PROBLEMATICS OF LARGE-SIZE BATCH WINDING OF TECHNICAL TEXTILES

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Abstract: *When weaving technical textiles we often encounter problems that are not known from weaving ordinary textiles. This is due to the significantly different mechanical properties of the fibers forming the fabrics. At the same time, productivity pressures cause additional complications, especially in the marginal areas of weaving, whether warping or just winding the resulting product. As the resulting batch becomes larger, it becomes corrugated and consequently damages the fabric. This problem has increased in our case when weaving 3D fabric. We were therefore faced with the task of solving this problem. In the solution, we used the classical mechanics of the continuum. Due to the complexity of the problem, we had to accept some simplifications, such as the assumption of radial isotropy of the wound fabric. It turned out that the resulting relationships are quite complicated, but with the use of computing, the problem is nevertheless solvable. The result of our work is the design of the wrapping program depending on the fabric being fabricated. We have also shown that there are certain boundaries that cannot be exceeded when packing.*

Keywords: *Technical textiles, batch winding.*

1 INTRODUCTION

Currently, two different fabric winding systems are commonly used. The first, historically old and essentially original, consists in winding the fabric on a central tube, which is traditionally placed, but not necessarily, directly on the weaving loom. The tube is driven by a single drive that delivers the required tensile force in the withdrawn raw woven. In principle, it is obvious that this force acting on the circumference is transferred from the tube to the towed fabric by already packed woven. This system, therefore, does not allow the creation of large batches as shown by the experience of generations of weavers.

The second, more modern system consists in separating the fabric from its weaving and removing the woven from the fabric. The tube on which the woven is wound reposes on two rollers that are driven separately. Their circumferential velocities are controlled to produce the desired tension in the cloth withdrawn from the loom. It is clear that the tension in the withdrawn fabric acts on the circumference of the wound fabric and therefore does not affect the already packed cloth. This type of winders can be further divided into two types, namely gravity and controlled pressure. In the first case, the contact force between the valleys and the goods is given by the weight of the packing, in the latter case the compressive force is generated by the auxiliary device and can be controlled. Figure 1 gives a schema of such large-size batch winder.

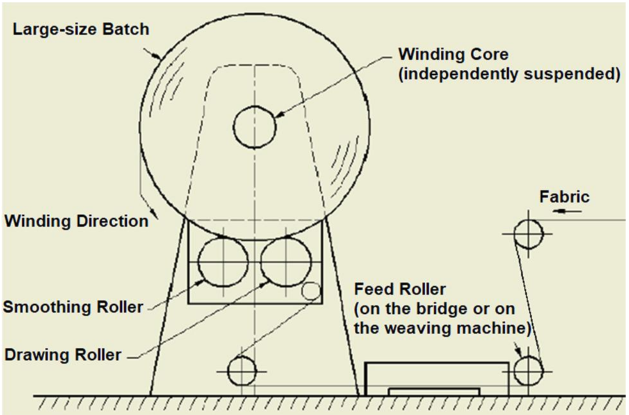

Figure 2 Scheme of large-size batch winder; courtesy of CEDIMA

2 BATCH GEOMETRY DESCRIPTION

The first problem encountered in describing a large-size batch is the description of its geometry. The batch can be considered a spiral.

Its length, depending on the outer radius, is expressed as follows:

$$L = \frac{R_2 \cdot \sqrt{t^2 + 4 \cdot \pi^2 \cdot R_2^2}}{2 \cdot t} - \frac{R_1 \cdot \sqrt{t^2 + 4 \cdot \pi^2 \cdot R_1^2}}{2 \cdot t} + \frac{t \cdot \operatorname{arcsin} h\left(\frac{2 \cdot \pi \cdot R_2}{t}\right)}{4 \cdot \pi} - \frac{t \cdot \operatorname{arcsin} h\left(\frac{2 \cdot \pi \cdot R_1}{t}\right)}{4 \cdot \pi} \tag{1}$$

