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SIMULATION OF FRICTIONAL CONTACT INTERACTIONS BETWEEN WARP YARNS AND HEDDLES WITHIN JACQUARD HARNESS FOR 3D WEAVING

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Abstract. The relative motions between warp yarns and heddles within the Jacquard harness used for 3D weaving induce frictional interactions between these elements which may generate both damage in the yarns and weaving errors.

To identify the interaction phenomena taking place within such harnesses, a finite element model, based on an implicit solution scheme [1], is proposed. In this model, all elements involved in the harness (cords, heddles, warp yarns) are represented using finite strain beam elements, and frictional contact elements are automatically created to account for frictional contact interactions. Motions defined by the Jacquard card for the shedding are prescribed as boundary conditions to the upper ends of the heddles. The resultant forces necessary to move the heddles are obtained as results of the simulation.

Simulation results for an interlock fabric, with 28 warp yarns, will be presented, showing the forces evolution applied to the heddles over a few dozen consecutive sheddings.

1 INTRODUCTION

The Jacquard harness is a major component of the weaving loom, acting as a shedding device controlling the motions of warp yarns to produce woven fabrics. The Jacquard harness is a system of cords, heddles (made generally from steel, they have an eyelet through which warp yarn is passed), and springs that transmit the movement to the individual warp yarns.

This study is concerned with the congestion phenomenon within the Jacquard harness. When weaving a thick interlock, the handling of the heddles in a limited space induces friction interactions between the different Jacquard harness elements: cords, heddles, eyelets, and warp yarns. These interactions are particularly important when a large number of warps are moved along the harness depth. Frictional forces between the harness elements can damage yarns or cause weaving errors. For example, when warp yarns are moved to open the shed, friction within the harness can prevent some of them to reach their expected positions, causing the weft yarn to be inserted in the wrong place and creating an unexpected weaving pattern.

To better understand congestion and locking phenomena within the harness, the target goal of the study is to simulate the motion of the different elements driven by the shedding of the actual weaving pattern. Since the focus is put on the shedding motions, only heddles and warp yarns will be considered. In particular, the insertion of weft yarns and the progressive forming of the fabric is out of the scope of the present work. Since harness elements (heddles and yarns) are considered as slender structures, we can define the modeling problem as a friction contact interaction of moving entities modeled as beams, to be solved using finite element analysis.

Some previous studies can be found in the literature dealing with the simulation of the weaving process. Finckh [2], (2004) simulated the weaving process using Ls-Dyna[1], a dynamic explicit finite element simulation code. Two models have been created, the first one with 3D solid elements at a yarn scale and the second with beam elements at a fiber scale. Heddles are represented by rings through which the warp yarns pass. The reed is represented by a set of rectangular surfaces perpendicular to weft yarns. The author presented an approach to simulate the weaving process step by step: shedding, weft insertion, and beating in and obtain a numerical model for 2D woven fabrics with polyester or aramid material properties.

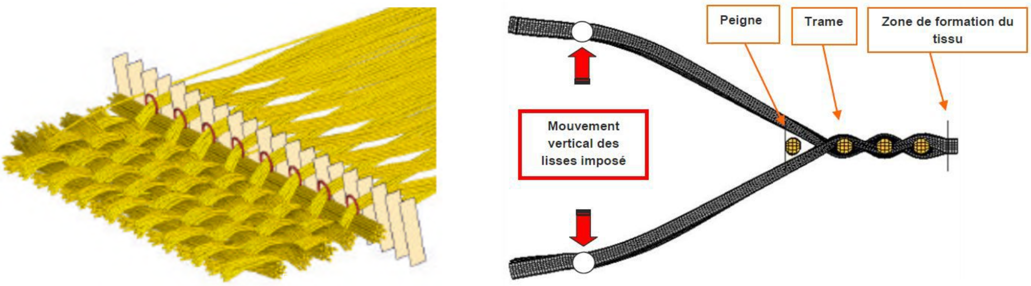

Figure 1: 2D models : Finckh's fiber scale model, 2004 [2] - Vilfayeau's yarn scale model, 2014 [3]

Vilfayeau project [3], (2014) focuses on the simulation of the weaving process by reproducing weaving key actions to obtain a deformed dry structure. Step-by-step simulation: shedding, weft insertion, and then beating in step has been conducted with the dynamic explicit element software Radioss[2].

The reed has been modeled as a rectangular surface with steel properties parallel to the weft yarn. The heddles were not modeled as mechanical elements, but their corresponding motions are transcribed via translation boundary conditions prescribed to a set of nodes of warp yarns. Using a 3D solid mesh with hexahedral elements with a transverse isotropic constitutive law, at the yarn scale, results for 2D woven fabrics (plain (1-1) & 2-2 twill weave) have been presented for E-glass fabrics. Vilfayeau contributed to a new approach in the simulation of woven fabrics, taking into account the influence of the weaving process on the final geometry.

Russcher and al. [4],(2013) simulated the weaving process with a dynamic explicit simulation code. A 5

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[1] LS-DYNA is an advanced general-purpose multiphysics simulation software package developed by the Livermore Software Technology Corporation (LSTC)

[2] RADIOSS is a multidisciplinary finite element solver developed by Altair Engineering company

layer 3D warp interlock unit cell was modeled at a micro-scale where yarns (both warp and weft) are represented as bundles of 80 or more filaments modeled as beam elements with aramid material properties. A step-by-step simulation is performed for the successive stages of the weaving. The constraining plates shown in Fig.2 are used to represent the environment of the considered unit cell within the whole fabric. This model aims to predict the microstructure of the unit cell of 3D interlock woven fabrics taking into account processing conditions such as warp yarns tension.

The work of Yang, 2015 [5], based on the so-called digital element approach [6, 7], aimed to develop a simulation tool for the interlock woven fabric process. Jacquard machine main components (warp yarns, weft yarns, and reed) have been modeled, without consideration of heddles, but representing their motions by displacement boundary conditions imposed on a set of nodes of warp yarns. Step-by-step simulation was carried out to produce the four primary weaving actions: weft insertion, beating up, shedding, and tacking up. The digital elements approach was used to model the behavior of filaments. According to this approach, each fiber constituting the yarn in the model is represented by a chain of two-node elements with only translation degrees of freedom. The simulation tool developed is capable of simulating the weaving of unit cells of 3D fabrics to characterize their initial geometries.

