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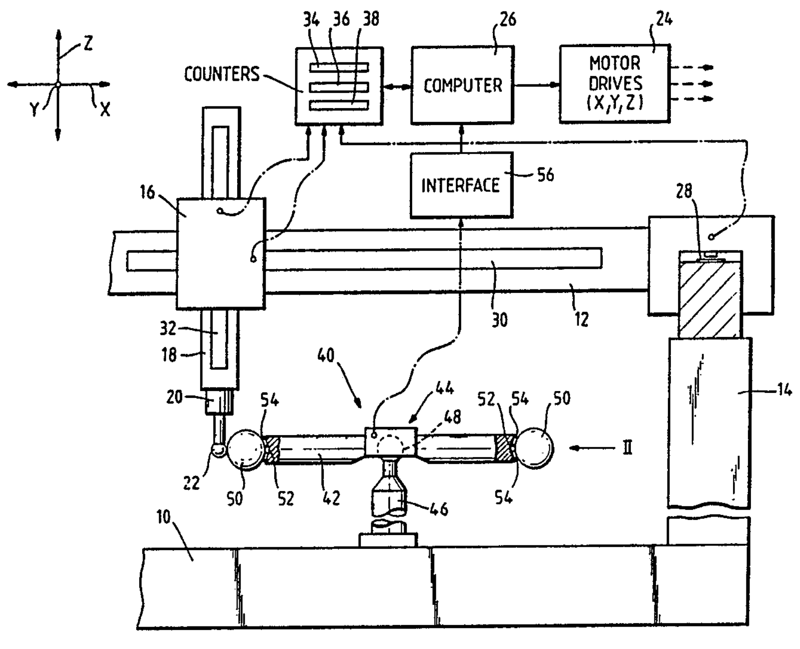

(57) Abstract

A device (40) for use in checking the volumetric accuracy of a measuring machine, comprises a bar (42) and contact balls (50) connected to either end of the bar via pressure sensitive elements (54). The pressure sensitive elements (54) may be piezo electric elements, or strain gauges. The bar (42) is pivotally mounted on a support (46) in order to allow it to adopt a plurality of different attitudes within the operating envelope of the measuring machine. The pressure sensitive elements (54) detect contact between a probe (20) and the device (40) thereby obviating the need to compensate for errors present in measurements taken due to pre-travel in the probe (20).

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TEST BAR FOR POSITION DETERMINATION APPARATUS

BACKGROUND TO THE INVENTION

This invention relates to position determination apparatus such as co-ordinate measuring machines, inspection robots and machine tools. More particularly, it relates to bars for testing the accuracy or repeatability of such apparatus.

It is known to make measurements on workpieces using such position determining apparatus, in which a probe is mounted for movement in three dimensions within a working volume of the apparatus. The probe is brought into contact with desired surfaces of the workpiece. When contact is made between the probe and the workpiece, this is detected by the probe, and readings are taken of the x,y and z co-ordinates of the point of contact.

It is known to check the volumetric accuracy and repeatability of positioning of such apparatus, in particular co-ordinate measuring machines, using a test bar. Examples of test bars are shown in DE-A-2603376 (Bendix), US-A-4,435,905 (Bryan), US-A-4,437,151 (Hurt), and in Tooling and Production, vol. 49, No. 2, May 1983, pages 40-47, "Measuring Up: Coordinate Measuring Machine Survey" by B Nagler, see page 43.

Such test bars usually have a fixed length. The apparatus is checked by touching the end, on both ends of the test bar with the probe, and calculating the length of the bar from the readings thus taken. This is repeated with the test bar in a number of different positions within the working volume of the apparatus, the results are compared, and any differences noted. In this way the entire working volume of the apparatus can be checked. The test bar may be pivotally mounted to facilitate repositioning within the working volume.

The prior art test bars just described have an accurately spherical test ball at one end or both ends, so that the centre of the ball can be calculated after taking four or more readings of the co-ordinates of points on the surface of the ball. The length which is measured is the length between the centre of one ball and the pivot point, or between the centres of two such balls on opposite ends of the bar.

Alternatively, International Patent Publication No. WO 85/05176 shows a test bar which facilitates the automation of a sequence of measurements over the volume of the apparatus. In place of the simple sphere provided on the end of the test bar, this specification describes a pivotable test bar, the free end of which has two longitudinally extending prongs which form a fork for engaging the stylus of the probe. A smaller ball is provided between the prongs for contacting the tip of the stylus in order to take a reading. The prongs and the smaller ball provide a kinematic location for the stylus tip, so that the point of contact with the end of the bar can be accurately known, thus obviating the need to take four or more readings on a ball. Because of the engagement with the prongs, the stylus can drag the end of the bar with it as the probe moves around the working volume, obviating the need for manual repositioning of the bar.

