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Simulation and optimisation of warp tension in the weaving process

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Abstract

Warp tension is a major parameter of the weaving process. The system analysis of a weaving machine leads to a simulation model for calculating the warp yarn tension. Validation of the simulation has demonstrated that the results correspond well with the reality. In a second step, an improved model of this simulation was used in combination with a genetic algorithm and a gradient based method to calculate optimised setting parameters for the weaving process. A cost function was defined taken into account a desired course of the warp tension. It is known, that a low and constant warp tension course is suitable for weaving. Using the genetic algorithm or the gradient based method leads to optimised weaving machine parameters. Applying the optimised setting parameters on a loom demonstrated that the quality of the produced fabrics can be improved. Further analysis of produced fabrics did not show an influence of optimised weaving machine parameters on the mechanical properties or productivity of the weaving process.

Keywords: Weaving; Optimisation; Simulation; Warp tension

Introduction

Development of weaving mills in high-wage countries aims at rising productivity and flexibility. The weaving mills are confronted by customer wishes to more and more product variety and shorten article length. Therefore productivity describes the capability to produce more meters of woven fabrics in a shorter period of time. It is important to reduce setup times in order to raise productivity. Setup time in weaving mills occurs mainly because of the change of the warp beam and adaptation of the weaving machine like changing working width or reeds finesse. In general, the mill workers have the necessary know-how to set-up a loom or the machine setting is stored in databases of the weaving mill [1].

In order to find optimised setting parameters for unknown articles, it is generally necessary to conduct experiments within the weaving mill. In order to raise productivity it is also important to reduce down-time of weaving machines. Down-time normally occurs through wrong weft insertion or broken warp yarns. While the removal of incorrect inserted weft is already automated on modern air jet looms, the repair of a broken warp has to be done manually. Exceptions are of course high strength warp materials like aramid or carbon. Breakage of warp yarns occurs if the warp tension is too high. In contrast, if the warp tension is too low, warp yarns attend to jam and then break. Furthermore, a too low warp tension leads to an unclean shed formation. A clear shed is needed in order to have less problem of weft insertion.

As described, knowledge on the course of the warp tension during weaving is essential in order to perfectly setup a weaving machine. Keller [2] and Schlichter [3] described methods for measuring warp tension during weaving. They presented an adequate measurement system that measures the dynamic warp tension during the weft insertion. Based on the results, De Weldige [4] presents an algorithm that can calculate the warp tension based on the examination of equilibrium of torque around the axis of a mass-spring backrest system. Chen [5], and Mirjalili [6] described a simulation of warp tension. Another approach can be obtained by using a model of the behaviour of the weaving machine, as described by Beitelschmidt [7] and yet another approach by Grobmann et al. is using transient computation of dynamic interactions between weaving machine and the fabric take-off system [8].

Klöppels et al. developed a motor driven backrest system to an air jet loom in industry [9]. They also calculated motion curves for the backrest taking into account parameters like fabric construction, warp yarn properties, warp drawing in and weaving machine settings. For the production of a 6- pick twill under industrial conditions, the motor driven backrest system reduced warp breaks around 61% compared to weaving machines with negative backrest and 74% compared to identical weaving machines.

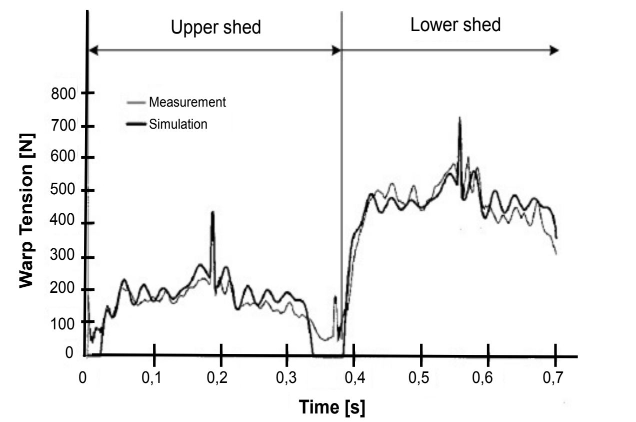

Figure 1: Comparisons of warp tension measurement and simulation by De Weldige [4].

