

BALANCING APPARATUS AND METHOD

FIELD OF THE INVENTION

The present invention relates to an apparatus and method for varying a rotational balance status of a device. In particular, it relates to an apparatus and method for reducing a rotational imbalance of a device that has fixed or variable imbalance at a relatively low level.

BACKGROUND OF THE INVENTION

Due to uneven distribution of mass on rotational parts, machines or devices generally encounter an imbalance when rotating. In certain applications, the imbalance generates vibrations which can cause wear and damage to machine parts such as bearings, bushings, shafts and gears. In magnetic disc drives such as hard disc drives (HDD) and servo pack writers (SPW), the imbalance can contribute to track misregistration and hence affect positioning accuracy of the read/write head element. In addition, imbalance can result in disc slippage and excessive wear of bearings. In these applications, the rotational imbalance is undesirable, hence reduction of the imbalance becomes necessary.

Balancing technologies are developed to reduce rotational imbalance in order to reduce vibrations, and hence reduce wear and damage of machine parts. In HDDs and SPWs, positioning accuracy of read/write heads can be increased by adopting appropriate balancing technologies. Conventional balancing technologies generally include measurement of the imbalance value and position, and adding a balancing mass onto or removing an excessive mass from the relevant area of the machine so that the imbalance can be reduced and/or compensated.

Various approaches are developed for reducing rotational imbalance. In one attempt as disclosed in US Patent No. 5,422,776 issued to Thorson et al, an apparatus for balancing a disc pack assembly provides imbalance correction by the use of precision manufactured plugs which are attached to a spin motor at various selected locations.

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Unfortunately, because the plugs are permanently fixed to the disc pack, the balancing process cannot be reversed, hence this attempt is not suitable for imbalance reduction in the event where the imbalance status is changed during operation. In addition, the cost of utilizing this approach is relatively high.

US Patent 6,219,328 issued to Kume et al discloses a disc rotating apparatus comprising a turntable and a holding frame with an annular groove that is circumferentially partitioned to form a plurality of accommodating portions to accommodate steel balls. Due to rotation of the turntable or disc, each steel ball is displaced within the accommodating portion and moves from the inner side of the accommodating portion to the outer side, thereby correcting the imbalanced state wherein a center of gravity of the disc is deviated from an axis of a rotary shaft of turntable.

According to this patent, balancing balls are displaced by the centrifugal force due to the distance of deviation of the center of the gravity from the axis of rotation. The balancing process can be reversed in the event that the imbalance status is changed. However, in order for the balancing balls to move to the balancing positions to reduce imbalance, the centrifugal force must be sufficiently high. Accordingly, balancing operation in this manner has a relatively low sensitivity, and hence is not suitable for the compensation of imbalance at a relatively low level, as for example in the case of a HDD or SPW. The imbalance reduction achieved is not sufficient for applications such as HDD or SPW.

There is therefore a need to provide a balancing apparatus and method having a relatively high sensitivity, which is suitable for imbalance reduction in applications wherein the initial imbalance value is relatively low, such as in an HDD. There is also a need to provide a balancing apparatus and method having a relatively high sensitivity, which is suitable for imbalance reduction in applications wherein the initial value of imbalance changes frequently, such as in an SPW.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the present invention, there is provided an apparatus for varying a balance status of a rotating device. The apparatus comprises a base body for attaching to the rotating device, a plurality of balancing members arranged to be disposed around the axis of rotation of the base body, and a driving device for actively controlling the movement of the plurality of balancing members. Each of the plurality of balancing members is movably mounted to the base body for movement between a respective first radially inner position and a respective second radially outer position.

When the apparatus of the present invention is attached to a rotating device and rotates theretogether in an initial state before the balancing process, the plurality of balancing members are initially retained at the first position. The driving device can be controllably activated to generate a force on one or more of selected balancing members, so as to displace the selected balancing member from the first position to the second position to vary the balancing status.

