Superluminal Velocities in the Synchronized Space-Time

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Within the framework of the non-gravitational generalization of the special relativity, a problem of possible superluminal motion of particles and signals is considered. It has been proven that for the particles with non-zero mass the existence of anisotropic light barrier with the shape dependent on the reference frame velocity results from the Tangherlini transformations. The maximal possible excess of neutrino velocity over the absolute velocity of light related to the Earth (using the clock with instantaneous synchronization) has been estimated. The illusoriness of the acausality problem has been illustrated and conclusion is made on the lack of the upper limit of velocities of signals of informational nature.

1 Introduction

In the special relativity (SR) the velocity of establishing connection between two events "1" and "2" (particle motion, information transfer, quantum teleportation and so on) could not exceed the velocity of light c in vacuum. The attempts to overcome such a prohibition encounter the problem of causality principle violation, namely, if in the initial inertial reference frame (IRF) K a signal moves with the superluminal velocity $u > c$, then exists such IRF K' that moves with the velocity $v < c$, but $\mathbf{v} \cdot \mathbf{u} > c^2$, in which the event-effect "2" anticipates the event-cause "1", $t'_2 < t'_1$ (while in the K IRF – $t_2 > t_1$). In some papers (see, e.g. [1]) the extreme paradoxicalness of this problem, namely, the appearance of the acausal loops, when the cyclic process terminates at the point of its beginning, but before its beginning, is discussed. The absurdity of acausality leads one to the conclusion about the existence of the isotropic light barrier, i.e. in the space of the possible velocities of particles and signals that realize the cause-and-effect relationship the velocity vectors lie inside the sphere of the radius c. In other words, the 4-interval between the cause-and-effect events could be the time-like one only. The event-effect must be inside the light cone of the future event-cause. All the mentioned above follows from the Lorentz transformations (LT).

Below, however, we will show that the causality principle violation is illusory, and the assumption about the possibility of the appearance of the acausal loop is wrong. This problem is discussed in detail in Sect. 6, while here we will indicate only the important fact noted by Leonid I. Mandelstam in his SR-related lectures [2]: the time involved in LT is measured by the clock synchronized by the light signals with *a priori* assumption about the light velocity invariance. The consequence of such synchronization (in fact, the consequence of the light velocity invariance postulate) is the relativity of simultaneity: the spatially split events, simultaneous in one IRF, are not simultaneous in the other one, i.e. $t'_2 \neq t'_1$ at $t_2 = t_1$. Mandelstam in the same lectures explained also that in case of using the clock with instantaneous synchronization at the spatially split points the simultaneity of events will be absolute. Hence the irrefutable logical conclusion follows about the non-invariance of the velocity of light measured using the clock with instantaneous synchronization (because from the light velocity invariance the simultaneity relativity follows). The principal possibility of such synchronization was proven in the works by Vitaliy L. Ginzburg and his followers (see, e.g. [3]). Namely, the clock at the points "1" and "2" could be synchronized by means of a photo relays switched on by the light spot that moves from "1" to "2" with the velocity $V = \omega R$ at the light source rotation with the angular velocity ω (the light source being located at the distance R). Since the product ωR could be, in principle, unrestrictedly large, $\omega R \gg c$, then $V \gg c$ as well, i.e. such synchronization can be considered almost instantaneous. For instance, the above light spot produced by the emission of the *NP*.0532 pulsar in the Crab nebula moves the Earth surface with the velocity $V = 1.2 \times 10^{22}$ m/s ($\omega = 200$ rad/s, $R = 6 \times 10^{19}$ m). Another way of almost instantaneous synchronization was realized in Marinov's experiments [4, 5] on measuring the velocity of the Earth with respect to the ether (see below Sect. 3).

