Implementation of a PC-based operator interface for a paper machine drive*

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ABSTRACT

Personal computers (PCs) are increasingly being used in industrial applications. Graphical user interface (GUI) software and Windows®-based operating systems are proving to be cost effective, rugged, and reliable. Over the past 4 years, these advances have allowed the successful installation of several human-machine interface (HMI) systems for paper machine winders (1–3). The HMI monitors the operation of a winder and provides complete machine control.

An operator interface was developed to both monitor and control a multisection paper machine drive. The application described highlights the use of a redundant multicomputer network to replace existing benchboard controls. New monitoring and control features and a unique reel roll-density-control scheme were included. The goals achieved were increased paper production and improved control of reel building.

Application:

A PC-based operator interface increases paper production and improves control of reel building.

TODAY, AN INCREASING NUMBER of process control systems are implemented with user-friendly graphical user interface (GUI) development software packages running on standard personal computers (PCs). These PC-based GUI systems have proven to be powerful, inexpensive, and easy to modify by mill personnel after sufficient training.

Previously the winder system block diagram *(2, 3)* consisted of a human-machine interface (HMI) hardware configuration using three PCs connected to an Ethernet local-area network (LAN), as shown in **Fig. 1.**

Each PC was also connected to the winder drive programmable logic controller (PLC). To implement a hot backup strategy, two PCs were installed in the operator's benchboard—complete with touchscreen color monitors. If any PC failed, the winder would continue to operate.

The system designed and installed for Stone-Consolidated Corp.'s PM No. 7 at Fort Frances, ON, Canada, consists of eight office-grade Pentium® computers that are networked. The computers cooperatively control a sectional paper machine digital DC drive system and auxiliary machine controls. Details of PM No. 7 are shown in **Tables I and II.**

Incorporating such a system into a paper machine operator interface allows increased flexibility over existing drive controls. Included within the HMI are the existing benchboard controls. New features provide an operator with extensive drive and operating information. For example, an operator can monitor and store paper machine drive parameters, trend variables, view drive status, log alarms and event histories, and analyze interlock diagrams. All of these features assist an operator in diagnosing drive operational problems, therefore decreasing downtime and increasing efficiency.

Since papermaking is a continuous process and is in the critical path of mill production, the HMI must be a reliable system. Several key issues were in the forefront during project design and implementation:

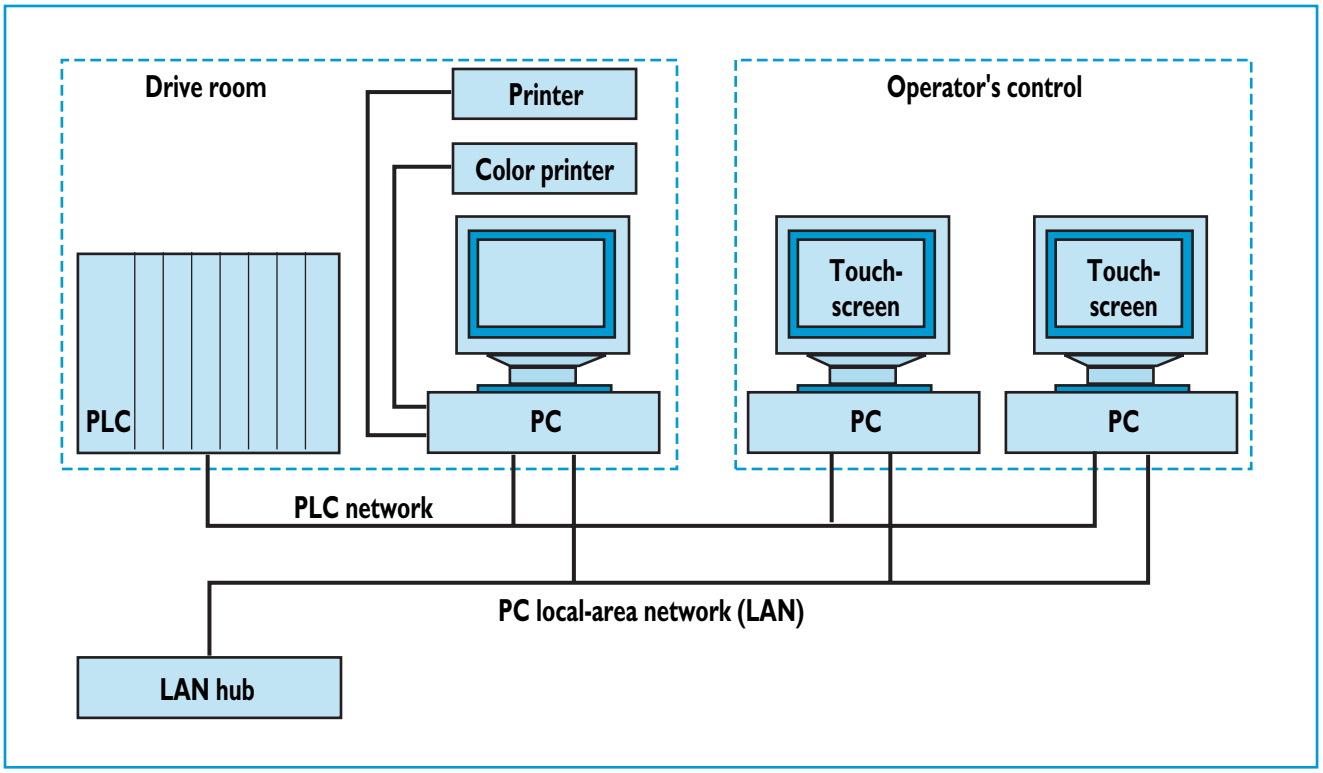
- Upgrade the drive system hardware and software
- Specify capable HMI system hardware
- Design a flexible communication system
- Test the system
- Incorporate all the necessary controls into the system.

DRIVE UPGRADE

The first step in building a solid HMI system involved upgrading the older digital-drive controllers with newer, faster ones. The original drive controllers used 16-bit, 8-MHz microprocessors. These microprocessors became so heavily overloaded that any attempt to connect a laptop computer to a programming port brought the paper machine to a halt. The replacement controllers use 32-bit, 25-MHz microprocessors.

The new processors improved the data transfer speed to the HMI system. They also enabled the existing drive software to be revised to increase the paper machine speed. All references, speed feedbacks, speed loops gains, tension loop gains, and displays were recalibrated to allow a future speed of 4000 ft/min. Due to current limitations of the paper machine process, the present maximum speed is 3200 ft/min.