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Çelik and Eren present a mathematical analysis of warp elongation in weaving machines with positive backrest system [10]. Influences of backrest swinging angle, shed closing angle, backrest orientation angle and backrest phase difference on warp elongation are investigated. Results shown that especially shed closing angle and backrest phase difference have an important effect on warp elongation curve during one weft insertion. They concluded that by producing different motion curves with motor driven positive backrest, optimum warp elongation or warp tension curves can be obtained for weaving of different type of fabrics.

The research of Wolters aimed at an optimisation of the warp tension [11]. He trains neural networks with data obtained from well performing weaving machines. These neural nets are used in combination with the warp tension from De Weldige and a genetic algorithm and additional quality criteria for the course of the warp tension. His results demonstrates that such optimisation of warp tension results in less machine stops but the fabric quality could not be improved significantly. Furthermore, it is very time consuming to obtain data from well running weaving machines for the training of the neural networks. The difference in warp tension in the upper and lower shed position is caused by the shed geometry.

Likewise research was conducted for the knitting process. Recently Metzkes presented a continuum model with spatial dynamic of thread and axial transport movement [12]. He describes also the need of a constant and low yarn tension in order to obtain a flawless knitting process.

Thus, an alternative modelling of the weaving process will be presented in this paper in order to simulate the warp tension. In order to obtain optimised setting parameters for a weaving machine, by a given quality function, the simulation is combined with a genetic algorithm. In a test series, simulation and optimisation are validated regarding their accuracy and the effect of the optimisation on the fabric properties.

Simulation of Warp Tension

To introduce the principle of the simulation of warp yarn tension, some basic information about the weaving process needs to be given. A woven fabric is formed by crossing longitudinal yarns with transversal yarns. The longitudinal yarns are warped on the warp beam. Each warp yarn is fed through the eye of a heddle and then stretched to the fabric beam. Producing a woven fabric (by inserting the transversal weft yarns between the warp yarns) involves the following basic actions (Figure 1).

- Let off of yarn from the warp beam via the backrest system
- Forming of the shed by movement of the heddles
- Insertion of the weft yarn
- Beat up by the reed movement
- Taking up of the fabric by the fabric beam [13]

The shed is formed by moving some warp yarns in the upper position of the shed and the others in the lower position. Then, the weft yarn is inserted in the shed, using a method that varies depending on the type of loom: with a rapier, by air, by water, with a needle, with a projectile or with a shuttle. Subsequently, the weft is moved by the reed to the fabric edge. Next, another shed is formed and the next weft is inserted, beaten up and so on. Ultimately, by the shed movement, the warp yarns form a quad limited by the fabric edge, the upper and lower rest positions of the eye of the heddles and the warp stop system.

The mean tension exerted on the warps is dependent mainly on the difference between the circumference speeds of the warp beam and the fabric beam. Superimposed on that mean tension, there are tension changes caused by movements of the backrest system, the heddles, and the reed.

The system analysis shows that the four points of the shed form a quad. The displacement of the four edges of this quad is the basis for the warp tension model. This displacement can be determined in an analytical way by calculation, or by measuring of the movement on an actual machine. First of all, it is necessary to further clarify what is happening in these four points with respect to warp yarn. The warp is fixed at two of these points: one at the rim of the backrest system (P_1) and the other at the fabric edge (P_4) (Figure 3). The warp yarn glides at the following two points: at the warp stop (P_2) and in the eye of the heddles (P_3) [14]. The loom model used to calculate warp tension is based on the movement of these four points, which will be described in the following paragraphs.

P_1 belongs to the backrest system. The main tasks of the backrest system are as follows:

- Direction change of warps into the production direction
- Compensation of changes in warp tension
- Measurement of elements for the control of warp tension

The backrest system can be designed in different ways. Two main variants of this system can be distinguished: passive and active controlled backrest systems. In the passive variant, the roller of the backrest system is connected by a spring to the machine frame. Formerly, the deviation of the backrest-system was used to govern the mean yarn tension. If a passive backrest system is used, the movement of P_1 depends on the running speed of the loom and the transfer function of the mass/spring/damping parameters [15]. From this transfer function (amplitude and phase shift), the amplitude and the angle of the movement of P_1 can be determined.

