Feb. 5, 1946. E. W. REYNOLDS 2,394,482

METHOD AND APPARATUS FOR BALANCING ROTATING MEMBERS

Filed Oct. 9, 1941

FIG. 1

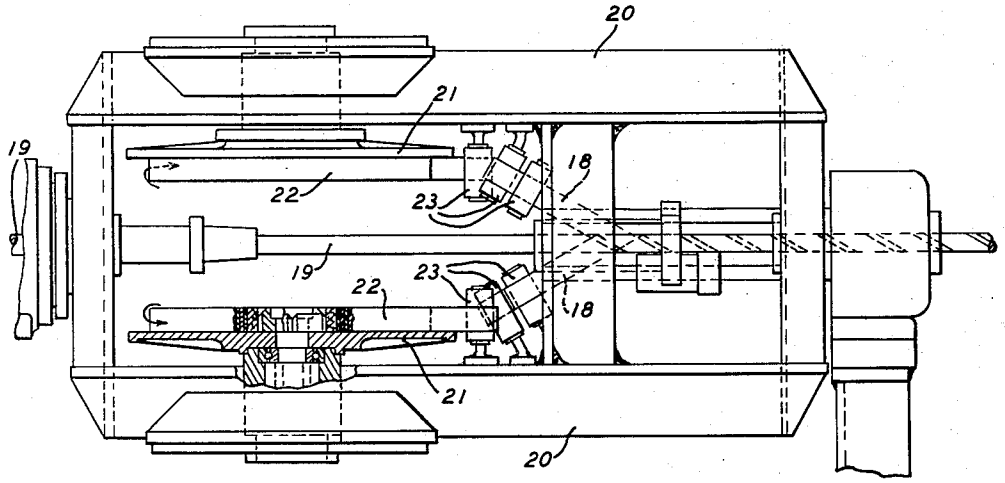


FIG. 2

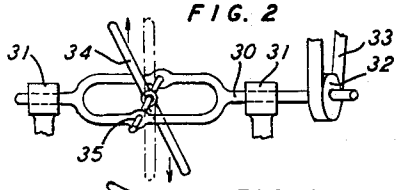


FIG. 3

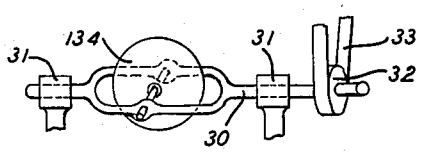


FIG. 4

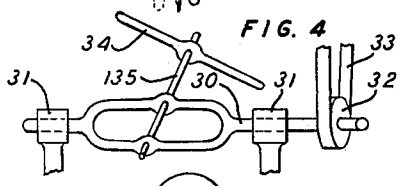


FIG. 5

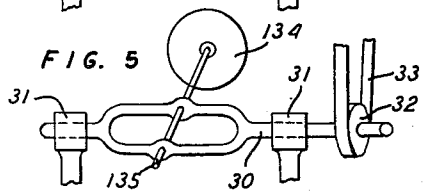


FIG. 7

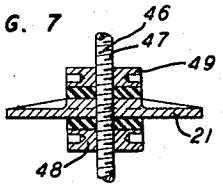
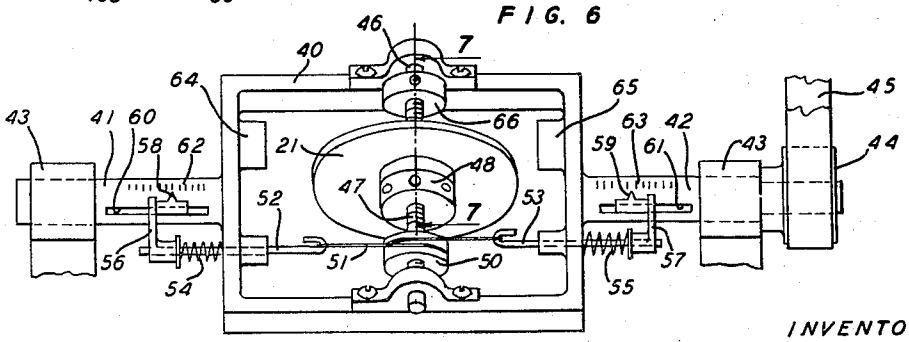


FIG. 6



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METHOD AND APPARATUS FOR BALANCING ROTATING MEMBERS

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4 Claims. (Cl. 73—66)

This invention relates to balancing rotating members, and more particularly to a method and means for measuring the effect of, and compensating for, a new and heretofore unknown type of unbalance in a rotating member.

