GAUGE OPTIMIZATION OF THE REFERENCE TENSION AND NIP-LOAD IN WINDING SYSTEMS USING WOUND INTERNAL STRESSES CALCULATION

By

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ABSTRACT

In the winding process, the quality of the roll is directly related to its stress state. The winding tension and nip-load are the most significant parameters which play an important role in the stresses generated within a roll during winding. If the stresses exceed a critical value, defects can appear in the roll and make the web non usable.

This work concerns the optimization of the maximal dispersion of the tension and nip load references. It consists to find automatically the maximum and minimum limits for the tension and nip load references, so that all curves ranging between these two limits or thresholds generate radial and tangential stresses located in another gauge fixed in advance, in accordance with the mechanical behavior of the material. The results lead to a practical gauge optimization of the reference tension and nip load for industrial applications.

INTRODUCTION

It is possible to optimize the tension and the nip-load references by optimizing the calculated radial and tangential stresses within a roll. Indeed, the model of stresses computation makes it possible to define a criterion J which can be minimized using an algorithm based on the principle of the simplex [2] or genetic algorithms [15].

Different works were published in the field of winding tension reference optimization. In [5], the criterion for tension adjustment was the tangential stress. A method for offline reference adjustment and for the first time online control based on prediction-correction using the simplex algorithm was presented in [4]. This method was tested numerically. In [13], the criterion of tension reference optimization was generalized by considering both the tangential and the radial stresses within the roll during winding. The same optimization algorithm was used, taking into account the dynamic tension model. Paper [14] presents the reference tension and nip-load optimization taking into account the air entrainment and the interlayer friction force.

In these previous papers, the aim was the determination of the reference tension which minimizes a criteria J calculated by means of the wound internal stresses model.

Another approach [13] deals with the estimation of the maximal dispersion of this reference tension, so that the tangential and radial stresses remain in a gauge. It consists in finding the maximum and minimum gauge values for the reference tension, so that all the curves ranging between these two limits (thresholds) generate radial and tangential stresses, themselves included in a gauge fixed in advance. Note that in this work, the nip-load was not applied and the interlayer frictions were not considered.

In the present work, both optimizations of the reference winding tension as well as the gauge for the nip-roll are concerned, based on the roll internal stresses. Moreover the model of the wound internal stresses takes into account the interlayer friction forces. Simulation results of the wound internal stresses for different tension references are given in the figures shown below.

The optimization problem is solved using genetic algorithms in order to avoid local optimums. The two gauges (for tension reference and nip-load reference) can be weighted separately depending of their importance.

TENSION AND NIP-LOAD OPTIMIZATION

In the first part, one has to optimize the nominal tension and nip-load references. The references optimization guarantees the production of a “perfect” roll. To optimize offline the references, a mathematical model of stresses computation is used to calculate a criterion (also called cost function) J :

$$J = J_T + J_R \tag{1}$$

with

$$J_T = \int_{R_{roll}}^{R_{max}} \left(\frac{\sigma_T(T_w, P_w) - \sigma_{T\,mean}}{\sigma_{T\,mean}} \right)^2 dr \tag{2}$$

and

$$J_R = \int_{R_{roll}}^{R_{max}} \left(\frac{\sigma_R(T_w, P_w) - \sigma_{R\,mean}}{\sigma_{R\,mean}} \right)^2 dr \tag{3}$$

T_w represents the winding tension, P_w is the nip-load, σ_T is the tangential stress and σ_R radial stress. The stresses can be calculated using a stresses state mathematical model, for instance models established by Bourgin & al. [11], Connolly & al. [12], or Hakiel [10]. In this work we used the model given by Hashimoto [14].

σ_{mean} is some averaged tangential or radial stress value, in a given range (gauge).

The optimization problem consists to minimize J with the given constraints:

$$\sigma_{T\min} < \sigma_T < \sigma_{T\max} \tag{4}$$

$$\sigma_{R\min} < \sigma_R < \sigma_{R\max} \tag{5}$$

$$\frac{F_T}{F_N} < \mu \qquad \{6\}$$

where F_T corresponds to the interlayer force [14], F_N is interlayer normal force [14], μ is a given maximum value of the "friction ratio" F_T/F_N in order to avoid interlayer slippage.

The tension reference and nip-load reference are optimized using genetic algorithms in order to minimize the cost function J. Of course, the convergence towards a minimum does not guarantee that it is the global minimum and not a local one. One way to overcome this difficulty is to start the algorithm with different initial values. The existence of a solution depends on the gauge.