In modern machines, there is no need to use the backrest system to measure the actual value of the total yarn tension since this can be measured easily, e.g. by yarn tension sensors. Thus, the backrest system can be controlled by an actor to compensate for yarn tension changes. In general, this actor is realized by an eccentric. The absolute position of P_1 caused by the rotation motion of an active backrest system can be calculated by the following formula:

$$s_{br} = s_{b0} . \sin(\phi - \phi_{b0}) \quad (1)$$

where $s_{br} \triangleq$ movement of P_1, $s_{b0} \triangleq$ amplitude of the movement, $\phi \triangleq$ loom crank angle and $\phi_{b0} \triangleq$ Phase shift of the loom crank angle. Figure 2 shows the main elements of the active backrest system.

The position of P_2 is fixed, so there is no movement of this point. P_3 is located in the eye of heddles inside the healds. As described, the heald movement is necessary to form the shed. To obtain fast running looms, this movement is realized by cam systems. The movement of the heddle in such a case can be described analytically, e.g. by a polynomial function. An easier method is to measure the movement and present the obtained data in a look-up Table. Because of the movement of the heddles to form the shedding quad, we identify P_{3o} as the upper position and P_{3u} as the lower position (Figure 3). A measurement of the heald movement is shown in Figure 4. With the help of the table the movements of the point P_{3o} and P_{3u} during the weaving process can be calculated. The reference point or zero point of the model is defined as the position P_2 of the warp stop motion in case of a symmetrical shed

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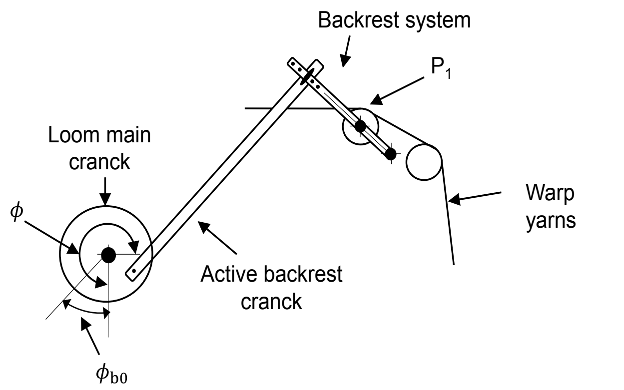

Figure 2: Active backrest system.

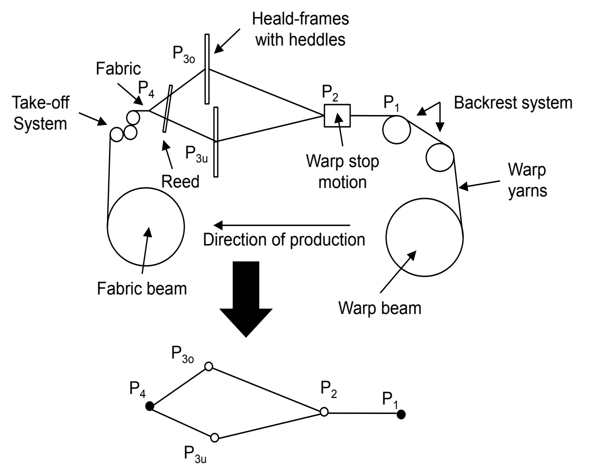

Figure 3: Model of a modern weaving machine and points in the model.

and no initial movement of the warp stop motion.

The heald movement can also be calculated by the following formula in this case

$$h_{heald}(\phi) = 2.\hat{h}_{heald} \cdot \left\{ \frac{\phi}{\phi_T} - \frac{1}{2\pi}\left[\sin(2\pi\frac{\phi}{\phi_T}) \right] \right\} \tag{2}$$

Where $h_{heald}(\phi) \triangleq$ heald movement during the weaving process, $\hat{h}_{heald} \triangleq$ maximum heald movement, $\phi \triangleq$ loom crank angle and $\phi_T \triangleq$ loom crank angle during change of shed [16]. In Figure 4 the formula applies only for the movement between the rest positions. Position 1 indicates the upper heald position and Position 0 the lower heald position.