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1. Winder system block diagram

Status/ change	Year	Comments
Original paper machine	1927	Beloit
Wet-end rebuild and dryer split	1954	Beloit new electric DC drive with analog control
Former rebuild	1985	Beloit Bel Baie III
Presses	1985	Beloit Tri-Nip
Breaker stack	1985	Beloit
Drive upgrade	1985	New electric DC drive with digital control
Reel upgrade	1988	Added reel centerwind drive

1. PM No. 7 machine history

HMI HARDWARE DESCRIPTION

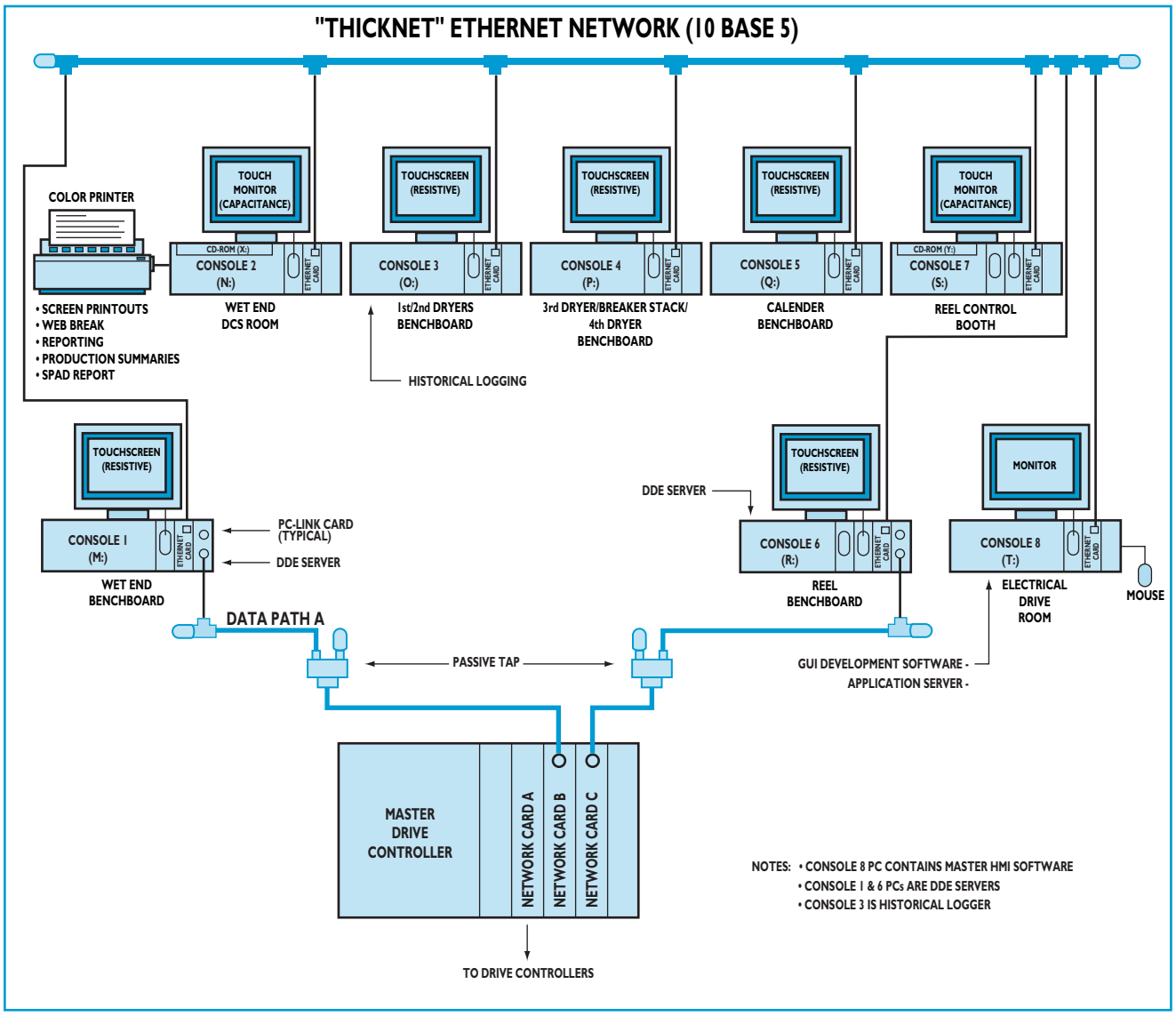
The HMI computer network connects the paper machine drive control system to the PC-based operator GUI. Eight PCs run the Microsoft Windows NT™ operating system and the GUI application software. **Figure 2** shows the eight computers and monitors connected via a Thicknet Ethernet LAN. Five units are located at various operator benchboards along the machine:

- Wet end
- First/second dryers
- Third dryer/breaker stack/fourth dryer
- Calender stack
- Reel.

The HMIs located at the operator benchboards consist of air conditioned NEMA 4X enclosures housing resistive touchscreen bezels and 17-in. color monitors. The enclosures are suspended from swing-arm assemblies (designed by mill personnel), allowing operators to position HMIs where convenient. See **Figs. 3 and 4.**

One HMI is located in the wet-end distributed control system (DCS) room and another in the reel control booth. Both use 17-in. color desktop capacitive touch monitors. The development HMI is in the electrical drive room. It uses a standard 17-in. color monitor and a mouse as a pointing device. Resistive touchscreens can be used by an operator wearing gloves. However, capacitive units are better suited to a control booth environment.

Figure 5 shows a typical HMI computer inside an existing benchboard. Each computer was installed in a benchboard after first removing the old (almost unviewable) cathode ray tube (CRT) displays. Mill personnel chose this location for a number of reasons: close proximity to the touchscreen monitors, easy installation, and ample room for maintenance. The primary drawback to the installation may be excessive dust collection on PC motherboards due to inadequate air cooling and filtering



2. HMI system configuration

at the benchboard openings. We recommended that the mill personnel inspect and clean the PCs every 6 months.

