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(57) Abstract: A system and a method for balancing an elongate structure (1) rotating about an axis, such as a spindle (3) carrying, at an end, a grinding wheel (5), includes an automatic balancing device (9) near the grinding wheel. The system includes also a manually-operated balancing device (10) at the opposite spindle end and a dummy balancer with a mechanical piece with rotational symmetry (29). The dummy balancer is coupled to the spindle in the place of the automatic balancing device and in the absence of the grinding wheel, to perform preliminary balancing operations (51-57) by means of the manually-operated device.

DESCRIPTION**«SYSTEM AND METHOD FOR BALANCING A ROTATING STRUCTURE»**

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Technical Field

The present invention relates to a system for balancing a structure of a machine tool including a spindle, rotating about a longitudinal axis and carrying a grinding wheel coupled, in a removable way, substantially to a first end of the spindle, the system including a first vibration-detecting sensor at a first transversal section, near the first end of the spindle, a first, automatic, balancing device coupled to the spindle substantially near the grinding wheel, and a processing, display and control unit connected to the first vibration-detecting sensor and to the automatic balancing device for controlling in an automatic way the automatic balancing device on the basis of signals output from the first vibration-detecting sensor.

The invention also relates to a method for balancing a structure of a machine tool including a spindle defining a longitudinal axis, rotating about it and carrying a grinding wheel coupled, in a removable way, substantially to a first end of the spindle, by means of a system including at least a first vibration detecting sensor and at least a first, automatic, balancing device, the method including the step of automatically controlling the first, automatic, balancing device on the basis of the signals provided by the first vibration-detecting sensor.

Background Art

The problem of balancing grinding wheels of grinding machines is known from time.

Undesired vibrations are generally present in a grinding machine, and generated by out-of-balance conditions of the

- 2 -

grinding wheel due to various possible reasons depending on the grinding wheel itself, like shape and/or constitution defects (inhomogeneity of the materials, concentricity errors between the external abrading surface and the internal centering hole, etc.), inaccurate assembling to the rotating spindle (hence causing the grinding wheel center of gravity to be spaced apart from the axis of rotation), and, in general, deterioration due to wear and/or splinter occurring during the machining of the workpieces. These vibrations cause inaccuracies of the features of the machined workpieces - more specifically roundness errors like ovality and/or lobing - and introduce loads and stresses that may damage the machine tool.

Known balancing apparatuses, or balancers, are coupled to the grinding wheel and comprise movable masses, driven by electric motors that adjust the position of the masses, in the course of the wheel rotation, along radial or angular paths in order to compensate the previously mentioned out-of-balance conditions. The driving motors are also part of the apparatus, rotate along with it and the grinding wheel, and are power supplied and controlled by a stationary, external power source, by means of an electric connection, including, for example, a brush collector and slip rings, or by means of a contactless connection, for example of the inductive type.

The characteristics (like, for example, the amplitude) of the vibrations generated as a consequence of the out-of-balance are picked up by processing the signals provided by an appropriate sensor and displayed, or processed in a proper unit (that often comprises the previously mentioned power supply source, too) for providing suitable balancing signals and for controlling the motors to drive the movable masses.

A balancing apparatus comprising the previously mentioned characteristics is disclosed in U.S. patent US-A-3698263.

The automatic balancing of grinding wheels generally takes place in a heuristic way, i.e. on the basis of cycles for

displacing the two masses in the balancing device in order to continuously reduce the vibration detected by the sensor until there is obtained its complete elimination or in any case its reduction to acceptable values. For example, it is possible to control, in the course of the rotation, angular displacements of the masses, taken together and/or individually, in a direction and/or in the other, on the basis of the trend of the signal of the vibration-detecting sensor, until said signal reaches zero or a value very close to zero.

However, should the longitudinal layout dimensions of the grinding wheel be greater than, or even comparable with, its diametral dimensions (as in the case of grinding wheels of centerless grinding machines), or should the machine tool have two grinding wheels coupled to the same shaft, at longitudinally spaced out positions, a single balancing device that operates, in substance, along a transversal plane is not sufficient for achieving the appropriate balancing. In fact, besides the so-called "static" out-of-balance at a specific area, it is not possible to disregard the dynamic torque out-of-balance, caused by the fact that the axis of rotation does not coincide, in general, with the axis of inertia of the rotating system. In similar cases it is known to utilize two balancing devices, substantially identical to each other and arranged at longitudinally separate positions, for carrying out a dynamic balancing of the grinding wheel, or of the grinding wheel(s)/shaft system.