In all the above prior art devices, contact between the probe and the test bar is determined by the probe itself. Whilst such a probe may give extremely repeatable results, it will normally be subject to pre-travel, that is a certain small distance will be moved between the instant of contact and the instant at which a trigger signal results from the probe. Moreover, many such probes have a different value of pre-trvcel in different directions of contact. The result of all this is that the inaccuracies measured by the use of the test bar are a combination of the inaccuracies due to the apparatus itself and those due to the probe. If a different probe is used, different accuracy values will be obtained. It would be desirable to be able to measure any inaccuracies which are due to the apparatus itself, separately from any which are introduced by the probe.

SUMMARY OF THE INVENTION

The present invention provides a test bar for a position determining apparatus, comprising:

an elongate member,

a probe-contacting element at at least one end of the elongate member, and

means forming part of the test bar for detecting contact between the probe-contacting element and a probe.

Preferably the detecting means comprises one or more piezo-electric elements or strain gauges, which may suitably be arranged between the probe-contacting element and the elongate member. Preferably the elongate member has bearing means for pivotably locating the elongate member with respect to the apparatus. In one form, there are two said probe-contacting elements, one at each end of the elongate member, each having its own said detecting means.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described by way of example, with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of a co-ordinate measuring machine with a first embodiment of test bar,

Fig. 2 is a view of the test bar of Fig. 1, in the direction of arrow II,

FIg. 3 is a block circuit diagram of part of an interface circuit for the test bar of Fig. 1,

Figs. 4,5 and 6 are partial views illustrating alternative constructions for the test bar of Fig. 1,

Fig. 7 is a view on the line VII-VII in Fig. 6,

Fig. 8 is a view corresponding to Fig. 1 but showing a further embodiment of test bar,

Fig. 9 is a detail of Fig. 8, and

Fig. 10 is a view in the direction of the arrow X in Figs. 8 and 9.

DESCRIPTION OF PREFERRED EMBODIMENT

The co-ordinate measuring machine shown in Fig. 1 is generally conventional and comprises a bed or table 10 upon which (in normal operation) workpieces to be measured are placed. A gantry 12 is mounted on uprights 14 (only one of which is shown) for movement in a direction Y. A carriage 16 is slideable in a direction X on the gantry 12, and a quill 18 is slideable in the vertical, Z direction in the carriage 16. The bottom end of the quill 18 carries a touch probe 20, which has a workpiece-contacting stylus 22. As is well known, the stylus 22 is articulated in the probe 20 to prevent damage when it is brought into contact with a workpiece. Specifically, touch probe 20 is a touch trigger probe in which the stylus 22 is biased into a kinematically defined rest position which is precisely fixed with respect to the quill 18. It should be noted however, that since, in the present invention the ball bar produces a signal, any type of touch probe would suffice.

In normal operation for inspecting a workpiece, the probe 20 can be positioned anywhere within a three dimensional working volume of the co-ordinate measuring machine, in order to touch desired surfaces of the workpiece, under the action of X,Y and Z motor drives 24 of the machine (not shown in detail) which control the above-noted X,Y and Z motions. This is done under the numerical control of the computer 26. The position in space of the stylus 22 at any given moment is determined from respective scales 28,30,32 which have corresponding read heads, feeding pulses to X,Y and Z counters 34,36,38, which are connected to the computer 26. The probe 20 provides a trigger signal to the computer 26 via an interface (not shown) whenever it touches a workpiece surface, and at that time the computer 26 freezes the outputs of the counters 34,36,38 and reads them in order to determine the X,Y and Z coordinates of the point which has been touched.

Fig. 1 also shows a test bar 40 according to one embodiment of the present invention. It comprises an elongate bar 42 which is mounted at a central pivot point 44 upon a pillar 46 which is placed on the table 10. At the pivot region 44, the pillar 46 has a ball 48 which is received in a corresponding socket in the underside of the bar 42, thus enabling the bar 42 to pivot in any direction, either horizontally or vertically. The pivot region 44 has a clamping means (not shown) so that once pivoted into a desired orientation, the bar 42 can be clamped into that position.

