Design of Roll to Roll Manufacturing Machine for Flexible Electronics

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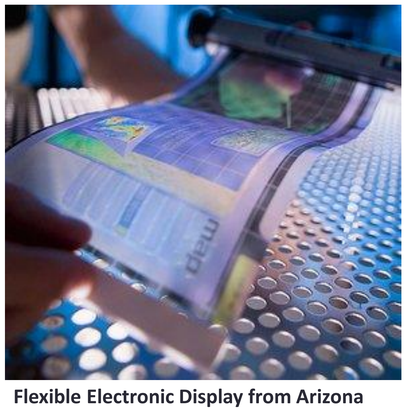
ABSTRACT

Roll to Roll (R2R) manufacturing consists of processing flexible materials (referred to as webs) by transporting on rollers from an unwind roll, through processing machinery, to a rewind roll. This type of processing has numerous advantages over batch processing: it saves time and cost, reduces delay time, and increases efficiency. Because of this, the electronics industry has great interest in developing R2R manufacturing for printed flexible electronics. This research project aims to contribute to this by designing, building, and experimenting with a lamination device compatible with Oklahoma State University's modular R2R platform. Printed electronics are often constructed from several layers (or webs) of different material which are thermally laminated together. The modular R2R platform allows great flexibility in designing different experiments and expanding the capabilities of the machine. The new lamination capability will be achieved by a small roller applying pressure to a large roller internally heated by circulating water. The pressure is applied on the small roller's axis by a lever and a pneumatic cylinder controlled electronically using feedback from a pair of load sensors.

BACKGROUND

FLEXIBLE ELECTRONICS:

- New, developing technology
- Portable, flexible, lightweight
- Expected to revolutionize the electronics manufacturing industry
- R2R processing is very efficient, so companies and laboratories have invested much research into making electronics in R2R form.
- While advancements have been made, work needs to be done to optimize the process
- Already existing flexible electronics:
  - LG Phillips has created a thin and flexible electronic paper to replace newspapers
  - Thin flexible OLED display devices are on the market, will replace LCDs
  - Flexible polymer based solar cells are also on the market.
- Future: wearable devices, medical prosthetics …



Flexible Electronic Display from Arizona State University and HP

ROLL-TO-ROLL MANUFACTURING:

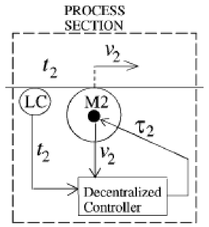
R2R processing works by unwinding a flexible material, running it through various processing machinery, and rewinding it, all in one continuous process. Because it is a continuous process, it is more efficient than batch processing, which requires time/money to move from processing one batch to processing another. R2R also permits the efficient manufacture of devices with one extremely long dimension; e.g., a TV screen stretching the length of a hallway. R2R plays a role in the manufacture of aircraft, appliances, automobiles, bags, books, diapers, boxes, newspapers, and much more.

The flexible material is called the web. Web handling is the systematic control of the web and all the processes that occur on it as it travels through the entire system. The two primary parameters that must be controlled are the web tension and web velocity.

There exist many different R2R processes, including coating, printing, drying, embossing, and slitting to name a few. This project is concerned with the design of a heating and lamination module. This module will be used in Dr. Pagilla's modular R2R platform. This platform will allow a great variety of experiments to be performed. The lamination process is important because flexible electronics are constructed from several layers of substrate which are laminated together.

BACKGROUND

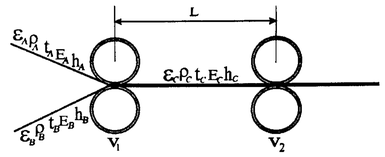
For each processing module, there are a set of dynamic equations which govern these parameters. See the figure below.

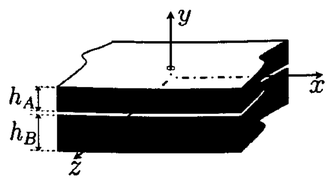


$$L_2\dot{t_2} = AE[v_2 - v_1] + t_1v_1 - t_2v_2$$

$$\frac{J_2}{R_2}\dot{v_2} = (t_3 - t_2)R_2 + n_2u_2 - \frac{b_{f2}}{R_2}v_2.$$

In lamination, two webs combine to form a new web. Young's modulus *E* is modified





