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Hydraulics/Fluid Power

Moving Heavy Structures with Pump Controlled Hydraulics

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Background

The Texas Department of Transportation (TxDOT) operates a fleet of ferries between Galveston Island and Bolivar Peninsula as an integral part of State Highway 87. This ferry system serves over 2 million vehicles and 6 million passengers each year, navigating one of the nation's busiest waterways. The present facilities consist of two ferry landings on each side of the route, with associated vehicle staging areas, vehicle loading ramps (transfer spans) and other marine structures. The design of the existing marine structures dates back to the 1970's although many of the structures have been revamped several times over the years.

Continual growth in traffic volumes and the desire to have operational redundancy led to the decision to add a third ferry landing at each terminal. For economic reasons, the plan to upgrade the facility called for the retention of one of the existing slips at the Galveston site and two of the existing slips on the Bolivar site along with the related transfer span and hoist equipment. Among the primary goals for the new facilities was to update the design of the transfer span system to improve vessel operations, improve system reliability and to reduce ongoing maintenance and repair costs.

Figure 1

Each existing slip consisted of a 29 foot long transfer span structure and its associated lift system. The transfer spans are simply supported between the fixed trestle and the vessel while loading or unloading, and are operated via a pair of hydraulic cylinders mounted to steel lift towers. A pair of wire-rope suspended counterweights act to reduce the cylinder forces required to operate the transfer span. Each terminal is equipped with a single hydraulic power unit (HPU) which provides power to operate both existing slips. A typical slip is shown in Figure 1. Both transfer spans at each site are powered via a central hydraulic power unit (HPU) located in a machinery room onshore.

The design team, working closely with the TxDOT operations and maintenance staff, selected a unique design concept for the three new transfer span locations. The new transfer span design is illustrated in Figure 2 and utilizes an overhead linkage-type counterweight system, eliminating the additional offshore tower structures.