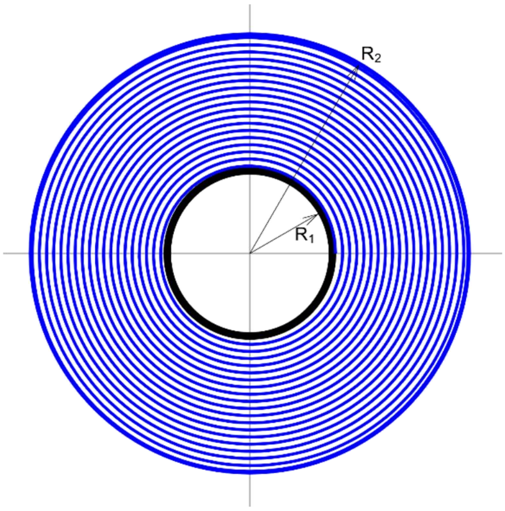

Figure 2 Schema of batch winding

Obviously, the relationship in this form is inappropriate for further calculations. An approximate relationship is therefore needed:

$$l = \frac{R_1 + R_2}{2} \cdot 2 \cdot \pi \cdot \frac{R_2 - R_1}{t} = \frac{\pi \cdot \left(R_2^2 - R_1^2\right)}{t} \qquad (2)$$

Check for $t \to 0$:

$$\lim_{t\to 0}\left(L - l\right) = \lim_{t\to 0}\left(\frac{R_2 \cdot \sqrt{t^2 + 4\cdot\pi^2\cdot R_2^2}}{2\cdot t} - \frac{R_1 \cdot \sqrt{t^2 + 4\cdot\pi^2\cdot R_1^2}}{2\cdot t} + \frac{\operatorname{arcsinh}\left(\frac{2\cdot\pi\cdot R_2}{t}\right)\cdot t}{4\cdot\pi} - \frac{\operatorname{arcsinh}\left(\frac{2\cdot\pi\cdot R_1}{t}\right)\cdot t}{4\cdot\pi} - \frac{\pi\cdot R_2^2 - \pi\cdot R_1^2}{t}\right) = 0 \qquad (3)$$

Thus, if we know t and l:

$$R_2 = \sqrt{\frac{t\cdot l}{\pi} + R_1^2} \qquad (4)$$

If we know R_2 and l:

$$t = \pi \cdot \frac{R_2^2 - R_1^2}{l} \qquad (5)$$

It follows from previous relationships that we have a relationship with three variables t, l and R_2, which are interdependent. To describe the velocity geometry, one of these variables should be defined as independent and the other two parameters. For other purposes and also with respect to the purpose of our work, the variable length of the packing l will be independent, the layer thickness t will be the parameter and the radius of the packing R_2 will be solved from the relations. Otherwise, we would have to continuously measure both the length of the woven fabric and the diameter (the radius) of the wrapper. A key step in the next step will therefore be to determine the thickness t.

3 FABRIC THICKNESS ESTIMATION

3.1 Plain weave fabrics

To estimate the thickness t, we use the formulation following [3]. Its assumptions are:

- double-sinusoidal cross-section shape of the thread
- 100% fabric filling (close to limit values)

The bulk filling of the cloth in plain weave and with high values of sett then moves around the value $\kappa=2/\pi$. By means of volume filling it is possible to estimate the thickness t in mm of such fabrics by means of their parameters:

$$t = \frac{\gamma}{\rho} \cdot \frac{\pi}{2} \qquad (6)$$

Estimating the thickness of a cloth in a non-plain weave binding (e.g. twill or satin) can be done in an analogous manner, but the relevant models have not yet been prepared. Similarly, no analysis has been performed so far and no model of leno binding has been developed. For any measurement as the basis for optimizing the winding of such fabrics, it would be necessary to measure the actual wrapping.

3.2 3D fabrics

The main motivation of our work is to master 3D fabrics, more accurately the so-called distance fabric. It consists of two fabrics, for example in plain weave, interconnected by a set of threads.

