INDUSTRIAL DATA PROCESSING APPLICATIONS REPORT

Applications	Papermaking Process Control
Type of Industry	Fine Rag Content Paper Manufacturer
Name of User	Harding-Jones Paper Co., Middletown, Ohio
Equipment Used	IBM 1710 Process Control System

Synopsis

Harding-Jones, one of the few privately-owned fine rag content bond and ledger paper mills remaining in the country, is increasing production through a closed-loop computer controlled paper-making process utilizing an IBM 1710 process control system.

With objectives such as time savings in grade changes, better weight control, increased production and improved product quality, the system has allowed Harding-Jones to realize production gains, while maintaining or improving product quality characteristics, and a more efficient use of manpower.

Utilizing the computer to mathematically define various stages of the papermaking process, Harding-Jones has been able to arrive at essential valid decisions, where formerly they had to rely on trial and error. Because the system senses production difficulties before they occur it can make the necessary changes in the operation before a serious problem can develop.

Harding-Jones' process control system regulates the operation of the mill by collecting and analyzing data from 38 sensing devices along the length of the paper machine. These highly sensitive instruments measure variables such as raw stock consistency, flow rates, temperatures and machine speeds.

The most effective combination of historical operating standards for each grade of paper is stored in the computer and automatically applied during subsequent runs. Any deviations from the levels that occur during the manufacturing process are automatically detected by the sensing instruments and fed into the computer. Instruments controlling the machine are then adjusted to bring quality back to its highest level, automatically, or on a closed loop basis.

The paper machine operator can increase the production rate by merely dialing a new speed into the computer.

Harding-Jones successful application of process computer control is equally significant when considering that only twelve months after the installation date, its control complex became fully operational and self-supporting with closed-loop control of grade changes.

The Harding-Jones Paper Co., one of the 20 privately-owned fine paper mills remaining in the U.S., is far from being in the front rank of an industry characterized by large corporations with multiple plants. Yet, its experience with a digital process control computer indicates that a firm need not be a giant in its field to reap high dividends from industrial automation. Harding-Jones presently relies on an IBM 1710 process control system for closed-loop operation of its papermaking machine. This system, company management reports, has proved its economic viability and brought about appreciable productivity increases while maintaining or improving important quality characteristics.

Background to Process Control

Harding-Jones has been a producer of rag content air dried bond and ledger papers for over 100 years and now employs approximately 100 people. Production averages 19 tons a day on one paper machine with a maximum speed of 600 feet per minute, trimming to 72 inches. The machine has an open headbox and a single slice with an adjustable lip.

The Middletown, Ohio, plant is a specialty mill, producing hundreds of private watermarks for merchants or their customers in the U.S. or overseas. Many orders, therefore, are in increments of as little as 500 pounds, and there may be from 12 to 15 grade changes per day. Consistent paper formation and quality are of utmost importance, yet difficult to attain in the face of these necessary production upsets. Furthermore, the mill is too small to maintain a research department or an extensive technical staff. Management felt that these deficiencies could be largely overcome by computer process control and this led to an investigation by Virgil Perry, vice president of manufacturing, of the feasibility of such an installation.

The objectives of the computer process control project were based on the results of a preliminary evaluation of economic and technical feasibility. Six months of production data were analyzed in order to determine possible incentives for computer control. Because of the mill's moderate size, objectives had to be primarily directed toward rapid economic payout. The following were formulated as having the most significant economic potential:

1. Increased production
2. Better basis weight control
3. Reduced grade change times
4. Improved product quality

Determination of actual benefits to be gained through fulfillment of each objective required complex computations. Thus, there proved to be a considerable variance in grade change times, even in cases where a number of identical changes were considered. In such instances, the minimum change time was considered the standard, save that in order to be conservative, changes of less than 15 minutes were given no room for improvement. Savings in grade change times were expressed as increased production and converted to profit. Results of the study indicated a reasonable potential grade change time reduction of 28 percent.

Regulatory basis weight control is directed toward reducing the variation due to changes in consistencies, stock characteristics, and other minor upsets which can occur while on grade during a run. For the Harding-Jones calculations, excess basis weight lost or given away was approximated by taking the difference between finished weight and nominal weight for each order. If the observed variation, when applied to nominal weight, caused a violation of the minimum acceptable basis weight limit, the appropriate adjustment was made. Results of the study indicated potential pulp savings of 1.78 percent.

Potential production increase resulting from an overall machine speed increase was estimated by examining variations in speed data within grades. For each grade a reasonable target speed was selected, usually the highest speed for the grade. The Harding-Jones paper machine is not dryer-limited or drive-limited on any grade, the primary restraints on speed being formation, watermark and other quality considerations. The mean speed was substracted from the selected target speed giving the expected speed increase. This was in turn related to increased production and profit. Results of the study indicated a reasonable potential overall speed increase of 5.9 percent.

