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

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

Introduction:

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

Relative reference frames of observations, related to states of motion of macrobodies, 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, the phenomenon of inertia compels a moving macrobody (in its stable state) to travel in a straight-line path.

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

Resultant of two motions:

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

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

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

(3) If they are in any direction other than the direction of the additional structural distortions already present and maintaining the inertial motion of the macrobody, accelerate the macrobody in their direction and deflect the macrobody's present direction of motion. Depending on the direction, they may enhance or diminish macrobody's linear speed.

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

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

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

During macrobody's displacement towards the centre of curvature of its path, certain part of additional work (producing its motion in a 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 structural distortions together form resultant additional structural distortions in the matter-field, to produce its motion in the resultant direction. Instantaneous changes in the resultant direction of the macrobody's motion curve its path.

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

'Centrifugal force':

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

Observations related to the states of motion of macrobodies do not appear true in accelerated (non-inertial) reference frames. Instead, in an accelerated reference frame, moving macrobodies appear under the actions of external efforts that are not 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.

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

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

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

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

'mv' is the linear momentum of the macrobody. Considering the magnitude of the 'centrifugal force' in terms of linear momentum of macrobody;

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

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

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

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

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

Motion in circular path:

The mechanism of motion, envisaged in this concept, explains the motion of a macrobody in a circular path without the assumption of 'centrifugal force' and with respect to an absolute reference frame. Currently, due to a lack of absolute reference, we are unable to determine the true parameters of a macrobody's motion. It is also understood that the state of motion of the macrobody has some 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 macrobody's motion by checking symmetry of its shape.

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

In Figure 1, the linearly moving macrobody is currently at position O. POBT is part of its circular path. OA is its instantaneous displacement in magnitude and direction in unit time, due to the present linear speed. Y'Y is its instantaneous displacement, in magnitude and direction in unit time, due to the 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 macrobody.

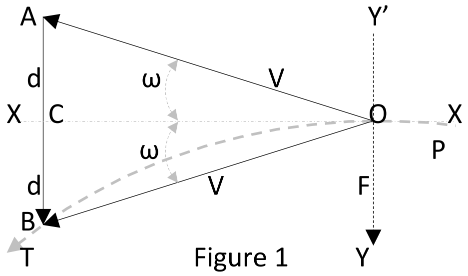

Figure 1

From Figure 1, the direction of instantaneous linear motion of the macrobody is deflected outwards from tangent XX to the circular path. [The reason why instantaneous linear motion appears tangential to the 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 the tangent XX to the circular path. Magnitudes of angular deflections, ω, are proportional to the macrobody's centripetal acceleration and curvature of the circular path.

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

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

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

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

Magnitude of additional work, done about macrobody (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, the macrobody is displaced to position B, the result of the original additional work associated with the macrobody's momentum and the additional work introduced by the centripetal effort in unit time.

Let OA represent macrobody'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, the macrobody moves in a circular path. At the same time, the system of efforts on the macrobody is not balanced, and the magnitude of external effort on the macrobody is not nil. To move in a circular path, the macrobody's instantaneous linear speeds at all points on its path should be the same, while the magnitude of external effort also remains constant. Therefore, in circular motion, a macrobody can appear in a steady state of motion even while it is under the action of an external effort.

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

Average linear velocity of the macrobody, 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 macrobody along tangent, v = V Cos ω

Macrobody continues to move in a circular path. The 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 macrobody moving at constant linear speed, moving in a circular path, as shown in Figure 1. OA represents the magnitude of additional work in association with its momentum or its instantaneous present linear speed, V. AB is the magnitude of additional work introduced for its displacement due to the action of centripetal effort, Y'Y. OB is the resultant additional work in association for its instantaneous resultant linear speed. Since OA = OB, the macrobody travels in a 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 macrobody in circular path is measured with respect to tangents to the path.

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

Total angular deflection of macrobody'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 the action in inertial reference frame; External effort, $F = ma = 4mv\ \text{Tan}\ \omega$ **(3)**

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

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

In a rotational reference frame, the magnitude of centripetal effort (equal and opposite to the 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 the magnitude of angular speed, the magnitude of 'centrifugal force' is directly proportional to the magnitude of angular speed of the macrobody. Should the angular speed of the macrobody approach or exceed (п/2) rad/sec per completed circular path, the result given by equation (1) becomes illogical.

