Effect of Varying Standoff on Helical Winding

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1.0 Introduction

This report summarizes the results of work on Task 5, "Model/Simulate the effect of changing the standoff", on the Statement of Work for Year 2, ABB Project on Transformer Winding. With ABB's permission, a more detailed description of this work will be submitted as a paper to an appropriate journal before the end of 1994.

2.0 Problem statement

The goal of the stated task was to determine the effect of changing the perpendicular distance of the filament delivery point (i.e., the "standoff") from the surface of the mandrel during helical winding. In particular, a method was sought of keeping the support as close as possible to the mandrel surface most of the time, but moving out to a safe distance in the presence of conductors which have been cut and are protruding. After a conductor is avoided, the support should move back to the minimum standoff.

The modeling step of this task involves determining the interaction between in-and-out motion of the filament support and the resultant filament trajectory on the mandrel surface. The simulation step involves determining the effect of reducing the standoff on end-region buildup. Beyond these steps, initial work has been done on devising a method of recognizing and avoiding protruding conductors, and this work will be reported in the paper mentioned above.

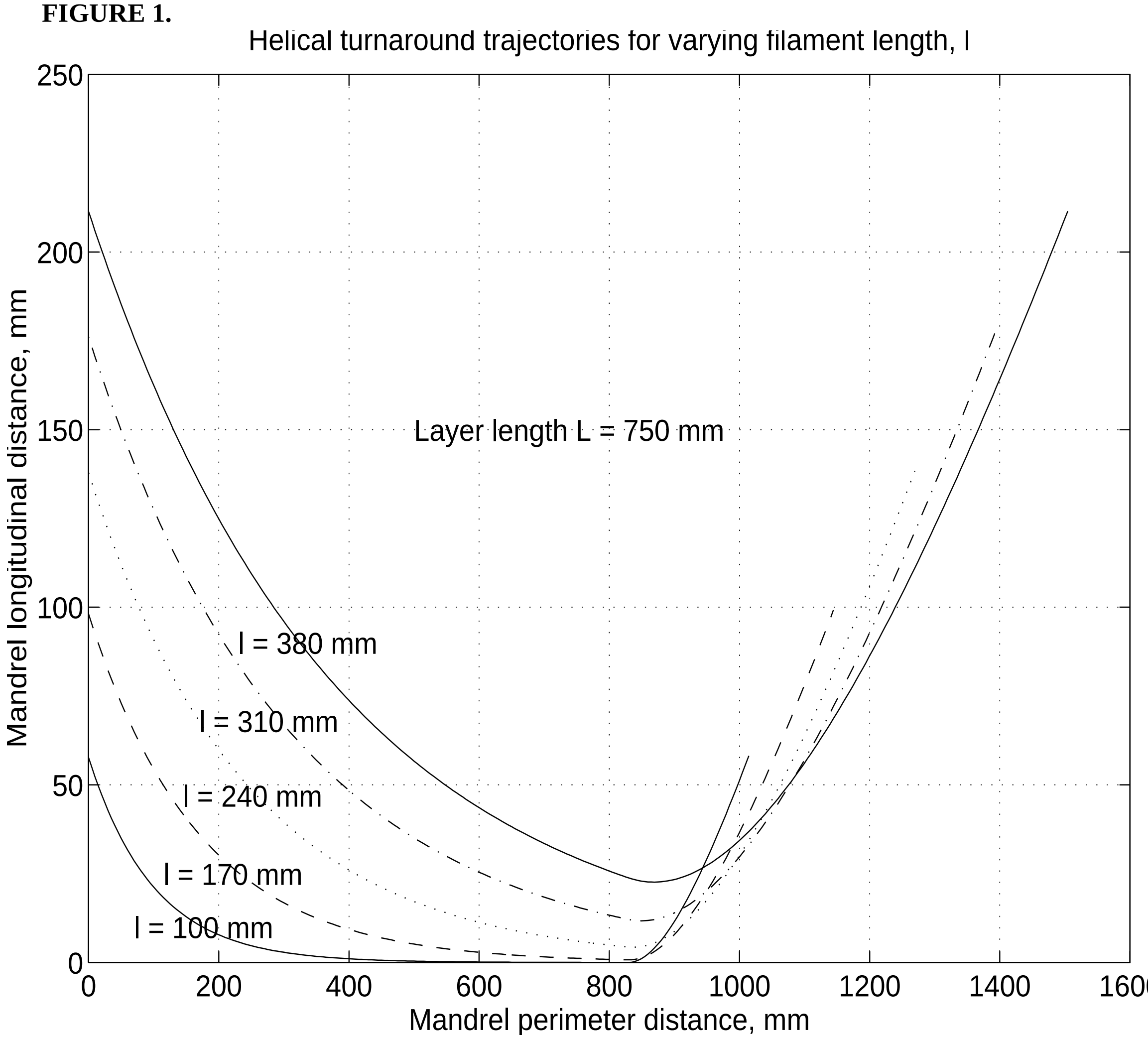
3.0 Modeling

Our prior work on modeling the winding process ("Filament Winding Algorithms for Arbitrary Convex Mandrel Shapes", July 9, 1992, Report fulfilling Task V for Year 1) limited the support to a single degree-of-freedom (DOF), lateral motion parallel to the mandrel axis. The current task required extension of this model to two DOF, one lateral and one perpendicular to the mandrel axis. Although not needed for the current problem, we have extended this to a third DOF for the sake of completeness and generality. The resulting model is thus applicable not only to trajectory planning for conventional winding machines, but also for robotic winding. As before, non-axisymmetric shapes are handled by the model, as well as circular cylinders. Details of this model will be provided in the paper mentioned above.

