

Valve-based compensation for controllability improvement of the energy-saving electrohydraulic flow matching system

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Introduction

- **Current mobile machinery**

- **High energy consumption**
- **Low energy efficiency**
- **Poor adaptability under different load conditions**

- **Regulations and standards**

« ...exhaust pollutants ... of non-road mobile machinery (IV)»

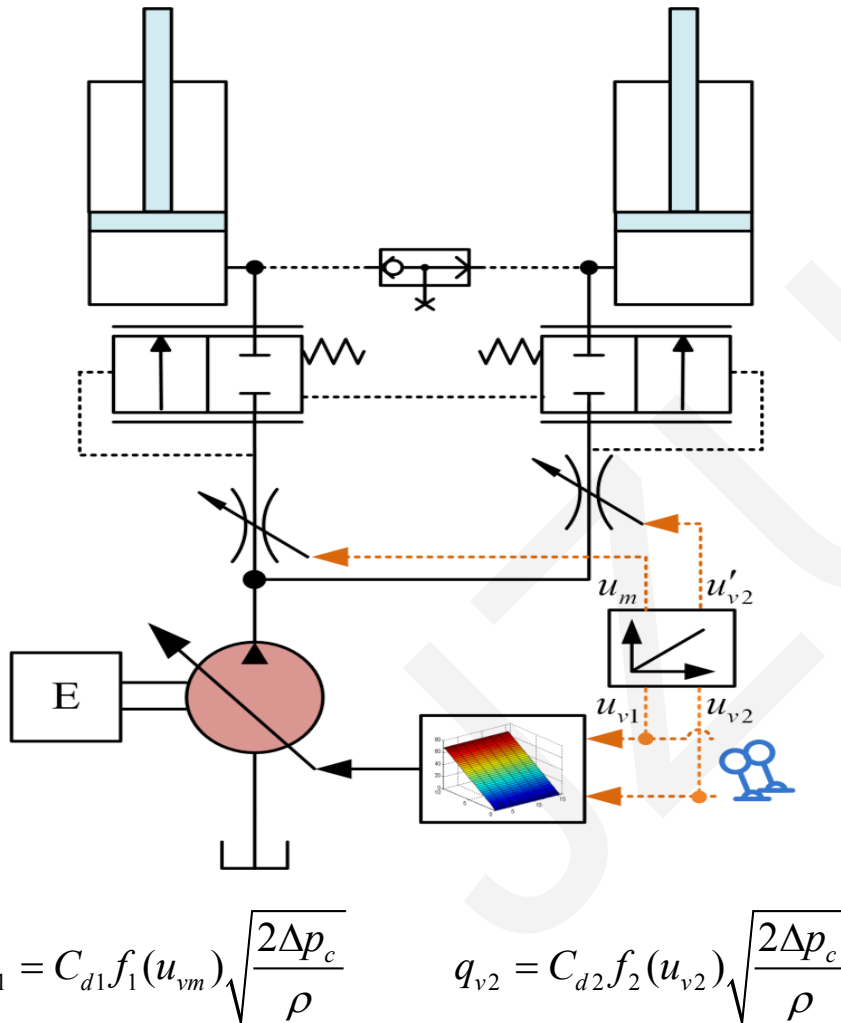
- **Demand of mobile hydraulics**

- **High efficiency**
- **Good controllability**
- **High safety performance**

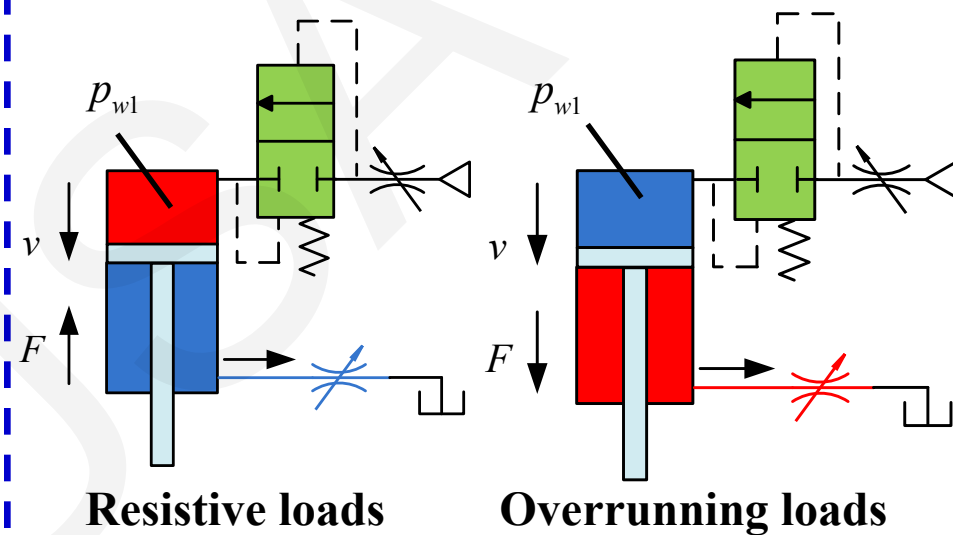


Problem statement

● Energy saving with EFM control



● Problem statement

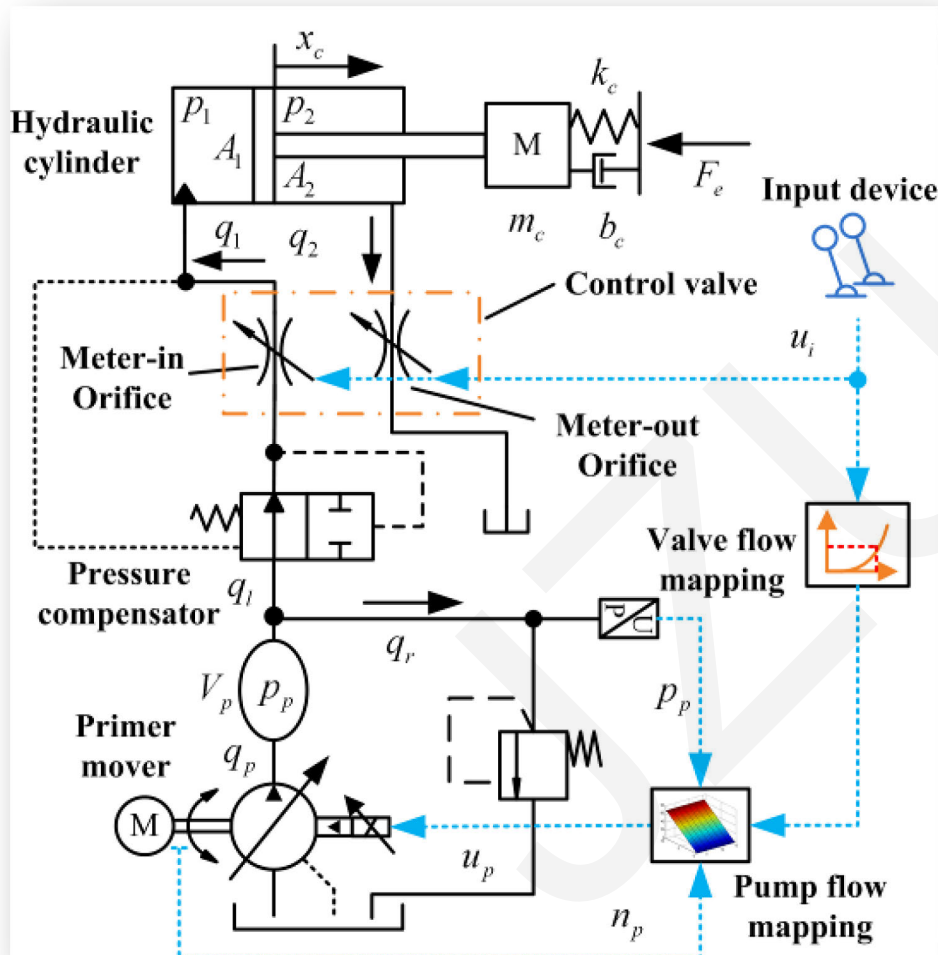


● In overrunning loads, the velocity control performance is deformed.