At each end of the elongate bar 42, there is provided a ball 50 having an accurately spherical surface. As seen more particularly in Fig. 2, each ball 50 is received in a conical recess 52 in the end of the bar 42. It is mounted in the conical recess upon three spaced pressure sensitive elements. Specifically the elements 54 are piezo-electric elements. In the view shown in Fig. 2, the ball 50 has been omitted for clarity, but its position is indicated by a phantom line.

The piezo-electic elements 54 are sensitive to the shock wave generated in the associated ball 50 by the impact whenever the stylus 22 touches the ball 50, and also to the subsequent stress caused by the contact. The shock wave is the earliest indication of probe-test bar contact, and so it is preferable to use piezo-electric elements since they are capable of detecting the shock wave. It is possible however to use as an equivalent, one or more strain gauge arrays to detect stress. The elements 54 are connected to the computer 26 via an interface 56, part of the circuitry of which is shown in Fig. 3. To improve noise immunity, it is advantageous to include at least part of the circuitry of Fig. 3 within the bar 42 itself, rather than in a separate remote interface unit.

Referring to Fig. 3, the outputs of the three piezo-electric elements 54 are first amplified by respective charge elements 58, and then taken to respective absolute value circuits 60. These rectify the signals, and then feed them to respective comparators 62. Here, the signals are compared with a threshold voltage from the reference souce 64, so that the comparators provide an output signal whenever the piezo-electric element output exceeds a certain value. The outputs of the comparators 62 are wire OR-ed, giving a combined trigger output on a line 70 which can be further processed in the interface 56 and taken to a trigger input of the computer 26. Resistors 66,68 in a feedback circuit around the comparators 62 provide a degree of hysteresis for the trigger output. It will be appreciated that the trigger output on the line 70 is caused by whichever of the piezo elements 54 is first to exceed the given threshold. The use of three piezo-electic elements at different orientations, together with the circuit described, ensures that a trigger signal is generated whatever the direction of contact between the stylus 22 and the ball 50, and whatever the direction of propogation of the resulting shock wave. The absolute value circuits 60 ensure that an immediate trigger signal is generated irrespective of whether the initial acceleratioin applied to a given piezo element is positive or negative.

When employing strain gauge arrays it is necessary to modify the interface since strain gauges are resistive devices, whereas piezo-electric elements are capacitative.

The mounting of the balls 50 in the bar 42 as described in respect of Figs. 1 and 2 can be modified if desired. One modification is shown in Fig. 4, where the end of the bar 42 and the ball 50 have opposing flat surfaces 72,74, three spaced piezo-electic elements 54 being sandwiched between the flat surfaces. The three elements 54 may be replaced by a single piezo-electric element provided it is made responsive to shock waves resulting from contact between the stylus 22 and ball 50 in any direction.

Fig. 5 shows an arrangement in which the ball 50 is located on the free end of a rod 76 which is located in a bore 78 within the end of the bar 42. Four piezo-electric elements are provided. one of these, 54', is located between the end of the rod 76 and bottom of the bore 78, while the other three, 54", are radially spaced around the rod 76, between the rod and the cylindrical surface of the bore 78. A similar circuit to that of Fig. 3 is used, but with four sets of components 58,60,62 instead of three.

Figs. 6 and 7 show a modified version of Fig. 5, in which the same reference numerals denote similar parts. Instead of the piezo-electric elements 54,54", there is a single annular piezo-electric element 90, surrounding the rod 76 in the bore 78. The element 90 is sensitive to shear, so as to be responsive to stylus contact from any direction.

The test bar in Fig. 1 has a fixed length between the centres of the two balls 50. In use, the stylus 22 is touched at each of four or more points on the surface of one of the balls 50, using manual control of the movement of the quill 18 or under the action of a numerical control programme in the computer 26. Whenever a contact is made, this is detected by the piezo-electric elements 54 and a trigger output on the line 70 is taken to the computer 26. This takes readings of the X,Y,Z co-ordinates of the quill 18 at the contact point from the counters 34,36,38, in the usual manner. From the X,Y,Z co-ordinates of the four or more points touched, the computer 26 then calculates the co-ordinate of the centre of the ball 50. The whole procedure is repeated to obtain the co-ordinates of the centre of the other ball 50 at the opposite end of the bar 42. The distance between the two centre points is then easily calculated. To determine the accuracy of the machine over the entire working volume, the procedure just described is repeated at many different positions and orientations of the test bar 42 within the three-dimensional working volume of the machine, and the results are compared.

