Case Study –
Development of a Custom Hilliard Smart Brake Control System to Manage Tensions on a Conveyor Take-Up Winch

Michael Murray – The Hilliard Corporation, Elmira, New York

ABSTRACT

As bulk material handling machinery designs become more powerful and increasingly efficient, braking system designs must also progress to satisfy the demand to control speed and stop machines in routine and, most importantly, during emergency stopping events.

Brakes are no longer straightforward *on* or *off* mechanical devices. Sophisticated *Smart Brake* deceleration controls with system status monitoring, fault acknowledgement and feedback are required to maintain system integrity under all stopping conditions. This is particularly crucial on belt conveyor systems, where tension management and personnel safety are of paramount importance.

Following is a case study regarding the development of a customized Hilliard *Smart Brake* control system, designed to manage tensions on an overland coal conveyor tension winch.

INTRODUCTION

In mid-2008, Hilliard was approached by a conveyor manufacturer and asked to develop a specialized brake system for use with a constant tension winch, to be installed on a new four mile long cable supported coal conveyor at a steel mill in Eastern Europe.

CABLE SUPPORTED COAL CONVEYOR

The winch would utilize a 125 horsepower electric motor to drive a wire rope drum with cables and sheaves to maintain conveyor belt tension during all phases of conveyor operation. Under normal conditions, the winch would pay cable in or out as needed to maintain the necessary tension on the conveyor belt. However, the winch could not be allowed to release tension completely in the event of a system-wide power failure or control fault. It was deemed costprohibitive to provide a back-up power system to operate the winch motor. Hilliard was solicited to supply a *smart brake* system to ensure that the winch tension could be maintained and/or reduced in a controlled manner, in the event of an electrical supply failure or at the loss of the winch control signal. Based on the dynamics of the conveyor system, the brake would need to increase and/or decrease torque on the winch drum in order to manage the cable tension.

A brake torque rating of 16,500 Lb·Ft (22,370 Nm) on the output side of the gearbox was required to hold the winch under the maximum tension setting.

The client would monitor the operation of the conveyor system and control the winch drive to maintain adequate belt tensions under normal operating conditions. Two 4-20 mA signals would be sent to the Hilliard brake controller; one signal representing the actual tension of the winch and the other representing the target tension for the winch. These signals would be used by the brake controller to determine and maintain the required brake torque at the winch.

DESIGN APPROACH

The project involved the adaptation of a standard, proven *smart brake* system to:

- Generate and modulate the required braking torque based on input signals from the client's control system.
- Control the brake torque on the winch for up to 60 seconds after a power failure.
- Function in low ambient temperatures at site, which could reach -20°F (-29°C).

A Hilliard BrakeBOSS™ electro-hydraulic *smart brake* controller was modified to suit the winch brake control requirements.

Based on the torque and kinetic energy requirements, Hilliard utilized two model GMRSH Spring-Applied, Hydraulic-Released caliper disc brakes, each producing a maximum tangential force of 7,870 Lbf (35kN) at nominal stroke. The calipers act on a 30-inch (762 mm) diameter brake disc, fitted to a single-engagement flexible gear coupling situated between the gearbox and the wire rope drum of the winch.

This case study is focused on the specialized brake controls, therefore, details related to the disc brake calipers and associated equipment is purposely limited.

The BrakeBOSS™ hydraulic control system incorporates an electro-hydraulic power pack with a programmable logic controller (PLC) to continuously adjust the braking torque produced to follow a preselected profile.

The design utilizes high-quality, commercially-available components, including:

• 2 HP motor and integral gear pump, mounted to a 5-gallon reservoir.
• HYDAC cartridge-style poppet valves (near zero leak-rate) with manual overrides.
• Solenoid coil plugs with LED indicators to aid in troubleshooting.
• Allen-Bradley Micrologix™ controller (PLC).
• Allen-Bradley PanelView™ Plus Graphic Terminal (HMI).
• SUN Hydraulics® electro-proportional relief valve with Lynch™ digital display driver.
• Siemens SITOP DC power supply and uninterruptable power supply (UPS) battery back-up.
• High-pressure filter with electrical clogging indicator.
• Hand pump for manual operation.
• NEMA 12 enclosure.
• Hydraulic accumulator bank.