Ten different grade and basis weight combinations, comprising 18 percent of the total production, were selected for economic evaluation. The results were extrapolated across all grade and basis weight combinations since the study grades were purposely chosen to be a representative sample of the total production. The preliminary investigation included the development of the following installation plan:

1. Feasibility study
2. Decision to install control computer
3. Hire programer-operator and develop training program
4. Preliminary system design-specify instrumentation
5. Order instrumentation
6. Detailed system design-flow charts
7. Final justification
8. Installation of Instruments
9. Programing
10. Program testing and debugging
11. Final instrument wiring and checkout
12. Control system installation and checkout
13. On-line program testing and debugging
14. On-line data collection, analysis and reporting
15. Limit checking and operator guide
16. Development of closed loop control strategy
17. Install additional equipment (disc file)
18. Implement closed loop control strategy

This plan and the results of the preliminary technical and economic evaluation were passed upon by the Harding-Jones board of directors, resulting in agreement on the installation of an IBM 1710 system with a central processor memory of 20, 000 positions of alphanumeric core storage. The system configuration specified consisted of: IBM 1622 card reader, IBM 1311 magnetic disc

IBM 1710 PROCESS CONTROL COMPUTER SYSTEM regulates paper machine operations which undergo from 12 to 15 grade changes per day.

drive, IBM 1711 data converter, IBM 1712 multiplexer and terminal unit, IBM 1717 output typewriter, and IBM 026 keypunch.

The nine-month period preceding the 1710's installation was spent by Harding-Jones and IBM personnel in specification and installation of instruments, derivation of equations for on-line calculations, design and construction of the computer room, and specifications, programing and testing of the control strategy, which underlays the entire Harding-Jones system.

The first step in defining the measurements, calculations and control functions to be performed by the computer was the development of an accurate paper machine flow diagram. From the flow diagram, material balance equations were derived, and this and other information about the process was used in deriving the equations for on-line calculations and specifying instruments. As is normal at this stage of installation, these activities were not clearly defined then. However, their results were to be continually refined through an evolutionary process.

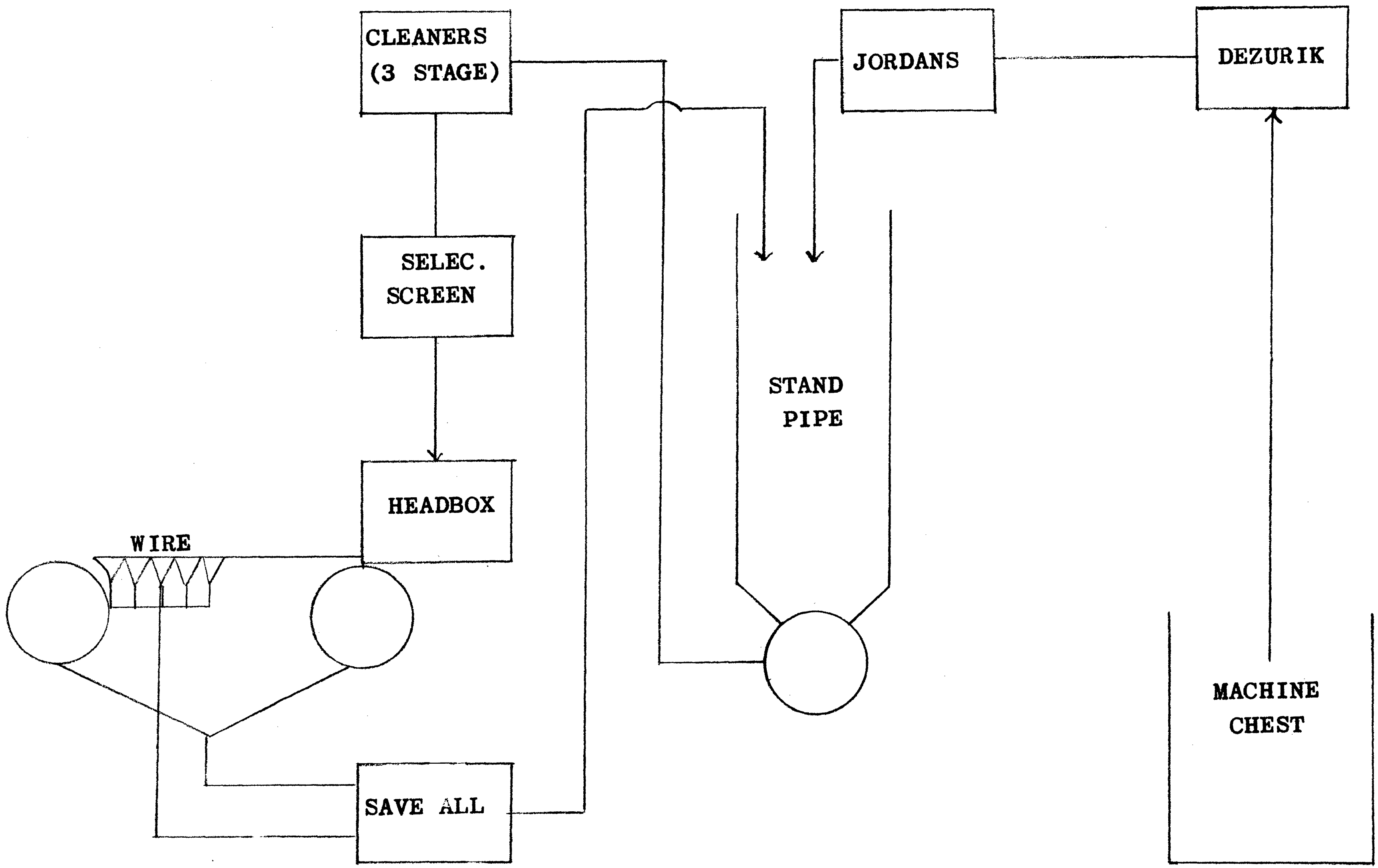
At the start of the project the following instruments were already in use:

Jordan ammeters (three)
Beckman-Foxboro pH controller
Dezurik-Foxboro consistency regulator
Flatbox vacuum gates (five)
First dryer speed
Couch vacuum gage
Traversing beta ray gage

The following other instruments were installed specifically to provide information to the 1710 computer:

Magnetic flowmeter - headbox flow
Magnetic flowmeter - tray flow
Magnetic flowmeter - flatbox flow
Magnetic glowmeter - jordan flow
Saveall effluent flow
Headbox level
Machine chest level
Headbox temperature
Machine size temperature
Jordan input temperatures (two)
Jordan output temperatures (two)
Dryer discharge temperature (two)
Shake amplitude and frequency
Selectifier screen back pressure
Wire speed
Steam header temperature
Air drier size temperature and speed

In addition to the conventional types of measurements (flows, temperature, levels, etc.), a number of specially designed sensing devices were required to provide the 1710 computer with such information as wet and dry deckle, slice position, and a number of measurements and signals from the beta ray gage. It was planned that the computer would become an integral part of the mill operation, controlling basis weight, production rate, grade changes, and other functions. It, therefore, had to be so equipped as to sense every significant paper machine events such as breaks, the status of certain shower and white water flows, several status indicators from the beta ray gage, and the beginning and end of a reel. Some of these functions were merely sensed; others were important enough to bring on a program interrupt. The following special instrumentation system interrupts, and test indicators were incorporated at strategic points in the papermaking cycle:



PAPER MACHINE FLOW DIAGRAM

Measurements

Wet deckle (slidewire circuit)
Slice position (slidewire circuit)
Beta ray gage position (slidewire circuit)
Beta ray gage measurement (slidewire circuit)
Beta ray gage set point (slidewire circuit)
Dry deckle (photo cells mounted on traversing mechanism)

System Interrupts and Test Indicators

Begin winding interrupt
Beta ray gage measuring interrupt
Bad paper switch on interrupt
Bad paper switch off interrupt
Dry end break interrupt
Beta ray gage range switch no. 1
Beta ray gage range switch no. 2
Beta ray gage measuring
Beta ray gage measuring
beta ray gage controlling
Machine chest stock input
Dandy fresh water shower
Jordan white water flow
Dry deckle

A manual entry unit was also installed in the control room so that, in addition to automatically gathered on-line data, the computer could also receive information from the machine tenders. A printing station was installed nearby so that the tenders could also request information from the 1710. Control outputs included:

Reel change light (relay)
Reel change alarm (relay)
Machine speed (reversible electric motor drive)
Headbox flow (pneumatic valve actuator - set point)
Slice opening (reversible electric motor drive)
Jordan flow (reversible electric motor - valve actuator)
Consistency (pneumatic valve actuator - set point)

All wiring to the computer was two and three conductor 18 gage copper, twisted, insulated and shielded with mylar aluminum tape. Low level analog input lines were run in a separate metal tray. High level signal-interrupts, test indicators, and analog output lines were run in separate conduits.

The magnetic flowmeters and most of the other instrumentation were installed during the mill's yearly two-week July shut-down. The IBM multiplexer and terminal unit was brought in one month ahead of the remainder of the computer system equipment to allow completion of all wiring and check out of all instruments. These extra efforts resulted in the virtual elimination of noise and calibration problems when the computer went on line.

Control Strategy

The on-line calculations performed by the computer are designed to fulfill two primary goals:

- To aid operators in tending the paper machine
- To enable the implementation of computer control functions.

