MOTION IN CIRCULAR PATH

According to 'MATTER (Re-examined)'

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Abstract: All natural (inertial) motions are in straight lines. Rotating motion or motion in circular path is the result of simultaneous straight-line motions of 3D matter-particles of a macro body, in different directions at differing linear speeds, appropriate to their locations in it. A macro body, moving in circular path, is under a constant inward effort. It simultaneously has two linear motions; one linear (centripetal) motion due to centripetal effort towards centre of circular path and another linear motion due its momentum in a direction deflected outward from tangent to circular path. Outward component of linear motion gives rise to assumption of imaginary 'centrifugal force'. Centripetal motion not only compensates outward component of linear motion but also deflects direction of linear motion inward. Explanations on rotary motion with respect to absolute (inertial) reference frame can give real parameters without use of imaginary entities. Work, invested by external effort about a macro body, continues to act even after cessation of external effort, until it is stabilized and macro body's motion attains steady state. Phenomenon of inertial delay operates not only during application of external effort but also during its cessation. Ignoring this fact caused the assumption that direction of instantaneous linear motion of a macro body, moving in a circular path, is tangential to its path. In following explanation, motion of a macro body in circular path is described, in accordance with alternative concept, presented in the book 'MATTER (Re-examined)'. For details, kindly refer to same [1].

Keywords: Effort, Force, Work, Inertia, Motion, 'Centrifugal force', Centripetal effort, Momentum.

Introduction:

Displacement of an object, in space, is with respect to external reference. Reference could be a point in stable and homogeneous universal medium or with respect to another object in space. Universal medium, outside basic 3D matter-particles, substitutes for absolute space. Universal medium provides an absolute reference. With respect to absolute reference, all parameters of a macro body are true. When another macro body provides reference, we have relative motion. For relative motion, motion of reference macro body, depending on its relative direction of motion, adds to or subtracts from motion of referred macro body to give apparent parameters of macro body or its path.

Relative reference frames of observations, related to states of motion of macro bodies, may be generally classified into inertial and non-inertial reference frames. Newton's laws of motion are true in any reference frame that is moving at a constant velocity (inertial reference frame). In an inertial reference frame, at any instant, phenomenon of inertia compels a moving macro body (in its stable state) to travel in straight-line path.

Motion of a macro body, in curved path, is combination of numerous straight-line motions. Action of external effort on macro body is to change its state of motion or direction of its path. External effort, curving its path, acts at an angle to direction of its (inertial) motion. For steady motion in circular path, external effort on macro body has to be of constant magnitude and perpendicular to its (instantaneous) average straight-line path. Principle of motion in curved path is similar to motion in circular path, with small differences in relative direction and duration or changes in magnitude of external effort.

Resultant of two motions:

Action of external effort on a macro body is to introduce additional distortions into its matter-field. Magnitude of total additional distortions in matter-field of a macro body is the magnitude of total additional work associated with it. Work, required for creation of macro body's constituent 3D matter-particles, for their development into various unions and for integrity and stability of macro body is intrinsic with its matter-field. Additional distortions, in matter-field, determine state of macro body's motion. Due to latticework-structures of universal medium, additional distortions in it (except those produced by gravitation) cannot remain stationary at any location. Additional distortions in a macro body's matter-field are transferred through universal medium, in the direction of their introduction. 3D matter-particles of macro body, which happen to be in the path of moving-distortions, are also carried along with them. Displacements of constituent 3D matter-particles, move macro body, as a whole. Newly introduced additional distortions in matter-field;

(1) If they are in same direction as additional distortions, already present and maintaining inertial motion of macro body, add together to accelerate macro body and enhance its speed.

(2) If they are in opposite direction to additional distortions, already present and maintaining inertial motion of macro body, subtract from each other to decelerate macro body and reduce its speed.

(3) If they are in any other direction to additional distortions, already present and maintaining inertial motion of macro body, accelerate macro body in their direction and deflect macro body's present direction of motion. Depending on direction, they may enhance of reduce macro body's linear speed.

Additional distortions in a matter-field travel only in straight lines and thus directing steady state motions of all its constituent 3D matter-particles in straight lines. As long as magnitude (and direction) of additional distortions (additional work) in its matter-field remains constant, a macro body continues to move at constant linear speed in straight-line path. Change in magnitude (or direction) of additional distortions produce instability in macro body's state of motion. It takes certain time for the changed additional distortions to stabilize. This delay is accelerating/decelerating period of macro body.

External effort introduces additional distortions into macro body's matter-field in its own direction. These additional distortions form another set, supplementary to original additional distortions, which are already moving the macro body at constant linear speed in straight path. Additional displacement of constituent 3D matter-particles deflects whole macro body from its original direction of motion. As macro body is deflected away from original direction of steady linear motion, part of 3D matter-particles of macro body moves away from path of moving additional distortions in its matter-field. Irrespective of displacements of constituent 3D matter-particles of macro body, additional distortions in its matter-field continue to be transferred in same direction and are lost from matter-field, into universal medium. Magnitude of total additional work, in the direction of macro body's original linear motion, diminishes.

In the mean time, due to its linear motion, macro body is moving away from direction of additional distortions due to external effort. If action of external effort is only for a limited period, macro body is gradually carried away from influence of additional distortions due to external effort, which escape into universal medium, outside macro body's matter-field. If external effort on macro body acts continuously, as in the case of motion in circular path, introduction of additional distortions into macro body's matter-field continues at a constant rate, same as the rate of additional distortions lost from it. Due to constant renewal of additional distortions by external effort, macro body accelerates continuously at a constant rate. At the same time, as magnitude of newly introduced additional distortions and additional distortions lost from matter-field are equal, total magnitude of additional distortions in macro body's matter-field remains constant in magnitude. Constant magnitude of additional distortions in macro body's matter-field moves it at a constant linear speed. Because of this; though macro body (moving in a circular path) is accelerating continuously at a constant rate, its linear speed remains constant.

