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(71) Applicant: **SEIKO SEIKI KABUSHIKI KAISHA**
3-1, Yashiki 4-chome
Narashino-shi Chiba(JP)

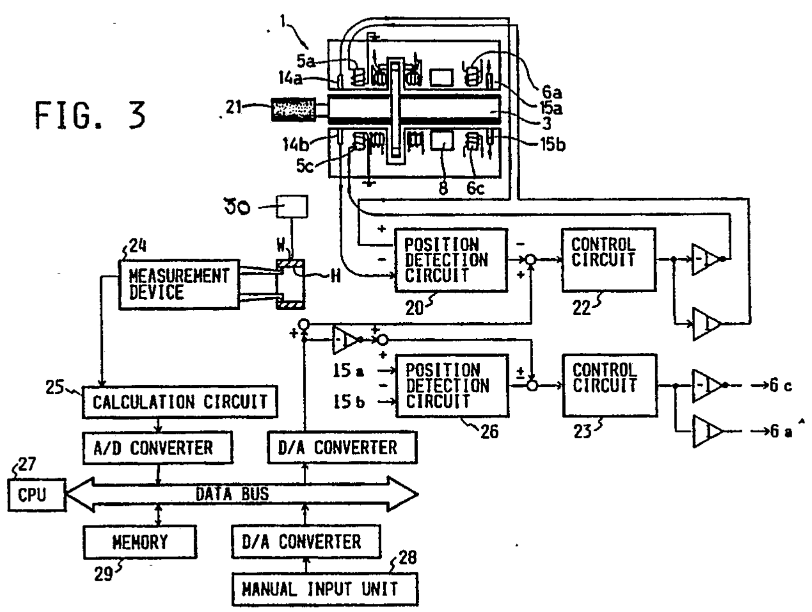
(72) Inventor: **Oshima, Jinichiro, c/o SEIKO SEIKI K. K.**
3-1 Yashiki, 4-chome
Narashino-shi Chiba(JP)

(74) Representative: **Miller, Joseph et al**
J. MILLER & CO. Lincoln House 296-302 High Holborn
London WC1V 7JH(GB)

(54) **Grinding machine.**

(57) A grinding machine comprising first mounting means (30) for mounting a workpiece (W) which is to be ground; second mounting means (3) for mounting a grinding member (21) to effect grinding of the workpiece (W); drive means (8) for effecting relative rotation of the first and second mounting means (30,3); and tilting means (23-29) for effecting relative tilting of the first and second mounting means (30,3) so that the workpiece (W) can be accurately ground to predetermined dimensions characterised in that at least one of said first and second mounting means (30,3) is constituted by a shaft (3) which is mounted within a housing (1), the housing (1) having electromagnets (5,6) which are arranged to produce a magnetic force which is effective to float and radially support the shaft (3); the said tilting means (23-29) electrically controlling the electromagnets (5,6) so that the magnetic force produced by the latter can be adjusted to tilt the shaft (3) with respect to the housing (1).

FIG. 3



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GRINDING MACHINE

The present invention relates to a grinding machine.

According to the present invention, there is provided a grinding machine comprising first mounting means for mounting a workpiece which is to be ground; second mounting means for mounting a grinding member to effect grinding of the workpiece; drive means for effecting relative rotation of the first and second mounting means; and tilting means for effecting relative tilting of the first and second mounting means so that the workpiece can be accurately ground to predetermined dimensions characterised in that at least one of said first and second mounting means is constituted by a shaft which is mounted within a housing, the housing having electromagnets which are arranged to produce a magnetic force which is effective to float and radially support the shaft; the said tilting means electrically controlling the electromagnets so that the magnetic force produced by the latter can be adjusted to tilt the shaft with respect to the housing.

Preferably, the shaft is a rotor shaft which is driven by said drive means.

The tilting means preferably includes measuring means for measuring the amount of taper present in a surface of the workpiece which is being ground, and calculating means connected to the measuring means for calculating the angle of relative tilt of the first and second mounting means required to correct for the said taper, the tilting means in operation producing the said relative tilt.

The said electromagnets are preferably spaced from each other axially of the shaft, the tilting means in operation causing the magnetic forces produced by the respective electromagnets to be varied relative to each other.

In one embodiment, the rotor shaft is arranged to receive a grinding wheel thereon. In this case, the measuring means may be arranged to measure the amount of taper present in the bore of the workpiece.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a side sectional view of a part of one embodiment of a grinding machine according to the present invention;

Figure 2 is a front sectional view of part of the structure shown in Figure 1;

Figure 3 is a block diagram of the grinding machine employing the structure of Figures 1 and 2;

Figure 4 is a flow chart illustrating the operation of the grinding machine of Figure 3;

Figure 5 is a side view of a grinding wheel during its use in a known grinding operation of a workpiece;

Figure 6 is a partial sectional view showing a machined hole in a workpiece produced by the known grinding operation; and

Figures 7 to 10 are schematic sectional views of a workpiece undergoing a known grinding operation.