These on-line calculations include:

1. Stock flow from jordans
2. Jordan hp-hr/ton
3. Jordan watts
4. Dry stock to machine
5. Headbox consistency
6. Slice velocity
7. Headbox flow (gpm)
8. Drag (fpm)
9. Freeness
10. Predicted basis weight (lb/ream)
11. Dry stock from machine (lb/min)
12. Regulated consistency (avg)
13. Regulated calibration factor
14. Instantaneous regulated consistency
15. Shrinkage
16. CD trim allowance
17. MD trim allowance
18. Trim allowance
19. Production rate
20. Actual machine speed
21. Reel weight
22. Total production
23. Bad paper
24. Chest consistency
25. Dry stock in chest (lb)

The development of the control strategy which these calculations represent was begun during the preliminary investigation and continued through the pre-installation period, with new refinements being constantly developed thereafter. The control scheme was directed toward the specific objectives which resulted from the preliminary investigation - grade change control, basis weight control, and production rate monitoring and control.

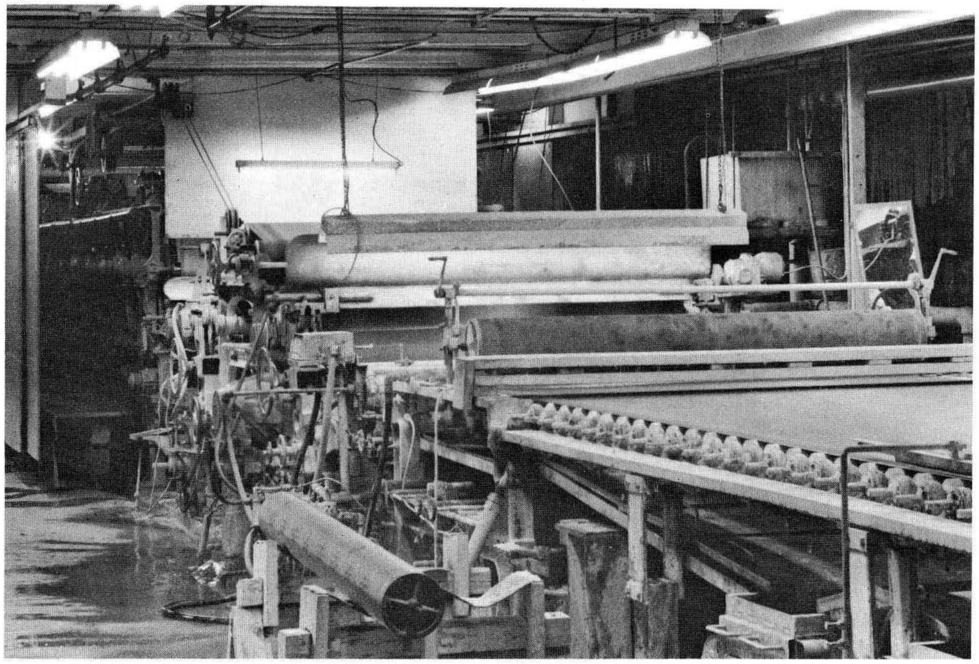
Grade Change Control computerized implementation involves two distinct areas:

- Determination of the final set-points or values for each of the important control variables for a new grade.

- Development of the rate, order, and magnitude of change for each important control variable.

The development of standard setpoints was designed to substitute the computer's vast information storage and retrieval capabilities for the machine tenders' reliance on past experience or trial and error in arriving at setpoints for a new grade. The 1710 was used to accumulate a number of sets of data for each grade and basis weight combination from each of several runs. This information was refined by simple statistical methods in order to arrive at dependable operating standards for the important control variables for each grade or basis weight. Only data collected when the paper machine was at or near steady state was used in developing standards.

The data refinement program was designed to consider only data collected while paper of acceptable quality is being produced. This condition is determined by the status of the "good paper button" used by the machine tender to enter information into computer. When any variable falls outside the statistical limits determined by experimentation, the entire set of data is discarded by the program. In addition, the program is highly biased toward higher production rates. The system is designed to make current grade standards almost instantaneously accessible. Up to 16 days of raw data can be stored, although analysis is normally performed weekly during paper machine downtime.



THIRTY EIGHT SENSING INSTRUMENTS, located down the length of Harding-Jones paper machine, continually feed operating data to IBM 1710 control system.

Through this method, sound operating standards were developed for most grades, about 90 percent of total production, over a period of six to nine months. Since the standards include many calculated variables and a considerable amount of statistical analysis was required in the development period, use of the computer was vital from the very start of the data collection phase. In addition, many of the programs written during the development period are used in closed-loop operation.

The problem of how to change the paper machine from production of one grade to that of another at first presented some problems because of the vast number of ways in which this change could be made. These could range all the way up to creation of a complete mathematical model, consisting of a set of equations describing all pertinent interrelationships of the important process variables. However, after numerous techniques for development of a suitable grade change control strategy, it was decided that the methods used by machine tenders would serve as a reasonable starting point. The tenders' experience in making grade changes over the years permitted the development of a workable control strategy. In most cases, this strategy includes the consideration of a number of variable and process interrelationships. The mere implementation of a standard operating procedure does much to reduce grade change times and to raise the average production rate by eliminating differences between operators. The best actions of the best operators are reproduced with optimum consistency and uniformity.

