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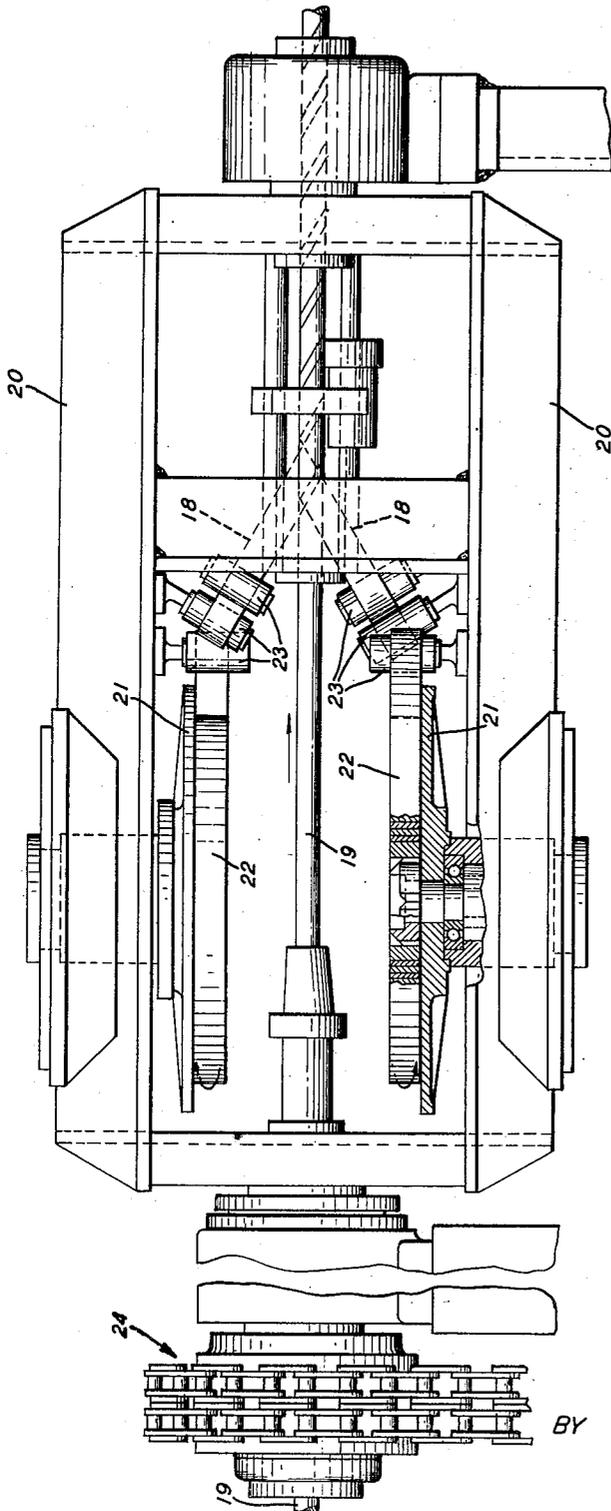
E. W. REYNOLDS
ROTARY MECHANISM BALANCED FOR ROTATION
ABOUT TWO NONPARALLEL AXES

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2 Sheets-Sheet 1

FIG. 1



INVENTOR
E.W. REYNOLDS

BY
w. c. farwell
ATTORNEY

UNITED STATES PATENT OFFICE

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ROTARY MECHANISM BALANCED FOR ROTATION ABOUT TWO NONPARALLEL AXES

Ellwood W. Reynolds, Westfield, N. J., assignor to Western Electric Company, Incorporated, New York, N. Y., a corporation of New York

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6 Claims. (Cl. 57-15)

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This invention relates to rotary mechanisms and more particularly to a type of unbalance heretofore not apparent in industrial machinery and appearing only in apparatus in which a member is simultaneously driven in two modes of high speed rotary motion about nonparallel axes.

This application is a continuation in part of copending application Serial No. 414,269, filed October 9, 1941, by the present inventor, and upon which application U. S. Patent 2,394,482 was granted on February 5, 1946.