The piezo-electric elements 54 generate the signal immediately upon contact between the stylus 22 and the ball 50. In the prior art, where the trigger signal was generated by the probe 20 in response to this contact, the accuracy as measurred would depend not only on the accuracy of the co-ordinate measuring machine itself, but also on the accuracy of the probe 20, including any pre-travel of the probe. Thus, the volumetric accuracy which can be determined with such a prior art arrangement is valid while a given probe is mouned in the machine, but will not be valid if the probe is changed. With the present embodiment of the invention, however, the accuracy as determined is completely independent of the accuracy of the probe 20. Of course, if in any given case it is also desired to know the combined accuracy of the machine and the probe, the present test bar can also be used in the conventional manner.

If desired, the double-ended test bar of Fig. 1 may be replaced by a single-ended test bar having a ball 50 at only one free end. In place of the pivot region 44, the other end of such a test bar has a ball which is received pivotably in a socket which is placed on the table 10. It can be magnetically clamped in a desired orientation in the socket, as is well known. The standard length of such a test bar is between the centre of the ball 60 at the free end and the centre of the socket in which the bar is received. The single ball 50 is supported on piezo-electric elements 54, the same as in the test bar 40 in Fig. 1.

Figs. 8,9 annd 10 show an alternative test bar according to another embodiment of the invention, mounted on the same co-ordinate measuring machine as Fig. 1. Parts which correspond have been given the same reference numbers as in Fig. 1. The test bar 80 shown in Fig. 8 is a development of that shown in International Patent Publication No. WO 85/05176, incorporated herein by reference. It is intended to permit automation of the checking of the volumetric accuracy of the machine, as described in that publication, and will not be described fully here.

Briefly, however, the test bar 80 has a means for enabling both universal pivoting of the stylus 22 about the ball at its free end, and relative translational movement of stylus and bar. Specifically there is provided at a free end of the bar 80 a pair of parallel, horizontal, longitudinally extending prongs 82 which form a fork for engagement with the stylus 22. This enables the movement of the quill 18 to cause pivoting of the test bar 80 into any desired position. The end of the bar 80 also has a spherical ball surface 84 which is located below and between the prongs 82. When it is desired to take a co-ordinate reading, the quill 18 is moved inwards (preferably radially inwards) so that the stylus 22 contacts the ball surface 84, at a kinematically defined position on the ball surface because it is also in contact with the two prongs 82.

The modification, with respect to the aforementioned International Publication, can be seen more clearly in Fig.9. Instead of being mounted directly to the end of the bar 80, the ball 84 is supported on the end of the bar via a piezo-electric crystal 86. This is connected to an amplifier 58, absolute value circuit 60 and comparator 62 to generate a trigger output signal in the same way as described in Fig. 3. However, since the stylus 22 always hits the ball 84 in the same (radial) direction, only one piezo-electric crsytal 86 is needed in order to reliably pick up the signal, and one set of components 58,60,62.

Fig. 9 also shows that optionally, the piezo-electric crystal 86 and ball 84 are mounted to the end of the bar 80 via a layer of a rigid sound insulating material 88, such as a rigid foam ceramic material. This reduces any risk of false triggering of the piezo-electric crystal 86 as a result of noise travelling to it via the bar 80, such as machine noise or any noise caused by the sliding of the stylus 22 against the prongs 82.

The above embodiments of the invention have detected the contact using one or more piezo-electric elements. This is preferred beacuse piezo-electric elements can give the most accurate results without the need for correction of systematic errors. However, other means may be provided in or on the test bar to detect the contact, such as strain gauges, electromagnetic detectors, photoelectric detectors, or even electrical switching elements.

CLAIMS

1. A device for use in calibrating a position determining apparatus comprising an elongate member, a contact element for contact by a touch probe and a means forming part of the device for detecting contact between the contact element and a probe.

2. A device according to claim 1 wherein the means for detecting contact comprises a sensitive element adapted to generate a signal responsive to stress in the contact element.

3. A device according to claim 2 wherein the pressure sensitive element is a piezoelectric element.

4. A device according to claim 2 wherein the pressure sensitive element is a strain gauge.

5. A device according to any one of the preceding claims wherein the member is mounted on a support for universal pivotal motion about a pivot point.

6. A device according to any one of the preceding claims wherein the contact element is connected to the member via the pressure sensitive element.

7. A device according to any one of the preceding claims wherein the contact element comprises a spherical contact surface at an end of the member.

8. A device according to any one of the preceding claims comprising a contact element provided at each end of the member.

