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Controlling Proportional Valve Amplifier Cards - Methods and Practice

by

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INTRODUCTION

There is more to moving a draw bridge than just pushing the start button, moving a joystick or turning a crank. The intent of this paper is to describe a number of different architectures for PLC control of the bridge's motion profile, and to look at the causes of leaf oscillation at the fully open and especially at the fully closed position. Draw bridges continue to be built today using hydraulic proportional control. "Hydraulic" actuation of bridge motion provides a number of options; electrical, hydraulic cylinder, hydraulic motor, and mechanical. Motion Control circuits can be either open loop or closed loop and can be accomplished in the following ways: via proportional flow/direction control, or using pump pressure and displacement control, or via hydrostatic transmission control both open loop and closed loop.

THE BASIC MOTIONS

The "classic" motion profile for hydraulic cylinder-operated draw bridges, also known as a velocity versus time curve, is a modified trapezoid. (Figure No. 1.) The opening and closing motions are comprised of: (Figure No. 2), 1) the acceleration phase, 2) a constant velocity phase, 3 & 4) a deceleration phase, 5) a creep speed phase, and 6) a final deceleration/stopping phase. The acceleration and deceleration phases generally occur within 5 to 10 seconds, the creep speed phase generally occurs within 5 seconds, the final deceleration/stopping phase occurs within fractions of a second, and the entire cycle is completed within approximately 70 seconds. The distance that the hydraulic cylinder travels (Distance = Velocity * Time) can be calculated and is equal to the area within the boundary of the velocity vs. time curve. Per Figure No. 2, the acceleration phase (section 1) is a triangle, the constant velocity phase (section 2) is a rectangle, the deceleration phase (section 3) is a combination of a triangle with a rectangle (section 4) whose height is determined by the creep speed, the creep speed (section 5) is another rectangle, and the final deceleration to stop (section 6) is represented by the smallest triangle.

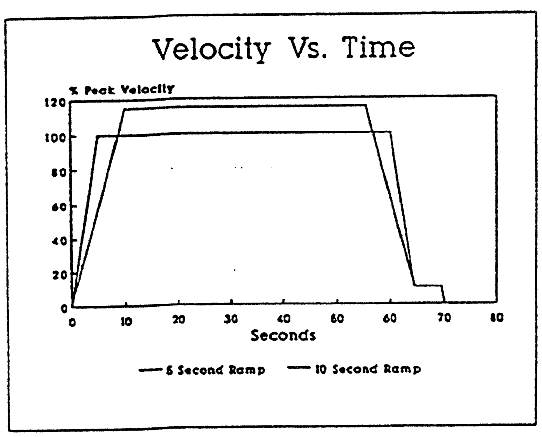

Figure No. 1

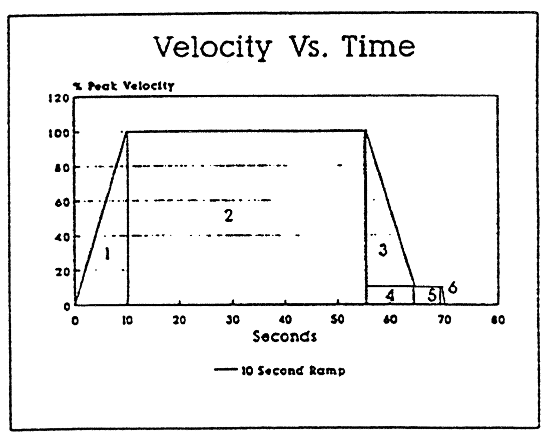

Figure No. 2

ACCELERATION & BRAKING (DECELERATION)

Acceleration and deceleration (phases) are often referred to as ramp. Referring to Figure No. 3, the slope of the "ramp" can be expressed as the change in velocity over a specific time period divided by the specific time period, or delta v / delta t, or viewed as delta leaf angle / delta t. Looking at the system from the perspective of the force being applied by the hydraulic cylinders, a portion of the force will be producing the actual acceleration, a portion will be overcoming friction and a portion will be associated with damping forces. Changes in acceleration (ramp) made in order to maintain a constant cycle time (opening/closing) can have a dramatic effect on the peak velocity of the cylinders. Changes in peak hydraulic cylinder velocity can have a dramatic effect on the location of the nearly open and nearly closed limit switches. How far the limit switches are located from the trunnion axis of rotation can also have a dramatic effect on the "resolution" of the limit switches. The greater the radial distance between the switch location and the center of the axis of rotation, the better.

