Fundamental Advances in Pulp Screening Technology

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Abstract

Pulp screening is an essential process in the manufacture of high-quality paper and board products. Screen performance is determined by the screen rotor and cylinder. Both components have been the subject of technical innovation that has led to: reduced power consumption, cleaner accept pulp, increased capacity, and reduced fibre loss. In the case of the rotor, small-scale turbulence and three-dimensional flow structures have been determined to be of at least equal significance to the backflushing effect of the rotor elements. A comprehensive model of the rotor action has been developed to embrace both pulsation and non-pulsation effects. Two novel rotor designs that follow from this model are discussed in the context of mill trials. One is based on a solid-core rotor that has waveform features on the leading edge of the each rotor element. With these features, the rotor is able to achieve higher capacities, or to operate at lower speeds to save energy, or to operate with smaller slots for increased accept cleanliness. The second rotor is a foil-type design that has a thicker foil to increase wake turbulence. Swept foils and supports ensure that strings and other debris do not accumulate on this rotor. The screen cylinder has also benefited from recent innovation. In particular, a novel manufacturing technique has increased both the precision and accuracy of the slot widths which is of critical importance in allowing small slots to be used. Moreover, even for the same slot width, increased precision can provide a 5-point increase in debris removal efficiency. Advanced technology is thus seen to have a powerful impact on screen performance in a wide range of mill applications.

Introduction

Pulp screening is an essential operation in the production of high-value pulp and paper products, and screens are present in virtually all pulp and paper mills. Pulp screens have screen slots as narrow as 0.10 mm and thus are able to remove a high percentage of contaminants that would otherwise reduce paper appearance, strength, and surface quality. Pulp and paper producers have become increasingly reliant on screening because of its reliability, efficiency and low-cost.

Screening is used in all segments of the pulp and paper industry and its importance is increasing because of the increasingly stringent demands for high-quality paper and board products. The challenge of providing increasingly-higher levels of cleanliness is compounded by the increasing quantity and variety of contaminants in recycled paper furnishes.

The basic parameters used to assess pulp screening are:

- Capacity – expressed either in terms of a volumetric or a mass-based flows, i.e. either l/min or t/day;
- Runnability – which is a subjective quantity reflecting the ability of screens to operate reliably even during variations in feed consistency and furnish quality;
- Efficiency – the degree of contaminant removal;
- Power – as consumed by the pulp screen rotor;
- Fiber loss – the amount of desirable fiber rejected by the final stage of the screen system.

The two essential performance components in a pulp screen are the screen cylinder and the screen rotor. The screen cylinder has either holes or slots. “Accept” pulp flows through these apertures and leaves the screen through the accept port, while the oversize contaminants and reject pulp do not pass and exit from the reject port of the screen. The screen rotor backflushes the apertures and clears them of blockages. It also establishes the flow conditions adjacent the screen cylinder surface that supports the screening action.

Screen apertures are intrinsic to overall performance, with aperture size being the primary variable. Narrow slots provide the highest levels of contaminant removal, but also tend to reduce capacity, illustrating a typical trade-off made in optimizing the screen configuration for a particular application. The screening action that blocks the passage of contaminants from the accept pulp can be divided into two fundamental mechanisms: “Barrier screening” prevents the passage of oversize contaminants when they cannot fit through the apertures regardless of their orientation. “Probability screening”, on the other hand, restricts the passage of contaminants that could pass through the apertures if presented in a certain way, but that tend not to pass because their size, shape or stiffness makes it difficult for the contaminants to follow the flow streamlines through the apertures.

Small slots have been made practical through the use of contours on the feed-side of the screen cylinder surface. Contours came into more widespread use in the 1980s and are believed to work by: 1) streamlining the flow through the slot, 2) inducing turbulence to disperse fiber flocs and any fibers that have accumulated at the slot entry, and 3) reducing the potential for fibers to become immobilized at the slot entry. Like slot width, contour height is specified according to the particular application, i.e. considering the feed pulp consistency, pulp character, and the nature of the contaminants.

Improved rotor technology also has the potential to increase screen capacity for a given slot size, or conversely to make smaller apertures possible without a loss of capacity. Power is an additional consideration with rotor technology. The trade-off in some cases then becomes one of power versus capacity (or versus minimum aperture size). There has been great diversity in rotor designs since pressure screens were developed in the 1960s. Four common designs are shown in Figure 1, though well over one hundred rotor designs have been used commercially. Rotors are generally classified as either “open” or “closed” designs. Open rotors have foils, and pulp passes on both sides of these foils. Closed rotors have a cylindrical core that elements are attached to, and pulp passes over the surface of the element adjacent the screen cylinder. In either case, the intent is for the foils or elements to pass within a few millimeters of the cylinder surface and to clear any pulp fibres that have accumulated within the cylinder apertures.