4.0 Simulation

In order to determine the effect of reducing the standoff on the end-region buildup, equations relating the band trajectory on the mandrel surface to support motion for a circular cylinder were used. These equations were presented in the earlier report "An Overshoot Algorithm for Filament Winding of Circular Cylinders." They include the filament length, *l*, as a variable. The filament length is defined as the distance between the filament delivery point (in this case, the filament comb), and the filament band's tangent point to the surface of the mandrel. A plot is shown below of the end-region band trajectory for five different values of the filament length for a typical layer length.

FIGURE 1.



It is possible to parametrize the equation relating the *x*-axis (mandrel perimeter position) and *y*-axis (mandrel longitudinal position) values above so that only three parameters are needed: *l* (the filament length), *L* (the layer length), and the product rn_{ψ} (the mandrel radius times the number of pause turns). Of these, the filament length has the most significant effect on the width of the end region, which is equal for a given trajectory to the difference between the maximum and minimum *y*-axis values in the above plot plus half the band width (typically half of 40 *mm*).

The relationship between the filament length and the width of the end-region remains fairly constant for different layer lengths. This relationship is shown for three representative layer lengths in Figure 2. The rate of change of the end-region width with respect to the change in filament length is shown in Figure 3. The incremental benefit of decreasing the filament length increases as the filament length gets smaller. Figure 2 can be used to determine the benefit of reducing the filament length in terms of decreased end-region width. For example, if the filament length is decreased from 200 *mm* to 100 *mm* by performing "conductor avoidance," the size of the end region will be reduced from 20 + 115 = 135 *mm* to 20 + 55 = 75 *mm*. Half the band width is assumed here to be 20 *mm*, and the values 115 *mm* and 55 *mm* are the y-axis values corresponding to the filament lengths 200 *mm* and 100 *mm*, respectively.

FIGURE 2.