Sensors and a controller may be used to determine the balancing status before and after the movement of the balancing members. If the imbalance is reduced after the movement of the selected balancing members, one or more other balancing members may be displaced by the driving device in a similar manner until the desired imbalance reduction level is reached. If the imbalance status of the rotating device changes, the rotation speed of the device can be reduced so as to lower the centrifugal force acting on balancing members in order to allow the balancing members to return to the first end. In this way the initial state can be restored, and the balancing procedure can be repeated by displacing one or more balancing members in different positions in a similar manner.

In accordance with a second aspect of the present invention, there is provided a method for varying a balance status of a device between an initial state and an altered state, the rotating device having an axis of rotation, the method comprises mounting a plurality of balancing members to the device around the axis of rotation, and displacing

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one or more selected balancing members to a second position which is away from the axis of rotation. Each of the plurality of balancing members is movably mounted for movement between a respective first radially inner position and a respective second radially outer position. The device rotates while the plurality of balancing members are retained at the first position. A force is applied to a selected balancing member so that to displace the selected balancing member from the first position to the second position and in the meantime, the remainder of the balancing members are retained at the respective first positions. The rotational balance status can therefore be varied.

In one embodiment, an electromagnetic force is applied to the selected balancing member to displace the selected balancing member to the second position.

Additional steps of the method may include, for example, comparison of the balancing status to determine the effect of the displacement of the selected balancing member. In the event that reduction of imbalance is desired, and if the imbalance is reduced but not to an acceptable level, one or more other balancing members can be displaced by applying forces thereon. If the imbalance is reduced to an acceptable level, the one or more displaced balancing members can be fixed to the second position.

If the imbalance status of the rotating device changes, the balancing members can be returned back to the first position, by either reducing the rotational speed of the device or applying a force on balancing members in a direction towards the axis of rotation, so that one or more other balancing members can be displaced to reduce the imbalance.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects and advantages of the present invention will be described in detail with reference to the accompanying drawings, in which:

Fig. 1A is a perspective view showing an apparatus according to one embodiment of the present invention;

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Fig. 1B is a perspective view showing an apparatus according to another embodiment of the present invention;

Fig. 2A is a perspective view showing the apparatus of Fig. 1A when attached to a rotational device and rotating in an initial state;

Fig. 2B is a partial top view of Fig. 2A;

Fig. 3A is a perspective view showing the apparatus of Fig. 1A when attached to a rotational device and rotating in an altered state;

Fig. 3B is a partial top view of Fig. 3A;

Fig. 3C is a partial cross sectional view of Fig. 3B along A-A;

Fig. 3D is a partial cross sectional view showing an alternative configuration of Fig. 3C;

Fig. 3E is a partial cross sectional view showing another alternative configuration of Fig. 3C;

Fig. 4 is a top view of an apparatus according to the present invention showing an example scheme of imbalance reduction;

Fig. 5 is a top view showing an apparatus according to a further embodiment of the present invention;

Fig. 6 is a top view showing an apparatus according to a further embodiment of the present invention;

Fig. 7 is a top view showing an apparatus according to a further embodiment of the present invention;

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Fig. 8 is a top view showing an apparatus according to a further embodiment of the present invention;

Fig. 9A is a block diagram showing a method for varying a balance status according to the present invention;

Fig. 9B is a block diagram showing a method following the steps of Fig. 9A with additional steps to reduce the imbalance;

Fig. 9C is a block diagram showing a method following the steps of Fig. 9A with additional steps to increase the imbalance.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1A, 1B, 2A, 2B, 3A, and 3B show an apparatus 10 for varying a rotational imbalance of a rotating device according to one embodiment of the present invention. The rotating device onto which the apparatus of the present invention is attachable, is shown generally as a disc 2 (Fig. 2A). Apparatus 10 comprises a base body, such as a base plate 100, a plurality of balancing members, such as twelve steel balls 202, 204, ..., 224, and a driving device, such as an electromagnet 320. Disc 2 has an axis of rotation 2a. Base plate 100 has an axis of rotation 100a, and can be attached to disc 2 through the alignment with axis of rotation 2a. Base plate 100 is therefore rotatable together with disc 2 with respect to axis of rotation 2a. Alternatively, other numbers of the steel balls, such as 18, 36 or the like can be used according to the present invention.