During macro body's displacement towards centre of curvature of its path, certain part of additional work (producing its motion in straight-line path) is lost from its matter-field and certain part of additional work (producing its motion towards the centre of curvature) is stored in its matter-field. These additional distortions together form resultant additional distortions in matter-field, to produce its motion in resultant direction. Instantaneous changes in resultant direction of macro body's motion curve its path.

Since direction of macro body's motion changes continuously, additional distortions due to original inertial motion and additional distortions due to action of external effort (which are transferred in corresponding straight-line directions) are continuously modified. Additional distortions, in macro body's matter-field at any instant, are compatible for present displacements of its constituent 3D matter-particles. Magnitude of resultant linear (instantaneous) speed of macro body corresponds to magnitude and direction of total additional distortions in its matter-field.

'Centrifugal force':

To move in circular path, a linearly moving macro body requires action of an external (centripetal) effort that accelerates macro body towards centre of its path. Displacement along its straight-line path and displacement due to acceleration by centripetal effort towards centre, together, result in macro body's circular path. It should be noted that at every instant, macro body is moving towards centre of its circular path under acceleration provided by centripetal effort, taking it nearer to centre. Considering this motion in inertial frame of reference, macro body would logically move in a path, spiralling towards centre. Since this does not happen, it is illogical to consider this action in inertial frame of reference. In order to overcome this inconsistency, situation is considered in rotational frame of reference (non-inertial reference frame). Continuous centripetal acceleration of macro body justifies this choice.

Observations, related to states of motion of macro bodies, do not appear true in accelerated (non-inertial) reference frames. Instead, in an accelerated reference frame, moving macro bodies appear under actions of external efforts, which are not in fact present. These types of apparent efforts are called 'pseudo (or imaginary) forces'. Since rotational motion is always an accelerated motion, 'pseudo (imaginary) forces' are always associated with rotating frames of reference.

In order to balance efforts on macro body in various directions and thereby reduce magnitude of total resultant effort on it to nil value, an imaginary effort ('centrifugal force') is assumed to act on macro body (moving in circular path) in opposite direction to centripetal effort. 'Centrifugal force' is assumed to accelerate macro body by an equal magnitude as that is provided by centripetal effort, but in opposite direction. Neutralisation of acceleration due to centripetal effort (presumably) prevents macro body from spiralling towards centre of its circular path. Having efforts in opposite directions (in perpendicular direction to linear path), leaves macro body free to pursue its motion in circular path at a constant speed.

'Centrifugal force' is an assumed quantity (peculiar to a macro body moving on circular path) that has equal magnitude and dimensions as centripetal effort (which keeps macro body on its circular path) but apparently acts in opposite direction. 'Centrifugal force' is invoked by observer to maintain validity of Isaac Newton's second law of motion in a rotating (or otherwise accelerating at a constant rate) reference frame. In inertial reference frame, 'centrifugal force' refers to a 'fictitious effort', which appears to act on macro body (moving in circular path). In non-inertial reference frame, it refers to 'reaction' to centripetal effort, by which macro body (moving in circular path) influences other macro bodies. When used as 'fictitious effort', it is useful in analyzing motion of a macro body in rotating reference frame. All attributes of real effort are assigned to 'centrifugal force'.

Since Newton's first law of motion is not applicable in rotational reference frame, a macro body moving in circular path is assumed to maintain its circular path, when resultant of system of efforts on it is nil. This is achieved, when magnitude of 'centrifugal force' is equal to magnitude of centripetal effort and they are in opposite directions. In rotating reference frame, it is assumed that motion of a macro body under inertia (its steady state of motion) is along circular path about centre of rotation. 'Centrifugal force' appears only when there is centripetal effort present in a system. Magnitude of action of 'centrifugal force' is equal to magnitude of action of centripetal effort and opposite in direction.

Magnitude of imaginary 'centrifugal force', on a macro body moving in circular path, can be increased by increasing either (1) its linear speed, (2) its mass, or (3) radius of its circular path (distance from centre). None of these methods augment or create real effort in the direction of 'centrifugal force'. Magnitude of imaginary centrifugal force on a macro body, moving in circular path at (small) constant linear/angular speed is given by the relation; $F = mv^2 \div R$. Where F is magnitude of 'centrifugal force', m is 'mass' of macro body, R is radius of circular path, v is average (tangential) linear speed of macro body. 'Centrifugal force' is usually expressed in terms of acceleration due to gravity.

'mv' is linear momentum of macro body. Considering magnitude of 'centrifugal force' in terms of linear momentum of macro body;

Splitting above equation for magnitude of 'centrifugal force'; $F = (mv)\,\omega$ **(1)**

where 'ω' is angular speed of (linearly moving) macro body, along its circular path.

Outward departure of macro body from tangent to circular path, $d = v \operatorname{Tan} \omega$ / unit time

For small values of 'ω', $\omega = \operatorname{Tan} \omega$, $d = v \operatorname{Tan} \omega = v\omega$

$$F = mv^2 \div R = mv\,(v \div R) = mv\omega = md$$

Under the assumption that macro body's linear speed is unaffected; its linear momentum remains constant. Magnitude of 'centrifugal force' on macro body (moving along circular path at constant linear speed) is equal to magnitude of centripetal effort (but in opposite direction) on it. Change in magnitude of centripetal effort by external action is automatically reflected in magnitude of 'centrifugal force' and in corresponding change in magnitude of angular speed of macro body. Equation (1) remains valid only for small values of macro body's angular speed, where value of 'ω' is much less than π/2 per rotation.