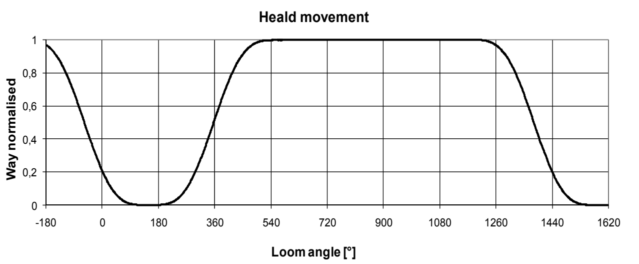

Figure 4: Measured heald movement.

The reed movement is needed to push the weft to the fabric edge, where P_4 is located. The impact of the reed movement has an influence on the warp tension, since the edge of the fabric is moved and the warps are lengthened. A good approach is to use the following formula (depicted in Figure 5). In reality the reed movement can be more complex.

$$s_{fe} = \min\left\{0, \frac{[s_{r0} - \sin(\phi - \phi_{r0}) - s_{r1}]}{s_{r0} + s_{r1}}\right\} \tag{3}$$

Where $s_{fe} \triangleq$ movement of the fabric edge, $s_{r0} \triangleq$ amplitude of the reed movement, $s_{r1} \triangleq$ position for touching the fabric edge, $\phi \triangleq$ loom crank angle and $\phi_{r0} \triangleq$ displacement angle of the reed.

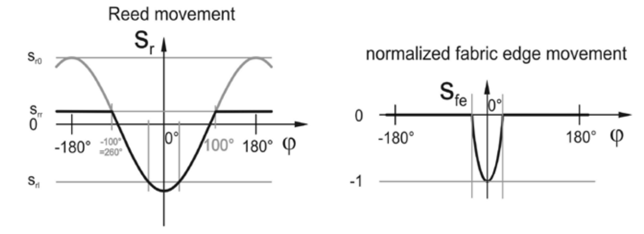

Figure 5: Reed and fabric edge movement.

The tension of the yarn is described by of the following function:

$$\sigma = E.\varepsilon \tag{4}$$

Where $\sigma \triangleq$ tension, $E \triangleq$ Young Modulus and $\varepsilon \triangleq$ elongation. In the textbooks, the Young Modulus is normally presented as a constant value, which is correct if the elongation ε is small and the material is a metal or something similar. In this model, the force/strain relationship is important; in general it is represented as follows:

$$F = \frac{EA}{s}.ds \tag{5}$$

Where $A \triangleq$ area, $s \triangleq$ yarn length and $ds \triangleq$ change of yarn length. It is known that in real yarns the factor $\frac{EA}{s}$ is nonlinear [17]. In a future model of the warp tension, this nonlinearity can be taken into account by using a look-up Table.

By determining the movement of P_1 to P_4 it allows the whole model to be described and the warp tension simulation to be realized. The simulation is programmed using the MatLab software from MathWorks, Natick (MA), USA [18]. First of all, the position of the four points is calculated for each degree of the main-shaft revolution represented by φ of the loom. The yarn tension F(φ) is then calculated as follows:

$$F(\phi) = EA.\varepsilon(\phi) \tag{6}$$

Where

$$\varepsilon(\phi) = \frac{l_\phi - l_0}{l_0} \tag{7}$$

and

$$l_\varphi = s_{br} + s_h + s_{fe} + l_0 \tag{8}$$

With $l_\varphi \triangleq$ length of warp during the weaving process, $s_{br} \triangleq$ change of warp length caused by back-rest movement, $s_h \triangleq$ change of warp length caused by heddle-frame movement, $s_{fe} \triangleq$ change of warp length caused by reed movement and $l_0 \triangleq$ the initial (closed shed) distance of the points P_1 to P_4.

Therefore, another way to describe the movement of a point (e.g., for P_1) can be obtained by the following equation:

$$P_1(\varphi) \ + dP_1(\varphi) \tag{9}$$

Where $P_1(\varphi)$ is the movement during the weaving process, P_{1in} is the initial position and dP_1 is the change of the point position.

