APPROACH-FLOW STABILITY

Monitoring the stability of a paper machine

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ABSTRACT

Product variation is a source of problems ranging from out-of-spec production to web breaks and machine downtime. The stability of the paper machine's approach-flow system is key to reducing product variation. Thick-stock feed to the approach-flow system is regulated by the basis-weight valve, which is also sensitive to changes in retention on the former. Because variations in the rate of thick-stock flow lead to system variations, it should be possible to monitor paper-machine stability by tracking changes in thick-stock flow. The utility of the proposed method is illustrated using raw data from mill control systems. Potential use of the method in statistical process control is also discussed.

Application:

This paper suggests a method paper machine operators might use to monitor and perhaps improve system stability and product consistency.

With the market demanding greater product consistency each day, papermachine operators are being forced to review all operational practices in an effort to weed out chronic system upsets and maximize machine uptime. One of the keys to a successful review of system practices is an understanding of "system stability."

This paper presents a concept of system stability for a papermaking process, details the elements of the system that determine its stability, and suggests a means of measuring stability.

BACKGROUND

This study was carried out under the aegis of an *ad hoc* subcommittee of the Papermakers Committee of the TAPPI Paper and Board Manufacture Division. The subcommittee was formed in response to the paper industry's long struggle to monitor operations and improve product consistency, as well as its need to find ways to ensure that paper-machine trials produce valid results. The subcommittee had two principal objectives.

1. Define the term "stable" in the context of paper-machine operations.

2. Develop a means of monitoring a paper-machine system with the ultimate goal of quantifying the system's stability.

Knowing that product variations are linked to approach-flow stability, the subcommittee began to look for indicators that could be used to monitor and ensure the stability of a paper machine, thus minimizing web breaks and production of off-specification paper. The subcommittee began with the premise that the adjustment of the basis-weight valve per unit time is an accurate indicator of a system's stability, since it monitors the approach flow and is sensitive to changes in retention on the former.

The following discussion shows how this premise is supported by mill data. The impact of this approach on the statistical process control (SPC) system is also discussed.

DEFINING "STABILITY"

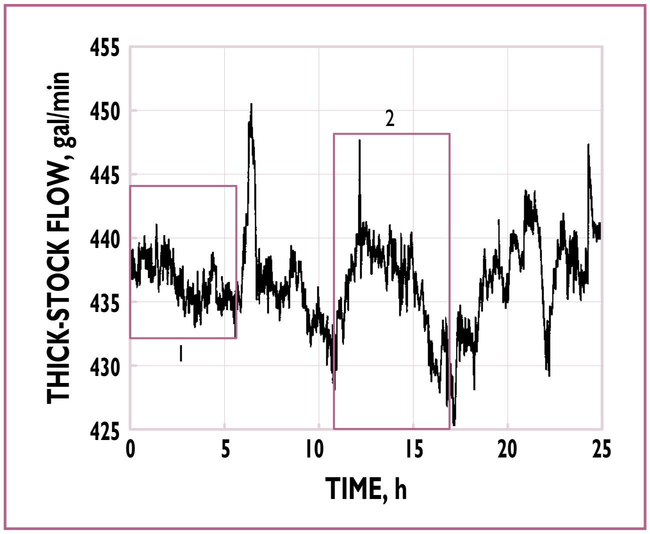
Thick-stock flow rate

The amount of thick stock passing through the fan pump from the machine chest and stuffbox is controlled by the basis-weight gauge at the reel. The stuffbox flow rate is regulated by the basis-weight valve, which is varied to maintain as constant a basis weight as possible.

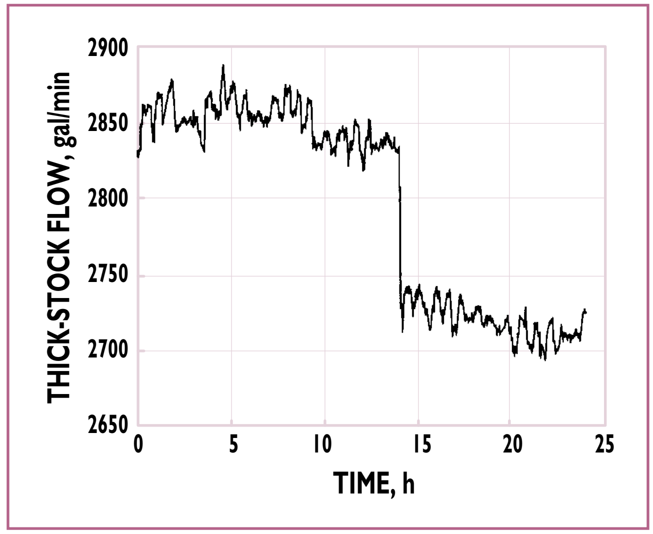
The feedback loop between adjustment of the basis-weight valve and the subsequent measurement of basis weight downstream at the reel is on the order of 2 min for a typical paper machine. This creates a discrepancy between the measured consistency and the actual consistency of the stock coming into the basis-weight valve. This discrepancy is an inherent source of variability in the product, and the variability is at a minimum when the relationship between measured and actual consistency remains stable. However, any change in stock quality—fines content, ratio of furnish components, or the level of refining and quality of individual furnish components—will change the relationship between the measured consistency and the actual consistency. The central point of the current work is to demonstrate that by monitoring the pattern of this change, it is possible to monitor system stability and to determine which element in the furnish is changing.