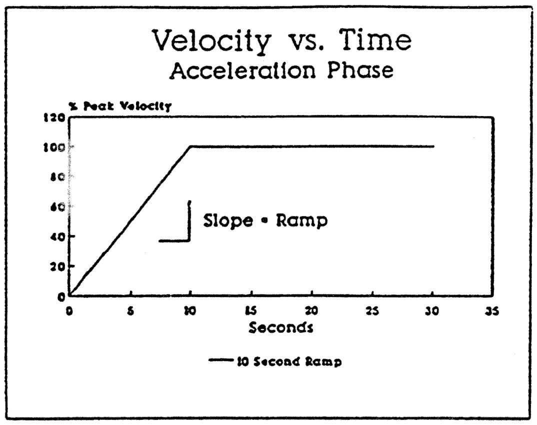

Figure No. 3

AMPLIFIER CARDS, INPUTS AND ADJUSTMENTS

Commercially available proportional valve amplifier cards offer two types of "inputs", discrete and differential. Referring to Figure No. 4, Discrete Velocity inputs can be controlled on the amplifier card by selecting, via contact closure, discrete analog values preset by the individual onboard multiple turn potentiometers. Likewise, the Discrete Acceleration and Deceleration Rate can be set via a separate multiple turn analog potentiometer. The value of these velocity settings" can be monitored via the test points on the face of the card with a volt meter. The number of different discrete velocity settings and discrete acceleration rate settings, is limited by the card's construction. By taking advantage of the Differential Input feature of the amplifier cards and a PLC equipped with an Analog Output Module, Figure No. 5, virtually an infinite number of velocity settings and an infinite number of acceleration rates can be "selected". Using the differential input for velocity control does not necessarily prevent the use of the amplifier card's onboard ramp time controller, Figure No. 6. By jumpering the amplifier card's ramp controller to zero ramp time, the analog output signal from the PLC can be programmed to control both the velocities and acceleration rates, Figure No. 7.

