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(72) Inventor: **Sorbi, Federica**
43100 Parma (IT)

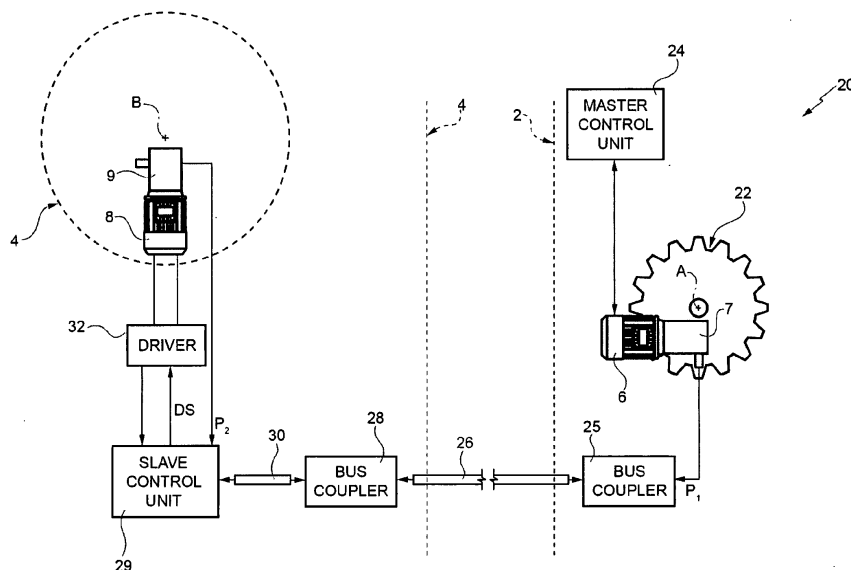
(74) Representative: **D'Angelo, Fabio et al**
Studio Torta S.p.A.
Via Viotti, 9
10121 Torino (IT)

(71) Applicant: **SIDEL S.p.A. con Socio Unico**
Parma (IT)

(54) **System and method for synchronizing the rotating motions of elementary parts of a plant for processing of containers**

(57) A synchronization system (20), for a plant (1) having at least a first (2) and a second (4) rotating parts cooperating in the processing of containers (3), the first (2) and second (4) rotating parts being driven in a respective rotating motion around a respective rotation axis (A, B) by independent first (6) and second (8) electric motors; the synchronization system (1) is provided with: a first position sensor (7) coupled to the first rotating part (2) to measure a rotating position thereof around the respective rotation axis and generate a position information

signal (P_1); and a control processing unit (29) coupled to the second rotating part (4) to control the second electric motor (8) thereof, based on the position information signal (P_1) received from the first position sensor (7), thereby tracking the rotating motion of the first rotating part (2). A single digital coupling bus (26) is envisaged to couple the first (2) and second (4) rotating parts and transfer the position information signal (P_1) to the control processing unit (29).

**FIG. 2**

Description

[0001] The present invention relates to a system and to a method for synchronizing the rotating motions of elementary parts of a processing plant, generally intended for processing of containers.

[0002] In particular, the following discussion will make explicit reference, without this implying any loss of generality, to a combined bottling plant for packaging fluid food products in bottles or similar containers, and to the synchronization of rotating motions of at least two processing machines of the bottling plant, for example a blowing machine used for the formation of plastic bottles starting from preforms and a filling machine for filling the formed bottles with a fluid food product, the two processing machines being generally required to operate at different velocities.

[0003] As it is known, a combined bottling plant includes a number of cooperating processing machines, performing a number of corresponding operations, such as formation, filling, labelling and capping of containers, for example plastic bottles.

[0004] The various processing machines are arranged in a desired operating sequence, at a close distance one with respect to the other, and conveying assemblies, each including a number of transfer starwheels or analogous conveying elements, allow transfer of the containers among the various processing machines, through the operating sequence.

[0005] Figure 1 schematically shows an exemplary arrangement for a combined bottling plant 1, including a blower machine 2 (only diagrammatically shown), which receives at its input preforms and provides at its output formed bottles, and a filler machine 4 (also diagrammatically shown), which receives at its input the formed bottles and fills the same bottles with a liquid food product, making them available for successive processing steps (e.g. for labelling and/or capping operations). In a manner not shown, the combined bottling plant 1 may also include a reservoir arrangement for the possible temporary accumulation of bottles during their transfer within the plant.

