Drainage interactions between the headbox, forming fabric(s), dewatering elements, and their impact on converting operations

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ABSTRACT: This paper outlines the forces acting between the headbox, wire, and drainage elements on the paper machine. The report analyzes the influence of forming fabric on sheet characteristics and properties achieved in the converting operation. At the instant the jet shoots out of the headbox, significant interactions occur in the open air space of the gap former and as the fiber mat initially forms on the fabric surface. Hydraulic, gravitational, chemical, and shear stress forming forces combine to influence the finished quality of the paper. The forming surface plays a critical role as fibers are retained or lost in the initial dewatering stage. What starts on the wet end of the paper machine with fabric surface topography, rigidity, and drainage interactions significantly affects the converting operation.

Application: The report is useful as a learning tool and refresher on forming zone dynamics and interactions.

Forming fabrics play an integral part in the physics of drainage and in finished sheet quality. In many articles, the interaction between the jet with the forming wire is inferred but not explored in much detail. This paper describes some of the forces acting between the headbox, wire, and drainage elements in the fourdrinier, gap former, and top wire processes. It relates characteristics developed on the wet end of the paper machine to their impact on converting operation. This study also focuses on fabric-to-fabric interactions in the twin wire process.

INTERACTIONS

Head box/jet

Headboxes must deliver a well dispersed furnish suspension with a level of microturbulence sufficient to minimize fiber flocculation. To a large degree, the dispersion of fibers at headbox discharge determines the uniformity and quality of the sheet. Modern headbox systems allow fine-tuning of the basis weight through computer-controlled slice adjustments and dilution systems that compensate for machine-direction (MD) and cross-direction (CD) profile variation. Fourdrinier systems that use pulse inducing drainage elements and blade forming gap formers offer some hope of improvement, but they are not the solution to headbox flow problems for high speed operations. In the roll former, the headbox has more effect on paper structure because there is no chance to reorient fibers down the process.

In that brief moment when the jet shoots out of the headbox, it interacts with the open air space and gravity. The setup of the throat opening and slice are critical on fourdrinier machines, affecting fiber distribution and sheet quality. Machines with layering capability rely on the ability of the former to limit mixing that inevitably occurs at the nozzle tip and drainage elements. Flow patterns that develop have the potential to mix fibers carefully segregated by layering techniques when using multilayer headboxes. In twin wire forming, one of the problems with the free jet is mixing of stock layers, which reduces sheet purity. The industry considers an actual layer purity of better that 90% a good result because of these machine factors [1]. One of the challenges machine builders face is reducing the mixing and turbulence in the jet by eliminating the open air space from the nozzle tip to the point of fabric capture.

It is interesting to consider the impact of flow variation as the jet leaves the nozzle. The friction of the nozzle is replaced by air with a lower coefficient of friction and the boundary layer at the surface of the jet accelerates. Paper products such as copy and printing grades that require very similar properties on each side are sensitive to fiber orientation differences through the thickness of the sheet. Unbalanced forces developed in the gap and at wire contact can result in paper that has curling tendencies of one surface relative to the other. Ideally, paper would be isotropic, containing the same stress forces throughout the thickness of the sheet. As the jet is trapped between the wires, the fiber suspension is impacted by velocity differences between the jet and the wire which impact the sheet interface and profile through the thickness of the sheet as velocity flow gradients develop. These internal boundary layer forces influence formation and fiber orientation in the product [2].

Jet/wire tension

The wire tension interaction plays a significant role in sheet quality, particularly in the twin wire process. If tension is too high, it can destroy sheet formation by introduction of high levels of shear stress [1]. If tension is too low, it leads to inadequate dewatering and water handling problems, along with slippage, instability, and wear and guiding issues. It is very important to understand that "plastic wires" have deformation limits that cannot be exceeded without serious results. Wire tension is a design-dependant variable with multilayer layer fabrics holding the advantage over single layers. The increase of material in these structures allows more resistance to deformation and stretching. Note that the tension measured at one location is not one fixed value around the loop. Fabrics stretch and shrink as they travel around the forming loop, moving in and out of elements and drive rolls. Tension is highest just before the drive roll, up to 1.5–2.0 times the average. As paper machine tension is increased the fabric pulls much tighter on roll surfaces and bearings. A further consideration before determining an operating tension level is construction of the former. Wear and drive loads increase as tension is increased in the interaction of the fabric with vacuum elements and blades in the machine loop. As tension increases on the twin wire former, dewatering increases in relation to the tension divided by the radius of the forming roll. Fourdriniers typically run in the 4.5-7.1 kN/m (25-40 pli) range of average tension. Multilayer tension recommendations are in the 6.3-9.8 kN/m (35-55 pli) range for high speed twin wire formers. The minimum theoretical fabric tension needed to overcome the centrifugal force in twin wire forming caused by the jet with thickness *t* and density p equals $T>= ptv^2$. This shows that the minimum tension for 15 mm stock thickness with a velocity of 20 m/s is 6 kN/m (33.6 pli) [3]. The actual fabric tension of a fabric should be adjusted to minimize tension levels but still should overcome theoretical minimums by approximately 2 kN/m (11 pli).

