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Problematics of curved laminated composites

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1. Introduction

The use of composite materials on textile machines is a matter of decades. As the demands on the quality of the final product increase, so do the demands on the precision of the parts that are directly involved in the fabric creation. In our paper we deal with the issue of production of the so-called batten for the DIFA weaving machine, which is intended for the production of 3D textiles, the so-called DIstance FAbric.

2. Problem analysis

The existing VEGA weaving machine was used as the basis for the construction of the DIFA loom, from which the basic components were taken over. However, it soon became apparent that while the precision with which existing parts are made is sufficient for weaving *ordinary* fabric, it will be necessary for the DIFA machine to change the technology of their production in order to reduce shape imprecisions.

The above mentioned batten on the VEGA and DIFA machines basically consists of a metal (steel made) tube and four C/E composite plates, which are glued to the tube (see Fig. 1). The tube represents the main element supporting the bending loads, the composite plates form a kind of clamps into which other textile technology devices are fixed, such as weft picking nozzles, various sensors and especially the reed and, in the case of the DIFA machine, also the supports for so called pulling bar. The whole then forms a two-hole profile, extremely stiff in torsion. The reed and the rail for the pulling bar must be very precisely positioned with respect to other devices, the main criterion here being their parallelism.

As can be seen from Fig. 1, the clamps are formed by a curved laminated plate. It is laminated from unidirectional plies of carbon/epoxy prepreg. In order to achieve sufficient bending and torsional stiffness, only the plies at angles of 90 (in the plane of section) and ±45 degrees are comprised in the stacking sequence, see Fig. 2. The sequence is symmetrical according to the assumption that the resulting part will not twist due to the change in temperature during the cool down after curing. This assumption turned out to be wrong, so we profited of a major change of the batten conception (consisting in the change of principle of static balancing) to redesign the clamps.

3. Design of clamps

As can be seen from Fig. 1, the new clamps are similar in shape, only the dimensions differ. A further difference then consists in the different way the clamps are loaded: in DIFA loom the inertial forces of the reed do not sufficiently compensate the force of the weaving resistance. Both of these facts were taken into account when designing the new stacking sequence of the

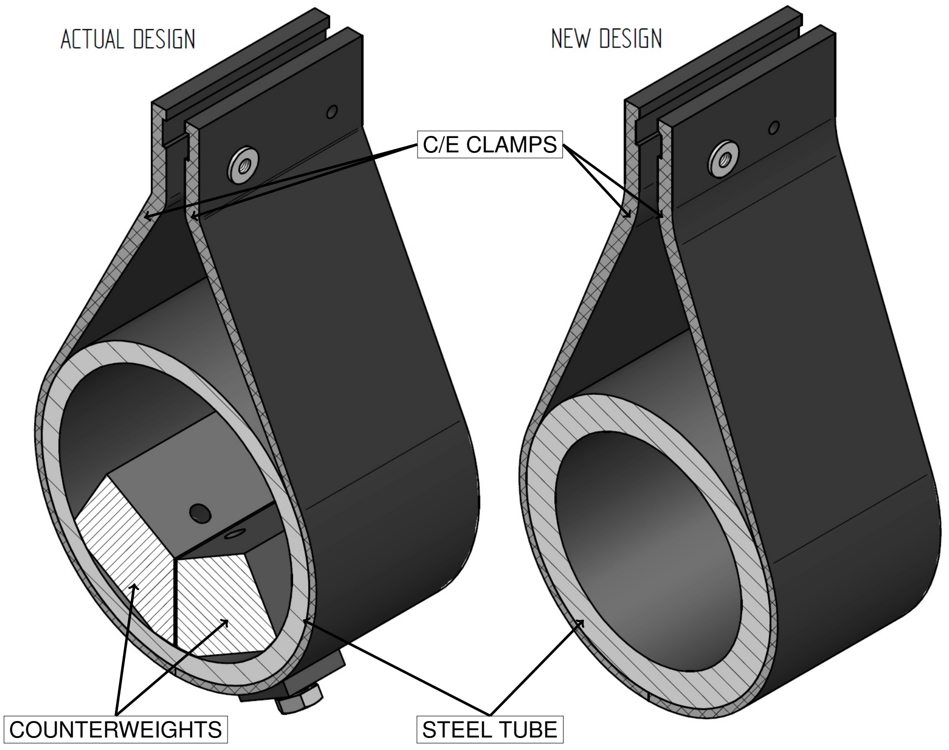

Fig. 1. Section of the batten

plies. The stacking sequence was then determined using classical lamination theory to meet the requirements for strength and stiffness of the batten. While a supposedly *non twisting* symmetric sequence was found we were aware from the beginning of its temperature dependent twisting behavior.