The present study considers three complementary technologies directed to improved screen performance:

- Active-pulse rotor technology The back-flushing pulse induced by the rotor has been cited as the principle rotor action, with both pulse frequency and strength receiving study [1]. More recently, small-scale turbulence and large three-dimensional flow structures have been determined to be of at least equal significance [2]. The present study reviews these fundamental effects and proposes a comprehensive model of the rotor action which embraces both pulsation and non-pulsation effects.
- String-resistantant rotor technology While screening is directed to contaminant removal, a high concentration of contaminants can challenge the operation of the screen itself. Hard, abrasive contaminants can lead to accelerated wear. In response, improved industrial-grade chrome surface treatments have been developed. Stringy contaminants can lead to build-ups on the rotor, which will grow to the point that the accumulated masses can jam between the rotor and screen cylinder. Design features that reduce string accumulation are discussed herein.
- High slot-precision cylinder technology A novel manufacturing technique has increased slot-width precision and accuracy in screen cylinders. This is of critical importance in allowing small slots to be used. Moreover, with the same slot width, increased precision can provide a 5-point increase in debris removal efficiency.

Figure 1. Some different rotor designs have come into use since pressure screens were introduced in the 1960s including: a) the “bump-type” rotor from the 1960s, b) the “stud-and-nut” foil rotor (1970s), c) a “modified bump” rotor (1990s), and d) a cantilever foil rotor (2000’s).

The goal of the rotor is simple: to maximize screen capacity and promote the passage of fibres through the screen slots. The action of the rotor is, however, somewhat complex, combining several essential mechanims. The relative role of each mechanism will vary according to the rotor design and its rotational speed:

Backflushing Pulses The backflushing pulses developed by the screen rotor are derived from a decrease in pressure as the fluid (i.e. the pulp) accelerates through the gap between the rotor tip and the feed-side of the screen cylinder. This well-known fluid mechanics phenomenon is commonly called a “Venturi” or “Bernoulli Effect” [1,2]. Between pulsations, the flow through the screen apertures is driven by the pressure drop from the feed to the accept side of the cylinder. With the passage of the rotor foil or element, the pressure on the feed side of the cylinder decreases to the extent that the flow will temporarily reverse direction and pass from the accept to the feed side of the cylinder. This causes a backflushing flow through the cylinder apertures and the removal of any fibres or other material that has accumulated with the aperture entry [3]. Smaller clearances between the cylinder and rotor, and increased rotor speeds will increase this effect [4].

Fluid Activity Large and small-scale turbulence and other forms of fluid “activity” are also important in the removal of incipient fibre accumulations within the apertures. Fibres may have become immobilized at the slot entry by a flow bifurcation that leads to fibre “trapping” [5]. High-frequency flow variability at the aperture entry will destabilize the balance of forces inherent to fibre trapping and prevent a significant accumulation of fibres. The bump rotor (Figure 1a) is an example of a rotor that relies more on fluid activity than outright pulsations / flow reversals given that the “land area” of each bump facing the cylinder is relatively small. The arrangement of elements and their shapes has been used to develop fluid activity, as seen in the modified bump rotor (Figure 1c).

Flow Field Development The “screening zone” of pulp screen is defined as the annular space between the rotor and screen cylinder. If the rotor did not turn, flow would enter one end of the screening zone and pass axially through the screening zone, with the axial velocity (i.e. the velocity upstream of an aperture) decreasing steadily as flow as drawn off through the screen cylinder. The screen rotor, however, induces a largely circumferential flow within the annular screening zone. Thus flow upstream of an aperture is relatively uniform through the length of the screening zone, even as the accept flow is drawn off, because the upstream flow is a vector sum which is dominated by the circumferential flow component. The rotor thus provides an easily-controlled, relatively uniform , high-speed flow field ahead of the apertures which is critical to the preferential passage of fibres to contaminants [6].

Reject Zone Pressurization While the screen rotor provides a relatively uniform flow field through the screening zone, the nature of screening flows causes water to flow more easily through apertures than fibres. Pulp consistency thus increases axially as the flow spirals towards the reject end of the screening zone [7]. Higher consistencies will lead to the increased accumulation of fibres within the apertures between backflush pulses. Anecdotal evidence suggests that most of the accept flow passes through the cylinder in the first third of the screening zone. Thus, overall capacity is limited by not making full use of the remaining two-thirds of the cylinder. The AFT GHC™ Rotor solves this problem by using angled rotor elements to pressurize the reject-end of the screening zone, which leads to increased flow through the latter two-thirds of the cylinder apertures and, in effect, a more balanced flow and increased overall capacity [8]. Alternatively, instead of increased capacity, a smaller slot can be used for a higher degree of contaminant removal. In a third approach using the GHC Rotor technology, rotor speed can be reduced without a loss of capacity. Reduced rotor speed is also supported by the use of an optimized element cross-section in the GHC Rotor design [9]. Power savings in excess of 30% were found relative to some of the older rotor designs shown in Figure 1.

Active-Pulse Rotor Technology: AFT GHC2™ Rotor

Many rotors have been developed to accentuate the strength of the pressure pulsation for increased backflushing, or to streamline the rotor elements for reduced power consumption. Certain other rotors have attempted to induce “fluid action” or wake turbulence to reduce any fibre accumulations with the apertures between pulsations, as discussed above. The use of angled elements to pressurize the reject-end of the screening zone and thus to enhance screen performance has proved to be successful, as shown in the GHC Rotor [8].

The AFT GHC2 Rotor was developed to combine all three of the rotor mechanisms to further enhance pulp screen performance. As with the original GHC Rotor, the GHC2 element has a cross-section that has been optimized to provide a strong suction pulse with minimal fluid drag (i.e. minimal power consumption). Similarly, the angled elements pressurize the reject end of the screening zone to balance the accept flow and maximize capacity. What is distinctive with the GHC2 design, however, is the presence of a waveform on the leading edge of the rotor elements, as shown in Figure 2. The streamtubes shown in Figure 2a were generated using computational fluid mechanics, and show how the flow over the element is disturbed by the waveform on the leading edge, which has a commercial name of PowerEdge™. Fluid activity is thus introduced simoultaneously with the pressure pulse for maximum effect and the activity persists in the wake of the element.