Macro body, moving in circular path is continuously changing direction of its velocity and therefore, accelerates towards centre of path. External effort, required to produce this acceleration, is provided by centripetal effort. If macro body is moving at constant speed, provided by inertia, centripetal effort is the only external effort on it. If centripetal effort is terminated, macro body (because of inertia) appears to continue to move in straight-line path, tangential to its previous circular path. Observation of this fact has led to the assumption (without any logical reason) that direction of macro body's instantaneous linear motion is always tangential to its circular path. This assumption is valid only in cases, where value of angle subtended by tangential displacement of macro body in unit time and trigonometric ratio of angular displacement of macro body are approximately equal ($\omega \approx \operatorname{Tan} \omega$). Therefore, 'centrifugal force' is an analytical convenience, rather than a scientific fact.

Length of segment of a circle is usually assumed equal to product of angle subtended by it at centre and length of circle's radius. Hence, instantaneous tangential linear speed of a macro body, moving in circular path, is assumed equal to product of angular speed (in radians) and radius of circular path. It may be noted that; however small a segment of curve is, its length is different from length of tangent (enclosed by angle subtended by the segment) at any point on segment. For all practical purposes involving small macro bodies moving in curved paths of reasonably large radius, calculations based on these assumptions do not make observable differences. However, if macro body involved is very large with reasonably large radius of curvature of its path or macro body is very small with small radius of curvature of its path, considerable discrepancy will appear in result.

Motion in circular path:

Mechanism of motion, envisaged in this concept, explains motion of a macro body in circular path without assumption of 'centrifugal force' and with respect to absolute reference frame. Currently, due to lack of absolute reference, we are unable to determine true parameters of a macro body's motion. It is also understood that state of motion has certain effects on its body-parameters. (E.g. Contraction of length in the direction of motion, etc.) Hence, it should be (at least, theoretically) possible to assess true parameters of a macro body's motion by checking symmetry of its shape.

In order to sustain motion in a circular path, in a system unaffected by external influences, three conditions should be satisfied. First, macro body should have a linear motion at a constant speed (linear momentum). Second, external (centripetal) effort of constant magnitude should act on macro body, in perpendicular direction to and towards centre of circular path at all times. Third, instantaneous linear speed and future linear speed of macro body should be equal and constant. These conditions can be satisfied only in systems as shown in figure 1.

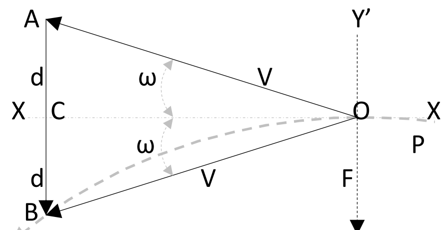

Figure 1

In figure 1, linearly moving macro body is currently at position O. POBT is part of circular path. OA is its instantaneous displacement in magnitude and direction in unit time, due to present linear speed. Y'Y is its instantaneous displacement, in magnitude and direction in unit time, due to centripetal effort, represented by arrow F. OB is resultant instantaneous displacement in unit time, in magnitude and direction (future linear speed) and OC is its average displacement in unit time, v. OC is along the tangent, XX, to circular path POBT at O. Angle between tangent OC and direction of resultant motion OB is angular speed, ω, of macro body.

From figure 1, direction of instantaneous linear motion of macro body is deflected outwards from tangent XX to circular path. [Reason as to why instantaneous linear motion appears tangential to circular path is explained below]. Magnitudes of instantaneous displacements due to present and future linear speeds, V, are equal and they are angularly deflected equally in opposite directions from tangent XX to circular path. Magnitudes of angular deflections, ω, are proportional to macro body's centripetal acceleration and curvature of circular path.

Centripetal motion, AB, is equal to magnitude of displacement, Y'Y, due to centripetal effort, F. There is no need for imaginary 'centrifugal force' in the system to account for macro body's departure, away from centre of circular path. This departure is due to deflection of macro body's current linear motion from tangent to circular path, XX. Centripetal displacement not only accounts for neutralisation of outward departure of path from tangent, but also accounts for inward departure of path from tangent, to maintain circular nature of macro body's path.

In calculations, involving a macro body's motion in circular path, effects of inertia associated with centripetal effort, after its termination, are not taken into consideration. It is assumed that as soon as centripetal effort ends, all its effects also cease. This belief is based on observed path of a 3D matter-particle detached from rim of a rotating wheel (or similar phenomena). Tangential motion of detached 3D matter-particle is an apparent phenomenon and it is not true direction of particle's instantaneous motion, until it is stabilised as a straight-line path. It takes inertial delay for external effort to stabilise its effect on a macro body. Only after inertial delay, macro body reaches its stable state of motion. Hence, it is only logical to think that termination of external effort also takes similar inertial delay to stabilise its effect on macro body.

Radius of curvature of circular path, $R = v / \omega$ (for very small values of ω)

F is magnitude of centripetal effort, m is mass of macro body (representing its matter content) and 'a' is macro body's centripetal acceleration. Additional work introduced by centripetal effort is equal to its action on macro body, which is proportional to its acceleration, a, in the direction of effort. Considering motion of macro body in absolute reference frame (an inertial reference frame with respect to universal medium); Centripetal acceleration, $a = F \div m$

Magnitude of additional work, done about macro body (in perpendicular direction to its circular path) in unit time, for centripetal acceleration; $AB = a \div 2$ (ignoring constancy of proportion and putting, duration, t , equal to one unit in equation; displacement = $at^2/2$)

At the end of unit time, macro body is displaced to position, B, which is the result of original additional work associated with macro body's momentum and additional work introduced by centripetal effort in unit time.