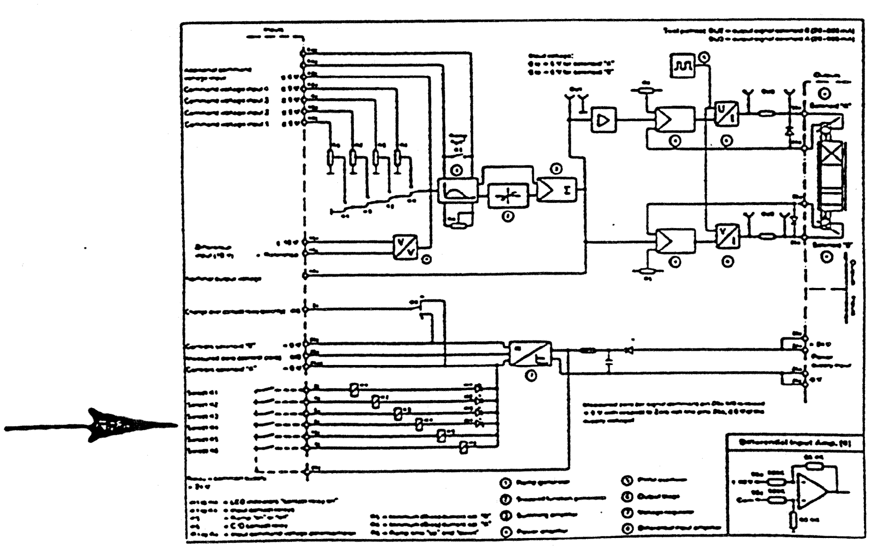

Figure No. 4

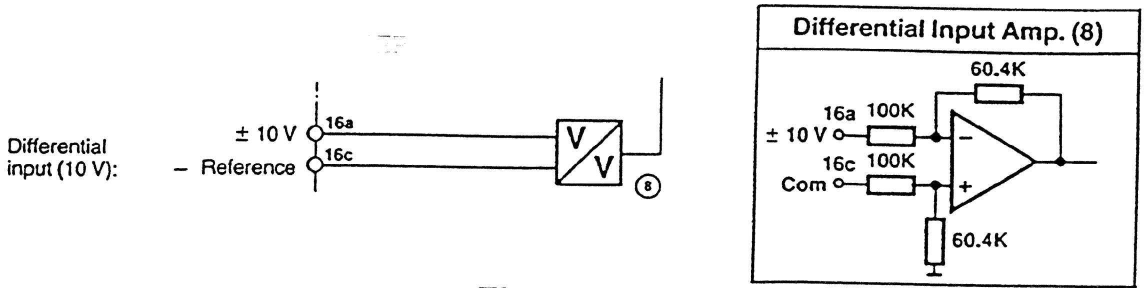

Figure No. 5

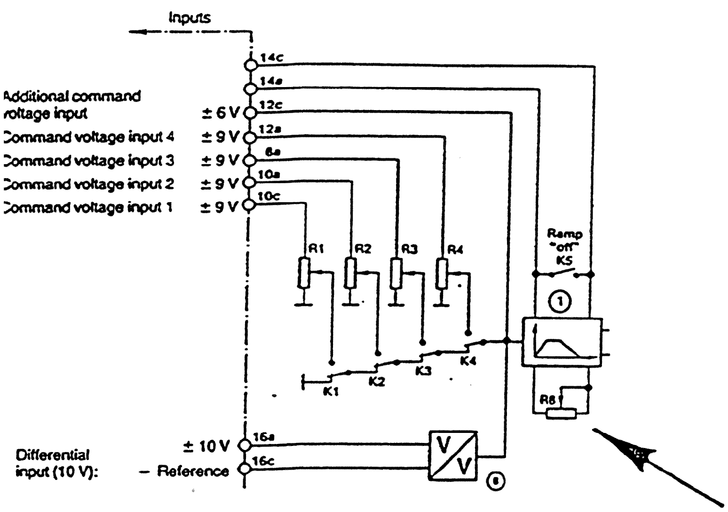

Figure No. 6

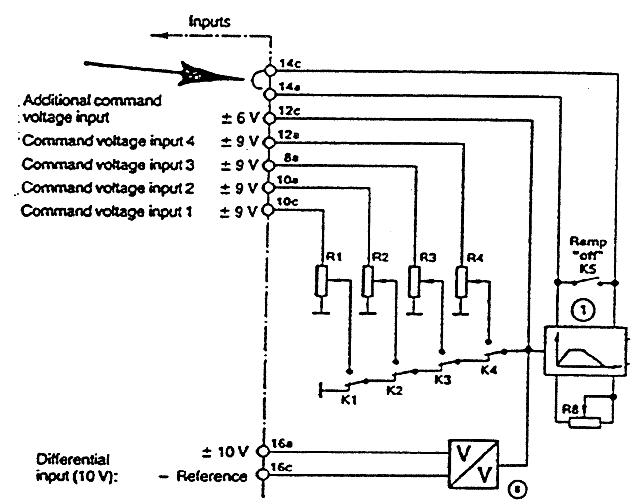

Figure No. 7

SIMPLE AND COMPLEX VELOCITY/ACCELERATION PROFILES, PLC LOGIC METHODS

Using the amplifier card's acceleration rate control, the PLC logic is required to provide only discrete values via the analog output module (discrete voltage settings corresponding to discrete velocity settings). Smoothly transitioning from any of the velocity settings to another setting is thus accomplished by the amplifier card's acceleration rate control. Figure No. 8 depicts sample rungs of logic to produce these discrete values where the number of "counts" is in proportion to the output voltage which is correspondingly proportional to the hydraulic cylinder speed. Contact closures in the program signaled by limit switches, etc. as an example, enable the different rungs. Hypothetically, there could be multiple position limit switches or timers to select full speed, creep speed #1, creep speed #2, ..., creep speed #n. In fact, hypothetically, one could construct an approximation of a complex wave form (braking curve) such as an asymptotic or S shape profile.

