Web dynamics analysis using finite element simulations

D. Knittel

University of Strasbourg, Faculty of Physics and Engineering,
3 rue de l'Université, 67000 Strasbourg, France
Phone : +33 6 71 20 31 30 Email : knittel@unistra.fr

This work focuses on web dynamics and wrinkles analysis in industrial web handling systems by using finite element modeling. The main objective is to simulate wrinkles in a real environment with the control part of the system, depending on mechanical parameters and process data. The effects of misaligned rollers and a roller deflection are specifically analyzed in order to study the influence of parameters.

1 Introduction

Roll-to-roll plants produce large range of everyday products. With high production rate, few discharges or minimum waste, it permits low production cost. Moreover web are stored and transported as rolls which make them really convenient to manipulate.
In web handling systems, commonly, the web is a flexible material such as foil, paper, textile, metal and plastic film. Stages of productions are varied such as coating, plating, laminating, printing, cutting and slicing. One of the main objectives, while maintaining the web tension within an acceptable range around the web tension reference in the entire processing line, is to reach an expected speed. The control of roll-to-roll machineries is ensured by cascading control. First, a loop controls the speed of each motor. Secondly, the external loop controls the web tension. The speed controllers are easy to calculate by identification of parameters. Because of the coupling between the different parts of the system, the web tension control is more difficult and has been studied for several years [1]. Using the H_∞ approach gives optimized results [2-4].
Usually 1D models are used for the study of roll-to-roll system, especially for longitudinal and for control purposes [5, 6]. They do not take into account cross-machine component of the elastic web dynamics. Therefore, those models cannot be used to study one of the most recurring defects in roll-to-roll systems: wrinkles.
Wrinkles are a complex phenomenon. Usually they come from shear stress because of non-uniformities of web tension, web temperature, web thickness, etc. Shear stress can partially be represented as an oriented compressive stress. One can easily understand the criticality of a compressive stress in a roll-to-roll flexible web that leads to a permanent destruction of the material.
In order to address these problems and to optimize web handling systems, it is needed to develop new models. Finite element modeling is adapted for this task because of its general simplicity. The objectives are to use simple laws of physics on a subdivided system to model complex and large scale systems.

The studied industrial generic roll-to-roll system, composed of four motor driven rollers and three load cells, is divided into several subsections that are controlled independently. The web speed is performed directly by the master-speed roller whereas the other rollers are web tension controlled using a load cell in each process section. In such industrial control structure, each motor is also speed controlled.

In this work wrinkles due to a misaligned roller on a generic industrial and controlled system are studied. A 3D finite element model that represents a generic industrial system is used to study wrinkles with the control part that is taken into account. The friction ratio between the web and rollers and the misalignment angle of one roller are changed.

2 Classical buckling theory

The first wrinkle models were developed by Gehlbach and Good [7-9] which are prediction models for isotropic webs (using beam and thin plate buckling [10]). After this, Good and Beisel [11] create a model of buckling of an-isotropic web. By using the classical buckling theory [8], Hashimoto[12] focuses more on a paper-web wrinkle prediction model based on experimental observations of an-isotropic webs. The theory was validated by experiments on paper-web with different Young modulus. The web velocity is taken into account in the friction law only.
The work of Jacques [13] shows good results on the prediction of wrinkles for metal sheet and also helps drastically the understanding of such wrinkles. Apart from this work, published finite element models [14] of troughs and wrinkles do not take into account the contact between the web and rollers.

Simple web traction can produce troughs if the tension is sufficient. In fact, when the web is deformed longitudinally due to its elastic properties, the web has the tendency to retract laterally on its center (Poisson's ratio) and therefore produces compressive stresses. If these stresses exceed the bending stress, the stresses lead to out of plane web deformations (troughs) which cannot be reproduced by 1D models.

Gehlbach et al. [8] established the algebraic wrinkles model. The main goal is to find the limits in term of web tension and roller misalignment angle. When these limits are reached, wrinkles can appear.

Figure 1 shows, for example, the area of wrinkling created by the critical misalignment angle curve and the critical web tension curve for a given plant and web. In this case, for a nominal friction of 0.5 (between web and rollers), wrinkles will appear if the web tension exceeds 500 N/m and if the misalignment angle of roller is higher than 0.02 degrees.