● How to identify load condition?
 ● How to control the valve opening to minimize its pressure loss?

System modeling

● System layout based on electrohydraulic flow matching



• Mathematical model

$$p_p(s) = \frac{\beta_e}{V_p s} [q_p(s) - q_l(s)]$$

$$q_2(s) = k_q x_v(s) + k_{pq} p_2(s)$$

$$(m_c s + b_c + \frac{k_c}{s}) v_c(s) = A_1 p_1(s) - A_2 p_2(s) - F_e(s)$$

$$q_l(s) = q_1(s) = A_1 v_c(s) + \frac{V_1}{\beta_e} s p_1(s)$$

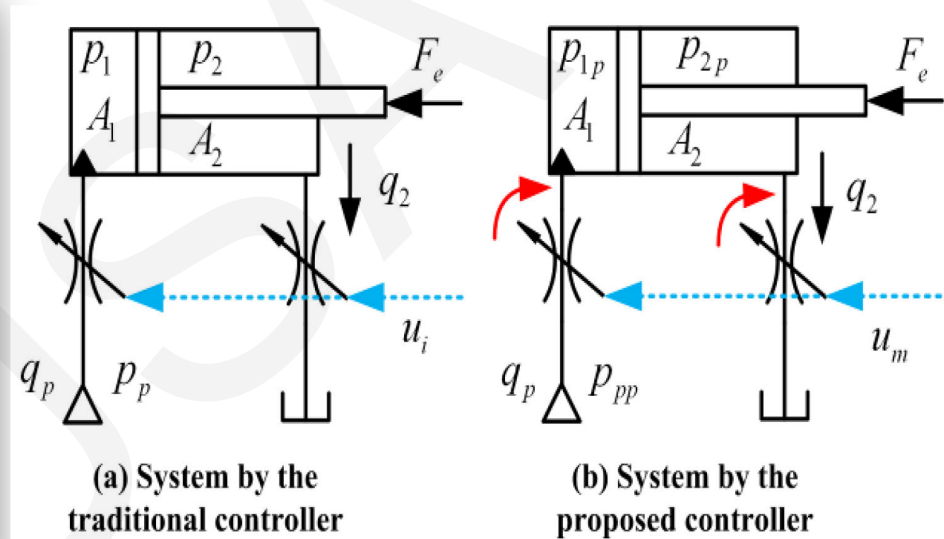
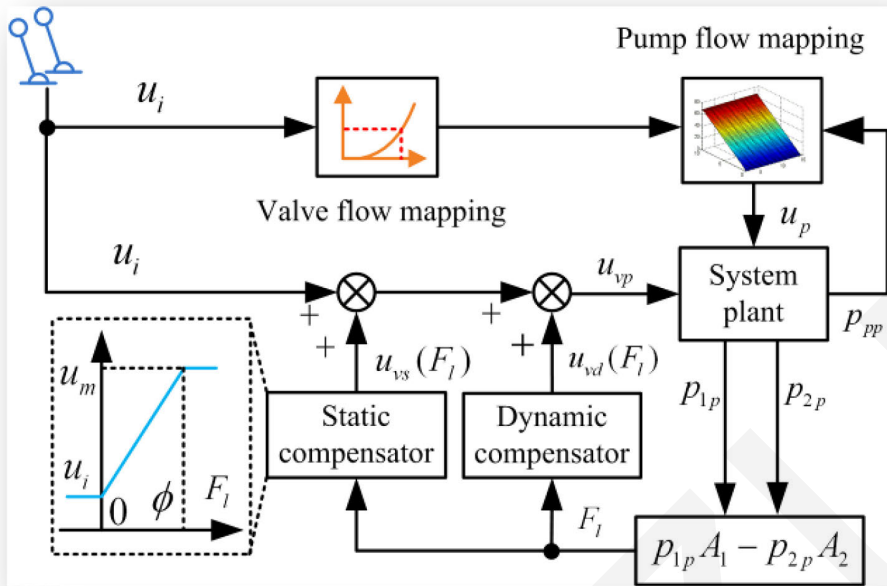
$$q_2(s) = A_2 v_c(s) - \frac{V_2}{\beta_e} s p_2(s)$$