Jet/drainage elements

The interaction of the jet with the surface of the wire is critical to achieve final sheet properties in lightweight products. The jet-to-wire ratio is a key control parameter in controlling the MD:CD ratio for most grades. The free jet of the fourdrinier has both horizontal and vertical components as it hits the wire. The vertical component, set by the free jet angle, is responsible for the dewatering effect along with gravity on horizontal tables. The use of gap former technology has become common in the industry with pure roll gap forming limited to the tissue segment. The blade gap formers commonly used to produce fine paper and newsprint grades hold the advantage of generating pressure pulses with the ability to improve formation, but at the expense of lower retention than the roll formers. Drainage rate also depends on the furnish, fiber orientation geometry, basis weight, and construction of the paper machine water removal systems relative to the influence of gravity on white water flow path.

Shear forces induced by velocity differences between the free suspension and wires, coupled with the initial headbox turbulence, are the main factors affecting paper formation and orientation characteristics [3]. Twin wire machine designs that use roll surface dewatering of the jet along a curved surface cause a velocity gradient in the radial direction. At 10 mm of wire separation, a roll radius of 800 mm and a jet speed of 1600 m/min, the suspension velocity along the outer wire will be 20 m/min lower than that along the inner wire. This may cause some difference in paper structure differences between the top and bottom of the sheet [2]. As the wires move into and out of rolls and vacuum elements, acceleration and deceleration occurs given the construction and physical properties of synthetic monofilament forming fabrics.

As the surfaces press into the forming sheet, surface- and retention-related mechanisms come into play that depend on the topography of the fabric and related fiber support. A proper balance is critical in the wire surface topography to respond to the challenges of high-speed operations as dwell time in the forming zone is reduced. As machine speeds increase, time across the drainage elements is significantly reduced, while resisting stresses from higher centrifugal forces, and machine vibrations must be overcome. Monoplane surfaces, as found in extra support and plain weaves designs, are critical in producing papers such as newsprint and fine papers that require low wire mark, while a surface with high plane difference helps enhance the bulk and sheet transfer in grades such as tissue. Top wire units, due to moving water upward against gravity, must match proper fabric surface and drainage potential to achieve optimum results. Uniformity of the weave structure is critical to the finished paper properties. As fabric manufacturing processes become more consistent, the paper becomes more consistent. Fabric manufacturers are using sophisticated mathematical techniques and other methods to analyze warping, weaving, and heatset processes, with measurable benefits for the papermaker's customers.

The thickness of the paper is inversely proportional to the forming length. This means the forming length directly affects the z-direction sheet compression and overall structure. J.H. Jong and coauthors have shown that in the jet impingement region, the wire effect is important until the mat grows to a certain height. This work shows there are three distinct regions of pressure drop for the mat. The first, called the *linear region*, exists below 17-18 g/m^2. In that region, the pressure drop increases almost linearly with an increase of basis weight. In the second region, called the *transition region* (between 17-18 g/m^2 and 40 g/m^2), the pressure drop increases only a little with the increase of basis weight. The third region, called the *no-effect region*, exists for basis weights of 40 g/m^2 and more where no significant change of pressure drop is observed. The web itself is the main source of drainage resistance in the production of heavy basis weight grades. As the flow increases on one side of the web, drainage resistance will increase the drainage rate on the opposite side [4]. In the gap former, there is a linear correlation between web thickness and the centrifugal force in the gap. These higher forces require an increased fabric tension to insure stability as massive amounts of water pass through in a very short period of time [5]. Herzig and Johnson noted in their study that in fast-draining pulp species up to 70% of the total pressure differential measured was due to wire resistance for a 10 g/m^2 basis weight sheet. For slow draining pulps, wire resistance contributed less than 20% at the same basis weight [6].

One interesting phenomenon is that of fabric rigidity in the forming zone and its importance to sheet quality. Rigidity on twin wire formers producing newsprint, which relates to fabric bending, plays a role in eliminating machine direction streaking that can be induced by tension differences across the width of the fabric. Uneven flow from the headbox as the jet smashes into the outer fabric can be a source of problems. The more resistant the fabric is to bending in the CD, the better the chance of producing a well-formed sheet. This fiber-to-jet interaction is very important.

The mixing of air with the white water carried back into the sheet is a source of formation problems. Air disturbing the sheet can result from problems in the delivery system up to the headbox, air carried back into the forming zone with the fabric, or in water handling problems down the table. Several machines have experienced problems with entrained air being carried with the fabric into the forming zone and disrupting the sheet formation. If the blade of the doctor is not properly fitted to a roll surface, whitewater can adhere to the surface of the roll and create air or water spotting on the finished sheet when it moves back into the sheet path [7].

