Development of pressure former for continuous nanopaper manufacturing

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Abstract.

Introduction

This paper will cover the development of pressure forming machine for the research of continuous production of nanopaper. Nanopaper is a type of paper which consist of smaller cellulose fibres in the length range of nanometers in contrast to larger fibres of typical paper. Nanopaper generally has a lower weight, higher abundance, better biodegradability and renewability as well as higher strength and rigidity [1]. Significant motivation for nanopaper research has been use-cases where it can replace plastic.. Nanopaper can also be used for electrical purposes by inserting highly conductive electrical circuits into the nanopaper during the manufacturing process [2].

The main challenge with nanopaper is the slowness of manufacturing. The draining and drying can require a long time, up to a few days [1]. The machine developed in this paper was constructed in order to study a faster method of producing samples for research. The pressure former unit was designed for studying the wire speed, forming pressure, paper thickness parameters and their relations when producing nanopaper with nanocellulose mass of various compositions.

Currently, several different methods exist for producing nano paper including several drawing methods, cellulose synthesis, spray deposition, electrospinning, and more [3, 4, 5, 6, 7, 8]. Some of these methods are efficient and fast due some optimisation of the methods, but there is still lots of room for improvement in terms of the availability and feasibility of these [7, 9]. Pressure forming of nano paper had not been studied before this paper.

Methods

Studying the pressure forming process requires the adjustment of three main parameters: wire velocity, forming pressure and thickness of the paper. The figure below, Fig. 1, shows these main parameters and their respective components. Additionally, there were some other choices which were made in order to assist in meeting the design requirements for the machine. Firstly, it was decided that there were to be four rolls holding the belt instead of the minimum requirement of three, due to having to add a scraper on one extra roll which scraped excess scrap material off the wire. Additionally, extra space was left at the top of the frame beneath the wire for future modifications. The choices made in regards to the main components are explained in the subsequent paragraphs.

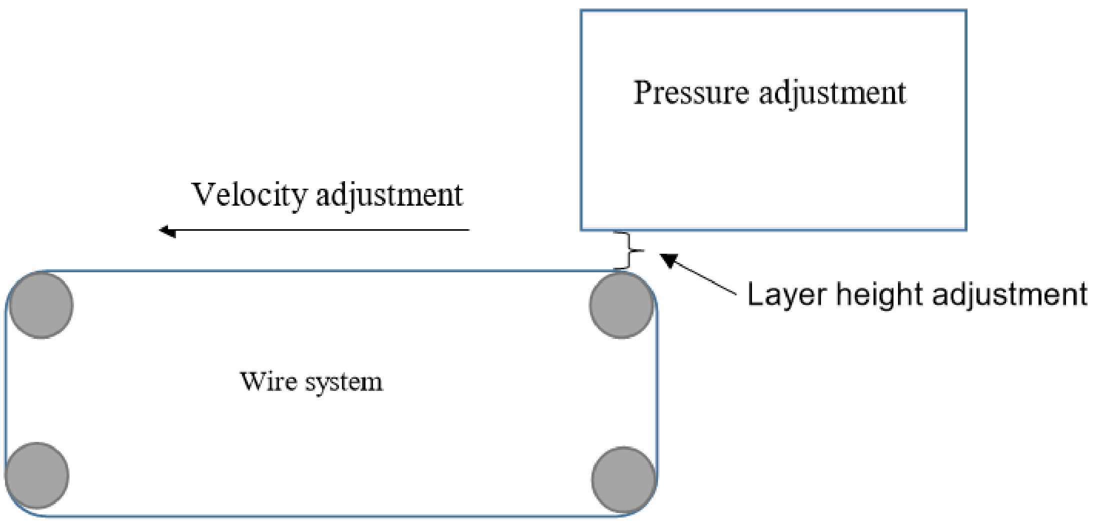

Fig.1 main parameters and relationship between them

In the continuous pressure forming process, the nanopaper web is formed into a moving wire. To study the effect of the wire velocity, the velocity has to be adjustable and stay constant after adjustment in order to produce uniform samples. A DC motor and transmission with high gear ratio was chosen for smooth operation. The velocity adjustment was performed with closed-loop PID control of the motor using a rotary-encoder to measure the wire belt velocity, motor driver to for variable velocity operation and microcontroller for controlling.