The PLC can also control the acceleration/deceleration rates which can be accomplished via the addition of a rung of logic that adds-to or subtracts-from the velocity "count" on each scan of the PLC logic, Figure 9. This process will produce a velocity (acceleration) "ramp", Figure No. 10. Those familiar with the internal workings of PLCs will recognize that due to variances in scan time, scan to scan, an error in the aggregate ramp (time) will result; however, the absolute value of this error over a 5 to 10 second ramp is insignificant.

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Rung 2:8
THE NEXT 5 RUNG'S WOULD MOVE COMMAND SIGNALS TO THE PROPORTIONAL DIRECTIONAL
CONTROL VALVE (DCV PROP VALVE) WITH NO RAMP. THESE COMMAND SIGNALS WOULD
IMMEDIATELY MOVE THE SPOOL OF THE OF THE PROP VALVE TO A POSITION, THIS
POSITION WOULD CONTROL A RATE OF FLOW THROUGH THE VALVE WHICH WOULD TRANSLATE
TO THE SPEED OF THE BRIDGE SPAN OPENING OR CLOSING. THE HIGHER THE SOURCE
VALUE OF THE MOVE INSTRUCTION THE FASTER THE SPEED.
| FA-OPEN   |FA NEARLY |FA FULL   |FA-CLOSE  |E-STOP                                HS OPEN
| Operator  |OPEN      |OPEN      |Operator  |HS-ESOC                               COMMAND
| Input     |LS        |LS        |Input     |Input                                 SIGNAL TO
| OPEN      |Input     |Input     |CLOSE     |                                      PROP DCV
| BRIDGE    |                     |BRIDGE    |                                      VALVE
|   I:1       I:2        I:2        I:1        I:1                                    83
|----] [--------] [--------] [--------]/[--------] [-------------------------+----( )---------------+--
|    14         2          3          13         1                           |     12               |
                                                                             |                      |
|                                                                            |    Analog            |
|                                                                            |    Output To         |
|                                                                            |    DCV               |
|                                                                            |    Prop Valve        |
|                                                                            |                      |
|                                                                            | +MOV---------------+ |
|                                                                            +-+MOVE              +-+
|                                                                              |Source       32766|
|                                                                              |                  |
|                                                                              |Dest        O:4.1|
|                                                                              |                 0|
|                                                                              +------------------+