Thus far, there have been no calculations of the forces caused by the friction in the heddles or the warp stop. Also, the forces caused by the yarn regarded as swinging string have not been taken into account. Furthermore in this paper, the simulation of the eccentric controlled backrest system is realized. The algorithm for the movement was realized as an analytic function within Matlab.

By using Matlab, the simulation can be used as a subroutine for a general user interface (GUI). Therefore a GUI was provided for the convenience of the user. The GUI is separated into three main areas: input data, visualization of the model, and simulated warp tension. In the input area, the user can define the initial points P_{1i} to P_{4i} material data such as fineness and Young-Modulus, amplitude of backrest movement, the maximum value of the elongation of warp caused by reed movement, and mean warp tension. Hence, the simulation needs 19 input parameters and the program calculates the warp tension for four weft insertions, which is equal to 1440° machine angle.

Optimisation and Cost Function of Warp Tension

The general objective of an optimisation is the search for the minimum of a target function. The target function is sometimes called cost function. One of the most challenging problems is the formulation of this cost function, in such a way, that the result of the mathematical calculation meets the intentions of the user of the optimisation. The choice of this cost function is essential for the calculating time and the quality of the result [19,20]. In the present case the cost function CF is defined as the difference between a desired warp tension $F_{desired}(\varphi)$ and the simulated warp tension $F_{Sim}(\varphi)$. The cost function is calculated for four loom crank angle turns, equal to 8π, since the used weave pattern for this research is a 3/1 satin structure.

$$CF = \int_0^{8\pi} (F_{desired}(\varphi) - F_{sim}(P_1, \ldots, P_n, \varphi))^2 d\varphi \tag{10}$$

Criteria for an optimal warp tension course, meaning $F_{desired}(\varphi)$ are described by Wolters [21]. In general, these criteria aim at having a low and constant warp tension in the lower shed. In the upper shed a sufficient tension is needed in order to have a clear shed. By combining the desired cost function within the warp tension simulation and an appreciated optimisation algorithm it is therefore possible to receive an optimised loom setting parameter. In the already described GUI, it is possible for the user to integrate the necessary $F_{desired}(\varphi)$.

After having the right cost function, it is necessary to choose an optimisation algorithm in order to minimize the cost function. There are many different algorithms proposed in literature to reach objective of the optimisation, such as Newton's method, gradient methods, hill climbing, artificial bee colony optimisation, genetic algorithm etc. All optimisation methods can be described by the following three characteristics. First, they need a set of starting values for the calculation. Second, the more information about the optimisation problem will be integrated in the algorithm, the faster the optimisation will be conducted. Third, it needs to be decided whether the result of the optimisation is a local or global optimum [19,20]. In this presented paper an evolutionary algorithm and a gradient based method is used.

termination criterion is not straightforward From the optimisation point of view using the gradient based method, the problem is reduced to a quadratic minimization problem with nonlinear equality and box constraints on the parameters. Due to the small number of parameters subject to optimisation a discrete gradients using finite differences is easily obtained and also computationally efficient. Then; an interior point method is used to solve the constrained minimization problem. The method converges with less than 100 iteration steps and up to a tolerance of $1 \cdot e^{-6}$ in all tested cases [22,23].

One disadvantage of gradient-based methods using adjoints is the development cost. In addition the method is relatively intolerant of difficulties like noisy objective function spaces or categorical variables. Also the gradient-based methods find a local rather than a global optimum. Rapid convergence is the main advantage of a gradient-based method [24].

With evolutionary algorithms an arbitrary starting combination of the genotypes will be generated and from them the cost function will be calculated. In each generation those individuals will survive, who will best fit the minimization of the cost function. These individuals will reproduce by recombination and mutation the genotypes of the next generation. This circuit will continue, until either the maximal amount of generations is reached or the cost function of subsequent generations will be less than a minimum [20,21].

Evolutionary algorithms treat the function evaluation as a "black box". Consequently, development cost is minimal. Evolutionary algorithms are tolerant of noise and have no difficulty with categorical variables or topology changes. In general evolutionary algorithms find a global optimum. The key disadvantage is they are very slowly, especially near an optimum. A second weakness is that determining a termination criterion is not straightforward [24].