The thick-stock flow rate required to maintain constant basis weight at the reel at constant speed is determined by

1. Retention, which is a charcteristic of both the chemistry of the system and the fines ontent of the furnish coming onto the former of the paper machine.



1. Run chart showing change in thick-stock flow in response to fluctuation in quality of stock from high-density storage

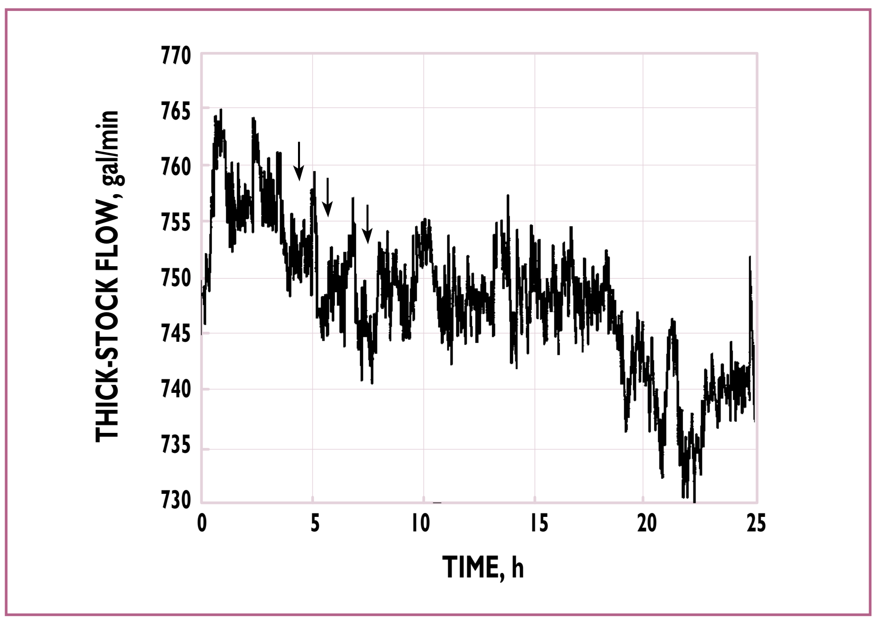


2. Run chart showing change in thick-stock flow in response to "chest height bouncing," i.e., a change in the ratio of furnish elements

2. The actual consistency of the stock coming into the basis-weight valve, as opposed to the measured consistency.

System-specific white-water balances, as they relate to the fresh-water addition and the clarity of the sewered excess white water, will have some control on the chemistry and on the fines in the system. They also impact on system "glitches" (unexplained rapid swings in the thick-stock flow rate).

The variation in system fines will cause swings in drainage and in the "compactibility" of the web in the press section. Quality variations in the furnish and in the ratio of the elements in the final furnish also have an impact on drainage, strength, and the structure of the final product (i.e., the size of the pores in the paper and thus sizing requirements). Thus, variations in the thick-stock flow rate will lead to system variations, and as a result, are a measure of the stability of a system.