9. A device according to any one of the preceding claims wherein the contact element is connected to the member via three equally spaced pressure sensitive elements.

10. A device according to any one of claims 1 to 5 wherein the contact element provides a kinematic support for a spherical surface.

11. A device according to any one of claims 1 to 5, or claim 10 further comprising means for providing a connection between the member and a stylus of the touch probe, the stylus having a spherical element at its free end, said means enabling universal pivotal motion of the stylus about the free end of the stylus and relative translational movement between the stylus and the member.

12. A device according to claim 11 wherein said means comprises a pair of rods connected to the member, whose axes are spaced apart and extend parallel to each other.

13. A device according to claim 12 wherein an abutment for the spherical element is provided adjacent the connection of the rods to the member.

14. A device according to claim 12 or claim 13 wherein the rods provide a pair of mutually convergent surfaces, the direction of convergence being perpendicular to the direction of extension of the member.

15. A device according to claim 14 wherein the abutment and the convergent surfaces provide the kinematic support.

16. A device according to any one of claims 13 to 15 wherein the abutment is connected to the member via the pressure sensitive element.

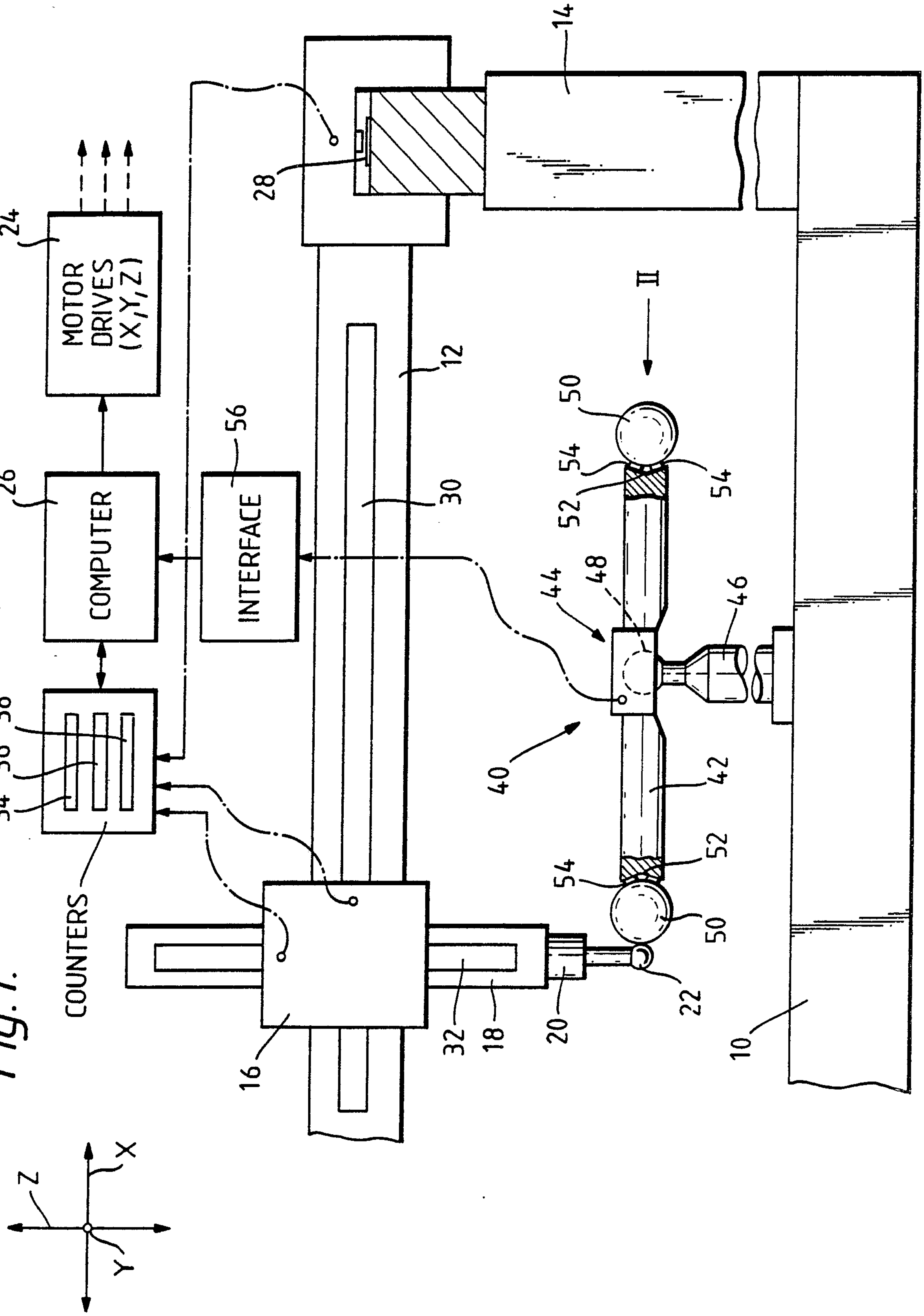
MOTOR DRIVES (X,Y,Z)
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Fig. 1.