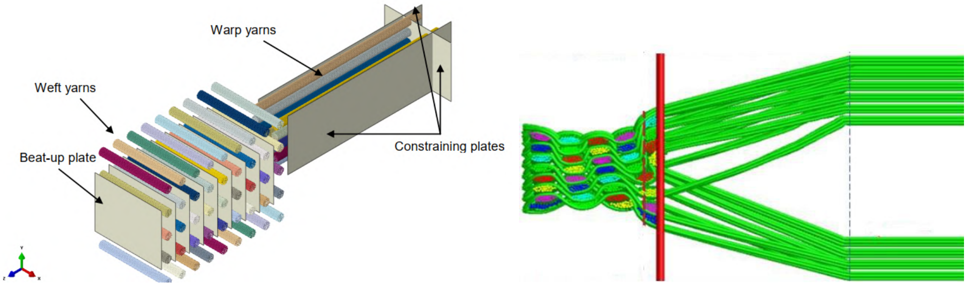


Figure 2: 3D models: Russcher's fiber scale model, 2013[4] - Yang's fiber scale model, 2015[5]

To our knowledge, based on this state of the art, none of the works dedicated to the simulation of the weaving process was focused on the congestion phenomena taking place within the Jacquard harness. The goal of the present work is to address specifically this issue, using a finite element simulation approach [1] developed to account for frictional contact interactions within filament assemblies. Among various applications, this approach has been used to determine the initial configuration of interlock fabric unit cells [8].

The presented study aims at simulating the motions of the different elements in the harness, namely the heddles and the warp yarns, to determine the efforts variations in the heddles due to the frictional interactions, and to predict possible blocking situations due to congestion.

After introducing the basics of the simulation approach, the shedding device for 3D interlock fabrics and its operation are presented. An appropriate procedure to remedy issues related to the determination of ready-to-start configuration, in which each warp yarn is inserted in its assigned heddle is discussed. Results illustrating the ability of the proposed approach to determine the efforts in the heddles for the simulation of an actual case study are finally presented.

2 BASICS OF THE SIMULATION APPROACH

The finite element simulation approach employed in this study has been developed to model the mechanical behavior of wire or filament assemblies, displaying frictional contact interactions and subject to large displacements. This approach, based on an implicit solution scheme, is briefly summarized hereafter, while the detailed description is provided in [1].

2.1 Finite strain beam model

The beam model used to represent each wire or filament of the considered assembly is based on kinematics which describes the displacement and the deformation of each cross-section using two variable directors. Denoting ξ_1 and ξ_2 the transverse coordinates of a material particle of the beam, and ξ_3 its curvilinear abscissa on the beam axis, the position $\mathbf{x}$ of this particle at any time is expressed in the following way:

$$\mathbf{x}(\xi_1,\xi_2,\xi_3,t) = \mathbf{r}(\xi_3,t) + \xi_1\mathbf{d}_1(\xi_3,t) + \xi_2\mathbf{d}_2(\xi_3,t), \tag{1}$$

where $\mathbf{r}(\xi_3,t)$ is the position of the center of the cross-section at abscissa ξ_3 and where $\mathbf{d}_1(\xi_3,t)$ and $\mathbf{d}_2(\xi_3,t)$ are two unconstrained directors. Considering these two variables unconstrained directors allows to account for cross-section deformations and circumvents the use of rotations. The kinematics of each cross-section is consequently described by nine degrees of freedom, and full Green-Lagrange strain tensors are derived, allowing to implementation of three-dimensional constitutive equations.

2.2 Contact detection

Frictional contact interactions are considered at discrete contact elements which are distributed all over the considered wire assembly. A contact element is defined as a pair of two material particles, located on the surface of interacting beams, which are predicted to enter into contact.

The detection of contact and the generation of contact elements are carried out in three stages. First, proximity zones defined by pairs of intervals on the beam axis which are stated to be close to each other, are determined. Then intermediate geometries, corresponding to the average between both beam segments constituting each proximity zone, are defined and used as geometrical support for contact elements. These intermediate geometries are discretized, and at each discrete location denoted $\mathbf{x}_k$, a geometrical procedure is used to determine which material particles $\xi_k^{(I)}$ and $\xi_k^{(J)}$ on the surface of interacting beams I and J are likely to enter into contact at this location. A unit normal contact direction denoted $\mathbf{n}_k^{(IJ)}$ is then determined, allowing the definition of a normal distance $\text{gap}(\mathbf{x}_k)$ for each contact element, expressed as:

$$\text{gap}(\mathbf{x}_k) = \left(\mathbf{x}^{(I)}(\xi_k^{(I)}) - \mathbf{x}^{(J)}(\xi_k^{(J)})\right) \cdot \mathbf{n}_k^{(IJ)}, \tag{2}$$

where $\mathbf{x}^{(I)}(\xi_k^{(I)})$ is the position of the material particle $\xi_k^{(I)}$ located on the surface of beam I.

This way of determining contact elements allows the contact particles to be located anywhere regarding the finite element mesh and is particularly suited to detect contacts at crossings between nearly orthogonal beams. Since the geometrical methods used to generate contact elements depend on the current configuration, the global process needs to be iterated within each loading step in order to gain accuracy when considering large loading increments.

2.3 Models for normal contact and frictional interactions

A regularized penalty model is used to determine normal contact reactions. A quadratic regularization is considered for very small penetrations in order to smooth the transition between contact and no-contact status. The penalty coefficient is adjusted at the level of each proximity zone to control the maximum penetration for each proximity zone.

A regularized friction model, taking into account a small reversible relative tangential displacement before real sliding occurs is considered for frictional interactions.

3 MODELS FOR HEDDLES AND WARP YARNS

Each heddle is modeled by a set often beam sections, with different material properties, representing its different parts, namely the upper cord, two metal rods on either side of the eyelet, and the eyelet itself constituted of two half elliptical rings and four struts (see Fig. 3). Special junction elements are considered to ensure the bonding at the connection points between the different beam sections.
Each warp yarn is modeled as a beam section. However bending and twitting stiffness coefficients are adjusted to account for the very low bending and twisting stiffness of the considered carbon tows due to their multi-filamentary construction.