Let OA represent macro body's present instantaneous linear velocity, V, at O.

OA = V units and AB = a / 2 units

As long as linear speed and magnitude of centripetal acceleration remain constant, macro body moves in circular path. At the same time, system of efforts on macro body is not balanced and magnitude of external effort on macro body is not nil. To move in circular path, macro body's instantaneous linear speeds at all points on its path should be same, while magnitude of external effort also remains constant. Therefore, in circular motion, a macro body can appear in a steady state of motion even while it is under action of an external effort.

Future instantaneous linear speed, $OB = OA = V$

Average linear velocity of the macro body, OC = v, which is tangential to circular path at O.

In right-angled triangles AOC and BOC; Side OC is common to both, Side OA = Side OB, Angles ACO and BCO are right angles. Triangles are similar; Side AC = Side BC

$$\angle AOC = \angle BOC = \angle(AOB \div 2) = \text{angular speed of macro body, } \omega$$

$$\text{Since AB} = a / 2, \quad AC = BC = a / 4 \qquad \textbf{(2)}$$

Average linear speed of the macro body along tangent, v = V Cos ω

Macro body continues to move in a circular path. Direction of its present instantaneous linear motion, OA, is deflected away from tangent XX, by an angle equal to its angular speed.

Magnitude of centripetal effort:

Consider a macro body moving at constant linear speed, moving in a circular path, as shown in figure 1. OA represents magnitude of additional work in association with its momentum or its instantaneous present linear speed, V. AB is magnitude of additional work introduced or its displacement due to action of centripetal effort, Y'Y. OB is resultant additional work in association or its instantaneous resultant linear speed. Since OA = OB, macro body travels in circular path, POBT. OC is its average (tangential) speed, v, at any point on its circular path.

Let AC = CB = d units, AB = 2d units/sec, OA = OB = V units/sec, OC = v units/sec,
$\angle AOC = \angle COB = \omega$ rad/sec, $\angle AOB = 2\omega$ rad/sec.

Angular speed of the macro body in circular path is measured with respect to tangents to the path.

Angular speed of macro body, $\angle COB = \omega$ rad/sec

Total angular deflection of macro body's path from OA to OB, $\angle AOB = 2\omega$ rad/sec

From triangle AOC; $v \div V = \text{Cos}\,\omega$, $V = v \div \text{Cos}\,\omega$, $d^2 + v^2 = V^2 = v^2 \div \text{Cos}^2\omega$

$$d^2 = \frac{v^2}{\text{Cos}^2\omega} - v^2 = v^2\left(\frac{1}{\text{Cos}^2\omega} - 1\right) = v^2\left(\frac{1 - \text{Cos}^2\omega}{\text{Cos}^2\omega}\right) = v^2\,\frac{\text{Sin}^2\omega}{\text{Cos}^2\omega} = v^2\,\text{Tan}^2\omega$$

$d = v\,\text{Tan}\omega$, Total radial displacement = $2d = 2v\,\text{Tan}\omega$

Let centripetal acceleration = a units/sec^2

Total displacement in unit time, $2d = at^2 \div 2 = a \div 2$ (putting time, t = unit measure)

$$\therefore\ a \div 2 = 2v\ \text{Tan}\,\omega, \quad a = 4v\ \text{Tan}\,\omega$$

Considering action in inertial reference frame; External effort, $F = ma = 4mv\ \text{Tan}\ \omega$ **(3)**

Where 'F' is magnitude of centripetal effort (external effort), 'm' is mass (neglecting effects of linear speed on mass of macro body) and 'a' is linear acceleration of macro body due to centripetal effort. In case of a macro body moving in circular path, centripetal effort is the only external effort on it. Hence, magnitude of centripetal effort on the macro body is given by above equation (3). Centripetal effort of this magnitude alone can maintain circular path of macro body. There is no need for an assumed 'centrifugal force'. Linear speed of macro body should remain constant and centripetal effort of constant magnitude must continuously act on it.

If magnitude of centripetal effort is less than (4 mv Tan ω), linear speed of macro body gradually reduces and it moves away from centre of circular path to trace larger circular path. If magnitude of centripetal effort is greater than (4 mv Tan ω), linear speed of macro body increases and it gradually moves towards centre of its circular path to trace a smaller circular path.

In rotational reference frame, magnitude of centripetal effort (equal and opposite to magnitude of 'centrifugal force') given by equation (1) is F = (mv) ω. This equation is valid only for very small values of angular speeds, ω. Irrespective of magnitude of angular speed, magnitude of 'centrifugal force' is directly proportional to magnitude of angular speed of macro body. Should angular speed of macro body approaches or exceeds (п/2) rad/sec per completed circular path, result given by equation (1) becomes illogical.

In inertial reference frame, magnitude of centripetal effort is given by equation (3) as $[F = (mv) 4 \operatorname{Tan} \omega]$. This value may be taken as equivalent to assumed 'centrifugal force' on macro body. Here, magnitude of centripetal effort is related to linear momentum of macro body by factor (4 Tan ω). Trigonometric relation to 'tangent of angular speed' limits action of centripetal effort to macro bodies with angular speeds below (п/2) rad/sec per each completed circular path. When angular speed of macro body approaches (п/2) rad/sec per each completed circular path, magnitude of centripetal effort approaches infinite proportions. This shows that as direction of external effort become perpendicular to direction of linear motion of macro body, additional work associated with macro body and producing its linear motion is lost from its matter-field. Macro body's original linear motion is (partly) lost. Macro body is displaced in perpendicular direction to its original linear motion. It does not respond to lost additional work from its matter-field any more. Therefore, angular speed of macro body is limited to much less than (п/2) rad/sec per each completed circular path.