In the manufacture of certain kinds of cable it may be desired to wrap a tape or other strand—it may be of paper, textile material, rubber or rubber compound, metal, or other substance as the case may be—about a cable core. To this end the core is caused to advance longitudinally, while a supply of the strand material, e. g. paper tape, is caused to revolve about the advancing core in a stationarily located orbit having the core substantially in its axis. In some instances this supply is a so-called "pad" of paper tape, i. e. a flat circular mass of tape wound on itself solidly in spiral turns or convolutions. Such a pad is ordinarily supported on a flat, relatively thin, coaxial, circular disc of suitable material, usually metal. The supporting disc is mounted to be freely rotatable on its own axis (and so on the axis of the pad supported on it) in a frame which in turn is rotatable about an axis at right angles to the axis of the disc. The core to be wound advances longitudinally along the axis of rotation of the frame. The frame is driven in rotation about the core and thus carries the disc and its pad in a circular orbit about the core and in a plane at right angles thereto and to the axis of the frame. The outer end of the tape composing the pad is led tangentially from the circular pad through suitable guides to the core and is served thereon by the combined action of the longitudinal advance of the core and the revolution of the pad in its orbit about the core. It results also that the tape is drawn tangentially from the pad and thus causes the pad and therewith its supporting disc to rotate on their common axis in the frame while at the same time they are revolving with the frame about the axis of the frame. It will be at once evident to anyone familiar with such mechanical motions and relations generally, that if such apparatus is to be run at any speed, questions of statical and dynamical rotational balance and of gyroscopic forces and stresses will arise. In the past these difficulties have been satisfactorily overcome by known means, the difficulties and their remedies being generally well understood. However, applicant has discovered that, when speeds of operation are attempted which are considerably above those heretofore contemplated in practice, a new and apparently not heretofore recognized periodic disturbance appears in the motion of the disc supporting the pad and becomes sufficiently great to require particular means to obviate its cause lest the tape or other strand being drawn off at high speed be severely jerked or even ruptured.

An object of the present invention is to provide a method for balancing a rotatable member by rotatively supporting the member on its axis, rotating this axis about another axis transverse thereto, measuring the tendency of the member to rotate about its own axis as a result of the rotation about the transverse axis, and compensating the member in accordance with the measurement to remove this tendency.

Another object is to provide an apparatus for effecting the above mentioned rotation and measurement.

Other objects and features of the invention will appear from the following detailed description of one embodiment thereof taken in connection with the accompanying drawing, in which the same reference numerals are applied to identical parts in the several figures and in which

Fig. 1 is a partly diagrammatic view in side elevation of an apparatus for serving paper tape on a longitudinally advancing cable core;

Fig. 2 is a diagrammatic view of an assembly of elements to illustrate the principle of the invention;

Fig. 3 is a similar view of another illustrative assembly;

Fig. 4 is a similar view of a third form thereof;

Fig. 5 is a similar view of a fourth form thereof;

Fig. 6 is a similar view of an apparatus for determining the angular position and excess mass of the master diameter of a member; and

Fig. 7 is a section on the line 7—7 of Fig. 6.