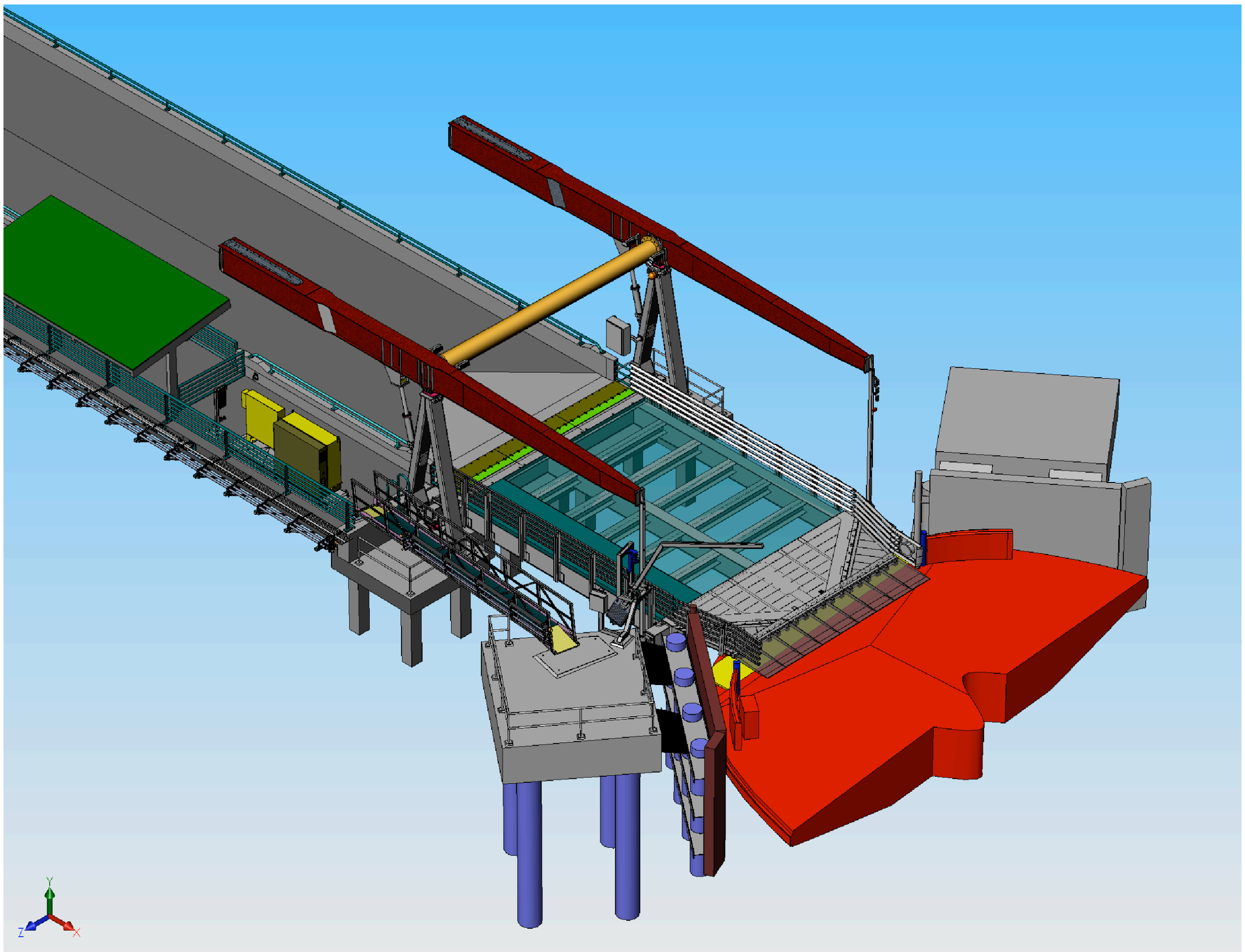

Figure 2

With the overall transfer span system concept established, the design team concentrated on developing a simple and reliable modular hydraulic system that could operate either the new transfer span design or the existing transfer spans. This remainder of this paper will discuss the unique hydraulic system that emerged from this design effort.

Design Goals

Initial discussions with the TxDOT operations and maintenance staff as well as initial site investigations identified several significant shortfalls with the existing hydraulic systems. The most critical of these shortfalls include:

- No operational redundancy (if an HPU at a site is down, neither slip at that terminal is usable)
- Sluggish performance in cold weather
- Concerns regarding with hydraulic leaks
- Corrosion protection and maintenance of cylinders in the marine environment

Any new hydraulic system that the design team developed would need to make significant improvements to address these key concerns. Because the existing transfer span configuration was to be retained at three of the existing slips, the new hydraulic system would also need to be flexible enough to operate either system.

Design Philosophy

The overall design philosophy for this new system was derived from three primary principles:

1. The overall system must be safe (no single point failure or credible failure cascade could lead to an uncontrolled movement of the span.)
2. No more than one slip should be inoperable at any point in time.
3. The new hydraulic systems must remain simple to operate, easy to maintain, and very reliable.

Overall system safety for both the existing and new transfer spans is accomplished by assuring redundancy in the primary actuators. In order to accomplish this, all of the main cylinders as well as the attaching structures would need to be designed to carry the entire unbalanced load of the transfer span as well as any dynamic loads without the assistance of the other actuator. In order to maintain reasonable operating pressures in these cylinders under normal operations, a system design pressure of 4500 psi was selected. During normal usage the hydraulic system would operate at slightly less than half of the 4500 psi design pressure. An integral counterbalance valve mounted directly to each cylinder protects the system against a sudden loss of hydraulic pressure.

In order to assure two operational slips at all times, each transfer span is operated by a single, dedicated HPU. Failure of any individual HPU will have absolutely no impact on the other two

HPUs. Redundant electrical power is available through the use of a backup generator set located at each terminal. Additionally a small mobile power unit is provided at each terminal that can be used to raise the transfer span if a power unit has failed with the span resting on the ferry deck, allowing a vessel to depart and continue operations using the remaining slips.

The relative complexity of the system is affected by a number of decisions. Should the system be pump controlled or valve controlled? Can the system operate at a single speed or different speeds for different operations? How automated (i.e. how "idiot proof") must the control system be? These issues are discussed in greater detail in the following sections.

