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# (54) Title: A METHOD FOR DYNAMIC NORMALIZATION OF ANALOGUE SINE AND COSINE SIGNALS, A SENSOR OR A SENSOR BEARING UNIT AND A MECHANICAL DEVICE

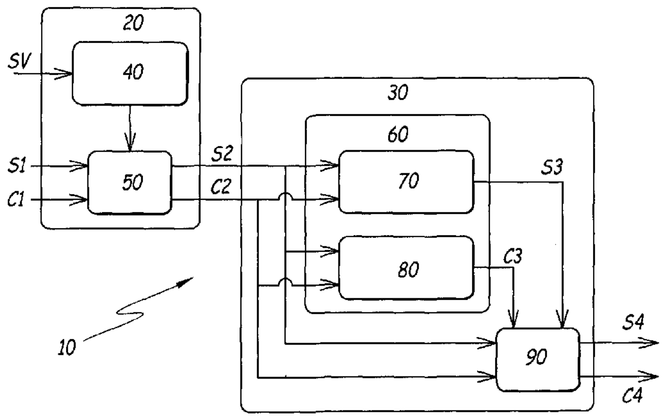



FIG.1

**(57) Abstract**: The invention relates to a method (10) for dynamic normalization of analogue sine and cosine signals, comprising at least the following steps: a step (60) of processing an offset normalized sine signal (S2) and an offset normalized cosine signal (C2), wherein a sine amplitude value (S3) is measured on the offset normalized sine signal (S2) reaching its peak when a zero-crossing is detected on the offset normalized cosine signal (C2) and a cosine amplitude value (C3) is measured on the offset normalized cosine signal (C2) reaching its peak when a zero-crossing is detected on the offset normalized sine signal (52); then a step (90) of amplitude normalization, wherein the offset normalized sine signal (S2) is normalized in amplitude by using the latest measured sine amplitude value (53) to get an output sine signal (S4) normalized both in offset and amplitude and the offset normalized cosine signal (C2) is normalized in amplitude by using the latest measured cosine amplitude value (C3) to get an output cosine signal (C4) normalized both in offset and amplitude. The invention also relates to a sensor or a sensor bearing unit comprising a controller configured to implement such method (10) and to a mechanical device comprising such sensor or sensor bearing unit.

WO 2014/198344 A1

# A METHOD FOR DYNAMIC NORMALIZATION OF ANALOGUE SINE AND COSINE SIGNALS, A SENSOR OR A SENSOR BEARING UNIT AND A MECHANICAL DEVICE

## TECHNICAL FIELD OF THE INVENTION

The invention concerns a method for dynamic normalization of analogue sine and cosine signals. The invention also concerns a sensor or a sensor bearing unit comprising a controller configured to implement such method. The invention also concerns a mechanical device, for example an electric motor, comprising such sensor or sensor bearing unit.

## BACKGROUND OF THE INVENTION

For motor control, it is known to use sensors of the RPSBU-type (rotor positioning sensor bearing unit), delivering analogue sine and cosine signals corresponding to the angular position of the rotor. Typically, such sensors are used for brushless motors and permanent magnet synchronous machines.

Several methods are known to calculate the angle of the rotor from the sine and cosine. One of these methods is the use of a look-up table. Signals are normalized and enter the look-up table, where the corresponding angle is calculated. The look-up table usually implements, on the one hand, one quadrant of the sine and cosine and, on the other hand, the polarity of the signals to determine which quadrant has to be applied. A normalization of the sine and cosine signals is then necessary. The entries in the look-up table run from 0 to 1, denoting at the output an angle between 0° and 90°. Typically, normalization is implemented by calculation as follows:

$$V_{\sin,norm} = \tfrac{2}{A}\left(V_{\sin} - B\right) \qquad \text{(Equation 1)}$$

Wherein: A is the peak-to-peak value of the amplitude of Vsin ;
Vsin is the sine measurement;
B is the offset of Vsin;
All these parameters are in Volts (V).