The Hydraulic Circuit is shown in figure 1. An electric motor, coupled to a gear pump, supplies high pressure hydraulic oil to charge the system. Oil flows through the high pressure filter (PF1) to remove contaminants that are 10 micron and larger in size, ensuring that the oil remains clean in the system. Pressurized oil charges the accumulator (ACC1) to the system pressure. Once system pressure is achieved, the electric motor is switched off via the PLC and a heavy-duty contactor. Solenoid operated directional valves control the flow of oil to the brake. The supply side solenoid valve (SV1) is normally closed and maintains the system pressure in the system accumulator (ACC1). The return side solenoid valve (SV2) is normally open and controls the return of oil to the reservoir. The two valves are solenoid operated and spring returned to the normally closed and normally open positions respectively. To release the brake, the valves (SV1 and SV2) are shifted when the PLC energizes the solenoids. During the tension control sequence, the brake control valve (SV3) is opened to allow fluid to pass through the electro-proportional relief valve (RV3) and return to tank.

When the PLC de-energizes the solenoids on the valves (SV1 and SV2), the valves return to the normal position, causing the brake line pressure to rapidly flow to the reservoir to apply the brake. During controlled braking, power is applied to the valves (SV1, SV2 and SV3), allowing the returning fluid to pass through the relief valve (RV3) and return to the tank. Initially, the relief valve (RV3) rapidly reduces the pressure to a pre-set level so that adequate braking torque is produced to counteract the out-of-balance load torque on the winch. The PLC then uses a proportional–integral–derivative (PID) loop to adjust the hydraulic pressure through the relief valve (RV3) as needed to maintain the necessary brake torque on the winch.

