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Pseudo Forces in Yarn Unwinding from Packages

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Abstract: In a recent paper we have shown the origin of the pseudo forces in equations of motion in a non inertial observation frame. In addition to Coriolis and centrifugal force, there is another pseudo force in rotating frames with time dependant angular velocity. This force affects the yarn dynamics. Using experimental data as an input, we will calculate oscillations of yarn tension for different package geometries and winding angles. We show how the winding angle and the package radius influence the angular velocity of the yarn during the unwinding. Since the pseudo forces on the yarn in the balloon depend on the angular velocity, this velocity has a large influence on the oscillations of yarn tension that we wish to reduce.

Index terms: **pseudo forces, dynamics of yarn, balloon theory, non inertial systems.**

I. INTRODUCTION

In production of garments thread unwinding exists in a sewing process. In order to achieve low and constant tension of thread or yarn it is necessary to optimize the process of unwinding. Computer simulation are now in use for this purpose, so it is important to obtain a mathematical description of yarn motion [1,2,3,4,5,6]. Bulding on this foundation we have simplified the problem even further. In paper [10] we have shown the origin of the pseudo forces in the equations of motion in a non-inertial reference frame. In a recent paper [11] we measured how the tension at the eyelet depends on the angular velocity of unwinding and we developed a mathematical model:

$$f(t) = sign(\sin t)\left|\sin t\right|^{\frac{1}{40}}. \quad (1)$$

which would permit to simulate the process of unwinding. We measured the unwinding speed, package radius and tension of yarn as we unwound yarn from parallel cylindrical packages. We used a balloon limiter, that limits the balloon radius.

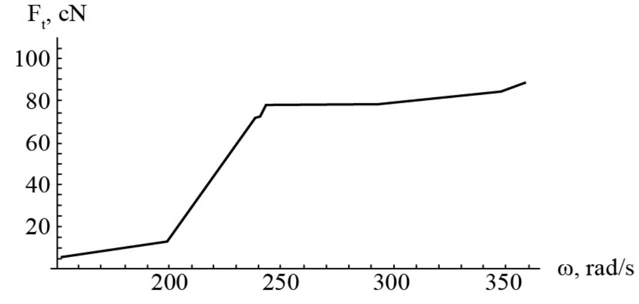

Figure-1. Dependence of tension T on angular velocity ω of the yarn [11].

We must emphasize that this dependence was obtained by measurements on a simple, parallely wound package. In spite of this we will use these date in our simulations of cross wound packages. This approximation has little influence on the qualitative features of our results. The unwinding will be discussed from a theoretical and practical point of view. In this paper we show how these forces enter the equation of motion for yarn in a rotating reference frame. In addition to the Coriolis and the centrifugal force, there is another pseudo force in rotating frames with the dependent angular velocity. This force affects the yarn dynamics.

II. THE EQUATION OF MOTION FOR YARN

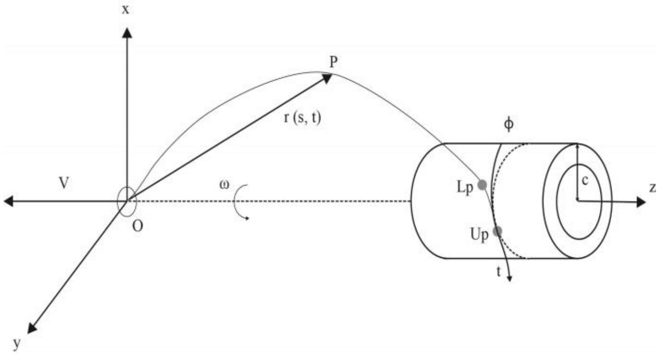

Figure-2. Unwinding yarn from packages. At the lift-off point Lp the yarn lifts from the package and forms a balloon. At the unwinding point Up the yarn starts to slide on the surface of the package. Angle ϕ is the winding angle of the yarn on the package [10].