To exert this kind of control, the 1710 computer system is programed to recognize the existence of certain commonly experienced conditions and to print out or apply directly the predetermined control strategy in each case. The objective is more consistent operation from run to run, day to day, shift to shift, and operator to operator, thereby reducing variations in product uniformity.

Although there are a great number of grades produced on the paper machine, the major types of change were narrowed down to 65. A list of the important control variables was made and the method used by each machine tender for each of the changes was recorded during weekly conferences. Not surprisingly, it was found that these methods varied widely among tenders. At this point, a comprehensive effort, taking in engineering analysis, operation data and, even trial and error, was made to arrive at initial standards for each type of change. As more work was done in this area, change procedures became simpler and more predictable. Additional refinements were made after the computer went on-line, permitting the collection of more comprehensive data for evaluation of change techniques.

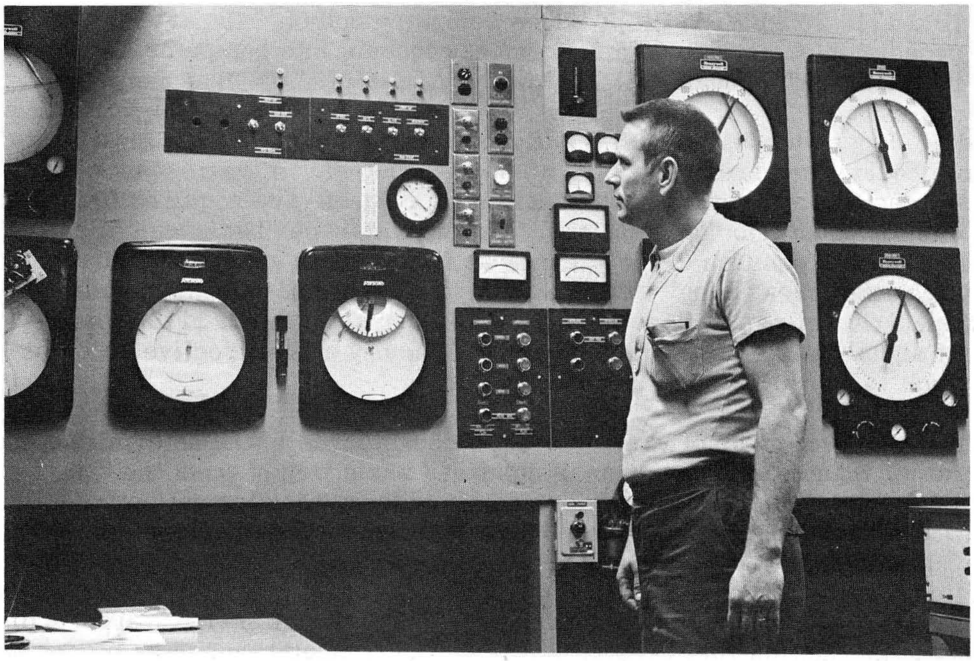
An important tool for acquiring process dynamics information has been the designed experiment, using the computer to collect and analyze data. The method is an expensive one, but data derived from a run of a few hours can result in control improvements which will pay off within a few months and whose usefulness will continue as long as the machine is in production.

In practice, the experiment was conducted by holding all variables constant at steady state, changing one at a time, and accumulating data while the machine returned to steady state. Dye was entered into the system at various points and at varying speeds and basis weights in order to determine time constants associated with the recirculation system and to derive more process dynamics information.

The results of these efforts have permitted Harding-Jones personnel to confirm a number of preliminary efforts and intuitive assumptions. The paper machine's tremendous inertia allows a great deal to be learned about the system's dynamics through the application of fairly simple techniques to relatively small amounts of data.

Another method of evaluating grade change control strategy is by simulating various control schemes on the computer using actual paper machine data as the basis for the simulation. This permits large numbers of control strategies to be tested simply and economically, since tons of off-grade paper result when such an evaluation is attempted on the paper machine. These methods are being considered by Harding-Jones to supplement, if need be, information about process dynamics derived from analysis of designed experiment data.