[0006] The blower machine 2 rotates around a first axis A, driven by a first asynchronous motor 6, e.g. a gear motor; a first position sensor 7, e.g. an incremental encoder, is coupled to the blower machine 2, and provides position information about the rotary motion thereof, which may be provided to a control unit (not shown) of the first asynchronous motor 6, in order to implement a position feedback control of its operation.

[0007] In an analogous manner, the filler machine 4 rotates around a second axis B, possibly parallel to the first axis A, driven by a second asynchronous motor 8, e.g. a brushless motor; a second position sensor 9, e.g. an absolute encoder, is coupled to the filler machine 4, and provides position information about the rotary motion thereof to a respective control unit.

[0008] The combined bottling plant 1 further includes a conveying arrangement for transporting the articles, in this case plastic bottles, and conveying them to and from the blower and filler machines 2, 4.

[0009] In particular, the conveying arrangement includes: an inlet conveyor assembly 10, receiving preforms from an input line 11 and feeding them to the blower machine 2; a transfer conveyor assembly 12, for displacing the formed bottles from the upstream blower machine 2 to the downstream filler machine 4; and an outlet conveyor 13, for feeding the filled bottles from the filler machine 4 to an output line 14.

[0010] Each conveyor assembly 10, 12, 13 includes a respective number of star wheels 15, each rotating around a respective axis of rotation and carrying the articles to be transferred along their periphery (at respective seats, in a known manner, here not discussed in details), or a combination of star wheels and linear conveyors, e.g. belt, air or chain conveyors. Each star wheel 15 may be provided with a respective electric motor (and with a suitable control unit and position sensor), to drive its rotary motion.

[0011] Conveyor assemblies 10, 12, 13 may also be selectively configurable in order to define alternative paths for the articles to be transferred to and/or from accumulation reservoirs (in a known manner, here not shown in detail).

[0012] In such kind of combined bottling plants, a common problem arises concerning synchronization of the rotary motions of the various rotating elements (so as to achieve a desired ratio or correspondence between the same motions), also in view of the fact that different rotation speeds may be required to the motors of rotating elements (e.g. due to different throughput rates of the operations being performed, being e.g. blowing or filling operations). For example, rotating elements may be required to have a same peripheral speed and a same angular position with respect to the seats for the articles (so as to allow transfer thereof from one rotating element to another).

[0013] Positioning errors occurring in the control of the rotary motions may indeed jeopardize the correct operation of the bottling plant, and the general efficiency of the processing being performed.

[0014] Moreover, transfer of analog and/or digital signals between the various rotating parts generally entails a large number of cables, with consequent complex and expensive installing operations and a high likelihood of errors and faults.

[0015] The aim of the present invention is consequently to solve, at least in part, the problems previously highlighted, and in particular to provide an improved solution for synchronizing the rotary motions of different rotating parts of the plant.

[0016] According to the present invention, a system and a method for synchronizing the rotating motions of elementary parts of a processing plant, designed for processing of containers, are provided, as defined in the annexed claims.

[0017] For a better understanding of the present invention, preferred embodiments thereof are now described, purely by way of a non-limiting example, with reference to the attached drawings, wherein:

- Figure 1 is a diagrammatic top view of an exemplary combined bottling plant for formation and filling of containers;
- Figure 2 is a schematic block diagram of a synchronization system according to the present solution; and
- Figures 3 and 4 are plots showing position tracking errors.

[0018] As will be discussed in detail, an aspect of the present solution envisages a coupling between the rotating parts of the plant, which have to be synchronized, through a single digital field bus, transferring digital signals carrying position information related to the rotary motion. The single digital field bus allows to achieve the desired synchronization, simplifying connections and minimizing the likelihood of errors.

[0019] According to another aspect of the present solution, deterministic delays introduced by the digital communication via the field bus are properly accounted for, by means of an extrapolation function, executed at a slave rotating part (that is to be synchronized to the motion of a master rotating part); the extrapolation function provides an estimated current position of the master rotating part, based on the received digital position information related to the rotating motion of the same master rotating part and the deterministic delay introduced by the digital communication link.

[0020] Figure 2 schematically shows an exemplary synchronization system 20, for synchronizing the rotating motions of two rotating parts of a plant for processing containers, e.g. the combined bottling plant 1 discussed with reference to Figure 1, in the example a blower machine, again denoted with 2, and a filler machine, again denoted with 4.