System Details

Hydraulic control systems can be divided into two broad categories, those that rely on the pump for control and those that relay on valves. Each of these approaches has specific advantages and disadvantages for a given design situation. Theoretically a pump controlled system can be more efficient than a valve controlled system but will be slower to respond and is not as easily adapted to power multiple actuators. A valve controlled system can respond to changes in load and flow more quickly, will be stiffer (i.e. have a higher natural frequency) than a pump controlled system and is more readily adapted to operating multiple actuators but will have reduced efficiency.

In this case, we are operating only one set of cylinders and the motion control requirements do not demand a control system capable of providing a fast response to changes in load. The pump control approach is best suited for this particular design and was selected by the team.

With the basic control approach decided, the team investigated the operational requirements for the HPU. Two specific design criteria drove the operational requirements. First, all systems (existing and the new) were to use a common HPU design in order to simplify maintenance, reduce the unit cost for the systems, and reduce the quantity of spares required on site. Second, the operational requirements for the new transfer span system called for a high and low speed movement to minimize the time required to deploy and lift the transfer span. Both of these requirements pointed to the need for an HPU that could vary the available flow as required in order too achieve the desired actuator speed.

Two basic approaches were considered for providing the variable volume delivery from the HPU. The first was to use a traditional variable displacement piston pump and electro-hydraulic servo system to control the flow exiting the pump. The second approach uses a fixed displacement pump driven by a variable frequency (VF) drive. The team eventually selected the VF Drive approach because it offered significant flexibility in pump selection and a very robust and dependable method for accomplishing speed control. This decision allows the use of a special type of piston pump called a "check ball" as the heart of our HPU. This pump utilizes a check ball assembly on the outlet of each piston chamber instead of a sliding valve plate to control the outlet porting from the pump. This type of pump is extremely durable, is relatively tolerant of contamination in the hydraulic oil and is very volumetrically efficient. One other significant advantage to the check ball pumps is that multiple pistons can be ported together to form multiple output flows. In this case we decided to utilize a single, 10 piston pump with two outlet ports, each of which is served by 5 pistons. This single pump provides two nearly identical flows out to the cylinders regardless of hydraulic pressure and allows the system to be operated on a single cylinder if required.

The remaining hydraulic system design was done based on the idea of keeping the system as simple as possible. The design team wished to hold the number and type of valves to a bare minimum and to select the most robust and dependable components available for the valves required. Aside from the cylinder counterbalance valves, we have employed large single-stage, directional control valves to set the cylinder direction and a few strategically placed relief valves to provide overpressure protection to the system. The final hydraulic circuit is shown in Figure 3.