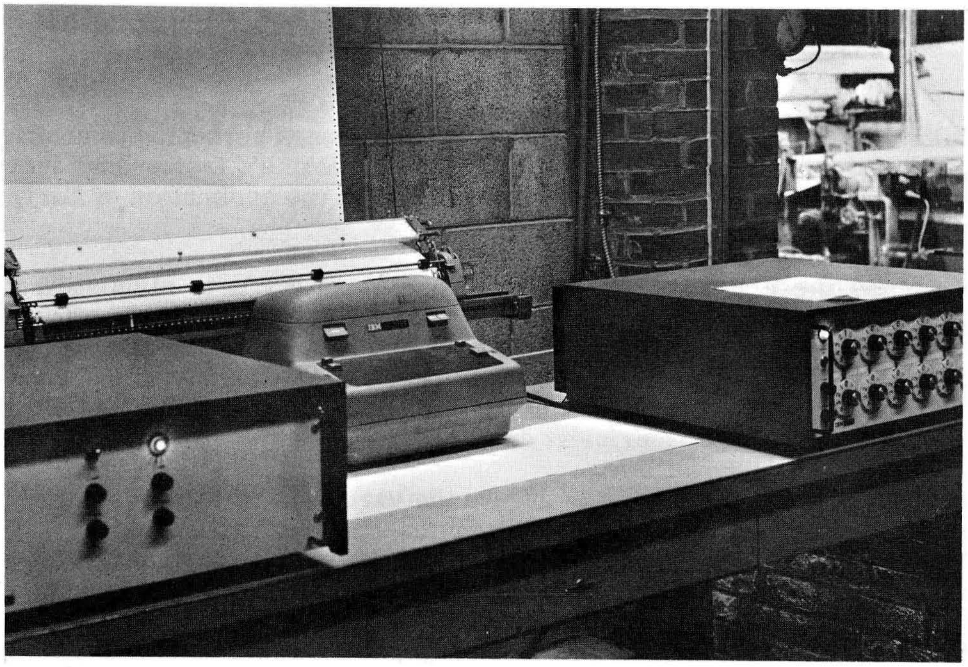
Basis Weight Control's purpose is to reduce the variations of basis weight during a grade run. Basis weight is measured at the dry end of the paper machine and, as measured, reflects the total weight per unit area of paper including fiber, filler, and moisture. Basis weight is also calculated accurately from wet end measurements, including thick stock flow rate and consistency, sewer flow and consistency, dry end machine speed (without considering machine direction stretch), and dry end deckle (without considering machine direction shrinkage). Sewer flow and consistency can be deter-



PRODUCTION FLOOR INSTRUMENT PANEL is used by Harding-Jones machine renders to determine process status.

mined by direct on-line measurements or by off-line measurements, in which case constant factors are carried in the computer program. Calculations for the basis weight equation include Dry Stock to Machine and Predicted Basis Weight (lb/ream).

Basis weight can also be calculated using headbox consistency (also a calculated parameter), headbox flow, and white water flow and consistency in place of the corresponding thick stock and sewer measurements. In either case the concept of steady state material balance is applied, in that stock entering the system is equated to stock leaving the system, and the resultant equation is essentially the same.



IBM 1717 TYPEWRITER provides computer output. Manual entry of process information and management requests into computer memory is performed through IBM 1713 MANUAL ENTRY UNIT at right.

At Harding-Jones, feedback from the beta ray gage is used both to recalibrate the consistency regulator and to provide the error signal for computer control. A good measurement of average basis weight, dry deckle, and several additional measurements are required for improved basis weight control and for production calculations. The instantaneous basis weight signal, the target basis weight setpoint, the position of the scanner as it traverses across the paper sheet, the position of the range switch, the "measuring" switch status, and a special position sensing apparatus consisting of two photoelectric cells provide the necessary information to the 1710 from the beta ray gate. The basis weight signal is integrated, smoothed statistically and corrective action is determined and applied to the stock valve, all by the digital computer.

In this manner, a number of variables can be considered in the determination of the proper control action rather than simple deviation of observed basis weight from the target. When more analysis of experimental data has been performed, feed forward dnformation from the predictive basis weight calculation will be incorporated into the control scheme.

Production Rate Monitoring and Control effects the most important economic factor in paper machine operation: the amount of salable paper produced per unit of time. The 1710 computer is used to monitor the production rate constantly, since the computation can be performed on a virtually instantaneous basis from on-line measurements (dry end speed, sheet width and basis weight). This computation involves the following individual calculations:

1. Shrinkage
2. CD trim allowance
3. MD trim allowance
4. Trim allowance
5. Production rate
6. Actual machine speed
7. Reel weight
8. Total production

The computer also performs production accumulation by integrating over a suitable time period.

Machine tenders are provided with information as to reel weight, order weight, and off grade production. They are warned 10 minutes and then again 3 minutes before a grade change is slated to occur. The computer then performs the change on a closed-loop basis.

The important consideration in this operation is that Harding-Jones does not maintain in-house inventory and that its paper machine has an average of 12 grade changes per day. This magnifies the financial impact of overruns and underruns. If an overrun cannot be sold, the excess production must be discarded or repulped as broke. Underrun which result in a rerun to fill the order constitute an unnecessary grade change. In addition to monitoring and accumulating production figures, the computer keeps track of stock preparation and machine chest availability to ensure that sufficient material is on hand to complete the present grade run.

Installation and Start-up

The installation and checkout of instrumentation, systems design, programing and testing were completed on schedule, nine months after Harding-Jones had decided to install the 1710. The thoroughness with which all phases of the work had been done resulted in a relatively trouble-free startup. However, the multiple interrelationships between the various programs and subprograms make it almost impossible to thoroughly test a real-time system until the processor goes on-line. Installation and testing of the computer control system hardware took about one week. Yet, it was several weeks before the system was thoroughly "debugged."