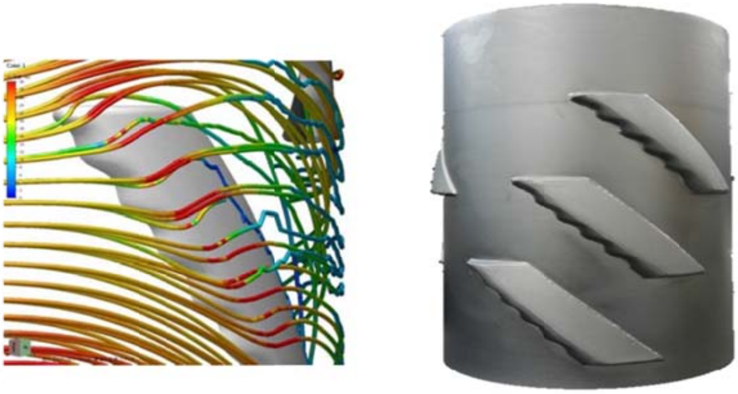

Figure 2. The AFT GHC2™ Rotor features PowerEdge™ technology. The image on the left (a) shows streamtubes passing over the element and demonstrates fluid action. Colour-coding shows velocity. The full rotor is shown on the left (b).

Increased fluid activity is the primary benefit of the PowerEdge, but Figure 2a also indicates that the impinging flow tends to be channelled towards the “valleys” of the PowerEdge feature. It would follow from the physics of the Bernoulli Effect, that a higher local velocity would be reflected in a lower pressure – and stronger suction pulse.

Pilot Plant Tests

To evaluate the effect of the PowerEdge feature on the suction pulse, GHC and GHC2 rotors were tested in an Aikawa Model 400 pilot plant screen (400 mm cylinder diameter; 498 mm cylinder height). A pressure transducer was installed on the cylinder surface. The pressure pulse traces shown in Figure 3 indicate that the PowerEdge feature led to an approximately 50% increase in the suction pulse at the same rotor speed.

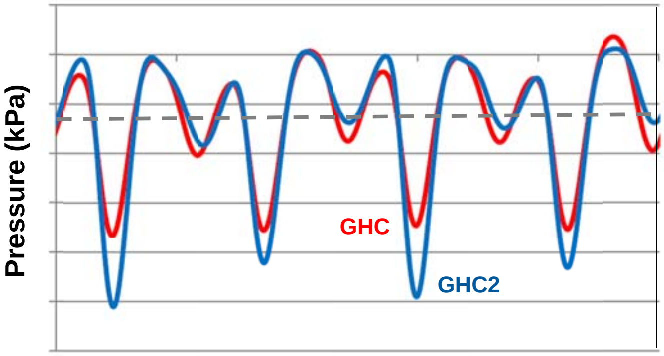

Figure 3. Pressure pulse traces taken on the inside cylinder surface. Each rotor had two rows of two elements, thus four rotor pulses represent two rotations of the rotor. The smaller pulses represent disturbances from the adjacent row of elements. The GHC2 Rotor provided a ~50% increase in suction pulse.

The same pilot plant trials showed that the GHC2 Rotor consumed slightly less power than the GHC Rotor, as shown in Figure 4. More significantly, the GHC2 Rotor is able to operate at a minimum rotor speed of about 2 m/s less than the GHC Rotor, leading to an energy saving of about 30%. Even greater savings can be obtained in comparison to competitor and other older-generation designs, where power savings can reach 50%, as shown in Figure 4.

Another importanf finding from the pilot plant tests was that reject thickening (i.e. the reject consistency divided by the feed consistency) was ~0.4 less with the GHC2 Rotor than with the GHC Rotor. The reduced level of thickening reflects the more effective removal of fibre accumulations from the cylinder apertures. Reduced thickening is associated with improved screen runnability and is especially important for screens opeating at high feed consistency. The promising pilot plant results led to a program of trials in a range of mill applications.

Mill Case Study No. 1

The GHC2 Rotor was installed in an eastern-Canadian bleached kraft mill. In particular, the rotor was installed in an Ingersoll-Rand Model 210 primary screen with a feed consistency of 2.0%. A variable-frequency drive was installed to explore the minimum operating speed.

By virtue of being able to operate at ~2 m/s lower minimum rotor speed, the GHC2 Rotor provided a 22% power saving relative to the benchmark GHC Rotor, with both rotors being optimized for minimum speed. The mill also benchmarked the GHC2 Rotor performance against some competitor rotors, at their existing speeds, and found:

- 58% power saving versus Competitor Rotor No. 1
- 55% power saving versus Competitor Rotor No. 2
- 46% power saving versus Competitor Rotor No. 3

The pulp furnish at this mill is quite abrasive with cylinder lifetimes of under one year. The PowerEdge feature also appeared to help reduce cylinder wear. While cylinders typically show high wear near the reject end of the screening zone, the cylinders run with the GHC2 showed a more even top-to-bottom wear pattern -- even when operated at a relatively high speed of 29 m/s. Moreover, when the GHC2 is operated at a lower rotor speed, one reduces both the frequency and energy of the abrasive impacts to further reduce wear. Impact energy is proprotional to the square of tip speed.