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

If a spinning macrobody is a mixture of different materials 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), the centripetal effort required to keep a 3D matter-particle in its circular path is proportional to its mass. The magnitude of centripetal effort that can be provided by the integrity of a macrobody depends on its consistency, and it is common to all its 3D matter-particles. For two 3D matter-particles of different masses, moving in the same circular path about the macrobody's centre of rotation, the centripetal effort required by each of them is proportional to its mass. As the 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 the centre of rotation. Outward motion of heavier 3D matter-particles is due to a lower magnitude of centripetal effort on them than that is required to keep their circular path stable, rather than due to the action of a 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 3D matter-content) of a macrobody and its absolute velocity. Mass is likely to change corresponding to the magnitude of its absolute linear speed even without changes in 3D matter-content. Linear speed in a relative reference frame is an observed value with respect to another macrobody, which may be moving in any direction at any linear speed. Therefore, the momentum of a macrobody, determined in a relative reference frame, has no relevance to its true parameters. Change in the momentum, according to (Newton's) second law of motion, is the product of (the constant) magnitude of 'force' and duration of its action on a macrobody. In this concept, 'force' is the rate of additional work invested in the matter-field of a macrobody by an external effort. Hence, in absolute terms, momentum is proportional to the total additional work in association with a macrobody. Momentum of a rigid macrobody is the sum of momenta of all its 3D matter-particles. Being proportional to the velocity, momentum is a vector quantity. It has both magnitude and direction. Although additional work associated with a macrobody is a scalar quantity, its actions are in the direction of its cause, the external effort. Additional work is transferred in the direction of the external effort that caused it.

Consider a small macrobody O, moving in a 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, the natural motion of the macrobody, OA, is in a straight line, slightly deflected outward from the tangent, XX, on its path. Action of the centripetal effort displaces the macrobody towards the centre of rotation during its travel, and curves its path. Figure 2 (not to scale) represents the displacements of the macrobody in unit time. It shows the macrobody at point O in its circular path, POBT. XX is tangent to the circular path at O. OA is the macrobody's instantaneous linear speed. OY is its displacement due to centripetal acceleration in unit time.

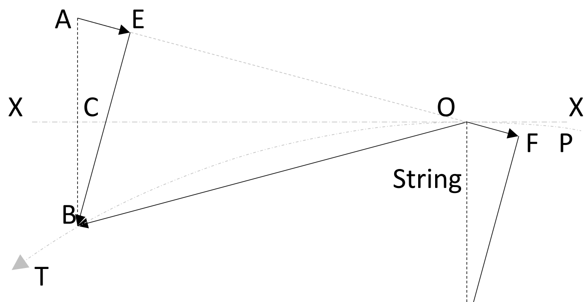

Figure 2

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

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

At the same time, the perpendicular component of action of centripetal effort, FY = EB, displaces macrobody to a new position, B, on the circular path. By doing so, macrobody's momentum is restored to the 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 macrobody 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 macrobody to position B on circular path. During its motion along circular path, macrobody'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 macrobody corresponds to the magnitude of additional work associated with it. As long as the magnitude of associated additional work remains constant, its momentum does not change. A change in 3D matter-content is accompanied by a corresponding variation in the linear velocity. The state of motion depends on the magnitude of the additional work associated with a macrobody. (Intrinsic work associated with it develops and sustains the integrity of its 3D matter-particles and the whole-body as a single unit). The magnitude of additional work remains constant unless changed by the actions of external efforts. This tendency gives rise to the phenomenon of 'conservation of linear momentum'. Changes in the 3D matter-content of macrobody cannot vary the additional work associated with it.

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

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

A reduction in the magnitude of centripetal effort reduces its action on the macrobody. Less additional work is invested in the matter-field. Its path fails to deflect to suit the motion in the original circular path, as shown in Figure 3. OY is displacement due to the action of the reduced centripetal effort. Resolved component of OY, OF acts in opposition to OA to reduce its magnitude to OE, which is more than the magnitude of OE in Figure 2. Macrobody loses less additional work associated with its original inertial motion. Lower magnitude of additional work (invested by

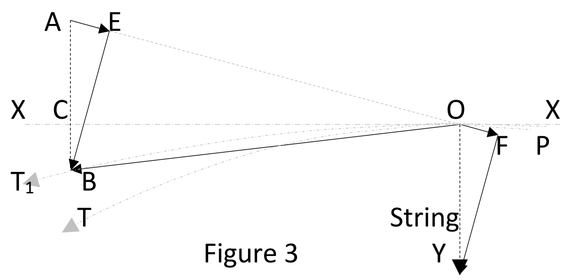

Figure 3

reduced centripetal effort) reduces deflection and magnitude of resultant motion, OB, from original inertial motion, OA. Macrobody's new path, $POBT_1$, is deflected less from the direction of its instantaneous linear motion, OA. (The original circular path is represented by POT). Outward deflection of instantaneous inertial motion moves the macrobody away from the centre of rotation and enlarges its circular path.

The magnitude of OB is less than that of OA. The instantaneous linear speed of the macrobody reduces. 3D matter-content of macrobody being the same, reduction in its linear speed reduces macrobody's linear momentum. Reduction in the centripetal effort on the macrobody, moving in a circular path, increases the diameter of the circular path with a corresponding reduction in the macrobody's linear speed and linear momentum. Both these factors contribute towards a reduction in macrobody's angular speed in its circular path.

An increase in the magnitude of centripetal effort enhances its action on the macrobody to invest more additional work with its matter-field. The macrobody deflects its path by a greater magnitude than that required to suit the motion in the original circular path, as shown in Figure 4. OY represents motion due to the 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 the magnitude of OE in Figure 2.