• System velocity

$$v_c(s) = \frac{B(s)}{A(s)} q_p(s) + \frac{C(s)}{A(s)} x_v(s) + \frac{D(s)}{A(s)} F_e(s)$$

Valve-based compensation method

● Compensator design



Valve signal:

$$u_{vp} = u_i + u_{vs}(F_l) + u_{vd}(F_l)$$

$$u_{vs}(F_l) = \begin{cases} u_m - u_i, & F_l > \phi \\ \frac{F_l}{\phi}(u_m - u_i), & 0 \leq F_l \leq \phi \\ 0, & F_l < 0 \end{cases}$$

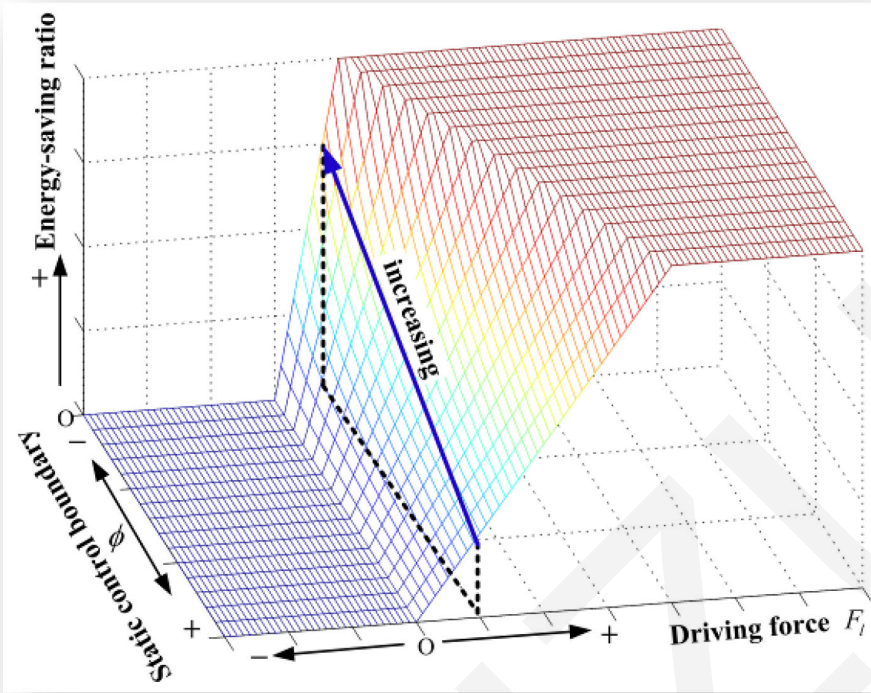
Static compensator

$$u_{vd}(F_l) = \begin{cases} k_{vd} [\dot{p}_{1p}(t) A_1 - \dot{p}_{2p}(t) A_2], & 0 \leq F_l \leq \phi \\ 0, & F_l > \phi \text{ or } F_l < 0 \end{cases}$$