As shown in Figure 5, in a known grinding machine, a grinding shaft S is elastically deformed due to grinding resistance during the grinding operation so that a grinding wheel G, which is carried by the grinding shaft S, is tilted. Therefore, a workpiece W is correspondingly set in an inclined position at a tilt angle α so as to avoid the tapering of a machined hole H.

However, when the grinding wheel G is worn down and its diameter therefore becomes smaller, the sharpness of the grinding wheel G changes and the tilt angle α of the grinding shaft S also needs to change. However, in practice, the workpiece W is held in a tilted attitude at the initially set angle α. Consequently, as shown in Figure 6, the machined hole H is broadened by an amount d on one side of the workpiece W (the left side of Figure 6).

When carrying out internal grinding as shown in Figure 7, the workpiece W is normally ground while positioned parallel to the grinding shaft S, and the grinding shaft S is shifted in the cutting or radial direction A while maintaining this parallel relationship. In such positioning, the grinding shaft is bent by an angle of tilt α due to the grinding resistance. If the grinding operation were finished in these conditions, the hole of the workpiece W would have a taper angle α as shown in Figure 8.

For this reason, the workpiece W may be set in a position in which it is inclined at the angle α as shown in Figure 9. By means of such a setting, the grinding operation is carried out to avoid the tapering of the machined hole H which is shown in Figure 5.

However, when the diameter of the grinding wheel G is reduced by dressing or wear, the sharpness of the grinding wheel changes to cause variation of the grinding resistance. Thus the sharpness or cutting efficiency is normally increased. Therefore, the degree of bending α of the grinding shaft S changes to β as shown in Figure 10. Nevertheless, the inclination of the workpiece W is held at the initially set value α. Therefore, as shown in Figure 10, the finished hole H is broadened on one side (the left side of Figure 10) so that the finished hole H has a taper $d = \alpha - \beta$. Then, when this tapering or broadening amount d exceeds a predetermined value over the product tolerance of the workpiece W, the grinding wheel G is replaced by a new one to carry out the grinding of several further workpieces W until the taper again exceeds the tolerance. When the taper exceeds the tolerance, the current grinding wheel G is again replaced by another new one to maintain the cylindricality of the machined workpieces W within the tolerance during the sequential grinding of the workpieces.

Further, in order to place the workpiece W in an inclined position corresponding to the initial tilt α of the grinding shaft S, a chuck of the workpiece, a table for supporting the chuck, and a spindle or spindle table must also be inclined. These members, however, have relatively great weight so that it is difficult to effect fine adjustment. Moreover, the adjustment thereof needs specific intuition and skill, thereby causing problems such as long adjustment time and poor accuracy.

Further, the sharpness of the grinding wheel changes during the course of the grinding operation and therefore the amount of tilt α of the grinding shaft S varies. The resultant tapering of the workpiece W exceeds a predetermined value over the product tolerance. For this, it could be possible to reset the workpiece W in another inclined position. However, such resetting is complicated and therefore is not practical in view of the above noted reason.

Consequently, in the prior art, the grinding wheel G has to be frequency replaced by a new one so as to maintain the initial sharpness. Therefore, the life of the grinding wheels is shortened and this causes increased production costs.

In contrast, in the grinding machine illustrated in Figures 1-3, the magnetic force produced by the electromagnets is electrically controlled to effect easy tilting of the rotor shaft so as thereby to tilt the grinding wheel. Thus the response is excellent and fine adjustment can be easily effected. The adjustment, moreover, does not need intuition or skill and can be carried out quickly. Further, the cylindricality of a machined workpiece can be ensured with a high degree of accuracy.

Moreover, in the embodiment of Figures 1-3, when the tapering of the workpiece exceeds a predetermined tolerance due to the change of the sharpness of the grinding wheel during the course of the grinding operation, the grinding wheel can be easily inclined to correct the tapering. Consequently, the grinding operation can be continued with the same grinding wheel without replacing it by a new one, or without dressing the grinding wheel. Accordingly, the life span of an individual grinding wheel can be effectively prolonged to avoid waste and to reduce production cost.

Turning now to the embodiment of Figures 1-3, as shown in Figure 1, a grinding machine according to the present invention comprises a magnetically supported spindle or housing 1 having a substantially cylindrical base 2 which constitutes an outer frame. A rotor shaft 3 is disposed in the base 2 so as to extend axially of the latter. A pair of radial magnetic bearings in the form of radial electromagnets 5 and 6 are provided in the base 2 adjacent opposite end portions of the rotor shaft 3 so as to magnetically float and radially support the rotor shaft 3. A motor 8 is disposed in the base 2 around an axially central portion of the rotor shaft 3 so as to drive the rotor shaft 3. A pair of axial magnetic bearings in the form of electromagnets 11 and 12 are disposed in the base 2 to control axial displacement of the rotor shaft 3, the electromagnets 11, 12 being disposed on opposite sides of a flange 10 which projects radially from a substantially central portion of the rotor shaft 3.