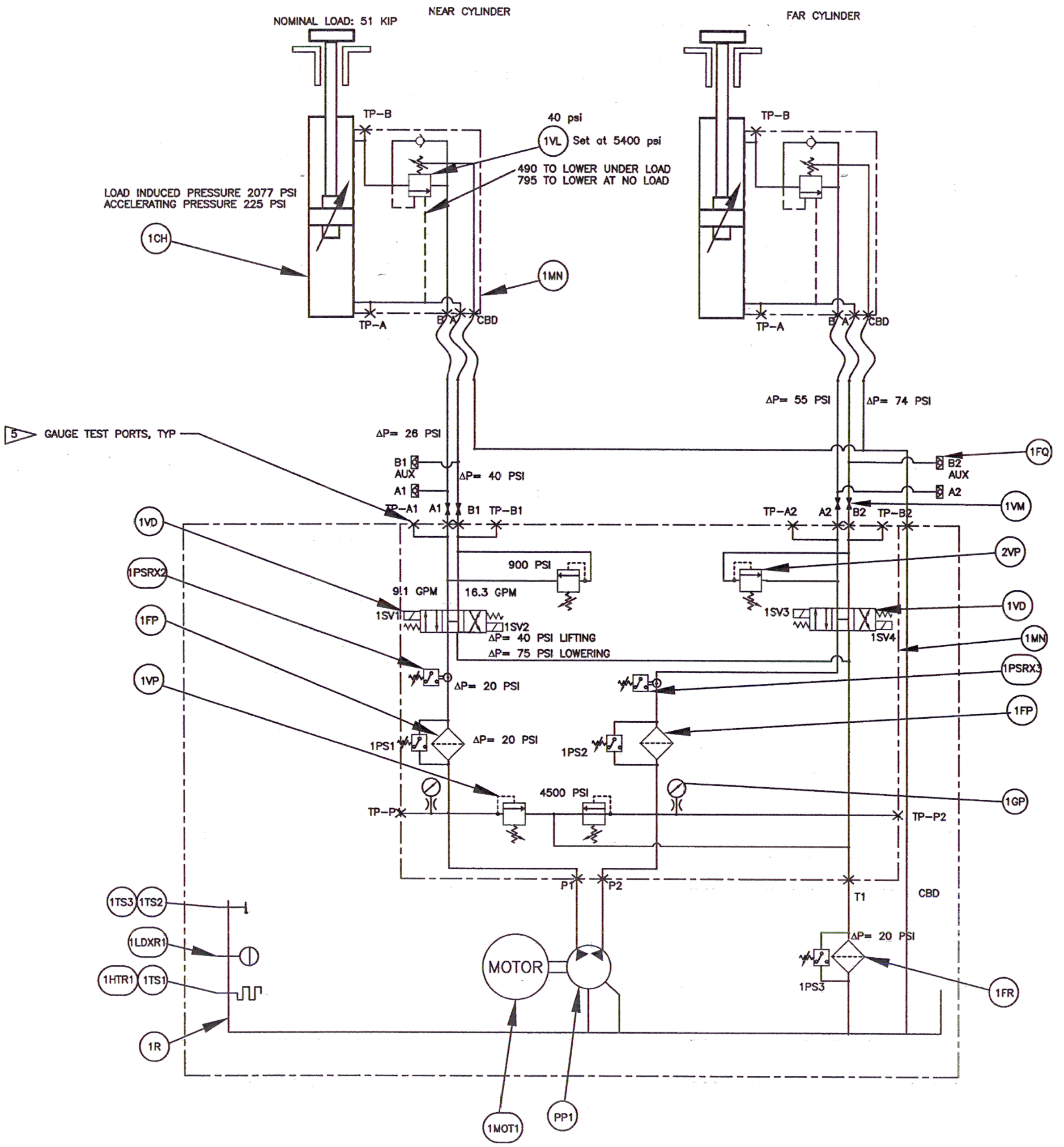
NOMINAL LOAD: 51 KIP
NEAR CYLINDER
FAR CYLINDER
TP-B
40 psi
1VL
Set at 5400 psi
490 TO LOWER UNDER LOAD
795 TO LOWER AT NO LOAD
LOAD INDUCED PRESSURE 2077 PSI
ACCELERATING PRESSURE 225 PSI
1CH
1MN
TP-A
B A CBD
ΔP= 55 PSI
ΔP= 74 PSI
5 GAUGE TEST PORTS, TYP
ΔP= 26 PSI
B1 AUX
A1
ΔP= 40 PSI
TP-A1 A1 B1 TP-B1
TP-A2 A2 B2 TP-B2
B2 AUX
A2
1FQ
1VM
1VD
2VP
1PSRX2
900 PSI
9.1 GPM
16.3 GPM
1SV1
1SV2
1SV3
1SV4
ΔP= 40 PSI LIFTING
ΔP= 75 PSI LOWERING
1FP
1PSRX3
1VP
ΔP= 20 PSI
1PS1
1PS2
4500 PSI
1GP
TP-P1
TP-P2
P1 P2
T1
CBD
1TS3 1TS2
1LDXR1
1HTR1 1TS1
1R
MOTOR
1FR
1PS3
1MOT1
PP1

Figure 3

The transfer span "float mode" which allows the span to follow the movements of the boat without interference from the hoist system is often incorporated into the hydraulic circuit. In our case we chose to incorporate a mechanical feature into the cylinder rod end connection detail that allows us to overextend the rod slightly, producing a mechanical float mode that is not dependant on the hydraulic circuit. The rod end connection detail is shown in Figure 4 below.