For the first six months of operation, the system performed three primary functions:

Printout of Important Measured and Calculated Variables: Only information considered important to operators is printed. Printout occurs at 15 minute intervals, on request, or on occurrence of special situations such as breaks, reel changes, grade changes and so forth.

Logged variables include:

Stock Preparation

Time
Stock in chest - lb.
DeZurik consistency - per cent
WW flow to jordans - gpm
Stock flow to jordans - gpm
No. 1 jordan amps. - amp
No. 2 Jordan amps. - amp
No. 3 jordan amps. - amp
Total jordan hp. - hr./ton
Jordan input temp. - ^{o}F
No. 2 jordan temp. diff. - ^{o}F
No. 3 jordan temp. diff. - ^{o}F

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	LOG SHEET VARIABLE CODE
	TIME
STOCK PREPARATION	STOCK IN CHEST - LB.
	De ZURIK CONSISTENCY - %
	WW FLOW TO JORDANS - GPM
	STOCK FLOW TO JORDANS - GPM
	#1 JORDAN AMPS
	#2 JORDAN AMPS
	#3 JORDAN AMPS
	TOTAL JORDAN HP - HR/TON
	#2 JORDAN TEMP - °F
	#2 JORDAN TEMP. DIFF. - F.°
	#3 JORDAN TEMP. DIFF. - F.°
FOURDRINIER	SCREEN BACK PRESSURE - PSI
	DRYSTOCK TO MACHINE - LB/MIN
	STOCK FLOW TO HEAD BOX - GPM
	HEADBOX CONSISTENCY - %
	HEADBOX LEVEL - INCHES
	HEADBOX TEMPERATURE - °F
	SLICE OPENING - INCHES
	DRAG - FPM
	SHAKE LENGTH - IN. PEAK TO PEAK
	SHAKE SPEED - CPM
	WIRE DRAINAGE - GPM
	FREENESS

	TRAY WW PH
	FIRST FLATBOX VAC. - IN. HG.
	SECOND FLATBOX VAC. - IN. HG.
	THIRD FLATBOX VAC. IN. HG.
	FOURTH FLATBOX VAC. - IN. HG.
	FIFTH FLATBOX VAC. - IN. HG.
	FLATBOX REMOVAL FLOW - GPM
	WET END DECKLE - INCHES
	COUCH VACUUM - INCHES HG.
	CLARIFIED WW FLOW TO SEWER - GPM
PRESS	FIRST PRESS VACUUM - INCHES HG.
DRYERS	FIRST DRYER SPEED - FPM
	RAW STOCK DRYER TEMP. - °F
	AFTER DRYER TEMP. - °F
	MACHINE SIZE TEMP. - °F
CALENDER	PREDICTED BASIS WEIGHT LBS/REAM
	ACCURAY BASIS WEIGHT LBS/REAM
	ACCURAY SET POINT - LBS/REAM
	DRY END DECKLE - INCHES
	SHRINKAGE - %
	TRIM ALLOWANCE - %
	REEL WEIGHT - LBS
	PRODUCTION RATE - LBS/HR
	TOTAL ORDER FINISHED PROD. - LBS
AIR DRYER	AIR DRYER SIZE TEMPERATURE - °F
	AIR DRYER SPEED - FPM

PERIODIC OPERATIONS REPORT is prepared by IBM 1717 computer output typewriter

Fourdrinier

Screen back pressure - psi
Dry stock to machine - lb./min.
Stock flow to headbox - gpm
Headbox consistency - per cent
Headbox level - in.
Headbox temp. - ^{o}F
Slice opening - in.
Drag - fpm
Shake length peak-to-peak - in.
Shake speed - cpm
Wire drainage - gpm
Freeness
Tray WW pH
First flatbox vac. - in. hg
Second flatbox vac. - in. hg
Third flatbox vac. - in. hg
Fourth flatbox vac. - in. hg
Fifth flatbox vac. - in. hg
Flatbox removal flow - gpm
Wet end deckle - in.
Couch vacuum - in. hg
Clarified WW flow to sewer - gpm

Press Dryers

First press vacuum - in. hg
First dryer speed - fpm
Raw stock dryer temp. - ^{o}F
After dryer temp. - ^{o}F
Machine size temp. - ^{o}F

Calendar

Predicted basis weight - lb./ream
Measured basis weight - lb./ream
Beta ray gauge set point - lb./ream
Dry end deckle - in.
Shrinkage - per cent
Trim allowance - per cent
Reel weight - lb.
Production rate - lb./hr.
Total finished prod. - lb.

Air Dryers

Air dryer size temp. - ^{o}F
Air dryer speed - fpm

Data Collection and Analysis: All measured and calculated variables are stored at periodic intervals for later analysis and combination with previous historical data for the grade. Raw data is first reduced to mean and standard deviation, discarding all but accurate, relatively steady state data. This information is then used to develop grade standards and variable interrelationships throu through exponential smoothing, analysis of variance regression analysis, or similar statistical techniques to combine all historical data according to grade.

