Energy Saving Control of Hydraulic Systems with Novel Programmable Valves

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OUTLINE

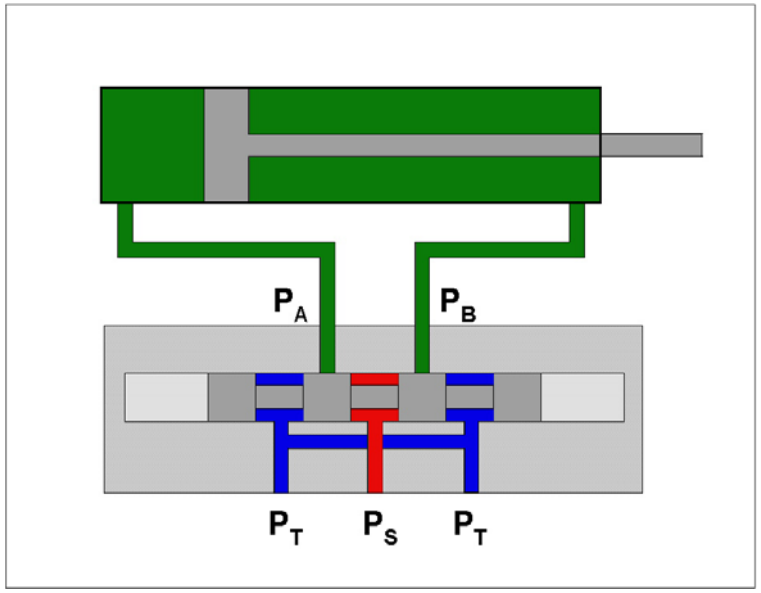
- Motivation
- Uniqueness of Proposed Programmable Valves
- Application to Boom Motion Control
  - Problem formulation and dynamic model
  - Energy saving ARC controller design
    - Task Level:

      Valve Utilization (or Mode Selection)
    - Valve Level:

      ARC Pressure Controller Design for Off-Side Chamber

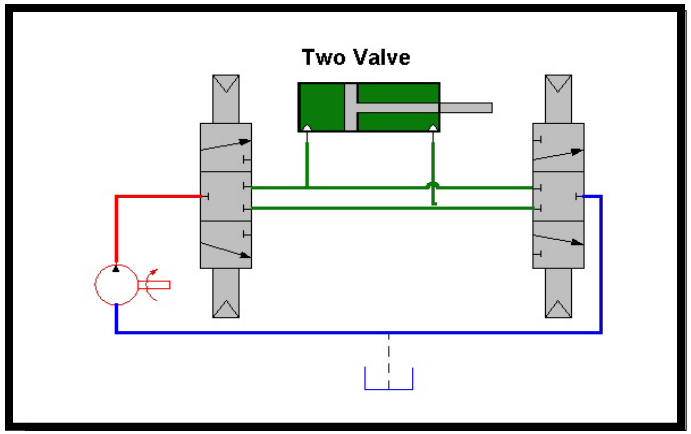
      ARC Motion Controller Design for Working-Side
- Experiment Results
- Conclusions

Motion Control with Conventional Valves



- Meter-in and meter-out orifice areas are coupled in 4-way directional control valves
- Cannot control all cylinder states (pressures of both chambers)
- Deadband for PDC valves
- Leakage for servo valves

Non-Conventional Valves

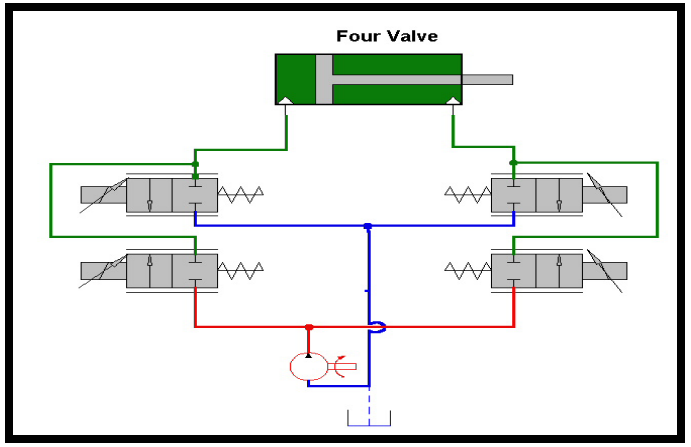


- Two valves:

Patented by:

J. Ardema, 1996

Uses two directional control valves to meter flows



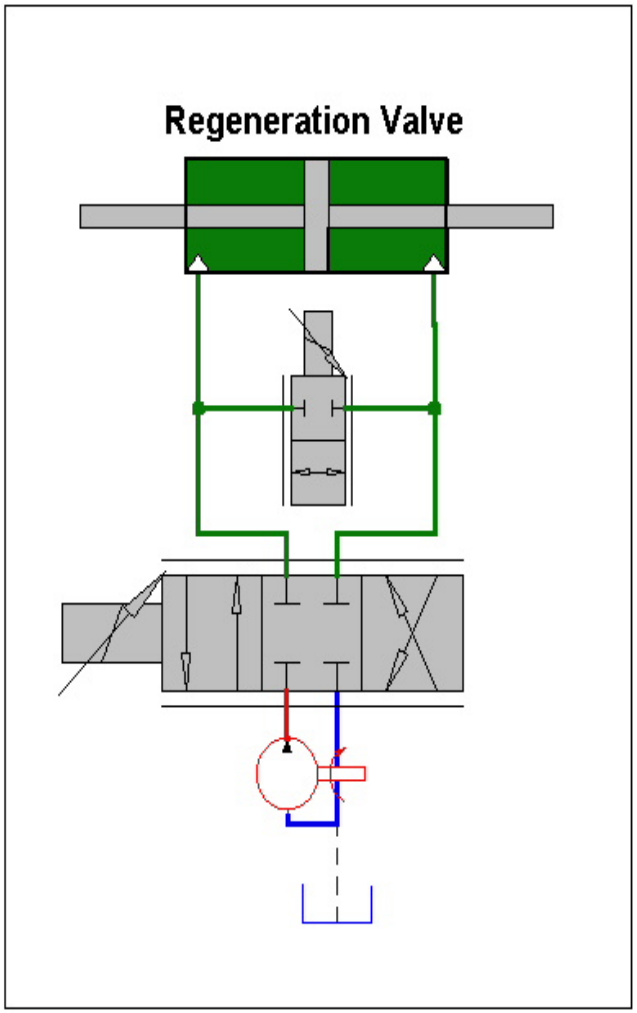
- Four valves

Used by both:

J. Ardema and D. Koehler, 1999
R. Book and C. Goering, 1999

Uses four poppet valves to independently control meter-in and meter-out flows

Regeneration Valves



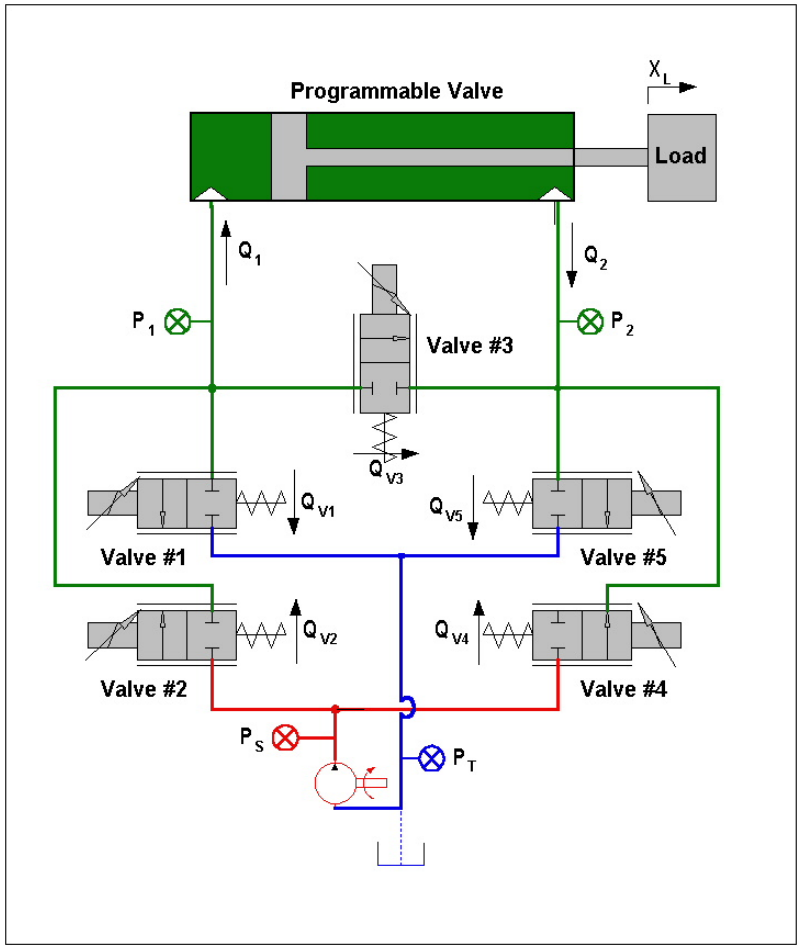
- Regeneration Valve

Patented by:

K. Garnjost, 1989.

Uses one additional valve to provide regenerative flow for energy saving but cannot control both chambers independently