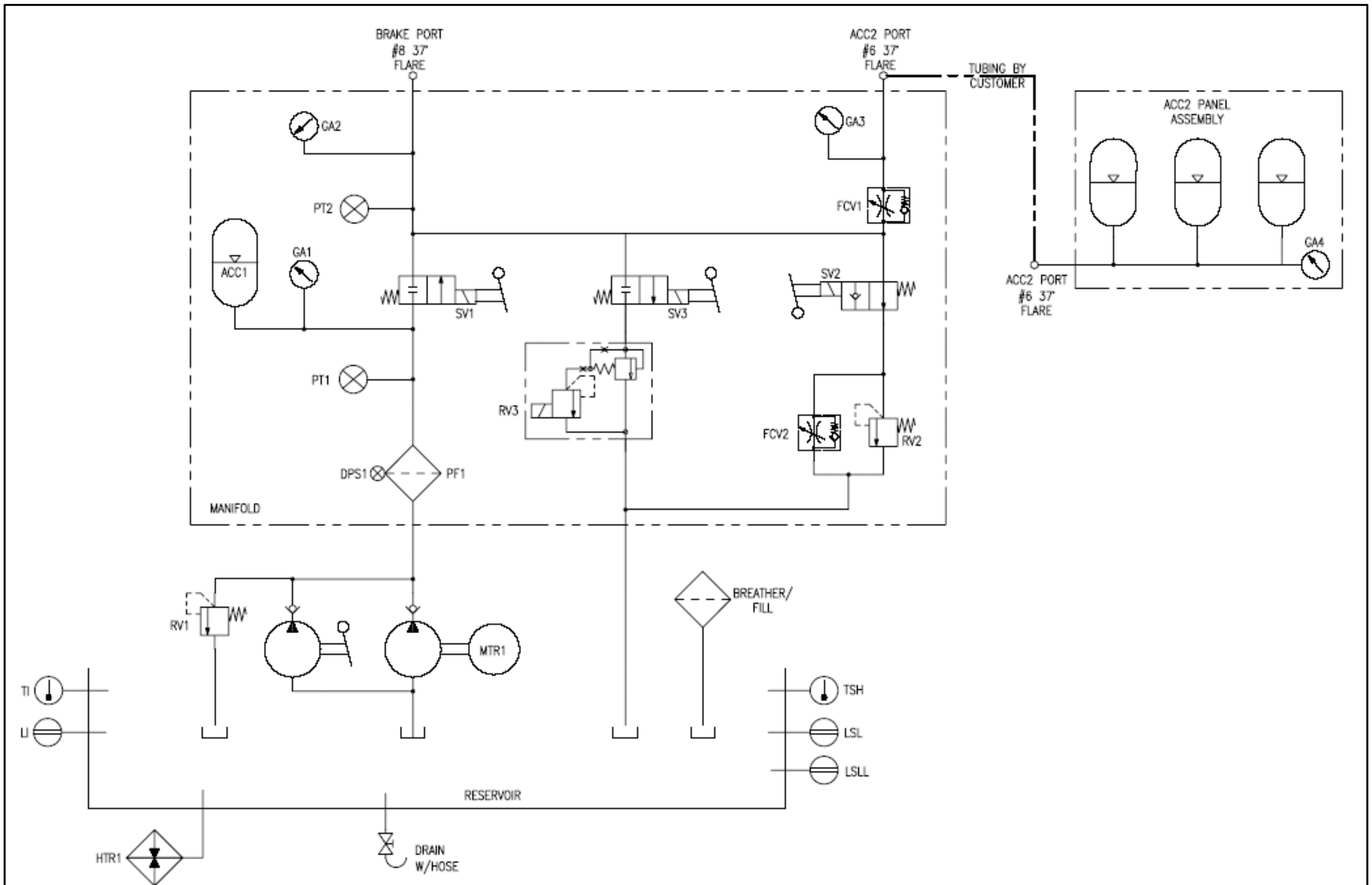


FIGURE 1 – HYDRAULIC CIRCUIT

An Uninterruptable Power Supply (UPS) is used to supply power to the PLC and valves during a power failure. However, this UPS is not capable of operating the pump motor to maintain hydraulic pressure. To ensure sufficient fluid volume to control the brake torque for up to 60 seconds without operating the pump, an accumulator bank consisting of three 2½-gallon accumulators is included. These accumulators are mounted in a separate cabinet, located adjacent to the BrakeBOSS™ control unit.

All components were reviewed with respect to operating at the low temperature of -20°F (-29°C). The standard hydraulic seals in the caliper brake are adequate. Because condensation is a concern at lower temperatures, the PLC and HMI are rated with a minimum operating temperature of 32°F (0°C). The solenoid valves are rated to -4°F (-20°C). Strip heaters are used in the BrakeBOSS™ and accumulator enclosures to maintain temperatures above 32°F (0°C).

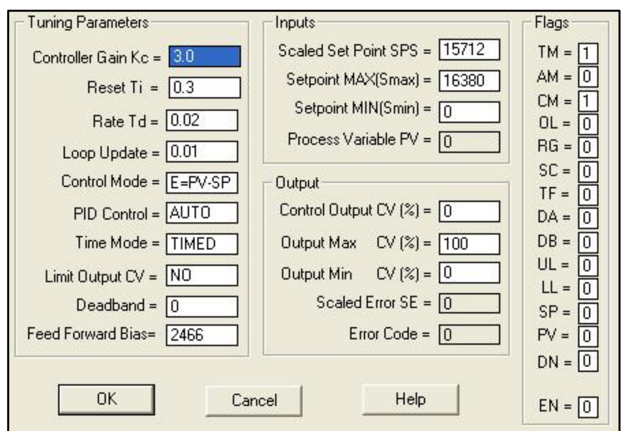
Exxon Mobil Corporation's Univis HVI 26 hydraulic oil is specified based on its outstanding viscosity characteristics over a wide temperature range, to maintain excellent fluidity conditions at low temperatures. Hydraulic seals for the caliper brakes, hydraulic power pack and valves are confirmed as being compatible with this fluid.

OPERATING MODES

Closed Loop Control Mode provides smooth and consistent brake torque adjustments under all operating conditions. The controller is calibrated at the factory according to the parameters provided by the client. Changes to the system settings are made through the operator interface (HMI) located on the outside of the logic panel enclosure.