In order to form the nanopaper web onto the moving wire, it was necessary to deposit the nanocellulose onto the wire at a constant rate. This meant that the flow rate out of the headbox, where the nanocellulose was initially stored, had to be kept constant in order for the nanopaper sample's layer height to be constant. In order to achieve this through the new pressure forming method for nanopaper production proposed in this project, the headbox needed to be kept under a constant, controllable pressure, which needed to be matched to the wire's velocity. This was done by connecting an accurate pressure gage to the headbox which measured the pressure inside. A valve connecting the pressurised air supply to the the inside of the tank was used to control the pressure and the user had to use both of these together in order to obtain the desired pressure and hence flow rate and a constant sample thickness.

In order to control the layer height of the nanopaper, the headbox was moved up and down, so that the vertical gap size between the top of the wire and the bottom of the headbox's opening were controlled to let out the right amount of nanocellulose for the desired layer height. In order to control the headbox's height in very small, very accurate increments (a few micrometers), two lead screws controlled by two stepper motors with four vertically aligned guide rails, two on either side of the headbox, were used. This was very accurate because each step was an exact angle the lead could turn and hence an exact distance that the headbox moved vertically.

References

[1] I. Gonzalez, M. Alcala, G. Chinga-Carrasco, F. Vilaseca, S. Bou, and P. Mutje, "From paper to nanopaper: evolution of mechanical and physical properties," Cellulose, vol. 21, no. 4, pp. 2599 - 2609, Aug 2014. [Online]. Available: https://doi.org/10.1007/s10570-014-0341-0

[2] M.-C. Hsieh, C. Kim, M. Nogi, and K. Suganuma, "Electrically conductive lines on cellulose nanopaper for flexible electrical devices," Nanoscale, vol. 5, pp. 9289 - 9295, 2013. [Online]. Available: http://dx.doi.org/10.1039/C3NR01951A

[3] H. Sehaqui, N. Ezekiel Mushi, S. Morimune, M. Salajkova, T. Nishino, and L. A. Berglund, "Cellulose nanofiber orientation in nanopaper and nanocomposites by cold drawing," ACS Applied Materials & Interfaces, vol. 4, no. 2, pp. 1043 - 1049, 2012, pMID: 22257144. [Online]. Available: https://doi.org/10.1021/am2016766

[4] L. Rozenberga, M. Skute, L. Belkova, I. Sable, L. Vikele, P. Semjonovs, M. Saka, M. Ruklisha, and L. Paegle, "Characterisation of films and nanopaper obtained from cellulose synthesised by acetic acid bacteria," Carbohydrate Polymers, vol. 144, pp. 33 - 40, 2016. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0144861716300819

[5] K. Uetani, T. Okada, and H. T. Oyama, "In-plane anisotropic thermally conductive nanopapers by drawing bacterial cellulose hydrogels," ACS Macro Letters, vol. 6, no. 4, pp. 345 - 349, 2017. [Online]. Available: https://doi.org/10.1021/acsmacrolett.7b00087

[6] L. F. Krol, D. Beneventi, F. Alloin, and D. Chaussy, "Microfibrillated cellulose-SiO2 composite nanopapers produced by spray deposition," Journal of Materials Science, vol. 50, no. 11, pp. 4095 - 4103, Jun 2015. [Online]. Available: https://doi.org/10.1007/s10853-015-8965-5

[7] D. Beneventi, E. Zeno, and D. Chaussy, “Rapid nanopaper production by spray deposition of concentrated microfibrillated cellulose slurries,” Industrial Crops and Products, vol. 72, pp. 200 - 205, 2015, special issue derived from International Conference on Bio-based Materials and Composites. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0926669014007109

[8] S. Lingaiah and K. Shivakumar, “Electrospun high temperature polyimide nanopaper,” European Polymer Journal, vol. 49, no. 8, pp. 2101 - 2108, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S001430571300222X

[9] H. Sehaqui, A. Liu, Q. Zhou, and L. A. Berglund, “Fast preparation procedure for large, flat cellulose and cellulose/inorganic nanopaper structures,” Biomacromolecules, vol. 11, no. 9, pp. 2195 - 2198, 2010, pMID: 20698565. [Online]. Available: https://doi.org/10.1021/bm100490s

[10] S. Lingaiah, K. Shivakumar, and R. Sadler, “Electrospun nanopaper and its applications to microsystems,” International Journal for Computational Methods in Engineering Science and Mechanics, vol. 15, no. 1, pp. 2 - 8, 2014. [Online]. Available: https://doi.org/10.1080/15502287.2013.833996