Energy Saving Programmable Valves

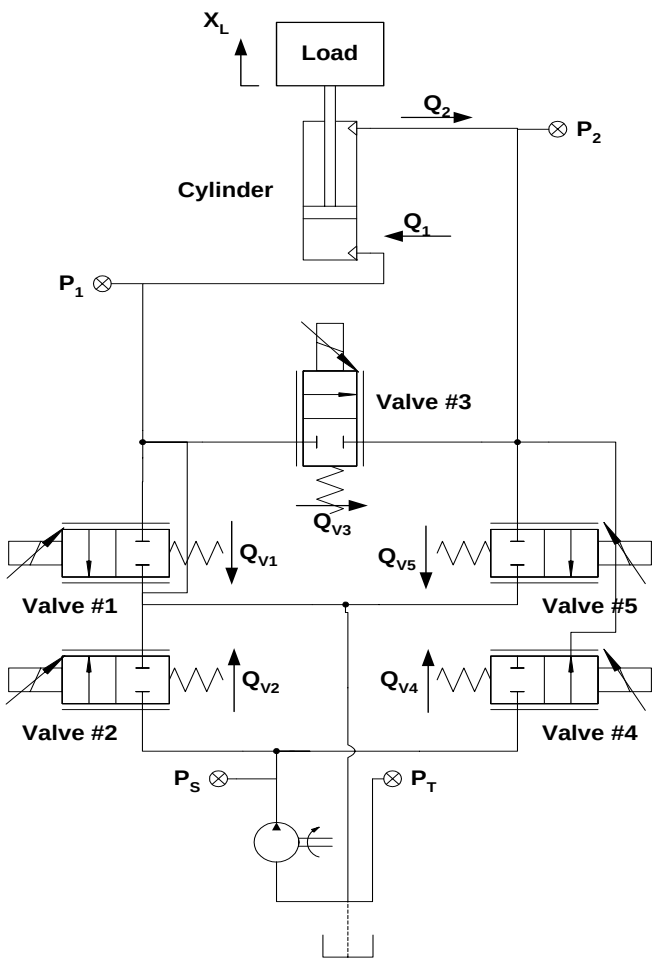


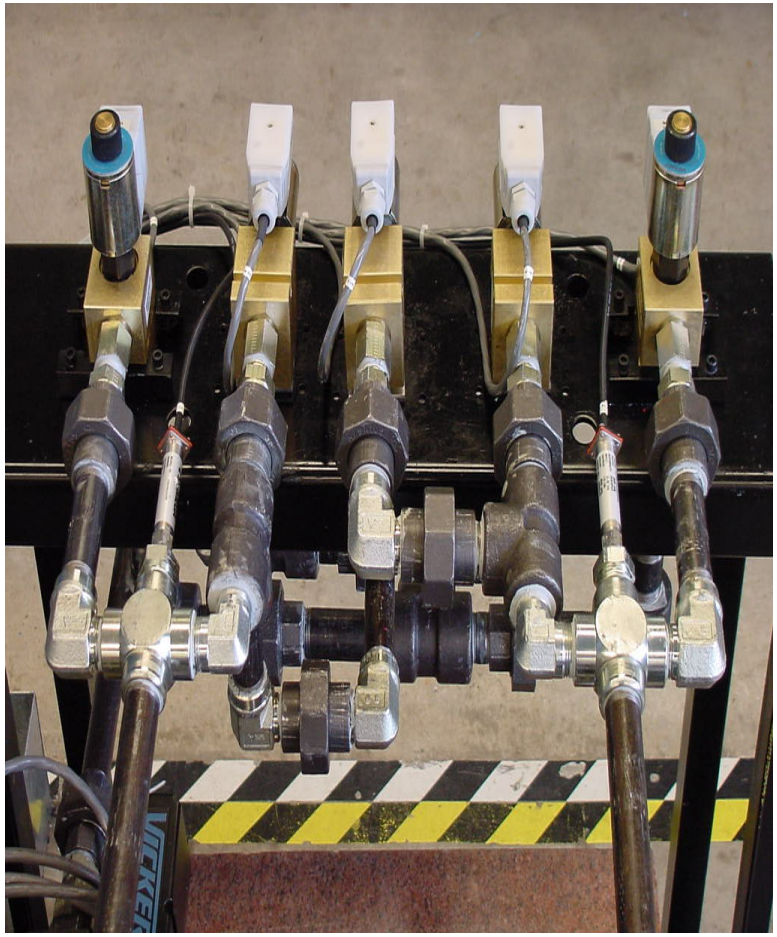
Purdue Energy Saving Programmable Valves

Developed by:
Bin Yao, 2000

- Take advantages of four valve configuration to control meter-in/meter-out flows independently for precise cylinder positioning
- Using an additional valve to precisely control cross-port flow (or regenerative flow) for energy saving

Purdue Programmable Valves





Overall Strategies

- The difficulties in the coordinated control of five cartridge valves for precision motion and pressure control are dealt with through a task level valve utilization (or mode selection) algorithm and local valve level ARC pressure and motion controllers.
- The nonlinear model based adaptive robust control (ARC) design in our previous studies is used to deal with the common difficulties in the precision control of electro-hydraulic systems directly to synthesize the desired load flow that is needed for precise motion control
  - nonlinear dynamics, large parameter variations, uncertain nonlinearities, and the mismatched model uncertainties
- Nonlinear adaptive robust pressure controller is developed to handle the pressure control of the off-side chamber for energy saving purpose

Task Level Valve Utilization

- Objective:

  Let Q_{1d} and Q_{2d} be the desired control flows to the two chambers of the cylinder that are needed to provide certain load pressure profile for motion tracking while maintaining the lowest possible cylinder chamber pressures to reduce the flow losses for energy saving. The task level of the controller determines how the five valves of the proposed programmable valve should be used in order to provide the required control flows Q_{1d} and Q_{2d}