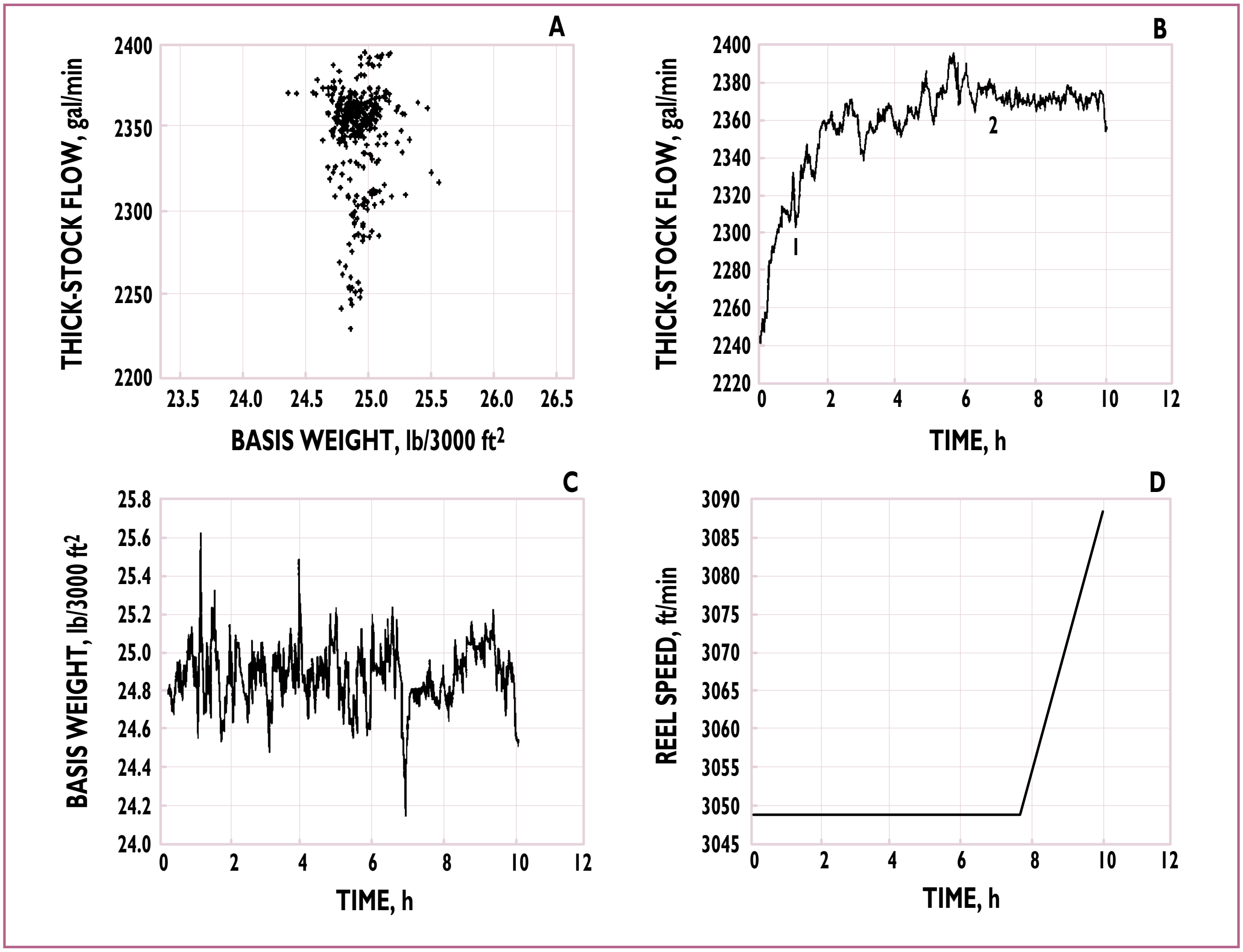


3. Run chart showing drop in thick-stock flow when retention-aid dosage is increased (arrows indicate time of addition)

Attention to detail will minimize variations. Even the simple addition of intermittent fresh-water showering can increase the amount of fines sewered by increasing the system's excess white water. Yet attention to such subtle stability details are often overlooked. While these topics are beyond the scope of this paper, they are critical to understanding the concept of stability and give us the keys to improving the stability cycles of the paper mill.

Previous work

Mardon examined a specific system and defined the major cycles controlling both the quality and quantity of the stock coming into the fan pump *(1–3)*. These included:



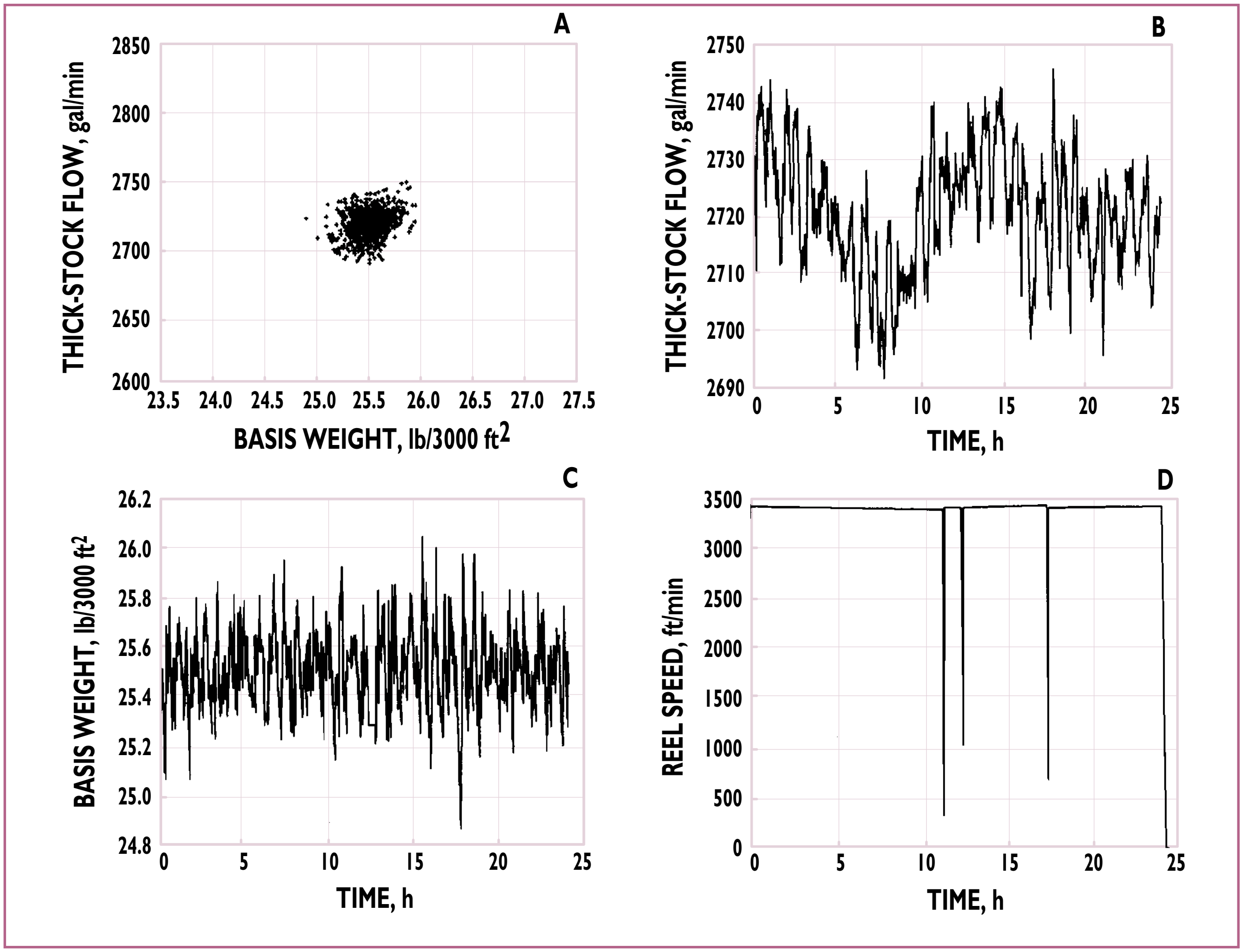
4. Run 1–(A) thick-stock flow as a function of basis weight, (B) change in thick-stock flow over time, (C) change in basis weight over time, and (D) change in reel speed over time