A radial position sensor 14 is provided in the base 2 adjacent to the front radial electromagnet 5 so as to detect the radial position of the front of the rotor shaft 3, and another radial position sensor 15 is provided in the base 2 adjacent to the rear radial electromagnet 6 so as to detect the radial position of the rear of the rotor shaft 3. Further, an axial position sensor 16 is disposed adjacent to a step portion 3a formed at the front end portion of the rotor shaft 3 (the left side in Figure 1) so as to detect the axial position of the rotor shaft 3.

A pair of mechanical bearings 18 and 19 are disposed in the base 2 around the opposite end portions of the rotor shaft 3 so as respectively to support the same at a reduced diameter portion 3b formed at the front end portion of the rotor shaft 3 and at another reduced diameter portion 3c formed at the rear end portion thereof. The rotor shaft 3 is thus directly and rotatably supported by the reduced diameter portions 3b and 3c when the radial electromagnets 5 and 6 are deenergized so that the rotor shaft 3 is no longer magnetically floated. A cylindrical grinding wheel 21 is attached to the front end of the reduced diameter portion 3b to grind a workpiece (not shown in Figure 1) when the rotor shaft 3 is rotated.

As shown in Figure 2, the front radial electromagnet 5 is comprised of four sections 5a-5d disposed around the rotor shaft 3 equi-angularly, and the rear radial electromagnet 6 is also comprised of four sections 6a-6d disposed equi-angularly around the rotor shaft 3 and axially spaced from the front radial electromagnet 5.

As shown in Figure 3, in the above constructed magnetically supported spindle 1, a radial position detector circuit 20 operates according to signals from a pair of sensor components 14a and 14b of the front radial position sensor 14 to detect the front radial position of the rotor shaft 3, and a radial control circuit 22 operates according to the detection results to electrically control the radial electromagnet sections 5a and 5c to regulate the magnetic force produced thereby so as to maintain the rotor shaft 3 in a predetermined radial position. In a similar manner, the rear radial electromagnet sections 6a and 6c are servo controlled through a pair of sensor components 15a and 15b of the rear radial position sensor 15, another radial position detector circuit 26 and another radial control circuit 23.

The Figure 3 construction further includes an inner diameter measurement device 24 for measuring an inner diameter of a machined bore or hole H of a workpiece W which is held in a mounting means 30; a calculation circuit 25 for calculating the amount of taper of the machined hole H based on the measurement result; a CPU 27 for controlling tilting of the rotor shaft 3 according to the amount of taper; a memory 29; and a manual input unit 28.

Next, a description is given of the operation of the grinding machine of Figures 1-3. Referring to Figure 4, in step P1, the internal grinding of an individual workpiece W is carried out by means of the rotating grinding wheel 21. In step P2, after finishing the grinding, the internal diameters of the opposite end portions of the machined bore H of the ground workpiece W are measured by means of the inner diameter measurement device 24. In step P3, the amount of taper of the machined bore H is calculated by means of the calculation circuit 25 according to the result of the measurement effected by the measurement device 24. In step P4, the calculated data is inputted into the CPU 27 (which constitutes the grinding machine controller) for effecting total control of the grinding machine. By repeating such operation, the amounts of taper of the ground workpieces W are sequentially determined, and the CPU 27 judges sequentially whether the thus obtained amounts of taper are within the tolerances. If the amounts of taper are within the tolerances, the grinding operation is continued as it is for following workpieces W. In step P5, if an amount of taper exceeds the respective tolerance, the CPU 27 operates to compare the actual amount of taper with correlation data which have been provisionally stored in the memory 29 so as to calculate the amount of tilt α of the rotor shaft 3 which is effective to correct or avoid an excessive taper. Then in the step P6, the grinding wheel 21 is accordingly tilted by the calculated amount α through the supporting rotor shaft 3 so as thereby to continue the grinding operation for the subsequent workpiece.