When used for conventional conveyor stopping brake functions, the BrakeBOSS™ control PLC accepts input from a speed encoder mounted on a pulley shaft and uses this information to control the brake pressure accordingly. For this winch project, the PLC program is modified to accept two client-supplied 4-20 mA signals, one representing the actual tension of the winch and the other representing the target tension for the winch. Based on these input signals, the PLC uses a proportional–integral–derivative (PID) loop to modulate the electro-proportional relief valve (RV3), thus changing the brake torque on the winch. The goal is to achieve convergence of the actual and target values so that the actual winch tension matches that of the target.

A PID window is established so that the PID loop can adjust the brake smoothly, without triggering a fault. The PID loop continues to adjust the brake torque to make the actual tension equal the target tension, even as these values fluctuate based on system dynamics. The range of this window is user adjustable, but is typically set to ± 10% of the target value. Momentary deviations outside of this window are permitted. However, a fault is triggered and the brake control system automatically enters fail-safe braking mode if the actual value remains outside of this window after a pre-set time delay. This user-adjustable time delay interval is usually set to 10 seconds.



PID LOOP SETUP SCREEN

Fail-Safe Mode is illustrated in Figure 2. If the control signals are lost, or there is a PLC or hydraulic valve malfunction, the control system will default to fail-safe mode. This provides a quick setting brake with very smooth application of brake torque to minimize the shock load on the winch. However, the fail-safe mode always produces the same braking torque, regardless of the tension requirements of the conveyor.

The brake is applied to the CONTROLLED BRAKING TORQUE level and then maintained at that torque for 60 seconds. The system uses the accumulator bank (ACC2) on the output of the manifold to provide sufficient volume of hydraulic fluid to maintain the CONTROLLED BRAKING PRESSURE. Once the accumulator bank has completely discharged, the brake will produce full static torque. Balancing the flow control valve (FCV2) on the manifold with the quick set relief valve (RV2) allows for calibration of the fail-safe braking performance, taking into consideration the overall system design and performance characteristics. These valves are factory set, but can be fine-tuned in the field if different fail-safe braking performance is desired.   The factory settings of these valves are listed on the door of the enclosure and on the drawing provided for the system.