Formation/wire

Why does one fabric with a significantly different fiber support index produce a sheet of similar or even surpassing quality to another given equivalent forming mechanics and furnishes? The answer lies in the forming surface topography and the ability of the support network to hold the sheet up to optimize formation and drainage. The initial drainage is very dependent on the support network. Then, at a transition point, the fiber network becomes more of the limiting factor than is the fabric. The jet impact on the forming surface can have a drastic impact on the MD and CD marking. This is due to fabric constructions, which can be monoplane or offer amplified plane differences depending on the paper properties required. If microtension differences exist across the fabric there is a great propensity for streaking in the base sheet. Weaving issues that cause flow patterns in the base sheet can influence this.

Fiber mat/separation points

For the conventional table, dewatering occurs at a rapid rate, then a slower rate, normally achieved by graduating the vacuum or vacuum effect (i.e.. blade angle) of the drainage elements. Wire moving over the blades generates a pressure pulse that causes shear and turbulence in the forming zone. The dewatering forces on a fourdrinier are pulsating rather than constant. They frequently have a reverse-directional component that tends to wash fines and fillers from the wire-side surface. The effects of dewatering pulses have both positive and negative consequences on paper quality. They remove large scale formation flocks, but at a cost of lower retention levels. For stratified sheets, this also involves a loss in layer purity.

As the web leaves the roll surface, a suction pulse is generated that can affect fiber bleed and separation efficiency. For a given wire tension and deflection, the local pressure event is mainly determined by wire speed, wire separation, and blade shape [8]. In the wire-to-wire and wire-to-felt transfer process, the wire surface must easily release the sheet to reduce fiber carryback. Optimizing the fabric surfaces for ease of transfer, care in set up of the separation angles (3%-5%), and transfer device optimization can effectively reduce fiber carryback.

Base sheet/showering systems

Proper showering is critical to the good formation of the sheet. Typical showering includes the use of flooded nip, knock off, and high pressure showers on both the roll and face sides of the fabric. Several vendors now offer showers that soak the fabric after sheet transfer and then use a blast of air to remove contaminants, fines, and residual water from the fabric. The type of fabric selected must insure that the proper shower water volume is used.

Forming impact on the converting operation

Experience shows that the forming surface topography directly affects fiber orientation, fines retention, and micro-density variations of the base paper. These combine to directly influence formation quality, surface smoothness, stretch, and strength of the paper-tensile ratio. That can carry through to converting operations, affecting sheet runnability, web breakouts, and printing quality, to name just a few. The converting operations efficiency in many instances directly links to paper characteristics developed on the wet end of the paper machine [8].

Drainage/chemical systems

One area of very important development work is the influence of chemicals introduced to the furnish and their interaction with the dewatering elements. The impact on the wire, fiber to fines composition, and impact of microflocks verses macroflocks in the rate of drainage are areas of interest for further study.

CONCLUSION

It is important to develop a balanced understanding of the interactions involved in the wet end dewatering process. As we evaluated how the jet and wire interacts the process team will be better able to meet the challenges of productivity and quality improvements on the paper machine. What was started on the wet end of the paper machine with fabric surface topography, rigidity, and drainage interactions has a significantly effect on the converting operation.

LITERATURE CITED

1. Odell, M.H., Kinnunen, J.S., "Method or Madness?" *Valmet PaperNews*, 14(3): 20(1998).
2. Norman, B., "Hydrodynamic Developments in Twin-Wire Forming – An Overview," Royal Institute of Technology, Conf. Proceedings, 329-339, (1995)
3. Erkkila, A.-L., Pakarinen, P., Odell, M., "The effect of forming mechanisms on layered fiber structure in roll and blade gap forming," *TAPPI 99 Proceedings*, Vol. 2, TAPPI PRESS, Atlanta, Georgia, USA, 1999, pp. 389-400.
4. Halmschlager, G., and Bachler, J, *Pulp Paper Eur.,* 2(2): 16(1997).
5. Jong, J.H., Baines, W.D., Currie, I.G., *J. Pulp Paper Sci.* 25(3): 95(1999).
6. Herzig, R., Johnson, D.B., *TAPPI J.*, 82(1): 226(1999).
7. Kenny, J., *Pulp Paper Intl.* 41(2): 29-30(1999).
8. Norman, B., *Paperi Puu* 78(6-7): 16(1996).

INSIGHTS FROM THE AUTHOR

Many articles and papers have inferred the interaction between the jet with the forming wire, but do not explore it in much detail. I wanted to bring information together for the industry that was useful as an educational tool.

This paper brings together knowledge from several sources. I felt the need to develop the information and personal knowledge into an overview document that could help others understand this topic. I hope it helps to explain and clarify what happens as the web forms into a finished product.

This paper should be useful as a learning tool and refresher on forming zone dynamics and interactions. I hope future documents will provide more detailed information concerning drainage and chemical systems.

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