In order to effect the tilting of the grinding wheel 21 with respect to the axis of the spindle 1, the CPU 27 operates according to the calculated amount of tilt to shift the detection signal fed from the front radial position detector circuit 20 to the front radial control circuit 22 in one direction, and to shift the other detection signal fed from the rear radial position detector sensor 26 to the rear radial control circuit 23 in the opposite direction. Consequently, the radial positions of the front and rear end portions of the rotor shaft 3 are moved from the central position in opposite directions, respectively, by means of the front and rear radial electromagnets 5 and 6 so as thereby to tilt the rotor shaft 3. By thus controlling the magnetic force produced by the electromagnets of the spindle 1, the rotor shaft 3 can be rotated while having a tilt according to the calculated amount of tilt α. Accordingly, the grinding wheel 21 is also tilted by the same angular amount while rotating to carry out the grinding. Namely, the inner diameter measurement device 24; the calculation circuit 25 for calculating the amount of taper; the CPU 27; and the memory 29 constitute a tilting means operative to effect electrical control of the magnetically supporting forces of the radial electromagnets 5 and 6 for tilting the rotor shaft 3 with respect to the axis of the spindle 1.

As described above, by electromagnetically controlling the spindle to effect the tilting of the grinding wheel 21, the response can be improved and fine adjustment can be facilitated. The adjustment of the tilting can be quickly carried out without specific intuition and skill. By effecting grinding with a tilted grinding wheel 21, the amount of taper of the workpiece W can be reduced below the tolerance so as to improve the cylindricality of the ground bore and thereby maintain the production quality of the machined workpiece. Therefore, the grinding wheel 21 does not need to be frequency replaced by a new one. The grinding wheel 21 can be used for a long time to effect successive grinding of workpieces for a lengthy period. Thus the life of an individual grinding wheel can be prolonged so as to promote its efficient use and thereby reduce production costs.

In the above described embodiment, the tilting of the rotor shaft is effected automatically by means of the CPU 27 during the course of the sequential grinding of workpieces after the sharpness of the grinding wheel has varied. However, as shown in Figure 3, such tilting of the rotor shaft can be effected by manually inputting an instruction into the manual input unit 28 to control the CPU 27 at the time of the start of grinding for setting the rotor shaft.

Further, in the foregoing description, the grinding wheel is attached to the magnetically floated rotor shaft, and this rotor shaft is tilted with respect to the cylindrical axis of the workpiece to be machined. However, the tilting can be carried out relatively between the grinding wheel and the workpiece. For example, the workpiece may be attached to a rotor shaft of a magnetically floating type spindle and this rotor shaft can be tilted. Namely, by controlling the rotor shaft to which the workpiece to be machined is attached and by which it is magnetically supported for rotation, the rotating workpiece can be tilted with respect to a stationary grinding tool to achieve the same effect.

In the illustrated embodiment described above, the tilting means operates to electrically control the magnetic force produced by the radial electromagnets of the magnetically floating type spindle so as easily to tilt the rotor shaft. Thus, the grinding wheel is also easily tilted while effecting grinding of the workpieces. Accordingly, the response is improved and the adjustment is facilitated. The adjustment does not need intuition or skill and consequently there can be quick adjustment which thereby improves the cylindricality of the machined bore. Further, when the amount of taper of the individual workpieces exceeds the predetermined tolerance due to variation of the sharpness of the grinding wheel during the sequential grinding of the workpieces, the grinding wheel can be easily tilted to avoid or correct the excessive taper. Therefore, without frequent replacement or dressing of the grinding wheel, the grinding wheel can be used for a long time to effect the sequential grinding of a number of workpieces. Thus, the life of the grinding wheel can be prolonged for economical use thereof so as to reduce machining costs.

Claims

1. A grinding machine comprising first mounting means (30) for mounting a workpiece (W) which is to be ground; second mounting means (3) for mounting a grinding member (21) to effect grinding of the workpiece (W); drive means (8) for effecting relative rotation of the first and second mounting means (30,3); and tilting means (23-29) for effecting relative tilting of the first and second mounting means (30,3) so that the workpiece (W) can be accurately ground to predetermined dimensions characterised in that at least one of said first and second mounting means (30,3) is constituted by a shaft (3) which is mounted within a housing (1), the housing (1) having electromagnets (5,6) which are arranged to produce a magnetic force which is effective to float and radially support the shaft (3); the said tilting means (23-29) electrically controlling the electromagnets (5,6) so that the magnetic force produced by the latter can be adjusted to tilt the shaft (3) with respect to the housing (1).

2. A grinding machine as claimed in claim 1 characterised in that the shaft (3) is a rotor shaft which is driven by said drive means (8).

3. A grinding machine as claimed in claim 1 or 2 characterised in that the tilting means (23-29) includes measuring means (24) for measuring the amount of taper present in a surface of the workpiece (W) which is being ground, and calculating means (25) connected to the measuring means (24) for calculating the angle of relative tilt of the first and second mounting means (30,3) required to correct for the said taper, the tilting means (23-29) in operation producing the said relative tilt.

4. A grinding machine as claimed in any preceding claim characterised in that the said electromagnets (5,6) are spaced from each other axially of the shaft (3), the tilting means (23-29) in operation causing the magnetic forces produced by the respective electromagnets (5,6) to be varied relative to each other.