4. Modified classical lamination theory

Let's have the basic equation of a thin plate behavior (we are using annotation as used by [1])

$$\begin{vmatrix} \mathbf{N} \\ \mathbf{M} \end{vmatrix} = \begin{vmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B}' & \mathbf{C} \end{vmatrix} \cdot \begin{vmatrix} \varepsilon_{\mathbf{0}} \\ \kappa_{\mathbf{0}} \end{vmatrix} - \Delta T \cdot \begin{vmatrix} \langle \alpha \cdot \mathbf{E} \cdot \mathbf{h} \rangle \\ \langle \alpha \cdot \mathbf{E} \cdot \mathbf{h^2} \rangle \end{vmatrix},$$

where $\varepsilon_{\mathbf{0}} = [\varepsilon_{0,x}, \varepsilon_{0,y}, \gamma_{0,xy}]'$, $\kappa_{\mathbf{0}} = [\kappa_x, \kappa_y, \kappa_{xy}]'$, $\langle \alpha \cdot E \cdot h \rangle$ and $\langle \alpha \cdot E \cdot h^2 \rangle$ being the terms of thermal expansion. In this relation the index 0 refers to the deformations of neutral surface.

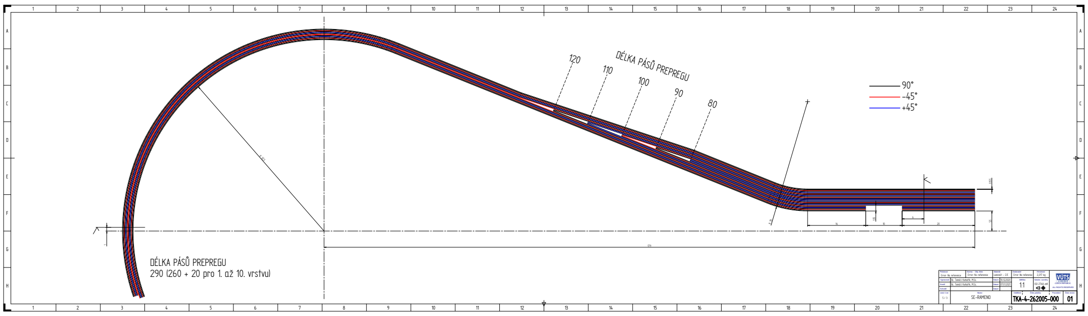

Fig. 2. Stacking sequence of the clamp

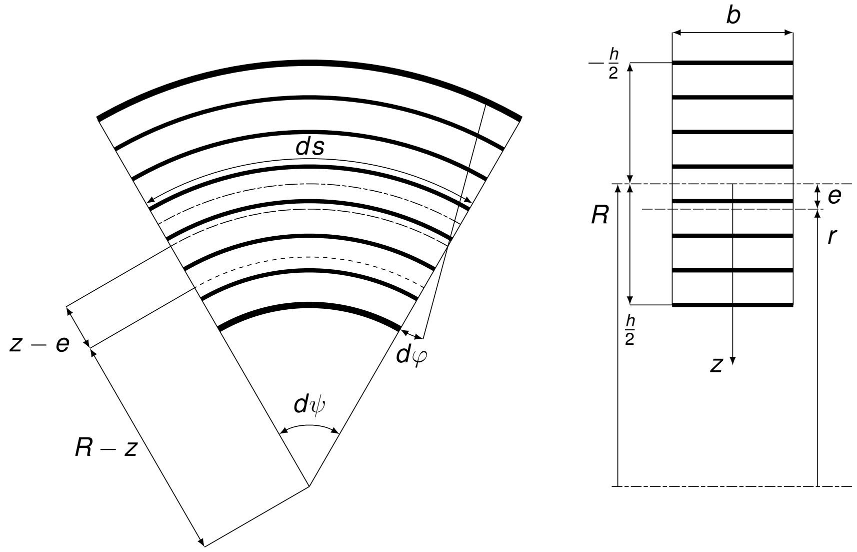

Fig. 3. Kinematics of a curved laminated plate

For a flat plate the terms of sub matrices $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$ are defined using the above mentioned classical theory as follows (see [1]);
per example