In this paper, for didactic reasons, we assume that the winding reference tension and the nip load are linear functions versus the radius (We assume that the reference tension remains at first constant and after a certain value of the roll radius it decreases linearly). The optimized results are shown on figures 1a to 1f:

Figure 1a – optimized linear tension reference

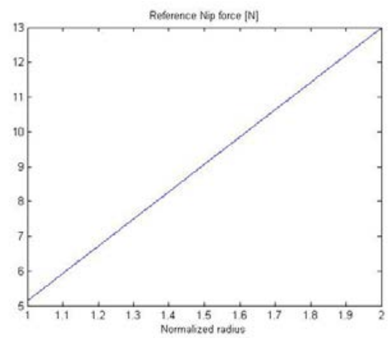


Figure 1b – optimized linear nip-load reference

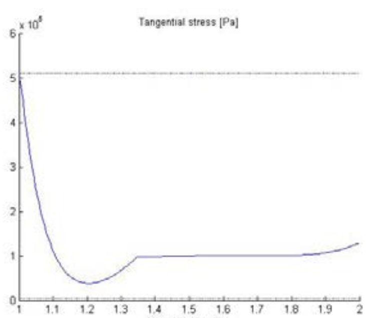


Figure 1c – tangential stresses

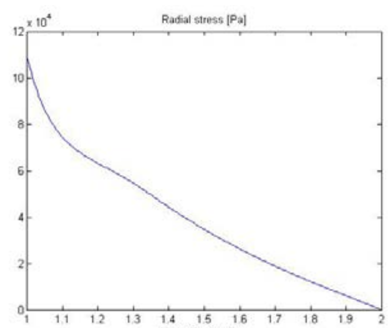


Figure 1d – radial stresses

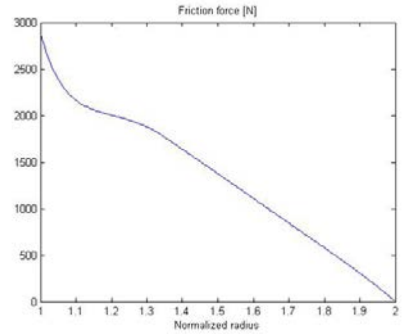


Figure 1e – friction force

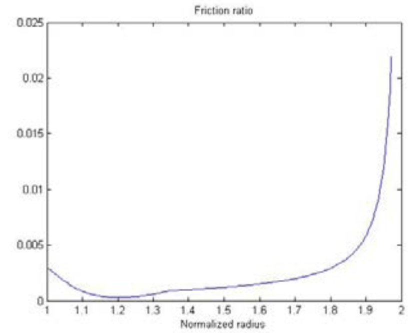


Figure 1f – friction ratio

OPTIMIZATION OF THE ADMIMISSIBLE TENSION AND NIP-LOAD DISPERSIONS

We assume that the dispersions around the nominal tension and nip-load references (previously optimized) are constant. These constant dispersions are now maximized with the constraints that the wound tangential and radial stresses have to be located in given gauges and the friction ratio F_T/F_N has to be smaller than a given value in order to avoid interlayer slippage.

The dispersions are maximized with genetic algorithms. The maximum values give the reference gauges for the tension and nip-load. The optimized results are shown on figures 2a to 2f :