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 revoluble about an axis at right angles to the axis of the disc. The core to be wound advances longitudinally along the axis of revolution of the frame. The frame is driven in revolution 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

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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 an apparatus comprising a member which is rotated rapidly about one axis while being simultaneously driven at relatively high speed in revolution about another axis which is not parallel to the axis of rotation, with minimal appearance of any periodic disturbance of the rotary motion of the member.

With the above and other objects in view, the invention may be embodied in a mechanical apparatus comprising a frame revoluble about an axis, means to drive the frame in revolution about the axis, and a member journaled in the frame for rotation about an axis fixed with respect to the frame and not parallel to the axis of revolution thereof, the said member being so constructed and proportioned that the moment of inertia of its mass around any diameter of the member through and perpendicular to the axis of rotation of the member is equal to the moment of inertia of its mass about the diameter of the member perpendicular to the first named diameter and to the axis of rotation.

Other objects and features of the invention will appear from the following detailed description of one embodiment thereof taken in connection with the accompanying drawings, 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 the essentials of Fig. 1;

Fig. 7 is a similar view of yet another illustrative assembly;

Fig. 8 is a similar view of an apparatus for de-

termining the angular position and excess mass of the master diameter of a member;

Fig. 9 is a section on the line 9—9 of Fig. 8;

Fig. 10 is a detached view of one disc of Fig. 6 with auxiliary lines to assist in defining the invention;

Fig. 11 is a similar view of another form of rotatable member;

Fig. 12 is a similar view of the star member of Fig. 7; and

Figs. 13, 14 and 15 are diagrammatic views of other explanatory mechanisms.

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 revoluble 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 13 are supported on the two discs 21. The tapes 13 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 revolution, to effect this last, by the chain drive generally indicated at 24 from any suitable moving member 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 of operation.

Consider now Fig. 2, in which a shaft 30 is horizontally journaled 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 30. But if the shaft 30 be rotated and thus twirls the bar about the shaft 30 and perpendicularly to the plane of the drawing, the bar tends to turn itself on the pin 35 at right angles to the shaft 30 into 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 in that position.

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 pre-eminence, 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 equi-distant 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

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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 Figs. 3 and 6 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 practice, 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 micro-structure 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.

It must not be thought, however, that circular uniformity about the axis of rotation is necessary for elimination of the master diameter effect. Consider for example the member 334 shown in Fig. 11. This consists essentially of two such bars 34 as the one shown in Fig. 2, united integrally on a common hub. If the two bars which make up the four armed spider 334 are truly identically alike in mass and in distribution of mass, the whole member 334 will be free from the master diameter perturbation when simultaneously ro-

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tated on its axis 35—35 and revolved about an axis not parallel to that axis.

In the case of the star shaped member 234 shown in Figs. 7 and 12, it will be found to be true that, if each ray of the star is identically like every other ray in mass and distribution of mass, this member 234 will also be free from the master diameter disturbance.

Consider now the several members 21 of Figs. 1, 6 and 10; 334 of Fig. 11; and 234 of Fig. 12. Let A—B be any diameter of such a member perpendicular to and through its axis of rotation; and let C—D be the diameter of the member perpendicular to both diameters A—B and 35—35 at their intersection. Now let the member in question be spun about the line A—B as an axis at a predetermined fixed speed. The spinning member then has a fixed moment of inertia which depends not only upon the mass of the member, but also upon the distribution of that mass along the diameter C—D. The more closely the mass is concentrated about the central point P along the two arms PC and PD, the less will be the moment of inertia of the member about the axis A—B. In similar fashion, the member will have a specific moment of inertia about its diameter C—D; and it will likewise have a characteristic moment of inertia about any diameter through P in the plane APC. Now, considering these facts, it will be clear that the necessary and sufficient condition that any such member as 21, 134, 234 or 334 be free from master diameter unbalance, is that the moment of inertia of the member about any diameter A—B through and perpendicular to the rotation axis of the member be equal to the moment of inertia of the member about that diameter C—D of the member which is perpendicular to the diameter A—B and to the rotation axis.