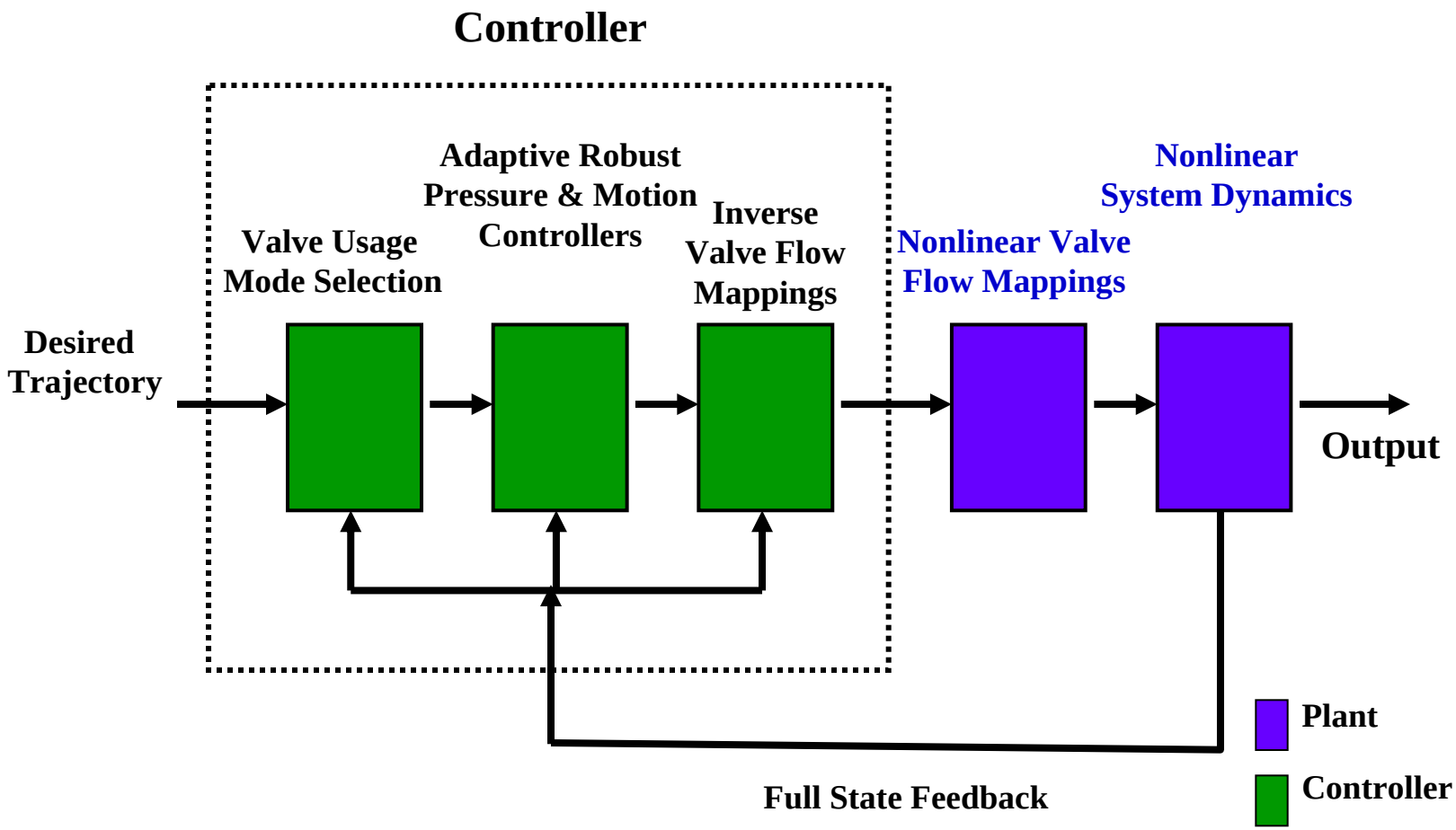
- Difficulties:

  Non-unique due to the added flexibility of independently controlling each of the five cartridge valves

- Working Mode Selection:

  The paper uses eight modes, of which five are for motion tracking control and three for regulation control.