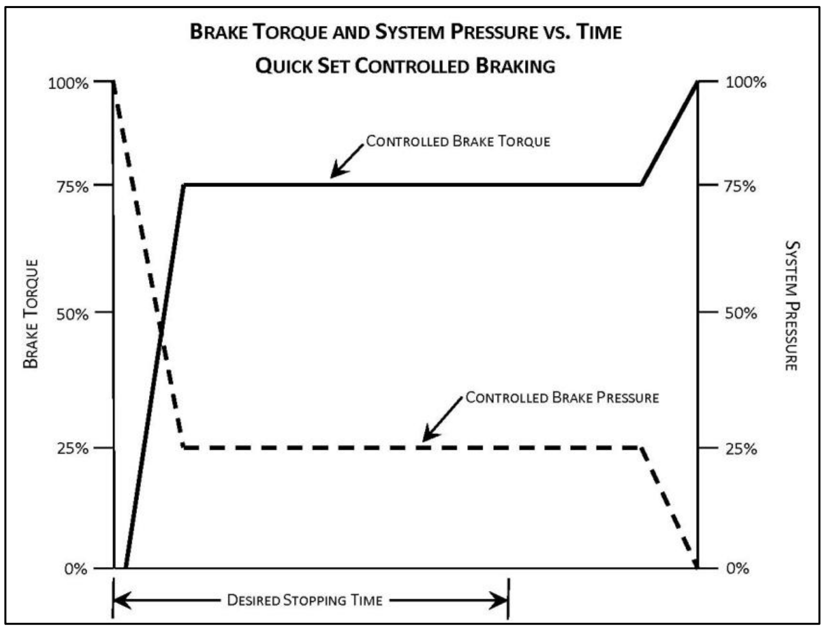


FIGURE 2 – QUICK SET CONTROLLED BRAKING

USER INTERFACE AND FEEDBACK

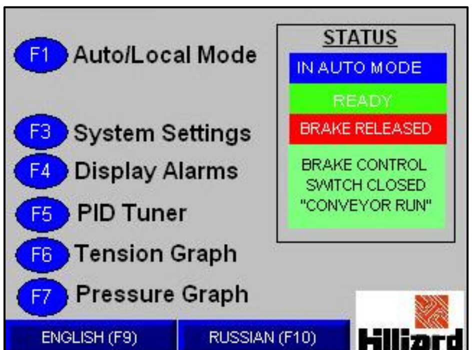
In addition to the 4-20 mA tension signals, the client provides a Brake Control Switch (BCS), a 24 volt DC relay that provides a run signal that is used to apply and release the brake system. When the PLC reads a closed BCS, the appropriate hydraulic valves shift, thus providing pressure to release the brake.   When the BCS relay is opened, the PLC initiates a controlled braking sequence.

The BrakeBoss™ PLC communicates the current system status to the client's control system via two hard-wired relays, one indicating *system ready* and the other indicating *system ready with alarms*. The brake apply/release control is initiated by the user. The client's control routine should allow the BCS to close only when a *system ready* signal is active and should automatically open the BCS when the *system ready* signal is removed. If a fault occurs, the *system ready with alarms* signal is activated in addition to the *system ready* signal.

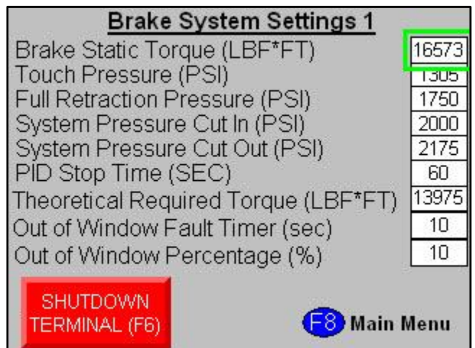
A system ready condition indicates that the system is in Auto mode. If at any point the system ready signal is removed, the BCS must be opened by the client's controls. The system ready signal is not active while the system is in Local mode.

A system ready with alarms condition indicates that there is a fault which should be corrected. This signal does not disable the brake controller, but is used to inform the user that a fault exists. The system ready with alarms signal is independent of the system ready signal. Faults and alarms are described later.

The brake system status is displayed on the main menu screen in the upper right hand corner.



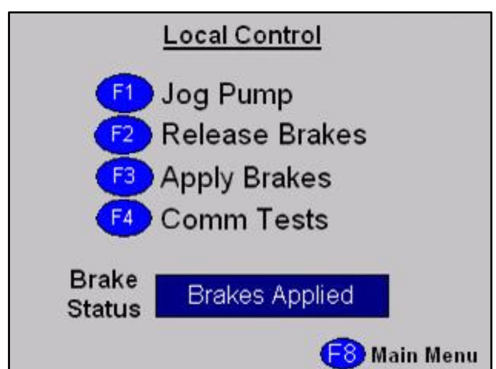
MAIN MENU SCREEN



BRAKE SYSTEM SETTINGS SCREEN

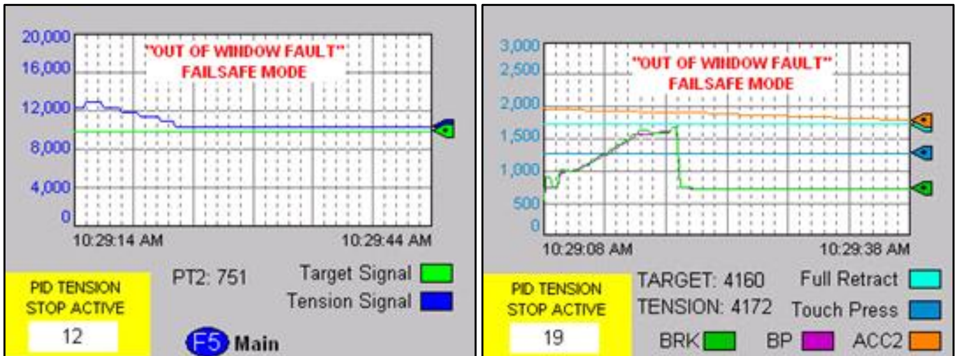
The user settings are adjusted via the brake System Settings pages that are accessed through the menu screen.