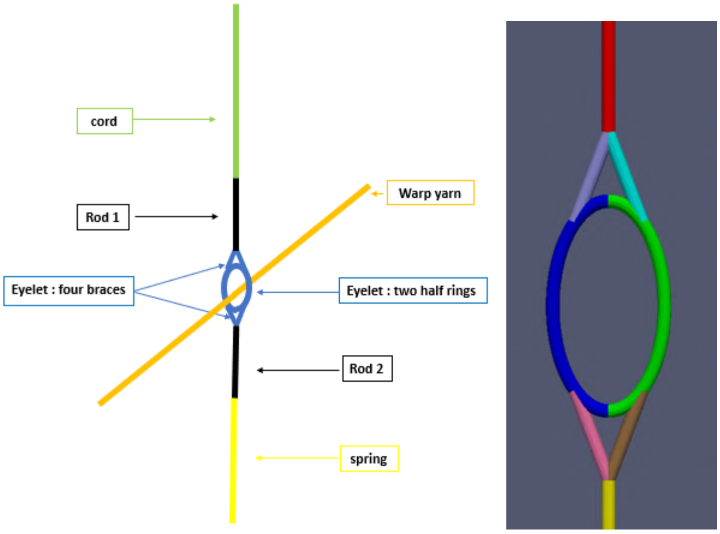


Figure 3: Heddle model

4 BASIC INTRODUCTION TO THE SHEDDING DEVICE OPERATION

In the model, the axis convention is as follows :

- Z axis : heddles direction (vertical)
- X axis : warp yarns direction (longitudinal)
- Y axis : weft insertion direction (transverse)

The harness acting as a shedding device is presented in Figure 4. Warp yarns, subject to a given tension

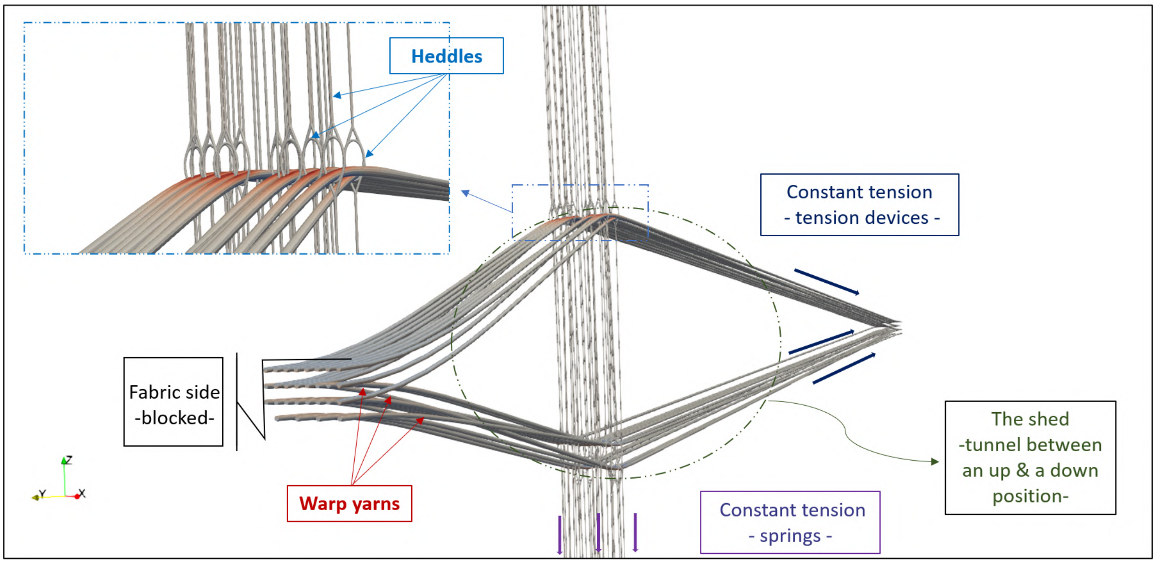


Figure 4: Simulation model at shedding phase

employing tension devices, are moved by heddles the eyelets of which they pass through. Displacements of warp yarns are locked in the three directions at their ends on the side of the fabric. A tensile load is applied to their opposite ends while locking their displacements in y and z directions. The motions of heddles are defined by a loom card defining for each weft yarn insertion which warp yarns should be in an upper position and which in a lower position.

5 DETERMINATION OF THE INITIAL CONFIGURATION

We call ”initial configuration” the configuration of the harness once the warp yarns have been inserted through the eyelets of the heddles. This configuration cannot be preliminary determined since the elements of the harness are deformed by contact interactions due to space constraints in a confined environment. For this reason, we generate a starting configuration in which the geometry of each element of the harness can be defined by simple geometries. This starting configuration is then gradually changed until reaching the initial configuration.

5.1 Heddles positioning

The heddles are positioned according to the harness board. A harness board is a plate drilled with holes through which the heddles pass (see Fig. 5). The harness board determines the position of the top end of each heddle in the plane xy. In the initial configuration, all eyelets should be located on the same (xy) plane with the same z coordinate.

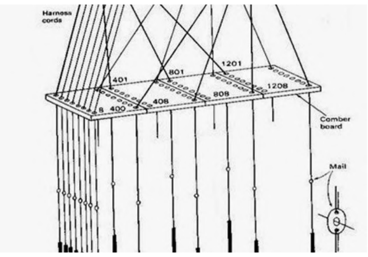


Figure 5: Harness board [9]

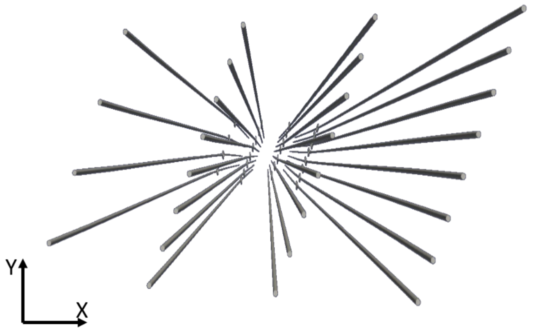


Figure 6: Heddles positioning

5.2 Warp yarns positioning

In multilayer interlock woven fabrics, warp yarns are arranged into columns as illustrated in Fig.8. Each column is composed of a given number of warp yarns. It is assumed that in the initial configuration all ends of warp yarns from the same column have the same y coordinate, but are separated in the z direction by a distance of the order of the thickness of weft yarns. The distance between columns in the y direction is one of the fabric parameters.