In Fig. 1 there are shown the essentials of an apparatus for serving paper tape on a cable core. The core 19 is advanced longitudinally from left to right, by suitable means not shown, through the axially hollow bearings or journals of a frame 20 rotatable about and substantially coaxial with the advancing core. Identically similar discs 21 are mounted in the frame diametrically opposite each other, in such wise as to be rotatable each about a central axis perpendicular to its disc and also perpendicular to the axis of the frame 20. Identically similar pads 22 of paper tape 18 are supported on the two discs 21. The tapes 18 are led from the pads 22 through identically symmetrical paths and over identically similar guide members to opposite sides of the same portion of the core and are there served thereon by

the combined action of the linear longitudinal advance of the core and the orbital motion of the pads around the core, the frame being driven in rotation, to effect this last, by means not shown.

Assuming now that all difficulties due to statical unbalance, dynamical unbalance, and gyroscopic forces and stresses have been met and overcome in ways generally familiar, the apparatus described will operate in an entirely satisfactory manner at all speeds within the ranges heretofore used. But when certain higher speeds are attempted to be employed, a heretofore unknown and peculiar difficulty arises. There appears what seems to be a periodic jerkiness in the motion of the discs 21 about their individual axes of rotation, which manifests itself in a periodically rising and falling resistance to the withdrawal of tape. Evidently at these higher speeds some heretofore negligible force becomes sufficiently great to make itself felt, alternately retarding and accelerating the rotary motion of the discs which is primarily due to the tangential pull of the tapes being withdrawn from the pads supported on the discs.

The discs 21 in the apparatus in which the phenomenon first appeared were made with all care. Each was geometrically symmetrical in form about its center. When tested in the ordinary way by rotation about a stationary axis each was found to be in substantially perfect static and dynamic rotary balance. The effect could not be accounted for by accepted gyroscopic forces.

After much study and experiment a theory was formulated which appeared to account for the observed phenomena and pointed out a successful method for obviating the difficulty, and for producing rotary members which are not affected by the periodic disturbance described, even at high speeds operation.

Consider now Fig. 2, in which a shaft 30 is horizontally journalled in stationary bearings 31 and can be driven by a pulley 32 and belt 33. A bar 34 of uniform cross section and density is pivoted as shown on a transverse pin 35 at its mid-point and is carefully adjusted to be in exact balance about its pivot 35. So long as the shaft 30 is stationary, the bar 34 will remain in whatever position it may be placed angularly with respect to the shaft. But if the shaft 30 be rotated and thus twirls the bar about the shaft, the bar tends to set itself at right angles to the shaft in the position shown in dotted lines. This is because each half of the bar tends to move outwardly under centrifugal force as indicated by the arrows drawn from the respective centers of gravity of the two arms of the bar. This creates a couple tending to turn the bar clockwise from the position shown toward the dotted line position in which the couple disappears and the bar remains.

Assume now that a circular disc 134 of flat sheet metal be pivoted at its center on the pin 35, as in Fig. 3, in place of the bar 34, and that the disc is carefully adjusted, as by filing its edge delicately, until it shows no tendency to rotate on the pin no matter how it is turned, i. e. so that it is in accurate balance about the pin on all diameters. Then, if the shaft 30 be rotated, it will usually be found that the disc will rotate in one direction or other on its pivot until a particular diameter stands perpendicular to the shaft 30. If one or both extremities of this diameter be marked as by tiny dots of ink, it will be found that the same diameter always sets itself at right angles to the axis of the shaft 30 when the shaft is rotated, although the disc remains in whatever position it is placed when the shaft is stationary. Now if material be removed from the disc in equal masses from two points along this "master diameter" which are on opposite sides of the pivot 35 and at equal distances therefrom, obviously neither the static nor dynamic balance already existing is altered in any way. Nevertheless, by cut and try, a state can be attained in this fashion in which the "master" diameter loses its preeminence, and the disc 134 no longer tends to turn about the pin 35 when the shaft 30 is rotated, but remains in whatever angular position relative thereto it was when rotation began.

If the correction just described, however, be carried too far, some other diameter of the disc will assume the role of master and insist upon placing itself at right angles to the shaft 30 when this is rotated.

The correction to remove this "master" character of any diameter in which it appears may also be accomplished by adding equal masses at two points of the diameter at right angles to the master diameter, the two points of mass accretion being equidistant from the axis of the pin 35 and on opposite sides of the pin.