In practice, correct amplitude and offset measurements during operation of the sensor-bearing unit are not available or difficult to get. Generally, only instantaneous data is available. Moreover, the peak-to-peak amplitude varies depending on temperature in operation, mounting conditions, between sensors from the same population, etc…

A first known method to obtain values for these parameters consists in using stored measurement data over one turn to update, each turn, the value for amplitude (difference between minimal and maximal values) and offset (mean value). This method requires using data stored inside the controller, which needs to be updated each turn. That is likely to slow down the control at high speed.

A second known method to obtain values for these parameters consists in using amplitude and offset from specification. This method is quite straightforward, but cannot deal with the varying amplitudes and offsets of the signals. The resulting error is that the look-up table is not fully used, since the "1" corresponding to the maximum amplitude is not reached except in very rare cases. Huge disturbances of the calculated angle may be observed due to incorrect amplitude normalization.

## SUMMARY OF THE INVENTION

The aim of the invention is to provide an improved method for dynamic normalization of analogue sine and cosine signals.

To this end, the invention concerns a method for dynamic normalization of analogue sine and cosine signals, comprising at least the following steps:

- a step of processing an offset normalized sine signal and an offset normalized cosine signal, wherein:
  - a sine amplitude value is measured on the offset normalized sine signal reaching its peak when a zero-crossing is detected on the offset normalized cosine signal and
  - a cosine amplitude value is measured on the offset normalized cosine signal reaching its peak when a zero-crossing is detected on the offset normalized sine signal; then
- a step of amplitude normalization, wherein:
  - the offset normalized sine signal is normalized in amplitude by using the latest measured sine amplitude value to get an output sine signal normalized both in offset and amplitude and
  - the offset normalized cosine signal is normalized in amplitude by using the latest measured cosine amplitude value to get an output cosine signal normalized both in offset and amplitude.

The method according to the invention allows a fast and efficient normalization without requiring large data storage in the controller. This method can be implemented for angle calculation purposes for electric motor control or various other applications.

According to further aspects of the invention which are advantageous but not compulsory, such a method may incorporate one or several of the following features:

- During the processing step, only the latest measured sine amplitude value and the latest measured cosine amplitude value are memorized.

- During the amplitude normalization step, the latest measured sine amplitude value and the latest measured cosine amplitude value are used to normalize respectively the amplitude of the offset normalized sine signal and the amplitude of the offset normalized cosine signal continuously between two updates.

- The phase shift between the offset normalized sine signal and the offset normalized cosine signal is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

- The output sine signal and the output cosine signal are used for angle calculation by applying an arctangent function to a division of the output sine signal by the output cosine signal.

- Prior to the processing step, the method comprises a step of offset determination, wherein an offset normalization parameter of an input sine signal and an input cosine signal is determined in relation with a value of supply voltage of a sensor providing the input sine signal and an input cosine signal; and a step of offset normalization, wherein the input sine signal is normalized in offset by using the offset normalization parameter to get the offset normalized sine signal and the input cosine signal is normalized in offset by using the offset normalization parameter to get the offset normalized cosine signal.

- The phase shift between the input sine signal and the input cosine signal is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

- The offset normalization parameter is set to half the value of supply voltage.

The invention also concerns a sensor or a sensor bearing unit comprising a controller configured to implement the method as mentioned here-above.

The invention also concerns a mechanical device, for example an electric motor, comprising a sensor or a sensor bearing unit as mentioned here-above.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained in correspondence with the annexed figures, and as an illustrative example, without restricting the subject-matter of the invention. In the annexed figures:

- figure 1 is a diagram illustrating a method according to the invention, including a phase of offset processing and a phase of amplitude processing;
- figure 2 is a graph illustrating the phase of amplitude processing;
- figures 3 and 4 are diagrams illustrating respectively the sine part and the cosine part the phase of amplitude processing; and
- figure 5 is a partial sectional view of a mechanical device equipped with a sensor-bearing unit according to the invention.

## DETAILED DESCRIPTION OF SOME EMBODIMENTS

A method 10 according to the invention, for dynamic normalization of analogue sine signal S1 and cosine signal C1, is shown on figure 1.