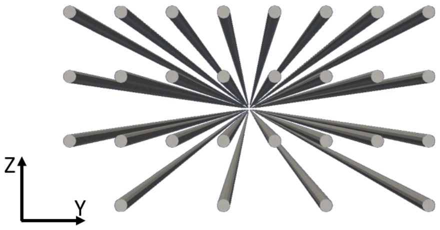


Figure 7: Warp yarns positioning

5.3 Issues about the initial configuration

Usually, due to the harness board configuration, the heddles which are assigned to the warp yarns of the same column, don't have the same y coordinate at their top end in the initial configuration. Moreover, since eyelets are located in the same plane in this configuration, their identical z coordinate doesn't match the different z coordinates at the ends of warp yarns.

The trajectory of each yarn to go through its assigned eyelet seems therefore difficult to predict preliminary.

For this reason we operate a shift on all these elements, both in y and z directions, to define a starting configuration in which warp yarns could be easily described by straight trajectories while passing through their assigned eyelet.

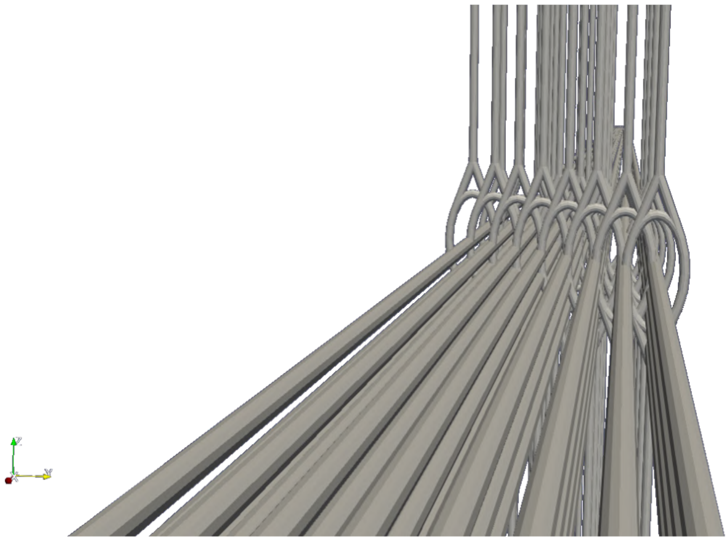


Figure 8: The nominal configuration

5.3.1 Starting configuration

To define the starting configuration, two offsets are made:

- an offset in y direction of the warp yarns allowing columns separation.
- an offset in z direction for heddles allowing the insertion of warp yarns into their eyelets.

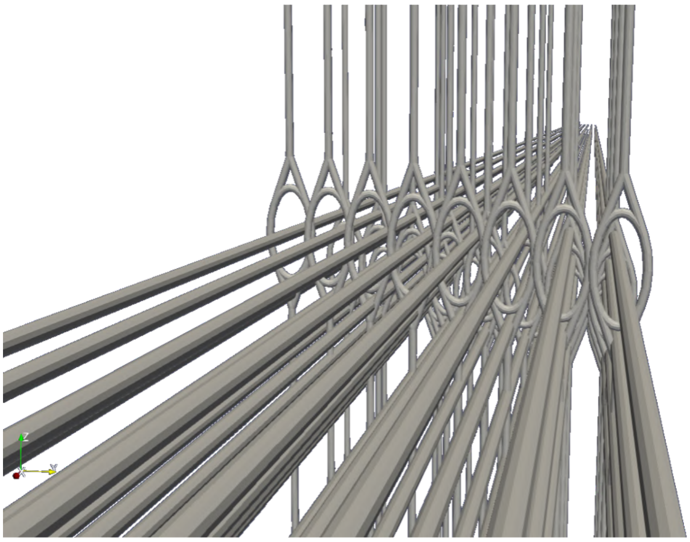


Figure 9: The starting configuration

- Removing inter-penetrations in the starting configuration
In the starting configuration, several heddles may have the same y coordinate. In this case, the warp yarn going through its assigned heddle may intersect the heddles assigned to other yarns. In this case of an initial intersection, the direction according to which the yarn is repelled using the standard contact determination algorithm is undetermined. For each initial inter-penetration between a warp yarn and a heddle, based on an analysis of the harness board configuration, it is possible to state on which side of the heddle the warp yarn should be repelled. The interpenetration is reduced to repel the yarn on the right side simply by adjusting the orientation of the normal contact direction defined by the contact detection algorithm so that points towards the correct side.

5.3.2 Transition phasis from the starting configuration to the initial configuration

Once the yarns have been repelled on the right side, a transition phasis is simulated. During this phase, the offsets in y and z directions used to define the starting configuration are gradually canceled. At the end of this phasis, a ready-to-start configuration is reached, in which each warp yarn is inserted in its assigned eyelet resulting from a mechanical equilibrium.