Twelve grooves 102, 104, ..., 124 are formed on base plate 100. Each groove lies along a radial direction of base plate 100, and all the grooves 102, 104, ..., 124 are disposed along a circumference of base plate 100 around axis of rotation 100a. Each groove has a first end 102a, 104a, ..., 124a (only 102a is indicated in Figs. 2A and 2B for illustration) adjacent to axis of rotation 100a, and a second end 102b, 104b, ..., 124b (only 102b is indicated in Figs. 2A and 2B for illustration) away from axis of rotation 100a. For

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ease of illustration, the distance from the center of the steel balls (when at the first end 102a, 104a, ..., 124a) to axis of rotation 100a is referred to as R_a (Fig. 2B), and the distance from the center of the steel balls (when at the second end 102b, 104b, ..., 124b) to axis of rotation 100a is referred to as R_b (Fig. 3B).

In one exemplary example, all the grooves are evenly disposed. Each steel ball has a dimension less than the width of grooves 102, 104, ..., 124. Steel balls 202, 204, ..., 224 are disposed one each in a corresponding groove, and are movable between first end 102a, 104a, ..., 124a and the second end 102b, 104b, ..., 124b, respectively.

A first retaining member, such as a permanent magnet ring 310 is disposed adjacent to first ends 102a, 104a, ..., 124a of grooves 102, 104, ..., 124. Alternatively, a plurality of individual permanent magnets 312 may be placed adjacent to first ends 102a, 104a, ..., 124a, as shown in Fig. 1B. When in the stationary state, steel balls 202, 204, ..., 224 are attached to first ends 102a by an attraction force F_{pm} of permanent magnet ring 310, as shown in Figs. 2A and 2B. The magnetization of permanent magnet ring 310 or individual permanent magnets 312 is configured such that the attraction force F_{pm} applied to steel balls 202, 204, ..., 224 is greater enough to overcome centrifugal forces F_{c1} of steel balls 202, 204, ..., 224 when disc 2, base plate 100 and steel balls 202, 204, ..., 224 rotate under a predetermined operational speed. Under this speed, disc 2, base plate 100 and steel balls 202, 204, ..., 224 rotate in a state in which the balance status is not substantially varied. In this context, this state is referred to as "initial state". When disc 2 together with base plate 100 and steel balls 202, 204, ..., 224 rotate in the initial state, the total force F_{t1} applied to each of steel balls 202, 204, ..., 224 is:

$$F_{t1} = F_{pm} - F_{c1} \quad (1)$$

Electromagnet 320 is disposed adjacent to second ends 102b, 104b, ..., 124b of grooves 102, 104, ..., 124, and does not rotate with disc 2 and base plate 100. When supplied with electrical current, electromagnet 320 generates an electromagnetic force F_e to apply to a selected steel ball, such as steel ball 202 as shown in Figs. 2B and 3B.

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During rotation, relative positions of grooves 102, 104, ..., 124 and balance status of disc 2 with respect to electromagnet 320 can be detected through a sensor 330 (Fig. 2A) coupled to axis of rotation 100a. A controller 340 is coupled to sensor 330 and electromagnet 320 to receive detected signals from sensor 330 and control the activation and deactivation of electromagnet 320.

Upon starting of the balancing process, electromagnet 320 is activated when one of the grooves 102, 104, ... , 124 (groove 102 as shown for illustration) rotates to a position in alignment with electromagnet 320. Electromagnet 320 is so configured such that when activated, electromagnetic force F_e generated thereby is greater than total force F_{t1} . As a result, steel ball 202 in groove 102 will be displaced from first end 102a towards second end 102b, as shown in Figs. 3A and 3B.