HMI COMMUNICATIONS TOPOLOGY

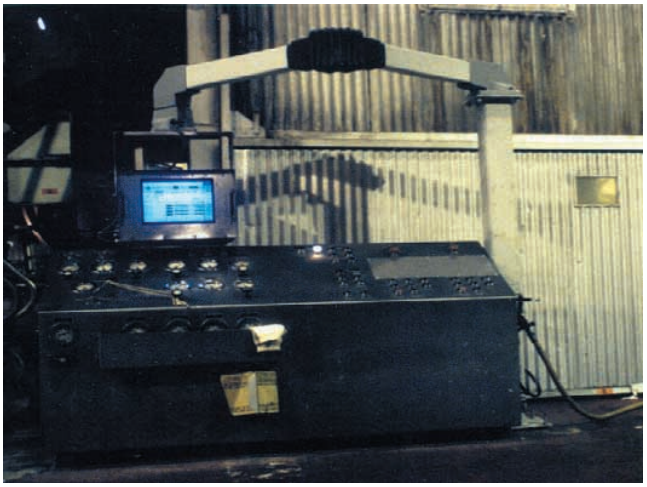
Designing an operator interface using GUI software development packages provides the flexibility of designing the system to perform in a predictable manner should system failures occur. Problems caused by computer hardware or network cable failures can be avoided with a redundant system. Incorporating a redundant data server in the HMI enables the paper machine to remain operational during potential computer failures.

To implement a redundant network architecture, two independent network cards were installed in the paper machine master drive controller rack. Figure 2 and **Fig. 6** show each card is connected to a PC set up as a data server.

The computers located at the wet-end and reel benchboards function as both operator interfaces and data servers. Information is transferred between the GUI applications and data servers using the network Dynamic Data Exchange (DDE) communication protocol incorporated into the Windows NT operating system. The two servers each run a DDE server application, which accepts requests to transfer data from any

Parameter	Result
Previous machine speed, ft/min	2800–2900
Current speed limit, ft/min	3200
Future speed, ft/min	4000
Product	Uncoated groundwood specialties
Basis weight, lb/ft^2	30–50/3300
Wire width, in.	248
Trim at reel, in.	213

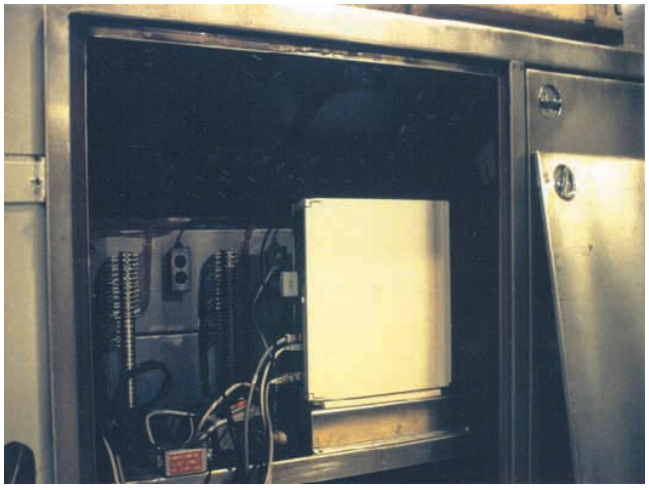
II. PM No. 7 machine specifications



3. First and second dryer benchboard with swing-arm assembly (prior to removal of existing operator CRTs on RHS of the benchboard)



4. First and second dryer benchboard with swing-arm assembly. Blank cover plate on RHS replaced existing operator benchboard CRTs.



5. Typical HMI computer placed inside an existing benchboard

GUI application over the 10-Mb/s Ethernet LAN. The DDE server responds to read/write requests by interfacing with the 1.5-Mb/s drive network via PC-Link cards located in the server PCs. Each PC-Link card communicates directly to a corresponding master drive controller network communication card over a coaxial cable. These are shown as Data Paths A and B in Figs. 2 and 6.

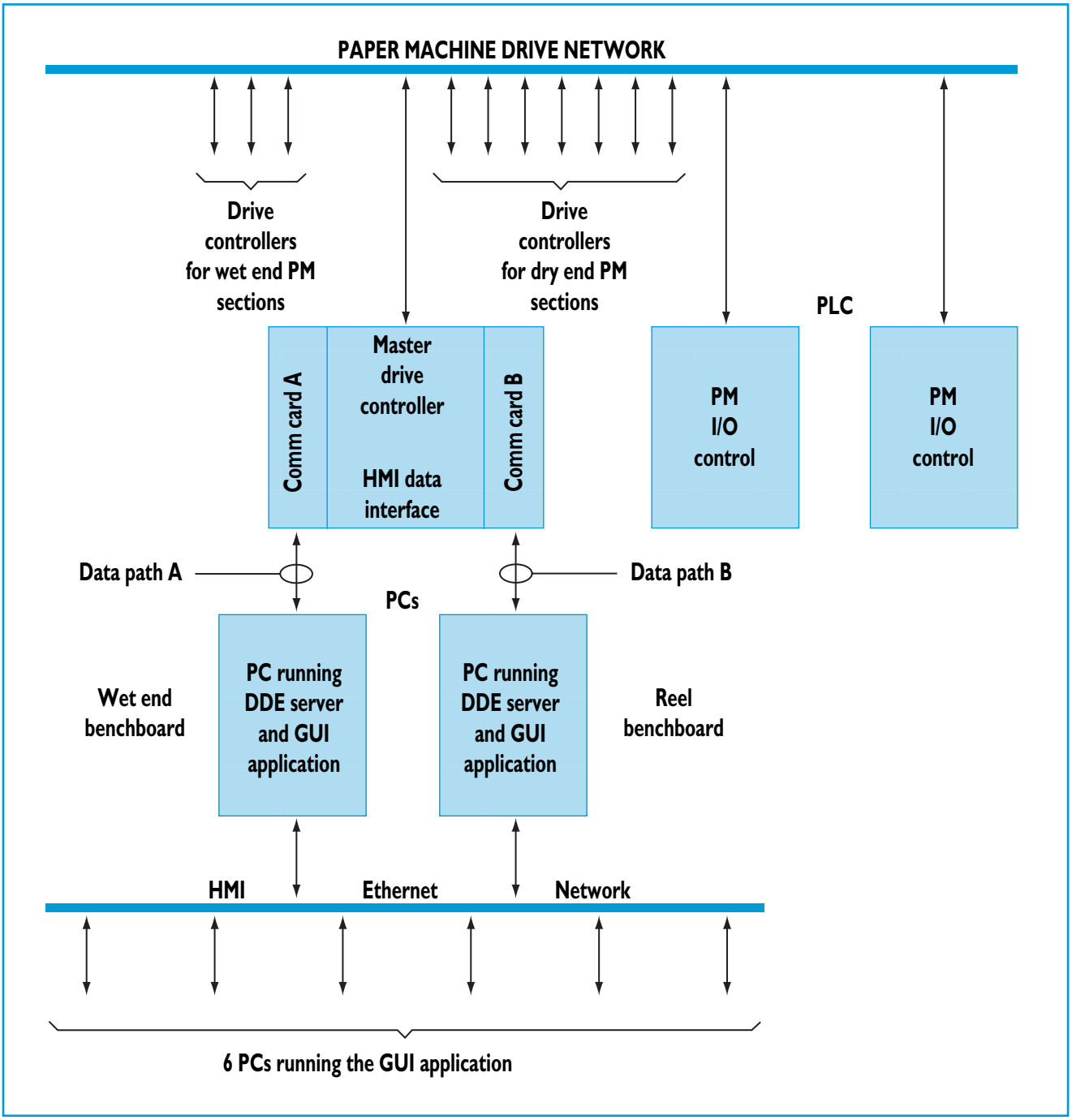
The six nonserver HMI computers can communicate with either DDE server. This topology permits seven of eight computers to remain operational should any of the following events occur:

- Loss of AC power to a computer
- Hardware lockup or failure of a computer
- Removal of a computer for servicing or maintenance
- A stopped GUI application, DDE server application, or critical operating system process
- Failure of the drive network link to a data server due to (a) damaged cable, (b) drive network communication card failure in the master drive controller, or (c) PC-Link card failure.

The GUI application and master drive controller software monitor communication pulses, or *heartbeats,* to determine if the communication link is functioning. A heartbeat is assigned to each GUI application and is toggled back and forth between each computer and the master drive controller. When a heartbeat remains in the same state for 15 seconds, a communication failure is detected. At this point, the GUI application with the communication failure will establish communications with the other data server if it is active.

Figure 7 shows the HMI network communications status screen. The heart-shaped graphic is animated to flash when active signals reach the HMI. The top row of the screen displays network status information, such as which computer is currently operating as the data server, the backup server, the historical trending server, and the application/report server.

This network topology provides fast data update intervals in the HMI. Data between the HMI and the drive system is divided into groups according to the required update interval. The DDE server is configured to group information such as motor speeds and loads to be the fastest so that greater detail can be viewed in the historical trends. Data such as status information are grouped as slow-updating. The update intervals for the different data groups range from 100 to 800 ms. Update intervals of 50 ms are possible, but this amount of resolution is not necessary for the application.



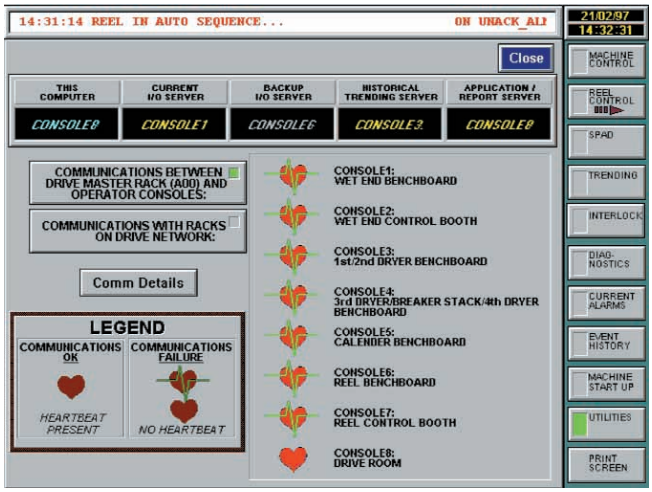
6. Network system topology

HMI SYSTEM TESTING AND MAINTENANCE

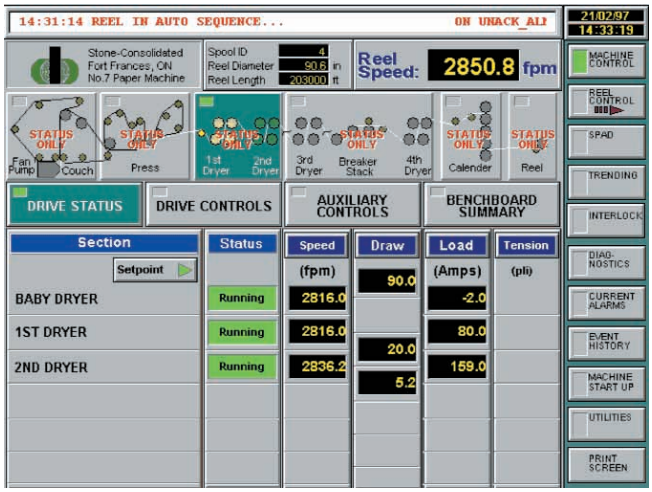
With PCs increasingly controlling industrial processes, engineers have proven that the PC can exist on the operating floor; however, careful system setup is required to ensure stability. A reliable system can be created using brand-name computers configured to meet the application required. In this case, staging was set up in an engineering-office environment to eliminate possible hardware conflicts or software bugs.

Six PCs were networked, loaded with application software, and run for several weeks in the office to monitor the stability of the system. Simulation software was written for the master drive controller to display, plot, and archive data in the HMI. Following the staging, one PC was taken to the mill, installed on the paper machine, and configured to run in monitor mode only. Testing continued with live data in the operating environment. An added benefit of testing during the initial software development stage is that ideas and concerns addressed by mill personnel can be implemented.

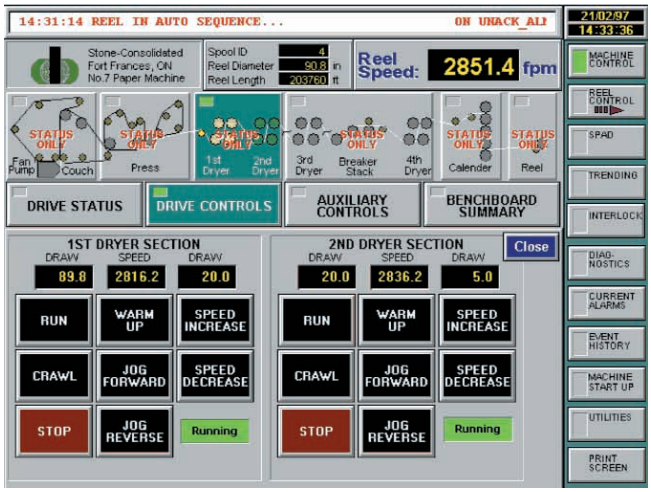
On-line system maintenance can also be easily performed by utilizing the system redundancy. Any of the computers, including the data servers, can be taken off-line while



7. HMI network Communications Status screen



8. Typical paper machine Drive Feedback screen (first and second dryer sections)



9. Typical Drive Controls screen (first and second dryer sections)

the paper machine is running to upgrade the GUI application software or to change the computer configuration. If an HMI is off-line, the operator is able to go to the nearest HMI and resume control.