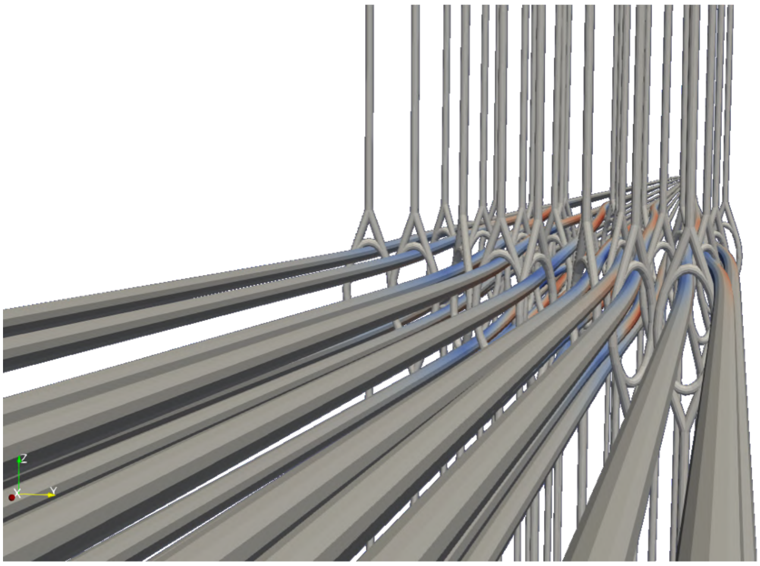
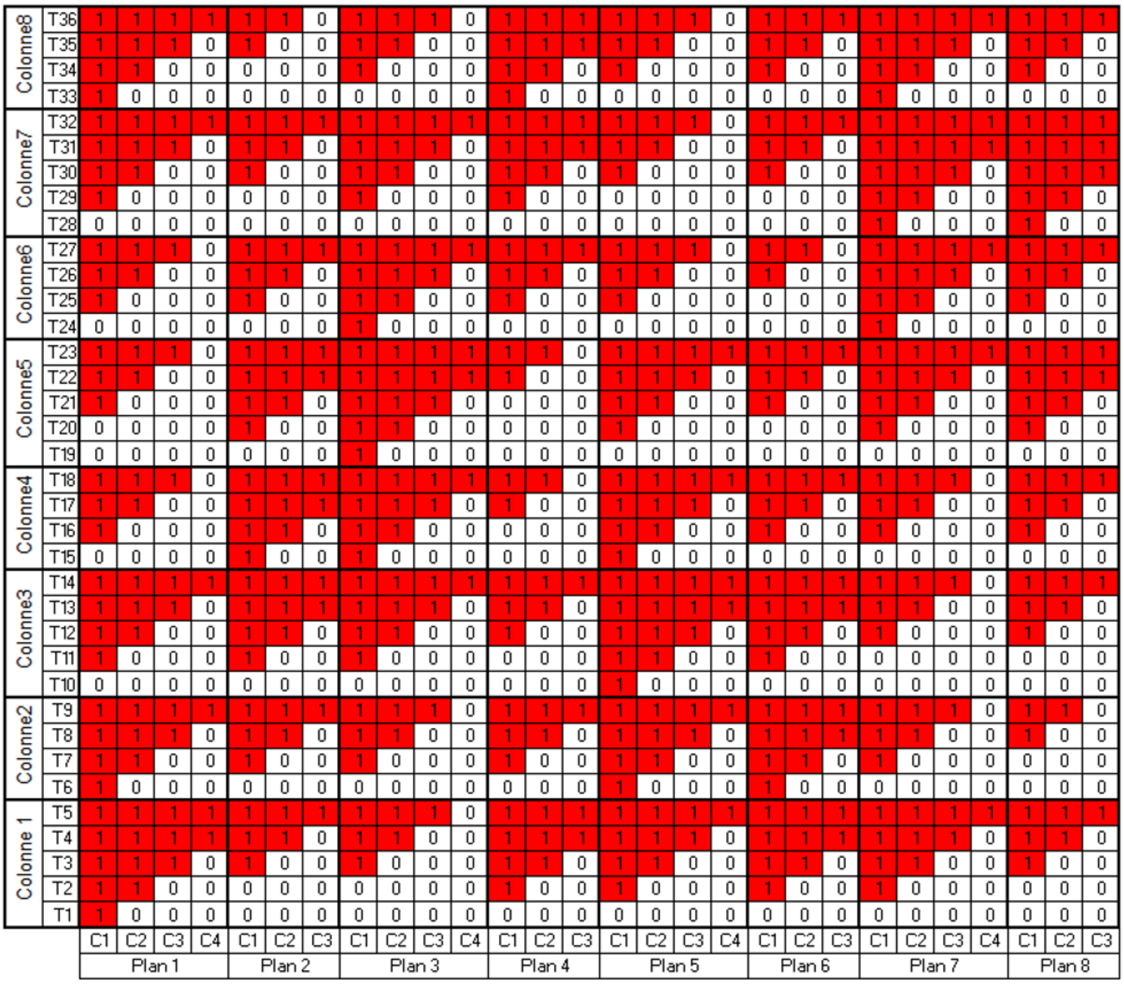


Figure 10: The initial configuration

5.4 Successive shedding configurations during the weaving process

The successive shed motions are defined by a line of the loom card (Fig. 11). Each cell of the line, assigned to a particular heddle, indicates if this heddle should be in an up (1) or down (0) position.

An open path through the warp yarns is created by raising some warp yarns by pulling their heddles and leaving others down. The shed is changed for each weft yarn insertion, as described by the corresponding line of the loom card. The displacement of heddles is prescribed at their top ends while a tensile force is applied to their bottom end in the range of spring return force.



		Plan 1				Plan 2			Plan 3				Plan 4			Plan 5				Plan 6			Plan 7				Plan 8		
		C1	C2	C3	C4	C1	C2	C3	C1	C2	C3	C4	C1	C2	C3	C1	C2	C3	C4	C1	C2	C3	C1	C2	C3	C4	C1	C2	C3
Colonne8	T36	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
	T35	1	1	1	0	1	0	0	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	1	1	0
	T34	1	1	0	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	1	0	0	1	1	0	0	1	0	0
	T33	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Colonne7	T32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
	T31	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1
	T30	1	1	0	0	1	0	0	1	1	0	0	1	1	0	1	0	0	0	1	0	0	1	1	1	0	1	1	1
	T29	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0
	T28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
Colonne6	T27	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1
	T26	1	1	0	0	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	1	0
	T25	1	0	0	0	1	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0
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Colonne5	T23	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T22	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1
	T21	1	0	0	0	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	1	1	0
	T20	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0
	T19	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Colonne4	T18	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1
	T17	1	1	0	0	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	0	1	1	0	0	1	1	0
	T16	1	0	0	0	1	1	0	1	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0
	T15	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Colonne3	T14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
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	T10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Colonne2	T9	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
	T8	1	1	1	0	1	1	0	1	1	0	0	1	1	0	1	1	1	0	1	1	1	1	1	0	0	1	0	0
	T7	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0
	T6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Colonne 1	T5	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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	T2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0
	T1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 11: Weaving matrix - loom card

6 RESULTS

The case study presented hereafter is a portion of a harness that is composed of 28 heddles corresponding to 8 columns of warp yarns arranged in 4 layers. Opening Amplitude is about 100 mm. Friction between all elements is considered in the simulation represented with Coulomb law with a friction coefficient of $\mu = 0.1$. The finite element total number is around 1900 for all the structure.
The transitions between the starting and the initial configurations, and between the successive shedding configurations are simulated incrementally, by prescribing the increments of displacements corresponding to each stage at the ends of the heddles and the warp yarns. 10 incremental steps are used for the transition between the starting and the initial configuration, and 100 steps for each shed opening.
3600 loading steps corresponding to 36 shed openings were carried out in total with a calculation time of 24 hours.

