

Low cost vacuum web coating system



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ABSTRACT

A low cost solution for a mini roll to roll web coating system is presented. The design is very simple and involves only three active rolls, two winding/unwinding rolls and a cooling drum. No extra load cells are used to control the web winding mechanism operation. To reach such result it has been necessary to develop an adequate control solution which acts on the two winding roll torques to make the web moving properly. The effect of the control mechanism is to increase electronically the total mechanical inertia of the roll to roll system. In such manner the stick-slip motion of the web, induced by the dry friction affecting the rotation of the rolls, is avoided. The effectiveness of this strategy has been corroborated: a first test showed that the web moves continuously while it is kept tense; in a second experiment a-Si material has been deposited by hot-wire chemical vapor deposition technique. For that material the optical transmission measurements at several points over the deposited area indicate a satisfactory uniformity. The presented tests validate the goodness of the new control method.

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1. Introduction

Roll to Roll (R2R) processing is a manufacturing technique for continuously depositing material on a flexible substrate. In the simplest R2R systems the flexible substrate is placed on an unwinding roll, from which is unwound to enter in a processing area. The material is deposited and the coated film leaves the deposition area to be wound on a rewinding roll. From simpler R2R coating apparatus to much more complex onto web coating systems for industrial purposes have been developed during the last three decades [1–6]. In many coating web processes the substrate at deposition area needs to be cooled to evacuate the heat generated during the deposition. The generated heat at the deposition area is evacuated using a cooling drum as a deposition drum. The web has to be kept tense over the drum to make the cooling process effective.

The common strategy to control the web tension is to use two additional rolls acting as load cells placed between the two winding/unwinding rolls and the cooling drum [7]. The load cells are used as force sensors to measure the local tension of the web. Their signals are fed back to servo amplifiers to adjust the motors, or the brakes torque acting on the winding/unwinding rolls in such a way that the web is kept independently to the external perturbations.

Moreover the proposed system is for scrolling velocity in the order of centimeter per minute. Without an adequate control based on load cells, at this speed regime, external perturbations like dry and viscous frictions can affect the tension of the web. Moreover at high web tension the axes of the rolls undergo high radial forces which make the existence of dry friction even more significant as explained by the Coulomb model. As it will be showed in this paper, an important dry friction can also determine stick-slip velocity profile. This phenomenon is well known to affect machine with strong dry friction, and its suppression can be difficult [8,9].

The purpose of this paper is to show that for R2R processing with winding speed, less than 10 cm/min, the system can be controlled without using any load cell, just increasing electronically the total inertia of the system. In that case, problems due to the presence of external and non-linear torques are overcome and it is showed that the web is kept tense while moving continuously at a constant velocity. To experimentally test the goodness of this solution it has been used in a mini R2R system fabricated at the Universitat de Barcelona.

The paper is organized as follows: firstly, the mini R2R system is described and the design principle based on the electronic increasing of the total inertia is mathematically explained. Secondly the web motion at low velocity is studied experimentally. Thirdly, amorphous silicon has been deposited by hot-wire chemical vapor deposition (HWCVD) on PEN substrate to prove the effectiveness of the system in evacuating heat irradiated by the filaments and to test the uniformity of the deposited material.

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2. Characteristics and design basics of the mini R2R system

The mini R2R mechanical assembly is shown in Fig. 1. The system has been thought as laboratory multipurpose R2R system for vacuum coating over 10 cm width webs. The mini R2R is composed of two interchangeable unwinding/rewinding rolls and a cooled deposition drum. In the picture the small rolls are the interchangeable rewinding/unwinding rolls, and the central roll is the cooling drum. DC brushless motors fed by servo amplifiers are used to drive the rolls. The system is very compact and the three rolls were loaded inside a cubic vacuum chamber with a side length of 40 cm as showed in the picture. The system part that stands outside the chamber includes DC motors, connection shafts, gear boxes and belts. For the cooling drum the shaft is connected to the external rotating system via an O-ring shape feed-through providing hermetic sealing. Concerning the winding rolls, the roll is connected to the motor shaft by a damper and the mechanical arm is fed from the outside by a magnetic feedthrough.

In the case of R2R systems composed of only three active rolls the controls of the web velocity and the web tension can be easily decoupled. In our design the web speed is fixed by the rotation of the central cooling drum which is driven by a velocity controlled motor. On the other hand, the web is maintained in tension over the cooling drum controlling the torques supplied, by the two DC motors, to the winding and unwinding rolls. The torque applied to the unwinding roll is acting in the opposite direction respect to its rotation and it makes the motor working as a brake. In an ideal system, without any dry and viscous frictions, any supplementary load cell rolls would not be necessary to control and keep tense the web. However, as already mentioned in the introduction, this is not