All GUI changes are made using the development software installed on the application server located in the electrical drive room. The GUI application running at the paper machine benchboards is updated over the LAN by touching the UPDATE APPLICATION pushbutton located in the Utility screen. Figure 2 is a detailed diagram of the HMI system, which includes a color printer for screen printouts, web break reports, and production summaries.

BENCHBOARD FUNCTIONS IN HMI

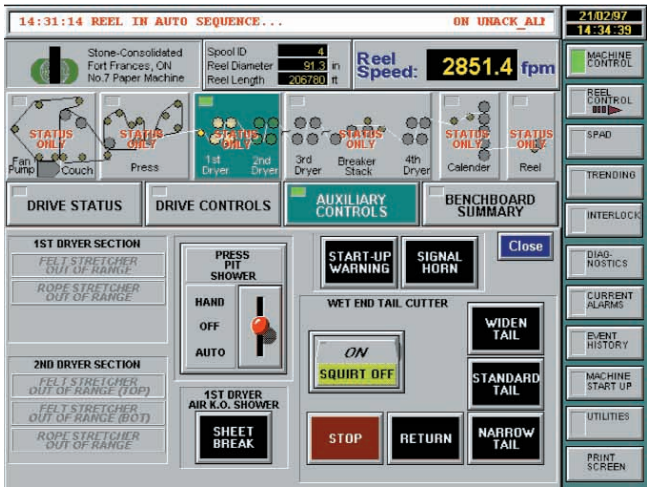
Replacing existing hardware benchboard controls with a PC-based operator interface reduces both maintenance and costly downtime. With the new HMI system, controls are implemented in the touchscreens, and their functions are configured in software. This allows improved flexibility when replacing existing operator controls. For example, the same control may be shown in multiple windows, providing customized control layouts for different modes of operation.

Figure 7 and **Figs. 8–21** are examples of screens developed for this application. Some have windows that are constantly visible (fixed), while others have windows that are only visible when requested (nonfixed). Many of the windows contain graphical pushbuttons which, when contacted (by touching an appropriate area of the monitors), will trigger either the display of another window or initiate another function.

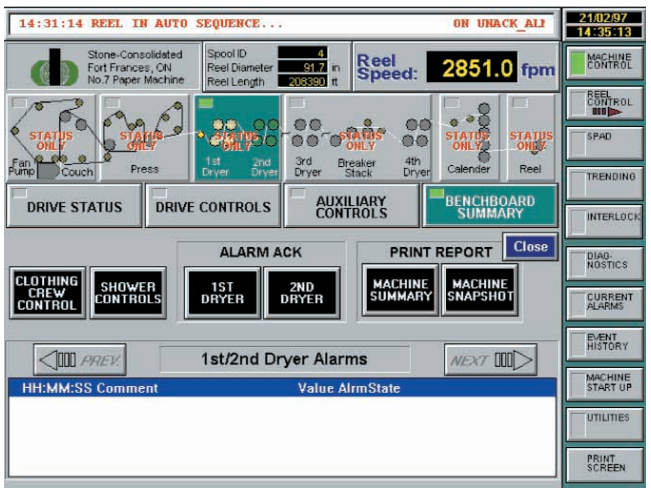
There are three different types of windows: Replace, Overlay, and Popup. A *Popup* window is typically small and appears on top of the existing display. A Popup window stays visible until the operator takes action as requested by the window. An *Overlay* window appears on top of the existing display. When an Overlay window is closed, any window(s) that were hidden by it will reappear. Touching any visible portion of a window behind an Overlay window will cause that window to be brought to the foreground as the active window. A *Replace* window will close any window(s) it intersects with, when it appears on the screen, including Popup types and other Replace-type windows.

Screen features

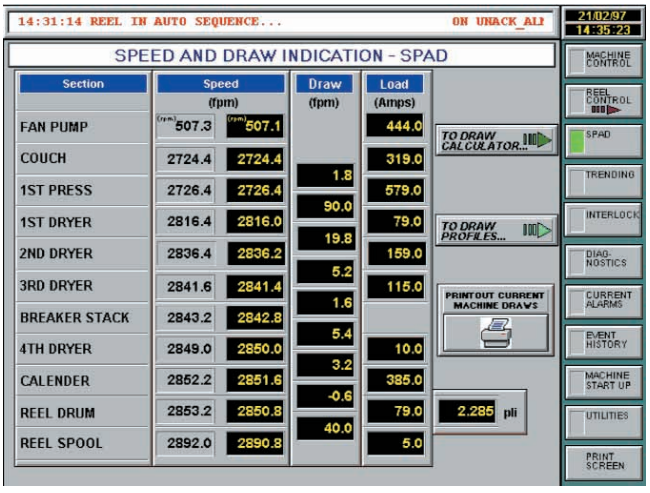
At the top of all screens is the Current Alarm window (fixed). This displays the paper machine's current active alarm, along with a description and time stamp. The HMI main menu (fixed) is also always visible on the right side of all screens. This menu provides access to all major HMI screens.



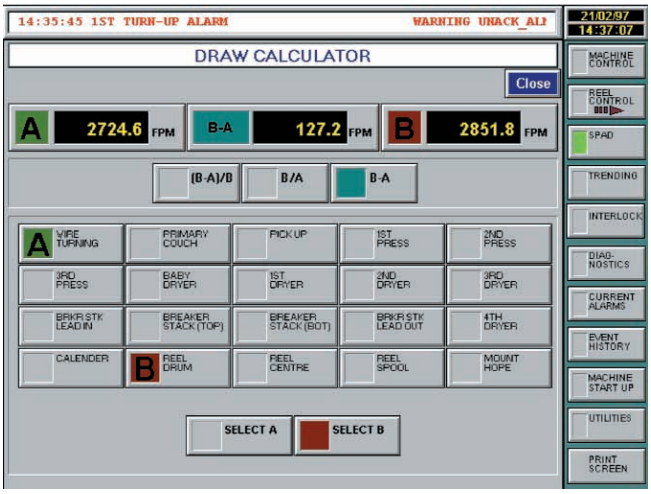
10. Typical Auxiliary Controls screen (first and second dryer sections)



