

MODELLING THE SEAM ARCHITECTURES FOR TEXTILE PREFORMING

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ABSTRACT

1. INTRODUCTION

Sewing of textile preforms offers a lot of opportunities for the future production of FRP parts. Although out-of-plane properties and damage tolerance abilities of the preform improve by stitching, stitching degrades the in plane properties of the preform. The choice of material and process parameters is crucial to realise the benefits of stitching. This demands modelling and simulation of stitched textile structures. Currently simple textile structures like multi layer woven fabrics and multi layer non-crimp fabrics can be modelled. This paper shows a concept for a mathematical modelling of stitching architectures including the generation of the thread surfaces. The model can help in realising two functions. On the one hand different material and process parameters can be taken into account and on the other hand the computed surface description including geometrical dependencies can be transferred into a structural mechanic model (e.g. WiseTex).

2. BASICS AND SCOPE OF THE CURRENT WORK

Due to the anisotropy of the inner structure of preforms made of NCFs, modelling and simulation is necessary to predict the mechanical properties of the FRP-part. Initial solutions for modelling of multiaxial multiply fabrics including the warp knitting seam exist [1]. The fibre disorientation caused by the seam has been taken into account [2]. The dimensions and shape of the disoriented regions have to be determined in practical tests and then can be implemented by modelling parameters designed for the software tool. Apart from the seam influencing the fibre orientation of the NCFs, the lay-up of the textile structure together with the stitching process can lead to deviations of the thread from the original thread path. The thread path is defined by the seam architecture which depends on the stitching technology. Currently there are four different types of stitching technologies mainly used for preforming. Among them, the common stitching technology i.e. double lock stitch and three other one-sided stitching technologies viz. tufting, blind stitch and OSS[®] exist. Additionally there is a prototype of a new one-sided stitching technology available at the ITA. The various seam architectures studied are presented in the following chapter.

Due to the interaction between the seam and the textile structure a more complex thread path appears depending on the material parameters and the process parameters [3].

The scope of the current work is to create geometrical models of the different seam architectures that would represent the real thread paths within the textile structure for a

given application. Additionally the models have to allow an implementation of the material and process parameters in the future and their integration in common simulation programs.

3. STITCHING TECHNOLOGIES INVESTIGATED

A general description of the three different types of stitching investigated, namely the double lock stitch, the tufting process and the ITA-one-sided stitching technology, is given in the following.

3.1 Double lock stitch

Using the double lock stitch, two threads are necessary. The stitching process can be described in six steps (Figure 1):

- Step 1: The needle penetrates the workpiece.
- Step 2: After the needle has reached the lowest position a loop is created due to the upwards movement of the needle. The loop is captured by the looper.
- Step 3: Due to rotary motion of the looper the loop is enlarged. The thread take-up lever releases the necessary amount of thread.
- Step 4: By the help of the looper the loop is directed around the complete bobbin thread. At this moment the thread take-up lever has released the largest amount of sewing thread.
- Step 5: The thread take-up lever starts drawing the thread back up. This movement is rather fast so that the loop can be released from the looper. At this point the two different threads are interlaced.
- Step 6: The position of the interlacement point (Figure 2) is determined by the further upwards movement of the thread take-up lever in combination with the stress of the thread. It can be either on the bottom, in the middle or on the top. [4, 5].