The Newton's second equation for a point-like particle in a rotating reference frame takes the form [7,8,9]:

$$\mathbf{F} - 2m\boldsymbol{\omega} \times \mathbf{v}' - m\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r}') - m\dot{\boldsymbol{\omega}} \times \mathbf{r}' = m\mathbf{a}' \quad (2)$$

In a non-inertial reference frame, the body is accelerated not only by the true external forces **F**, but also by the pseudo forces. These are the Coriolis, centrifugal and Euler's forces. There are numerous situations where the use of non-inertial reference frames is more convenient that that of inertial frames, in spite of the addition of the pseudo forces. In weather prediction it is, for example, necessary to solve a complex system of differential equations in a reference frame which is fixed to the Earth. Since the Earth is not an inertial reference frame (due to its rotation), it is crucial to take into account the Coriolis and centrifugal forces.

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Particularly important is the Coriolis force which makes the low-pressure systems spin in the counter-clockwise direction in the Northern hemisphere [16,17,18,19].

Non-inertial reference frames are also useful in studying the yarn unwinding. It may be used, for example, when working within the quasi-stationary approximation to describe the yarn unwinding from packages where layers have a large number of yarn loops.

The equations of motion which govern the motion of the yarn are known :

$$\rho D^2\mathbf{r} = \frac{\partial}{\partial s}(T\mathbf{t}) + \mathbf{f} - 2\rho\boldsymbol{\omega}\times D\mathbf{r} - \rho\boldsymbol{\omega}\times(\boldsymbol{\omega}\times\mathbf{r}) - \rho\dot{\boldsymbol{\omega}}\times\mathbf{r}, \quad (3)$$

we have established them in our previous paper [10, 12,13,14,15]. They can be partially analytically solved, as we show in the following. Here ρ is the mass per unit length of the yarn, D is the comoving time derivative operator, T is the yarn tension and **f** is the density of external forces acting on the yarn. We identify three pseudo forces that act on an infinitesimal segment of yarn in a non-uniformly rotating frame:

1. $-2\rho\boldsymbol{\omega}\times D\mathbf{r}$ the Coriolis force
2. $-\rho\boldsymbol{\omega}\times(\boldsymbol{\omega}\times\mathbf{r})$ the centrifugal force
3. $-\rho\dot{\boldsymbol{\omega}}\times\mathbf{r}$ an additional force due to changing rotational velocity of the non-inertial observation frame. It is the Euler's forces.

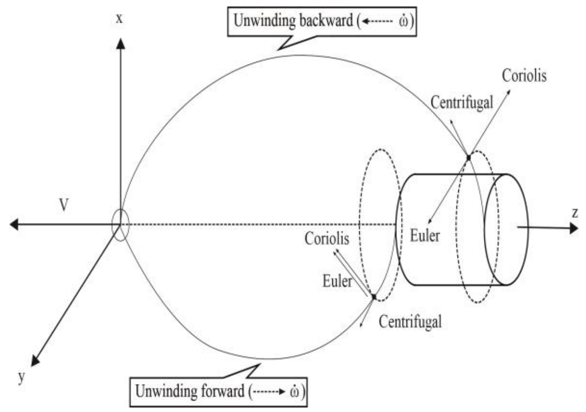

Figure-3. Pseudo forces on a short yarn segment.

III. RESULTS OF SIMULATION AND DISCUSSION:

In Fig. 4 we show the results for the oscillations of tension for a range of four winding angles $\phi_0 \sim 0°$, $\phi_0 = 10°$, $\phi_0 = 20°$ and $\phi_0 = 30°$ for a very small package radius of c=70 mm and for unwinding velocities, V=1400 m/min, respectively. We observe very high tension in the yarn for all enumerated winding angles. The tension oscillates from 11,2 cN to 182 cN.

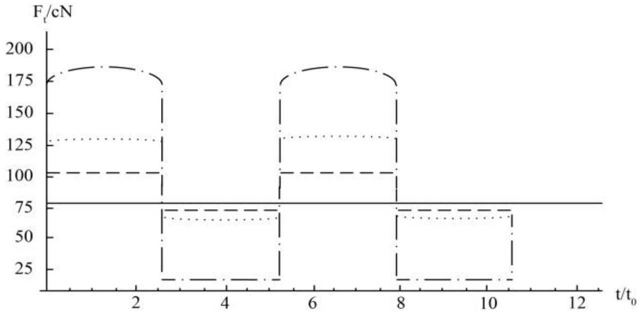

Figure-4. Variation of the tension T_0 during the unwinding of the yarn from a cylindrical package for different winding angles. V=1400 m/min, c=70 mm. φ~0° (full line), φ=10° (dashed line), φ=20° (dotted line), φ=20° (dot-dashed line)

Figure 5 shows the time dependence for three winding angles 0°, 5° and 10° for package radius c=500 mm and unwinding velocity V=2000 m/min. For packages with such large radius the tension and the tension oscillations are very small for all winding angles.