This method 10 includes a phase 20 of offset processing and a phase 30 of amplitude processing. The phase 20 includes a step 40 of offset determination and a step 50 of offset normalization. The phase 30 includes a step 60 of amplitude determination and a step 90 of amplitude normalization. The step 60 includes two sub-steps, more precisely a sub-step 70 of sine amplitude determination and a sub-step 80 of cosine amplitude determination.

Input measured parameters for implementing method 10 include the sine signal S1, the cosine signal C1 and a supply voltage SV.

Analogue signals S1 and C1 are voltage signals coming from a sensor equipping a mechanical device, for example an electric motor. Analogue signals S1 and C1 are discretized to allow their treatment by the controller. The phase shift between signals S1 and C1 is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

A measurement of the supply voltage SV of the sensor is available at a certain rate, for instance at each start-up of the sensor or at a desired frequency. In case of fluctuations of the nominal value of the supply voltage SV over time, a measurement may be made each turn of the rotor, each minute or at any other desired frequency.

During the step 40 of offset determination, the measured supply voltage SV is used to determine an offset normalization parameter ONP. In a preferred embodiment, the ideal offset of the signals S1 and C1 is equal to half the supply voltage SV. Thus, parameter ONP is set to half the supply voltage SV. For a supply voltage SV having a nominal value of 5 Volts, the parameter ONP is equal to 2,5 Volts.

In practice, parameter ONP for offset normalization can be determined by using a model of the sensor design and/or the controller design, considering that the offset of the signals S1 and C1 is very sensitive to the supply voltage SV and not so sensitive to other design variations (mainly resistance tolerances).

During the step 50 of offset normalization, the sine signal S1 and cosine signal C1 are normalized by using the offset normalization parameter ONP. More precisely, parameter ONP is added or subtracted from signals S1 and C1 to center them around zero, that is to center them on the ordinate axis on an angle/amplitude graph, as shown on figure 2. In the preferred embodiment mentioned here-above in step 40, parameter ONP equal to half the supply voltage SV is subtracted from each of the sine signal S1 and cosine signal C1 to center their amplitude on zero.

During step 50, the measured sine signal S1 becomes an offset normalized sine signal S2 and the measured cosine signal C1 becomes an offset normalized cosine signal C2. The phase shift between signals S2 and C2 is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

During the step 60 of amplitude determination shown on figure 2, the controller detects only zero-crossings on the offset normalized sine signal S2 and cosine signal C2.

On figure 2, the angle corresponding to both offset normalized sine signal S2 and cosine signal C2 is represented in degrees on the abscissa axis, while the amplitude of these signals S2 and C2 is represented on the ordinate axis. Figure 2 shows two sinusoidal curves, corresponding respectively to sine signal S2 and signal C2. The sine signal S2 reaches its peak when the cosine signal C2 is zero, while the cosine signal C2 reaches its peak when the sine signal S2 is zero.

When a zero-crossing is detected on the sine signal S2, a measurement of a cosine amplitude C3 is done on the cosine signal C2 reaching its peak. This measurement of the cosine amplitude C3 is used for the normalization of the cosine signal C2 between this position and 180° (half a turn of the rotor) further, when a new update is realized.

When a zero-crossing is detected on the cosine signal C2, a measurement of a sine amplitude S3 is done on the sine signal S2 reaching its peak. This measurement of the sine amplitude S3 is used for the normalization of the sine signal S2 between this position and 180° (half a turn of the rotor) further, when a new update is realized.

Figure 3 shows the sub-step 70 of determination of the sine amplitude S3 in a more detailed way. Block 71 corresponds to the detection of negative zero-crossings on the cosine signal C2, with the measured value of the cosine signal C2 being inferior to zero while the previous measured value of the cosine signal C2 was not inferior to zero. Block 72 corresponds to the detection of positive zero-crossings on the cosine signal C2, with the measured value of the cosine signal C2 being superior to zero while the previous measured value of the cosine signal C2 was not superior to zero. Block 73 corresponds to an operator "OR" and is placed after the two parallel blocks 71 and 72. Block 74 corresponds to the measurement of sine amplitude S3. Block 74 processes sine signal S2 and data coming from block 73. Block 74 comprises a trigger 75 and an enabler 76. Trigger 75 triggers a measurement of sine amplitude S3 each time than block 73 registers the detection of a zero-crossing in block 71 or 72. Enabler 76 allows activation of trigger 75 from the first time block 73 registers the detection of a zero-crossing in block 71 or 72.