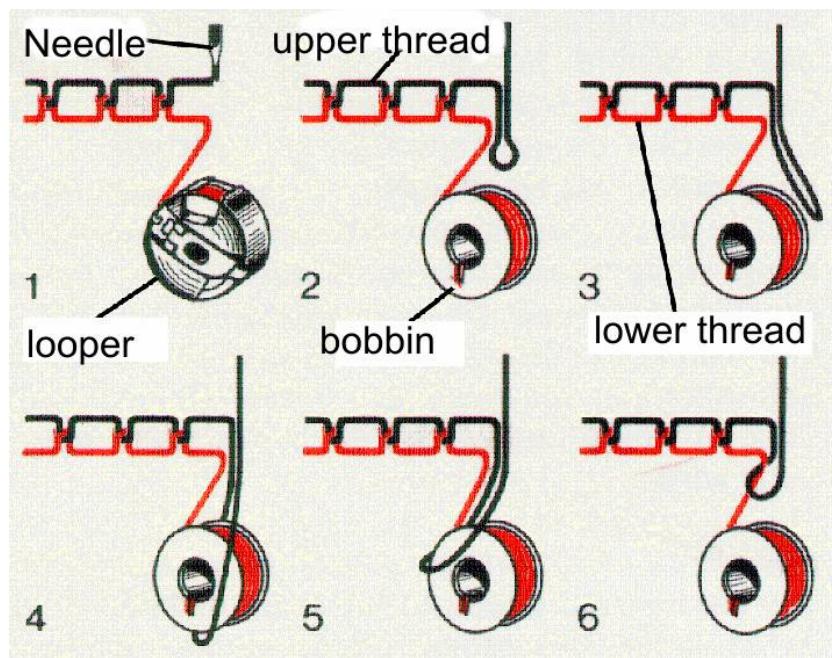


Figure 1: Principle of creation of double lock stitch [6]

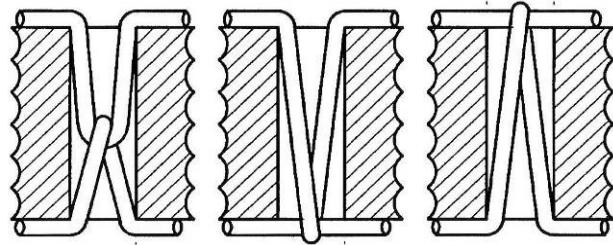


Figure 2: Possible positions of interlacement point with double lock stitch (left standard, middle bottom, right top)

3.2 Tufting

Tufting is a one-sided stitching technology. Same as with the other stitching technologies the needle penetrates the workpiece but it can also stay inside of the textile. After having reached the lowest position a loop is created with the movement of the needle back up. In opposite to the double lock stitch no looper and no second thread are present in this technology. There is no interlinking. The thread only stays inside of the workpiece due to friction forces. This leads to almost no stresses within the structure and therefore the amount of fibre disorientations is reduced. Additional advantages are that the amount of tools is lower, there is a possibility to tuft directly in the curing form, it is possible to create complex 3D preforms including thick layers and the infeed angle can be varied.

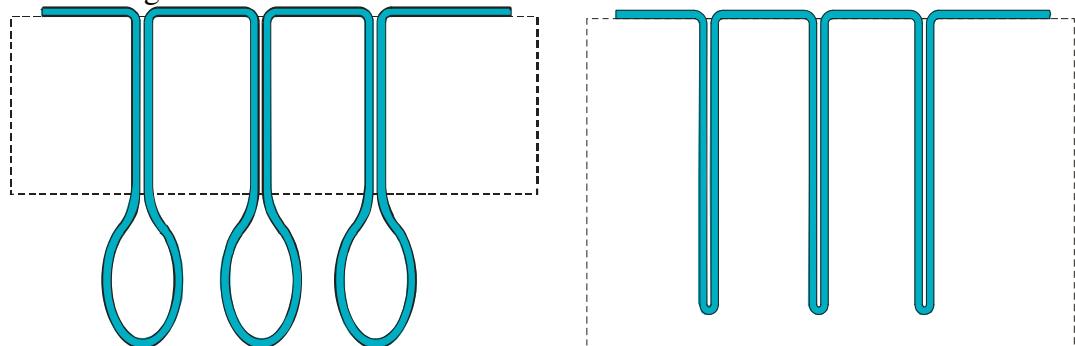


Figure 3: Principle of tufting, left stitch through the textile, right stitch within textile

3.3 ITA-one-sided stitching technology

This stitching technology was developed at the ITA and it is based on two angled needles which penetrate the workpiece from the top. The loop of the one needle is directed through the loop of the other needle and the other way around.