In order to make abundantly and certainly clear that the problem to which the present invention is directed is not one of the various types of unbalance effects or of gyroscopic precessional effects well known in the mechanical arts, the following considerations are presented:

Fig. 13 illustrates the effect customarily termed static unbalance. This figure shows a circular uniform disc being mounted on a shaft 72 driven by a pulley 32 and belt 33. If the belt 33 be removed, the disc will turn under gravity until the unbalanced mass 71 is at the bottom. If the shaft 72 and disc 70 be driven by the belt, the centrifugal force of the mass 71 pulls radially away from the axis of the shaft thus, for example, tending to lift the shaft in its bearings when the mass is at the top of its orbit and to pull the shaft down when the mass is at the bottom of its orbit. This is the commonest of rotary unbalances and the chief source of vibration in rotary machines. A characterizing and identifying feature of static unbalance is that it tends to shift the shaft 72 bodily away from its position, parallel to itself. Static unbalance exerts stress on the shaft journals 73 and 74 at all times in the same direction as each other. Static unbalance does not per se tend to change the angular position of the shaft. Static unbalance can be completely and exactly annulled (a) by removing the mass 71 or (b) by securing a counterbalancing mass or mass to the disc to have a precisely equal and opposite centrifugal effect.

Fig. 14 illustrates the effect known as dynamic unbalance. A thick, rigid disc 80 on a shaft 82 in journals 83 and 84 and drivable by a pulley 32 and belt 33, has identical masses 81 and 81 secured to opposite faces at opposite ends of a di-

ameter. This assembly is in complete static balance, the mass 81 exactly balanced by the mass 181. When the assembly is driven in rotation, the centrifugal pull of the mass 81 is precisely equal to the centrifugal pull of the mass 181. And these two pulls are precisely opposite in direction. But they are not in the same straight line. At the instant shown in Fig. 14 the pull of the mass 81 on the shaft 82 is upward at the point X, while the mass 181 pulls equally and oppositely down at the point Y. Thus there is created a mechanical couple acting on the shaft and tending at the instant shown, to turn the shaft counterclockwise in the plane of the drawing. This effect is dynamic unbalance; and it is to be noted that dynamic unbalance stresses the journals in opposite directions at any given instant, while static unbalance stresses the journals always in the same direction.

Fig. 15 shows the essentials of the well known gyroscope. A heavy disc 90 on a shaft 92 is journalled at 93 and 94 in a bar 95 which is pivoted at 96 to be vertically tiltable in a yoke 97 supported on a stationary base 98 and pivotable thereon about a vertical pin 99. The shaft 92 and disc 90 can be driven at high speed by a motor 133 which is also a counterbalance for the mass of the disc 90 about the pivot 96. The bar 95 and yoke 97 make a universal mount for the system 133, 92, 90 on the base 98. Now if the parts are in the position shown with the disc 90 rotating with the shaft 92 at high speed in the journals 93 and 94, driven by the motor 133, the whole represents all the essentials of a standard gyroscope unit. The characteristic properties of a gyroscope upon which it is believed that all practical application of such units are based, are two. The first is, that so long as pivotal motion on the pins 96 and 99 is free, the base 98 may be translated or rotated in any desired way while the shaft 92 will turn on the pivots to remain always parallel to its original direction. This is the property on which such devices as gyrocompasses are based. This property is of no relevancy, however, to the present invention. The second important characteristically gyroscopic property is that, assuming the parts as shown in Fig. 15, if an attempt be made to compel an angular change of position of the shaft 92, the shaft will move angularly but at right angles to the direction of the urge. If, for example, an effort be made to tilt the shaft 92 on the pivot 96 to swing the disc 90 down and the motor 133 up, the shaft will refuse to tilt vertically but will execute a horizontal turn on the pivot 99, the direction of this turn depending on the direction of spin of the disc. This characteristic gyroscope property underlies, for example, the stability or anti-rolling gyroscopes installed to give steadiness to some ocean going vessels. So long as the rotating shaft 92 is free to turn on either pivot, it will refuse to submit to be turned on the other. However, if sufficient constraint and brute force be employed, say on the journals 93 and 94, the shaft can be compelled to pivot as desired, with the production of a correspondingly heavy stress on the journals at right angles to the turn or pivot motion of the shaft. As long as the pivot motion of the shaft is of constant rotary speed, the gyroscopic stress on the journal bearings remains constant and at right angles to the pivot motion and in opposite directions on the two bearings. There is nothing inherently vibratory or periodic about this effect. It is continuous and continuously proportional to the pivot speed.