[0021] The blower machine 2 acts as a master, so that the first axis A is the master axis; the filler machine 4, which is to be synchronized to the rotating motion of the blower machine 2, acts as a slave, so that the second axis B is the slave axis; in other words, the rotating motion of the filler machine 4 has to track, according to a desired relation, the rotating motion of the blower machine 2, the rotation speeds being possibly different and independently controllable.

[0022] The blower machine 2 includes a rotating wheel 22, which is driven by the first asynchronous motor 6, controlled by a master control unit 24, for example including a PLC (Programmable Logic Controller), which provides suitable control signals thereto; in a manner not shown, a power supply is provided to power the first asynchronous motor 6 and the master control unit 24.

[0023] The synchronization system 20 includes the first position sensor 7, coupled to the blower machine 2, in particular to the rotating wheel 22 and first asynchronous motor 6, and configured to detect the position of the rotating wheel 22 during its rotation around the first axis A.

[0024] The first position sensor 7 may be an incremental encoder, providing a first digital position signal P_1 , carrying information about the encoder count and detected position. In a known manner, here not shown and not discussed in detail, the first digital position signal P_1 is also supplied to the master control unit 24, in order to implement a feedback control of the actuation of the first asynchronous motor 6.

[0025] The synchronization system 20 includes a master bus coupler 25, in the example arranged at the blower machine 2, which receives the first digital position signal P_1 and is interfaced to a digital coupling bus 26, in particular a field bus, operating with an Ethernet protocol, e.g. the Powerlink protocol; the digital coupling bus 26 is arranged and configured to transfer digital signals between the blower machine 2 and the filler machine 4.

[0026] The synchronization system 20 further includes a slave bus coupler 28 and a slave control unit 29, in the example arranged at the filler machine 4.

[0027] The slave bus coupler 28 is interfaced to the digital coupling bus 26, so as to receive the first digital position signal P_1 from the first position sensor 7 of the blower machine 2.

[0028] The slave control unit 29, for example including a PLC, is coupled to the slave bus coupler 28 through a digital link 30, e.g. an X2X link, thus receiving the first digital position signal P_1 .

[0029] The slave control unit 29 is also coupled to a driver unit 32, which is configured to drive the second asynchronous motor 8, e.g. a brushless motor, of the filler machine 4.

[0030] In a known manner, which is not discussed in detail here, the slave control unit 29 carries out a feedback control of the actuation, through the position information received from the second position sensor 9, e.g. an absolute encoder, coupled to the filler machine 4 and providing position information about the rotary motion thereof (through a second digital position signal P_2).

[0031] The slave control unit 29 is configured to carry out suitable program and software instructions, in order to synchronize the rotating motions of the filler machine 4 to the respective rotating motion of the blower machine 2, based on the position information carried by the received first digital position signal P_1 .

[0032] In particular, the slave control unit 29 generates driving signal DS for the driver unit 32, also based on the first digital position signal P_1 in such a manner that the rotating motions of the blower and filler machines 2, 4 are synchronized.

[0033] According to an aspect of the present solution, the slave control unit 29 is configured to take into account a delay, in particular a deterministic delay, associated to the digital transmission of information through the digital coupling bus 26.

[0034] The Applicant has indeed realized, through tests and simulations, that the delay associated to the digital coupling bus 26 may cause position errors while tracking or synchronizing the master and slave axes.

[0035] In particular, the position error due to the deterministic delay in the reading of the first digital position signal P_1 ,

is proportional to the speed of rotation of the rotating wheel 22 of the blower machine 2.

[0036] This feature is shown in Figure 3, where a time plot of the tracking position error is depicted, at three different speeds of the blower machine 2: 5000 b/h (bottles per hour); 30000 b/h; and 15000 b/h.

[0037] A maximum position error of about 4,8 mm occurs at the highest speed of 30000 b/h. This position error corresponds to a tracking latency of 5,1 ms, considering a pitch between the bottles carried by the blower machine 2 equal to 113 mm:

$$latency = \frac{position_error}{speed * pitch} = \frac{4,8mm}{30000b/h * 113mm}$$

[0038] In order to solve possible problems associated to the position errors, the slave control unit 29 is configured to execute an extrapolation algorithm, in order to estimate an actual position of the rotating wheel 22 of the blower machine 2 based on the position information carried by the received first digital position signal P₁.