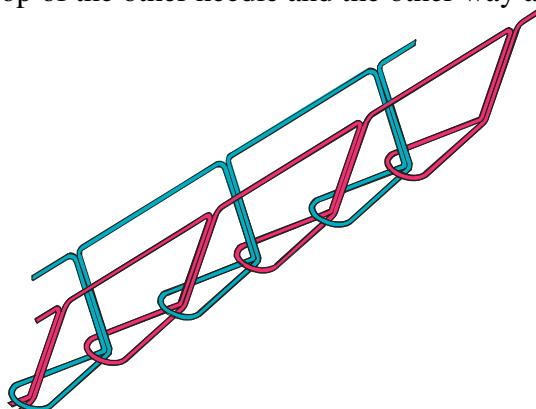


Figure 4: Seam of ITA-one-sided stitching technology

The left needle leaves the workpiece and creates a loop underneath the textile. The right needle stitches through the workpiece and dips into the loop of the left needle. The left needle then moves up to its highest position, at the same time the left loop is drawn together. The right needle reaches its lowest position. Then the needles start tilting, the left needle tilts into the direction of the feed motion and the right one into the opposite direction. In the meantime the stitching head moves forward. After the tilting is completed the two needles are still in their extreme positions. The right needle then moves upwards and creates the loop of the right needle. Now the left needle stitches through the workpiece and dips into the loop of the right needle and the process is repeated.

On the top surface two tracks of the seam are visible while the bottom surface shows one track of interlaced loops.

4. BASIC PRINCIPLE OF MODELLING

The modelling described in this paper was done with MATLAB[®]. MATLAB[®] is a software package for numerical calculations and for the visualisation of data in a technical-scientific context. Its basis is a matrix of which the dimensions don't need to be defined explicitly. As a consequence numerical problems can be solved within a short period of time.

To be able to model the yarn in MATLAB[®] the following rules are defined:

1. The course of the thread is determined by the coordinates following the centres of the threads. These coordinates are defined for characteristic parts of the seam, e.g. for a straight part or a curved part.
2. Curved parts are subdivided into smaller units of certain angles to have a more fluent appearance and avoid discontinuities. The radius of the curves can be defined as a multiple of the radius of the thread.
3. Circles with the radius of the threads are then defined around the centre line coordinates which create the hull of the thread.
4. The flange of the circles has to be rotated depending on the thread course so that it is always perpendicular to the course direction. For this the coordinates need to be rotated and added to the previous position of the thread section.

Figure 5 shows the graphical user interface of MATLAB[®] under windows.