5. A grinding machine as claimed in claim 2 or in any claim appendant thereto characterised in that the rotor shaft is arranged to receive a grinding wheel (21) thereon.

6. A grinding machine as claimed in claim 5 when dependent upon claim 3 characterised in that the measuring means (24) is arranged to measure the amount of taper present in the bore (H) of the workpiece (W).

7. A grinding machine comprising;
a spindle (1) of the magnetic bearing type having a rotor shaft (3) disposed rotationally along an axis of the spindle (1) for effecting grinding of a workpiece (W), and magnetic bearing means including electromagnets (5,6) for producing magnetic force effective to float and radially support the rotor shaft (3); and tilting means (23-29) operative to electrically control the magnetic force produced by the electromagnets (5,6) for tilting the rotor shaft (3) with respect to the spindle axis by a given tilting angle effective to set a dimension of a ground workpiece.

FIG. 1

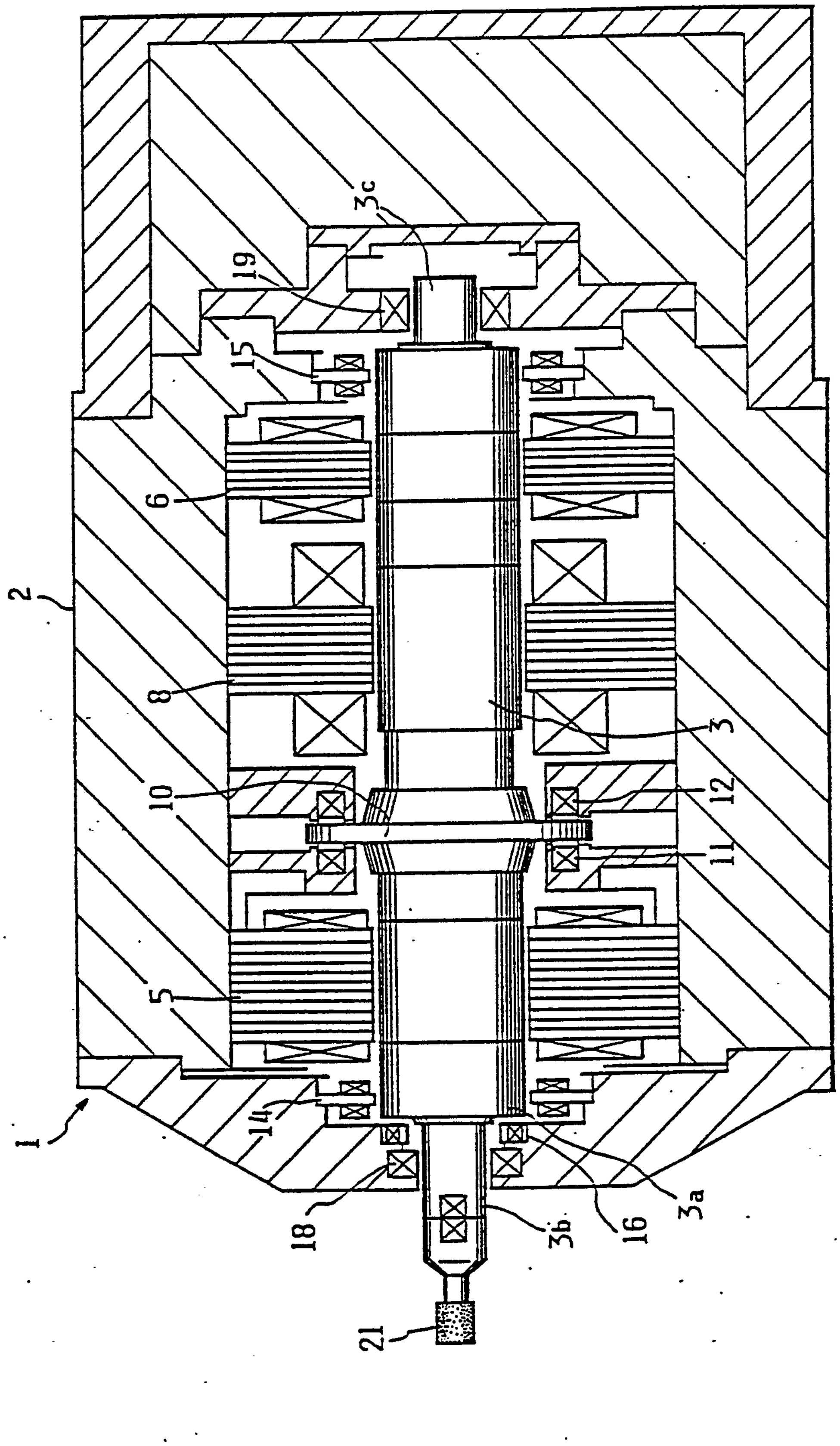
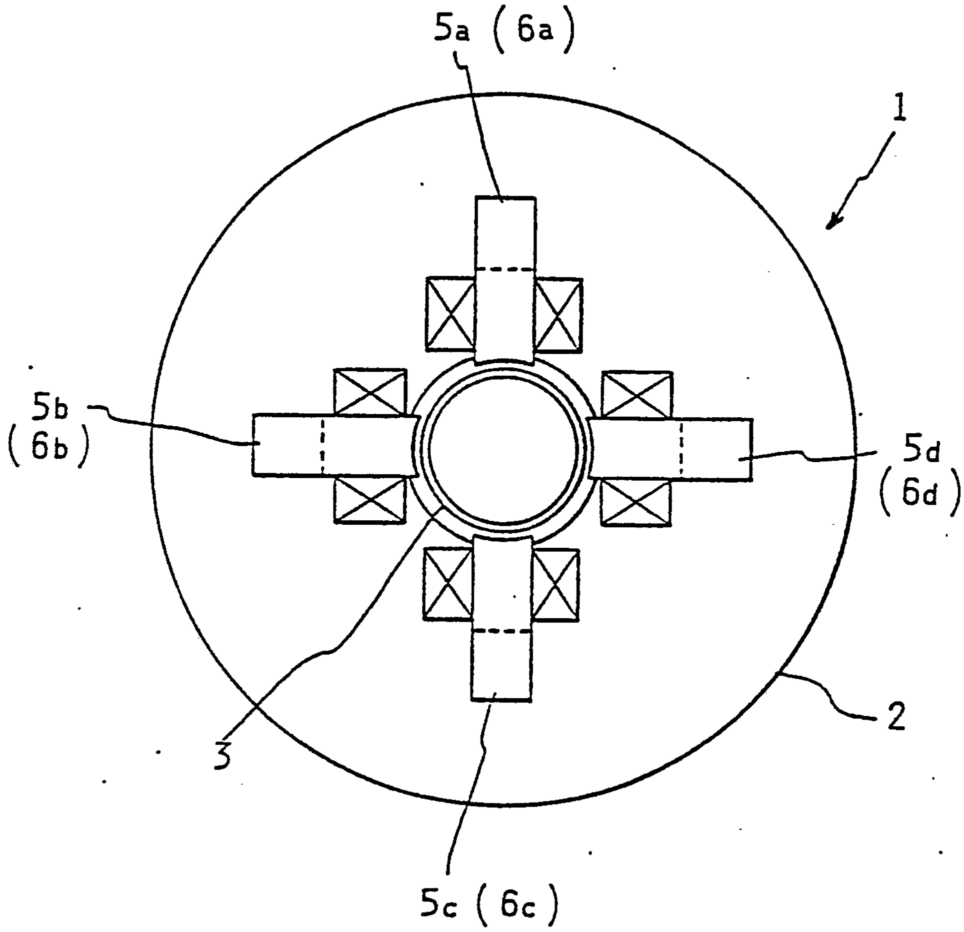