[0039] In detail, the extrapolation algorithm envisages the calculation of the speed and acceleration of the rotation associated to the master axis, based on a number of consecutive position measures and associated values of the first digital position signal P₁, according to the following expressions (supposing a uniformly accelerated motion):

$$v(t_1) = \frac{x(t_1) - x(t_0)}{t_1 - t_0}$$

$$a(t_1) = \frac{v(t_1) - v(t_0)}{t_1 - t_0}$$

$$x_{extr}(t_1) = x(t_1) + \frac{1}{2} \cdot a(t_1) \cdot del^2 + v(t_1) \cdot del$$

wherein: x(t_i) are the positions measured by the first position sensor 7 coupled to the blower machine 2 at respective times t_i (corresponding e.g. to consecutive processing cycles of the synchronization system 20); v(t_i) and a(t_i) are the calculated speeds and, respectively, accelerations of the rotating wheel 22 of the blower machine 2 at times t_i; del is the deterministic temporal delay associated to the digital transmission of information through the digital coupling bus 26 (and possible further digital coupling means); and x_{extr}(t_i) is the estimated current position of the rotating wheel 22 of the blower machine 2 at times t_i, as determined through the extrapolation algorithm.

[0040] The slave control unit 29, through the extrapolation algorithm, is thus able to estimate the actual position x_{extr} associated to the master axis and to minimize the positioning errors in the synchronization of the slave axis with the same master axis.

[0041] In this connection, Figure 4 shows the time plot of the tracking position error at the three exemplary speeds of the blower machine 2: 5000 b/h; 30000 b/h; and 15000 b/h.

[0042] Thanks to the extrapolation algorithm (in this exemplary case considering a delay of 15,3 ms for the extrapolation operations), the tracking position error is greatly reduced with respect to the case shown in Figure 3, having a substantially constant value of about 0,1 mm at the various speeds.

[0043] The deterministic temporal delay del associated to the digital transmission of information may vary, depending on the arrangement and protocol for the digital information link coupling the master and slave parts of the plant; in any case, the value of this delay is known to the slave control unit 29.

[0044] For example, in the embodiment shown in Figure 2, the delay is due to the digital coupling bus 26 and digital link 30, and the Ethernet transmission protocols implemented thereon.

[0045] The value of the delay, determined based on the characteristics of the digital transmission means, may also be confirmed and, in case, adjusted, via empirical tests and evaluations.

[0046] The advantages that the described system allows to achieve are clear from the foregoing description.

[0047] In particular, it is again underlined that the synchronization system allows to minimize positioning errors in the tracking between the rotating parts in the plant, in a simple and reliable manner.

[0048] Indeed, the costs and complexity of the cabling between the rotating parts of the system are greatly reduced, thanks to the use of a single digital field bus connection.

[0049] The extrapolation algorithm implemented at the slave control unit also allows to account for any deterministic delay due to the digital transmission of information through the field bus.

[0050] Finally it is clear that modifications and variations may be applied to the system described and shown, without departing from the scope of the appended claims.

[0051] In particular, it is clear that the discussed synchronization method may be applied also in the case where a greater number of rotating parts are to be synchronized, e.g. in a bottling plant including also a labeller machine and/or a capping machine and/or a pasteurization machine, in addition to, or substitution of, the blower and filler machines.

[0052] The digital coupling bus 26 may couple the various rotating parts in a manner that is substantially analogous to what discussed previously, with each slave rotating machine being able to achieve synchronization and tracking based on the position information received from a master rotating machine, extrapolated based on the respective deterministic delay associated to the arrangement of the same slave rotating machine with respect to the master machine.

[0053] In general, the described synchronization system may be advantageously employed in any case where two or more rotating parts are to be synchronized in a processing plant.

[0054] Accordingly, the type and configuration of the elementary parts of the bottling plant 1, previously shown and discussed, is to be considered only as exemplary: e.g. the electric motors could be of a different kind, so as the position sensors, that could include any kind of sensors able to track the position with respect to the respective rotating axis.

Claims

1. A synchronization system (20), for a plant (1) including at least a first (2) and a second (4) rotating parts cooperating in the processing of containers (3), the first (2) and second (4) rotating parts being driven in a respective rotating motion around a respective rotation axis (A, B) by independent first (6) and second (8) electric motors; the synchronization system (1) including:

a first position sensor (7) coupled to the first rotating part (2) and configured to measure a rotating position thereof around the respective rotation axis (A) and to generate a position information signal (P_1); and
a control processing unit (29) coupled to the second rotating part (4) and configured to control the second electric motor (8) of the second rotating part (4), based on the position information signal (P_1) received from the first position sensor (7), thereby tracking the rotating motion of the first rotating part (2),
characterized by including a single digital coupling bus (26), coupling the first (2) and second (4) rotating parts and configured to transfer the position information signal (P_1) to the control processing unit (29).