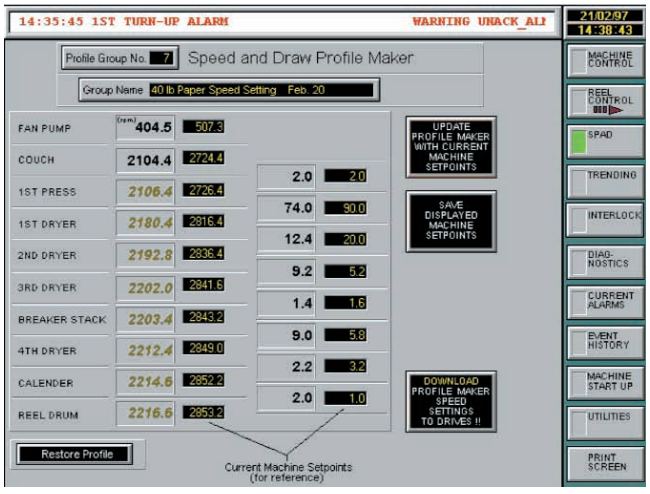
11. Typical Benchboard Summary screen (first and second dryer section)



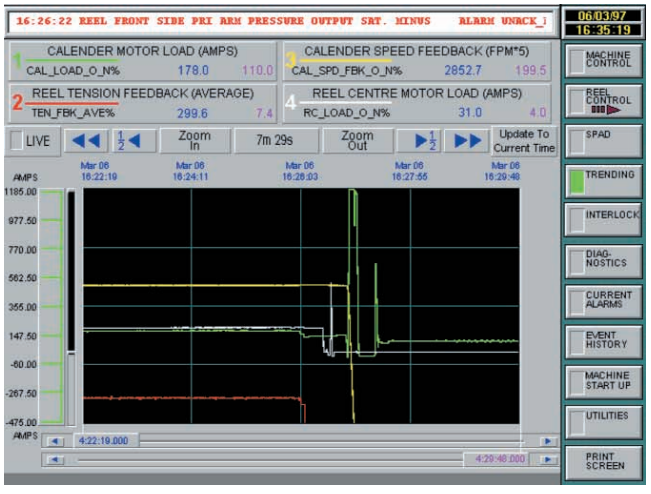
12. Paper machine SPAD screen



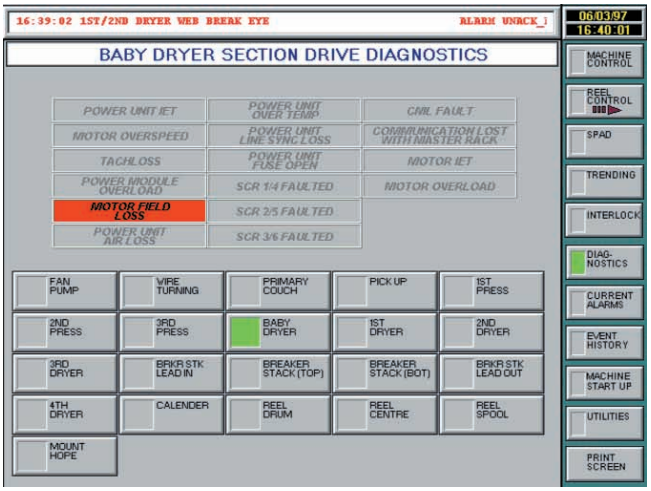
13. Paper machine Draw Calculator screen



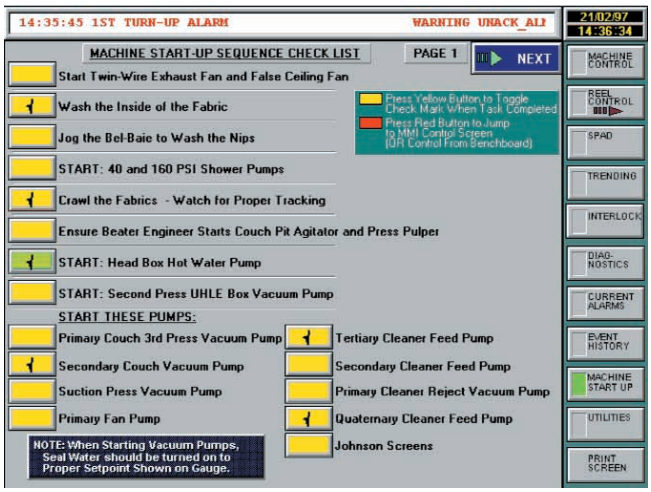
14. Paper machine Speed and Draw Profile Maker screen



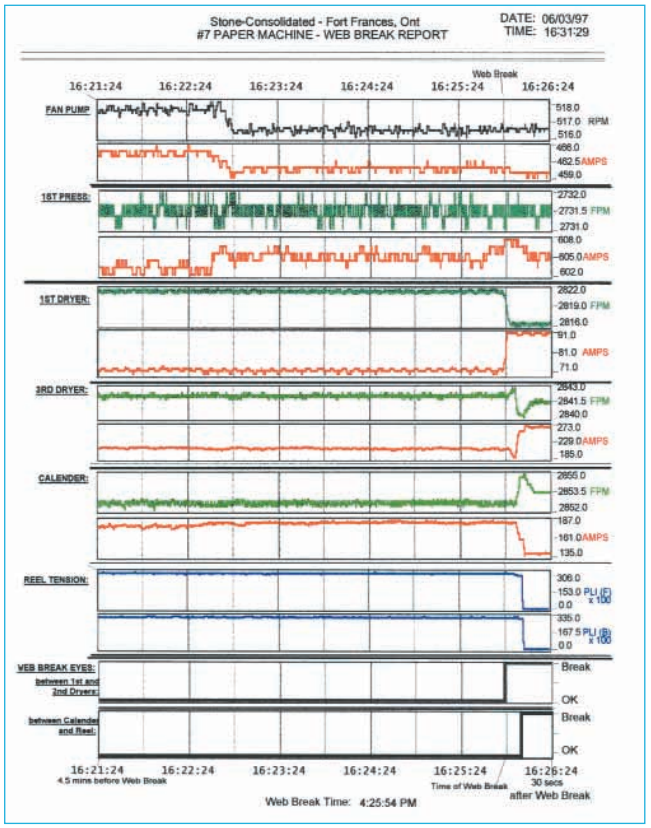
15. Typical four-pen trending screen



16. Typical Section Drive Diagnostics screen



18. Machine Start-Up Sequence Check List screen



17. Web break report

The screen controls are organized in a top-down architecture with the Paper Machine section selection at the root. The screen in Fig. 8 is the Overview window or Machine Control for the entire machine, with a graphical overview along the top row. From this, the desired machine section is chosen. Just below the machine graphic are four pushbuttons; they are labeled DRIVE STATUS, DRIVE CONTROLS, AUXILIARY CONTROLS, and BENCHBOARD SUMMARY. The pushbuttons display the status or control window for the selected machine section.