Validation of warp tension simulation and optimisation

Validation in general contains two steps. First, the simulation of warp tension will be validated, since the results of the simulation have to be close to the measurement of the warp tension on a real weaving machine. Only in the case that the analogy between simulation and measurement is adequate, the use of a genetic algorithm in order to improve the weaving process makes sense. Hence, in a second step it will be checked, if the weaving process and quality of the fabrics does improve using new calculated weaving machine parameters.

For the validation of the warp tension simulation, measurements of the warp tension on an OmniPlus 800 air jet weaving machine from Picanol nv, Ieper, Belgium with an active backrest system were conducted. The measurements were done using an analogue yarn tension sensor form BTSR International S.p.A. Partita, Olgiate Olona, Italy (Figure 6). The sensor is installed between back rest system and warp stop motion of the weaving machine. Setup of the weaving machine is done according to Table 1. These parameters were also used as input parameters for the simulation.

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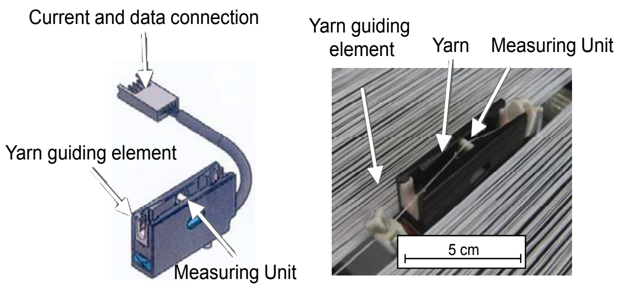

Figure 6: Yarn tension sensor.

Parameter	Value	Unit
General weaving machine settings		
Speed	800	rpm
Warp / Weft material	PES	
Warp count	740	dtex
Weft count	740	dtex
Warp density	20	yarns/cm
Weft density	14	yarns/cm
Weaving pattern	twill 1/3	
Closed heald angle	340	°
Warp mean force (single yarn)	150	cN
Active backrest position P1		
Backrest X-position	560	mm
Backrest Y-position	30	mm
Warp stop position P2		
Warp stop X-position	225	mm
Warp stop Y-position	20	mm
Upper heald position P3o		
Upper Heald X-position	-365	mm
Upper Heald Y-position	37	mm
Upper heald position P3u		
Lower Heald X-position	-365	mm
Lower Heald Y-position	-28	mm
Fabric Edge position P4		
Fabric edge X-position	-552	mm
Fabric edge Y-position	0	mm
Active back rest system		
Amplitude of movement	0,9	mm
Phase shift to loom crank angle	20	°

Table 1: Setup of loom before optimisation.

In Figure 7 the comparison with the measurements shows a good similarity with the simulation, especially the change of tension caused by the movement of the heald frames. In addition, changes in warp tension caused by the reed movement are simulated in a sufficient way.

There of course still are some discrepancies. These discrepancies result from simplifications of the model. Especially the position of point P_2 is not constant during weaving. Additionally there are dynamic effects: vibrations of the warp yarns, jamming of the warp yarns at the point of collision during up and down movement, oscillating heddles in the shed, the movement of the warp stop drop wires etc. Because of the complexity of the effects they are not taken into account for the presented simulation.

In a second step, the optimisation was investigated. The necessary cost function is chosen in such a way, that the warp tension is reduced and in the same time much more constant compared to the first warp tension measurements (Figure 8). Four weaving machine parameters

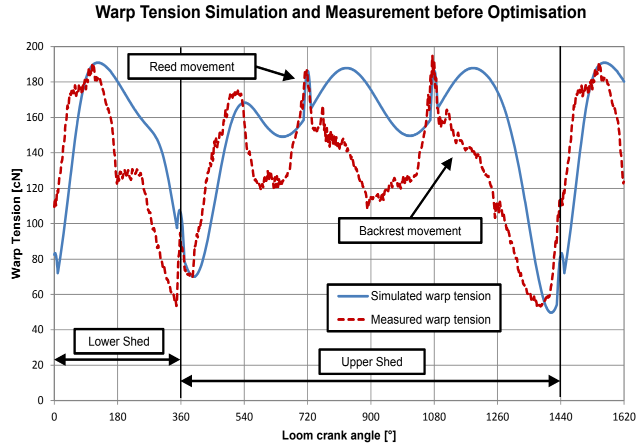

Figure 7: Comparison of warp tension simulation and measurement .

were chosen to be optimised: vertical warp stop motion position, closed heald angle, backrest angle phase shift to loom crank angle and the warp mean force. These parameters can be adapted on the loom with less effort of time compared to the other weaving machine parameters used in the simulation.