2. The system according to claim 1, wherein the digital coupling bus (26) is a field bus.

3. The system according to claim 1 or 2, wherein the control processing unit (29) is configured to control the second electric motor (8) of the second rotating part (4) also based on a transfer delay (del) associated to the transfer of the position information signal (P_1) through the digital coupling bus (26).

4. The system according to claim 3, wherein the control processing unit (29) is configured to execute an extrapolation algorithm to estimate an actual position (x_{extr}) of the first rotating part (2), as a function of the position information signal (P_1) and the transfer delay (del).

5. The system according to claim 4, wherein the extrapolation algorithm is designed to determine the speed and acceleration of the rotating motion of the first rotating part (2) based on a number of consecutive measures of the rotating position thereof by the first position sensor (7), and to determine the actual position (x_{extr}) of the first rotating part (2) as a function of the determined speed and acceleration and the transfer delay (del).

6. The system according to claim 5, wherein the extrapolation algorithm executes the following calculations:

$$v(t_1) = \frac{x(t_1) - x(t_0)}{t_1 - t_0}$$

$$a(t_1) = \frac{v(t_1) - v(t_0)}{t_1 - t_0}$$

$$x_{extr}(t_1) = x(t_1) + \frac{1}{2} \cdot a(t_1) \cdot del^2 + v(t_1) \cdot del$$

wherein: $x(t_1)$ and $x(t_0)$ are position measures by the first position sensor (7) at respective times (t_1) and (t_0) ; $v(t_1)$ and $v(t_0)$ and $a(t_1)$ and $a(t_0)$ are the determined speeds and, respectively, accelerations, at times (t_1) and (t_0) ; del is the transfer delay; and $x_{extr}(t_1)$ is the actual position at time (t_1) , as determined through the extrapolation algorithm.

7. The system according to any of the preceding claims, further including a first (25) and a second (28) bus couplers, coupled to the digital coupling bus (26) and, respectively, to the first (2) and second (4) rotating parts.
8. The system according to any of the preceding claims, wherein the first rotating part (2) acts as a master, and the second rotating part (4) acts as a slave.
9. The system according to any of the preceding claims, wherein the plant (1) is a bottling plant, the first rotating part (2) includes a blower machine for forming bottles starting from preforms, and the second rotating part (4) includes a filling machine for filling the formed bottles.
10. A plant (1) for processing of containers (3), including at least a first (2) and a second (4) rotating parts cooperating in the processing of the containers (3), the first (2) and second (4) rotating parts being driven in a respective rotating motion around a respective rotation axis (A, B) by independent first (6) and second (8) electric motors; wherein the plant (1) further includes a synchronization system (20), according to any of the preceding claims.
11. A synchronization method for a plant (1) including at least a first (2) and a second (4) rotating parts cooperating in the processing of containers (3), the first (2) and second (4) rotating parts being driven in a respective rotating motion around a respective rotation axis (A, B) by independent first (6) and second (8) electric motors; the synchronization method (1) including the steps of:
 - at the first rotating part (2), executing measures of a rotating position thereof around the respective rotation axis (A) and generating a position information signal (P_1); and
 - at the second rotating part (4), controlling the second electric motor (8) thereof, based on the position information signal (P_1), thereby tracking the rotating motion of the first rotating part (2),
 - characterized by** including the step of transferring the position information signal (P_1) from the first (2) to the second (4) rotating parts, via a single digital coupling bus (26).
12. The method according to claim 11, wherein the step of transferring includes transferring the position information signal (P_1) via a field bus.
13. The method according to claim 11 or 12, wherein the step of controlling includes controlling the second electric motor (8) of the second rotating part (4) based on a transfer delay (del) associated to the transfer of the position information signal (P_1) through the digital coupling bus (26).
14. The method according to claim 13, wherein the step of controlling includes executing an extrapolation algorithm to estimate an actual position (x_{extr}) of the first rotating part (2), as a function of the position information signal (P_1) and the transfer delay (del).
15. The method according to claim 14, wherein the step of executing an extrapolation algorithm includes determining the speed and acceleration of the rotating motion of the first rotating part (2) based on a number of consecutive measures of the rotating position thereof, and determining the actual position (x_{extr}) of the first rotating part (2), as a function of the determined speed and acceleration and the transfer delay (del).
16. The method according to any of claims 11-15, wherein the plant (1) is a bottling plant, the first rotating part (2)

includes a blower machine for forming bottles starting from preforms, and the second rotating part (4) includes a filling machine for filling the formed bottles.