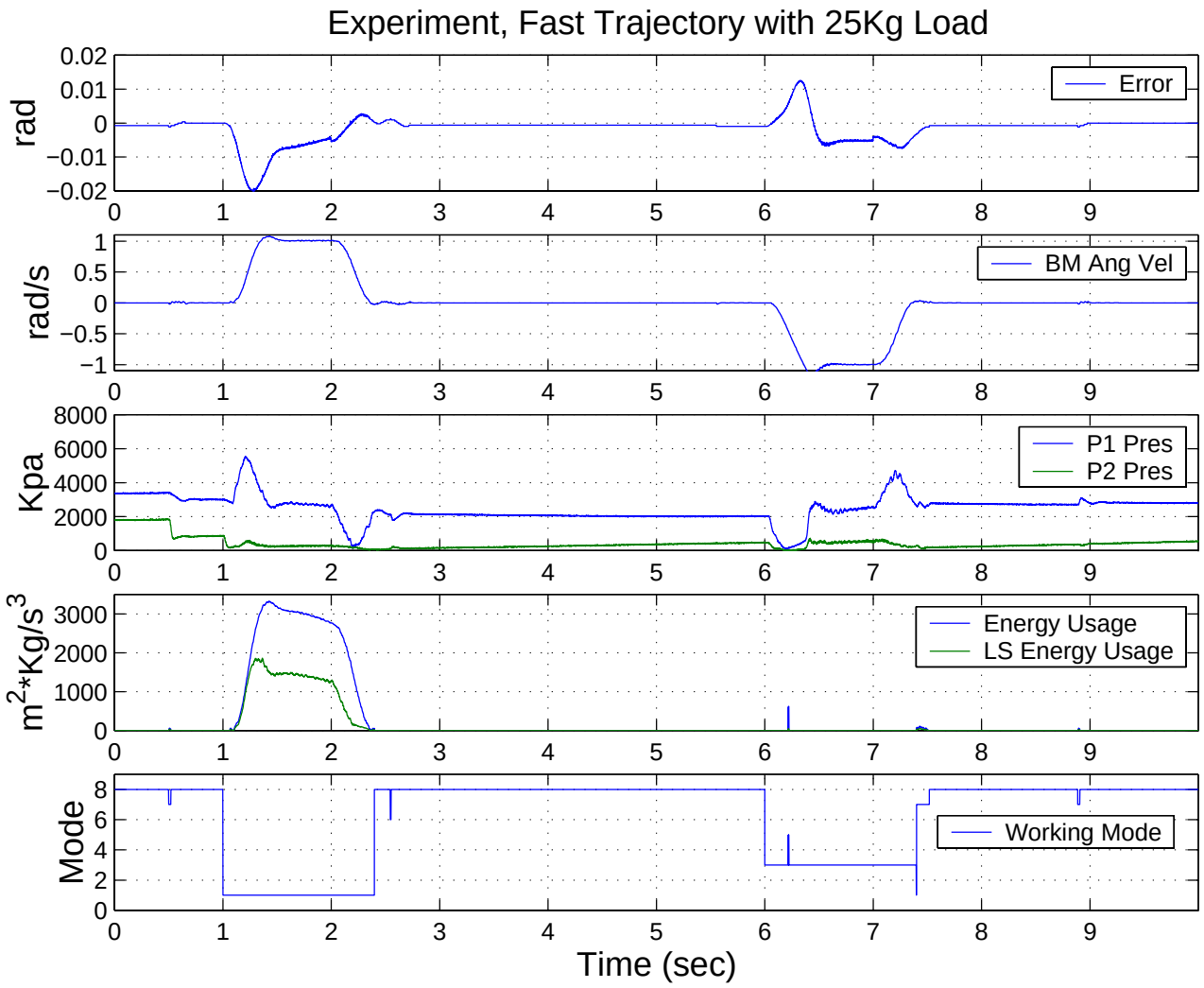
Overall Controller Structure



Point-Point Positioning with Load

Experiment Results

(Boom up and down with a speed of 1 rad/s for a rotational angle of 1 rad)



Note that no pump energy is used for boom down motion, and even with the cheap cartridge valves, maximum position tracking error less than 0.02 rad is achieved

Conclusion

- The utilization of the programmable valves results in significant gains in reducing pump energy usage while achieving excellent tracking performance.
- The significant gains in energy saving is realized through precise control of regenerative flows in maintaining working-side chamber pressure for motion tracking while keeping off-side chamber pressure at desired low level.
- Excellent tracking performance is guaranteed by the ARC technique.

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VICKERS