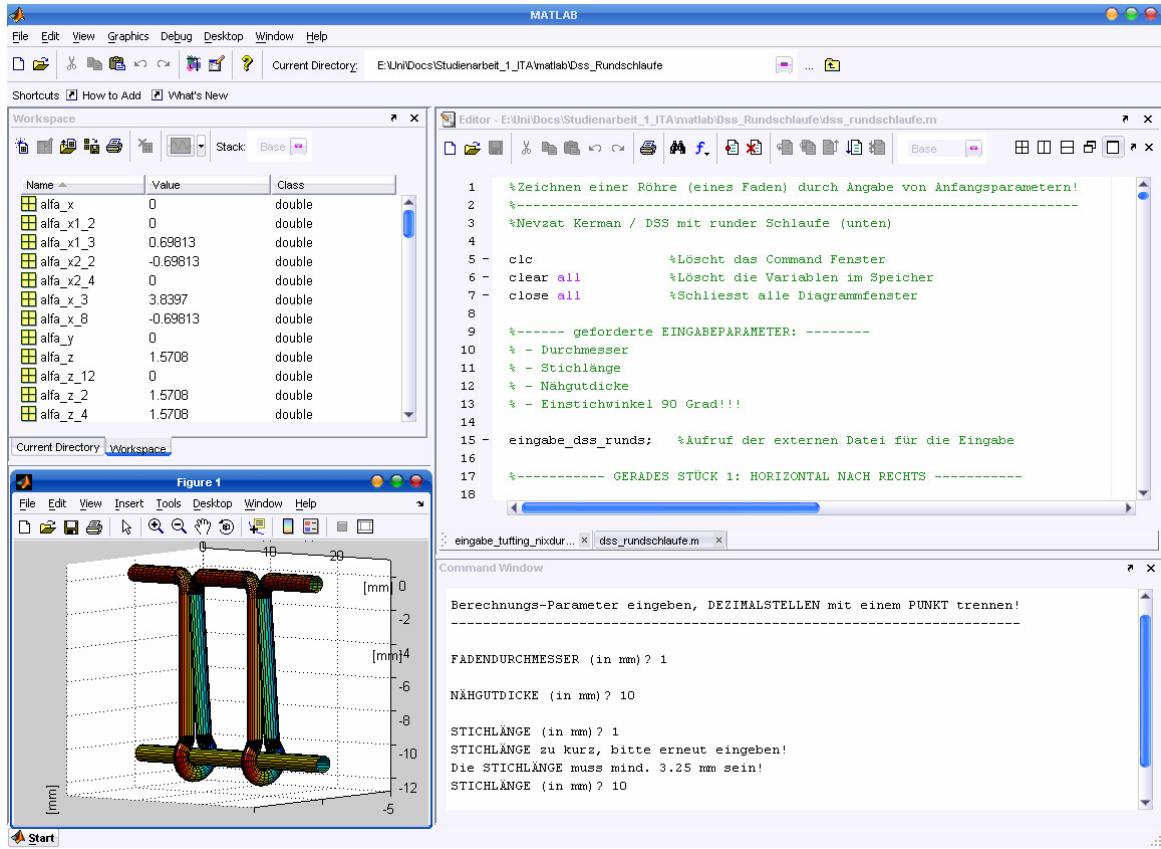


Figure 5: Graphical User Interface of MATLAB® (Version 7.0) under Windows

5. GEOMETRICAL MODELLING OF THE SEAM ARCHITECTURES

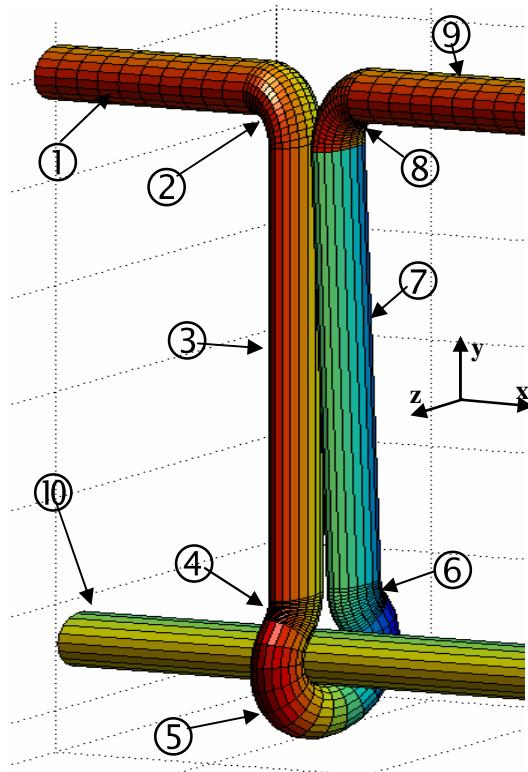
To have consistent course of actions when creating the different types of seams the following aspects are taken into account:

1. Each stitching technology is programmed separately
2. For each stitching technology one input file is defined which includes the variable parameters thread diameter, thickness of the workpiece, stitch length, possibly infeeding angle and the calculated values to ensure plausibility (keeping the stitch distances without collision of the threads)
3. Sub-Functions are defined and saved in separate files to simplify recurrent program parts.
4. One stitch is subdivided into different sections depending on the thread position. A complete thread course is realized adding the different sections.
5. After the simulation of one stitch the second stitch is realized repeating the first stitch.
6. The stitch is displayed as surf and can be viewed from all sides (three-dimensionally) in the “camera view”-mode of MATLAB®.

In the following the stitching technologies described above are modelled.