1. The quality of the furnish elements. Variation in furnish quality tended to have a 2–3-h cycle, depending on production rate and on the capacity of the digester and outside pulpers. With a continuous digester, the 2–3-h pattern would probably change. Two good examples illustrating how a quality shift in a furnish element affects thick-stock flow rate are shown in the boxed areas of the run chart in **Fig. 1**.

2. The ratio of the furnish elements. This is related to a phenomenon known as "chest-height bouncing" and tended to follow a 30–40-min cycle. Mardon found that this cycle was related to the distance between the probes in stock chests and occurs primarily where the amount of stock coming from an individual stock chest is rpm-controlled rather than flow controlled. An example of this "chest-height bouncing" cycle on the thick-stock flow rate is illustrated in the run chart shown in **Fig. 2**.

Variations in thick-stock flow rate revealed the effect of furnish quality on the stability of a given system. By SPC standards, the greater the three-sigma variation of the thick-stock flow rate, the less stable is the paper-machine system.

System stability also is related to the white-water loop's retention of fines and filler over time. Changes in retention caused a shift in the long-term (4 h or more) thick-stock flow rate. The "retention shift" is normally seen as a change in the slope of thick-stock flow in a run chart, as seen in **Fig. 3**, which shows a drop in thick-stock flow when retention



5. Run 2–(A) thick-stock flow as a function of basis weight, (B) change in thick-stock flow over time, (C) change in basis weight over time, and (D) change in reel speed over time