$$E_{cy} = \frac{E_AE_B(h_A+h_B)}{E_Ah_A+E_Bh_B}.$$

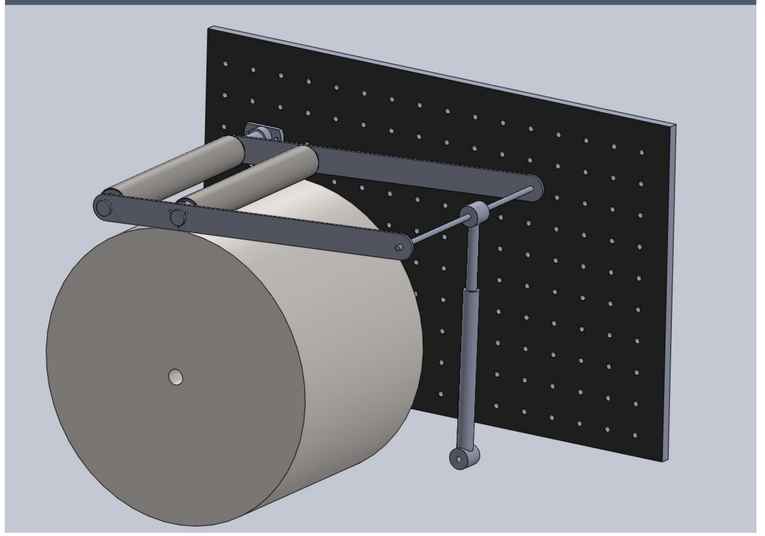
DESIGN REQUIREMENTS

- System should be able to accept web at various speeds
- At constant speed, the system should deliver heat to the web at a constant rate and distribution (both linearly and laterally)
- At constant speed, the system should apply pressure to the webs with equal distribution linearly and laterally
- The system should be able to apply 50-60 lbs force total, or about 10 lbs per linear inch over the web
- The pressure applied should be controlled by software, preferably the same software that controls the rest of the R2R system
- The system should have load sensors to verify that the pressure is applied with the appropriate magnitude and distribution
- The system must accept web with a width of at least 6 inches
- The system must be powered by the lab air supply, at 115-125 psig

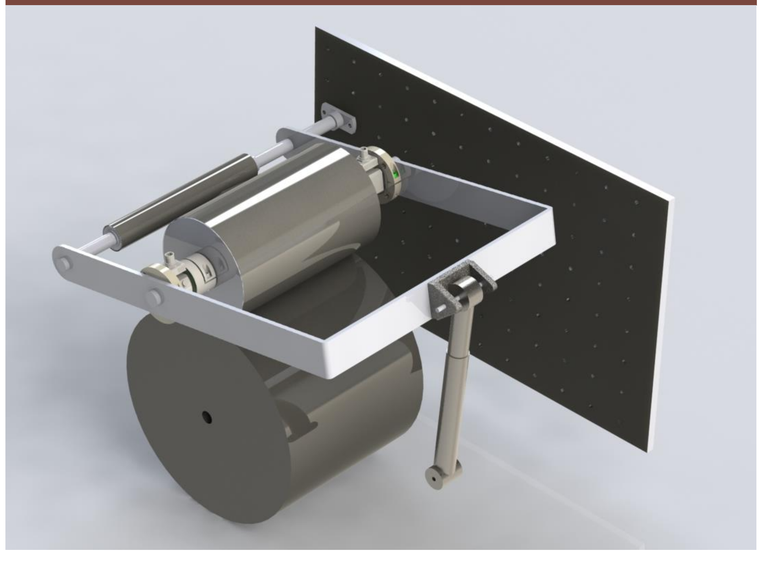
PROTOTYPE MODEL

- To achieve heat transfer, a 12.5" diameter heated roller from Webex Inc. was selected. The roller is heated by circulating hot water through the interior of the roller with a special screw. The screw has an increasing pitch which results in more even lateral heat distribution.
- The nip roll is located above the heated roller and pressure is applied by a pneumatic cylinder acting on a lever.
- A secondary fixed roll exists in order to feed the nip roll with web at a constant angle. Constant angle means the pressure applied is solely a function of the pneumatic cylinder and not the velocity of the web.
- The lever provides a 4:1 mechanical advantage to the actuator

PROTOTYPE MODEL



FINAL DESIGN



- Stronger lever arm made from ¼" sheet metal either bent or connected by L brackets. According to my bending stress calculations, the previous lever arm would have yielded.
- 6" diameter nip roll. This size is more similar to that used in industry.
- Dual MAGPWR TS Load Cells from MAXCESS. Model: TS-50-SC-EC12. Load capacity: 50 lb. If the load is distributed equally, the load cells should return identical values.
- Stainless steel pneumatic cylinder. 1"-12" stroke. Bore size: 1-1/16". This was sized using the equation $F = P \cdot A = P \cdot \pi/4 \cdot D^2$
- The lever provides a 2:1 mechanical advantage to the actuator