5.1 Modelling of double lock stitch

As mentioned earlier the thread is subdivided into different sections and modelled using the respective formulas.



Sections:

1. Straight horizontal yarn in x-direction
2. 90° bend down in y-direction
3. Straight section down in y-direction
4. 40° bend around the x-axis
5. Loop around lower thread
6. 40° bend around the x-axis
7. Straight section up in y-direction
8. 90° bend to the right in x-direction
9. Straight horizontal yarn in x-direction (repetition of the stitch)
10. Lower thread

Figure 6: Subdivision of double lock stitch in different sections

Figure 7 shows models of double lock stitched preforms with different stitch lengths (2 mm left and 4 mm right). The shape of the sewing thread, at the point of interlacement at the bottom of the preform and the region of the needle entry at the top of the preform deviates from the theoretical shape of the seam architecture shown in Figure 6 and is additionally influenced by the stitching parameters.

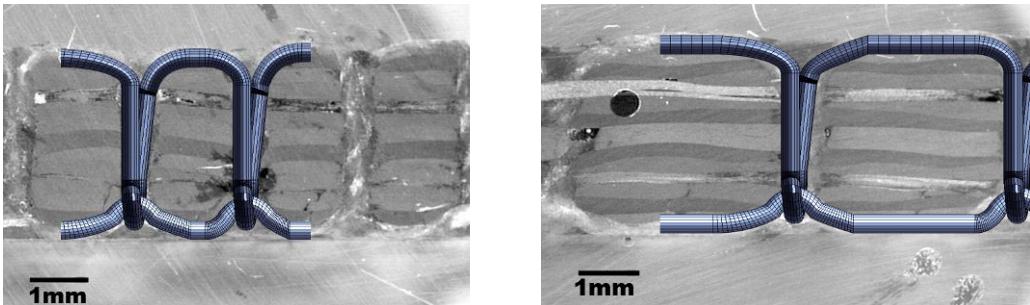
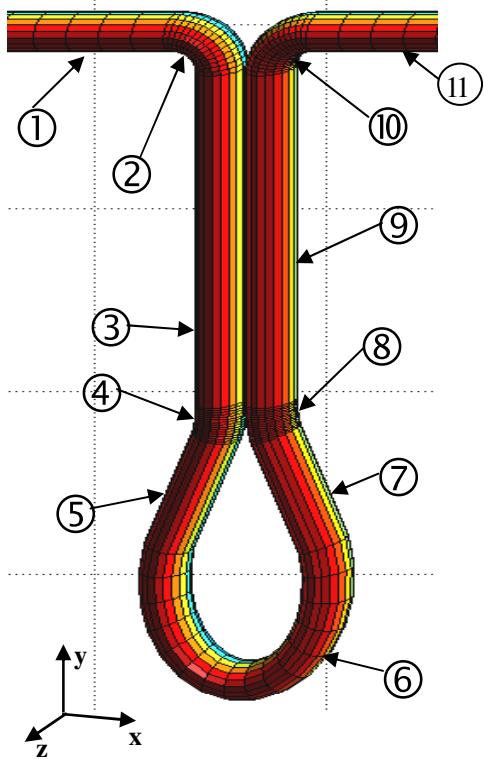


Figure 7 Microscopic images and models of seams for 2 mm (left) and 4 mm (right) stitch length

5.2 Tufting

For tufting we have to distinguish between a stitch in which the needle stitches through the textile and a stitch in which the needle stays in the textile. Both types of stitches are described in the following starting with the stitch in which the needle stitches through the textile.

To achieve the tufting seam the thread is again subdivided into different sections which are calculated with the respective formulas and then modelled.