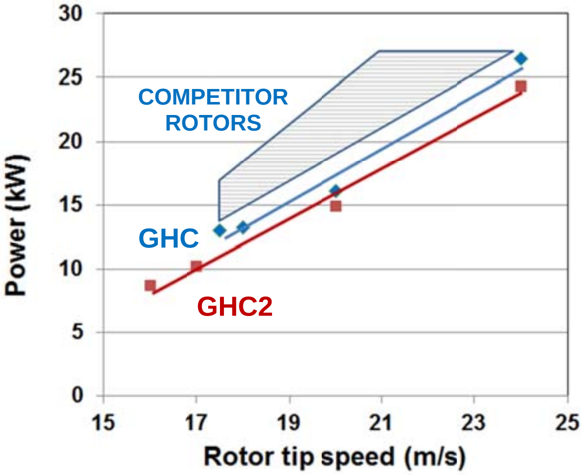

Figure 4. The superior energy savings available from the GHC2 Rotor are shown to be derived from both: 1) a reduction in power at a given rotor tip speed ("Drop-In Savings") and 2) the ability to operate reliabily at lower rotor tip speeds ("Slow-Down Savings"). Significant savings are seen against the GHC Rotor, but much greater savings are found against older-style competitor rotors.

Mill Case Study No. 2

A second mill case study was made at a Central European deinked pulp mill. In this case, the GHC2 Rotor was installed in a primary Voith MSS 10/06 primary pulp screens with a 0.20 mm slot width and 0.6 m/s slot velocity. The feed consistency was 3.4% and the volumetric reject rate was 25%. An original equipment manufacturer (OEM) rotor was operated in a parallel primary screen with a comparable screen cylinder. The study showed:

- 14% less power was consumed by the AFT GHC2 Rotor relative to the OEM rotor at the same rotor tip speed of 18 m/s;
- the full mill production could be handled by a single screen equiped with a GHC2 Rotor operating at a tip speed of 18 m/s, enabling the second screen to be shut down and thus saving 43% in energy costs as well as additional maintenance costs;
- stickies removal increased by 8 percentage points for the screen equipped with the AFT GHC2 Rotor relative to the OEM rotor at the same nominal mill operating conditions (including equivalent mass reject rates).

GHC2 Applications

The GHC2 has been installed in a range of mill applications including OCC, kraft and deink pulp mills including screens as large as the M1600 Centrisorter (~1.2 m diameter). Some selected installations are shown in Table 1.

Table 1. Selected GHC2 installations.

Country	Furnish	Position	Screen Model	Principal Benefits
Canada	SWK	Primary	IR 210	22% energy savings
Finland	HWK	Primary	Ahlrstrom M1600	33% energy savings
Finland	SWK	Secondary	Ahlstrom M800	Reduced dP by 12 kPa
Germany	DIP	Primary	Voith MSS 10/06	43% energy savings
USA	SWK	Primary	IR 212	Improved runnability
Canada	OCC	Primary	KBC PS30	Increased capacity by 15%
Finland	SWK	Primary	Ahlstrom F6R	20% energy savings Increased efficiency[1]
Finland	SWK	Secondary	Ahlstrom F4	27% energy savings Increased efficiency[2]
Finland	SWK	Tertiary	Ahlstrom F2	9% energy savings

[1] Reduced slot width from 0.27 mm to 0.20 mm.
[2] Reduced slot width from 0.30 mm to 0.20 mm

Some general guidelines ave been developed from mill studies and pilot plant work to understand how the GHC2 benefits mill operations. Table 2 summarizes these benefits relative to the performance of AFT's GHC Rotor under two possible scenarios: one where the mill simply substitutes the rotor at the same operating speed, and the other where the rotor tip speed is decreased by 2 m/s to take advantage of the GHC2 Rotor's more effective rotor action. Thus one can, for example, obtain an ~30% power savings from a lower tip speed, or substantially increase debris removal possible by operating with a smaller slot, as two of the many possible strategies available by using a GHC2 Rotor with PowerEdge technology.

Table 2. Benefits obtained the the GHC2 Rotor relative to the GHC Rotor under two possible operating scenarios.

	Same Tip Speed	2 m/s Lower Tip Speed
Energy	~	30% less
Thickening Factor	0.4 less	0.2 less
Cylinder / Rotor Lifetime	=	~ 20 to 30% longer
Pressure Differential	7 kPa less	=
Maximum Slot Velocity	20% higher	10% higher
Maximum Feed Consistency	0.5% higher	=
Debris Removal Efficiency[1]	=	=
Debris Removal Efficiency (using smaller slots)	substantially higher	higher

[1] at the same mass reject rate

String-Resistant Rotor Technology: AFT EPX™ Rotor

As the world's largest supplier of performance components for pulp screens, AFT offers a range of designs to suit the particular needs of pulp mills globally. Mills typically use a foil-type (open) rotor in screens located immediately upstream of the papermachine. This minimizes the possibilty of pressure pulsations from the screen passing to the headbox, which would result in basis weight variations. Certain mills use the same screen for fine screening of the pulp. If this pulp is heavily contaminanted with debris and stringy contaminants, operating problems can result. Traditional foil-type rotors offer a number of surfaces where strings can accumulate and build up, including on the foils themselves. In some mills, the accumulation of the debris can be significant, as shown in Figure 5, and the contaminants will jam between the rotor and cylinder, causing the screen to stop.