Note that in the classical physics the clock at the spatially split points is considered synchronized just by the instantaneous signals. As shown below, to explain the lack of interference in the Michelson-Morley (MM) experiment [6] there was no necessity to change the above synchronization and, thus, discard such a fundamental property of time as the absolute simultaneity of the spatially split events. The theoretical model of relativistic processes for the case of instantaneously synchronized clock was developed, mainly, in the Frank R. Tangherlini's Ph.D thesis [7, 8] (see also [9]). In this model, the existence of a dedicated absolute inertial reference system (AIRF), in which the velocity of light is isotropic, is postulated. It seems most naturally to represent this reference system as resting with respect to the ether. Note that the lack of the ether does not follow from the MM experiment, this experiment failed only to find its presence for the reason explained in Sect. 2. The second postulate of this theory is the invariance of the average velocity of light at the motion along the closed contour, just this property of the light velocity follows with the necessity from the MM experiment and all the following interference experiments, in which the light either passed twice the same distance or moved around a closed loop (see, e.g. [10, 11]). The following space-time transformations (i.e. the Tangherlini transformations, TT) [7, 8] are obtained from the above postulates:

$$x' = \gamma(x - vt), \qquad y' = y, \qquad z' = z; \tag{1}$$

$$t' = \frac{t}{\gamma}, \qquad \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2}. \tag{2}$$

Here (x, y, z, t) are the coordinates and time of the point event in AIRF K, whereas (x', y', z', t') are those in the IRF K' that moves with the velocity v along the X-axis in AIRF K.

A detailed discussion of the above transformations as well as the new ways of their deriving could be found in [12–19]. Relation (2) demonstrates the absolute simultaneity: from the condition $\Delta t = 0$ follows that $\Delta t' = 0$ as well. Therefore, one may, similarly to [18, 19], call TT the "synchronized transformations".

One may call the TT-based theory the "non-gravitational SR generalization" (see Sect. 7 below).

As shown in the pioneer work [7, 8], the main experimentally verified LT and TT consequences coincide (since they do not depend on the way of synchronizing the clock). In particular, both TT and LT equally successfully explain the MM experiment [6] and all the following interference experiments. The same results are obtained by calculating the momentum-energy characteristics as well (see below equations (29) and (30)).

Only the values of velocities (and other physical values determined by the time derivative) differ. In Sect. 2, the transformation properties of the velocity characteristics in the Tangherlini theory (TTh) are described and the "coefficient of recalculation" of these characteristics from TTh to SR and *vice versa* is obtained. These results are used in Sect. 3 to obtain the theoretical estimates of the possibility of the excess of the neutrino velocity u' (with respect to the Earth) over the absolute velocity of light c, i.e. the velocity of light with respect to AIRF. It is proved in Sect. 4 that the particle having a non-zero rest mass cannot go before the light when moving in the same direction in any IRF. Its velocity u' may only exceed the absolute velocity of light c, i.e. the situation may occur when $c < u'(\theta') < c'(\theta')$, where c' is the velocity of light with respect to IRF K'. Thus, in TTh the light barrier (isotropic in SR) appears to be anisotropically deformed, and the degree of such deformation depends on the velocity v of IRF K'. The light cone undergoes the similar deformation (see Sect. 4). It is explained in Sect. 5 why the mass of the particle moving with the velocity exceeding the absolute velocity of light c remains real (unlike the tachyon mass in SR). Section 6 is dedicated to the discussion of the properties of time in TTh and SR. The illusoriness of the problem of violation of the causality principle in SR and, hence, that of prohibition of motion with superluminal velocity have been found. The final remarks and conclusions are presented in Sect. 7.

