Nonlinear Dynamics of High-Speed Transport for Staple Yarns

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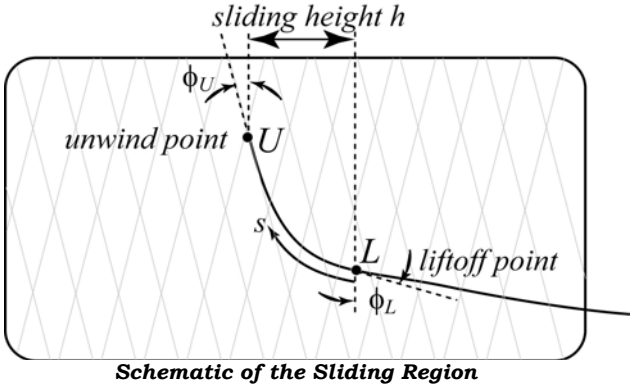
In earlier work [NTC F97-C05], we validated mathematical models of high-speed unwinding of continuous-filament yarns by relating yarn tension to the balloon that forms during winding. We are now seeking to improve the correlation between mathematical models and experimental measurements by better quantifying the non-uniformities of the staple yarns currently under study. Better math models will enable textile engineers to use computer-aided design to optimize the quality and productivity of high-speed yarn transport systems. In the previous effort we sought to relate yarn tension to the balloon that forms during winding. Now we are presently focused only on relating the tension to the path the yarn follows as it drags across the spool.

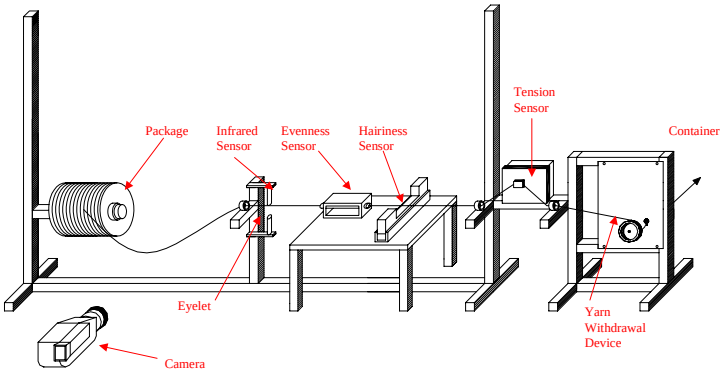
We are re-examiningand seeking experimental validation of some of the time-honored assumptions in the equations describing unwinding.

It has been five decades since researchers laid the groundwork for the equations governing the motion of yarn during unwinding. Forty five years ago, Booth[1] studied the effect of yarn sliding over the package surface during unwinding. The next year, Padfield[2] developed the fundamental equations of motion of an element in the yarn path from the eyelet to the lift-off (L) point and from the lift-off point to the unwinding (U) point. Our focus is now on this sliding region (See Schematic).



Schematic of the Sliding Region

Our measurements from the past year provided new information on the coefficient of friction for staple yarn still on the package and the yarn in the process of being unwound. But there were many instances when the path predicted by the equations of motion did not match the path captured by our high-speed camera (See Figure at top right). We are suspicious of three particular aspects of the formulation and solution of the equations of motion:



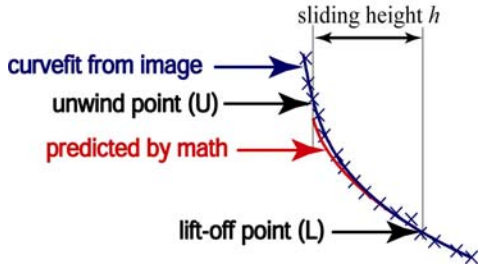
- the validity of Coulomb's friction law for this problem
- the assumption that the yarn obeys the mathematical description of a string along its entire path of motion,
- the boundary and initial conditions used to solve the first-order system of equations.

The first two items have survived nearly 50 years since Padfield's pioneering work,[2] and the last item has become an issue only in the past ten years as researchers sought numerical solutions.

Modeling the drag force on the package as Coulomb friction is a relic of Padfield's early work.[2] Researchers in other fields[1] have proposed that friction forces should depend on velocity as well as a measure of the normal force. We also suspect that electrostatic forces between the sliding yarn and the remaining yarn on the spool make up a significant portion of the normal force. This force will add to the existing normal force in the model to yield a better understanding of the resultant force on that yarn as it drags across the spool.

Ghosh and colleagues[3] have studied how fabrics bend under their own weight, yielding the notion of a curvature-dependent "bending" stiffness. We hypothesize that there are regions along the yarn path where the yarn acts more like a beam than a string, and we are trying to determine if a curvature-dependent stiffness could account for irregularities in our solutions during forward unwinding.

Finally, we are systematically evaluating the uncertainty introduced when a human identifies both the yarn path and the crucial unwind and liftoff points (See Figure below).



Measured Versus Predicted Path of Yarn

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[1] for example, de Wit *et al*[4].

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3. N. Zhou and T. K. Ghosh, *On-Line Measurement of Fabric Bending Behavior, Part I: Theoretical Study of Static Fabric Loops*, Textile Research Journal, **67**(10):712 (1997).
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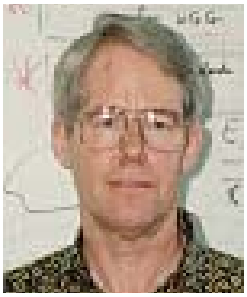

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