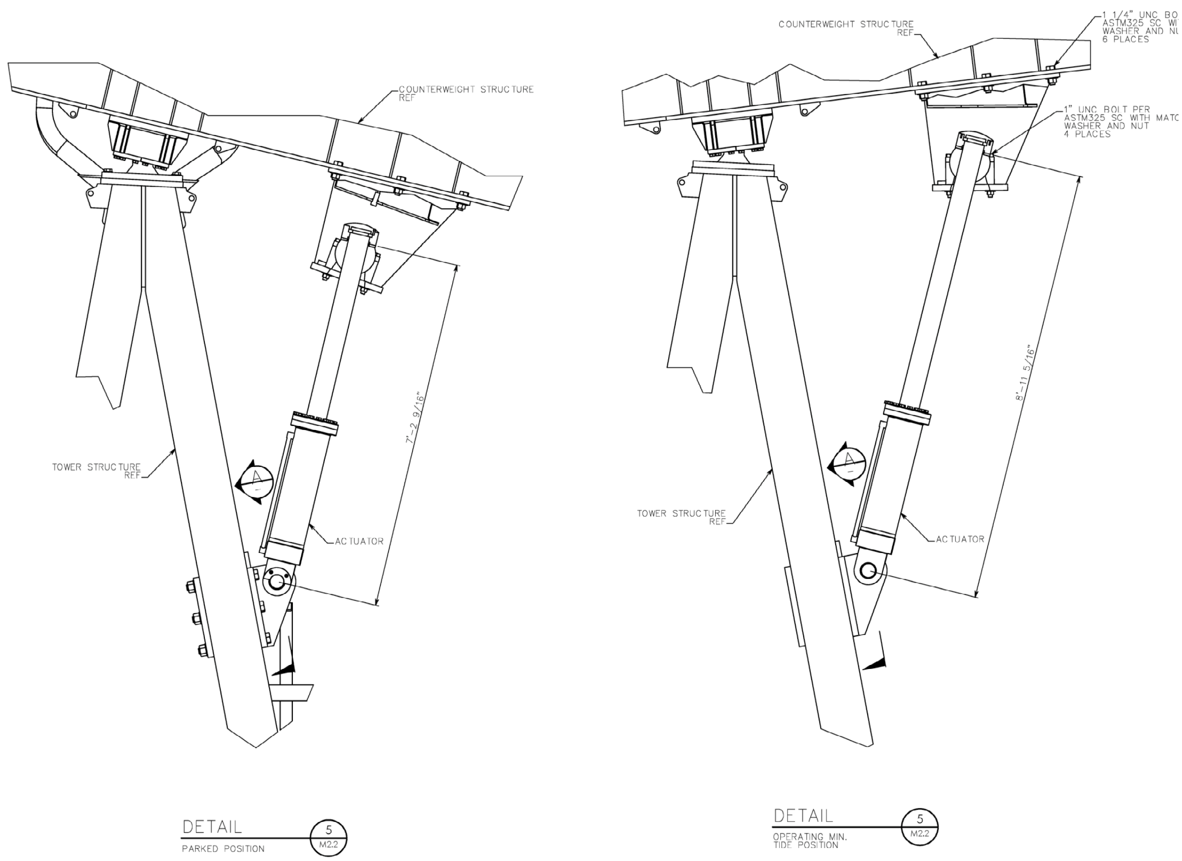

Figure 4

Conclusions

The hydraulic system presented in this paper represents a unique and innovative approach to the motion control of a heavy movable structure. The design team's goals of providing a standard power unit that was flexible enough to serve both the existing transfer span systems and the new transfer span systems have been accomplished. The team was also largely successful in developing a hydraulic system design that is simple and robust, one that should be very dependable and easy to maintain for the customer. The key design decisions that made this possible were:

- The use of pump control philosophy rather than valve control – all transfer spans are operated and controlled via a simple fixed-displacement hydraulic pump driven by a variable speed motor.
- Versatile hydraulic control units – all slips are operated via identical, dedicated hydraulic control units. This distributed and modularized installation improves system reliability and greatly simplifies maintenance.
- Mechanical "float mode" – The transfer span structure follows the motion of the boat via specially designed mechanical components, simplifying the hydraulic circuit and improving reliability of the system.

At the time that this paper was prepared, the new facilities are under construction. The hydraulic system shop drawings are under development and are likely to be complete Fall of 2004. We anticipate the first system will be complete and commissioning commenced sometime around the middle of 2005.