Figure 5. Stringy contaminants can hang up on the rotor foils and form into larger clumps which have the potential to jam between the cylinder and rotor.

The AFT EPX™ Rotor was developed specifically for such difficult applications and its key features are shown in Figure 6. The EPX Rotor is a foil-type rotor so as to minimize any pressure pulsations that could be transmitted downstream, as discussed previously. The thick foil cross-section provides effective pulsations and wake turbulence to clear any accumulated fibres from the screen apertures. The foils are staggered to distribute stresses on the screen cylinder and to develop some degree of fluid action.

The “swept” features of the EPX Rotor are distinctive and are particularly important to ensuring the good runnabilty of this rotor with highly-contaminated furnishes. The foil itself is inclined relative to the rotor axis so that any strings that impinge on the foil edge will slide along the foil and be released from the end of the foil. The support arms for the foils are set at an angle of 105 degrees from the rotor core as shown in Figure 6. Strings that impinge on the support arms will likewise move along the arm and be released. In this way, there are no locations for strings to build up on the rotor.

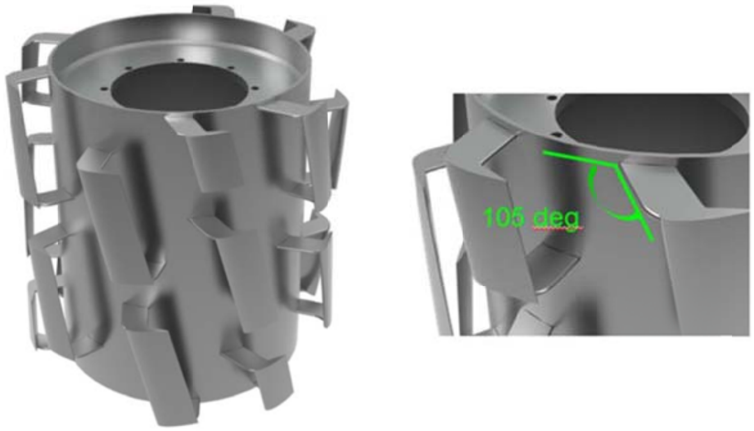

Figure 6. AFT’s EPX Rotor (above left), features swept foils and support arms (above right) ensure there are no sites for strings or other debris to accumulate.

An accurate rotor-cylinder clearance is provided by the dual-arm system for supporting the rotor foils. The backflushing pulse created by the rotor foil will be significantly diminished by an excessively large gap [4]. Measurements of the clearance in an industrial screen (Figure 7) show that the EPX Rotor has rotor-cylinder clearances consistently between 2.5 and 3.5 mm. In contrast, clearances for an older-style OEM rotor were measured in the same screen and found to range from 1.5 to 7.0 mm. These large clearances would lead to a greatly diminished backflushing action. There are anecdotal reports of cylinders becoming plugged in regions that correspond to the location of these large clearances.

The EPX Rotor has proven successful in solving plugging and runnability problems in a number of mills, as demonstrated by the following example:

Mill Case Study No. 3

The AFT EPX Rotor was installed at in a Metso TL450 primary headbox screen in a European OCC mill. The feed consistency was 1.3% and the screen cylinder had 0.15 mm slots. The screen had previously been operating with an OEM Helical Foil Rotor, but had suffered for a number of years with plugging problems and a high feed-accept pressure differential. Installation of the AFT EPX Rotor elminated the stringing and plugging problems. Pressure differential decreased. The mill is now able to run the screen reliably and without interruption. The mill also reported improved top-layer cleanliness.

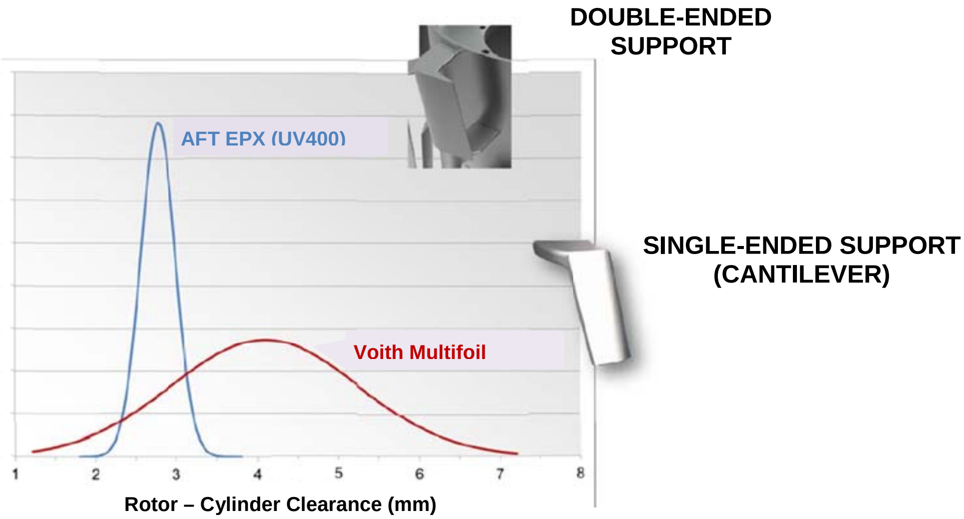

Figure 7. The double-ended support for the screen foil in the AFT EPX Rotor led to a more consistent rotor-cylinder clearance than the single-ended support found in a competitor rotor. A more consistent clearance leads to a more consistent and effective rotor pulse and better screen runnability.