Changes in the warp mean force have an influence on the general level of the warp tension during weaving, changes in the horizontal warp stop motion position influences mainly the relation of warp tension in upper and lower shed. Changes in the backrest phase shift to the loom crank angle mainly influence the timing of distribution in warp tension due to the warp beam movement. Therefor it is for example possible to reduce the tension peak occurred by the reed movement, when the reed peak takes place in the minimum of the back rest movement. Changes in the closed heald angle influences the 'position' of the reed-peak relative to the closed shed minimum.

The genetic algorithm was using 200 population, 50 generations and 20 Iterations and needed 300 seconds on a PC with an intel core i3 CPU at 3.3 GHz. The gradient based method took less than 10 seconds on the same computer. Both optimisations methods nearly calculated the same optimised settings points for the weaving machine (Table 2).

Figure 8 shows the simulation of the warp tension with weaving machine parameters before and after optimisation. The optimised weaving machine parameter creates a warp tension course, which is much closer to the desired warp tension course. However, the new calculated weaving machine parameters will not lead to a constant desired warp tension course, since the movement of the back rest system and reed always disturb a constant warp tension course in the simulation.

The optimised machine settings were used on the weaving machine

Parameter	Value before optimisation	Value after optimisation with genetic algorithm	Value after optimisation with gradient method	Unit
Warp stop Y-position	20	50,7	50,9	mm
Closed heald angle	340	345	340	°
Warp mean force (single yarn)	150	97,1	97,1	cN
Backrest phase shift to loom crank angle	20	-10	20	°

Table 2: Comparison of weaving machine setting before and after optimisation.

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in order to analyse the quality of the produced fabric and productivity of the weaving process. Analysis of the produced fabric before and after the optimisation of weaving machine settings was conducted accordingly:

- Breaking force and breaking elongation in warp and weft direction according to ISO 13934-1:2013[25]
- Fabric weight according to EN 12127:1997[26]
- Warp and weft crimp according to DIN 53852:1991-09[27]
- Air permeability according to EN ISO 9237:1995[28]

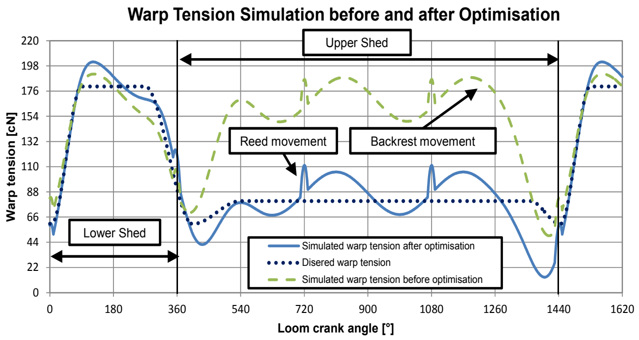

Figure 8: Comparison of simulated warp tension before and after optimisation including desired warp tension.

It is visible that the changes of weaving machine parameters closely do not influence the woven fabric quality, also the medium warp tension is reduced from 132,04 cN to 106,32 cN. Only the breaking force in warp direction was improved by around 0,3 kN. It is well known that the warp tension influence fabric quality, for the present case warp tension reduction was probably too low in order to have a stronger impact. Table 3 shows the results of these measurements and Figure 9a comparison of measured warp tension before and after optimisation.