Operator Guide Reporting: Several of the logged variables calculations are designed to aid machine tenders to make crucial production decisions. These include order weight, real weight, good paper produced, off-grade paper produced, stock remaining in the machine chest and its consistency and production rate. Tenders are notified when the order is 10 minutes from completion. Specifications for the next order are typed out at this time as well as the available grade standards. Operators are again warned three minutes from order completion by a flashing red light, and a buzzer is sounded when the change is to be made. Order specifications typed out include:

Order Information	Paper Specifications
Date	Grade
Production number	Basis weight
Quantity	Water mark
Number of reels	Size
	Deckle
	Color
	Finish
	Nips

For the first six months, operators gained confidence in the computer operation by gradually applying the standard setpoints and observing the results. The next three months involved a gradual transition to closed-loop control.

Closed-Loop Control

According to Perry and David Kirk and James Rolf of IBM, the changeover to closed-loop computer control involved three major changes:

- Installation of a 2 million character disk file (IBM 1311) to store the large amounts required of raw data, grade standards, and control programs.
- Shifting control of the entire computer operating system to the IBM executive routine, which automatically schedules directs all handling, analysis and control functions.
- Testing and refinement of the closed-loop control programs.

These changes altered the entire operating philosophy underlying the system and, therefore, required a considerable effort. This effort could not have been avoided to any extent, owing to the impossibility of delienating the final closed-loop system in advance.

Closed-loop functions are subject to the following breakdown:

1. Grade Change Control: Computer is in regulatory control mode on grade at start.
   a. Computer types out new grade specifications approximately 10 minutes before grade change.
   b. Tenders are again warned approximately 3 minutes before the change by a flashing red light activated by the computer.
   c. Buzzer is sounded at the exact time the change is made.
   d. Computer changes primary control variables to standard settings for the new grade, using grade change control strategy.
   e. Real-time feedback is used by the computer to monitor each loop during change.

f. Logs are resumed when the computer and the machine tender determine that the change is complete.

g. Tender makes minor adjustments to control variables not changed by the computer.

h. When quality is acceptable, tender pushes "good paper button" to signal the computer.

i. Computer shifts to regulatory mode and begins production monitoring calculations.

Through this scheme, the change is completed in one to 2 minutes, and acceptable quality is normally reached in 3 to 10 minutes.

2. Regulatory Control, including basis weight control:

   a. Computer scans and limit-checks all measured and calculated variables once every minute.

   b. If any control variable is out of limits (which are varied according to present conditions) corrective control action is applied by the computer taking into account the appropriate "dead band," determined experimentally.

   c. Logs of all measured and calculated variables are typed at 15 minute intervals, when any variable is out of limits, on request, or on the occurrence of special situations such as breaks, reel changes, etc.

   d. Basis weight is read repeatedly and integrated during each 12-second return sweep of the beta ray gage.

   e. Basis weight error and trend, and consistency regulator error and trend are used to correct the calculation of actual stock consistency.

   f. Factors from (e) above are used to calculate the required control action to the stock value which is applied automatically.

3. Speed Increase Program: When the paper machine is running acceptably on grade and it is felt that a higher machine speed could be reached, the machine tender can effect the change by performing the following actions:

   a. Set the desired speed in the manual data entry dials.

   b. Press the execute button located on the panel along side the dials.

   c. The computer calculates the required set points for the new speed and makes the changes on a closed-loop basis within a few seconds.

Results and Future Plans

Perry, who is in direct charge of computer activities at Harding-Jones maintains that the present control system has enabled machine tenders to duplicate the most effective performance derived from historical data. This has also virtually eliminated differences in performance among individual tenders. Perry reports the following results from the system's first three months of closed-loop operation:

- The development and continuing improvement of sound operating standards for each grade.
- Closed-loop computer control of grade changes resulting in a 14 percent average reduction in grade change times.

- An average overall production rate increase of seven percent due to the evolutionary improvement of operating standards and the application of the speed increase program.

- Maintained or improved formation, watermark and overall quality at the higher production rates.

Perry judges that of these four areas, the seven percent increase in production rate is the most significant economically, especially as quality has been maintained or improved. Also, there has been no perceptible increase in broke or off-grade production.

For the future, improvements are continuing steadily upward and there is no evidence of a reversal of the trend. Also, while machine speeds and production rates generally increase gradually with time, the increases experienced since the installation of the computer constitute a significant step change.

To derive further benefits from computer control, the following areas are under development or are slated for early implementation:

- Improved Regulatory Basis Weight Control: There are indications that an overall reduction in basis weight variation exists within the present control scheme, although there is insufficient experience to allow definite conclusions.

- Improved Grade Change Control: Information learned about process dynamics will be applied to grade change control to bring the system to steady state at the new level in the shortest possible time. This would be done by adding more than the required amount of stock to the system for a period of time during a change to a higher basis weight, then reducing stock flow to the steady state requirements in appropriate stepwise fashion.