Local control mode allows basic brake operations to be performed at the BrakeBOSS™ controller, including releasing and applying the brake. Care should be taken that these options are not used in any situation where a runaway or out of balance load condition exists on the machine. A communication (Comm) test is used to verify that all indicating sensors are communicating properly with the user's controls. While in local control, the ready signal is removed and the user's control cannot operate the system. The PLC will not allow the system to be returned to Auto Mode unless the brake is in the applied position.



LOCAL CONTROL MENU SCREEN

Tension and pressure graphs displayed on the operator interface (HMI) are used to evaluate the performance of the system when tuning the closed loop control. The tension graph displays the winch tension during a brake tension control sequence. The pressure graph displays the adjustments to the hydraulic brake pressure during a brake operation.



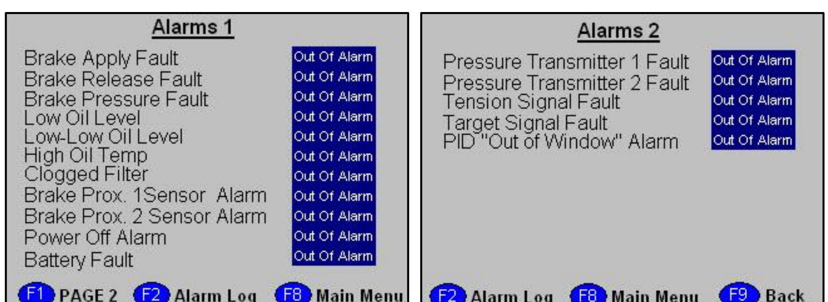
TENSION AND PRESSURE GRAPH SCREENS

Faults and Alarms alert the user to system anomalies. The PLC monitors the vital components in the brake circuit, allowing for easy fault recognition and reduced diagnostic time. The user identifies the brake system faults based on the state of registers at defined addresses in the PLC, accessed via a connection to the Ethernet hub located in the junction box.

The functions monitored and alarms generated are as follows:

Brake Apply Fault - In Alarm when the control indicates that the brake is applied but one or more of the brake proximity sensors are closed, indicating that the brake is released. Also in alarm if the PLC is in local mode with the brakes applied, but one or more of the brake proximity sensors are closed, indicating that the brake is released.

Brake Release Fault - In Alarm when the control indicates that the brake is released, but one or more of the brake proximity sensors are open, indicating that the brake is applied. Also in alarm if the PLC is in local mode with the brakes released, but one or more of the brake proximity sensors are open, indicating that the brake is applied.



ALARM DISPLAY SCREENS

Brake Pressure Fault - In Alarm when the pressure transmitter (PT2) detects that the pressure in the manifold is above the brake release pressure, but all proximity sensors are open, indicating that the brake is applied. Also in alarm when the pressure transmitter (PT2) detects that the pressure in the manifold is below the release pressure of the brake, but all proximity sensors are closed, indicating that the brake is released.

Low Oil Level Fault - In Alarm when the oil level is low in the reservoir, indicating that maintenance is required.

Low-Low Oil Level Fault - In Alarm when the oil level is too low to safely operate the pump. The PLC will disable the pump motor and not allow the pump to turn on until oil has been added to the reservoir.

High Oil Temperature Fault - In Alarm when the oil in the reservoir increases above a preset temperature.

Clogged Filter Fault - In Alarm when the differential pressure in the filter housing reaches a pre-set level, indicating that the filter cartridge is dirty and should be replaced.

Brake Proximity Sensor Alarm - In Alarm when the pressure in the manifold is above the brake release pressure, indicating that the brake is released, but any one proximity sensor is open, indicating that the brake is applied. Also in alarm when the pressure in the manifold is below the brake release pressure, indicating that the brake is applied, but any one proximity sensor is closed, indicating that the brake is released.

Power Off Alarm - In Alarm when there is an interruption in the main input power to the controller.

Battery Fault - In Alarm when the battery relay contact is closed, indicating a de-energized or disconnected battery.

Pressure Transmitter Fault - In alarm when the signal generated by the transmitter is less than 3 mA, which identifies that the transmitter is inoperative.