The thickness of the binding yarns layer must also be included in the calculation of the thickness of the 3D fabric. Their number per unit area is given by their warp density and their pitch in the direction of warp. Their weight (weight per unit area in g/m^2) is given by:

$$\gamma_3 = n \cdot l_3 \cdot \frac{j_3}{10^6} = \frac{1}{100} \cdot d_3 \cdot j_3 \cdot \frac{l_3}{r} \qquad (7)$$

Thickness of layer of binding yarns then is:

$$t_3 = \frac{\gamma_3}{\rho_3} \cdot \frac{1}{\kappa_3} \qquad (8)$$

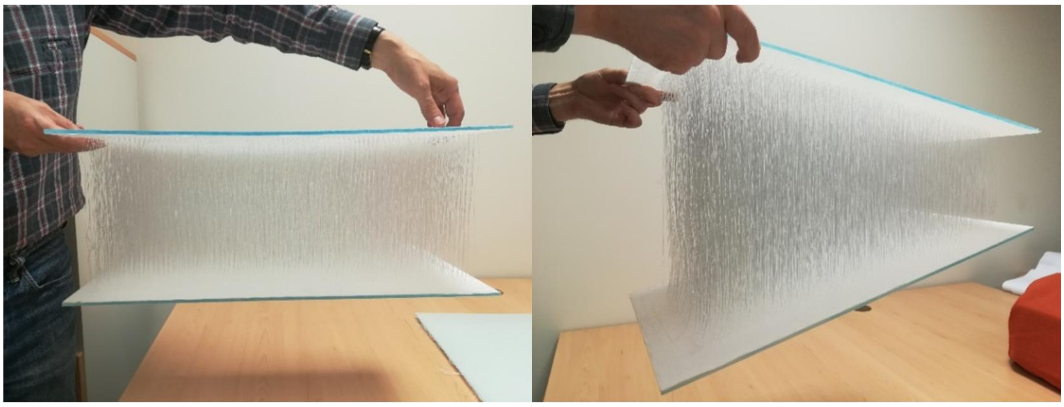

Figure 3 Examples of 3D fabrics

The fill value κ_3 should be determined experimentally, depending, for example, on the twist of the yarns or on the quality of the loop forming. The total weight of the 3D fabric is, of course, the sum of the weights of the surface fabrics and the weight of the staple yarns. The overall thickness is also determined in a similar manner.

4 THEORY

The following chapter presents a procedure for calculating the mechanical behavior of the batch.

4.1 Basic concepts

In our work, we came out of the idea of rotational symmetry of the batch. It is then possible to proceed as follows:

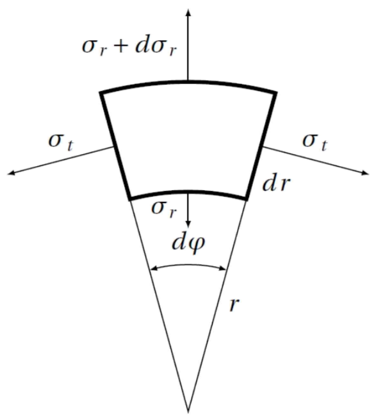

Figure 4 Balance of forces acting on an element

Equilibrium of forces in the radial direction yields as follows:

$$\frac{d}{dr}\left(r \cdot \sigma_r\right) - \sigma_t = 0 \tag{9}$$

Assuming radial isotropy of the batch we get following constitutional laws:

$$\begin{aligned} \sigma_r &= K \cdot \left(\varepsilon_r + \mu \cdot \varepsilon_t\right) \\ \sigma_t &= K \cdot \left(\varepsilon_t + \mu \cdot \varepsilon_r\right) + f\left(r\right) \end{aligned} \tag{10}$$

where K is stiffness and μ another Lamé's coefficient (it can be proved that they are meaningless in the case of radial isotropy and assuming state of planar deformations). Then *f(r)* is the force per width reported on unity of radius.