In the apparatus shown in Fig. 1, each disc 21 is mounted, it will be noticed, on a disproportionately large and rugged bearing. This is because, at the usual speeds of operation, a heavy gyroscopic stress is developed in this bearing against the frame supporting the bearing. The axis of the rapidly rotating disc 21, rigidly fixed in the frame 20, is forced by the revolution of the frame to pivotally revolve about the axis of the frame. Hence there develops a severe gyroscopic stress due to the effort of the axis of rotation of the disc to turn in the plane of the frame because of being forced by the frame to pivot in a plane at right angles to the frame.

Finally, as to a gyroscope, two things are to be noted. First that no gyroscopic effect is in any way, per se, periodic, pulsating or vibratory, nor gives rise to any periodic or vibrating perturbation or unbalance of motion. Secondly, there is no gyroscopic apparatus, device, or mechanism in the mechanical arts, i. e. no mechanism which employs the characteristic gyroscope properties for any useful purpose, in which the axis of the spinning gyroscope disc or wheel is compelled to pivot in the manner in which the revolving frame 20 compels the axis of the spinning disc 21 to pivot about the axis of the frame perpendicular to the axis of the disc. This is to say that there exists no apparatus dependent upon the gyroscopic properties, which has ever or can ever exhibit or be perturbed by or require correction of the master diameter effect or can present the problem to which the present invention is directed.

Summing up, then, these things from which applicant's discovery and invention are to be distinguished as wholly unrelated and not to be confused therewith, static unbalance may be evident wherever a member rotates and exhibits itself as a stress in both bearings, directed radially outwardly from the axis of rotation, stressing both bearings in the same direction at any given instant, and usually effective to cause vibration of the bearing supports. Dynamic unbalance may appear wherever a member rotates and exhibits itself as a stress in both bearings, directed radially outwardly from the axis of rotation along two, equal, parallel, spaced apart, oppositely directed vectors which rotate with the member, stressing both bearings but in opposite directions at any given instant, and usually effective to cause vibration of the bearing supports. Both static and dynamic unbalance effects can and do appear in rotary members whether their bearings are fixed in position or not.

Gyroscopic precession is not an unbalance in the same sense as the two effects just mentioned. It does not arise out of any symmetry or dissymmetry of substance or mass. It appears when an attempt is made to revolve the axle of a spinning wheel end over end, and exhibits itself as a pivoting reaction of the axle, apparently endeavoring to evade the issue by escaping sidewise. If the axle is prevented from sliding out by turning sidewise, the arrangement is not a gyroscope. If the axle is prevented from turning out sidewise a gyroscopic stress is produced on the bearings which is constant in direction and proportional in magnitude to the two non-parallel circular speeds.

The master diameter effect above described, analyzed and explained, exhibits itself solely as a circular effect. It is not radial. It presents itself as tending to periodically accelerate and decelerate the rotation of the disc 21. It does not and

cannot appear or become noticeably effective unless both circular speeds are present and considerable. And—and this distinguishes the master diameter effect clearly and widely and qualitatively from any of the other effects above discussed—the master diameter effect does not, per se, cause any stress whatever in or to the bearings of the rotating member. It is not discoverable until the constancy of rotation, the uniformity of rotary speed of the rotating member during each rotation, from part to part of each rotation, becomes a matter of importance. Neither static unbalance, dynamic unbalance, or gyroscopic precession, per se, exerts any effect on the rotational speed of the member in question. They may affect it by causing excessive friction in the bearings; but that is beside the point. They do not in themselves tend to increase or decrease the rotary speed of the member, whereas the sole and only evidence of the presence of the master diameter perturbation in the pad support 21, is the appearance twice in each revolution of the disc of an acceleration and deceleration of the rotary speed of the disc, when both circular speeds, the rotation of the disc on its axis and the enforced revolution of that axis with the frame 20, become considerable.