- 5 **17.** A computer program product, including software instructions configured to implement, when executed in the control processing unit (29) of the system according to any of claims 1-9, the synchronization method according to any of claims 11-16.

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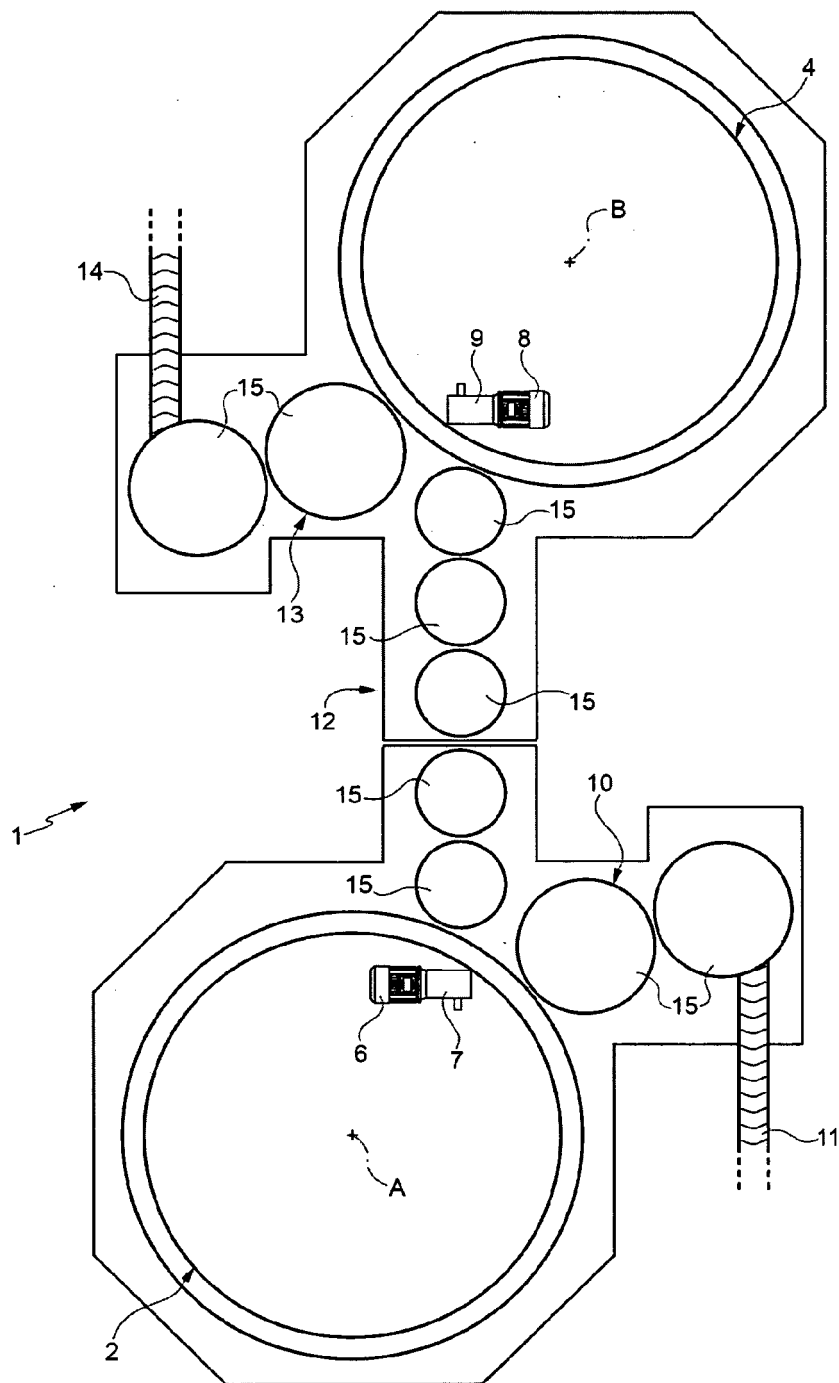