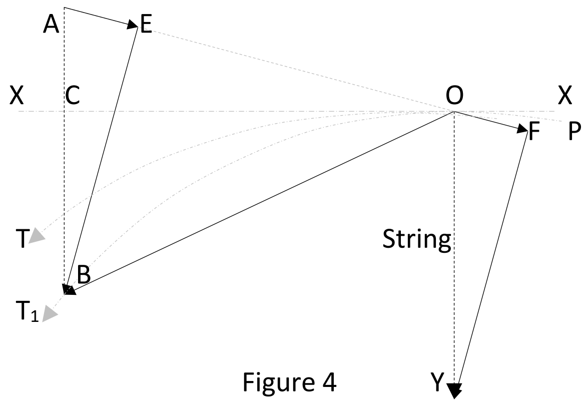

Figure 4

Macrobody 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. Macrobody's new path, $POBT_1$, is deflected more from the direction of its instantaneous linear motion, OA. The original path is represented by POT. Inward deflection of instantaneous inertial motion moves the macrobody towards the centre of rotation to shrink its circular path.

3D matter content of the macrobody being the same, an increase in its linear speed enhances its linear momentum. An increase in the centripetal effort on a macrobody, moving in a circular path, increases the magnitude of its resultant instantaneous linear speed and reduces the diameter of its circular path. Macrobody's linear momentum increases, corresponding to its linear speed. Both these factors contribute to the enhancement in macrobody's angular speed in its circular path.

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

Angular momentum:

Angular momentum is a property related to a rotating macrobody (or a macrobody moving in a circular path) representing its rotational inertia about an axis. It shows the ability of the macrobody 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 a centripetal effort of constant magnitude should act continuously on the macrobody to move it in a circular path.

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

In cases of macrobodies moving in circular paths, the magnitude of angular momentum is equal to the product of its linear momentum (product of its mass, m and average linear velocity, v) and the perpendicular distance r from the centre of rotation to a line in the direction of the macrobody's average linear motion and passing through its centre of gravity. Magnitude of angular momentum, L, of a macrobody 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 the radius of its circular path.

Use of 'r' in the equation facilitates ignoring continuous action by external effort – centripetal effort – on macrobody. The changing magnitude of centripetal effort on the macrobody varies the 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 a change in the magnitude of radius 'r' is considered as the cause of change in the average linear speed of macrobody. This phenomenon is the basis of the 'law of conservation of angular momentum'.

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

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

Rotary motion:

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

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

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

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

On termination of centripetal effort:

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

Let the 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 structural distortions, due to centripetal effort, during inertial delay = W/2

Centripetal acceleration is proportional to magnitude of additional work in macrobody'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 macrobody, due to reduced centripetal acceleration after termination of centripetal effort, during inertial delay = $a\,t^2 / 4$

Macrobody 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, the macrobody has no action by the terminated centripetal effort to curve its path. Macrobody continues to move in a steady state of linear motion under inertia associated with it, along OC, which coincides with the tangent to the circular path at point O. This is the reason why a macrobody moving in a circular path or a 3D matter-particle from a rotating macrobody, released from centripetal effort, moves in a tangential direction to its circular path. The original direction of macrobody's present instantaneous linear motion is along OA, which is deflected outward from the tangent, XX. Angular deflection of the direction of instantaneous linear motion, OA, creates an illusion that the body is trying to move away from the centre of curvature of the circular path under the action of an imaginary effort, 'centrifugal force'. Imaginary efforts cannot act on a real entity.

At any instant, a 3D matter-particle, O, (in Figure 5) at the periphery of a spinning wheel has two simultaneous motions. (Here, a very small part of the 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 the tangent, XX, is provided by its linear speed along the circular path, POBD. Another linear motion, OE, is the displacement provided by the centripetal effort due to viscosity, which maintains the integrity of the wheel. The centripetal effort accelerates the 3D matter-particle towards the centre of rotation of the spinning wheel. In this state, the system is stable, and the 3D matter-particle at the rim of the 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. The word 'constant' indicates that numerical values of speed, velocity and acceleration do not vary.

In Figure 5, curved line POBD shows part of the 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 the arrow, OE. Line XOX is tangent to the circular path at O. Resultant

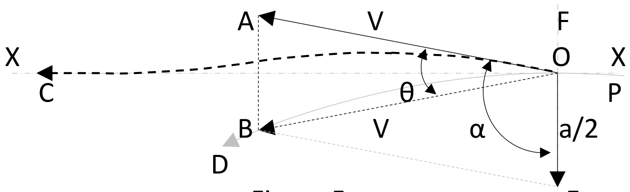

Figure 5

instantaneous motion of 3D matter-particle, along its circular path, POBD, is shown by the arrow, OB.

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

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

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

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

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

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

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

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

Conclusion:

The outward component of the instantaneous motion of a macrobody, moving in a circular path, is attributed to an imaginary ‘centrifugal force’. The action of external effort on a macrobody does not cease upon terminating the effort. Identical inertial delay is applicable after the termination of an effort, as during the initial period of the action of the effort. The direction of the instantaneous linear motion of a body moving in a circular path is deflected outward from the tangent to the circular path.

Reference:

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

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