When located at second end 102b, a centrifugal force F_{c2} is applied on steel ball 202. Since second end 102b is located further away from axis of rotation 100a than first end 102a, F_{c2} is greater than F_{c1} . By properly configuring the magnetization of permanent magnetic ring 310 or individual permanent magnets 312, R_a , R_b and attraction force F_{pm} satisfy the following conditions:

$$F_{c1} / F_{c2} = R_a / R_b \quad (2)$$

$$F_{c1} < F_{pm} < F_{c2} \quad (3)$$

It should be appreciated that under this configuration, when being displaced to second end 102b, centrifugal force F_{c2} applied on steel ball 202 overcomes attraction force F_{pm} of permanent magnetic ring 310 and therefore, when electromagnet 320 is deactivated to remove electromagnetic force F_e , steel ball 202 stays at second end 102b when disc 2 and base plate 100 rotates under the predetermined operational speed. Since steel ball 202 is displaced from first end 102a to second end 102b, and steel balls 204, 206, ..., 224 remain at first ends 104a, 106a, ..., 124a, balance status of disc 2 is varied. In this context, this state is referred to as "altered state".

By comparing the balance status of the “initial state” and the “altered state”, the effect of the variation can be determined. In the event that reduction of imbalance is desired, and the imbalance has not been reduced to an acceptable level, electromagnet 320 may be activated when another groove, such as groove 104, rotates to a position in alignment with electromagnet 320, so that steel ball 204 in groove 104 can be displaced from first end 104a to second end 104b. With the displacement of steel ball 204, the balance status of disc 2 is further varied, and comparison of balancing status can be made again to determine the variation of the imbalance. Further steel balls may be displaced in a similar manner until the desired imbalance variation level is achieved.

If the imbalance status is changed after steel ball 202 is displaced to the second end, the rotational speed of disc 2 can be lowered so that the centrifugal force on steel ball 202 can be reduced. When centrifugal force F_{c2} is less than attraction force F_{pm} of permanent magnetic ring 310, steel ball 202 returns to first end 102a. The balancing process can then be repeated by displacing a different steel ball, so that a new level of imbalance variation can be achieved.

In applications where axis of rotation 2a is vertically orientated, grooves 102, 104, ..., 124 may be tilted towards axis of rotation with first end 102a, 104a, ..., 124a lower than second end 102b, 104b, ..., 124b, so that to assist steel balls 202, 204, ..., 224 to attach to the respective first end, as shown in Fig. 3C.

Two or more steel balls can be respectively displaced to the second end in the above manner. Shown in Fig. 4 as an example, four steel balls are displaced to the second end in order to reduce an imbalance U_1 of a disc 42. Centrifugal forces F_1 , F_2 , F_3 and F_4 of each steel ball form a resultant force F which acts opposite to, and reduces imbalance U_1 .

Fixing means may be provided at second end of the grooves to permanently or temporarily attach one or more selected steel balls at the second end. In one example as shown in Fig. 5, adhesive 580 or the like is provided at second end 502b, 504b, ..., 524b. When selected steel balls are displaced to second end whereby the result of imbalance

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reduction is acceptable, adhesive 580 fixes the steel balls at the second end to form a permanent imbalance-reduction apparatus. In another example, the grooves are filled with a solidifiable liquid 590. When selected steel balls are displaced to respective second end to yield a satisfactory imbalance reduction result, liquid 590 is solidified by an external excitation (not shown), so that the selected steel balls can be permanently fixed at the second end.

In another example shown in Fig. 3D, where axis of rotation 2a is vertically orientated, grooves 102, 104, ... , 124 (shown as groove 114 for illustration) may be tilted away from axis of rotation such that first end 102a, 104a, ... , 124a (shown as first end 114a for illustration) is higher than second end 102b, 104b, ... , 124b (shown as second end 114b for illustration), so that when rotational speed is reduced, this tilted configuration will assist steel balls 202, 204, ... , 224 (shown as steel ball 214 for illustration) to attach to second end 114b, as shown in Fig. 3D. In another example shown in Fig. 3E, where axis of rotation 2a is vertically orientated, grooves 102, 104, ... , 124 have a recess or step (only one recess or step 254 is shown for illustration) adjacent to second end 114b so that when rotational speed is reduced, this recess or step assists to retain steel balls 202, 204, ... , 224 at the second ends, as shown in Fig. 3E with one steel ball 214 for illustration.