If spinning macro body is a mixture of different material of unequal densities and sizes, 3D matter-particles of higher matter-contents (mass) tend to have outward radial motion at higher speed, compared to those of lower mass. By equation (3), centripetal effort required to keep a 3D matter-particle in its circular path is proportional to its mass. Magnitude of centripetal effort that can be provided by integrity of a macro body depends on its consistency and it is common to all its 3D matter-particles. For two 3D matter-particles of different masses, moving in same circular path about macro body's centre of rotation, centripetal effort required by each of them is proportional to its mass. As magnitude of centripetal effort on all constituent 3D matter-particles is identical, heavier 3D matter-particles tend to enlarge their circular paths, by moving away from centre of rotation. Outward motion of heavier 3D matter-particles is due to lower magnitude of centripetal effort on them than that is required to keep their circular path stable, rather than due to action of fictional 'centrifugal force' on them. This is the working principle of centrifuge mechanisms.

Momentum and motion in circular path:

Momentum is the product of 'real mass' (equivalent to its matter-content) of a macro body and its absolute velocity. Mass is likely to change corresponding to magnitude of its absolute linear speed even without changes in matter-content. Linear speed in relative reference frame is an observed value with respect to another macro body, which may be moving in any direction at any linear speed. Therefore, momentum of a macro body, determined in relative reference frame has no relevance to its true parameters. Change in momentum, according to (Newton's) second law of motion, is the product of (constant) magnitude of 'force' and duration of its action on a macro body. In this concept, 'force' is the rate of additional work invested in matter-field of a macro body by an external effort. Hence, considering in absolute terms, momentum is proportional to total additional work in association with a macro body. Momentum of a rigid macro body is sum of momenta of all its 3D matter-particles. Being proportional to velocity, momentum is a vector quantity. It has both magnitude and direction. Although additional work associated with macro body is a scalar quantity, its actions are in the direction of its cause, the external effort. Additional work is transferred in the direction of external effort that caused it.

Consider a small macro body O, moving in circular path around a central point, to which it is attached by a rigid link or string OY, as shown in figure 2. At any instant, natural motion of macro body, OA, is in straight line, slightly deflected outward from tangent, XX, on its path. Action of centripetal effort displaces macro body towards centre of rotation during its travel, to curve its path. Figure 2 (not to scale) represents displacements of macro body in unit time. It shows macro body at point O in its circular path, POBT. XX is tangent to circular path at O. OA is macro body's instantaneous linear speed. OY is its displacement due to centripetal acceleration in unit time.

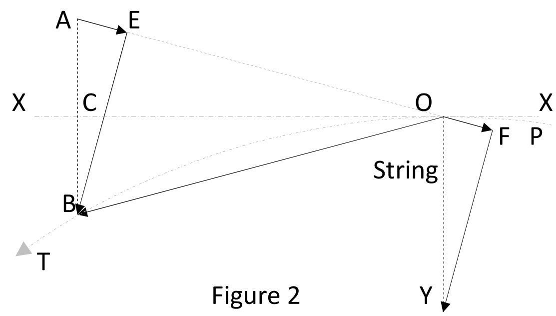

Figure 2

As macro body is moving in circular path, its future position at the end of unit time is at B. However, inertial action on macro body tends to take it to position A. This can be permitted only by extension of rigid link. Therefore, natural inertial motion of macro body due to its linear momentum attempts to increase length of rigid link. This action is assigned to imaginary 'centrifugal force'. Assumed action by 'centrifugal force' is nothing but an apparent action derived from macro body's linear motion. Inter-particle 'field effort' that maintains rigidity of link resists attempt by linear motion to extend its length. This reaction acts to pull macro body inward, towards centre of its path. Since reaction involves structural changes in matter-field of link, it is a real effort. This external effort, which is called centripetal effort, acts on macro body to curve its path.

Resolving displacement, OY, produced by centripetal effort, into two components; component, OF=AE, is in opposite direction and hence its action is to reduce linear speed (momentum) of macro body. It invests additional work with matter-field in opposite direction to additional work, which produces its inertial motion in straight line OA. Additional work corresponding to OF neutralises part of inertial motion OA by magnitude corresponding to AE. Total additional work in association with macro body is reduced to correspond to OE.

At the same time, perpendicular component of action of centripetal effort, FY = EB, displaces macro body to a new position, B, on circular path. By doing so, macro body's momentum is restored to value corresponding to its current linear motion, OB. Additional work, corresponding to component FY of action of centripetal effort, EB, adds to remaining additional work, corresponding to OE. Total magnitude of additional work in association with macro body now corresponds to OB, which is equal to magnitude of additional work, originally associated with it. Combining additional work corresponding to FY, which is perpendicular to additional work corresponding to OE, displaces macro body to position B on circular path. During its motion along circular path, macro body's momentum is kept constant, irrespective of continuous action of centripetal effort to accelerate it towards centre of circular path.

Linear momentum:

Linear momentum of a macro body corresponds to magnitude of additional work associated with it. As long as magnitude of associated additional work remains constant, its momentum does not change. Change in matter-content is accompanied by corresponding variation in linear velocity. State of motion depends on magnitude of additional work associated with a macro body. (Intrinsic work associated with it develops and sustains integrity of its 3D matter-particles and whole-body as a single unit). Magnitude of additional work remains constant unless changed by actions of external efforts. This tendency gives rise to phenomenon of 'conservation of linear momentum'. Changes in matter-content of macro body cannot vary additional work associated with it.