Patent application DE-A-2345664 describes a method and an associated apparatus for the dynamic balancing of an elongate grinding wheel for a centerless grinding machine, along two transversal sections relative to the longitudinal axis, by means of two devices each including a vibration-detecting sensor and an associated unit with movable masses, each device being arranged at one of the two sections. Processing, power supply and control units are alternately connected to the two balancing devices, for

controlling in sequence displacements of the masses of each of the devices on the basis of the signal received by the associated vibration-detecting sensor.

The issue of dynamic balancing arises also when a considerably long spindle carries a grinding wheel at a non-centered section, typically at an end thereof, and consequently it is possible that a dynamic torque out-of-balance be generated because the axis of inertia of the rotating structure does not perfectly coincide with the axis of rotation. In this case an automatic balancing device of the known type coupled to the grinding wheel at the associated end of the spindle is not in general sufficient, and it is known to utilize, as in the previously described cases, a second automatic balancing device, identical to the first, arranged at the opposite end of the spindle, in an application similar to the one disclosed in patent application No. DE-A-2345664. These known applications are rather complex and expensive.

Disclosure of Invention

An object of the present invention is to provide a system and a method for the dynamic balancing of rotating systems, more specifically elongate structures including tools like grinding wheels, that enable to eliminate or reduce to a minimum the unwanted vibrations in a way that is simple, safe and inexpensive.

This and other objects are achieved by a system according to claim 1, and by a method according to claim 5.

Brief Description of the Drawings

The invention is hereinafter described with reference to the annexed drawings, given by way of non-limiting example only, wherein:

figure 1 shows, in simplified form, an application of the system according to the invention, with some details

cross-sectioned, in a phase of the method according to the invention,

figure 2 shows, in simplified form, the application of the system of figure 1, in a different phase of the method according to the invention,

figure 3 is a cross-sectional view, with enlarged scale, of a detail of the system of figures 1 and 2, viewed along line III-III of figure 1,

figure 4 is an enlarged scale, perspective view of the detail of figure 3, and

figure 5 is a diagram with functional blocks of a balancing method according to the invention.

Best Mode for Carrying Out the Invention

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Figure 1 illustrates, in extremely simplified and partial form, an elongate rotating structure **1** that defines a longitudinal axis **L** and includes a shaft or spindle **3** carrying at one end a grinding wheel **5**, coupled in a known removable way.

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A grinding machine support **2**, for example the wheel-carrier, defines an axis of rotation **R** and supports the rotating structure **1** in such a way that the longitudinal axis **L** substantially coincides with the axis of rotation **R**, and the spindle **3**, that is driven in a known way not shown in the figure, can rotate about said axis **R**.

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A first vibration-detecting sensor **7**, for example of the piezoelectric type, is coupled to the support **2** near a first transversal section **S1**, near the end of shaft **3** where the grinding wheel **5** is coupled to.

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A first, automatic, balancing device **9** is housed in a suitable recess **8** at the end of the spindle **3** near the transversal section **S1**, and includes a pair of eccentric balancing masses - shown in simplified form and identified by reference numbers **11** and **12** - angularly movable about the longitudinal axis **L** by means of associated motors, not shown in the figure. The power supply for the motors and

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- 6 -

the controls relating to the angular displacements to be performed by the masses are transmitted to the automatic balancing device **9** by means of an electric connection with a per se known contactless coupling **13**, for example of the inductive type, including a stationary transmitter **15** and a rotary receiver **17**. The receiver **17**, also shown in figure 4, is part of the rotating structure **1** and is coupled to the spindle **3**, in a recess of the latter, at the end opposite the one carrying the grinding wheel **5**, centered relative to the longitudinal axis **L**. The stationary transmitter **15** faces the receiver **17** and is arranged at a limited distance from it. A longitudinal recess **14** in spindle **3**, with substantially cylindrical cross-section and centered on axis **L**, houses a cable, for example a spiral cable **16**, for electrically connecting the automatic balancing device **9** to the receiver **17**. In static conditions, the cable **16** is substantially centered along the longitudinal axis **L** of the spindle **3**.