2 Transformational properties of the velocity characteristics in the Tangherlini theory

Let $\mathbf{u} = (u_x; u_y; u_z)$ be the vector of the velocity of the particle with respect to AIRF K. Let us determine the value and direction of the velocity $\mathbf{u}'$ in IRF K' that moves with the velocity v along the X-axis in AIRF K. From TT (1), (2) we obtain [7, 8]:

$$u'_x = \gamma^2(u_x - v), \qquad u'_y = \gamma u_y, \qquad u'_z = \gamma u_z. \tag{3}$$

Hence, the below expressions for the velocity $u' \equiv |\mathbf{u}'|$ and angle $\theta' = (\widehat{\mathbf{u}', \mathbf{v}})$ follow from here:

$$u'(\mathbf{u}, \mathbf{v}) = \frac{\sqrt{(\mathbf{u} - \mathbf{v})^2 - \left(\frac{\mathbf{u}\times\mathbf{v}}{c}\right)^2}}{1 - \frac{v^2}{c^2}}, \tag{4}$$

$$\cos\theta' = \frac{\cos\theta - \frac{v}{u}}{\sqrt{\left(\cos\theta - \frac{v}{u}\right)^2 + \left(1 - \frac{v^2}{c^2}\right)\sin^2\theta}}. \tag{5}$$

If we use LT to calculate the velocity projections in IRF K', we obtain:

$$\tilde{u}'_x = \frac{u - v}{1 - \frac{uv\cos\theta}{c^2}}, \ \tilde{u}'_y = \frac{u_y}{\gamma\left(1 - \frac{uv\cos\theta}{c^2}\right)}, \ \tilde{u}'_z = \frac{u_z}{\gamma\left(1 - \frac{uv\cos\theta}{c^2}\right)}. \tag{6}$$

Here and below "$\sim$" denotes characteristics calculated from LT.

As seen, each of projections of the vector $\mathbf{u}'$ is obtained by multiplying the relevant projection of the vector $\tilde{\mathbf{u}}'$ onto the same "coefficient of recalculation"

$$\chi = \frac{1 - \frac{\mathbf{u}\cdot\mathbf{v}}{c^2}}{1 - \frac{v^2}{c^2}}; \tag{7}$$

$$u'_x = \tilde{u}'_x\chi, \qquad u'_y = \tilde{u}'_y\chi, \qquad u'_z = \tilde{u}'_z\chi. \tag{8}$$

Hence, two conclusions result here:

1. The directions of the vectors $\mathbf{u}'$ and $\tilde{\mathbf{u}}'$ coincide.
2. The value of the velocity in TTh is obtained by multiplying this value in SR u' by χ: $u' = \chi\tilde{u}'$, where

$$\tilde{u}'(\mathbf{u}, \mathbf{v}) = \frac{\sqrt{(\mathbf{u} - \mathbf{v})^2 - \left(\frac{\mathbf{u}\times\mathbf{v}}{c}\right)^2}}{1 - \frac{\mathbf{u}\cdot\mathbf{v}}{c^2}}. \tag{9}$$

The nature of the coefficient χ is easy to understand: it arises due to the difference in the ways of synchronizing the clock in SR and TTh. As the consequence of this difference, we obtain the following relation between the time intervals in

TTh and SR for the particle that moves with the velocity $\mathbf{u}$ in AIRF K (see Sect. 6):

$$dt' = \frac{d\tilde{t}'}{\chi}. \tag{10}$$

Thus, the time interval between two events (in the same IRF) differs dependent of the way of the clock synchronization. What time is more adequate to the physical reality — t' or $\tilde{t}'$? The answer to this question is discussed below in Sect. 6.

Using the reverse TT, one may express the coefficient χ through $\mathbf{u}'$ and $\mathbf{v}$ (and through $\tilde{\mathbf{u}}'$, $\mathbf{v}$):

$$\chi = 1 - \frac{\mathbf{u}' \cdot \mathbf{v}}{c^2} = \frac{1}{1 + \frac{\tilde{\mathbf{u}}' \cdot \mathbf{v}}{c^2}}. \tag{11}$$

Consider an important particular case: i.e. the transformational properties of the velocity of light. If in AIRF K the light propagates with the velocity c at the angle θ with respect to the X-axis, then we obtain from (4) and (5):

$$c'(v, \theta) = c\frac{1 - \frac{v}{c}\cos\theta}{1 - \frac{v^2}{c^2}}, \tag{12}$$

$$\cos\theta' = \frac{\cos\theta - \frac{v}{c}}{1 - \frac{v}{c}\cos\theta}. \tag{13}$$