Using deformation restrictions we obtain for the expression of deformation:

$$\begin{aligned} \varepsilon_t &= \frac{u}{r} \\ \varepsilon_r &= \frac{du}{dr} \end{aligned} \tag{11}$$

By expressing constitutional laws and putting them into the equation of radial equilibrium we get fundamental equation:

$$\frac{d}{dr}\left(\frac{1}{r} \cdot \frac{d}{dr}\left(r \cdot u\right)\right) = f\left(r\right) \tag{12}$$

Its solution is easy by double integrating its right side if the *f(r)* is "reasonably" simple. During this integration we will get 2 unknown constants of integration. In order to obtain their values we must provide two boundary conditions. The first one is obvious:

$$u\left(R_1\right) = 0 \tag{13}$$

which yields the non-deformability of the central tube.

The second one comes from the fact that the radial stress (or radial pressure) vanishes on the outer radius:

$$\sigma_r\left(R_2\right) = 0 \tag{14}$$

4.2 Practical use of mathematical model

For sake of simplicity of this presentation we will assume the polynomial form of the right side *f(r)*. Even then the resulting formulae are in form of a complex rational function. Figure 5 represents the behavior of the tangential stress in the batch for two standard shapes of tension (in function of *r*) as used in praxis.

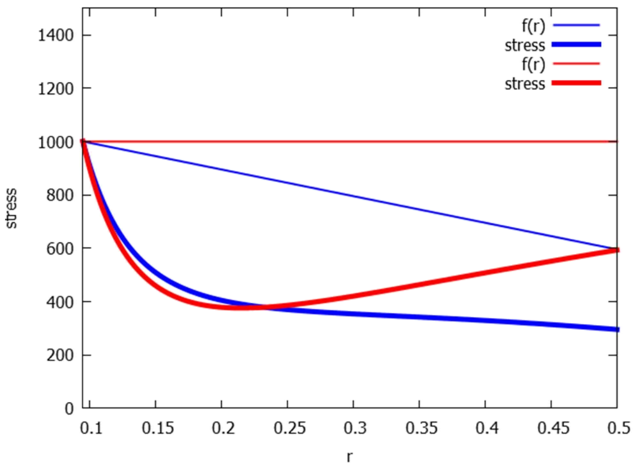

Figure 5 Tension of woven and resulting tangential stress in the batch

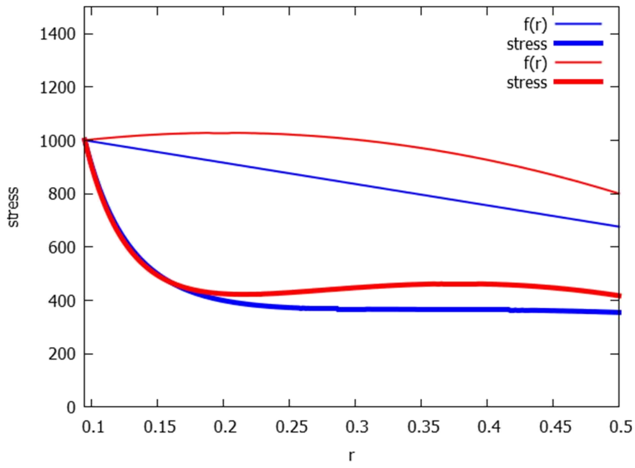

Figure 6 Optimized tension of woven and resulting tangential stress in the batch

It is obvious that such a variation of the cloth tension with the radius of batch has non-negligible effect on the shape of the tangential stress in the wound woven. Variation of the contact press is correspondingly important.

As the control system of winder allows entry of up to 5 point curve along the wound length of woven (not the radius of batch, there no device to measure it), we tried to shape the tension curve using a linear and a quadratic function (Figure 6).

It is known that "best" batches are those with little variation of the stress along the length of the woven (this stress is regularly checked in fabric factory using a special device). Evidently there is a function *f(r)* that allows the creation of large-size batch with a near-constant stress inside, at least along the majority of the wound length of cloth.