Obviously, considering Fig. 2 and its bearing on Fig. 3, when the shaft 30 of Fig. 3 is rotated, every diameter of the disc 134 must strive to set itself at right angles to the shaft. If the effective mass distributed along any diameter is greater than that along any other diameter, this most massive of all the diameters becomes the "master" and sets itself at right angles to the shaft. Conversely, if a master diameter appears, it is because a greater mass is distributed along that diameter than along any other diameter. Hence its master character can be destroyed either by diminishing the effective mass along it, or by increasing the effective mass along the diameter at right angles to it, or by a combination of both methods, care being taken to modify the mass along the diameter symmetrically with respect to its center.

Substantially the same general phenomena arise in the case of such arrangements as are shown in Figs. 4 and 5 (if air resistance effects be excluded in the case of Fig. 4, which may otherwise more or less annul or complicate the effects here in question). The fact that the plane of rotation of the bar 34 in Fig. 4 or of the disc 134 in Fig. 5 does not pass through the axis of the shaft 30, does not alter the "master diameter effect" discussed above in connection with Figs. 2 and 3. The bar 34 or disc 134 in being revolved once about the axis of the shaft 30 in Fig. 4 or Fig. 5 is also, in effect, compelled to rotate once about an axis through its center parallel to the axis of the shaft 30. Hence the "master diameter effect" appears in Fig. 4 or Fig. 5 in the same sense and value as in Fig. 2 or Fig. 3 respectively.

A moment's consideration of Fig. 4 and of the disc 21 in Fig. 1 will show that they are substantially the same arrangement, since the disc support 21 is rotatable about an axis which is at right angles to the axis of the frame 20 about which the support 21 is revolved by the motion of the frame. Hence if there be a master diameter in the disc 21, it will tend to set itself at right angles to the principal plane of the frame 20, and to resist being forced out of that position. But the disc 21 is being driven in rotation about its own axis by withdrawal of tape from the pad 22 to be

wound on the core 19. If, at any given moment, the master diameter of the disc 21 chance to be at right angles to the frame 20, the master diameter effect will oppose rotation of the disc during the next ninety degrees, i. e. until the master diameter comes to lie in the plane of the frame, at which instant the effect becomes zero. During the next ninety degrees, the effect tends to aid the rotation of the disc until the master diameter is again perpendicular to the plane of the frame. Thus this cycle of alternately opposing and assisting the rotation enforced by withdrawal of tape recurs twice in every rotation of the disc, and produces the periodic disturbance of the motion of the disc which may in practise, with high speeds of operation, become great enough to cause the tape to be ruptured.

Probably no piece of material from which a disc 21 is to be made, can be found, whether cast, molded, forged, rolled or otherwise made, which is so truly homogeneously uniform in microstructure and density, that a master diameter will not appear at sufficiently high speeds of revolution and rotation, no matter how accurately the disc is formed and balanced for static and dynamic symmetry. Indeed, a disc may be in perfect rotational balance so far as static and dynamic rotational errors are concerned and still be affected with variations of density, symmetrical radially with respect to the center while varying around the circumference of a circle within the disc and concentric with the disc.

To illustrate the order of magnitude of the quantities in question, the following are taken from a case in actual practise. A disc 21 was made of metal and carefully balanced statically and dynamically. It was about thirteen and one-half inches in diameter, one inch thick at its hub, one-eighth inch thick at its rim, had a plane upper surface, had twelve equi-spaced radial ribs on its under, conical face, and weighed about five pounds. In operation the frame carrying it revolved at speeds from zero up to 500 R. P. M., while the maximum speed of rotation of the disc (maximum when the pad of tape on it was about used up) varied proportionally from zero to 120 R. P. M. In this particular case, the master diameter effect became perceptible at about 200 R. P. M. revolution and 48 R. P. M. rotation, while at 500 R. P. M. revolution and 120 R. P. M. rotation, the effect was fatal to the tape which ruptured.

