Modelling lateral web dynamics for R2R equipment design

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Abstract

A model describing the lateral dynamic behaviour of a web between and on rollers is implemented to aid in the design of roll to roll equipment. The model is validated on an industrial setup, and disturbances acting on the web were estimated. The model equations were used to visualise the interdependence between the span length and the disturbances allowed. This resulted in a span length that was least sensitive to disturbances.

1 Introduction

Roll to roll production of solar cells, displays, and printed electronics is a likely approach to meet the high throughput demand in the future [1]. A plastic or metal web passes several processing stations, e.g. printing, lamination and slitting, to come to an end product. The current position accuracy of these processes is typical worse than 25 μm, while the alignment of the different processing steps has to be an order of magnitude better than what the state of the art equipment offers, to meet the future needs [2]. High accuracy web handling, as well as a correct mechatronic design, are needed to meet the allowed lateral and longitudinal displacement specifications and to minimise the internal stresses in the web. Misaligned rollers will introduce tension differences along the width of the web that can become larger than the longitudinal tension. As a result, the web will be in compression at a side, and a ‘bag’ will occur. In this work we investigate how accurate two adjacent rollers need to be aligned and how large disturbances can be before the web starts to show bags or other unwanted behaviour shows. This is investigated by implementing a model of the web behaviour. With this model a trade-off between span length, roller alignment and disturbances is made.

2 Modelling

The shape of the web between two roller as function of time is calculated in two steps: first, the motion equations describing the position of a web at the exiting roller are derived [3]. These equations describe the lateral acceleration as function of the entering angle and position, and the motion of the rollers. With this equation the web angle at the exiting roll can be calculated too. Secondly, with the web position and angle at the entering and existing rollers known, the shape of the web is determined between the rollers. The shape changes instantaneously by changing the web position or angles at the rollers, which assumes the web to be massless. The deflection of the web's centre-line is described by $\frac{\partial^4 y}{\partial x^4} - K^2 \frac{\partial^2 y}{\partial x^2} = 0$, in which y is the deflection, x the along-axis and K a parameter depending on the material properties, dimension and tension.

As introduced previously, no part of the web should be in compression. When the web is entering the span at an angle, whether this is due to a steering action or due to misaligned rollers, moments are introduced into the web. The moment results in a non-uniform tension distribution, and when the moment is too large, one side will be in compression. This is comparable to the behaviour of a beam. The *angle* at which the web gets into compression is called the critical angle. Furthermore, an angle at the entering web will also introduce lateral forces at the roller and a displacement of the web at the exiting roller. These effects should be limited to avoid lateral slip and drift respectively.

2.1 Model validation

The dominant behaviour of the model is validated on an industrial setup. A schematic representation of the setup is shown on the left of figure 1. The edge sensors are denoted by s_1 till s_5. The measured edge location for sensor s_2 till s_5 are given as blue lines in the right of the figure. The displacement guide changed its angle around the double arrow several times to excite the system.

A dynamic model is made that implements the above described approach for this setup in Matlab/Simulink. The edge of the web was predicted at the sensors s_2 till s_5. The position of the web at s_1 as well as the angle of the displacement guide were used as input for this prediction. The grey line shows the predicted lateral position at the sensors.

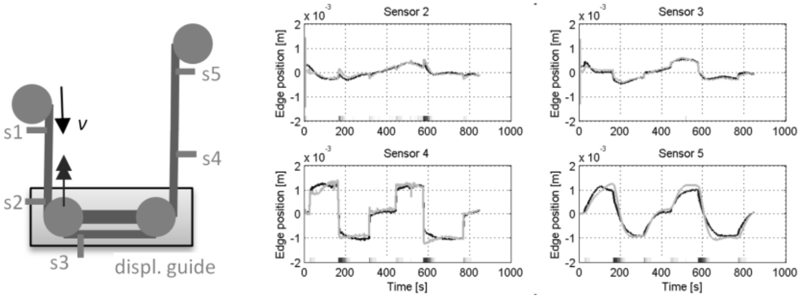

Figure 1: schematic view of the validation setup (left), and the simulation (grey) and measured (black) web positions.

The model predicts the position of the web at the sensors well. However, the model shows some overshoot when the displacement guide makes a large step. The angles between the web and the rollers at these steps is larger than the critical angle, resulting in compression. This is shown as marks at the bottom of the figure. Based on the sensor data, the angle of the entering web is estimated with a maximum amplitude of 1 mrad.

3 Design example

The dynamic model can be used for, e.g., concept comparison or sensitivity analysis. In this work we use it to investigate whether a web between two rollers will come into compression, introduces too large lateral forces on the roll, or drifts too much to the side, i.e. if it moves stably. These three criterions can all be related to the web angle at the entering web, and are all a function of the length between the rollers. The calculations were done for PET foil with a width of 300 mm, a thickness of 125 μm and a tension of 100 N. The maximal allowed lateral force was set to 10 N, with a maximal deflection at the exiting roller of 1 mm. In figure 2 the angles are plotted that would break one of these criterions. When the entering angle in combination with a specific length stays within the white area, the web will behave correctly. The dark grey area shows the angles that will result in compression, too large shear, or too much deflection for the *static* situation. It shows how well the rollers must be aligned to operate, even in the absence of disturbances. Until a certain length, increasing the length allows for larger misalignment errors.

The web when entering a span will have angle disturbances due to upstream steering actions. For the web to behave well with these *dynamic* disturbances, the magnitude of the angle, has to avoid the light grey area in figure 2 too. The lines shows which of the criterion is broken. This guides our design, as it shows what effect is responsible for the unwanted web behaviour. In this case, an optimal length of 1.3 m would result in the largest robustness to disturbances.

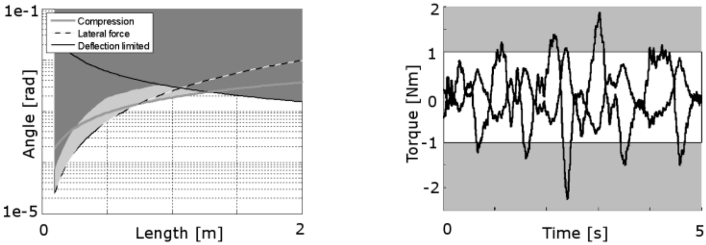

Figure 2: Allowed angles for the entering web (left), and the calculated moments when the length/disturbance is chosen in the light grey area.

The right-hand side of figure 2 shows an example of the simulated moment at the entering and exiting roller when the position and angle at the entering roller are approximately equal in size as the disturbances measured at our setup. The length of the span was chosen to be in the light grey area of the left hand figure. The figure illustrates that the web would sometimes be in compression due to these disturbances. This occurs if the moments exceed the middle area in the right hand side picture. The rollers were perfectly aligned in this simulation.

4 Summary

Based on the model calculations, the interdependence between length, disturbances and alignment errors is investigated. This showed that an optimal length could be chosen that allowed for maximal disturbances. With the dynamic model any design can be assessed to predict its performance and find sensitive design considerations. Furthermore, the models can be used to develop model based controllers.

References:

[1] Schwartz, E., “Roll to Roll Processing for Flexible Electronics,” MSE 542: Flexible Electronics, Cornell University, 2006

[2] Clemens, W. (ed), ”OE-A Roadmap for Organic and Printed Electronics, fourth version”, Frankfurt am Main, 2011

[3] Shelton, J.J., “Lateral Dynamics of a Moving Web,” Ph.D., Oklahoma State University, 1968.