Figure 4 shows the sub-step 80 of determination of the cosine amplitude C3 in a more detailed way. Block 81 corresponds to the detection of negative zero-crossings on the sine signal S2, with the measured value of the sine signal S2 being inferior to zero while the previous measured value of the sine signal S2 was not inferior to zero. Block 82 corresponds to the detection of positive zero-crossings on the sine signal S2, with the measured value of the sine signal S2 being superior to zero while the previous measured value of the sine signal S2 was not superior to zero. Block 83 corresponds to an operator "OR" and is placed after the two parallel blocks 81 and 82. Block 84 corresponds to the measurement of cosine amplitude C3. Block 84 processes cosine signal C2 and data coming from block 83. Block 84 comprises a trigger 85 and an enabler 86. Trigger 85 triggers a measurement of cosine amplitude C3 each time than block 83 registers the detection of a zero-crossing in block 81 or 82. Enabler 86 allows activation of trigger 85 from the first time block 83 registers the detection of a zero-crossing in block 81 or 82.

With the implementation of step 60, the controller memory is updated each quarter of turn of the rotor and comprises only the latest measured amplitude values S3 and C3. During sub-step 70, the latest measured sine amplitude value S3 is registered each half turn. During sub-step 80, the latest measured cosine amplitude value C3 is registered each half turn.

During the step 90 of amplitude normalization, the latest amplitude values S3 and C3 are used to normalize the amplitude of sine signal S2 and the amplitude of the cosine signal C2 at all time instants between two updates of amplitude. Sine signal S2 with normalized amplitude becomes signal S4, while cosine signal C2 with normalized amplitude becomes signal C4. Signals S4 and C4 are each offset normalized and amplitude normalized for subsequent angle calculation.

In view of the above, the normalization method according to the invention may be named "Quarter-Amplitude Normalization" (QAN). This method uses, each quarter of turn, an update of the sine amplitude S3 of offset normalized sine signal S2 or an update of the cosine amplitude C3 of offset normalized cosine signal C2 for amplitude normalization of output signals S4 and C4.

The invention provides a better precision for normalization and, consequently, a better precision for angle calculation from output signals S4 and C4. Only one value of sine amplitude S3 and one value of cosine amplitude C3 need to be stored inside the memory of the controller. The updated is made twice a turn of the rotor for each value S3 and C3. The method is efficient in case of changes with lower frequency than the frequency of the signals.

A mechanical device 100 according to the invention is partly shown on figure 5. Device 100 comprises a shaft 102, a housing 104 and a sensor-bearing unit 110, which is also according to the invention. Unit 110 comprises a bearing 112, an impulse ring 114, a sensor 116 and a controller 120. Bearing 112 is mounted between shaft 102 and housing

104. Sensor 116 comprises a detection cell 117, an electronic card 118 and a cable 119. Cell 117 is mounted on card 118 and associated with impulse ring 114 for tracking rotation of shaft 102. Cable 119 connects card 118 and cell 117 to controller 120. Alternatively, controller 120 may be integrated in sensor 116. According to the invention, controller 120 is configured to implement method 10 described here-above.

Other embodiments of the method 10, the mechanical device 100 and/or the sensor-bearing unit 110 can be implemented without leaving the scope of the invention. Particularly, the sensor-bearing unit 110 may be adapted to different mechanical devices 100 wherein a specific behavior is measured, as a movement of rotation or translation. For example, the unit 110 may equip an electric vehicle, a power steering, a starter alternator, a rack rails device or an in-wheel motor for fork lift truck.