From (13) we obtain:

$$\cos\theta = \frac{\cos\theta' + \frac{v}{c}}{1 + \frac{v}{c}\cos\theta'}. \tag{14}$$

Relations (13) and (14) coincide with the relevant SR formulae. Inserting (14) into (12) we obtain [7, 8]:

$$c'(v, \theta') = \frac{c}{1 + \frac{v}{c}\cos\theta'}. \tag{15}$$

In the 1^{st} degree of expansion in v/c, expression (15) coincides with that resulted from the Galilean velocity addition:

$$c'(v, \theta') = c - v\cos\theta' + o\left(\frac{v^2}{c^2}\right). \tag{16}$$

Formula (15) describes the anisotropy of the velocity of light in IRF K'. Such anisotropy was observed in [20, 21]. Note that formula (15) does not contradict the postulate of the light velocity invariance in SR, what is meant here are the two different velocities differing in the way of synchronizing the clock they are determined by. It is easy to state that formula (15) explains the lack of interference in the MM experiment [6] since the time of the "back and forth" motion is

$$t_{\uparrow\downarrow} = t_\uparrow + t_\downarrow = \frac{L}{c'(\theta')} + \frac{L}{c'(\theta' + \pi)} = \frac{2L}{c} = \text{invar}. \tag{17}$$

Formula (15) enables one to understand how the ether "hided" from Michelson (more exactly, it did not allow him to find it), i.e. at adding the reverse velocities in (17) the "ether terms" are mutually abolished. The reader has to recognize the methodological value of formula (15), since it indicates that the lack of interference in the MM experiment could be explained not postulating the assumption about the independence of the velocity of light on the observer's motion velocity. All the difficulties in the time behavior in SR seat in this assumption.

3 Estimation of the possible excess of the absolute velocity of light in IRF related to the Earth

Let us use equation (4) to obtain the estimate of the possible excess of the neutrino velocity over the absolute velocity of light. Let v and u be the velocity of the Earth and that of neutrino with respect to AIRF K (conditionally speaking, with respect to the ether), respectively, u' be the neutrino velocity value with respect to the Earth. According to Marinov's measurements [4, 5]

$$v = (360 \pm 40) \text{ km/s}. \tag{18}$$

The same estimate follows from the analysis of the experimental data on the light velocity anisotropy [20, 21].

Let us assume that the velocity u is very close to the velocity of light c: $u = c - \delta$, $\delta \ll c$. Taking also into account that $v \ll c$, we obtain from (4) to the accuracy of the first-order values over v/c and δ/c:

$$\frac{u' - c}{c} = -\frac{v}{c}\cos\theta - \frac{\delta}{c}, \qquad \theta = (\widehat{\mathbf{u}, \mathbf{v}}). \tag{19}$$

At the neutrino energies of the order of GeV, taking into account the smallness of the neutrino rest mass (several eV), $\delta \ll v$. Then

$$\frac{u' - c}{c} = -\frac{v}{c}\cos\theta. \tag{20}$$

The maximal value of the above excess is reached at $\theta = \pi$:

$$\left(\frac{u' - c}{c}\right)_{MAX} = (121 \pm 13.3) \times 10^{-5}, \tag{21}$$

This is approximately 50 times larger than the infamous CERN result [22] obtained with a technical mistake that, obviously, could not be considered the contestation of theoretical estimates (20) and (21). It is important to achieve the correct confirmation of estimates (20) and (21) for the sake of the further progress of physics. To do this it is necessary to ensure the clock synchronization close to instantaneous. One may also use the "light synchronization" (GPS) that is more convenient technically, but in this case one has to take into account in (15) the difference of velocities of electromagnetic signals propagating in the opposite directions.