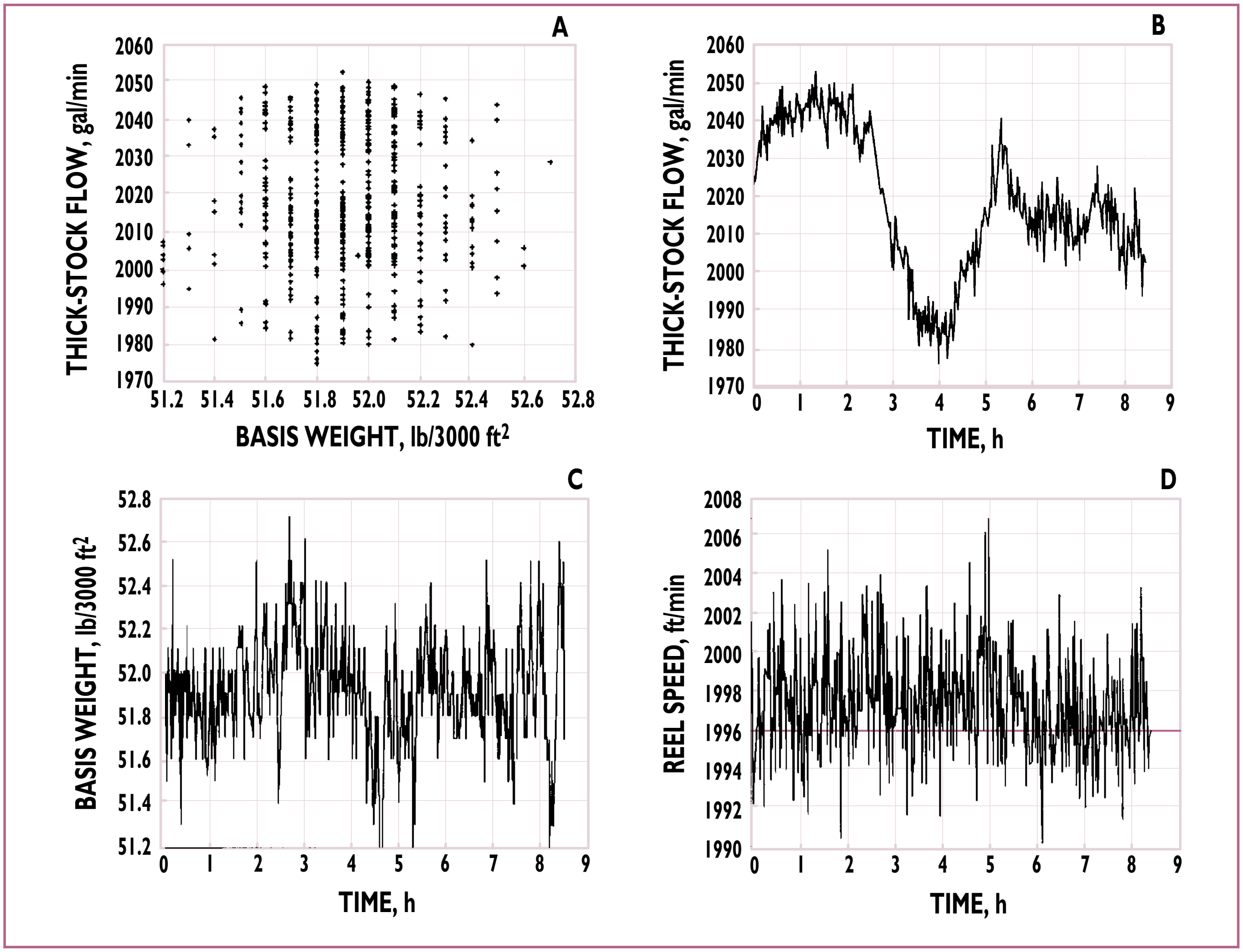
aids trigger an increase in first-pass retention. The arrows in Fig. 3 depict successive increases in the dosage of retention aid. Each increase caused an overreaction of the basis-weight valve, which closed to decrease the thick-stock flow. Each overreaction is followed by a recovery as the system fines are reduced. Figure 3 shows that the operator increased the dosage of retention aid several times during the adjustment period.

Gess *(4)* has shown that there is a significant time lag between the onset of a change in retention (e.g., a buildup of fines and filler in the white water of a paper-machine system) and the point at which such changes begin to affect drainage and retention. For example, a loss in first-pass retention increases the solids and fines in the white water. As the white water recriculates through the approach-flow system, there is a gradual buildup of fines in the furnish coming onto the sheet former. This, in turn, further reduces retention. If the basis weight of the product is to be maintained at a constant level, there must be an initial increase in the amount of thick stock flowing through the basis-weight valve.

The solids in the white-water silo increase because of the loss in retention. However, the dilution to a constant consistency (when on consistency control) will cause a steady increase in retention loss. This, in turn, will cause a steady increase in the amount of thick stock required. The pattern will continue as the fines and filler in the headbox stock build until they impact both retention and drainage. The lighter the sheet weight, the longer is the pattern of retention loss before it affects drainage.

Definition of "stability"

Using the change in thick-stock flow rate over time (gal/min/min) as a base, the subcommittee said that a paper machine was operating in a stable fashion when:



6. Run 3–(A) thick-stock flow as a function of basis weight, (B) change in thick-stock flow over time, (C) change in basis weight over time, and (D) change in reel speed over time

1. The slope of the change in thick-stock flow rate (gal/min/min) was as close to zero as possible (i.e., when retention was constant).

2. The three-sigma variation in the thick-stock flow rate (trended for the cycles of 4 h or more) was within a given range (i.e., when the quality of the furnish coming into the system was uniform).