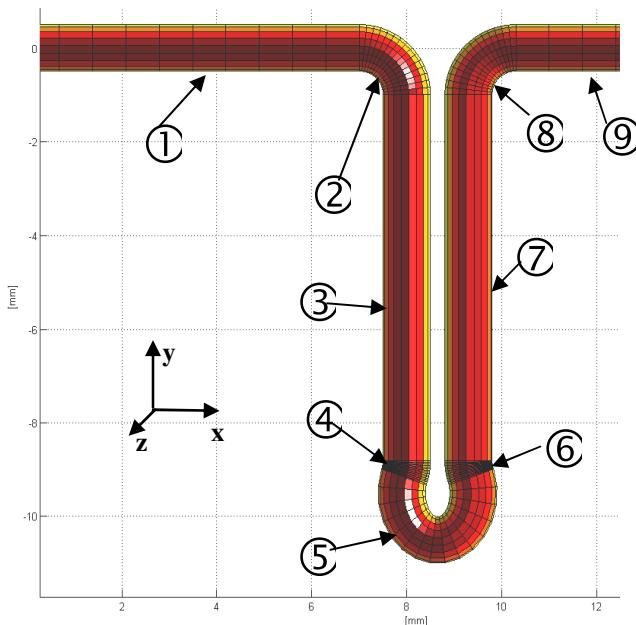


Sections:

1. Straight horizontal yarn in x-direction
2. 90° bend down in y-direction
3. Straight section down in y-direction
4. 20° bend around the z-axis
5. Straight part of the loop
6. 220° loop around the z-axis
7. Straight part of the loop
8. 20° bend around the z-axis
9. Straight section up in y-direction
10. 90° bend to the right in x-direction
11. Straight horizontal yarn in x-direction (repetition of the stitch)

Figure 8: Subdivision of tufting stitch in different sections (variation 1)

The only difference of the tufting seam in which the needle does not stitch through the textile is that the straight part of the loop is missing. The formulas in MATLAB® are identical apart from minimum changes.



Sections:

1. Straight horizontal yarn in x-direction
2. 90° bend down in y-direction
3. Straight section down in y-direction
4. 20° bend around the z-axis
5. 220° loop around the z-axis
6. 20° bend around the z-axis
7. Straight section up in y-direction
8. 90° bend to the right in x-direction
9. Straight horizontal yarn in x-direction (repetition of the stitch)

Figure 9: Subdivision of tufting stitch in different sections (variation 2)

5.3 ITA-one-sided stitching technology

The ITA-one-sided stitch is modelled against the stitching direction. The course of the seam is divided into different sections. With the help of the suitable formulas and command lines MATLAB® shows the calculated thread in three-dimensional form.