Note that in case of the use of the clock synchronized "according to Einstein" we may obtain from (9) for the situation under discussion:

$$\frac{\tilde{u}' - c}{c} = -\left(\frac{v}{c}\cos\theta\right)^2 \qquad \Rightarrow \qquad \tilde{u}' < c, \tag{22}$$

i.e. the "superluminal" motion would not be observed as is true according to SR.

Note a specific circumstance: the estimate (20) could be obtained from the Galilean velocity addition $\mathbf{u}' = \mathbf{u} - \mathbf{v}$, despite the fact that the velocities $\mathbf{u}'$ and $\mathbf{u}$ are relativistic. This is due to the fact that the Tangherlini transformations are the less correction of the Galilean transformations (GT) than the Lorentz ones. To make the velocity addition law (3)–(5) (that follows from TT) coincide in the first order with the Galilean one, the fulfillment of the condition $v \ll c$ is sufficient, whereas formulae (6) and (9) coincide with the Galilean ones only when $u \ll c$ and $v \ll c$, and this is demonstrated by formula (22).

4 Anisotropic deformation of the light barrier and light cone in the Tangherlini theory

It follows from (4) and (15) that the velocities of the particle u' and light c' in IRF K' that moves with respect to the ether may exceed the absolute velocity of light c. However, the following holds true:

Statement 1 *The velocity u' of the particle with a non-zero rest mass is always less than the velocity c' of light that moves in the same direction:*

$$u'(\theta') < c'(\theta') \tag{23}$$

Proof. Using formulae (4), (9), (11) and (15), we obtain:

$$\frac{u'(\theta')}{c'(\theta')} = \frac{\tilde{u}'}{c}\,\frac{1 + \frac{v}{c}\cos\theta'}{1 + \frac{\tilde{u}'v}{c^2}\cos\theta'} = \frac{1 + \frac{v}{c}\cos\theta'}{\frac{c}{\tilde{u}'} + \frac{v}{c}\cos\theta'}. \tag{24}$$

Since always $c > \tilde{u}'$, it follows from (24) that $\frac{u'(\theta')}{c'(\theta')} < 1$, i.e. *quod erat demonstrandum*.

Thus, it follows from TT that in IRF K' that moves with respect to the ether with the velocity v an anisotropically deformed light barrier appears:

$$u' < \frac{c}{1 + \frac{v}{c}\cos\theta'}.$$

Only in AIRF K ($v = 0$) this barrier takes a form of an absolute SR barrier. In other IRTs, the value of deformation depends on the velocity v of IRF with respect to the ether. Therefore, even in case when the velocity of particle exceeds, according to (20), the absolute velocity of light, it will not overcome the light barrier, this barrier is simply such deformed that the motion with the velocity exceeding the absolute velocity of light ($c < u' < c'$) becomes possible. Therefore, one has not to expect the "vacuum" Cherenkov effect. If the neutrino outruns its self-radiation, then, according to Kohen-Glashow calculations [23], it would lose almost its total energy for the production of a pair of particles, which has not been observed experimentally.

Thus, for the particle with the non-zero mass, even at $u' > c$, the term "superluminal motion" is conditional.

To obtain the equation that describes the light "quasi-cone" in TTh, we will use the non-invariant metric tensor [7, 8]:

$$g'_{\mu\nu}(v) = \begin{pmatrix} 1 & -\frac{v}{c} & 0 & 0 \\ -\frac{v}{c} & \frac{v^2}{c^2} - 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}. \tag{25}$$

The invariant 4-interval is:

$$dS'^2 = g'_{\mu\nu}dx'^{\mu}dx'^{\nu} = g_{\mu\nu}dx^{\mu}dx^{\nu} = \\ = c^2dt^2 - (dx^2 + dy^2 + dz^2). \tag{26}$$

For the light "quasi-cone" we obtain the following equation:

$$ct' - \frac{v}{c}\,x' = \pm\sqrt{x'^2 + y'^2 + z'^2}. \tag{27}$$

At $v \ll c$, this "quasi-cone" transforms into the SR light cone. Taking into account relation (15), equation (27) should be written in a form:

$$c'(\theta')t' = \pm\sqrt{x'^2 + y'^2 + z'^2}, \tag{28}$$

and this vindicates the use of the term "light quasi-cone".