The complete shedding process simulation of real interlock fabric can be reached. The simulation yields the shed shape as presented in Fig. 12.

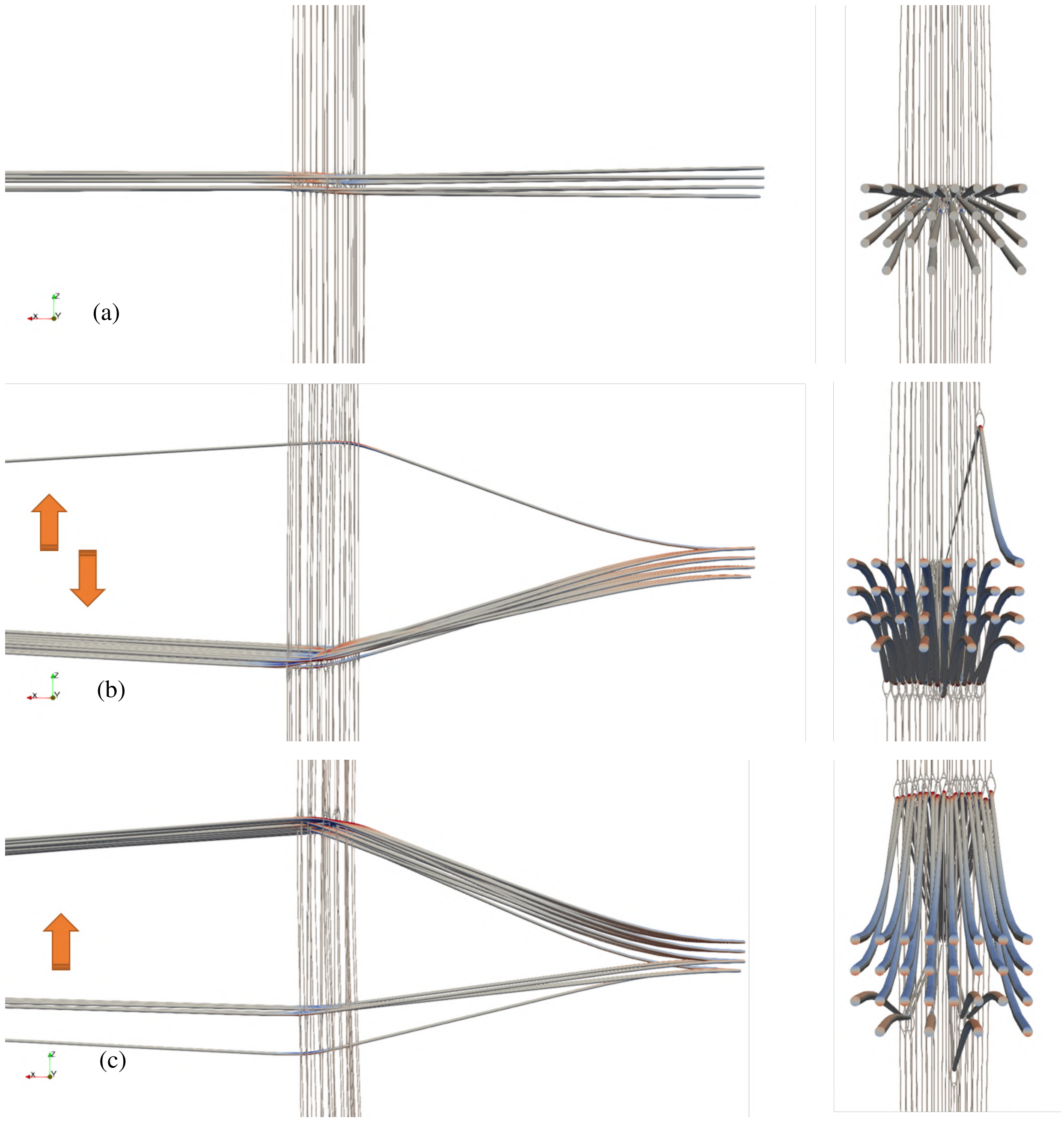

Figure 12: Simulation results - three stages during the shedding process simulation

Figure 12 shows three stages during simulation of the shedding process. Figure 12a shows the initial configuration [ready to start shedding]. Figure 12b shows the full opening of the first shed and figure 12c shows an intermediate stage of shed opening (shed for the 5th weft insertion of the loom card previously presented). Refer to Fig.13, where the deformation of the heddles during the process can be noticed easily in particular the eyelets rotating to adapt to the situation.

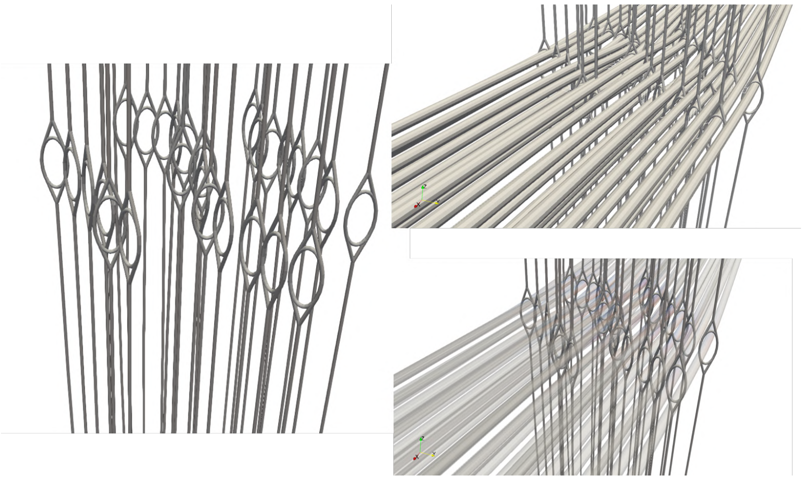

Figure 13: Simulation results - visualization of heddle deformations during the shedding process

Therefore, the results demonstrated the ability of the proposed approach to simulate the harness motion and thus to deduce the effort of the heddles as illustrated in the following section.