Experiment proved that at 1500 R. P. M. revolution, the maximum moment of the master diameter, with the master diameter at forty-five degrees to the frame axis, was about twenty-five inch pounds. Hence a periodic variation in tape tension of the order of thirty-three pounds would be caused by the master diameter effect in this disc at 1500 R. P. M. revolution speed.

On correcting the disc by adding mass in a total amount of about two and one-half ounces distributed symmetrically along the diameter at right angles to the master diameter, the disc could be operated without affecting the tape harmfully at 1500 R. P. M. revolution and 320 R. P. M. rotation. In fact these maximum practicable speeds were not limited by the master diameter effect, which was negligible, but by other factors having no relation thereto.

In order to determine the position of the master diameter and the value of its effective excess mass in a disc such as 21, or in any analogous centrally symmetrical, i. e. statically and dynamically balanced, member adapted for simultaneous rotation and revolution about non-parallel axes, an apparatus was designed as diagrammatically illustrated in Figs. 6 and 7. Here a frame 40 statically and dynamically balanced with respect to coaxial stub shafts 41 and 42, is rotatably journalled in supports 43 and can be revolved by a pulley 44 and belt 45. A transverse shaft 46 is removably mounted in the frame 40 aligned at right angles to the axis of rotation of the frame and freely rotatable in its bearings in the frame with respect thereto. The central portion of the shaft is formed with a screw thread 47 on which are engaged opposed clamp nuts 48 and 49. These nuts are preferably faced with rubber or other soft friction material on their adjoining faces, as indicated. With the shaft 46 removed from the frame the nut 49 may be removed, a member to be tested such as a disc 21 may be placed on the shaft and clamped thereon by and between the two nuts. A drum 50, preferably small in diameter relatively to the diameter of the member to be tested, statically and dynamically balanced with respect to the shaft 46 and having no master diameter of its own, or none of appreciable effect, is rigidly mounted on the shaft 46 about midway of one-half of the portion thereof within the frame. An inextensible, flexible cord, wire or tape 51 is wrapped one or more times about the drum and attached at its ends tautly to hooked rods 52 and 53 mounted to be freely slidable in opposite ends of the frame. Coil springs 54 and 55 respectively tend to keep the cord 51 taut and the hooks urged outwardly. Each hook has a transverse bar, 56 and 57 respectively, extending inwardly into engagement with a pointer button, 58 and 59 respectively, slidable in a corresponding slot, 60 and 61, in the stub shafts 41 and 42 respectively and associated in indicating relationship with a scale, 62 and 63, on the corresponding shaft. Counterweights 64 and 65 are provided to counterbalance the hooks and their associated parts; and a removable dummy drum 66 to counterbalance the drum 50.

With all elements in the position shown in Fig. 6, the scale readings are noted, and the frame 40 revolved at a suitable speed for a minute or two and stopped. If there is a master diameter in the disc 21, it will have rotated the disc one way or the other during the revolution of the frame, and so will have moved one of the pointers 58 and 59, against the effect of the corresponding spring 54 or 55. The nuts 48 and 49 are loosened, the disc turned a specified fraction of a turn, the nuts tightened again, and the operation repeated. From the results of a set of such operations, the position of the master diameter can be determined and the radius of gyration and the value of its excess mass determined, i. e. the mass required to be removed from the master diameter at the calculated radius on each side of its center to annul the master character of the diameter and remove the master diameter effect from the member.

It is believed to be self-evident from Fig. 6, that if, when the apparatus there shown is brought to a stop after having been revolved about the axis of the shafts 41 and 42 at a known maximum speed, there is recorded, say by the pointer 59, a displacement to the left of this pointer, then there must have been exerted upon the drum 50 at the moment of maximum speed of the frame 40 a torque measured by the displacement of the pointer and originating in the disk 21. The radius of the drum is known; and the force required to compress the spring 55 to the indicated distance