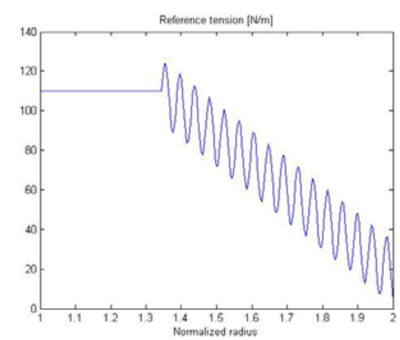


Figure 2a –tension reference with dispersion

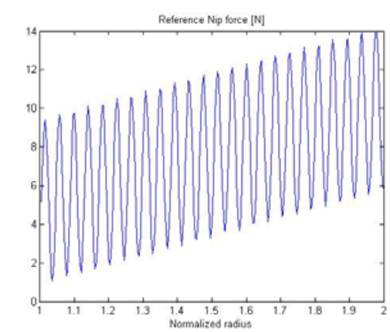


Figure 2b –nip-load reference with dispersion

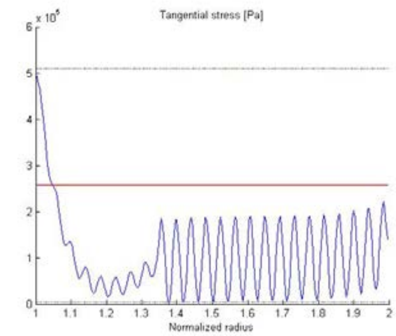
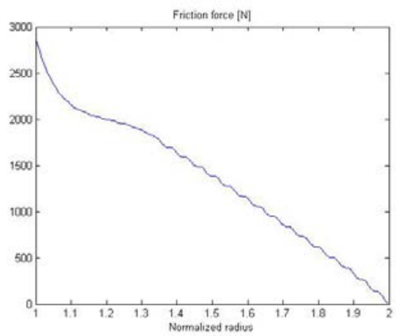


Figure 2c – corresponding tangential stresses

Figure 2d – corresponding radial stresses



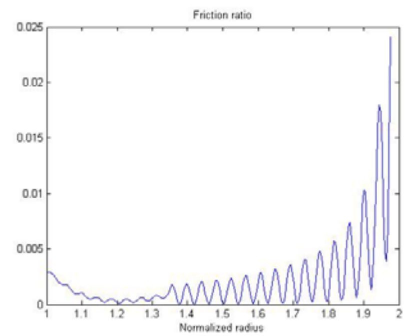
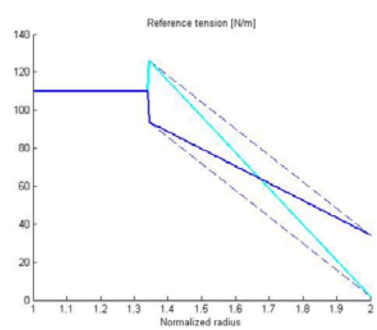


Figure 2e – corresponding friction force

Figure 2f – corresponding friction ratio

All tension and nip-load references located inside their gauges (illustrated in figures 3a and 3b by the dashed lines) respect the defined constraints : wound tangential and radial stresses are between given minimum and maximum values (stresses gauges) and the friction ratio is smaller than a defined value. The results are shown on figures 3a to 3f:



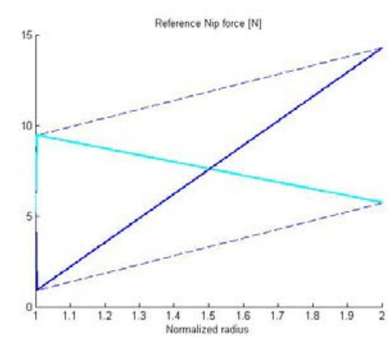


Figure 3a –tension references and the maximized gauge

Figure 3b –nip-load references and the maximized gauge

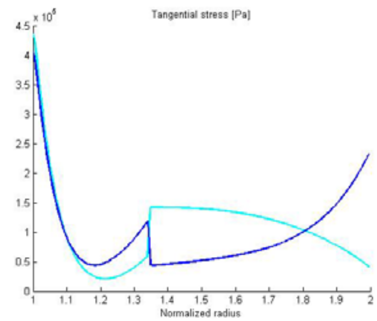


Figure 3c – corresponding tangential stresses

Figure 3d – corresponding radial stresses

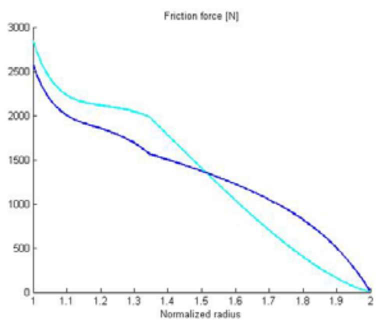


Figure 3e – corresponding friction forces

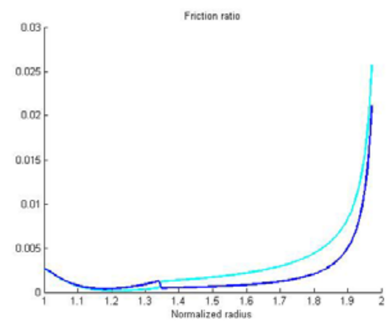


Figure 3f – corresponding friction ratios

MULTI-OBJECTIVE OPTIMIZATION

In this section, in the spirit of [13], we optimize two cost functions : the previously defined cost function J {1} with the constraints defined by equations {4} {5} {6}, and a new cost function J_2 related to the interlayer friction force F_T. In order to have F_T as constant as possible, we have chosen J_2 as the standard deviation of F_T .