6.1 Effort analysis

The vertical axis shows efforts on heddles and the horizontal axis presents in which step [0 - 3611] that effort is calculated during the simulation.

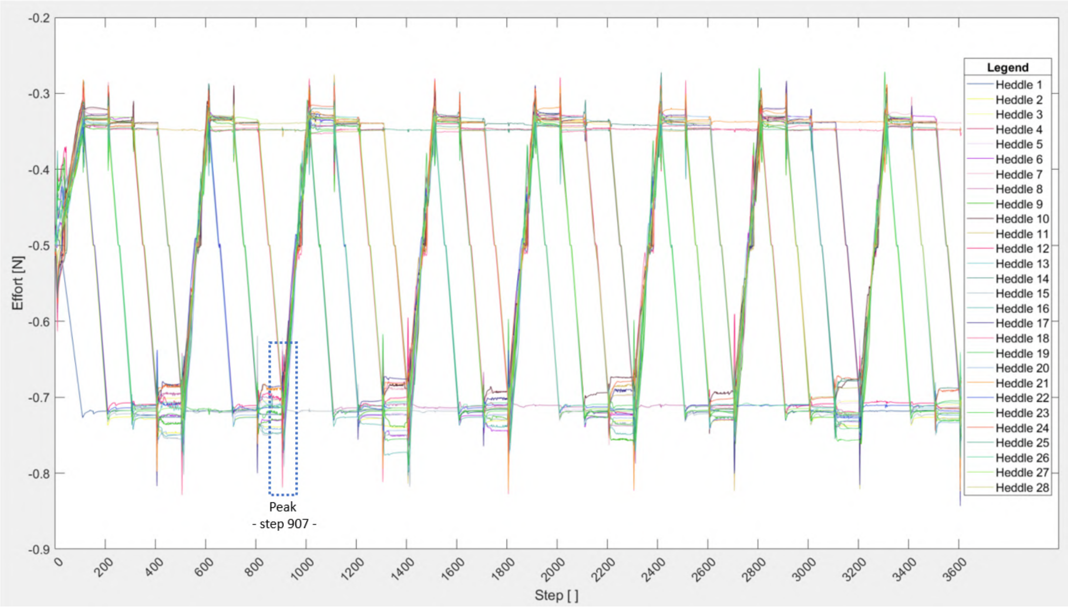

Figure 14: Simulation results : heddles effort curves

Looking at the efforts curves for the simulation of the whole loom card for 4-layers interlock, we notice eight blocs that can be repeated and that correspond to the eight columns of weft yarns supposed to be inserted. Essentially, two levels correspond to the upper and lower position of the heddles are highlighted.

The effort in the heddle depends on the warp yarn tension and the angles of the shed (see Fig. 15). To analytically verify the results of the forces, such a heddle gives in its true upper position the values of the following angles: $\alpha = 19.35°$ and $\gamma = 3.97°$ and in its lower position the following angles: $\beta = 15.69°$ and $\theta = 2.74°$. If we assume that warp yarns tension is $50cN$, applying the mechanical equilibrium of the efforts, we find values similar to those of the simulation.

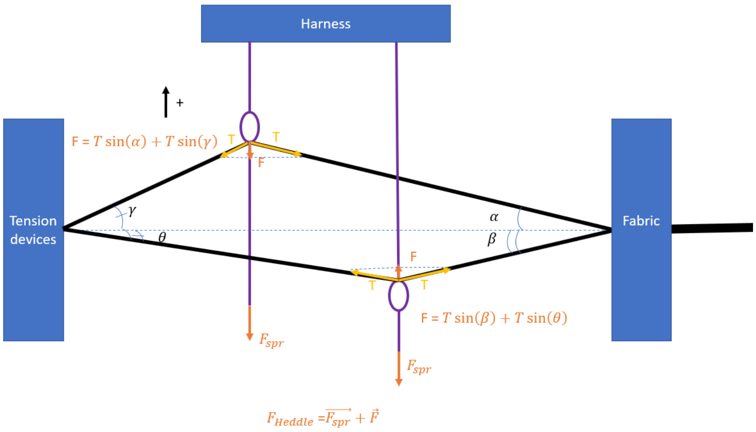

Figure 15: Schematic diagram explaining the loads acting on the heddles

During the ascent, the heddles in action interact with the neighbor's warp yarns (warp yarns of heddles already in their upper position), this allows transmission of effort between the heddles which are being raised and the others which are already in their upper positions. An illustration of a similar situation is represented in Fig. 16.

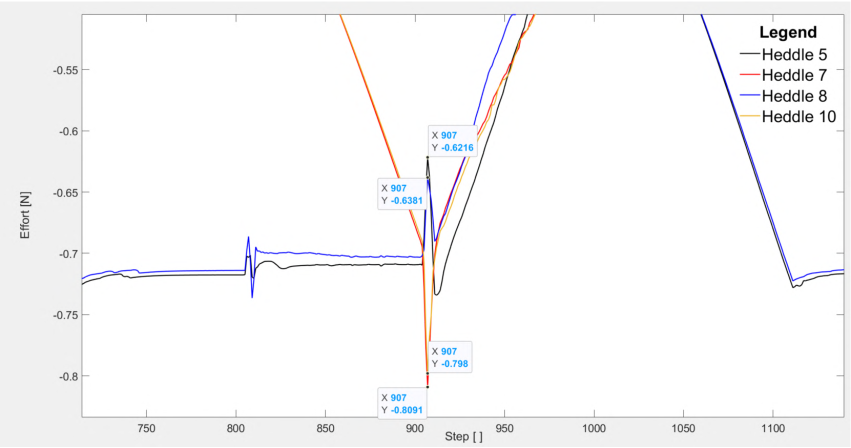

Figure 16: Heddles effort curves - zooming in on a peak

The peaks in the effort curves correspond to the phase where the two heddles 7 and 10 are currently reaching their upper position, where a friction contact interaction will occur with the neighboring warp yarns of heddles 5 and 8 which are already in their upper positions. In Fig. 17 a demonstration of the interaction between the heddle 7 (resp. heddle 10) and the wrap of heddle occurred during the ascent, this interaction caused an acting force on the eyelet 7 (resp. heddle 10) that raised the force amount, and a release of the effort of heddle 5 (resp. heddle 8).