Fig.2.

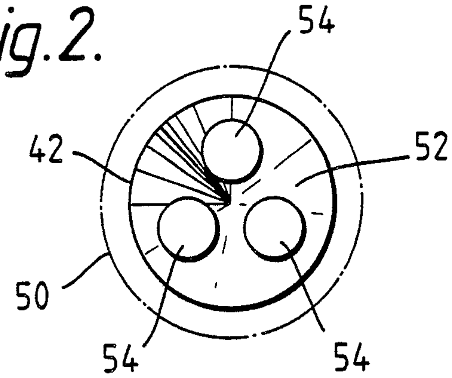


Fig.3.

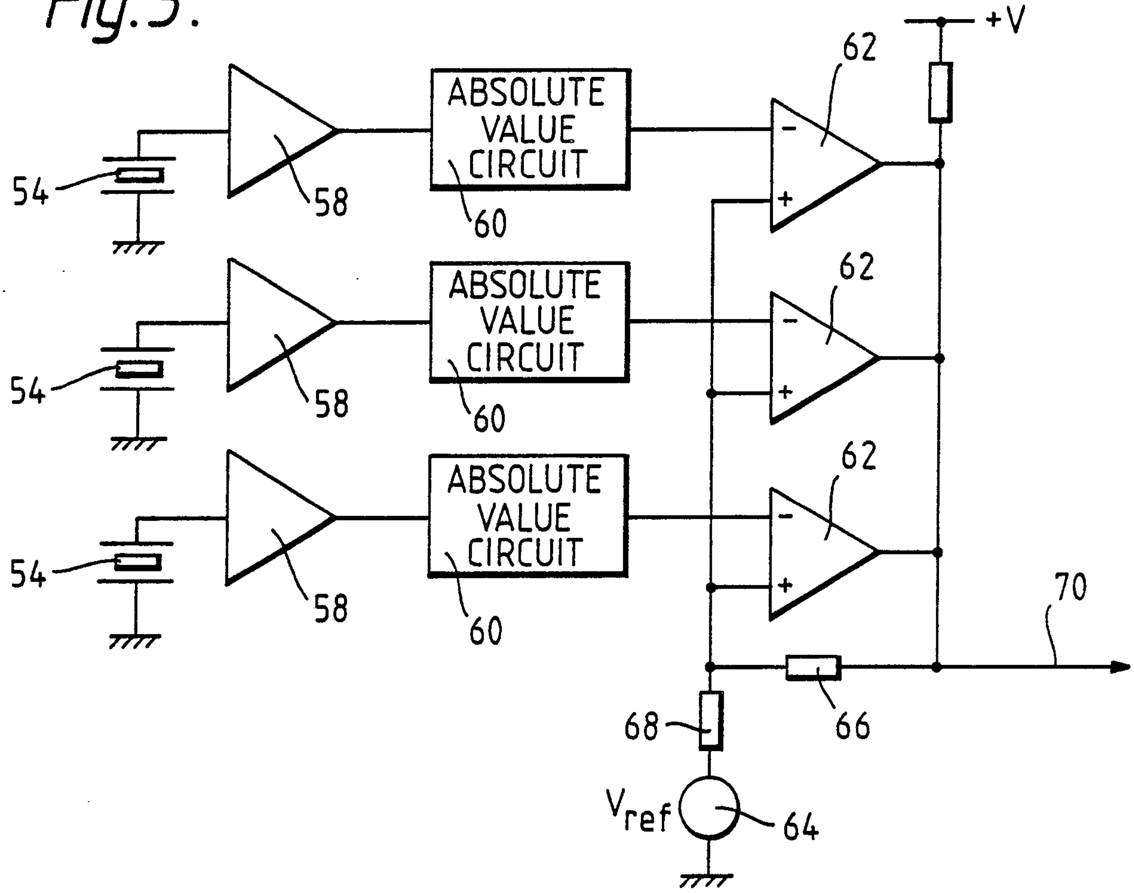


Fig.4.