We obtain a multi-objective problem, including constraints. This problem has been solved with the MOGA2 algorithm (multi-objective genetic algorithm) and leads to a Pareto curve : there is not a unique solution. The results are shown on figure 4.

Each point located on the Pareto curve gives different tension and nip-load references. Simulations have been made for different points.

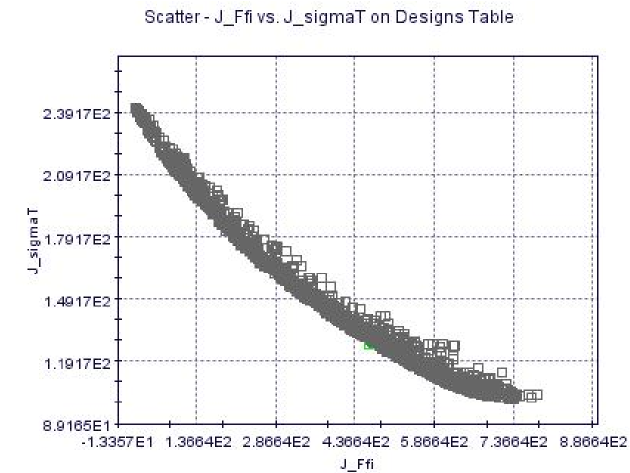


Figure 4 – Pareto curve

A good compromise between J and J_2 gives the optimal results illustrated on figures 5a to 5f:

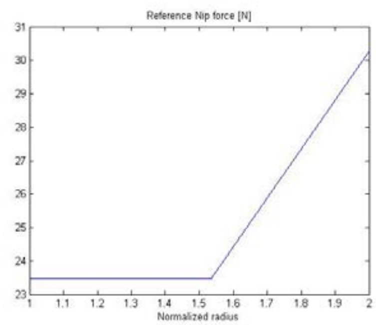


Figure 5a – tension reference

Figure 5b – nip-load reference

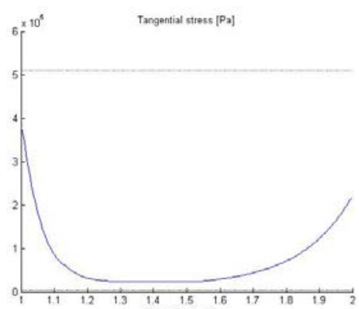


Figure 5c – corresponding tangential stresses

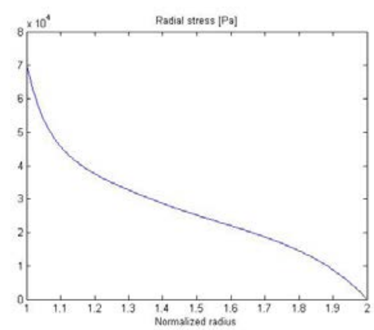


Figure 5d – corresponding radial stresses

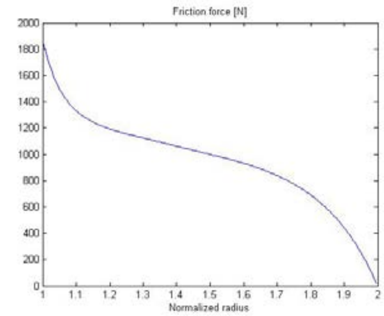


Figure 5e – corresponding friction force

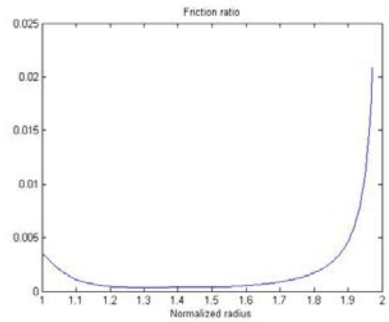


Figure 5f – corresponding friction ratio

As expected, with this multi-objective problem, the friction force is now more constant or at least presents fewer variations (compare figures 5.e and 1.e).

Around these new nominal references, references gauges can be calculated using the same approach presented previously.

CONCLUSION

A second approach presented in this paper consists to optimize the tension and nip-load references gauges, around the nominal references, so that all the references curves ranging between the minimum and maximum limits generate radial and tangential stresses, themselves included in a gauge fixed in advance. Moreover interlayer slippage is avoided. This references gauges calculation is of high practical importance for industry. In fact, it is more practical to define thresholds (gauges) than fixed values.

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