$$A_{11} = \sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot dz,$$
$$B_{11} = -\sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot z \cdot dz,$$
$$C_{11} = \sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot z^2 \cdot dz,$$

where K is total number of plies and z is distance from the neutral surface as given by the definition of ε by Kirchhoff's theory. The terms representing the thermal expansion are defined by

$$\langle \alpha \cdot E \cdot h \rangle_x = \sum_k \overline{\alpha \cdot E_{1,k}} \cdot (h_k - h_{k-1}) \text{ etc.}$$

Note: these relationships were used to determine the stacking sequence with respect to the required mechanical properties of the clamps.

The latter relations are based on the kinematics of a thin plane plate using Kirchhoff's theory. If we use the kinematics of a curved plate (see Fig. 3) to derive them, these relations get the following form

$$A_{11} = \sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot \frac{dz}{1-\frac{z}{R_x}},$$
$$B_{11} = -\sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot z \cdot \frac{dz}{1-\frac{z}{R_x}},$$
$$C_{11} = \sum_{k=1}^{K} \int_{h_{k-1}}^{h_k} \overline{E_{11k}} \cdot z^2 \cdot \frac{dz}{1-\frac{z}{R_x}},$$

It is clear from the form of the integrand in the above integrals that even for a symmetric stacking sequence, the members of submatrices $\mathbf{B}$ will not necessarily vanish. It follows that for such a curved laminated plate a coupling occurs between the thermal expansion in the membrane direction and the change in its curvature.

5. Solution of the problem

Although it is theoretically possible to find such a stacking sequence that the members of the submatrices $\mathbf{B}$ are zero, it is practically impossible to meet the requirements for the resulting stiffness of the clamps at the same time. Therefore, we chose an alternative solution to solve the batten problem. There are 2 variants of clamps to be produced, *left* and *right* or *odd* and *even*. These two designs differ in the positions of the layers at ±45 degrees, where the plies under $+45$ degrees in the *left* clamp are replaced by plies under -45 degrees in the *right* one and vice versa. The twist of these *mirror twins* due to thermal expansion should be inverse. By combining two pairs of *left* and *right* clamps on one tube (see Fig. 4), we obtain an untwisted batten. The price for this is an uneven distribution of the clamping force of the reed.

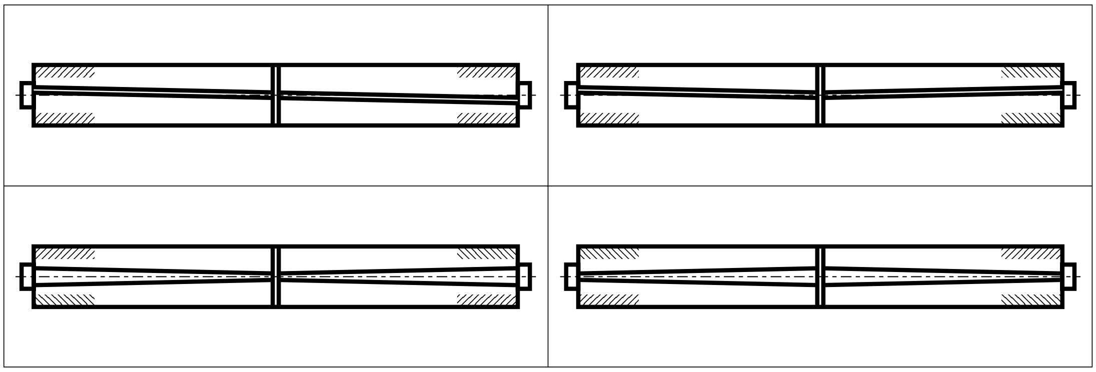

Fig. 4. Combinations of clamps; the current design is top left, the preferred new one is bottom right

6. Conclusion

Using the classical lamination theory, we were able to determine the origin of the clamps twisting as well as the practical impossibility of a *clean* solution. We also verified these calculations using FEM. The solution was to change the technology at the cost of increasing the production costs due to more complex logistics.

References

[1] Gay, D., Composite materials, 3rd Edition. Hermes, Paris, 1991. (in French)