FIG. 1

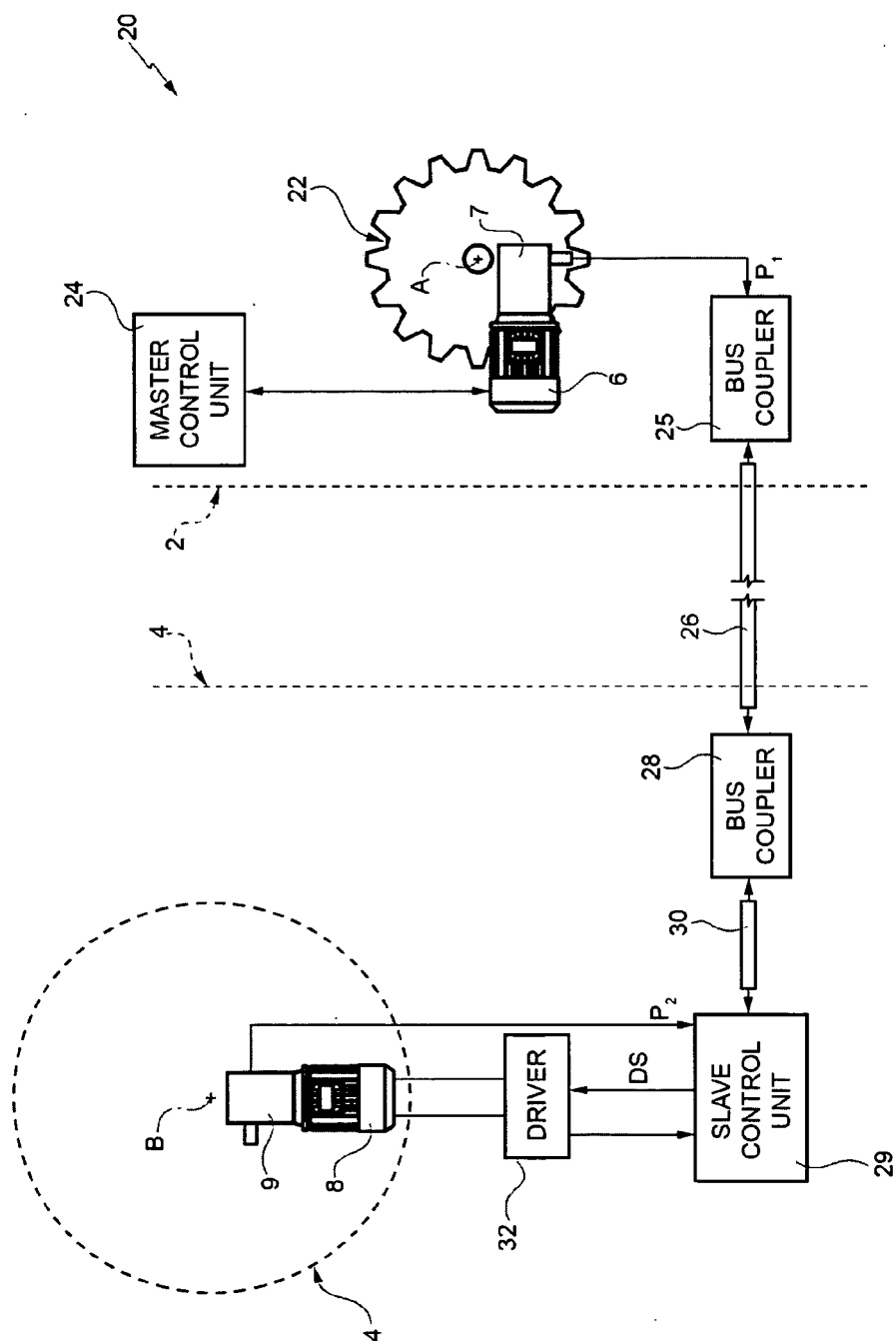


FIG. 2

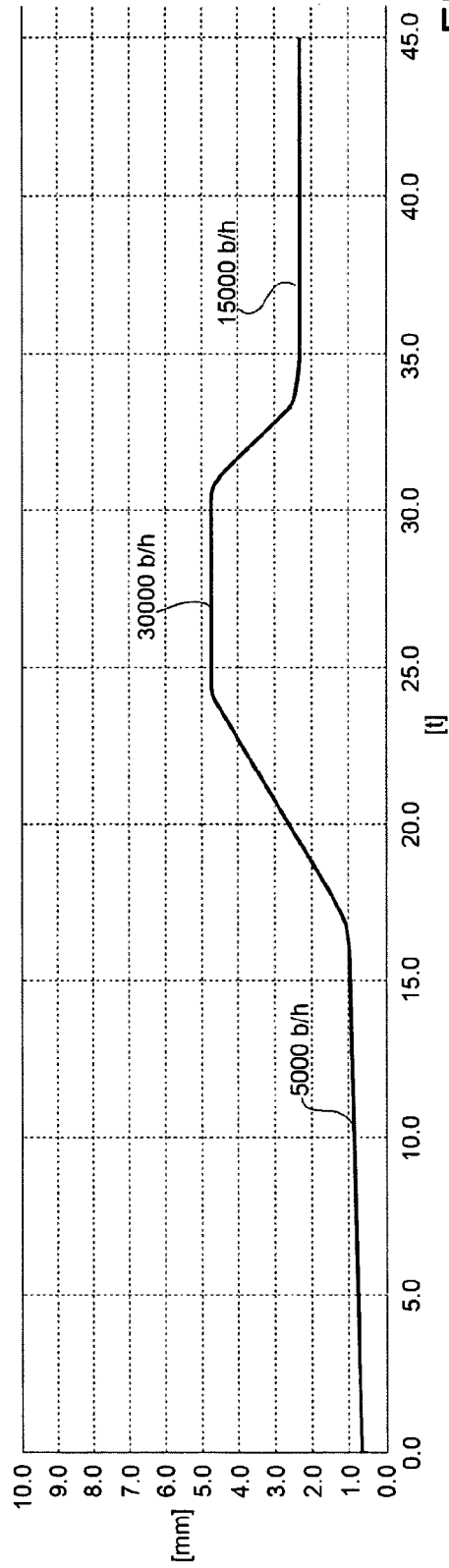


FIG. 3

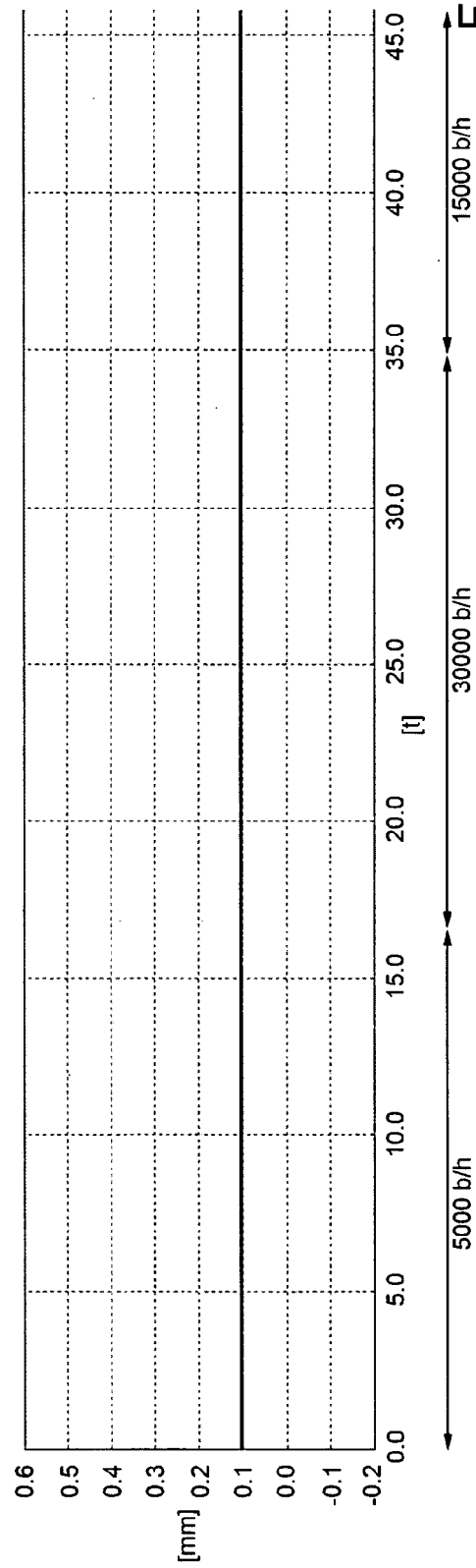


FIG. 4



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Application Number
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 April 2013	Examiner Luepke, Erik
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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The members are as contained in the European Patent Office EDP file on
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