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, twice in each revolution of the disc, 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, even at these speeds, 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. 8 and 9. Here a frame

40 statically and dynamically balanced with respect to coaxial stub shafts 41 and 42, is rotatably journaled 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. 8, 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. 8, 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 disc 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

f r pound-feet. Since the master diameter tends to turn the disc counterclockwise, the master diameter must lie in the upper right and lower left quadrants of the disc 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 disc 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 disc (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 disc 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 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 the appended claims.

What is claimed is:

1. A mechanical apparatus comprising a frame revoluble about an axis, means to drive the frame in revolution about the axis, and a member journaled in the frame for rotation about an axis fixed with respect to the frame and not parallel to the axis of revolution thereof, the said member being so constructed and proportioned that the moment of inertia of the mass thereof about any diameter of the member through and perpendicular to its axis of rotation is equal to the moment of inertia of the said mass about the diameter of

the member perpendicular both to the first named diameter of the member and to the axis of rotation.

2. A mechanical apparatus comprising a frame revoluble about an axis, means to drive the frame in revolution about the axis, and a member journaled in the frame for rotation about an axis fixed with respect to the frame and perpendicular to the axis of revolution thereof, the said member being so constructed and proportioned that the moment of inertia of the mass thereof about any diameter of the member through and perpendicular to its axis of rotation is equal to the moment of inertia of the said mass about the diameter of the member perpendicular both to the first named diameter of the member and to the axis of rotation.

3. A mechanical apparatus comprising a frame revoluble about an axis, means to drive the frame in revolution about the axis, and a member journaled in the frame for rotation about an axis fixed with respect to the frame and perpendicular to and intersecting the axis of revolution thereof, the said member being so constructed and proportioned that the moment of inertia of the mass thereof about any diameter of the member through and perpendicular to its axis of rotation is equal to the moment of inertia of the said mass about the diameter of the member perpendicular both to the first named diameter of the member and to the axis of rotation.

4. An apparatus for serving strand material on a longitudinally advancing core and comprising a frame revoluble about an axis, means to pass a core to be served along the axis of the frame, means to drive the frame in revolution about the axis, and a strand supply support journaled in the frame for rotation about an axis fixed with respect to the frame and not parallel to the axis of revolution thereof, the said support being so constructed and proportioned that the moment of inertia of the mass thereof about any diameter of the support through and perpendicular to its axis of rotation is equal to the moment of the said mass about the diameter of the support perpendicular both to the first named diameter of the support and to the axis of rotation.

5. An apparatus for serving strand material on a longitudinally advancing core and comprising a frame revoluble about an axis, means to pass a core to be served along the axis of the frame, means to drive the frame in revolution about the axis, and a strand supply support journaled in the frame for rotation about an axis fixed with respect to the frame and perpendicular to the axis of revolution thereof, the said support being so constructed and proportioned that the moment of inertia of the mass thereof about any diameter of the support through and perpendicular to its axis of rotation is equal to the moment of inertia of the said mass about the diameter of the support perpendicular both to the first named diameter of the support and to the axis of rotation.

6. An apparatus for serving strand material on a longitudinally advancing core and comprising a frame revoluble about an axis, means to pass a core to be served along the axis of the frame, means to drive the frame in revolution about the axis, and a strand supply support journaled in the frame for rotation about an axis fixed with respect to the frame and perpendicular to and intersecting the axis of revolution thereof, the said support being so constructed and proportioned that the moment of inertia of the mass

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thereof about any diameter of the support through and perpendicular to its axis of rotation is equal to the moment of inertia of the said mass about the diameter of the support perpendicular both to the first named diameter of the support and to the axis of rotation.

ELLWOOD W. REYNOLDS.

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