Rung 2:9
AFTER NEAR OPEN LIMIT SWITCH IS MADE A MOVE FUNCTION SWITCHES THE COMMAND
SIGNAL OUTPUT TO PROP DCV SWITCHES TO A LOWER VALUE, LOWER VALUE IS A LOWER
VELOCITY OF THE SPAN UNTIL FULL OPEN LIMIT IS MADE.
| FA-OPEN   |FA-CLOSE  |E-STOP    |FA NEARLY |FA FULL                               Near Open
| Operator  |Operator  |HS-ESOC   |OPEN      |OPEN                                  LS Made
| Input     |Input     |Input     |LS        |LS                                    Low Speed
| OPEN      |CLOSE     |          |Input     |Input                                 Open
| BRIDGE    |BRIDGE    |                                                            Command
|   I:1       I:1        I:1        I:2        I:2                                    83
|----] [--------]/[--------] [--------]/[--------] [-------------------------+----( )---------------+--
|    14         13         1          2          3                           |     13               |
|                                                                            |    Analog            |
|                                                                            |    Output To         |
|                                                                            |    DCV               |
|                                                                            |    Prop Valve        |
|                                                                            |                      |
|                                                                            | +MOV---------------+ |
|                                                                            +-+MOVE              +-+
|                                                                              |Source        3276|
|                                                                              |                  |
|                                                                              |Dest        O:4.1|
|                                                                              |                 0|
|                                                                              +------------------+
```

Figure No. 8

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Rung 2:13
AFTER THE NEAR FULLY OPEN LIMIT SWITCH IS MADE THE SPEED/VELOCITY OF THE SPAN
SLOWED TO A CREEP UNTIL THE SPAN IS FULLY OPEN. THE SPEED AT WHICH THE SPAN
SPEED IS DECELED FROM FULL SPEED TO CREEP SPEED IS A FUNCTION OF THE SUBTRACT
FUNCTION FROM THE PLC OUTPUT TO THE PROP DCV. THE HIGHER THE SOURCE B NUMBER
THE FASTER THE DECEL, THE LOWER THE NUMBER THE LONGER THE DECEL.
| FA-OPEN  |FA-CLOSE |E-STOP  |FA NEARLY |FA FULL                                Analog      DECEL
| Operator |Operator |HS-ESDC |OPEN      |OPEN                                   Output To   SPAN SPEED
| Input    |Input    |Input   |LS        |LS                                     DCV Prop    TO A LOWER
| OPEN     |CLOSE    |        |Input     |Input                                  Valve       SPEED
| BRIDGE   |BRIDGE   |
|   I:1      I:1       I:1      I:2       I:2                                    +LEQ---------------+     B3
|----] [--------]/[--------] [--------]/[--------] [----------------------------+-+LESS THAN OR EQUAL+----( )--------------+--
|   14       13        1        2         3                                     | |Source A    O:4.1|     17               |
|                                                                               | |                0|                      |
|                                                                               | |Source B    3270|                       |
|                                                                               | |                 |                      |
|                                                                               | +-----------------+                      |
|                                                                               | DECEL                  Analog            |
|                                                                               | SPAN SPEED             Output To         |
|                                                                               | TO A LOWER             DCV Prop          |
|                                                                               | SPEED                  Valve             |
|                                                                               |   B3                  +SUB---------------+ |
|                                                                               +----]/[---------------+SUBTRACT           +-+