A second, manually-operated, balancing device **10** is coupled to the end of spindle **3** opposite the one carrying grinding wheel **5**, more specifically it is mechanically coupled to receiver **17**. The manually-operated device **10**, also shown in figures 3 and 4, includes a graduated ring **19** and two displaceable elements or segments **21** and **22** that can be set at known pre-fixed angular positions identified by the graduated ring **19**. The locking of the segments **21** and **22** in the desired position and their releasing are manually performed by utilizing suitable tools, according to a per se known procedure.

A second vibration-detecting sensor **27**, for example of the piezoelectric type, is coupled to support **2** near a second transversal section **S2**, at the end of shaft **3** where the receiver **17** is coupled to.

A processing, display and control unit **40** is connected to the first vibration-detecting sensor (**7**), to the second vibration-detecting sensor (**27**), and to the stationary transmitter unit **15**.

A dummy balancer **29**, consisting of a mechanical piece with rotational symmetry, has shape and external dimensions similar to those of the automatic balancing device **9**, and is coupled to the spindle **3**, housed in recess **8** instead of automatic device **9**, in a preliminary phase of the method according to the invention, as hereinafter described and shown in figure 2. The mechanical piece or dummy balancer **29** is made, for example, from aluminum and has specific manufacturing features that guarantee the coincidence between the axis of inertia and the geometrical axis of symmetry.

In figure 5 the functional blocks of the diagram indicate the steps of a balancing method according to the present invention and more specifically:

- Block **50**: the balancing cycle starts;
- Block **51**: the grinding wheel **5** and the automatic balancing device **9** are removed from spindle **3** and the dummy balancer **29** is placed in recess **8** at the end of the spindle **3**, and is mechanically coupled to the cable **16** (see figure 2);
- Block **52**: the segments **21** and **22** are placed in known angular positions;
- Block **53**: spindle **3** is caused to rotate and unit **40** detects and memorizes the signals provided by the second vibration-detecting sensor **27**;
- Block **54**: spindle **3** is stopped and at least one of the segments **21** and **22** is displaced to a different known angular position;
- Block **55**: spindle **3** is caused to rotate again and the unit **40** detects and memorizes the signals provided by the second vibration-detecting sensor **27**;
- Block **56**: as the spindle **3** is stopped, depending on the signals detected and memorized at steps **53** and **55**, unit **40** processes and displays information relating to angular balance positions of the segments **21** and **22** that enable to balance the assembly including spindle **3** according to the arrangement shown in figure 2;
- Block **57**: the segments **21** and **22** are placed in the angular

- 8 -

balance positions displayed in unit **40**;

Block **58**: the dummy balancer **29** is removed from recess **8** and the automatic balancing device **9** is mounted in its place and coupled to spindle **3**, whereto there is also
5 coupled the grinding wheel **5**;

Block **59**: spindle **3** is driven into rotation and unit **40** receives the signals of the first vibration-detecting sensor **7** only;

Block **60**: the positions of the masses **11** and **12** are
10 automatically changed in the course of the rotation of spindle **3** by control signals transmitted to the associated motors by unit **40**, through the contactless coupling **13**;

Block **61**: on the basis of the signal provided by sensor **7**, it is detected whether it is necessary to furtherly change
15 the position of the masses **11** and **12**; and

Block **62**: the balancing cycle ends.

The operation of the system according to the method of figure 5 is as follows.

In the course of the grinding operations, it may become
20 necessary to carry out a balancing cycle, for example, as a consequence of the substitution or the dressing of the grinding wheel **5**. In any case, the decision as to whether carry out the balancing cycle is made by an operator or by the grinding machine logic - not shown in the drawings -
25 connected to unit **40** (block **50**).