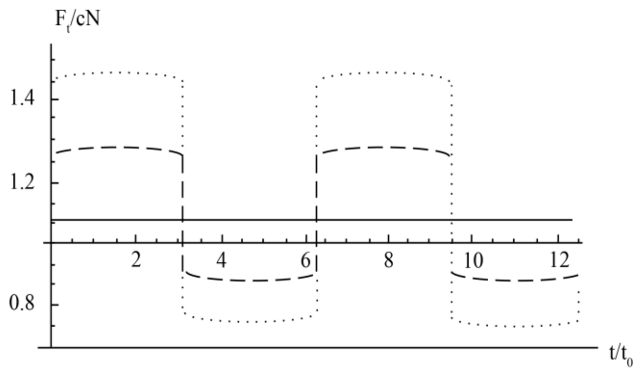

Figure-5. The tension T_0 for large package radius and for different winding angles. V=2000 m/min and c=500 mm. φ~0° (full line), φ=5° (dashed line), φ=10° (dotted line).

The effect of pseudo forces can be estimated by comparing them to each other. Let us compute the ratio between the Euler and the centrifugal force :

$$\frac{m\dot{\omega}r'}{m\omega^2 r'} = \frac{\dot{\omega}}{\omega^2}. \quad (4)$$

The angular acceleration is written as

$$\dot{\omega} = \frac{\omega_{\max} - \omega_{\min}}{t}, \quad (5)$$

This velocity can be related to the period of the motion (the time during which one loop of yarn is unwound) t=n2π/ω_0. We have

$$\frac{\dot{\omega}}{\omega^2} = \frac{2\pi}{n}\frac{\omega_{\max} - \omega_{\min}}{\omega_0}. \quad (6)$$

The factor 2π/n can be assumed to 1. Hence,

$$\frac{\acute{\omega}Y}{\omega^2} = \frac{\omega_{\max} - \omega_{\min}}{\omega_0}. \qquad (7)$$

In Figures 6, 7 and 8 we plot the amplitude of yarn tension oscillations as a function of unwinding velocity V=1000-2000 m/min and winding angles from 0º to 20º for three different package radii, namely c=500 mm, c=200 mm and c=70 mm. For all the packages we notice that the tension oscillations are larger at high unwinding velocity and for larger winding angles. The amplitudes become particularly high for velocities above V=1600m/min and for angles larger than ϕ=5º. For large radius of c=500mm (Fig. 8) the tensions oscillations are very small in the full range of parameters, thus from such packages it should be possible to unwind yarn at all velocities and for all winding angles. For smaller package radius of c=70mm, however, the unwinding is only possible for sufficiently small winding angle below 5º.

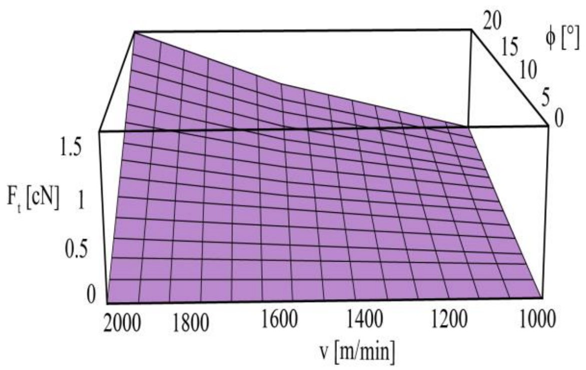

Figure-6. Comparison of the amplitude of the tension oscillation as a function of the unwinding velocity V and the winding angle φ. c=500 mm

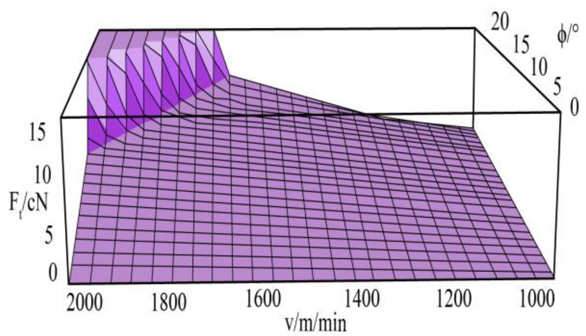

Figure-7. Comparison of the amplitude of the tension oscillation as a function of the unwinding velocity V and the winding angle φ. c=200 mm