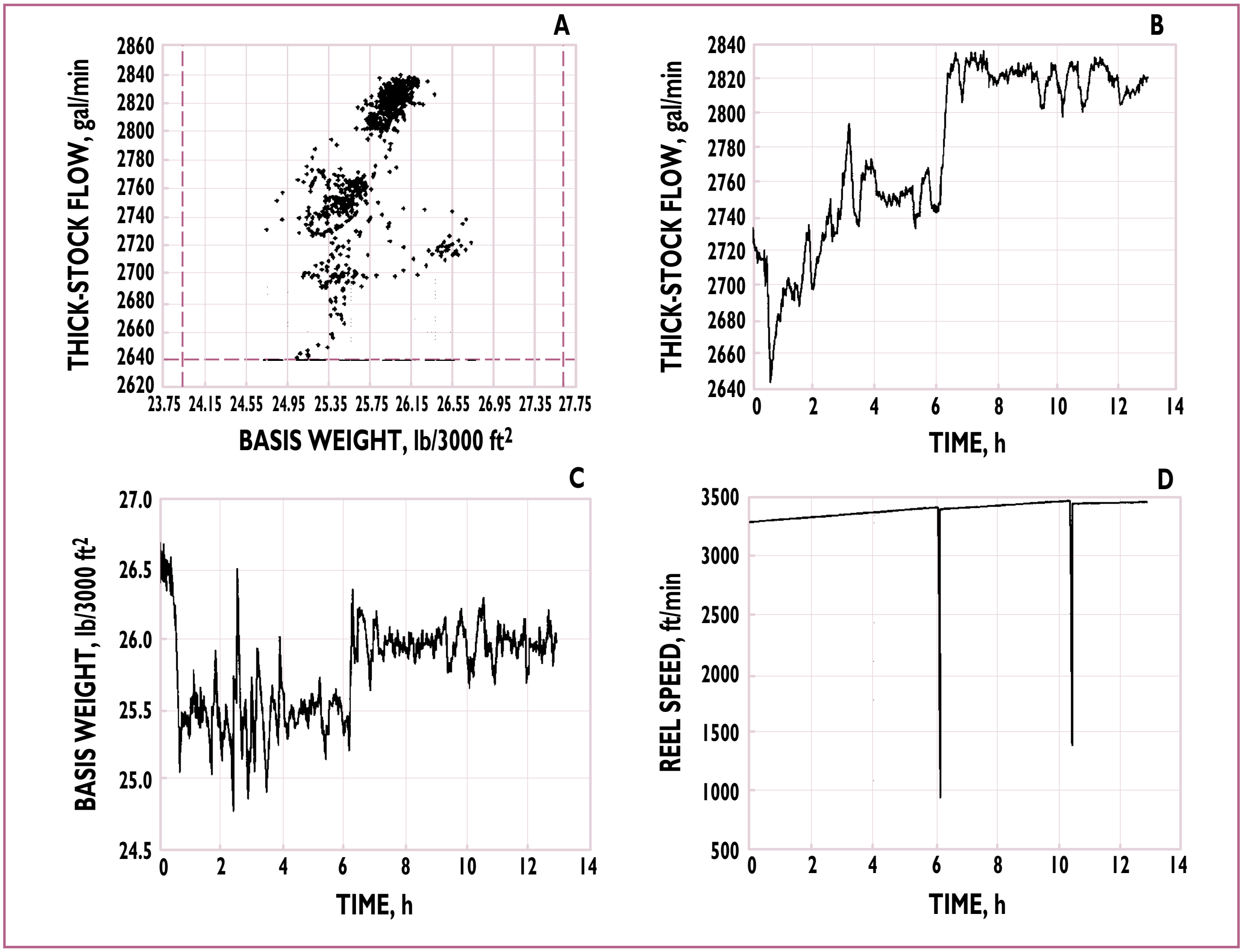
Sufficient data have not yet become available to quantify stability by assigning values to these two functions. Thus, the application of true SPC control limits has not yet been attempted, and it is acknowledged that the run charts discussed later in this paper are a subjective indicator of stability.

However, the technique does have an immediate practical application. By tracking the thick-stock flow rate, mills can ensure that chemical or mechanical trials are conducted only when the machine is operating in a stable mode. Under stable conditions, an operator needs only a few minutes to tell if the given change has a positive or negative effect on the machine system.

Future work

The fact that a process is "in control" means only that the process is consistent. It doesn't guarantee that the process will make paper that meets specifications. To be both "good" and "in control," the control limits of the process must fall well within the specification limits of the product.

The subcommittee believes that the currently accepted levels of instability in approach-flow systems can be reduced by fine-tuning existing control systems. Current systems are designed to operate within conventionally acceptable limits of variation. Raw data from sensors are averaged out to fit these conventional



7. Run 4–(a) thick-stock flow as a function of basis weight, (b) change in thick-stock flow over time, (c) change in basis weight over time, and (d) change in reel speed over time

variation limits, effectively filtering the information and making it invisible to operating personnel. However, the available raw data are capable of tracking thick-stock flow with a precision that could reduce system variability. This is demonstrated by the run charts presented in the next section of this paper, which were developed from raw instrument data.

The charts presented in the following discussion demonstrate the need to monitor the stability of the machine system more closely, especially in cases where unexplainable system swings produce off-specification paper. New display-screen options and data-storage logic will be needed to meet this challenge.