A preliminary phase of the balancing cycle according to the present invention is manually carried out - from time to time - in a substantially deterministic way by means of the device **10**, on the rotating assembly that includes the
30 spindle **3**, the receiver **17** and the dummy balancer **29** in the recess **8**, before coupling grinding wheel **5** or after having removed it from spindle **3** (block **51**).

After having placed the segments **21** and **22** in known angular positions, for example at 180° mutually opposite positions,
35 as shown in figure 3 (block **52**), spindle **3** is driven into rotation and unit **40** detects and memorizes the signals provided by the second vibration-detecting sensor **27** (block

53). The rotation is stopped and one of the segments, for example segment **21**, is placed in a different known position, for example it is displaced by 60° with respect to the previous position (block **54**). Again spindle **3** is driven into rotation and unit **40** detects and memorizes the signals of the second vibration-detecting sensor **27** (block **55**). The rotation is stopped and, depending on the signals detected and memorized at steps **53** and **55**, unit **40** processes and displays information (block **56**) relating to angular balance positions, i.e. positions at which segments **21** and **22** have to be set in order to achieve the balance condition of the rotating assembly including the spindle **3** and the receiver **17** according to the arrangement shown in figure 2. Thereafter, the segments **21** and **22** are actually placed in the angular balance positions displayed in unit **40** (block **57**).

The manually-carried out preliminary phase - identified by reference number **49** and including the preliminary steps **51** to **57** in the diagram of figure 5 - ends, and the mechanical piece **29** is replaced, in the recess **8** of spindle **3**, with the automatic balancing device **9**. Moreover, the grinding wheel **5** is coupled to the spindle **3** (block **58**).

The automatic balancing phase of the rotating structure **1** starts, and takes place in a known way, under the control of unit **40** and on the basis of the signals provided by the first vibration-detecting sensor **7** only (blocks **59**, **60**, **61** and **62**).

The herein described system and method enable to achieve in an extremely simple and safe way the dynamic balancing of structure **1** including the grinding wheel **5** arranged at the end of the spindle **3**, without the need of utilizing additional, expensive and delicate automatic balancers. In fact, by performing a few, rapid and simple preliminary steps, the manually-carried out balancing phase enables to compensate in advance the causes determining the dynamic torque out-of-balance of the structure **1**, apart from those due to changes in the shape, structure or arrangement of

grinding wheel **5**. The latter causes are then compensated in a known way - during the rotation of spindle **3** - by means of the single automatic balancing device **9** located in correspondence of the grinding wheel **5**. It is pointed out
5 that the above-mentioned preliminary steps are usually to be carried out just once for a specific rotating assembly including spindle **3** and receiver **17**.

Other systems and methods according to the invention can include differences with respect to what has been herein
10 described, for example, as regards the manufacture, the arrangement and the coupling of the two balancing devices **9** and **10**, the known angular positions at which the segments **21** and **22** are arranged or, more generally, the known configurations for the manually-operated device **10**, or
15 other.

CLAIMS:

1. System for balancing a structure (1) of a machine tool including a spindle (3), rotating about a longitudinal axis (L, R) and carrying a grinding wheel (5) coupled, in a removable way, substantially to a first end of the spindle (3), the system including
- a first vibration-detecting sensor (7) at a first transversal section (S1), near said first end of the spindle (3),
 - a first, automatic, balancing device (9) coupled to the spindle (3) substantially near the grinding wheel (5), and
 - a processing, display and control unit (40) connected to the first vibration-detecting sensor (7) and to the automatic balancing device (9) for controlling in an automatic way the automatic balancing device (9) on the basis of signals output from the first vibration-detecting sensor (7),
- the balancing system further including
- a second, manually-operated, balancing device (10), with displaceable elements (21, 22) manually set at adjustable positions, coupled to the spindle (3) near a second section (S2) longitudinally spaced out from said first section (S1),
 - a second vibration-detecting sensor (27) near said second transversal section (S2), and
 - a mechanical piece with rotational symmetry (29) adapted to be coupled to the spindle (3) instead of the automatic balancing device (9),
- the processing, display and control unit (40) being electrically connected to the second vibration-detecting sensor (27) for processing associated electric signals and identifying angular balance positions of said displaceable elements (21, 22) adapted for balancing the structure when the mechanical piece with rotational symmetry (29) is coupled to the spindle (3).

