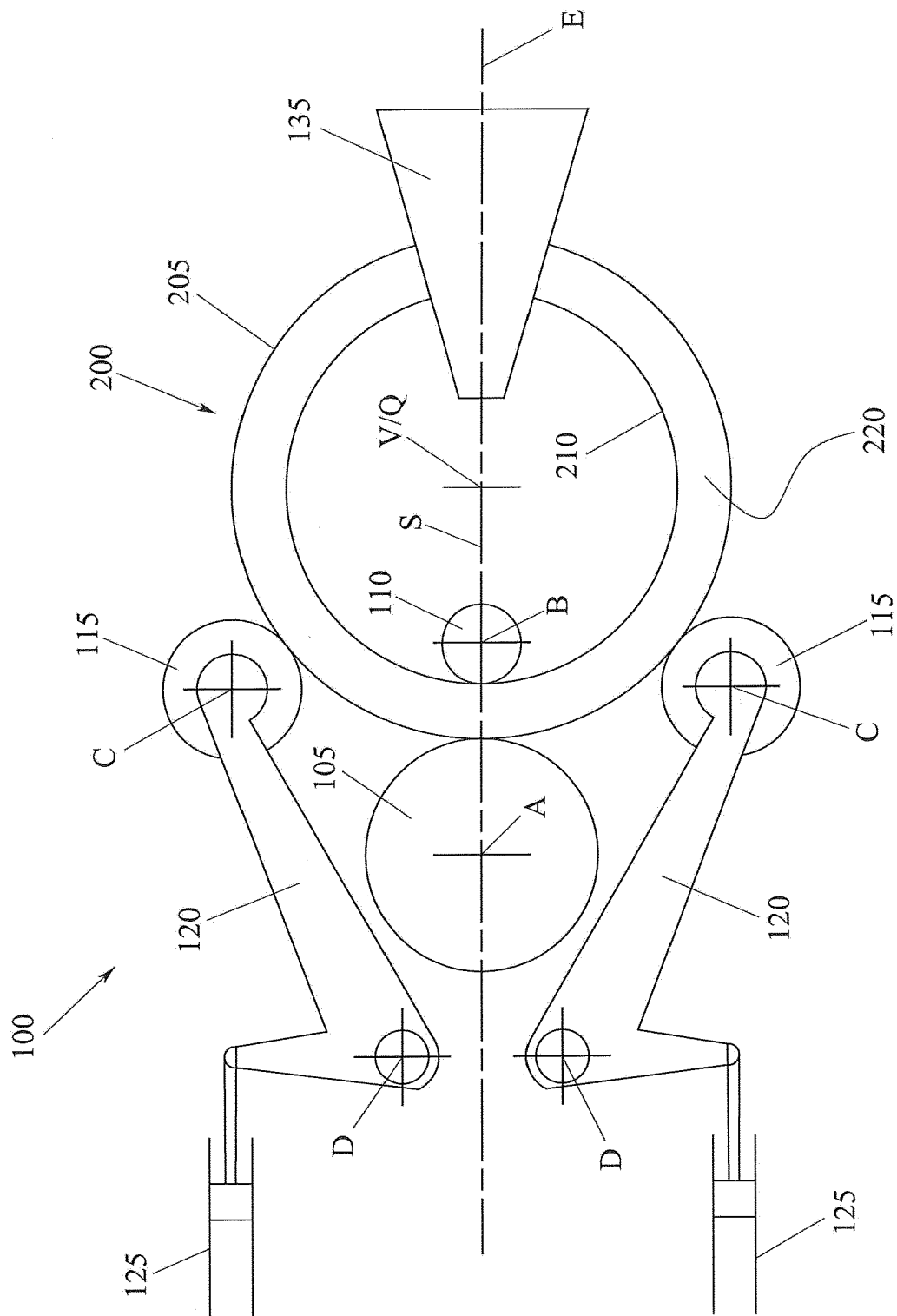


FIG. 2

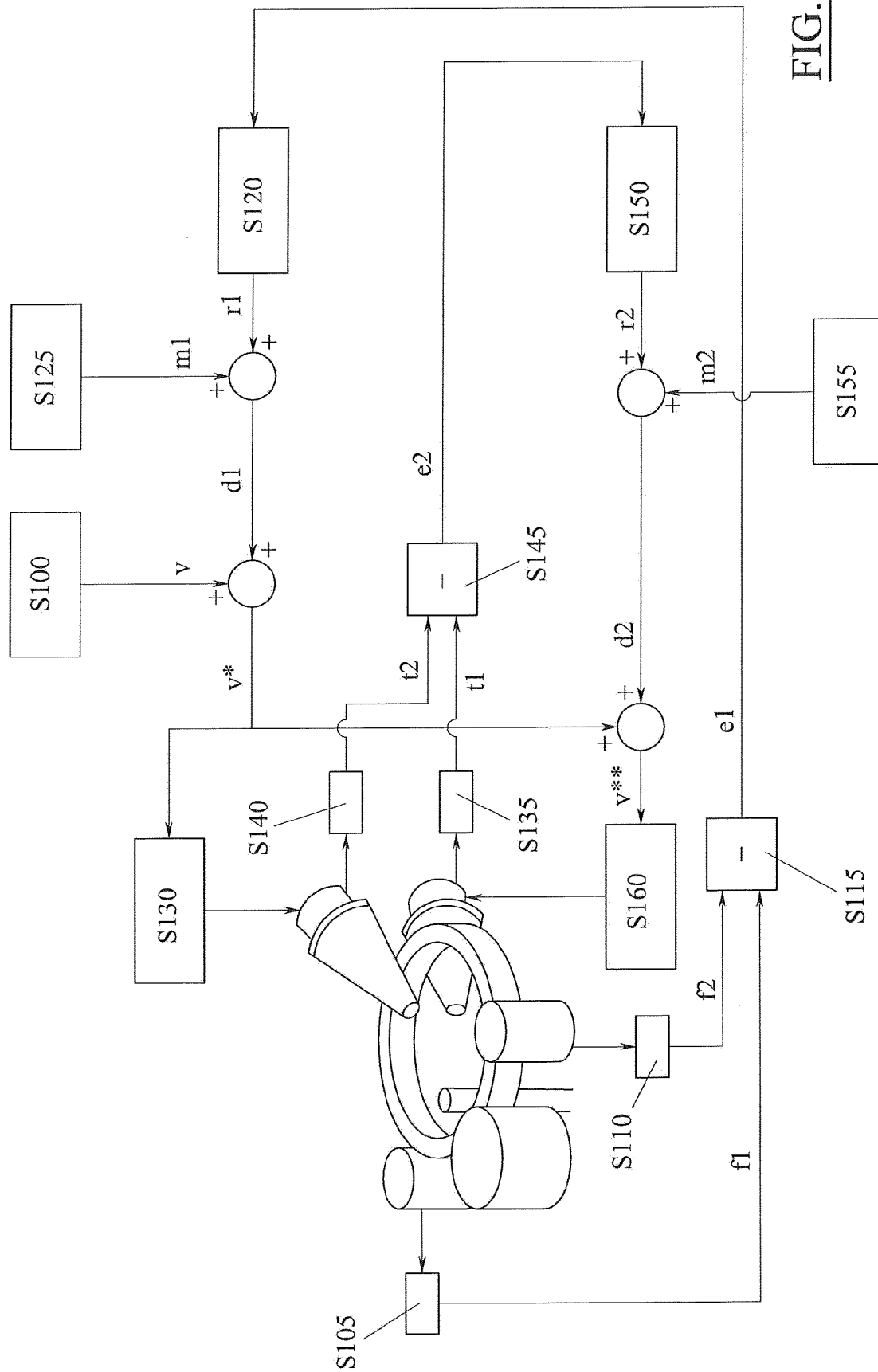


FIG. 3

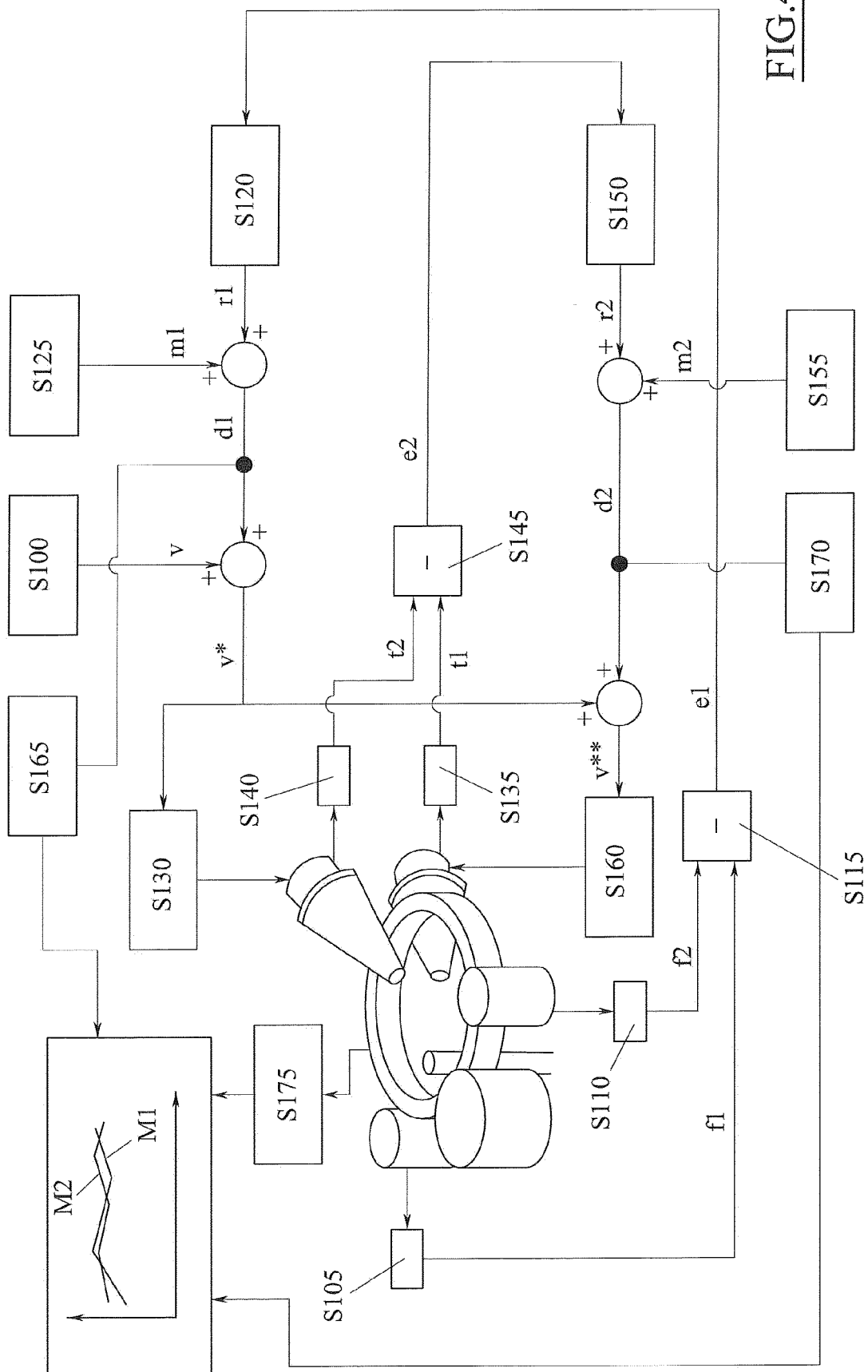


FIG. 4

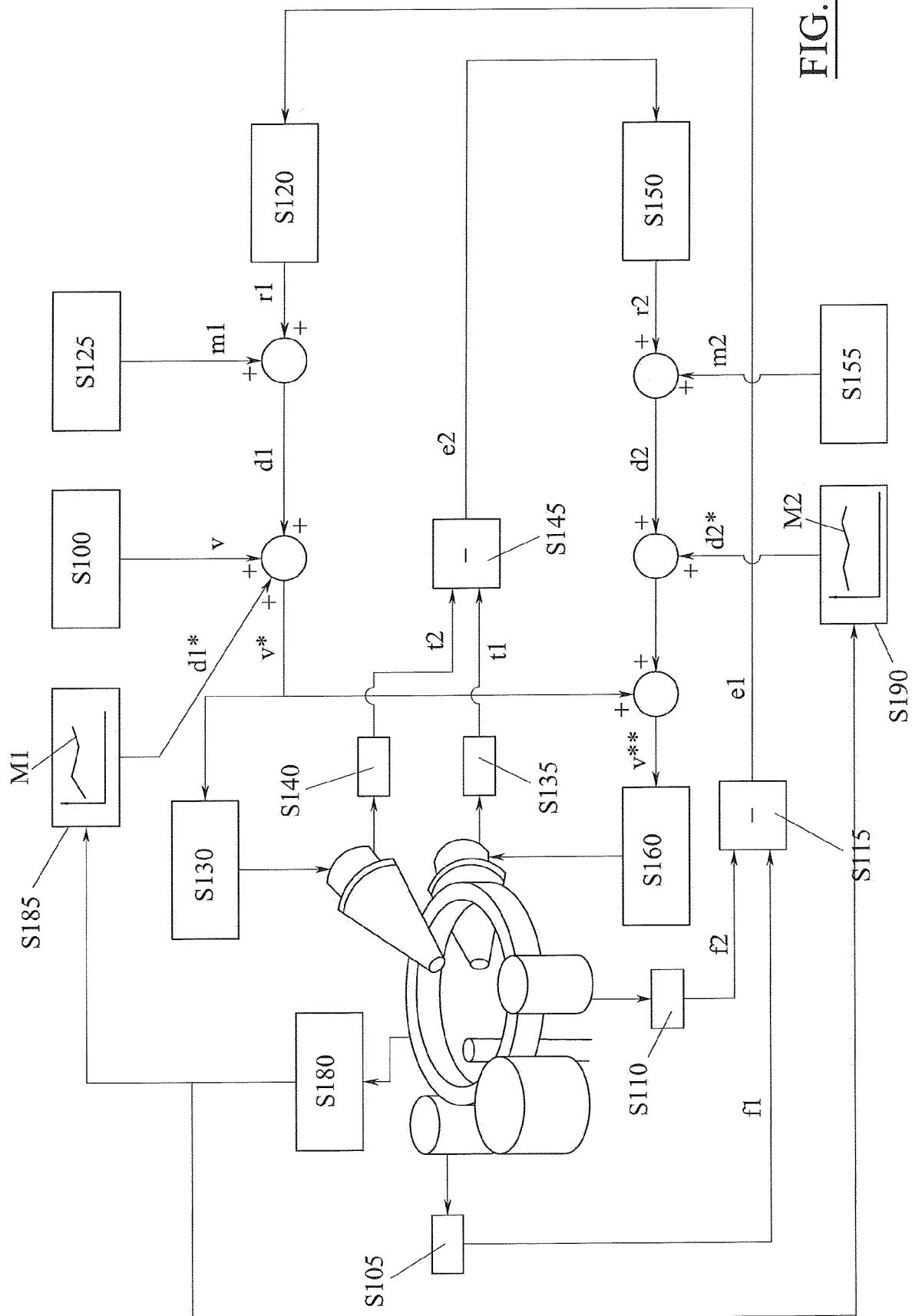


FIG. 5



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Application Number

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| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                                         |                                                                                                                                                                                                                                                                              |                                            |
| Place of search<br><b>Munich</b>                                                                                                                                                                                                                       |                                                                                                                                                                         | Date of completion of the search<br><b>16 February 2023</b>                                                                                                                                                                                                                  | Examiner<br><b>Ritter, Florian</b>         |
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