Tension Signal Fault - In alarm when the tension signal to the PLC is severed or there is a PLC hardware malfunction.

Target Signal Fault - In alarm when the target signal to the PLC is severed or there is a PLC hardware malfunction.

PID Out of Window Alarm - In Alarm when the actual tension is out of the set window percentage of the target tension, beyond the preset time delay.

BRAKEBOSS™ CONTROL UNIT DURING FINAL ASSEMBLY

TESTING AND VERIFICATION

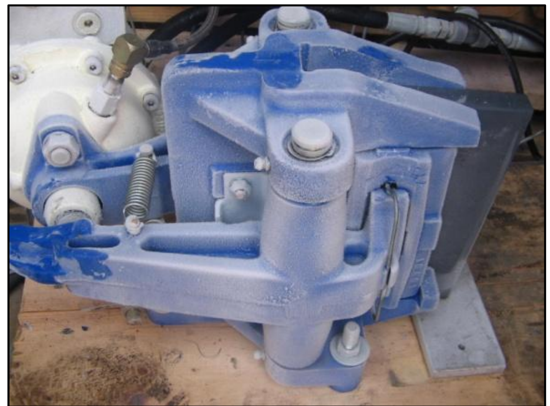
Prior to delivery, the client required verification of the brake system when operating at the anticipated low ambient temperature of -20°F (-29°C). Testing was carried out in Hilliard's dedicated cold-room facility, a fully insulated building which utilizes refrigeration units to maintain low ambient temperatures for product testing. The brake system was installed and connected in the cold-room for verification. Pressure transducers installed at the brake cylinders and hydraulic manifold were monitored by the brake controller PLC and data was transmitted via Ethernet to a notebook computer (PC).

TEST PREPARATIONS IN COLD ROOM

Thermocouples mounted in the oil reservoir, logic panel, uninterruptable power supply (UPS), accumulator cabinet and in the room were used to measure temperatures. Data acquisition equipment was used to record these values.

Custom programs were created to monitor all systems during testing. Performance was displayed graphically in real-time and also saved to data files for further analysis.

The brake system was operated in all possible scenarios and results were recorded. The system was verified to be fully-functional at -20°F (-29°C) and the client subsequently certified the design.



GMRSH BRAKE AT -20°F

INSTALLATION AND COMMISSIONING

The brake system and tension winch were installed and commissioned in May of 2011. Hilliard service engineers were at site to assist with start-up and to verify the brake system operation. During commissioning, minor inconsistencies were identified, diagnosed and rectified.

The user's analog tension signal cables were not properly shielded, resulting in electrical interference and nuisance brake fault alarms. Although the cable shielding was corrected, the user added digital signals transmitted by Ethernet, to ensure the quality and reliability of the control signals. The PLC program was modified so that the system reverts to the analog signals for control input, in the event of Ethernet communication failure.

A Park Mode was added for use when the tension winch is operated manually. When the PLC receives a dedicated park mode input signal from the user, the brake is applied fully, bypassing the closed loop and fail-safe modes.

A Communication Alarm was added to identify when there is an interruption in the Ethernet connection.

Additionally, the user's main input power to the brake unit was problematic. The supply voltage would often drop off significantly, causing a reduction in the horsepower capacity of the pump motor. At reduced horsepower, the operating pressure could not be reached and the pump motor continued to operate. The result was overheating of the oil in the reservoir which eventually triggered the high oil temperature alarm. Once recognized, the end-user resolved the voltage inconsistency to ensure adequate input power for the system.

CONCLUSION

By applying comprehensive design expertise and wide-ranging knowledge of industrial brake systems, Hilliard successfully developed and delivered a state-of-the-art *smart brake* control system for this conveyor tension winch project. The client and the end-user are pleased with both the equipment and with Hilliard's outstanding on-site service.

The equipment and control logic design for this project is based on Hilliard's field-proven BrakeBOSS™ H3 brake controller. Since the installation of this system, several additional systems have been delivered to clients for use on various bulk materials handling equipment.

TENSION WINCH WITH BRAKEBOSS™ *SMART BRAKE* SYSTEM