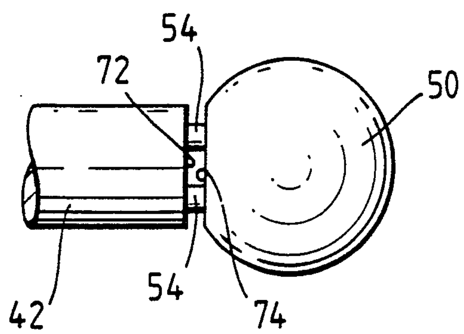


Fig.5.

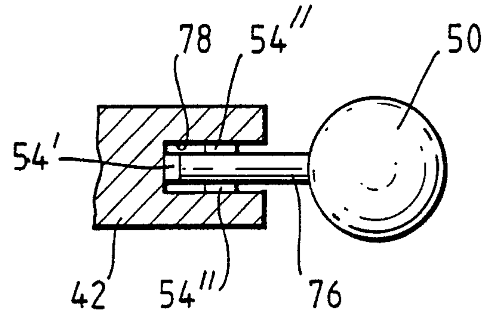


Fig.6.

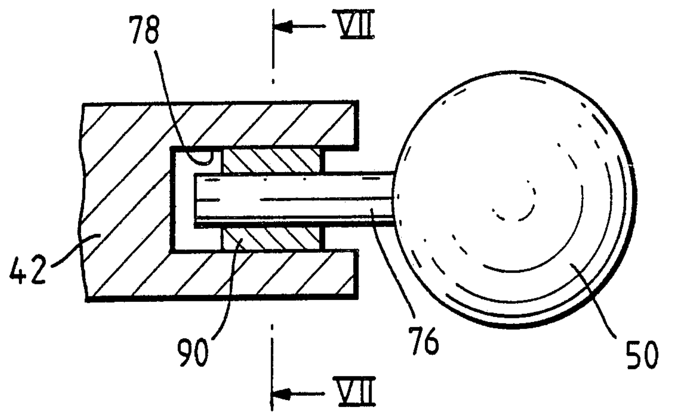


Fig.7.

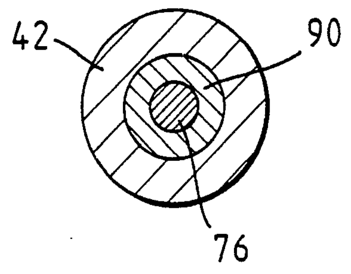


Fig.9.