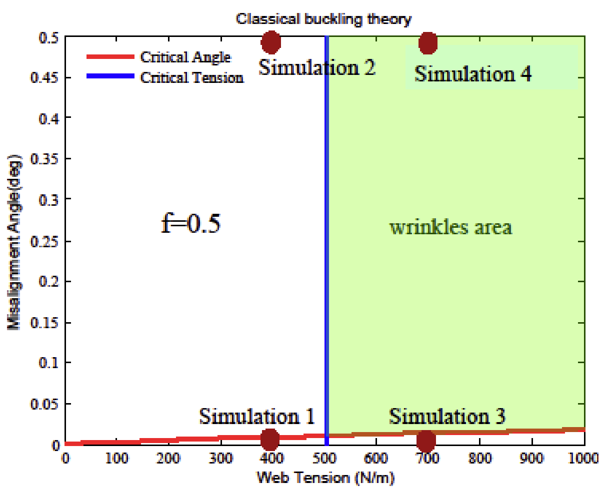

Figure 1: wrinkles area (application of the classical buckling theory)

3 Web dynamics control

Four motor driven rollers compose the studied system. Moreover there are three load cells upstream of the master roller to measure the web tension. The Matlab//Simulink software environment is used for the programming of the non-linear model.
An industrial cascading control structure is used and illustrated in Figure 2. It is a commonly used control structure in Roll-to-Roll systems. Each motor is firstly torque controlled (by controller C_c). This control

loop has to be very fast and can be approximated by a gain. Then the controller C_v is used to control the roller velocity. Finally, C_t is the controller for the web tension.

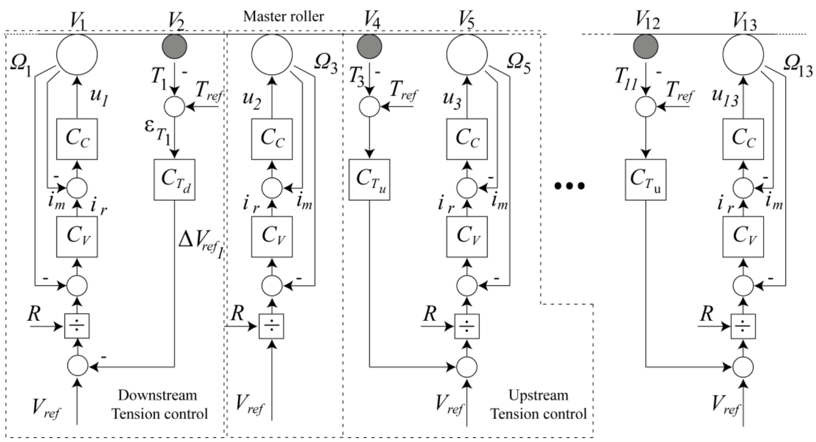

Figure 2: industrial control structure

In our study, the velocity control is guaranteed by an IP controller. Such type of controller does not introduce a zero in the closed-loop transfer function in contrast to PI controllers.

The PI tension controller is automatically calculated (optimized) by H_∞ synthesis approaches.

4 Web dynamics and finite elemengt modeling

For the studied system, the last motorized roller is the master roller. The second idle roller is the one that is misaligned. We analyze the equivalent stresses (von Mises) in order to have an idea of potential plastified area and of maximum lateral stresses. An area of low localized equivalent stresses next to an area of high localized equivalent stresses is a sign of potential wrinkles. In fact, a wrinkle can be created if a moving part of the web (low localized equivalent stresses) meets an anchor point of the web (high localized stresses). This will result in a high localized stresses area that is mainly composed of high compressive stresses [18, 19].

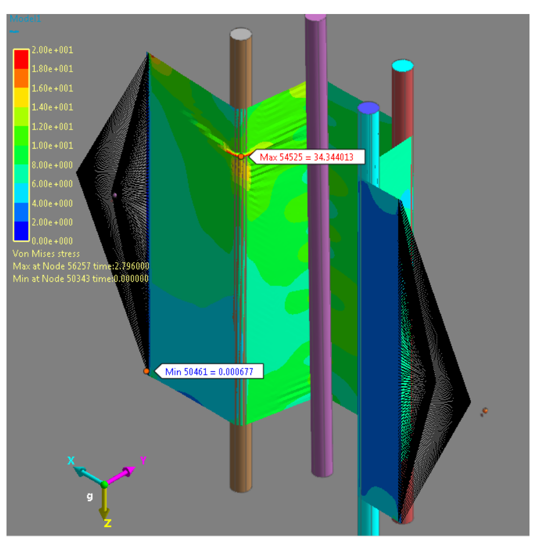

Figure 3: Von Mises stress for a system with a misaligned roller

Figure 3 shows the von Mises web stress for the studied plant with a misaligned roller. One can see the appearance of a wrinkle.

