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Bridge Speed Controlled By Closed Loop Control of the Hydraulic Pump Motor Speed

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Introduction

The Matlacha replacement bridge is owned by and located in Lee County, Florida. It is a single leaf, Bascule Bridge with a hydraulic operating system comprised of two cylinders, two 60 Hp

main pumps and a 5 Hp auxiliary pump that serves double duty as a conditioning system pump and a backup, manually controlled bridge operating pump. The leaf is counter weight assisted, which means that the leaf is significantly tip heavy. The innovative design of this system includes use of vector controlled adjustable speed drives for the pump motor speed control with feedback from the bascule leaf, itself, to provide control of the actual leaf speed rather than the flow to the hydraulic cylinders. This provides for consistent operations regardless of wind conditions or oil viscosity. The second innovation is the use of a single hydraulic pump when closing, to reduce energy consumption.

Purpose of the Design

The typical hydraulic bridge operating system is such that the pump motors are run at full speed with constant pressure, controlled by a proportional pressure relief valve and variable flow, controlled by a proportional directional control valve. The ideal speed/position curve is trapezoidal with the leaf accelerating uniformly, then running at a constant full speed, followed by a uniform deceleration to approximately 10% of full speed, then abruptly stopping at the full closed or full open position. In reality, it is the speed of the hydraulic cylinder that is being controlled with preset flow rates in the control valve amplifiers. The speed of the leaf is an approximation of the trapezoidal curve because the motion of the hydraulic cylinder is linear while the leaf is angular. This is not necessarily a problem when operating the bridge except during those last few degrees when closing and seating the leaf. Because the Matlacha bridge is a single leaf the live load supports are at the tip of the leaf rather than at the bascule pier. Thus, the closure speed between the leaf and the live load supports is greater than a double leaf bascule. The initial goal of the design was to better control the speed of the leaf at low speed when seating, but as the design developed, there were opportunities to reduce the energy costs, reduce field start up time, and provide for multiple levels of redundancy.

Design Considerations

The design development was driven by the following:

- Smooth Repeatable Operation
- Energy Savings
- Ease of Startup
- Redundancy

Smooth Repeatable Operation

The control of the hydraulic system was a merging of valve control and motor control. The system had to provide for high flow for full speed operation and low flow during slowdown and stopping, especially during seating. Typically, the counterbalance valves and flow control valves are sized for the full flow but at low flow they are inefficient and have a tendency to operate erratically as the valves pinch off then relieve pressure. In some cases, two counterbalance valves, one for full flow and one for creep speed flow, are provided for each direction. The speed of the hydraulic cylinder is typically controlled by a proportional, directional control valve and system pressure is controlled by a proportional control valve to prevent slamming of the system when the directional valve is cracked open. The control valves are typically preset for anticipated conditions and do not provide for speed control of the actual driven leaf because they do not react to changes in oil viscosity, wind loading, or the changing of the leaf moment as it rotates.

The Matlacha design uses the pump motor speed for speed control. The directional control valves and pressure control valve are simple solenoid operated valves that operate simultaneously with the energization of the pump motors. The acceleration and deceleration of the leaf is controlled by the ramp programming in the VSD motor controllers. As the directional valve is already open when pump motors start the acceleration is smooth and very similar to a machinery operated bridge.

When opening the bridge both pump motors accelerate and operate at full speed until the leaf reaches the nearly open limit switch. Slowdown is controlled by ramping both pump motors down, then stopping one pump. Creep speed is maintained by a single pump motor until it is stopped at the full open limit switch. The pumps alternate lowering duty to assure that each drive is operating properly.

When closing the bridge, only one pump is used. The pump is accelerated and operated at full speed until the leaf reaches the nearly closed limit switch. The signal from the nearly closed limit switch triggers the drive to switch preset speed to reference speed. The target speed is a programmed value while the feedback signal input is proportional analog signal. The feedback signal is generated by a control loop that originates from an encoder coupled to the rotary limit switch shaft. Because there are no direct mechanical reducers or shafts in a hydraulic operating system, the speed feedback pick up device had to be driven by the trunnion shaft. An encoder was used to provide a measurable signal where a tachometer would be impractical. The encoder provides pulses to a frequency transmitter that in turn provides the proportional analog signal to the pump motor drives. The motor drive uses the feedback signal and controls motor pump speed as required to maintain a constant creep speed of the leaf as it is seated.

In this application, when landing the leaf, the drive slowed the motor to a stop while the hydraulic accumulator discharged into the system, then ramped the pump motor back up to maintain speed. The tight speed control plus the internal buffers in the cylinders produce a consistent smooth landing.

Energy Savings

In typical hydraulic systems, the all hydraulic pump motors are started prior to operation of the bridge and run at full speed for the duration of the operation. Although the pumps are usually pressure compensated and running with a minimal load they are still using energy even when the leaf is not being moved. The Matlacha system operates the pump motors only when the leaf is to be in motion. Further only one motor is being used when closing the bridge. Because the motors are not running idle when not in use and only one motor is being used for half of the cycle, energy savings approach 30% of the typical hydraulic bridge system. Operating expenses are reduced accordingly.

Ease of Start Up

The Matlacha drive system was designed to be fully operational without the control desk or main control panel. By providing the control panel with its own control power transformer and UPS, the drive system could be operated just as soon as the hydraulic system was installed and 480 volt power was available. This allowed for more complete shop testing and allowed the leaf to be operated before the control house was finished and without the installation of the control desk. Shop testing was done using a portable generator.

Local controls on the control panel doors allow for selection of local or remote control, selection of normal versus single motor operation, a raise and lower joystick, and manual-off-auto controls for the system cooling and conditioning pump. Indication lights are provided for span position, span locks pulled, pump motor running, control mode and hydraulic system warnings and shutdown alarms.

In this application, the hydraulic power unit, cylinders and piping were installed and ready to be commissioned, well ahead of the control house completion. Due to an approaching expiration of the channel closure permit, the leaf had to be operational before the control house was complete and before the leaf position limit switches and encoder were installed. The leaf was operated using the conditioning pump and the local manual hydraulic directional valve until the completion of the rest of the control system installation.

Redundancy

The combined hydraulic control system and the bridge control system provides several levels of redundancy. The leaf can be operated at normal speed using the push buttons on the control desk or the joystick mounted on the hydraulic control panel door. Indications on the door include bridge full closed, nearly closed, nearly open, fully open, and span locks pulled. The system will not operate in local control mode unless the span locks are pulled. A selector switch is provided to switch operation both pumps to single pump only in the event of a motor or pumps failure.

The oil cooing and conditioning loop is operated by a 5 hp pump. It normally operates by cycle timer or a thermostat and auto-off-manual mode selector switch is provided on the door to bypass normal operation. If both main pumps are not operational, (or during startup), the conditioning pump motor can be put into bridge operating service by closing the conditioning circuit valves, turning the motor control to manual then using the manual directional valve to direct flow to the cylinders. The conditioning pump can also be controlled from a joystick mounted the control desk.

Conclusion

Overall, the system exceeded expectations. The feedback control maintained good speed control and was consistent with either drive. The VSD allowed for adjusting operating times by keypad entry to the drives rather than tweaking tiny pots on an amplifier card with jeweler's screw driver. The pump motors could even be run faster than 60 Hz. If a drive needs to be replaced, the setup of the new drive is as simple as swapping out the keypad interface and downloading the parameters of the previous drive. The only thing that might have been done differently was the sizing of the accumulator. Although the system worked as it should, a smaller accumulator might have been less disruptive to the motor operation.