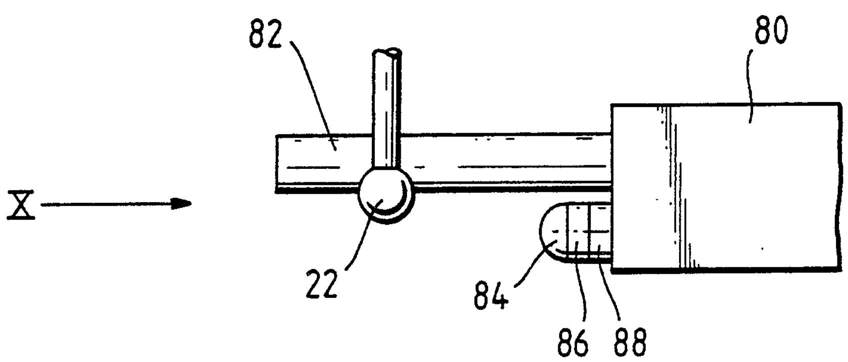
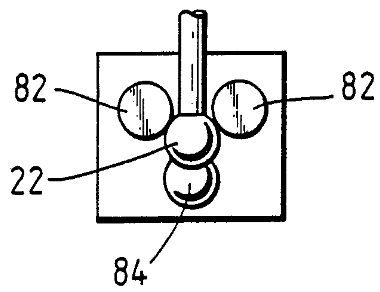
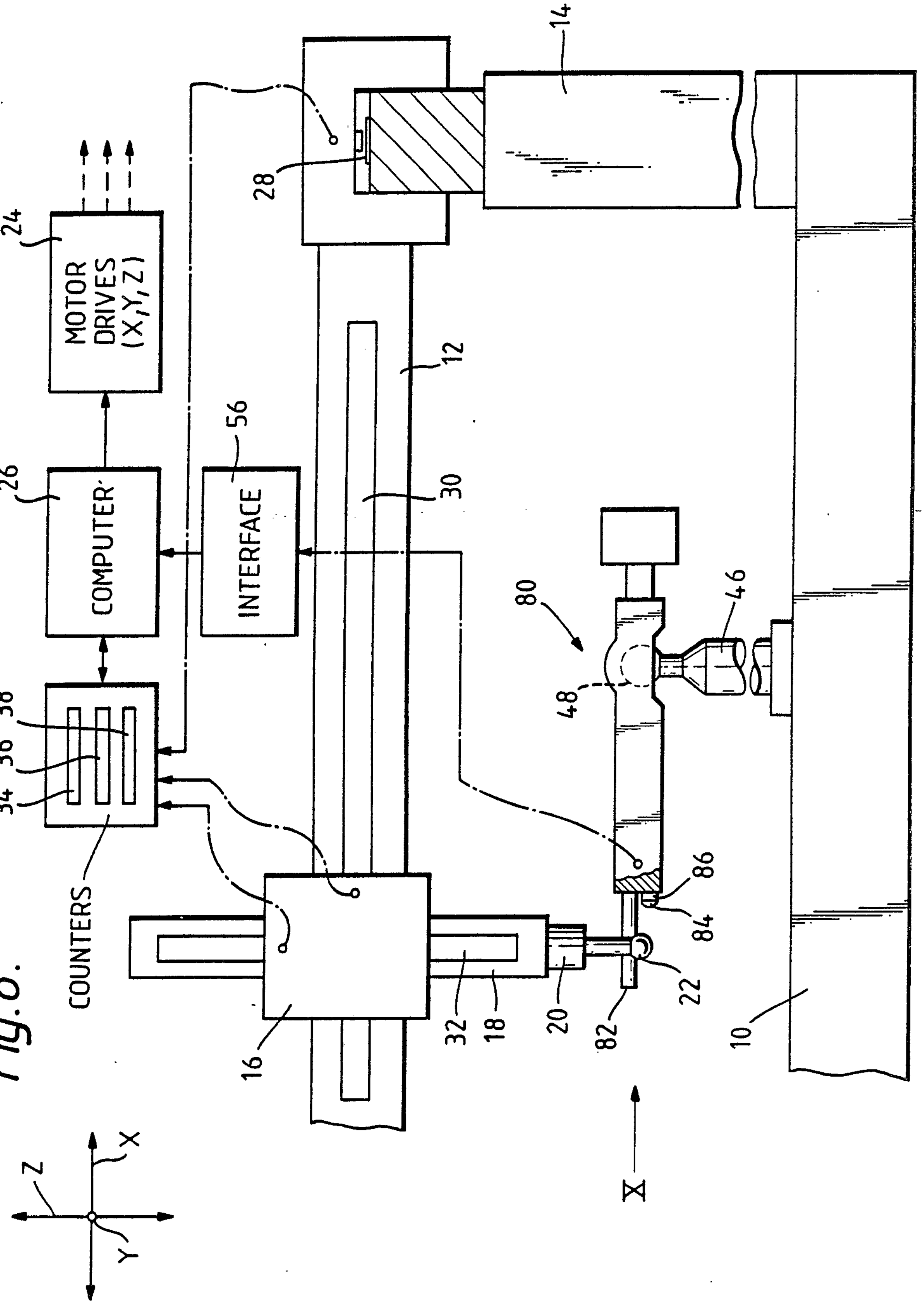


Fig.10.

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COUNTERS
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Fig. 8.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/00567

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 01 B 21/04, G 01 B 3/30

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	G 01 B 21, G 01 B 3

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	WO, A, 85/05176 (RENISHAW) 21 November 1985, see abstract; figures (cited in the application) --	1,5,7-10
A	Tooling & Production, vol. 49, no. 2, May 1983 B. Nagler: "Measuring up: Coordinate measuring machine survey" pages 40-47, see pages 43,44, central column (cited in the application) --	1
A	GB, A, 2136573 (MAUSER-WERKE) 19 September 1984, see the whole document	1,4

* Special categories of cited documents: [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
25th August 1989	18 SEP 1989
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	T.K. WILLIS

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 8900567
SA 28886

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 11/09/89
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A- 8505176	21-11-85	EP-A- 0180610	14-05-86
		US-A- 4777818	18-10-88
GB-A- 2136573	19-09-84	DE-A- 3309122	20-09-84
		JP-A- 59174710	03-10-84
		SE-A- 8401140	16-09-84

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82