<u>High Slot-Precision Cylinder Technology: AFT MacroFlow2</u>

Enhanced slot precision significantly benefits screen performance. Traditional manufacturing processes use welds, glue, riveting or rolling to connect the wires to the support structure. The standard deviation of slot widths is typically in the range of 10 to 15 microns. More advanced manufacturing techniques, with state-of-the-art laser cutting, cylinders made in-the-round, and novel wire-ring locking techniques have reduced the standard deviation below 10 microns. The AFT MacroFlow2 cylinder (Figure 8) is an example of this.

Great care is taken in selecting the appropriate slot width and contour type. Some individual wires are shown in Figure 9, with their shape defining the contour and the minimum spacing between them defining the slot. Slot width is typically specified as small as possible, and thus to have the highest level of debris removal while still providing adequate screen capacity. Increased slot width variability will lead to more undersized and oversized slots. Undersized slots will tend to plug with pulp, causing a reduction of screen capacity – or alternatively, the possibility of undersized slots will lead to a larger-than-ideal slot being specified to avoid the critical loss of capacity. More oversized slots increase the possibilities for contaminants to pass through the screen cylinder and into the accept pulp.

Screen cylinders are typically designed with all the slots having the same width. Some variation in slot width exists, however, and it comes from a range of sources: The wedgewires themselves are typically formed by a rolling process and can vary slightly in width. The methods used to install wedgewires in the support rings during cylinder manufacture will also lead to some slot width variation. For example, the process of cutting notches in the support rings is, to some degree, imperfect whether it is based on lasers or machine tools. Applying a layer of glue (also known as “metal bonding”) will introduce variability. In constructions where the wires are welded to support rings, the heat of welding will introduce additional variability into the wire spacing and slot width. Some designs involve cutting the notches and installing the wires while the screening “mat” is flat and additional variability is introduced when the mat of the wires and support structure is rolled into a cylinder. Also, even after the cylinder in installed in the mill process, contaminants such as glass and sand can erode the slot width and lead to not only wider slots but also more variable slot widths, with both factors leading to reduced screen efficiency.

Figure 8. The AFT MacroFlow2 wedgewire cylinder is shown on the left, with a series of support rings holding the wedge wires that define the slots. A close-up of the interior (feed-side) of the cylinder is at the right.

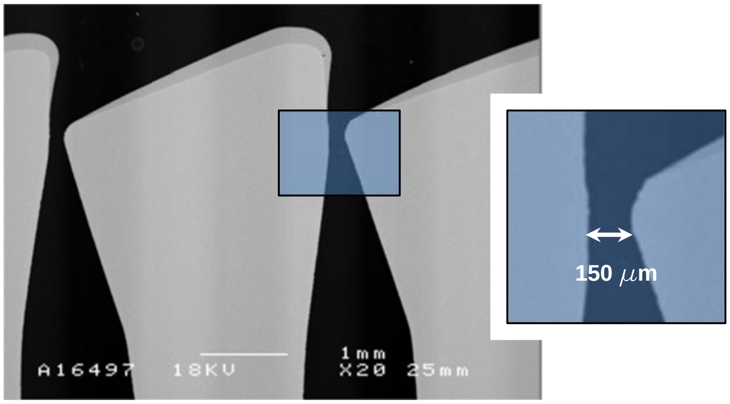

Figure 9. Close-up images of individual wire cross-sections. Two slots are shown in the image on the left and the close-up of a single slot is shown in the inset at the right. A layer of chrome is apparent on the top of the wire, which has been applied for wear protection. The nominal slot width is 150 μm, which is defined by the minimum width in the “throat” of the slot.

The variation of slot width can be expressed as a normal (i.e. Gaussian) distribution which is characterized by a mean (*w*) and standard deviation (σ) with 95% of slot widths falling within a range of $\pm 2\sigma$ of the mean. Some typical slot width distributions are shown in Figure 10 which demonstrate the practical impact of variations in the mean (accuracy) and standard deviation (precision). A measure of accuracy is given as μ^*, which is the difference between the target width and the mean. Cylinder A has a mean of 135 μm, which is 15 μm below the target slot width of 150 μm (mediocre accuracy) and has slot widths ranging mainly from 105 to 165 μm (mediocre precision). Some of the slots in Cylinder A are so small that they may be prone to blinding. Cylinder B represents something close to an ideal slot width distribution, with excellent accuracy (its mean matches the 150 micron target) and very good precision, with the range of slot width extending from about 110 to 150 μm. Cylinder C is the worst of the three cylinders with poor accuracy ($\mu^* = 25$ μm) and precision ($\sigma = 25$ μm).

Table 3 provides a summary of some brochure claims and actual measurements made for a number of industrial screen cylinders. Limitations in traditional manufacturing processes, based on the use of welds, glue or rolling, will commonly lead to standard deviations of about 15 μm. Some inexpensive, commodity-grade cylinders have even higher levels of standard deviation. Conversely, more advanced manufacturing techniques, with state-of-the-art laser cutting, cylinders made in-the-round, and novel wire-ring locking techniques, as seen in MacroFlow2 have reduced variability in slot width to standard deviation values below 10 μm.