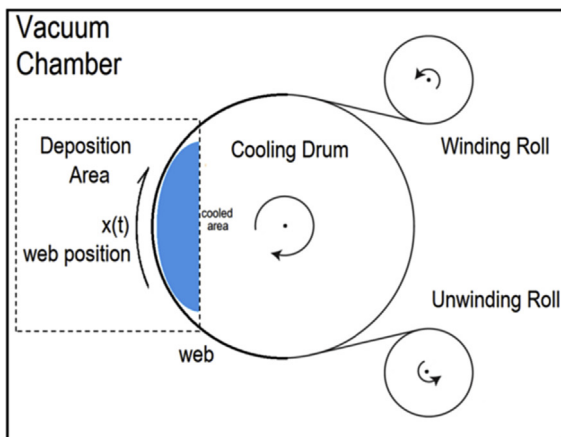
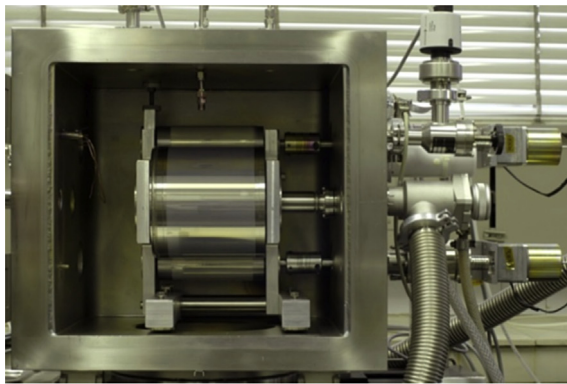


Fig. 1. Picture of the Roll to Roll system fabricated at the Universitat de Barcelona (top). 2-D Scheme of the mini Roll to Roll system inside the vacuum chamber (bottom).

the case as in real systems. Fig. 2 shows the simplest realistic model we will use here to explain the behavior and then justify the design of our R2R system without load cells.

The three rolls are coupled together by means of the tensed web and they are considered as a single rigid rotating system characterized by a total rotating inertia

$$I_{tot} = I_c + \frac{2R_c}{R_{W/R}} I_{W/R} \quad (1)$$

where I_c and $I_{W/R}$ are the rotational inertias of the cooling drum, and of the winding/unwinding rolls, respectively. $R_c/R_{W/R}$ is the ratio between their radii. The inertia $I_{W/R}$ includes also the inertia of the two DC motors rotors connected to the winding/unwinding rolls. All internal degree of freedom of the R2R are not considered here. Since it is interesting to study the web position $x(t)$ and not its rotation around the cooling drum axis, the total mass $m = I_{tot}/R_c^2$ is introduced to describe the system as a linear motion system, like the one sketched in Fig. 2 at the bottom.

The coupling between the rotating body and the cooling drum motor controlled in velocity mode is affected by a viscous friction, which can be expressed in the linear motion model by a friction resistance R_f . The stiffness of the coupling has also to be taken into account introducing in the translational system a spring with k as force constant. One end of the spring is connected to the total mass m , while the other end is forced to move at a constant velocity v_{ref} .

Since v_{ref} is very low, the dry friction plays an important role in determining the behavior of the web movement. To start moving the spring has to be compressed to overcome the static limit friction force F_{lim} . This takes a time $t_1 = F_{lim}/kv_{ref}$. After this lapse of time, the value of the dry friction drops suddenly by a value F_a , by switching from a static to a dynamic regime.

The evolution of the web position $x(t)$ starting from this moment is governed by the following equation of movement

$$m\ddot{x} + R_f\dot{x} + kx = kv_{ref}t + F_a. \quad (2)$$

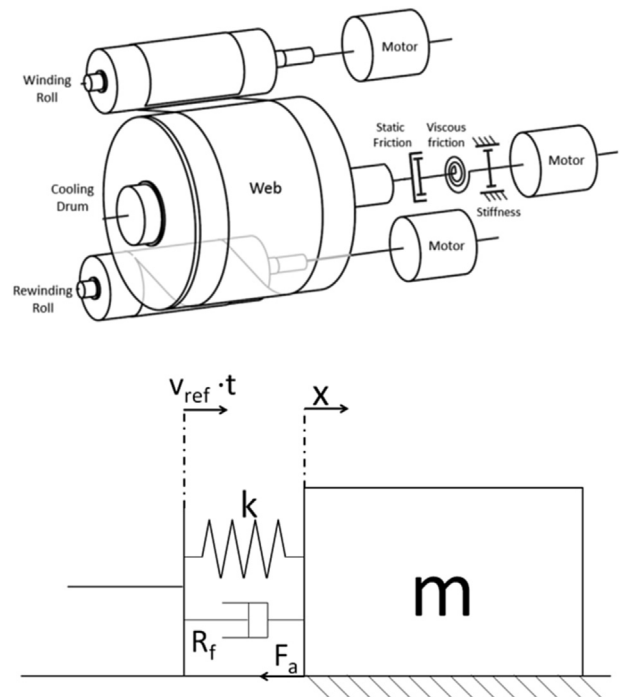


Fig. 2. System rotational motion model (top). System linear motion model (bottom).

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