In a last step, the long-time running behaviour of the loom before and after optimisation was analysed. In order to do so, the machine was kept running for three hours with the initial setting and an additional three hours with the optimised setting parameters. In both cases 144.000 woven picks were produced. The amount of weaving machine stop related to warp breakage or non-insertion of the weft was recorded. In summary it is shown, that by using the present simulation, optimisation

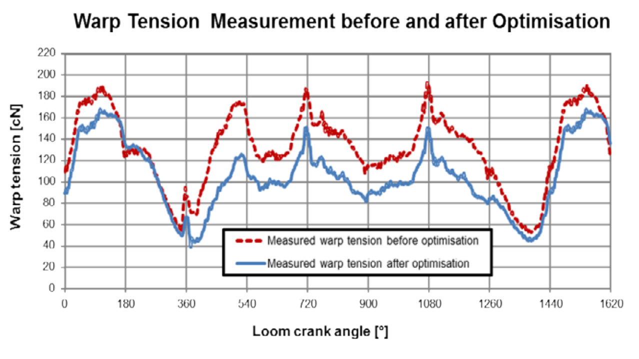

Figure 9: Comparison of measured warp tension before and after optimisation.

algorithms and the right cost function, there was no notable change in the weaving machine productivity. The machine was running without any stops using the initial or the optimised setting parameters (0 warp stops per 100000 picks). Thus, fabric defects occurred irregularly in the middle of the fabric using the initial weaving machine settings (Figure 10). Filaments of the warp threads break in the eye of the heddles. These broken filaments did form a fabric defect. One reason for filament breakage could be because the warp tension was too high.

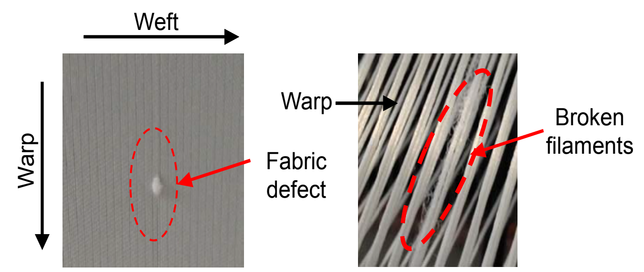

Figure 10: Fabric defects.

Also the fact that the defects just occurred in the middle of the weaving machine can prove this theory. Warp tension is highest in the middle of a weaving machine due to the warp tension bow [29]. The fabric defects vanished using the optimised machine settings. A major explanation of these results is that the choice of desired warp tension course $F_{desired}(\varphi)$. The course was chosen in such a way, that stress on the warp is lower and more constant compared to the initial settings. In addition, warp tension in the upper shed of $F_{desired}(\varphi)$ was still high enough choose to produce a clear shed.

Conclusion and outlook

In this paper, the development of a warp tension simulation was presented. A system analysis of modern weaving machines lead to suitable simulation model to calculate the warp tension. The validation of the simulation demonstrates that the results correspond well in reality. In a second step, an improved model of this simulation was used in combination with a genetic algorithm and a gradient based method to calculate optimised setting parameters for the weaving process. In order to do so, a cost function was defined taking into account a desired course of the warp tension. By literature it is known, that a low and constant warp tension course is suitable for weaving.

Using the genetic algorithm or the gradient based method leads to optimised weaving machine parameters. Both algorithms do get nearly the same results for the optimised weaving machine setting. Applying the optimised setting parameters on a loom did not demonstrate that the productivity of a weaving machine can be raised. Analysis of the produced fabrics did not show an influence of optimisation on the fabric quality. The reduction of warp tension was not sufficient in order to have an impact on the mechanical properties of the fabric. Thus, fabric defects could be eliminated using the optimised weaving machine settings.

In the future, adaption of the simulation using a spring-mass backrest system can be done. Thereby the movement of the backrest system is described by a differential equation of second order. Other aspects like the dynamic behaviour of a yarn during the beat up process were not taken into account for the simulation. In order to improve the simulation, the influence of the movement of the heddles, the friction caused by the yarn movement in the heddles, and the crossing of warps could be added. In real yarns, the factor EA/s is quite nonlinear [6]. In a future model, this can be taken into account by using a look-up Table.

Also a combination of the simulation and optimisation system with the automatic position system of back rest system and warp stop motion, as presented by Osthus [30] could further fasten the setup process of the weaving machine. In addition use of other models like regression models and aspects of self-optimisation could be of interest in order to further improve the weaving process.

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