Due to latticework-structures of universal medium, additional work associated with a macro body can be transferred only in straight line. State of motion of a macro body, corresponding to certain value of additional work, can remain steady only as long as macro body (as a whole) is not deflected away from line of transmission of additional work (its matter-field). If macro body is deflected away from this straight-line, part of additional work is lost and its velocity reduces. If macro body is deflected from its straight-line motion by action of another external effort, macro body moves in resultant direction, while losing whole or part of additional works in both directions. Current displacements of its 3D matter-particles create additional work corresponding to resultant motion in association with matter-field, to change macro body's momentum to correspond to its present state of motion [1].

Centripetal effort continuously acts on a macro body, moving in circular path, to introduce additional work in its matter-field. At the same time, due to macro body's constant change of direction of motion, it loses part of additional work associated with its linear motion. Therefore, magnitude of total additional work, associated with macro body, moving in circular path, remains constant. Continuous action by constant magnitude of centripetal effort preserves constancy of linear speed and linear momentum of macro body. Magnitude of original inertial action on macro body is preserved.

Reduction in magnitude of centripetal effort reduces its action on macro body. Less additional work is invested with matter-field. Its path fails to deflect to suit motion in original circular path, as shown in figure 3. OY is displacement due to action of reduced centripetal effort. Resolved component of OY, OF acts in opposition to OA to reduce its magnitude to OE, which is more than magnitude of OE in figure 2. Macro body loses less additional work associated with its original inertial motion. Lower magnitude of additional work (invested by reduced centripetal effort) reduces deflection and magnitude of resultant motion, OB, from original inertial motion, OA. Macro body's new path, $POBT_1$, is deflected less from direction of its instantaneous linear motion, OA. (Original circular path is represented by POT). Outward deflection of instantaneous inertial motion moves macro body away from centre of rotation and enlarges its circular path.

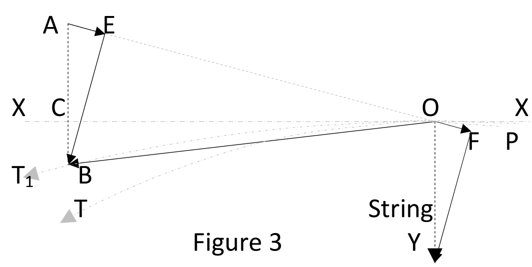

Figure 3

Magnitude of OB is less than that of OA. Instantaneous linear speed of macro body reduces. Matter-content of macro body being the same, reduction in its linear speed reduces macro body's linear momentum. Reduction in centripetal effort on macro body, moving in circular path, increases diameter of circular path with corresponding reduction in macro body's linear speed and linear momentum. Both these factors subscribe towards reduction in macro body's angular speed in its circular path.

Increase in magnitude of centripetal effort enhances its action on macro body to invest more additional work with its matter-field. Macro body deflects its path by greater magnitude than that is required to suit motion in original circular path, as shown in figure 4. OY represents motion due to action of enhanced centripetal effort. Resolved component of OY, OF acts in opposition to OA to reduce its magnitude to OE, which is less than magnitude of OE in figure 2.

Macro body loses more additional work associated with its original inertial motion. Higher magnitude of additional work (invested with its matter-field by enhanced centripetal effort) increases deflection and magnitude of its resultant motion, OB, from original inertial motion, OA. Macro body's new path, $POBT_1$, is deflected more from direction of its instantaneous linear motion, OA.

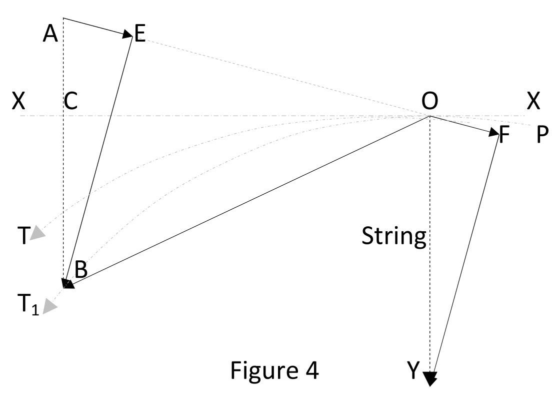

Figure 4

Original path is represented by POT. Inward deflection of instantaneous inertial motion moves macro body towards centre of rotation to shrink its circular path.

Matter content of macro body being the same, increase in its linear speed enhances its linear momentum. Increase in centripetal effort on a macro body, moving in circular path, increases magnitude of its resultant instantaneous linear speed and reduces diameter of its circular path. Macro body's linear momentum increases, corresponding to its linear speed. Both these factors subscribe towards enhancement in macro body's angular speed in its circular path.

Similar arguments hold good for linear momenta of every 3D matter-particle in a rotating body. In this case, centripetal effort on 3D matter-particles is continuously present, even when macro body is not rotating. It preserves integrity of macro body.

Angular momentum:

Angular momentum is a property related to rotating macro body (or macro body moving in circular path) representing its rotational inertia about an axis. It shows ability of macro body to continue its angular motion at a constant rate, presumably, without external torque on it. Since all inertial motions are in straight lines, it is imperative that centripetal effort of constant magnitude should act continuously on macro body to move it in circular path.

Although parameters of circular motion appear theoretically steady, it cannot be termed as a steady state of motion. Continuous action of centripetal effort necessitates uninterrupted linear acceleration of macro body towards its centre of rotation. Angular momentum can be sustained only as long as action of centripetal effort is present. Hence, angular momentum is an assumed parameter under imaginary conditions. In order to satisfy 'balance of efforts' during steady state of angular motion, real centripetal effort (acting continuously on macro body moving at a constant angular speed) is neutralised by imaginary 'centrifugal force' in opposite direction. This may help mathematical derivations but does not represent reality of actions. Angular momentum is a vector quantity, requiring specification of both magnitude and a direction for its complete description.