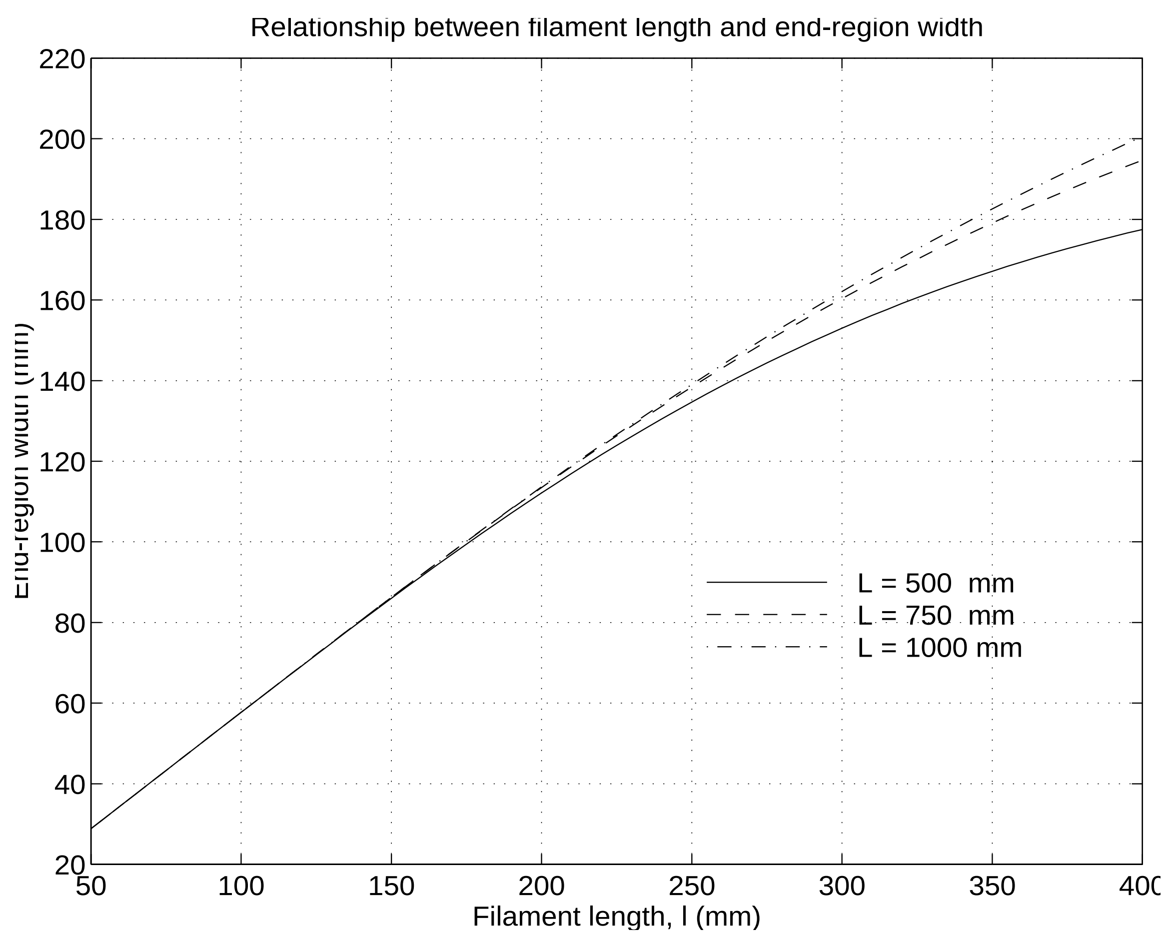
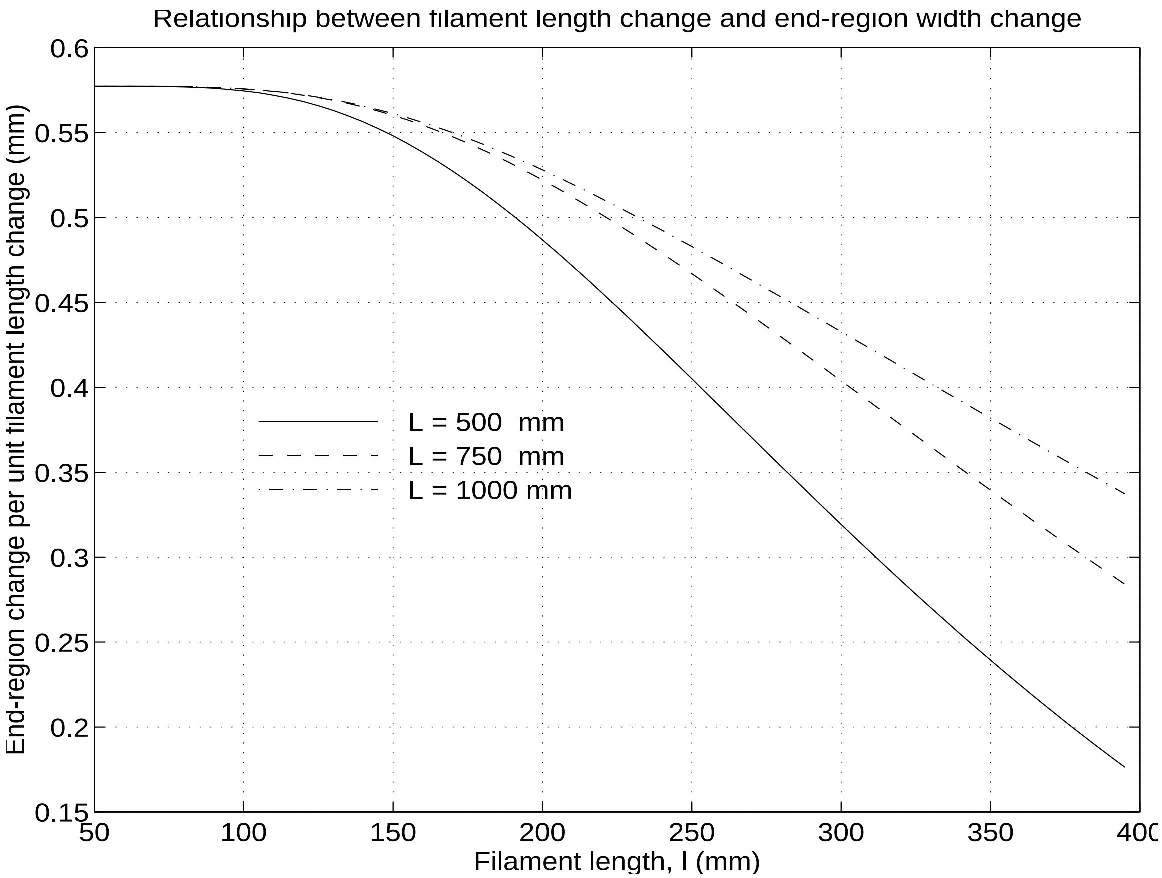