2. The system according to claim 1, wherein said manually-operated balancing device (10) is coupled to the spindle (3) at a second end of the spindle opposite to the first end.

3. The system according to claim 2, including a contactless coupling (13) adapted for achieving the electric connection between the automatic balancing device (9) and the processing, display and control unit (40), the contactless coupling (13) including a stationary transmitter (15) and a rotary receiver (17) coupled to and rotating with the spindle (3) about the longitudinal axis (L, R), the rotary receiver (17) being arranged at said second end of the spindle (3) opposite the first, electrically connected to the automatic balancing device (9) by means of a cable (16).

4. The system according to claim 3, wherein the manually-operated balancing device (10) is mechanically coupled to said rotary receiver (17) and includes a graduated ring (19), said displaceable elements (21, 22) being adapted to be manually arranged in different mutual angular positions identified by the graduated ring (19).

5. A method for balancing a structure (1) of a machine tool, including a spindle (3) defining a longitudinal axis (L), rotating about it (R) and carrying a grinding wheel (5) coupled, in a removable way, substantially to a first end of the spindle (3), by means of a system including at least a first vibration detecting sensor (7) and at least a first, automatic, balancing device (9), the method including the step (59-61) of automatically controlling the first, automatic, balancing device (9) on the basis of the signals provided by the first vibration-detecting sensor (7),

wherein the system further includes a second vibration

- 13 -

detecting sensor (27), a second, manually-operated, balancing device (10) with displaceable elements (21, 22), and a dummy balancer (29) with a mechanical piece having rotational symmetry,

5 the method being characterized by the following preliminary steps:

- 10 ▪ removing (51) the grinding wheel (5) and replacing the first, automatic, balancing device (9), with the dummy balancer (29), the latter being coupled to the spindle (3) coaxially and concentrically with respect to said longitudinal axis (L),
- 15 ▪ placing (52, 54) the displaceable elements (21, 22) of the manually-operated balancing device (10) in different known positions,
- 20 ▪ detecting and processing (53, 55) signals provided by the second vibration-detecting sensor (27) in correspondence of said different known positions of the displaceable elements (21, 22) and identifying (56) angular balance positions of said displaceable elements (21, 22) adapted for balancing the structure (1) in the absence of the grinding wheel (5),
- 25 ▪ placing (57) the displaceable elements (21, 22) of the manually-operated balancing device (10) in said angular balance positions, and
- 30 ▪ replacing (58) the dummy balancer (29) with the automatic balancing device (9), and coupling the grinding wheel (5) to the spindle (3).