In cases of macro bodies, moving in circular paths, magnitude of angular momentum is equal to product of its linear momentum (product of its mass, m and average linear velocity, v) and perpendicular distance r from centre of rotation to line in the direction of macro body's average linear motion and passing through its centre of gravity. Magnitude of angular momentum, L, of a macro body moving in a circular path; $L = m\ v\ r$. Where 'm' is mass (representing its matter-content), 'v' is its average linear speed and 'r' is radius of its circular path.

Use of 'r' in equation facilitates to ignore continuous action by external effort – centripetal effort – on macro body. Changing magnitude of centripetal effort on macro body varies magnitude of its average linear speed 'v' and radius 'r' of its circular path. Currently, continuous action of centripetal effort (which is neutralised by assumed action by imaginary 'centrifugal force') is ignored and change in magnitude of radius 'r' is considered as cause of change in average linear speed of macro body. This phenomenon is the basis of 'law of conservation of angular momentum'.

To find real angular momentum of a macro body, moving in circular path, it is necessary to consider its parameters and parameters of its motion in absolute terms. Only real angular momentum can be considered, proportional to total additional work associated with macro body. By considering additional work associated with matter-field of macro body as the basis, radius of circular path does not appear in the equation. Radius of curvature of path, R, may be calculated from macro body's angular speed, ω, and average linear speed, v, in absolute reference frame by equation; $R = v / \omega$.

Angular momentum of a macro body, moving in circular (curved) path, is derived by relating its linear momentum to an axis perpendicular to the plane of and through centre of its circular path. No singular macro body can remain static in space. Therefore, all references with respect to macro bodies are relative references. Parameters of a macro body, moving in circular path, in relative reference frame cannot give its real angular momentum, corresponding to total additional work associated with it. Circular path in relative reference frame is not circular path in absolute reference frame. Behaviour of an independent macro body corresponds to its real parameters and real parameters can be obtained only in absolute reference frame. Angular momentum of a macro body, moving in circular path, becomes zero on termination of action by centripetal effort on it. Macro body is left only with its linear momentum. In other words, its angular momentum is not conserved. Angular momentum lasts only as long as centripetal effort is active.

Rotary motion:

Generally, macro bodies in solid state have higher viscosity. This keeps its integrity under usual conditions. Hence, every 3D matter-particle in a rotating solid macro body moves in circular path about its centre of rotation. Viscosity of body-material provides ample centripetal effort on its 3D matter-particles, to keep them in their circular paths. As centripetal effort is inherent in solid macro body, its actions are usually ignored, unless spin speed of macro body is very high or its radial size is very large.

In cases of spinning macro bodies, angular momentum is derived by relating linear momenta of all its 3D matter-particles to an axis of rotation. Sum of angular momenta of all 3D matter-particles gives angular momentum of macro body. It is equal to the product of moment of inertia of macro body about axis of rotation and its angular velocity. Angular momentum is not one of macro body's real parameter. Moment of inertia of a macro body depends on location of its axis of rotation. Magnitude of angular momentum depends on choice of observer in selecting axis of rotation. It is related more to relative location of spin axis than to macro body. Being proportional to velocity, linear momentum has direction; consequently, when a macro body rotates, momentum of each 3D matter-particle has moment about any point in its plane of rotation. Sum of these moments of momenta is called angular momentum of macro body about that point.

Angular momentum characterizes rotary inertia of a macro body about its axis of rotation. Since whole-body-linear motion of a spinning macro body is not usually considered during determination of its angular momentum, such angular momentum corresponds to relative reference frame with respect to centre of rotation of macro body. Centre of rotation of macro body is assumed static in space. In a rotating integral macro body, centripetal effort is provided by adhesion within it. Since this effort is always present, as long as rotating macro body maintains its integrity, magnitude of its angular momentum obeys law of conservation of angular momentum.

If macro body's axis of rotation is outside its border, its angular momentum has to be considered as in the case of angular momentum for macro bodies moving in circular paths (described in above paragraph). In cases of spinning macro bodies moving in curved paths, their angular momentum due to spin motion, angular momentum due to motion in curved path and momentum due to linear motion remain distinctly separate. In each case, additional work, associated with it, maintains its distinctive identity in macro body's matter-field. Changes in any one of them cannot vary the other two. However, motion of macro body may appear as resultant of all motions.

On termination of centripetal effort:

We shall consider the effects, when action of centripetal effort on a macro body (moving in circular path POBT in figure 1) is terminated, at point O. During inertial delay, after termination of centripetal effort, additional work already introduced into matter-field of macro body (at the instant of termination of centripetal effort) continues to accelerate it towards centre of circular path. Since centripetal effort is now terminated, magnitude of original acceleration due to additional work, introduced by centripetal effort, gradually reduces. This action continues until all acceleration components of additional work, introduced by (now-removed) centripetal effort are lost from macro body's matter-field. As magnitude of acceleration becomes zero after inertial delay, we can take average magnitude of acceleration during inertial delay is equal to half the value of acceleration during action of centripetal effort.

Let magnitude of additional work, due to centripetal effort, in steady state of motion in circular path = W

Magnitude of additional work, due to centripetal effort, at the instant of its termination = W

Magnitude of additional work, due to centripetal effort, at the end of inertial delay = 0

Average magnitude of additional distortions, due to centripetal effort, during inertial delay = W/2

Centripetal acceleration is proportional to magnitude of additional work in macro body's matter-field.