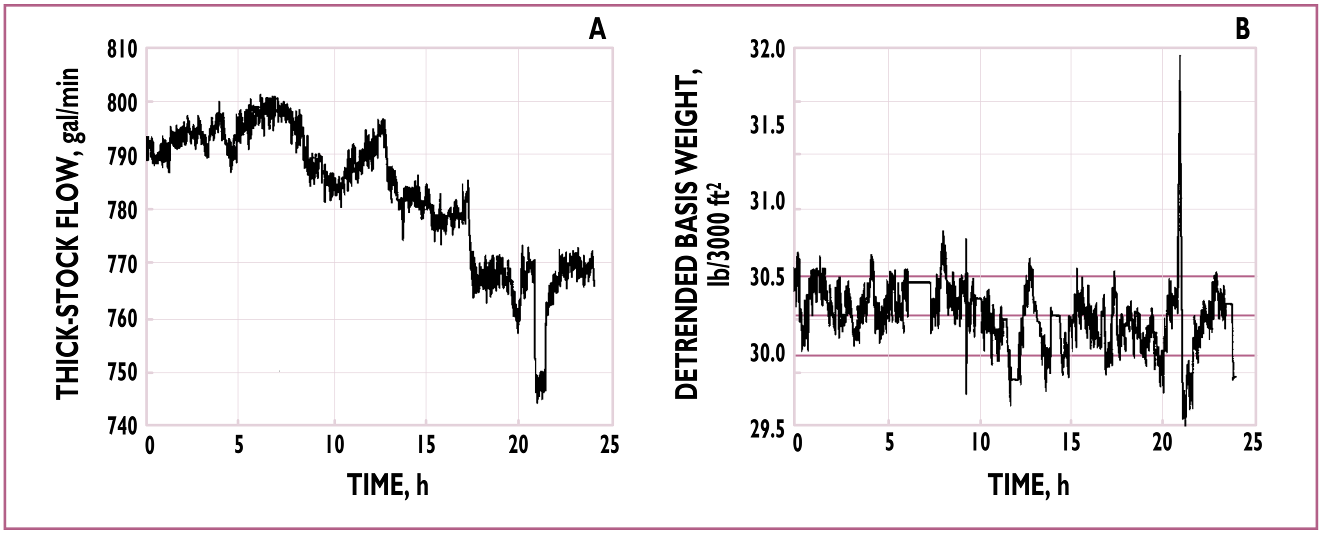
MILL DATA

There are several ways to look at stability when discussing a given production run on a particular paper machine. As already noted, stability could be quantified using some combination of the slope and the three-sigma variation of thick-stock flow rate. However, a specific "stability number" based on these parameters has not yet been developed.

Studies have suggested that it is possible to illustrate stability by developing a scatter diagram of the thick-stock flow rate vs. the basis weight. Run stability is denoted by the size of the box containing the plotted points, with a smaller box indicating greater stability. Four production runs—each showing a different characteristic—were selected for examination.

Stability patterns

Figures 4–7 illustrate raw data from four different production runs. Parts A of Figs. 4–7 show the scatter diagrams for thick-stock flow rate vs. basis weight, where a low degree of scatter indicates stability. Parts B–D of Figs. 4–7 are run charts for



8. "Glitch" pattern I–(A) change in thick-stock flow over time and (B) control chart showing ±3s variation in basis weight

thick-stock flow, basis weight, and reel speed, respectively. The run charts for thick-stock flow (Parts B for Figs. 4–7) show both slope changes and variations in the thick-stock flow rate during the production of a given run of paper. The long-term (4 h or more) slope changes are indicative of the fines content of the dilute stock at the headbox and of the retention of fines.

Run 1—instability after a grade change. Figure 4 shows the patterns for a production run that began immediately after a grade change to a higher basis weight. Although the change in basis weight was accomplished in a matter of minutes (Fig. 4C), the thick-stock flow did not reach zero slope for approximately 4h (Fig. 4B). The change to a higher basis weight (with no change in the chemistry or furnish) produced an instantaneous increase in first-pass fines retention. Because of the increase in retention, the thick stock used to maintain the basis weight had to be increased until the fines balance was reestablished. The production rate is shown in Fig. 4D. After the fines were cleaned out of the white water and the slope of the thick-stock flow rate reached zero (i.e., the run was stabilized), the production rate was increased by 40 ft/min, as seen in Fig. 4D.

Figure 4A is a scatter diagram of the thick-stock flow vs. the basis weight being produced. Clearly, the points fall into two distinct groupings. This indicates that:

1. Two papers were produced during this particular production run. Unfortunately, the paper manufactured during the first part of the run did not meet the specifications of the grade that was being manufactured.

2. The paper made when the fines were being decreased had a higher fines content. This is seen in the area marked "1" in Fig. 4b. A second paper was made when the system adjusted itself to the change in fines. This is shown in the zone marked "2" in Fig. 4B.