According to a particular embodiment, method 10 may only include phase 30 of amplitude normalization. In this case, input parameters for implementing method 10 include the offset normalized sine signal S2 and the offset normalized cosine signal C2.

In addition, technical features of the different embodiments can be, in whole or part, combined with each other. Thus, the method 10, the device 100 and/or the sensor bearing unit 110 can be adapted in terms of cost, functionality or to any specific requirements of the application.

## CLAIMS

1. A method (10) for dynamic normalization of analogue sine and cosine signals, comprising at least the following steps:
   - a step (60) of processing an offset normalized sine signal (S2) and an offset normalized cosine signal (C2), wherein:
     - a sine amplitude value (S3) is measured on the offset normalized sine signal (S2) reaching its peak when a zero-crossing is detected on the offset normalized cosine signal (C2) and
     - a cosine amplitude value (C3) is measured on the offset normalized cosine signal (C2) reaching its peak when a zero-crossing is detected on the offset normalized sine signal (S2); then
   - a step (90) of amplitude normalization, wherein:
     - the offset normalized sine signal (S2) is normalized in amplitude by using the latest measured sine amplitude value (S3) to get an output sine signal (S4) normalized both in offset and amplitude and
     - the offset normalized cosine signal (C2) is normalized in amplitude by using the latest measured cosine amplitude value (C3) to get an output cosine signal (C4) normalized both in offset and amplitude.

2. The method (10) according to claim 1, wherein during the processing step (60), only the latest measured sine amplitude value (S3) and the latest measured cosine amplitude value (C3) are memorized.

3. The method (10) according to any one of the previous claims, wherein during the amplitude normalization step (90), the latest measured sine amplitude value (S3) and the latest measured cosine amplitude value (C3) are used to normalize respectively the amplitude of the offset normalized sine signal (S2) and the amplitude of the offset normalized cosine signal (C2) continuously between two updates.

4. The method (10) according to any one of the previous claims, wherein the phase shift between the offset normalized sine signal (S2) and the offset normalized cosine signal (C2) is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

5. The method (10) according to any one of the previous claims, wherein the output sine signal (S4) and the output cosine signal (C4) are used for angle calculation by applying an arctangent function to a division of the output sine signal (S4) by the output cosine signal (C4).

6. The method (10) according to any one of the previous claims, wherein prior to the processing step (60), the method comprises:
   - a step (40) of offset determination, wherein an offset normalization parameter (ONP) of an input sine signal (S1) and an input cosine signal (C1) is determined in relation with a value of supply voltage (SV) of a sensor providing the input sine signal (S1) and an input cosine signal (C1); and
   - a step (50) of offset normalization, wherein:
     - the input sine signal (S1) is normalized in offset by using the offset normalization parameter (ONP) to get the offset normalized sine signal (S2) and
     - the input cosine signal (C1) is normalized in offset by using the offset normalization parameter (ONP) to get the offset normalized cosine signal (C2).

7. The method (10) according to claim 6, wherein the phase shift between the input sine signal (S1) and the input cosine signal (C1) is comprised between 80 and 100 degrees, preferably equal to 90 degrees.

8. The method (10) according to claim 6 or 7, wherein the offset normalization parameter (ONP) is set to half the value of supply voltage (SV).

9. A sensor or a sensor bearing unit (110), comprising a controller (120) configured to implement the method (10) according to one of the preceding claims.

10. A mechanical device (100), for example an electric motor, comprising a sensor or a sensor bearing unit (110) according to claim 9.