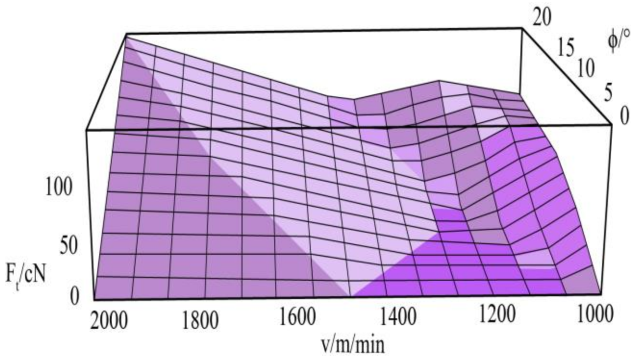

Figure-8. Comparison of the amplitude of the tension oscillation as a function of the unwinding velocity V and the winding angle φ. c=70 mm

The amplitude of the angular velocity are written as

$$\Delta\omega = \omega_{\max} - \omega_{\min} = \frac{2V}{c}\tan\phi_0.$$

(8)

In the calculation we have used the value for ϕ < 25°, we have tan ϕ ~ ϕ.

We get

$$\Delta\omega \approx \frac{2V\phi_0}{c}. \qquad (9)$$

We can compute the average angular velocity during unwinding as follows

$$\omega_0 = \frac{(\omega_{\max} + \omega_{\min})}{2} = \frac{V}{c}\frac{1}{\cos\phi_0} \approx \frac{V}{c}.$$

(10)

Here we made use of the small-angle approximation $\cos(\phi_0) \approx 1$.

In Fig. 9 we plot the comparison of the amplitude of the tension oscillation as a function of the unwinding velocity V and the package radius c. The winding angle is constant, φ =5°.

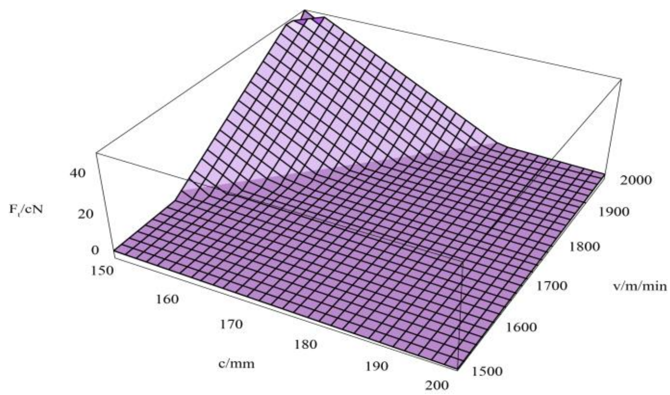

Figure-9. Amplitude of the tension oscillation as a function of the unwinding velocity and the package radius

We notice that the lines of amplitude are straight lines. This means that the amplitude of tension oscillations at constant angle depends only on V/c, as expected from equation (10). This suggest the possibility to make a compromise: if it is known that the yarn is damaged at some given amplitude of tension oscillations, then the possible choices of package radius c and unwinding velocity V lie of a straight line. One can thus use small package radii with small unwinding velocities or large packages with correspondingly higher unwinding velocities. The ratio between the pseudo forces can then be rewritten as

$$\frac{\acute{\omega}Y}{\omega^2} = 2\phi_0.$$

(11)

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IV. CONCLUSION

We have demonstrated the analogy between the Newton's equation for a point particle and the equation of motion for yarn in a non-inertial reference frame. We have emphasized the commonly neglected Euler's force. We thus conclude, that the importance of Euler's velocity is equal to the ration between the difference of the angular velocity for unwinding in either direction and their average. We have shown that its affect by increasing the angle of winding has doubled. By increasing the winding angle the yarn tension oscillations are also increased. This is particularly noticeable for packages with small radius. Furthermore, we find that it is advisable for the winding angle to be below 5º.

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