The rise of the roller misalignment angle leads to an increasing of the mean value of equivalent stresses, the appearance of relatively high localized stresses areas close to relatively low localized equivalent stresses areas and the lateral displacement of some part of the web. These are signs of potential wrinkles appearances.
Moreover, the rise of the friction ratio (between rollers and web) leads also to wrinkles appearances.

Figure 4 gives the web tension and velocity references for the simulations with one flexible roller; in red (on fig. 4), the time corresponding on figures 5 and 6.

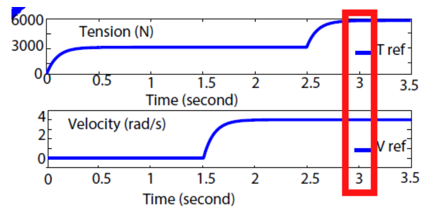

Figure 4: web tension and velocity references for the simulations

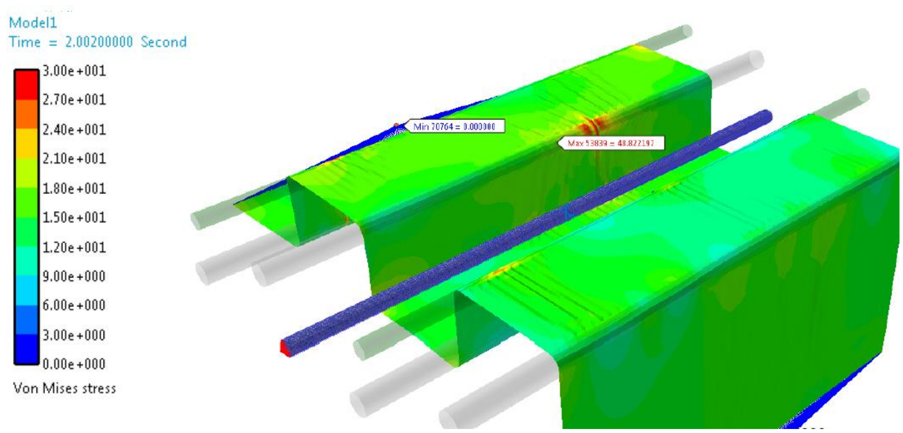

Figure 5: Von Mises stress for the system having one flexible roller (roller deflection)

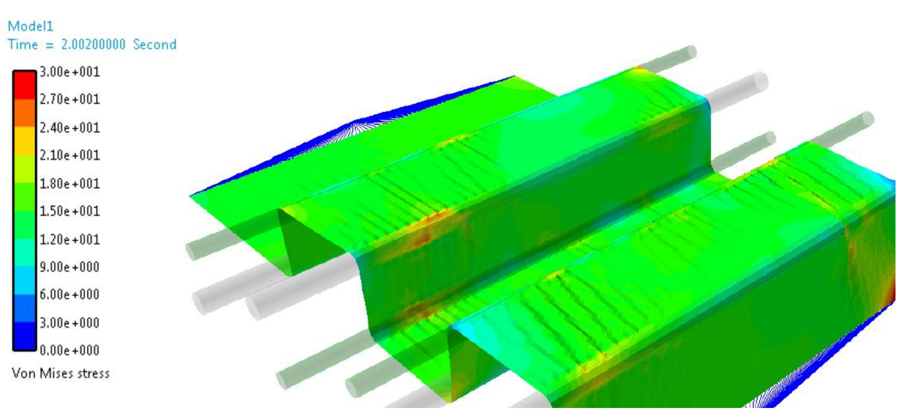

Figure 6: Von Mises stress for the system having No flexible roller (no roller deflection)

Figures 5 shows the von Mises web stress for the studied plant with one flexible roller (roller deflection), whereas figure 6 gives the results for the system having no flexible roller. One can see, by comparing the two figures, the influence of the roller deflection. In fact, in the case of roller deflection, there is an increasing of the maximum value of equivalent stress, and the appearance of relatively high localized stresses areas close to relatively low localized equivalent stresses areas. These are signs of potential wrinkles appearances

5 Conclusion

In this paper, wrinkles due to a misaligned roller on a generic industrial and controlled system are studied. A 3D finite element model that represents a generic industrial system is used to study wrinkles with the control part that is taken into account. One can observe the influence of the misalignment angle of a roller on the appearance of wrinkles on a generic industrial controlled system. These observations follow the classical buckling theory. With this 3D finite element model one can study with only a few adjustments different origins of wrinkles (roller deflection, roller shape, non-uniformities of the web, non-uniformities of the environment) and even the influence of the controllers structures and parameters on the appearance of wrinkles.

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