is known. Letting the radius of the drum be r and the force indicated on the scale **63** be f, the torque indicated is then fr pound-feet. Since the master diameter tends to turn the disk counterclockwise, the master diameter must lie in the upper right and lower left quadrants of the disk at an unknown angle a^0 to the axis of the shafts **41** and **42**. Assume that the excess mass of the master diameter is 2W and is evenly distributed along the length of the diameter. It may then be treated as if half of 2W were concentrated at each of the two midpoints of the radii composing the diameter. Let the radial distance of such a midpoint be R. Then by formulae of rotary motion to be found in any elementary text on mechanics, it can be shown that

$$W \sin 2\ (a^0+b^0)=\frac{5866fr}{R^2n^2}$$

where n is the maximum revolutions per minute of the frame **40** before the reading of the pointer **59** on the scale **63** was taken; and where b^0 is the maximum angular displacement of the disk **21** during the rotation of the frame **40**, as indicated also on the scale **63**. All the quantities in this equation are known except W and a^0. Let the experiment be made twice with different maximum rotary speeds of the frame **40**. Then there will be recorded two different angular displacements of the disk (each measured and therefore known) and two different values of f (each measured and therefore known). Substituting these in the formula above for n, b^0 and f respectively, two equations are obtained which can be solved for W and a^0. This value of a^0 locates the position of the master diameter in the disk as it stands in the apparatus. The corresponding value of W is the mass of material to be removed from about the midpoint of each radius of the master diameter, or to be added at about the midpoint of each radius of the diameter perpendicular to the master diameter, or to be compensated otherwise.

It is believed to be easily deducible from the above considerations that the simultaneously rotatable and revoluble member in question need not be a simple circular disc to exhibit the master diameter effect and to be correctible to remove it. A four-armed right-angled cross, a star or the like of any number of equally spaced, similarly shaped rays, any equal sided and equal-angled polygon, are all illustrations of configurations of such members which may be in static and dynamic balance about their axes of rotation and still may be affected with the master diameter effect disclosed.

While the invention is disclosed and described as illustrated by a pad support in a cable taping machine, it is not so limited, but appears to be applicable wherever a member is to be simultaneously rotated and revolved at speeds sufficient to make master diameter effect phenomena appear. The embodiments herein disclosed are illustrative and may be variously modified and departed from without departing from the spirit and scope of the invention as pointed out in and limited only by the appended claims.

What is claimed is:

1. The method of correcting master diameter unbalance in a member adapted to be rotated about one axis while being revolved at high speed about an axis not parallel to the first named axis, which method comprises steps of revolving the member about an axis not parallel to an axis of free rotation of the member and thereby creating in the member a force tending to set the master diameter of the member in a plane perpendicular to the said axis of revolution by motion about the said axis of free rotation, measuring the moment of the said force, calculating therefrom the position of the said diameter and the excess mass therealong, and modifying the distribution of mass in the member to annul the said force.

2. The method of correcting master diameter unbalance in a member adapted to be rotated about one axis while being revolved at high speed about an axis at right angles to the first named axis, which method comprises steps of revolving the member about an axis at right angles to an axis of free rotation of the member and thereby creating in the member a force tending to set the master diameter of the member in a plane perpendicular to the said axis of revolution by motion about the said axis of free rotation, measuring the moment of the said force, calculating therefrom the position of the said diameter and the excess mass therealong, and modifying the distribution of mass in the member to annul the said force.

3. Apparatus to determine the position and excess mass of the master diameter of a member adapted for simultaneous revolution and rotation about non-parallel axes, which apparatus comprises means to support the member to be freely rotatable about its axis of rotation, means to revolve the said supporting means and therewith the member about an axis not parallel to the axis of rotation of the member and thereby to create a force therein tending to set the master diameter in a plane at right angles to the axis of revolution, and means to measure the moment of the said force.

4. Apparatus to determine the position and excess mass of the master diameter of a member adapted for simultaneous revolution and rotation about axes at right angles to each other, which apparatus comprises means to support the member to be freely rotatable about its axis of rotation, means to revolve the said supporting means and therewith the member about an axis at right angles to the axis of rotation of the member and thereby to create a force therein tending to set the master diameter in a plane at right angles to the axis of revolution, and means to measure the moment of the said force.

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