1 / 3

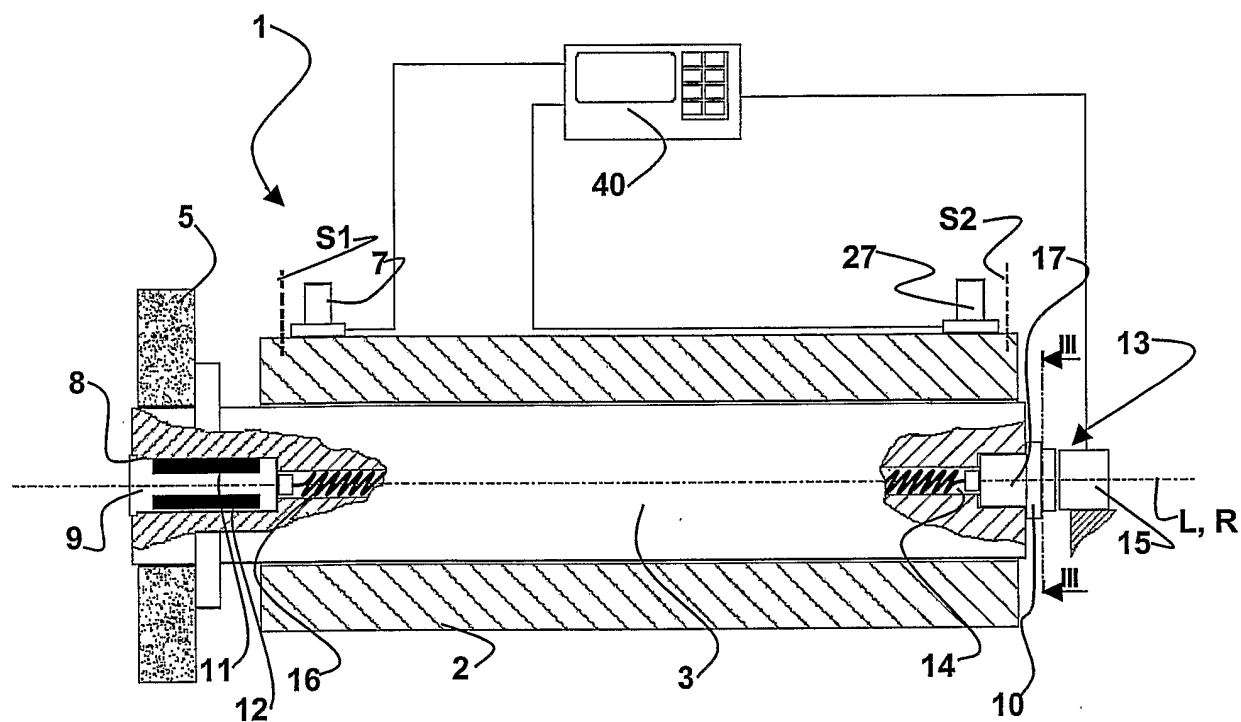


Fig. 1

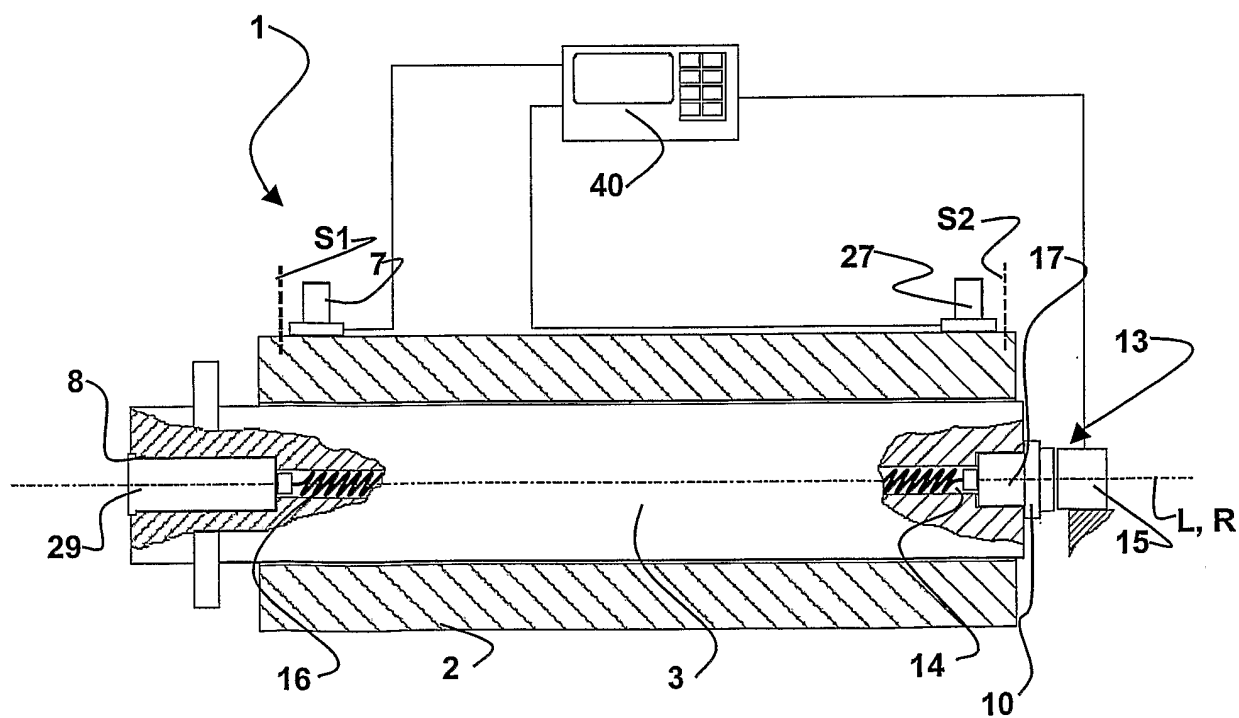


Fig. 2

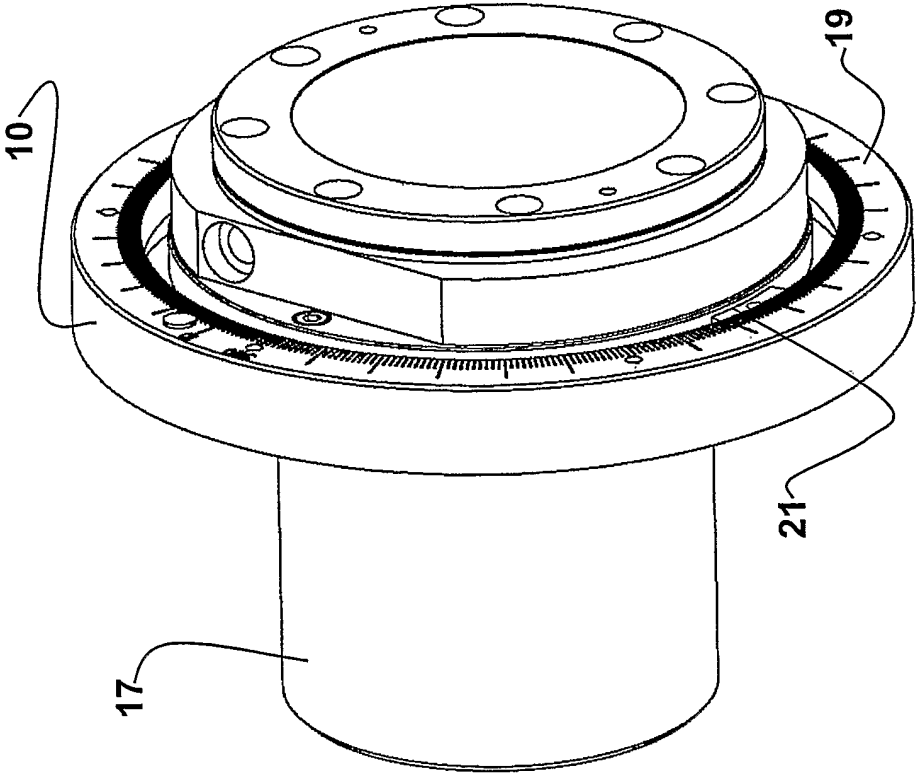


Fig. 4

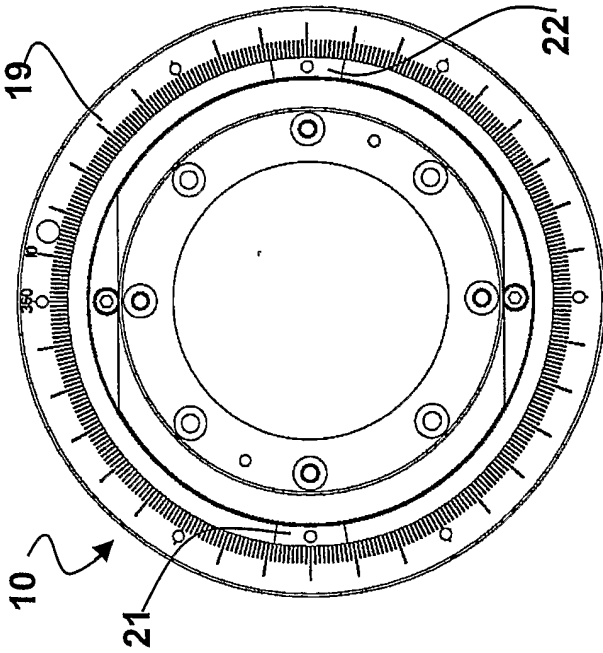


Fig 3

3 / 3

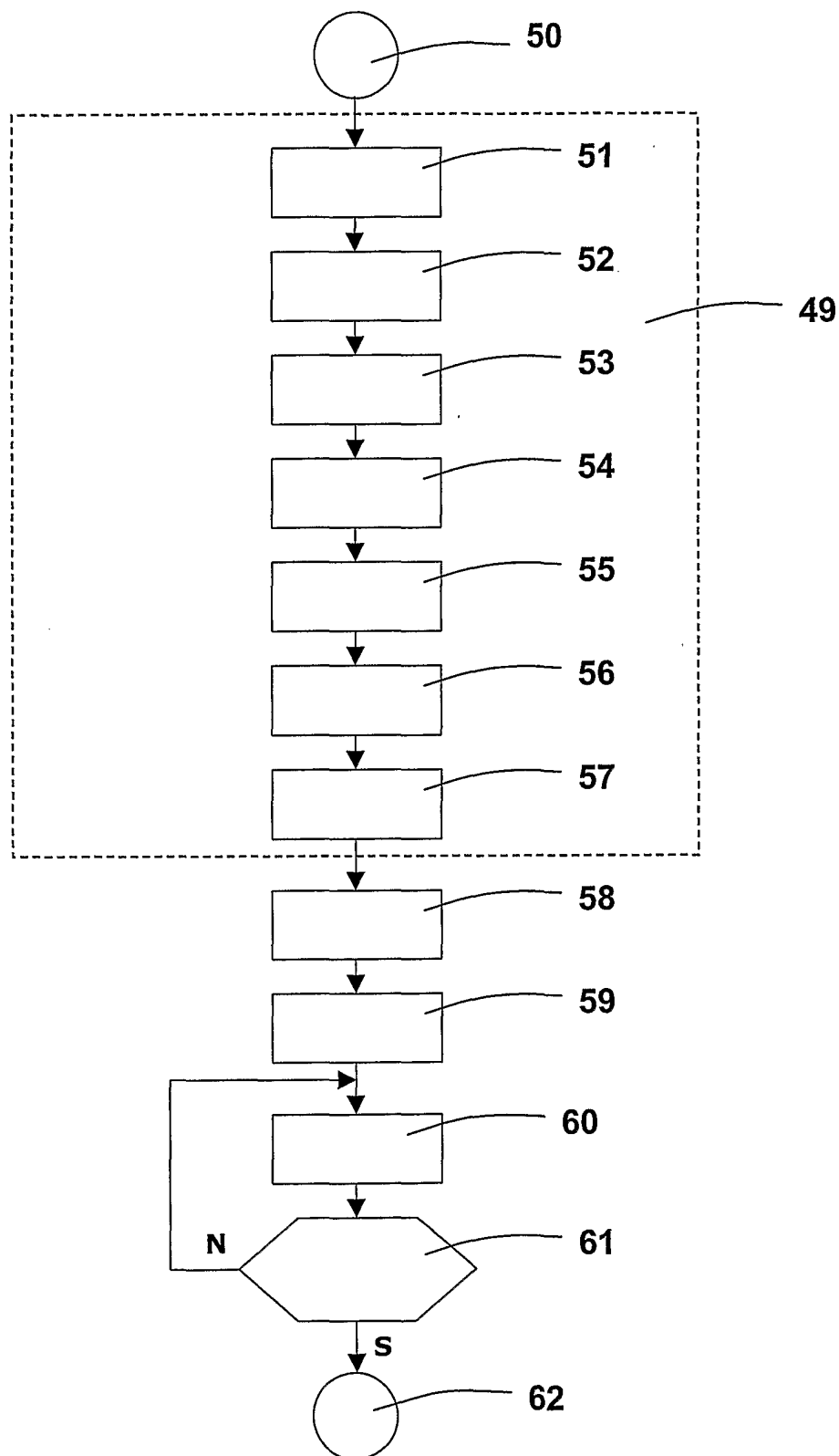


Fig. 5

INTERNATIONAL SEARCH REPORT

Intel Application No

PCT/EP 02/14768

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01M1/16 G01M1/38

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)

IPC 7 G01M B23Q B24B F16F

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 practical, search terms used)

WPI Data, EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Dietrich, A

INTERNATIONAL SEARCH REPORT

International Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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