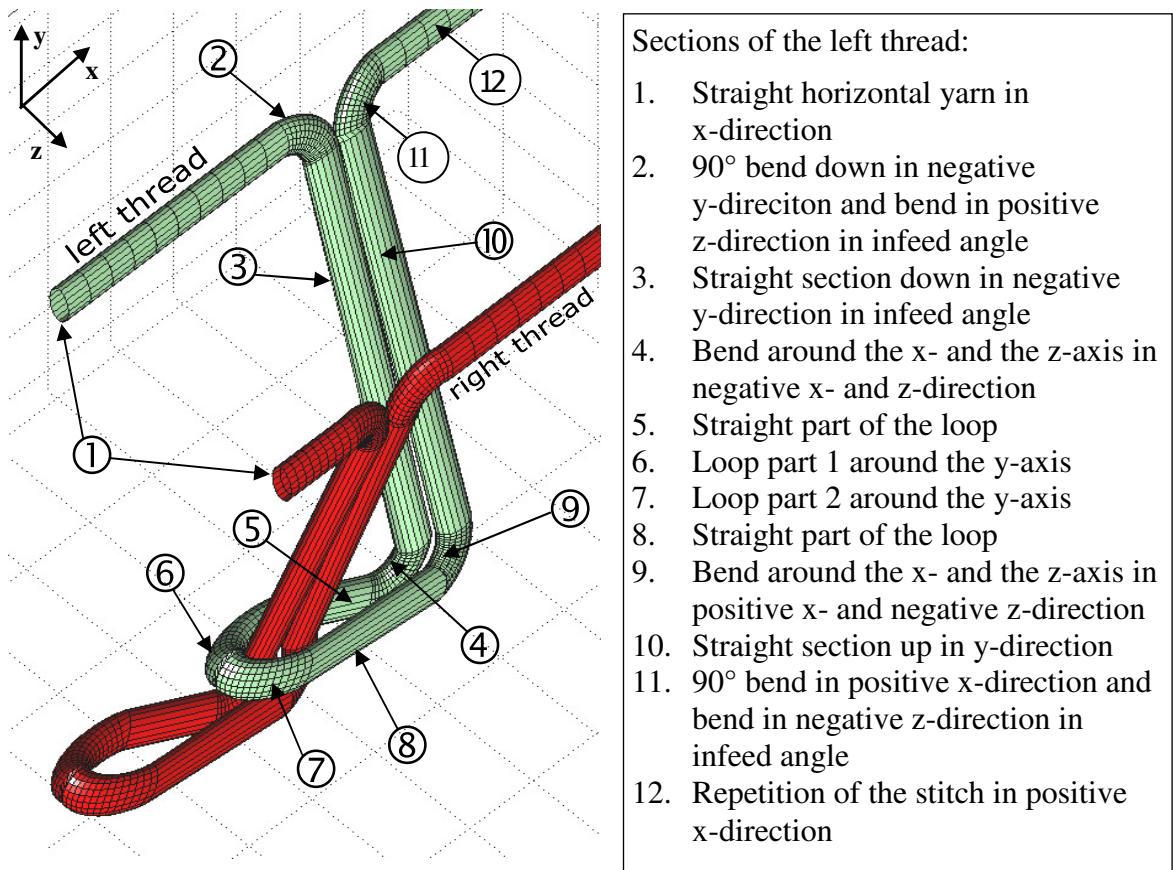


Figure 10: Subdivision of ITA-one-sided stitch in different sections

The ITA-one-sided stitch exists of two threads which are introduced in the workpiece symmetrical to each other but with an offset. Hence, the segments of the right thread (red) can be subdivided analogously to those of the left thread (red) (Figure 10). Besides, is to be mentioned, that in opposite to the double lock stitch there is the possibility to enter the infeed angle in the user-defined parametres.

Figure 11 shows the side view of the stitch including the used variables in the plausibility test and Figure 12 shows the bottom view. In this picture also the determination of the starting point and the length of the right thread are shown.