|                                                                                   17                 |Source A    O:4.1|
|                                                                                                      |                0|
|                                                                                                      |Source B      100|
|                                                                                                      |                 |
|                                                                                                      |Dest        O:4.1|
|                                                                                                      |                0|
|                                                                                                      +-----------------+
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Figure No. 9

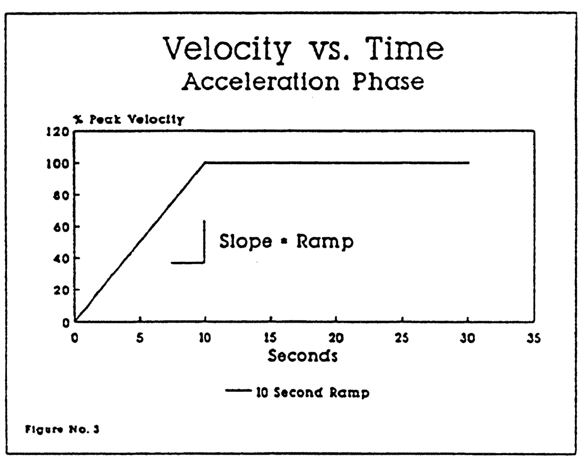

Figure No. 10

SYSTEM SHUTDOWN EFFECTS ON LEAF BOUNCE

Looking at the physics, a bascule leaf can be considered to be solely a mass load (the ratio of frictional forces to acceleration forces is minute). What must happen is that force must be applied to either accelerate or decelerate the structure, otherwise the mass would continue to move (or not move if it were at rest). Simply removing the driving force will not insure that the structure will stop in all cases! The rate at which that force is applied will be a primary factor with respect to leaf oscillation and especially to leaf bounce at the fully closed position. The rate at which the force is applied must be well below the compressive spring force of the leaf's natural frequency.

One must look at the time period between when the fully closed limit switch signals that the leaf is fully closed and when the leaf actually stops moving and comes to rest on the live load shoes. The amplifier card continues to apply its ramp rate control from the creep speed setting to zero; however, this assumes that the hydraulic power unit will continue to supply flow.

In practice, some systems shut down the HPU's pumps when the fully closed limit switch is tripped. The positioning of the limit switch then becomes critical in that the leaf continues to move until the hydraulic pressure decays to a point where the hydraulic circuit's components effect the leaf's motion. The actions of the hydraulic circuit can be affected by counterbalance valves stalling the cylinders motion and the pilot-to-open check valves closing and locking the cylinder into position or the pilot-to-open check valves can close prior to the leaf coming to a complete stop due to loss of pilot pressure. Is this happens, a large acceleration force of short duration is imparted into the structure. If the magnitude and/or duration is sufficient to be near the leaf's natural frequency (time constant, T=1/w), the leaf will oscillate ("bounce").

FINAL CREEP SPEED EFFECTS ON LEAF BOUNCE

In practice, it seems that the final creep speed prior to fully closed shutdown has the greatest influence on bounce (oscillation), due primarily to being easily controlled (adjusted), as opposed to the absolute amount of force the hydraulic cylinders are imparting onto the leaf. An increase in constant (full) velocity with respect to the (fixed) position of the nearly closed limit switch could result in the leaf never entering the creep phase. This condition of no creep speed prior to encountering the fully closed limit switch means the live load shoes are hit at a high velocity, this is a "hard" closing, Figure No. 11! Conversely, an increase in creep speed velocity with respect to the fixed position fully closed limit switch can also result in a "hard" closing. A dangerous and real example of an instance when this can happen is during functional checkout. Presuming that the specifications call for 2 pumps & 2 cylinders operation test versus the design operation test (2 pumps & 4 cylinders operation), without a corresponding change in the velocity command values, the relative speeds can double, the creep speed may never be reached, and a potentially damaging hard closing may result.

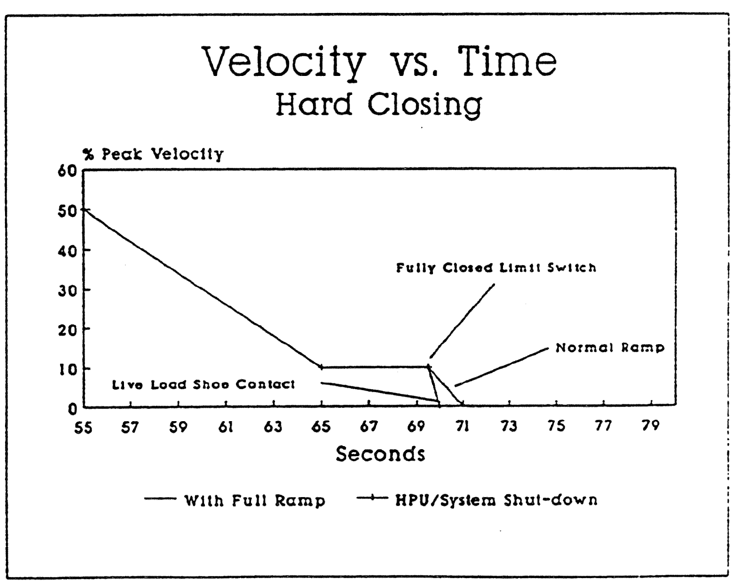

Figure No. 11

CONCLUSION

The PLC can be programmed to control all of the bridge's motions, from the moment the button is pushed to the moment the span is fully closed. Engineers should investigate the control options for future designs, Owners should be aware of the potential advantages, and Maintenance Personnel should consider the absolute certainty of velocity and acceleration settings through the use of PLC Logic Control.