1/3

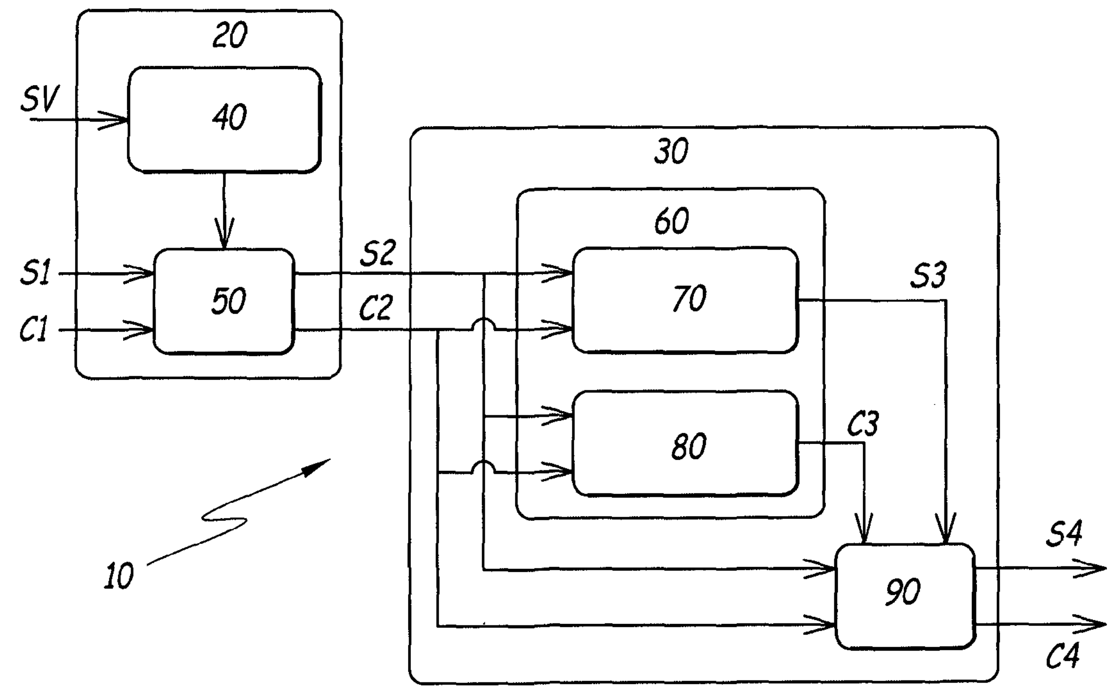
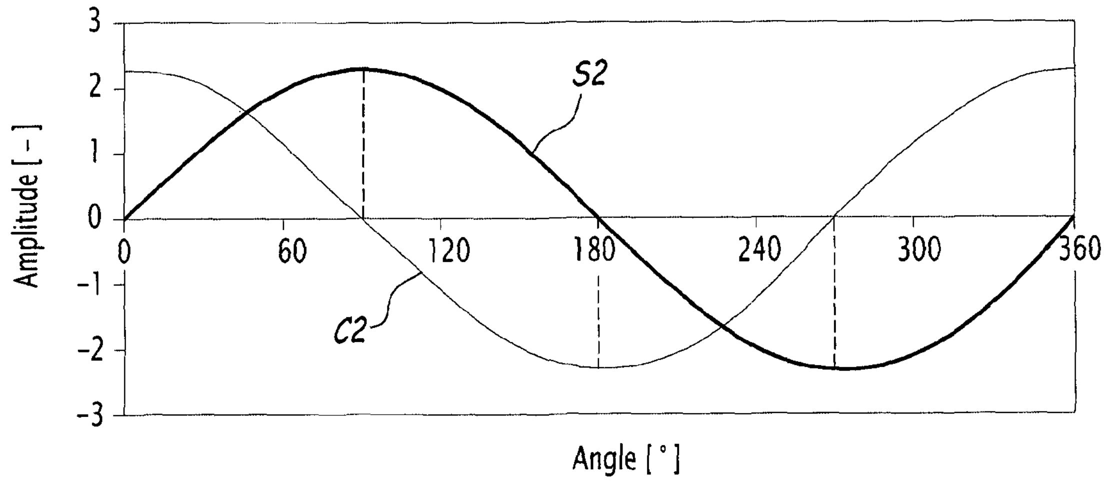

20
SV
40
S1
50
C1
S2
C2
30
60
70
80
S3
C3
90
S4
C4
10

FIG.1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0
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-2
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300
360
S2
C2
Angle [ ° ]