FIG. 2



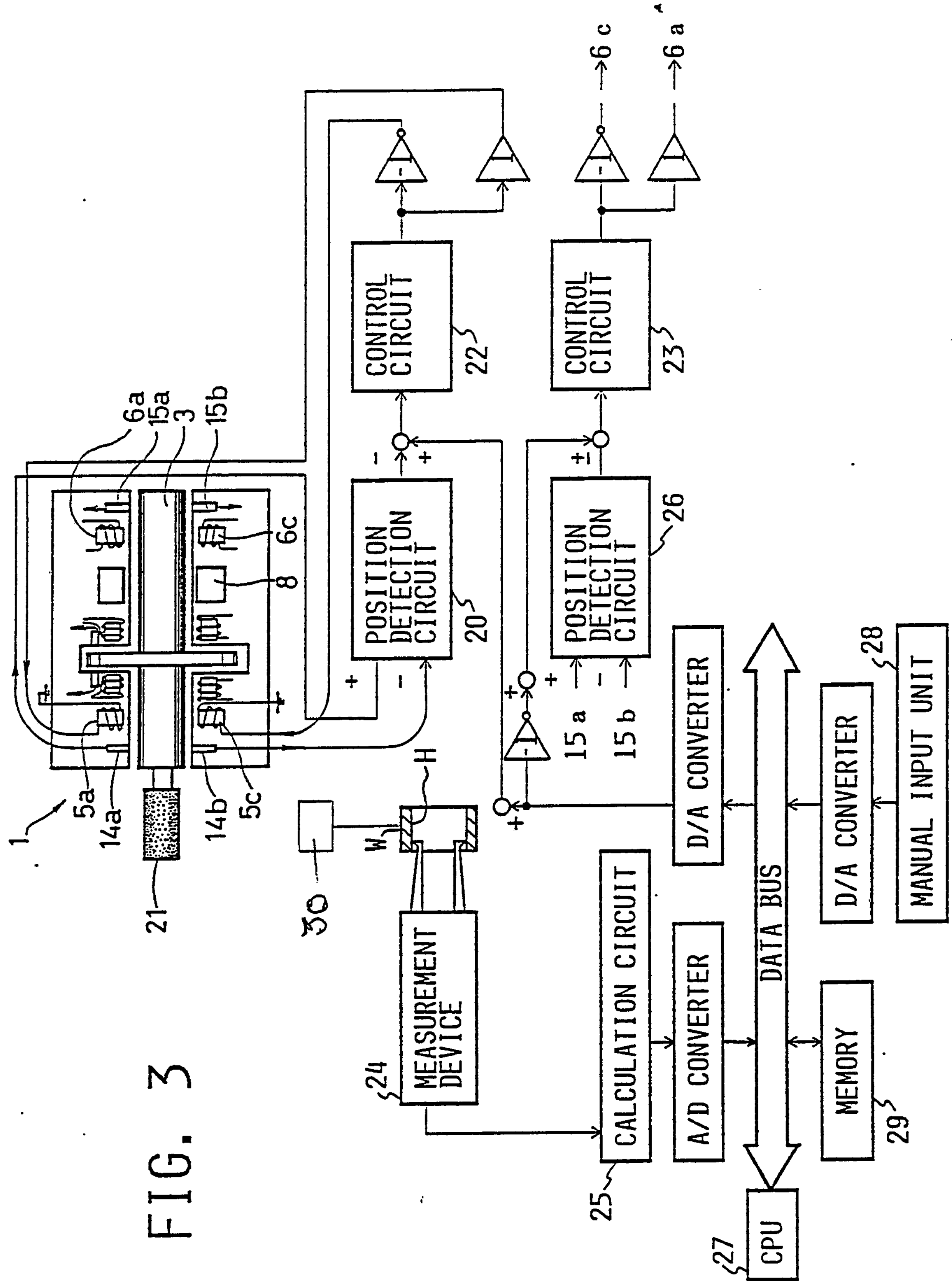

1
5a
14a
6a
15a
3
15b
6c
8
14b
5c
21
H
W
30
MEASUREMENT DEVICE
24
POSITION DETECTION CIRCUIT
20
CONTROL CIRCUIT
22
POSITION DETECTION CIRCUIT
26
CONTROL CIRCUIT
23
→6 c
→6 a
15 a
15 b
CALCULATION CIRCUIT
25
A/D CONVERTER
D/A CONVERTER
D/A CONVERTER
DATA BUS
MEMORY
29
MANUAL INPUT UNIT
28
CPU
27