Average centripetal acceleration during inertial delay = a/2. (Let inertial delay = t units)

Using equation of linear motion, displacement = ½ at^2, where 'a' is the linear acceleration; and 't' is time;

Displacement of macro body, due to reduced centripetal acceleration after termination of centripetal effort, during inertial delay = $a\,t^2 / 4$

Macro body attains its steady state of motion on completion of acceleration period and in the mean time; it is displaced by a distance, ($a\,t^2 / 4$), to point C on the tangent XX through point O on circular path. At point C, macro body has no action on it by terminated centripetal effort, to curve its path. Macro body continues to move in steady state of linear motion under inertia associated with it, along OC, which coincides with tangent to circular path at point O. This is the reason, why a macro body moving in circular path or a 3D matter-particle from a rotating macro body, released from centripetal effort, moves in tangential direction to its circular path. Original direction of macro body's instantaneous present linear motion is along OA, which is deflected outward from tangent, XX. Angular deflection of direction of instantaneous linear motion, OA, creates illusion that the body is trying to move away from centre of curvature of circular path under action of imaginary effort, 'centrifugal force'. Imaginary efforts cannot act on a real entity.

At any instant, a 3D matter-particle, O, (in figure 5) at periphery of a spinning wheel has two simultaneous motions. (Here, a very small part of wheel is taken as a unit 3D matter-particle and motions of its individual constituents are ignored). One motion, OA, displaced by an outward angular deflection from tangent, XX, is provided by its linear speed along circular path, POBD. Another linear motion, OE, is displacement provided by centripetal effort due to viscosity, which maintains integrity of wheel. Centripetal effort accelerates 3D matter-particle towards centre of rotation of spinning wheel. In this state, system is stable and 3D matter-particle at the rim of wheel moves in a circular path relative to its centre of rotation. 3D matter-particle has constant linear speed; it is simultaneously under constant radial velocity and constant radial acceleration. Word 'constant' indicates that numerical values of speed, velocity and acceleration do not vary.

In figure 5, curved line POBD shows part of circular path of 3D matter-particle, O. Its present instantaneous linear motion at O is represented by arrow, OA, which is equal to V (being displacement in unit time). Instantaneous lateral motion, a/2, due to centripetal effort is represented by arrow, OE. Line XOX is tangent to circular path at O. Resultant instantaneous motion of 3D matter-particle, along its circular path, POBD, is shown by the arrow, OB.

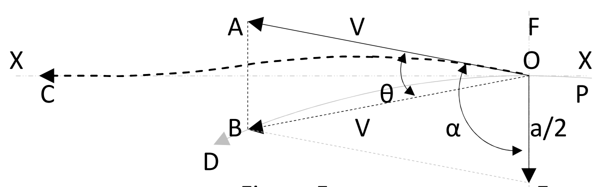

Figure 5

$$AB = OE = a \div 2, \quad OA = OB = V, \quad \angle AOB = \theta, \quad \angle AOE = \alpha$$

By parallelogram law of forces; $OB^2 = OA^2 + OE^2 + 2 \times OA \times OE \times \mathrm{Cos}\angle AOE$

$$V^2 = V^2 + \left(\tfrac{a}{2}\right)^2 + 2\,V\,\tfrac{a}{2}\ \mathrm{Cos}\,\alpha\,,\ \left(\tfrac{a}{2}\right)^2 = -2\,V\,\tfrac{a}{2}\ \mathrm{Cos}\,\alpha\,,\ \ a = -4\,V\,\mathrm{Cos}\,\alpha$$

$$\tfrac{a}{4V} = -\,\mathrm{Cos}\,\alpha = \mathrm{Cos}\,(180-\alpha)\,, \quad \alpha = 180 - \mathrm{Cos}^{-1}\,\tfrac{a}{4V}\,,\ \angle AOC = \tfrac{\theta}{2} = (\alpha - 90)\ \text{degrees}$$

Substituting value of α; outward deflection of present instantaneous linear motion from tangent:

$$\tfrac{\theta}{2} = \left(180 - \mathrm{Cos}^{-1}\,\tfrac{a}{4V}\right) - 90 = 90 - \mathrm{Cos}^{-1}\,\tfrac{a}{4V}\ \text{degrees} \qquad \textbf{(4)}$$

Let the 3D matter-particle detach from wheel, when it reaches point O. Linear speed tends to carry it in a direction, deflected outward from tangent to circular path, by (θ/2) degrees. At the instant of detachment, 3D matter-particle is also under centripetal effort and this effort has been providing its radial acceleration. When unity of 3D matter-particle with wheel is lost, centripetal effort is no more present, on it. However, radial acceleration, provided by centripetal effort, takes inertial delay to die away. If inertial delay is taken as unit time, displacement of 3D matter-particle in radial direction, i.e., towards tangent is numerically equal to half the magnitude of radial acceleration. In other words, direction of motion of detached 3D matter-particle changes to tangential line during inertial delay and by action of centripetal effort that existed at the instant of detachment. Curved dashed arrow OC, in figure 5, shows the approximate path of 3D matter-particle after it broke away from rotating wheel, until it achieves a steady state of motion along tangent, XX. If 3D matter-particle was originally moving along tangent, it would appear to fly away from rim along a path that is deflected inward from tangent. This does not happen.

Generally, component of linear motion of 3D matter-particle (deflected outward from tangent), perpendicular to tangent is attributed to imaginary 'centrifugal force'. In such case, present instantaneous linear motion of 3D matter-particle is assumed in tangential direction to its circular path, same as its average linear motion.

Conclusion:

Outward component of instantaneous motion of a macro body, moving in circular path, is attributed to imaginary 'centrifugal force'. Action of external effort on a macro body does not cease on terminating the effort. Identical inertial delay is applicable after termination of an effort as during initial period of action of effort. Direction of instantaneous linear motion of a body, moving in circular path, is deflected outward from tangent to circular path.

Reference:

[1] Nainan K. Varghese, *MATTER (Re-examined)*, http://www.matterdoc.info

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