As shown in Fig. 6, in an apparatus according to a further embodiment of the present invention, two groups of grooves 650 and 660 are formed on a base plate 600. A first group of grooves 650 has a dimension smaller than, and are disposed at each clearance of, the second group of grooves 660. Smaller steel balls 652 are movably disposed at grooves 650. When being displaced by the driving device 610, bigger and smaller steel balls 662, 652 can be selectively displaced. The smaller steel balls can be used to fine-tune the imbalance variation / reduction, in complementing with bigger steel balls 662 in grooves 660.

As shown in Fig. 7, in an apparatus according to another embodiment of the present invention, permanent magnetic balancers 760 are movably disposed in grooves 750. Permanent magnetic balancers 760 are disposed with one magnetic pole, such as N-pole, facing the axis of rotation 72. In this embodiment, a steel ring 730 is disposed

adjacent to the first ends 702a of grooves 750 such that when rotating in the initial state, permanent magnetic balancers 760 are attached to steel ring 730.

During the process of reducing rotational imbalance, if a selected permanent magnetic balancer is displaced to second end 702b and yields an unsatisfactory result, the electromagnet 710 can be activated by supplying a reverse electric current thereto, so that a repulsive force is generated to push the selected permanent magnetic balancer back to first end 702a restoring the initial state. The balancing process can then be repeated so that the desired imbalance reduction can be attained.

According to a further embodiment of the present invention shown in Fig. 8, an apparatus for imbalance reduction comprises two base plates 850 and 860, both are attached to the rotating device 82 and are rotatable together. The top plate is shown partially cut away for ease of illustration. Each base plate has grooves formed thereon and one set of balancers movably disposed in the grooves. The balancers can be displaced by the respective electromagnets 810 and 820.

Fig. 9A shows a method 900 of imbalance reduction according to the present invention. In a first block 910, a plurality of balancing members are attached to a rotational device at a first position adjacent to an axis of rotation of the device. In a next block 920, the device is rotated while the plurality of balancing members are retained at the first position. In a further block 930, an external force is applied on one or more of the plurality of balancing members to displace the balancing member from the first position to a second position away from the axis of rotation. In the meantime, the remainder of the balancing members are retained at the first position. The balancing status can now be varied.

As shown in Fig. 9B, in the event that reduction of imbalance is desired, additional steps may include, in block 940, comparing the imbalance status before and/or after the displacement of the at least one balancing members. If the imbalance value is reduced but has not reached the desired level, one or more other balancing members are displaced to

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the second end (block 942). If the desired imbalance reduction is achieved, the displaced balancing member can be fixed at the second end, as shown in block 944.

If the imbalance value is undesirably increased, the method further comprises, shown in block 946, allowing the at least one of the plurality of balancing members to move back to the first end, and repeating the balancing process by displacing another balancing member (block 948).

It should be appreciated that the ambit of the present invention is not limited to the reduction of imbalance, but can also be extended in applications where the increase of imbalance is desirable. As shown in Fig. 9C, in the event that increase of imbalance is desired, additional steps may include, in block 950, comparing the imbalance status before and/or after the displacement of the at least one balancing members. If the imbalance value is increased but has not reached the desired level, one or more further balancing members are displaced to the second end (block 952). If the desired imbalance increase achieved, the displaced balancing member can be fixed at the second end, as shown in block 954.

If the imbalance value is undesirably reduced, the method further comprises, shown in block 956, allowing the at least one of the plurality of balancing members to move back to the first end, and repeat the balancing process by displacing another balancing member (block 958).

Although embodiments of the present invention have been illustrated in conjunction with the accompanying drawings and described in the foregoing detailed description, it should be appreciated that the invention is not limited to the embodiments disclosed, and is capable of numerous rearrangements, modifications, alternatives and substitutions without departing from the spirit of the invention as set forth and recited by the following claims.