Drive Status. Drive Status contains a list of all drives in a selected machine section and displays the Speed Setpoint or Drive Status, Speed Feedback, Draw (speed difference), and Load of each drive. Figure 8 shows the first and second dryer sections. Touching Setpoint will display speed setpoint values in place of status indication. Touching Speed, Draw, or Load pushbuttons will change the numeric displays to bar graphs.

Drive Controls. Typical drive controls for a paper machine section are shown in Fig. 9. The pushbutton layout on the screen is similar to that of the original benchboard hardwired devices. This strategy is followed throughout the design of the interface, making it intuitive for the operator. Each section has a display of speed, upstream draw, and downstream draw located above the pushbuttons. The displays change when either the SPEED INCREASE or SPEED DECREASE pushbutton is touched. Adjacent to the pushbuttons are the drive status indications.

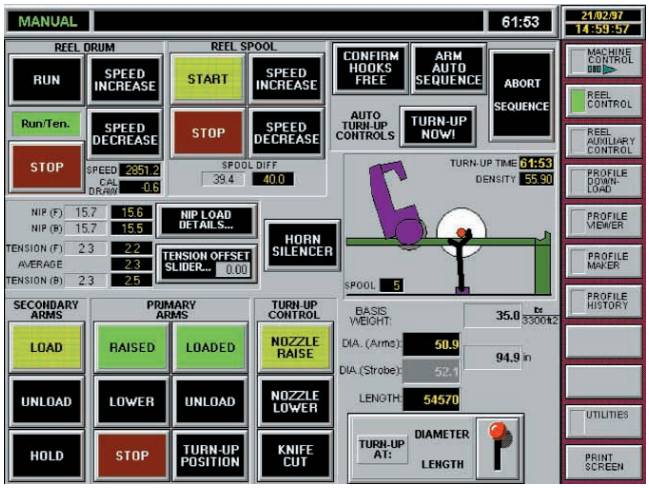
To ensure easy integration with the existing operator controls, the HMI operator interface pushbuttons at each benchboard were implemented to run in parallel with the existing hardwired benchboard pushbuttons.

Auxiliary Controls. An Auxiliary Controls screen for a section is shown in Fig. 10. The functions defined in this screen contain the remaining benchboard controls that were originally wired to the existing paper machine PLC. This type of screen includes typical pushbuttons, maintained and spring-return–type selector switches, and event annunciation.

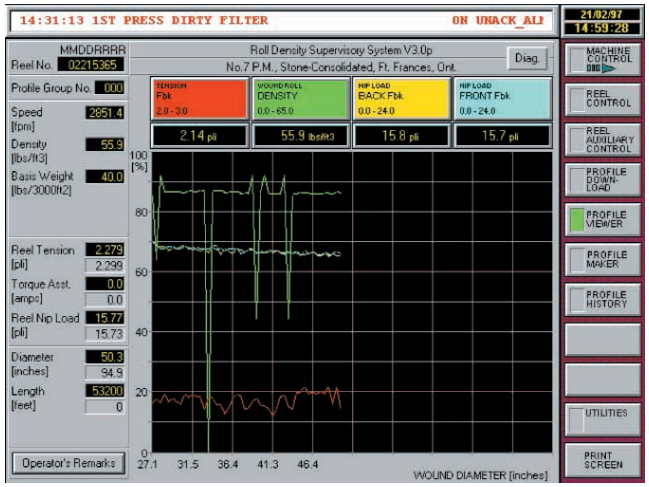
Benchboard Summary. A list of section-specific alarms can be acknowledged from the Benchboard Summary screen. Report printing and access to special operating modes are also available, as shown in Fig. 11.

New features only possible using an HMI

In addition to the machine control functions, enhanced features that are not possible using standard pushbuttons



19. Reel Control screen



20. Reel Profile Viewer screen

and pilot lights can easily be implemented through the use of HMIs. These features include trending, sophisticated alarming and event logging, generation of custom reports, special operating modes, and advanced machine control.

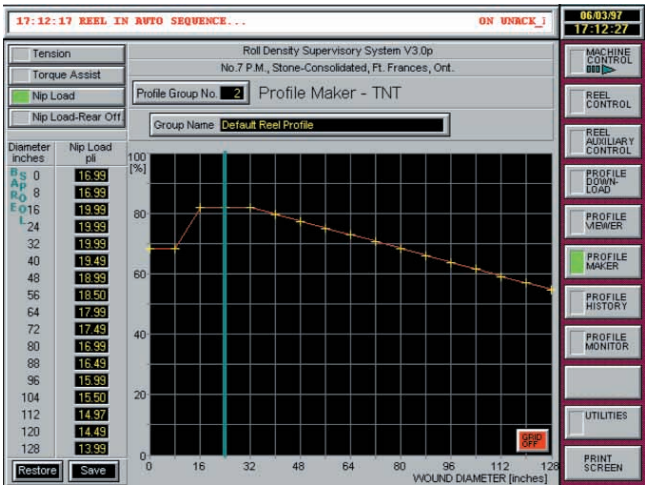
Feature 1. Figure 12 shows the paper machine Speed and Draw (SPAD) Indication screen, which displays speed and load of each section and draw between sections. Touching the TO DRAW CALCULATOR pushbutton allows the operator to view the actual speeds (A and B), draw (B–A), percentage draw [(B–A)/B], and draw ratio (B/A) between any two drive sections. Figure 13 shows the Draw Calculator screen.

The Speed and Draw Profile Maker screen, shown in Fig. 14, is accessible from the SPAD screen. This allows the operator to view and modify the operating setpoints or to save them as a recipe. The recipe can be recalled and downloaded to the drive control system.

A snapshot of the current machine sectional speeds and draws can be saved and compared with the current paper grade being produced. This enables faster startups when paper grades are changed. Operators simply choose the appropriate recipe and download it to the drive control system. All drives will than ramp to the preset speed and draw settings.