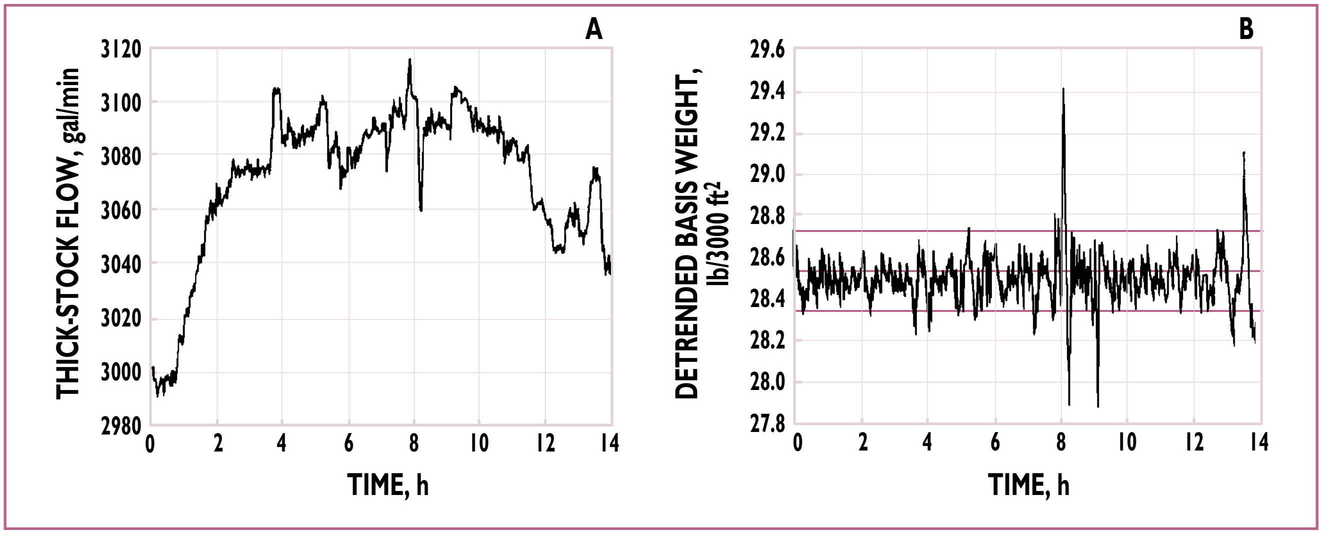
Run 2—stable system, narrow specifications. The plot of thick-stock flow vs. basis weight in Fig. 5A indicates that production during Run 2 had minimal variation in quality, i.e., all the plotted points fall into a very small area. There was some variation in the thick-stock flow rate, as shown in Fig. 5B, but it is in the range of ±0.73%. The production run shown in this set of plots is indicative of a stable system, and the paper manufactured during this run fits a narrow set of specifications.

Run 3—wide swings, broad specifications. Figure 6 shows a run with relatively wide swings in both thick-stock flow rate and basis weight. The size of the pattern of points in Fig. 6A indicates that the quality of the paper produced during Run 3 fits a broad set of specifications, in contrast to the paper produced during Run 2. Comparison of Figs. 5A and 6A illustrates the proposed concept of stability, with the smaller box in Fig. 5A indicating this system's greater stability.

Run 4—different levels of quality within a run. Figure 7 clearly shows that more than one quality of paper can be manufactured during a given production run.

Glitch patterns

An alternative to this subjective technique would be SPC analysis to determine the stability of a system.



9. "Glitch" pattern II– (A) change in thick-stock flow over time and (B) control chart showing ±3s variation in basis weight

KEYWORDS
Approach flow systems, flow, fluid flow, machinery, measurement, monitoring, on line measurement, paper machines, paper making equipment, process control, quality control, stability, statistical process control, stock flow, stabililty.

This would involve comparing the three-sigma variation of the trended thick-stock flow rate with the time-related basis-weight changes.

One would assume that the greater the three-sigma variation of these two types of plots, the less stable is the system. Such plots have a secondary value in that they can identify so-called "glitch" patterns. Glitches are undefined sudden shifts in either or both basis-weight plots and thick-stock flow-rate plots. A series of trended plots for basis weight and thick-stock flow rate showing two glitch patterns are presented in **Figs. 8 and 9.**

Fast Fourier transform analysis is a useful tool for investigating these glitches when used with a distributed control system. Using this technique, frequencies are defined, so a cause-and-effect assignment to system variables can be developed to eliminate such glitches.

CONCLUSIONS

It is possible to determine the "stability" of a given paper-machine system by plotting the thick-stock flow rate obtained from the computer system of a paper machine. The flatter the slope of the thick-stock flow rate and the lower its trended three-sigma variation, the greater is the stability of the paper-machine system. With the ability to track system stability, mills can know when to take measurements for the acceptance of a new machine or when to begin chemical trials that can be interpreted quickly and accurately.

A scatter plot of thick-stock flow rate vs. basis weight provides a pictorial representation of "stability." Such plots give machine operators a better look at what is happening in the approach-flow system so they can improve product consistency and prevent major machine upsets.

This approach could be used to develop a quantitative measure of the effect of mechanical alterations to the system, much as the two-sigma trending of cross-machine weight profiles has become for weight uniformity. Development of such a technique, however, will require SPC support to develop the control screens and data-storage systems required for everyday use by machine operators. **TJ**

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