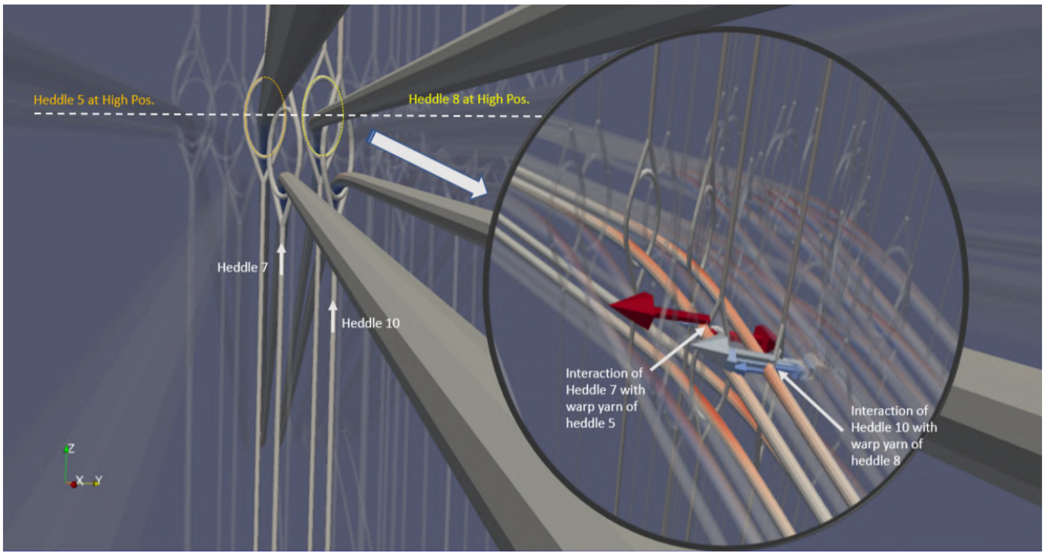

Figure 17: Situation of heddles that correspond to a peak

6.2 Discussion and perspectives

The effort curves are another way of defining the loom card, the results obtained show a good theoretical coherence with the considered weaving matrix.

The curves are not only useful for understanding peak loads, but they also enable the user to highlight problems without having to go back to the simulation visualization. If a heddle does not reach its expected position and remains locked during its traversal, the user can notice that directly through the curves. Thus, curves provide the advantage of knowing in advance what problems have been encountered.

The prospects for this work are going to be as follows, we would like to improve the simulation model's robustness and speed of simulation. The formulation and implementation of reduced modeling strategies to limit the cost of simulation while remaining representative of congestion phenomenon. We also plan to evaluate the influence of some technical parameters on the system such as the tension applied on the warp yarns and in particular the influence of the reed in the lateral confinement. Instrumentation with special measurement devices will be set up to measure the heddles tension and then validate the numerical model.

7 CONCLUSION

In summary, the main goal of this study was to model and simulate the shedding process of the Jacquard harness, precisely, to focus on congestion phenomena taking place within the harness. The problem can be set as a problem of frictional contact interactions between moving entities (heddles and yarns) modeled as beams, to be solved using finite element analysis with computation algorithms with an implicit solver.

Based on the actual weaving machine parameters, heddles movements are prescribed as boundary conditions dictated by the interlocking pattern given by the loom card. An appropriate remedy procedure for problems related to the ready-to-start configuration setting, in which each warp yarn is inserted into its assigned heddle, is introduced. Results demonstrated the ability of the proposed approach to derive heddles effort for the simulation of a real case study are also presented. A complete simulation of 4-layer interlock fabric with 28 warp yarns is presented for a calculation time of 24 hours.

The simulation results of the shedding process illustrate its abilities to represent congestion phenomena taking place within the Jacquard harness. The near-term objective is to validate the model by experimental results.

REFERENCES

[1] D. Durville, “Contact-friction modeling within elastic beam assemblies: an application to knot tightening,” *Computational Mechanics*, vol. 49, no. 6, pp. 687–707, 2012.

[2] H. Finckh, “Numerische simulation der mechanischen eigenschaften textiler flächengebilde - gewebeherstellung,” *LS-DYNA Anwenderforum*, pp. 1–15, 2004.

[3] J. Vilfayeau, *Modélisation numérique du procédé de tissage des renforts fibreux pour matériaux composites*. PhD dissertation, L’institut national des sciences appliquées de Lyon, 2014.

[4] L. Russcher, E. Lamers, C. Dufour, F. Boussu, P. Wang, and D. Soulat, “Modelling the microstructure of multilayer woven fabrics,” *In Proceedings of the 13th AUTEX World Textile Conference, Dresden, Germany*, 22–24 May 2013.

[5] X. Yang, *Dynamic simulation of 3D weaving process*. PhD dissertation, Kansas state university, Manhattan, Kansas, 2015.

[6] Y. Wang and X. Sun, “Digital-element simulation of textile processes,” *Composites science and technology*, vol. 61, no. 2, pp. 311–319, 2001.

[7] Y. Miao, E. Zhou, Y. Wang, and B. A. Cheeseman, “Mechanics of textile composites: Micro-geometry,” *Composites Science and Technology*, vol. 68, no. 7-8, pp. 1671–1678, 2008.

[8] D. Durville, I. Baydoun, H. Moustacas, G. Périé, and Y. Wielhorski, “Determining the initial configuration and characterizing the mechanical properties of 3d angle-interlock fabrics using finite element simulation,” *International Journal of Solids and Structures*, vol. 154, pp. 97–103, 2018.

[9] “textileapex.” https://textileapex.blogspot.com/p/about.html. Accessed: 23-03-2020.