5 EXPERIMENT

To verify this hypothesis, the following method was chosen: Several wires are gradually inserted into the batch in the weft direction during wrapping. The force that can be moved by these wires (moving them in the weft direction to one or the other side) is directly proportional to the contact pressure between the layers of the packing between which the wire is inserted. Assuming that the properties of both the fabric and individual wires are constant, both in the width direction of the fabric, both the length of the wire and the direction of the warp (i.e. the inserted wires are identical and the fabric sett do not change, nor changes of lubrication of the fabric, i.e. a constant coefficient of friction between the fabric and the wire can be assumed), it is possible to determine the relation of this force depending on the position of the respective wire to the radius on which the said wire is located. By this method it is possible to verify the contact pressure distribution along the radius of the packing.

The value of the coefficient of friction must be known to determine its absolute values. This can be determined either by a direct measurement by wire tweaking the fabric or by measuring the above-mentioned force immediately after wrapping the respective wire where the contact tension can be determined directly from the fabrics tension when packed. Unfortunately, both methods are burdened by a relatively large measurement error.

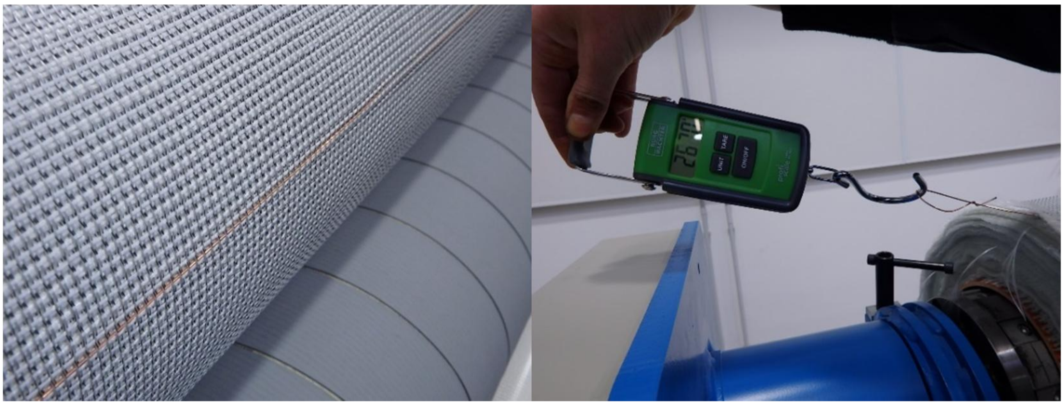

Figure 7 Arrangement of measuring wire and load cell

Another option would be differential measurement, i.e. the comparison of the measured values on individual wires), which are gradually located at the same depth below the surface of the packing. So we get sets of pairs [r_i, T_{iTheor}] and [r_i, T_{iExp}], assuming *f=const* it will be possible to put through a regression line whose slope will be directly proportional to *f*. However, this method has not yet been elaborated in more detail.

6 CONCLUSION

While we have developed a plausible mathematical model its credibility is to be verified. Presently an experimental campaign is prepared in cooperation with a fabric factory. Once this model is verified we should be able to predict behavior of any batch depending on the conditions of the winding.

In future a possible extension of the model for non-isotropic material could be found. Anyway the problems with the determination of the orthotropic moduli of the batch should be solved before.

Another way for a future development leads to find a reverse function $f(\sigma(l)=const)$ which should allow the loom operator to program in advance the best fitting tension function for any type of batch. Unfortunately the *f(r)* is rather complex and its reverse function may not exist.

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7 REFERENCES

1. Höschl C.: Flexibility and strength II (Pružnost a pevnost II), in Czech, (1st edition), VŠST in Liberec, Faculty of Mechanical Engineering. Liberec, 1992
2. CEDIMA Meziměstí s.r.o.: Basic Installation, Operating and Maintenance Instructions (2006 edition), Meziměstí
3. Dvořák J., Karel P., Žák J.: Study of Interactions between weaving process and weaving machine systems, VÚTS, a.s., 2018