CLAIMS

1. An apparatus for varying a balance status of a rotating device between an initial state and an altered state, the rotating device having an axis of rotation, the apparatus comprising:
 - a base body for attaching to the rotating device to rotate theretogether; the base body having an axis of rotation for alignment with the axis of rotation of the device;
 - a plurality of balancing members arranged to be disposed around the axis of rotation of the base body, each movably mounted to the base body for movement between a respective first radially inner position and a respective second radially outer position;
 - a driving device for displacing at least one selected balancing member from the first position to the second position for varying the balance status of the rotating device.
2. The apparatus as recited in claim 1, further comprising a first retaining device operable for applying a retaining force to retain the plurality of balancing members at the first radially inner position at a predetermined speed of operation of the rotating device.
3. The apparatus as recited in claim 2, wherein the driving device comprises an electromagnet for applying an electromagnetic force to a selected balancing member, wherein the electromagnetic force exceeds a balance of the retaining force minus a centrifugal force experienced by the selected balancing member at the first position to displace the selected balancing member from the first position to the second position.
4. The apparatus as recited in claim 3, wherein for the predetermined speed of operation of the rotating device, a centrifugal force experienced by the selected balancing member at the second position exceeds the retaining force.

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5. The apparatus as recited in claim 2, wherein the first retaining device further comprises a plurality of permanent magnets disposed adjacent to the plurality of the balancing members.
6. The apparatus as recited in claim 1, further comprising a second retaining device coupled to the base plate for retaining the plurality of balancing members at the second position.
7. The apparatus as recited in claim 6, wherein the second retaining device further comprises an adhesive for permanently fixing the at least one of the plurality of balancing members at the second position.
8. The apparatus as recited in claim 6, wherein the second retaining device further comprises a solidifiable liquid for permanently fixing the at least one of the plurality of balancing members at the second position.
9. The apparatus as recited in claim 1, wherein the base body having a plurality of grooves coupled around the axis of rotation of the body, each groove having a first end corresponding to the first position and second end corresponding to the second position, and the plurality of balancing members being movably disposed within the plurality of grooves.
10. The apparatus as recited in claim 9, wherein when the axis of rotation is vertically orientated, the second end of each of the plurality of the grooves is formed lower than the first end for retaining the plurality of balancing at the second position by gravity.
11. The apparatus as recited in claim 9, wherein when the axis of rotation is vertically orientated, the plurality of the grooves further comprises a recess adjacent to the second end for retaining the at least one of the plurality of balancing members at the second end.

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12. The apparatus as recited in claim 9, wherein the plurality of balancing members being magnetized and each having a first magnetic pole facing the first end.
13. The apparatus as recited in claim 9, wherein the plurality of grooves further comprises a first group of radially aligned grooves formed on the base plate for housing a first group of balancing members, and a second group of radially aligned grooves each formed in a clearance of the first group of radially aligned grooves for housing a second group of balancing members, wherein the first and the second groups of grooves house balancing members of different mass.
14. The apparatus as recited in claim 1, wherein the base body comprising at least two base plates, each having one group of balancing members disposed around the axis of rotation of the base body, and movably coupled to one base plate for movement between a respective first radially inner position and a second radially outer position.
15. A method for varying a balance status of a device between an initial state and an altered state, the rotating device having an axis of rotation, the method comprising:
 - mounting a plurality of balancing members to the device around the axis of rotation, each being movably mounted for movement between a respective first radially inner position and a respective second radially outer position, the balancing members being initially mounted at the first position;
 - rotating the device while retaining the plurality of balancing members at the first position;
 - displacing at least one selected balancing member to the second position to vary the balance status of the device, while retaining the remainder of the balancing members at the respective first positions.
16. The method as recited in claim 15, further comprising applying an electromagnetic force to displace the at least one selected balancing member to the second position.

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17. The method as recited in claim 15, further comprising retaining the selected balancing members at the second position.
18. The method as recited in claim 17, further comprising adhering the selected balancing members at the second position.
19. The method as recited in claim 17, further comprising solidifying a liquid to fix the selected balancing members at the second position.
20. The method as recited in claim 15, further comprising allowing the selected balancing members to move back to the first position.
21. The method as recited in claim 20, further comprising repulsing the selected balancing members to move back to the first position.
22. The method as recited in claim 15, further comprising, if an imbalance is reduced but still greater than a predetermined reduction level, displacing at least one other balancing member away from the axis of rotation to further reduce the imbalance.
23. The method as recited in claim 15, further comprising, if an imbalance is increased but still less than a predetermined increase level, displacing at least one other balancing member away from the axis of rotation to further increase the imbalance.