FIGURE 3.



Since the workers normally think in terms of the "standoff," i.e., the perpendicular distance of the delivery point from the surface of the mandrel, it is important to note the relationship between the standoff and the filament length. This relationship is given by the following equation: $l = \sqrt{d(d+2r)}$, where *l* is the filament length, *d* is the standoff, and *r* is the mandrel radius. The table below gives the relationship between filament length and standoff for three representative mandrel radii. The standoff ranges from 50 to 250 *mm* down the left-hand column, and the corresponding *l*-values are shown for a given value of *r* in the respective column. All units are in millimeters. Note that the standoff currently regarded as acceptable, 150 *mm*, results in rather large filament length values, especially as the mandrel radius increases.

d	*r* = 100	*r* = 200	*r* = 300
50	112	150	180
100	173	224	265
150	229	287	335
200	283	346	400
250	335	403	461

5.0 Conclusion

We have derived the quantitative relationship between support standoff and helical-layer end-region width. In addition, a model relating the 3-dimensional motion of the filament delivery point to the band trajectory on the mandrel surface was developed. This model gives the support more DOF than are necessary to achieve the band trajectory, so additional constraints are necessary to achieve a unique solution for the support motion. In the case of conventional winding, only one DOF is used (lateral motion). For winding in the presence of protruding conductors, an additional constraint is provided by the necessity of avoiding the conductors. In order to avoid conductors, further work is needed in the area of determining the conductor positions and planning the avoidance trajectory.