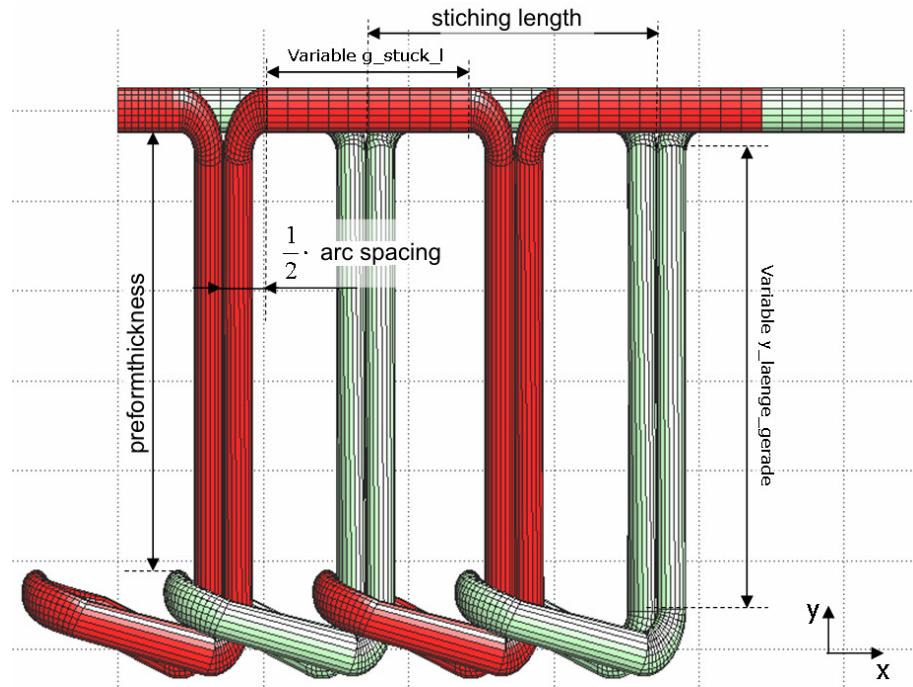


Figure 11: Side view including the used variables in the plausibility test

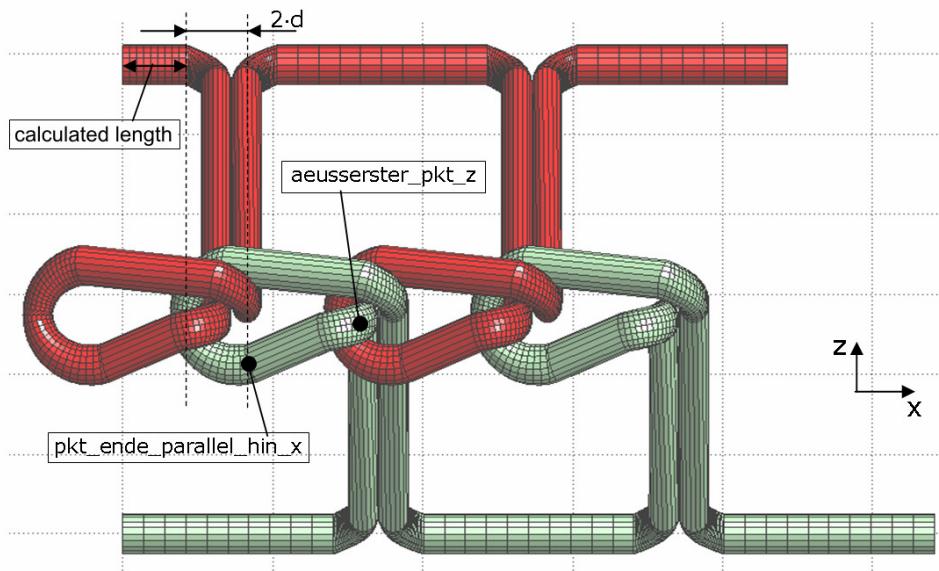


Figure 12: Bottom view; determination of the starting point and the length of the right thread

6. CONCLUSIONS

Glass and Carbon fibre reinforced plastics are used in more and more areas on account of their good specific mechanical qualities as well as their high energy absorbing capacity. For an economic production of the textile preforms an automation of the working steps is envisaged. Stitching technologies can be used to strengthen the structure in z-direction and this way increase the damage tolerance and delamination resistance. Therefore, stitching technologies are used not only for the fixation of the components, but also for strengthening. Fibres are disoriented due to the stitching which can lead to decreased in-plane properties. For the development of complex, load compatible structure it is inevitable to know the precise stitching path.

The work shown in this paper has realised the modelling of such a stitching path with the software MATLAB® in form of a graphical display. In addition using the interfaces the software enables the user to implement the models in simulation programs.

The thread is represented as a tube for the calculation. Depending on the type of stitching, input parameters as e.g. thread diameter, thickness of the workpiece, stitch length or infeed angle can be given. The course of the thread is determined by the centre coordinates of the threads. These coordinates are determined for characteristic parts of the thread course, e.g. for a straight or for a curved section, by means of simple point-to-point distance calculations depending on trigonometric relations. Circles with the radius of the thread are created around the centre coordinates representing the outer hull of the thread and finally giving the graphic result.

Modelled stitching technologies are double lock stitch, tufting with and without stitching through the textile and the ITA-one-sided-stitching technology. Additional or new stitching technologies can be created easily combining the formulas of these stitches.

In future works the mathematical variables of the geometrical models need to be linked to databases including material and process data by mathematical equations. The outer surface of the sewing thread needs to be designed with a varying cross-section so that compression in areas of deflection etc. can be realized. Finally, the models of the seams will need to be implemented into simulation programs (e.g. WiseTex) including the interaction between the seam and the textile structure.

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