FIG.2

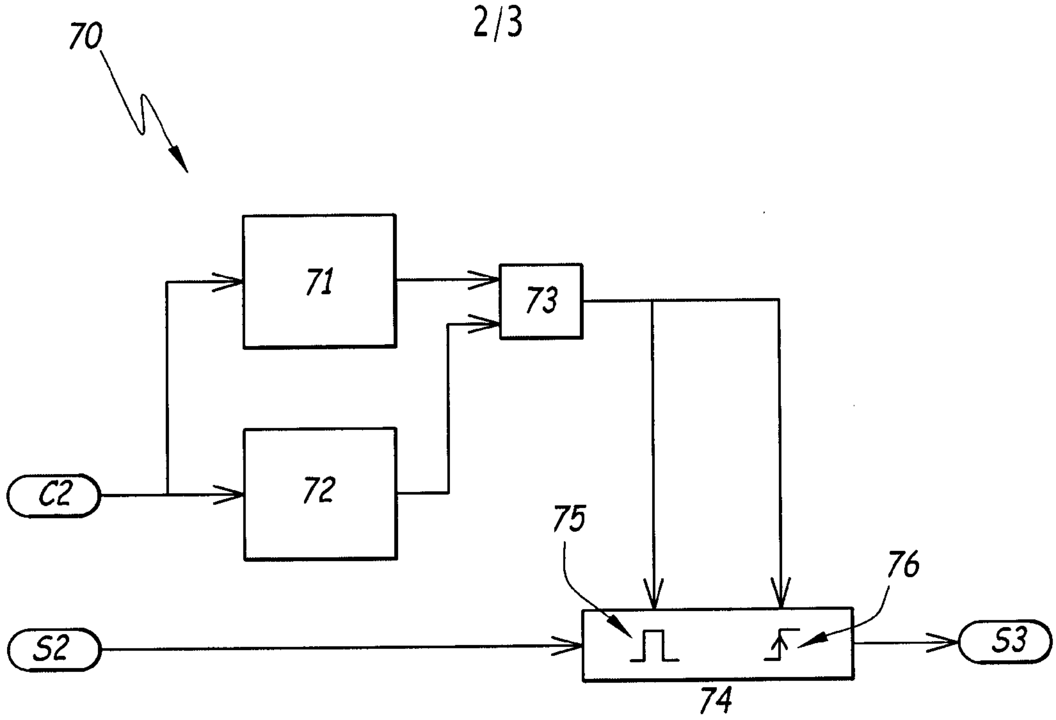


FIG.3

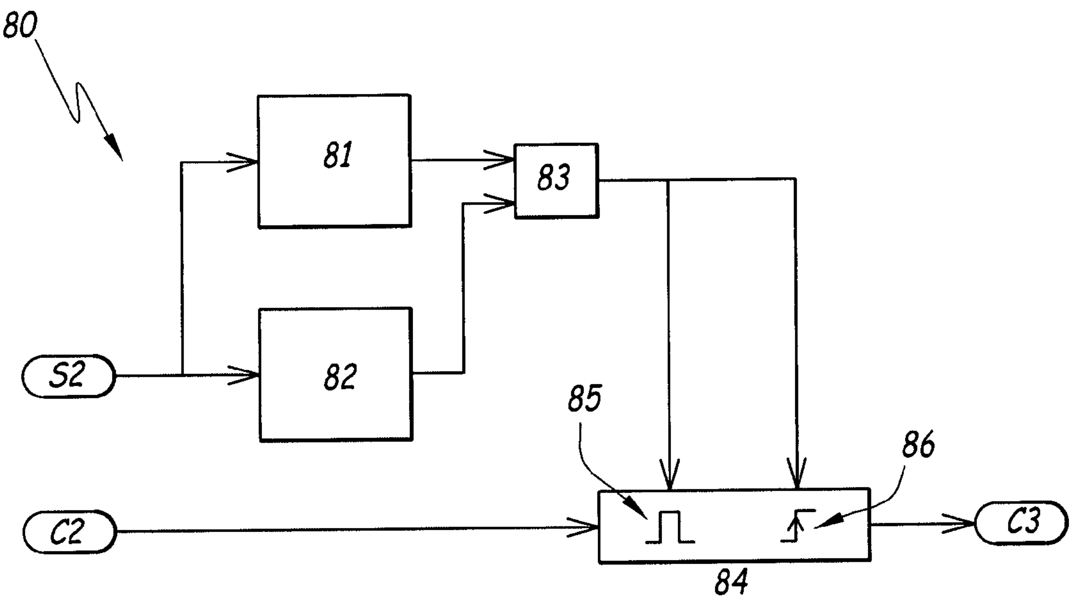


FIG.4

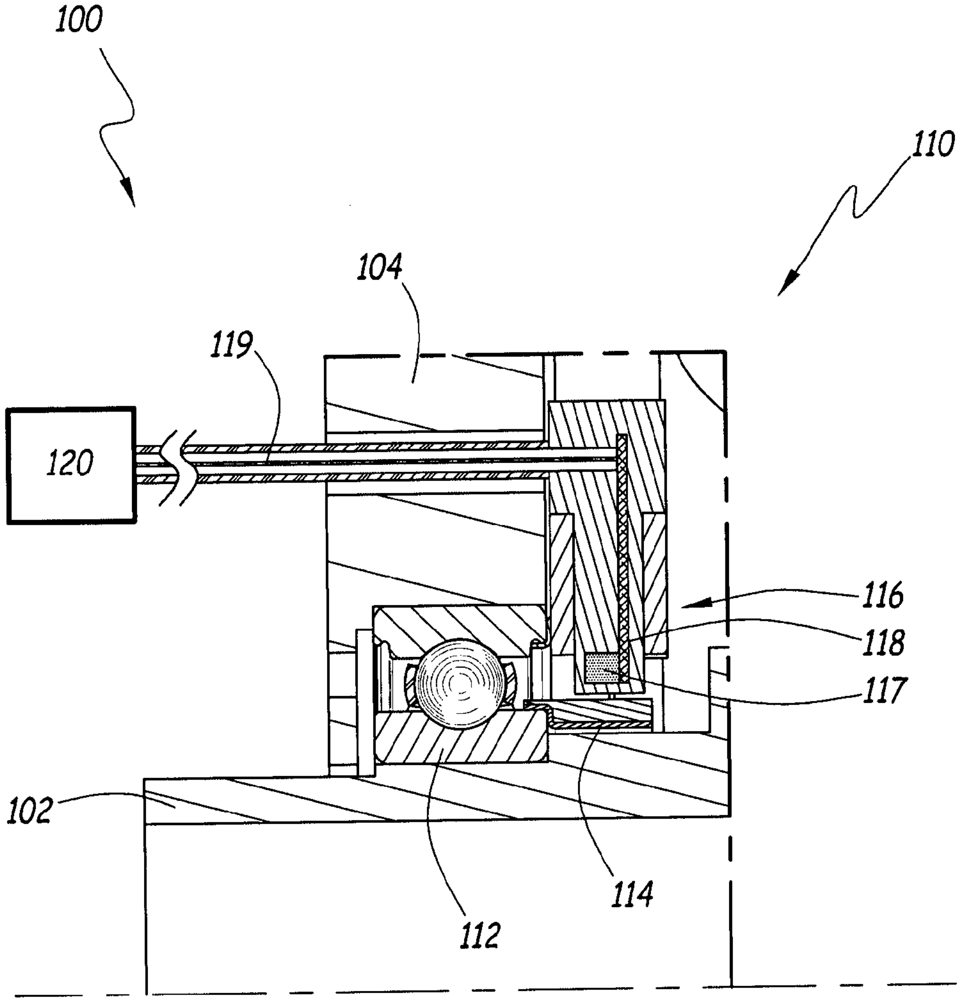


FIG.5

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/062431

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. G01D5/14 G01D18/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
G01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 3 February 2014 | 19/02/2014 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Kurze, Volker |

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Form PCT/ISA/210 (second sheet) (April 2005)

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PCT/EP2013/062431

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**Information on patent family members**

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