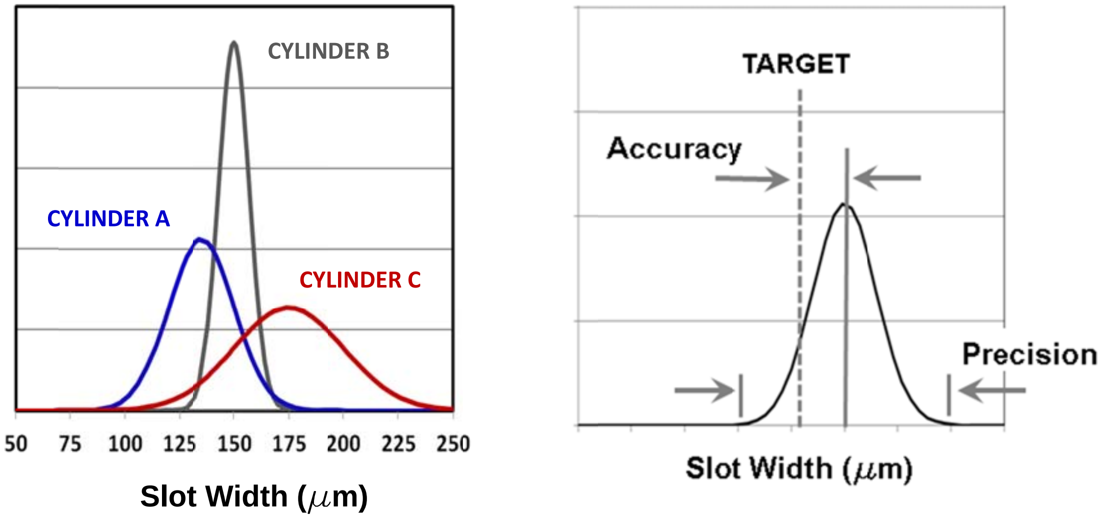

Figure 10. Slot size distribution for three cylinders (left): Cylinder B is close to the ideal (μ^* = 0 μm; σ = 7 μm), while Cylinders A (μ^* = *-15 μm;* σ = 15 μm) and C (μ^* = 25 μm; σ = 25 μm) suffer from poor accuracy and precision. The concepts of accuracy and precision are shown in the figure on the right.

Table 3. Slot width precision for some industrial screen cylinders.

Manufacturer	Advertised Standard Deviation	Measured Standard Deviation
Advanced Wedgewire	-	8 μm
Conventional Rolled Wedgewire	10 – 14 μm	15 – 20 μm
Conventional Riveted Wedgewire	10 μm	10 – 16 μm
Clamped Wedgewire	12 μm	14 μm
Conventional Notch Welded Wedgewire	12 μm	15 μm
Low-End Wedgewire	-	20 μm

It is self-evident that increased slot width variability and more oversize slots will lead to more oversize contaminants passing to the screen accepts and a decrease in contaminant removal efficiency. The more substantial issue is the quantitative relationship between slot precision and debris removal efficiency, which was the subject of a study by Gooding *et al.* [10]. The first part of the study was theoretical. Contaminant and fibre size distributions were each modelled by log-normal distributions. The analysis assumed:

- Slot velocity is equal for all slots; flow through each slot is proportional to its width.
- Very small slots will plug, which follows on the assumption that the nominal slot width was chosen to be as small as possible to achieve the greatest efficiency.
- The "plug-flow model" [7] applies to flow though the screen, which predicts axial changes in debris levels, consistency, fibre length distribution, etc.
- The likelihood of contaminants passing through a particular slot is proportional to the amount of flow through that slot and thus to the width of the particular slot.
- Contaminant removal is determined only by barrier screening. Passage is thus determined by a simple comparison of contaminant size to slot width.
- Fibre passage is determined by probability screening. Since slot velocity and the upstream velocity (driven by the rotor) is the same in all slots, passage varies only with fiber length and slot width.

Contaminants and slots both have a range of contaminant sizes (*x*) and slot widths (*w*). Efficiency and consistency changes (e.g. thickening factor) are calculated by integrating the distributions over all particle-size classes and slot widths. The benefit of improved slot precision is shown in Figure 11, which shows the increase in efficiency with reduced standard deviation. A low-end cylinder with a standard deviation of 20 microns has a debris removal efficiency of 75%. Reducing the standard deviation to 15 microns (representative of a typical wedgewire cylinder circa 2010) increases efficiency to 81%. A further increase in efficiency, to 86%, comes from the use of a state-of-the-art cylinder, such as the AFT MacroFlow2 with a 7 micron standard deviation. Thus one sees the potential for an improvement of 5 percentage points in efficiency by increasing slot precision.

An experimental study, using a small industrial pulp screen in a pilot plant setting, was made to confirm the theoretical analysis. Two screen cylinder configurations, which varied in slot precision, were tested to see how improved slot precision would affect screen performance, and in particular the thickening factor and contaminant removal efficiency.