Feature 2. The trending feature, shown in Fig. 15, provides the ability to plot variables versus time. Four variables are selected from a list of predefined tags, and the assigned color pens display their values over time. Figure 15 shows an example of a paper break at the reel with the following variables:

- Calender motor load (amps)
- Reel tension feedback (average)
- Calender speed feedback (ft/min)
- Reel centre motor load (amps).



21. Reel Profile Maker

The LIVE pushbutton toggles between viewing current data and historical trend viewing. With the Live mode turned on, displayed data are updated every 15 seconds. When the Live mode is turned off, information displayed on the screen is frozen, permitting historical data to be viewed. The left and right arrow controls provide the ability to zoom to any part of the graph. The data displayed are read from the historical logging computer, which stores information for the last 5 days. Approximately 200 MB of hard disk storage is required for each day saved.

Feature 3. Interlock diagrams, current alarms, and event-history screens can be accessed from the HMI main menu. These features are discussed in detail in the literature *(2, 3)*.

Feature 4. A typical Section Drive Diagnostics screen is shown in Fig. 16. Drive-related faults or alarms are summarized and displayed. Part of the screen is a menu that is used to select one of the sectional drives. The operator

is able to view the faults or alarms that caused a drive to stop or will not allow it to start.

Feature 5. A Utility screen gives operators access to communications status, computer diagnostic information, and a clean touchscreen window *(2, 3).*

A system security log-in feature is also accessed from the Utility screen. The user may log on to the HMI system to change machine profiles or settings that are normally inaccessible to the operators. When logged on as a system administrator, the user has the ability to set and synchronize the HMI computer clocks. The HMI application can also be updated after a programming change is made on the development computer.

Three significant features were included through the HMI to the paper machine: web-break reporting, machine startup sequence checklist, and reel control.

Feature 6. The Web Break Reporting facility allows custom reports to be created and printed automatically after a web break. The HMI software monitors the web-break detectors. When a break occurs, the system prints out a detailed report containing graphs of section speed, section load, and web-break detector status.

Archived data are recalled from the PC, and a trend graph displaying information 4.5 min before and 30 seconds after the break is printed for every section. This 5-min timeframe focuses on the data relevant to the web-break event. Since the information is shown graphically, the location and possible cause of the break can be quickly verified. Figure 17 is an example of a Web Break Report screen detailing a break that originated in the first dryer section.

Feature 7. The Machine Start-Up Sequence Check List, shown in Fig. 18, is one of two screens that has been included in the HMI to assist an operator at startup. As each task is completed, the operator confirms the task by pressing the yellow pushbutton to toggle the checkmark. Many steps can be displayed automatically if they are controlled from the HMI. In this case, a red pushbutton is pressed to display a screen showing the appropriate controls. When a step is completed, a green checkmark will appear.

Feature 8. Figure 19 shows the Reel Control screen, which provides the dry-end operator with direct access to all important reel control functions. They are the reel DC drives, secondary arms, primary arms, turn-up nozzle, and automated turn-up controls. Once an automatic sequence has been enabled, the reel will turn up at a preset diameter or length. A countdown timer, animated graphic, external horns, and warning lights notify the operator of the pending turn-up.

The reel operator is able to enter a precise diameter setpoint through the HMI to reduce the residual paper left on the reel spool at the winder. This is achieved by first entering the number and size of sets to be made and the thickness of waste paper to be left on the spool. The GUI application computes the reel diameter required and downloads the setpoint to the master drive controller, which determines the precise turn-up point.

The reel roll-density monitoring and control upgrades the existing reel to include the equivalent of a winder tension-nip pressure-torque difference (TNT) roll-density system. Load cells added to the primary and secondary arms monitor the applied nip pressure. Load cells added to the paper roll before the reel measure paper tension. Centerwind torque assist is applied by the DC drive (installed in 1988). Resolvers added to the pivot points of the primary and secondary arms monitor positions. Infrared optical sensors identify each reel spool and measure rotational speed. Data generated from these devices are used to monitor and control the built-roll density.

Using the HMI Roll-Density Supervisory System *(2, 3),* TNT curves or profile groups can be modified through the screens to alter the wound-roll parameters. As a roll is building at the reel, the calculated wound-roll density is displayed, as shown in Fig. 20, the Profile Viewer screen. This is a real-time trending chart, with four variables selected from a table of twelve.

In Fig. 20, the variables are tension feedback (FBK), wound-roll density, nip load back FBK, and nip load front FBK.

If a TNT curve in a wound-roll density profile group is too high or low, a new profile group can be downloaded to the master drive controller. This system improves the quality of parent rolls by providing tools to reduce wrinkles and enhance the building of a paper reel. Higher-quality-wound parent rolls result in smooth winder operation with fewer breaks.

Figure 21 is an example of a TNT Profile Maker screen. It shows how the 17 points of a nip load curve can be changed over a diameter range of 128 in. The same applies for tension, torque assist, and nip load-rear offset. A new profile group can be downloaded any time during reel building.

Twelve variables for each reel are stored and accessed through the Profile History screen *(2, 3).* Any reel can be selected for display in the Profile History screen from the Profile Recall screen. This screen contains a list of reels wound on a specific day. One reel can be selected and four variables at a time displayed in the Profile History screen. Three months of reel data are stored before external archiving is required.

CONCLUSIONS

Advancing technology allows precise monitoring and control compared to existing control systems.

Today's improved computer hardware, software, and operating system allow PC-based, object-oriented graphical user interfaces to reliably exist on the operating floor. Through careful design, an HMI system can provide an enormous amount of information to an operator. This increases the operator's understanding of the process and improves overall machine efficiency.

Future improvements to software and hardware will make HMI systems easier to implement, faster, and more robust as well as allow the paper machine to be more productive. One improvement is to link the HMI system to the existing millwide information system. Personnel throughout the mill will then be able to conveniently monitor the drive and control system status.

The installation discussed here was completed in early 1997. Mill personnel found the system to be user friendly and accepted the system with confidence. The HMI displayed information not previously available. Mill personnel were able to see and understand areas of inefficiencies that could easily be resolved.

One of the first significant improvements was the reduction of waste paper left on the reel spool at the winder. On average, the operators were able to reduce the residual paper from 4 in. to less than 2 in. using the HMI.

The paper machine startup speed was approximately 2850 ft/min. This will gradually increase as minor mechanical improvements are made. The HMI assists the operators with troubleshooting, improving startups and reducing downtime. **TJ**

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