5 Energy and momentum of the "superluminal" particle

Let us ascertain that at the "superluminal" motion, i.e. at $u' > c$, the mass of the particle remains real. According to TT (1), (2), one may obtain the following expressions for the momentum $\mathbf{P}'$ and energy E':

$$\mathbf{P}' = \frac{m\mathbf{u}'}{\sqrt{\chi^2 - \left(\frac{u'}{c}\right)^2}} = \tilde{\mathbf{P}}', \tag{29}$$

$$E' = \frac{\chi mc^2}{\sqrt{\chi^2 - \left(\frac{u'}{c}\right)^2}} = \tilde{E}'. \tag{30}$$

These expressions were obtained in [7, 8] from the extreme action principle with the certain-type Lagrangian. In [17], the same expressions were obtained by means of the two simpler methods: a) by using the notion "proper time" and b) by applying TT to the 4-vector of energy-momentum. It is easy to show that the Statement 1 provides the positiveness of the radicand expression in (29) and (30), including that at $u' > c$. Hence, there is no necessity to postulate the imaginary character of the rest mass m (in contrary to the tachyon hypothesis in SR).

6 Notion of time in TTh and SR. Acausality illusoriness

Let us discuss now the difference of the properties of time in TTh and SR resulting from the difference of the ways of the clock synchronizing. The TT set (1), (2) does not form a group, but, substituting:

$$t' \rightarrow \tilde{t}' = t' - \frac{v}{c^2}\,x', \tag{31}$$

we obtain the time part of LT:

$$\tilde{t}' = \gamma\left(t - \frac{v}{c^2}\,x\right) \tag{32}$$

(the co-ordinate parts in TT and LT are the same).

The Lorentz transformations form a group and, therefore, seem to be more preferred than TT. However, is it correct to call the time the value $\tilde{t}'$ that is a linear combination of the time t' and co-ordinate x'? One may call the quantity $\tilde{t}'$ the "quasi-time", and the derivative with respect to $\tilde{t}'$ the radius-vector $\mathbf{r}'$ – the "quasi-velocity". Then the second SR postulate sounds as follows: "the quasi-velocity of light is invariant". This coincides with the second TTh postulate, since the quasi-velocity of light equals to the average velocity of light when moving along the closed contour.

Let us express the relation between the intervals dt' and $d\tilde{t}'$ through the velocities v and $u'_x = dx'/dt'$. From (31) we obtain:

$$d\tilde{t}' = \left(1 - \frac{vu'_x}{c^2}\right)dt' = \left(1 - \frac{\mathbf{v}\cdot\mathbf{u}'}{c^2}\right)dt' = \chi dt' \tag{33}$$

and this explains the relation between the velocities in TTh and SR (see Section 2).

In IRF related to the Earth ($v \approx 360$ km/s), deviation of the coefficient χ from unit is insufficient (i.e. it is about 10^{-3}). However, for the precise measuring the velocities with announced error less than 10^{-3} (as in the CERN experiment [22] on finding the superluminal neutrino motion) this difference should be taken into account. Of particular consideration is the situation of the "superluminal" motion, i.e. when $u' > c$. It is seen from (2) that at $dt > 0$ the condition $dt' > 0$ always holds true as well, i.e. the time in TTh, as it has been always in physics, varies in any IRF towards one side, i.e. from the past to the future. No "backward time motion" does exist. As regards the interval $d\tilde{t}'$, it follows from (33) that given the fulfillment of the condition $\mathbf{v}\cdot\mathbf{u}' > c^2$ this interval becomes negative, i.e. $d\tilde{t}' < 0$ (at $dt' > 0$). This allows one to understand the illusoriness of the so-called problem of violation of the causality principle in SR: the illusion of the acausality arises due to neglecting the difference in the velocities of light in case of the opposite directions. Let us dwell upon this problem in more detail. Let the superluminal signal propagate in IRF K' along the X-axis from the point "1" to the point "2". According to the instantaneously synchronized clock, the motion time interval is $\Delta t' = t'_2 - t'_1$. If one uses the light synchronization (GPS) with fixing at the point "3" the light signals emitted at the points "1" and "2" (let us consider for simplicity that $x_3 = (x_1 + x_2)/2$), then the motion time interval is:

$$\Delta\tilde{t}' = \tilde{t}'_2 - \tilde{t}'_1 = \Delta t' - \frac{Lv}{c^2}, \qquad L = x_2 - x_1. \tag{34}$$

Thus, at $Lv/c^2 > \Delta t'$ (that is equal to the condition $u'v > c^2$) the "acausality" takes place, i.e. $\tilde{t}'_2 < \tilde{t}'_1$. Everything is extremely simple here, i.e. the light signal from the event-effect "2" is detected earlier than the light signal from the event-cause "1" due to the fact that the signal from the event-cause "1" moves (along the IRF motion direction) for a time longer than the total time of the superluminal motion and the reverse (i.e. in the opposite to the IRF motion) light beam motion from the point "2" to the point "3". The acausality illusion vanishes, if one, formulating the causality principle, clearly states the things implied as well, i.e. the event-effect always occurs later than the event-cause according to the clock with the instantaneous synchronization.

Perception of the illusoriness lifts the ban on the superluminal motion: the velocity of the signals of the informational origin (in particular, the quantum teleportation) could be arbitrarily large.

It is easy to understand that the assumption about the possibility of appearance of the acausal loop is wrong. Indeed, the intervals $\Delta t'$ and $\Delta\tilde{t}'$ between the events taking place at the same point coincide. Therefore, it follows from $\Delta t' > 0$ for the cyclic process that $\Delta\tilde{t}' > 0$ as well.

Note that in TTh, as seen from (2), the experimentally proven delay of time also exists. However, unlike SR, this delay depends not on the relative velocity of the two reference frames, but on the velocity of motion of a given IRF with respect to the ether. For the two reference systems K'_1 and K'_2 moving with the same velocities in the opposite directions $\mathbf{v}'$ and $\mathbf{v}'' = -\mathbf{v}'$ the time varies similarly, i.e. $t'' = t'$, though their relative velocity $2v'/(1 - (v'/c)^2)$ could be as much as desired large.

Obviously, the clock paradox doesn't take place in TTh.

7 Final comments and conclusions

The above discussion allows one to conclude that TTh is a wider theory than SR, however, all the TTh results almost coincide with those of SR in the cases when one may neglect the non-invariance of the velocity of light (this is a kind of application of the Bohr's correspondence principle). In IRF related to the Earth, this condition holds true very frequently. Just due to this, such a brilliant agreement of the SR calculations with a huge number of experimental data does exist. However, the motion with the superluminal velocities is out of the SR competence. As it had been shown above, the apparent violation of the causality principle at the superluminal velocities in SR is due to neglecting the light velocity difference in case of motion in opposite directions. Therefore, no restrictions on the velocity of particles and signals are imposed by the causality principle. However, as proven in Statement 1, when comparing the velocity of particle with the nonzero mass u' with that of the light c' in the arbitrary reference frame, condition $u' < c'$ is always valid (though in this case u' could be arbitrarily large, including the case $u' > c$).

In the case of the non-local correlation interaction between the "entangled states" of the quantum objects, the velocity of its propagation is not restricted at all. The experimental excess of this velocity over the velocity of light has been observed for the first time in the paper by Alan Aspect et al. [24] devoted to the correlation of the photon pairs polarized states. The theoretical justification of the possibility of information transfer with the superluminal velocity could be easily found, say, in [25]. The possibility of the technical realization of the superluminal signals in the communication networks is discussed in [26] in the section with the characteristic name "Superluminal communications".

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