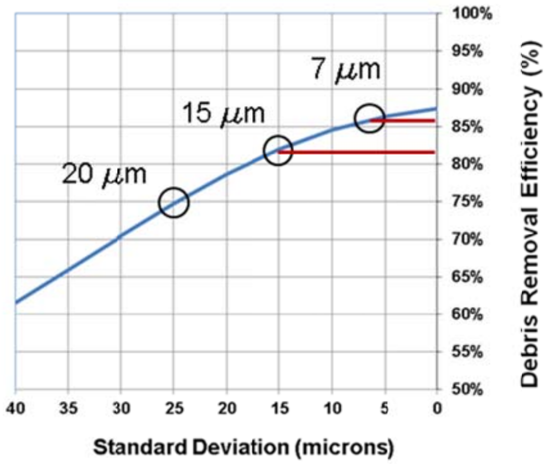

Figure 11. A theoretical assessment of slot precision (i.e. standard deviation) on contaminant removal efficiency for a range of slot widths. The contaminant size distribution has a mean of 175 μm and standard deviation of 40 μm.

Tests were made using a Beloit MR-8 pulp screen at the Pulp and Paper Centre of The University of British Columbia. The furnish for the trial was a 50-50 blend of reslushed market hardwood and softwood kraft pulps with a length-weighted average fiber length of 1.43 mm. The feed consistency to the pulp screen was 1%. Pulp was seeded with black polyethylene specks that had passed through 0.3 mm (300 μm) wide openings.

An AFT EP™ Rotor was operated at a tip speed of 12 m/s in these trials. Two cylinder configurations were created from a single cylinder that had a 0.15 mm nominal slot width, 3.2

mm wire width and 0.9 mm contour height. The initial slot width distribution had a standard deviation of 12 μm. Following a first trial, the slot width distribution was made worse by hammering a wedge into a specific number of slots causing the wires to deform, increasing the width of the wedged slot, and reducing slot width in the two adjacent slots. The standard deviation of the slot width distribution thus became 21 μm. This approach ensured that the average slot width, the wire shape and total open area remained exactly the same. A second trial was then run with the modified cylinder.

For each trial, the slot velocity was maintained at 1.0 m/s. Feed, accept and reject pulp samples were collected at four volumetric reject ratios (20%, 30%, 40%, 50%) for consistency and contaminant testing. Contaminant measurements were made by preparing handsheets and using image analysis to determine the number and size of contaminants.

Consistent with theoretical estimates, thickening factor was not much affected by the change in standard deviation. The impact on screen efficiency is shown in Figure 12. Accurate measurements of contaminant levels are difficult to obtain – even in pilot plant settings with artificial contaminants seeded into the pulp. To deal with the variability, the approach taken in this study was to make measurements at a series of reject ratios and to fit a curve to the data using a “least-squared” method and a curve form based on the plug-flow model:

$$E = R_M^{\frac{P_c}{P_p}} = R_V^{P_c}$$

where E is efficiency, R_M and R_V are mass and volumetric reject ratios, and P_C and P_P are the passage ratios for contaminants and pulp [7].

As expected, the screen cylinder configuration with the lower amount of slot width variability was found to have the higher contaminant removal efficiency. At a typical reject ratio of 25%, the benefit of the improved slot precision is seen to be 8 percentage points, which is consistent with the theoretical estimates shown in Figure 11.

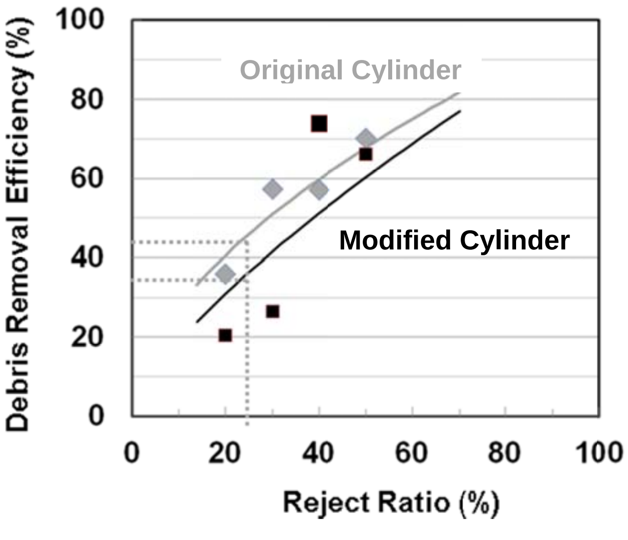

Figure 12. The impact of improved slot precision on debris removal efficiency, with the original cylinder (σ = 12 μm) having about 8 percentage points higher efficiency than the modified (σ = 22 mm) cylinder.

The findings provide clear and quantitative evidence of the value of improved slot precision, with advanced screen cylinder construction, such as the AFT MacroFlow2, providing an improvement in contaminant removal efficiency of about 5 percentage points without compromising capacity or any other screen performance parameter.

Conclusions

The AFT GHC2 Rotor, EPX Rotor and MacroFlow2 cylinder represent examples of how advanced technology can be used to enhance screen operation. The GHC2 Rotor is of general use. It can be used to provide reduced power, increased contaminant removal and higher capacity. The EPX Rotor is designed to enable good runnability with highly-contaminated furnishes that require a foil-type rotor. The MacroFlow2 cylinder provides more uniform slot widths, which benefits contaminant removal efficiency without compromising capacity. This equipment reflects the ongoing application of theoretical tools, plus practical mill knowledge, to develop technology that improves pulp screen systems.

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