FIG. 3

FIG. 4

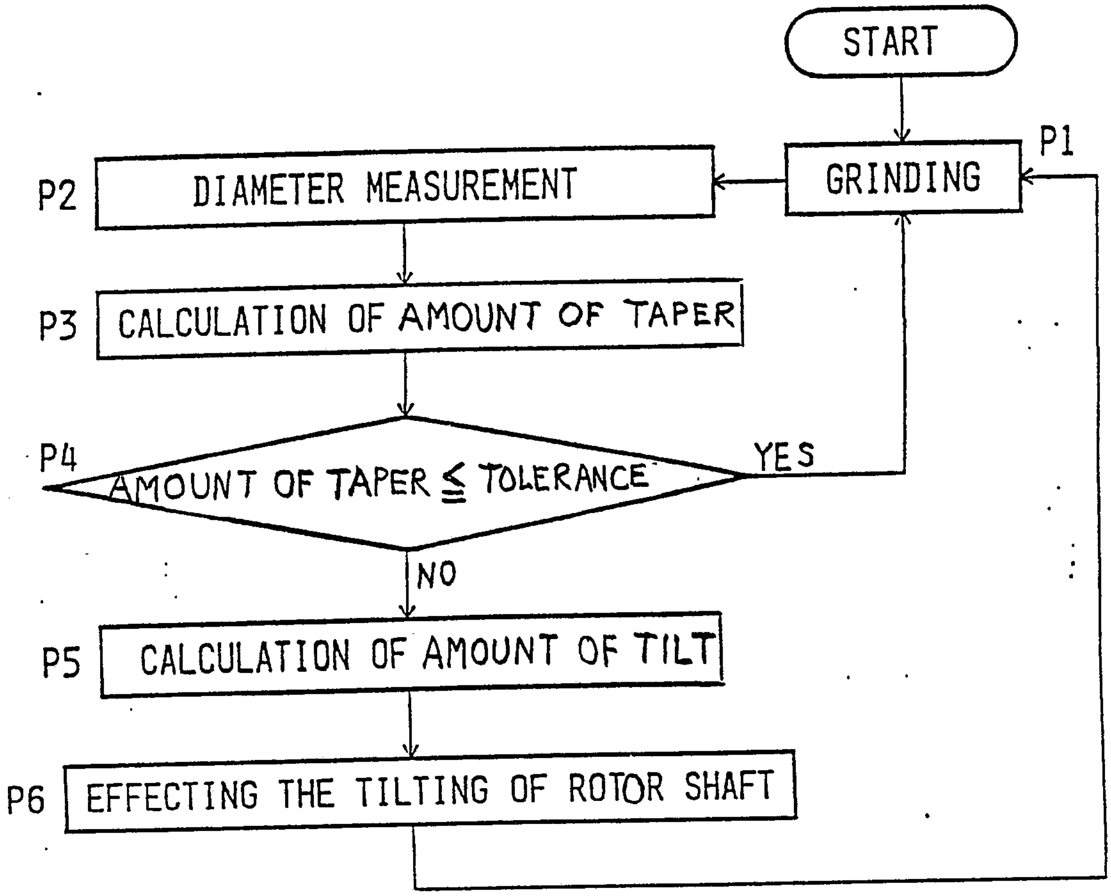


FIG. 5
PRIOR ART

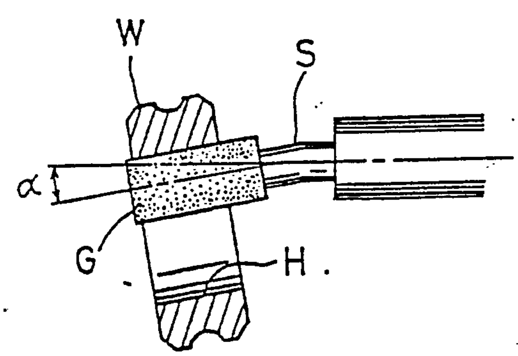


FIG. 6
PRIOR ART

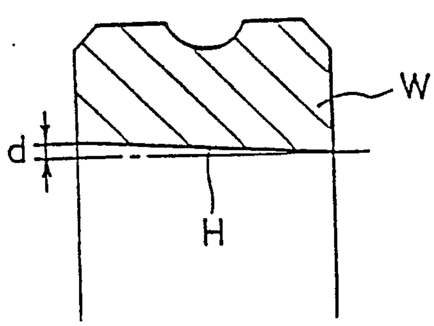


FIG. 7
PRIOR ART

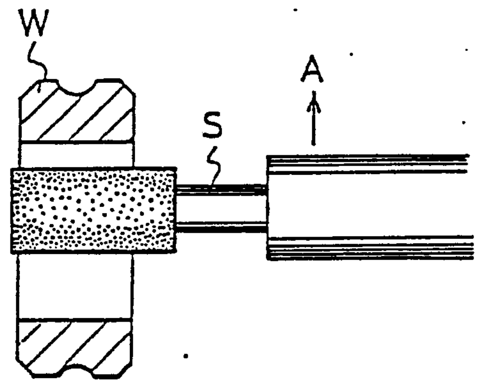


FIG. 8
PRIOR ART

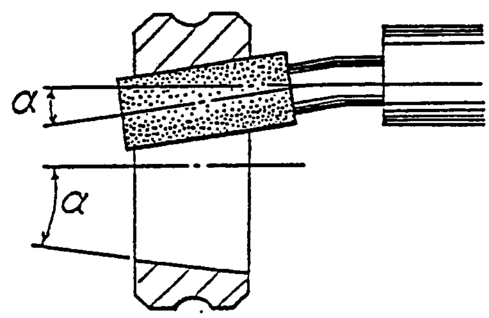


FIG. 9
PRIOR ART

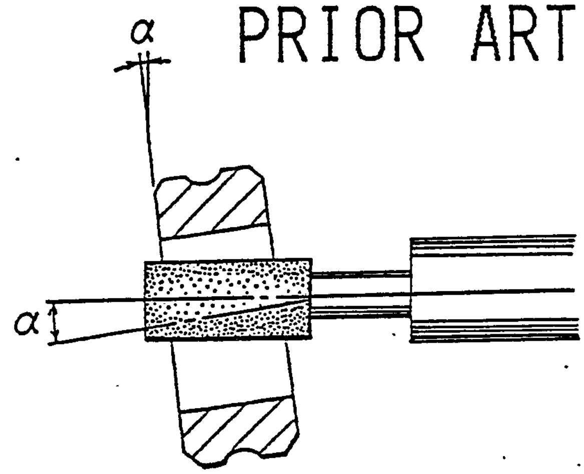


FIG. 10
PRIOR ART