Dynamic compensator

Valve-based compensation method

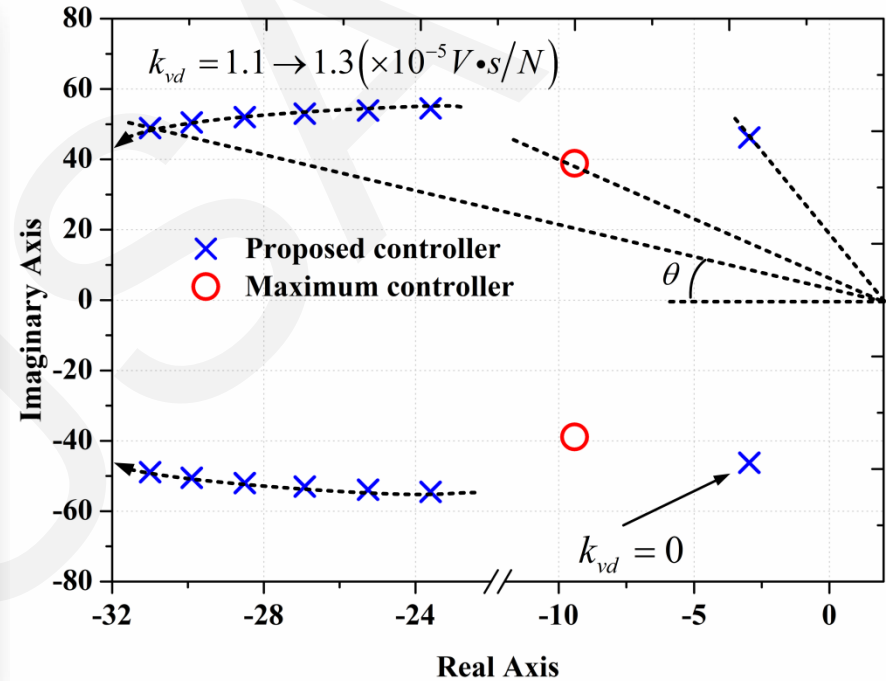
● Efficiency comparison



• Efficiency improvement

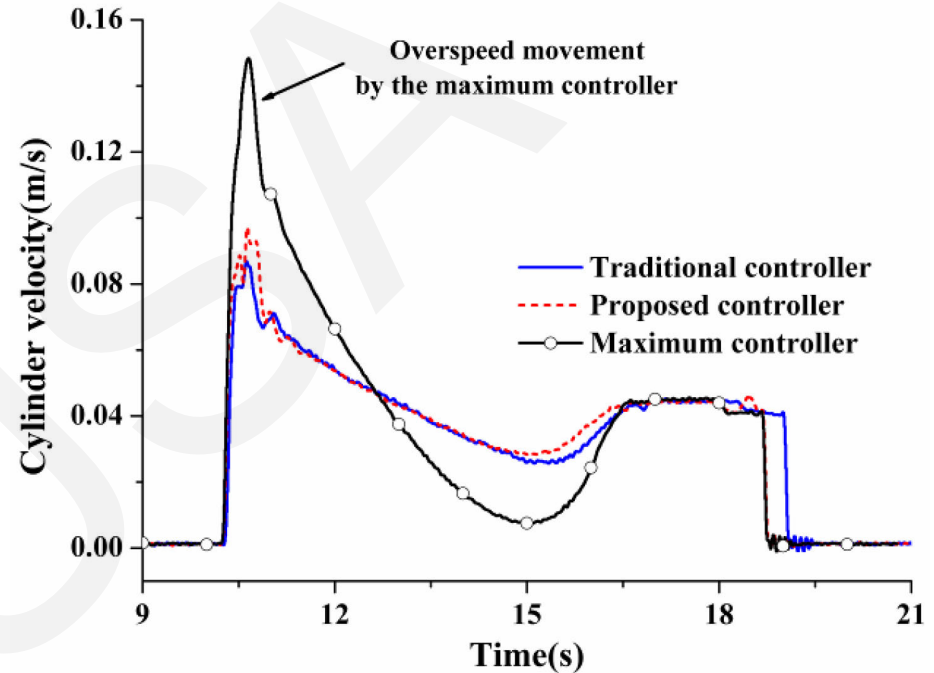
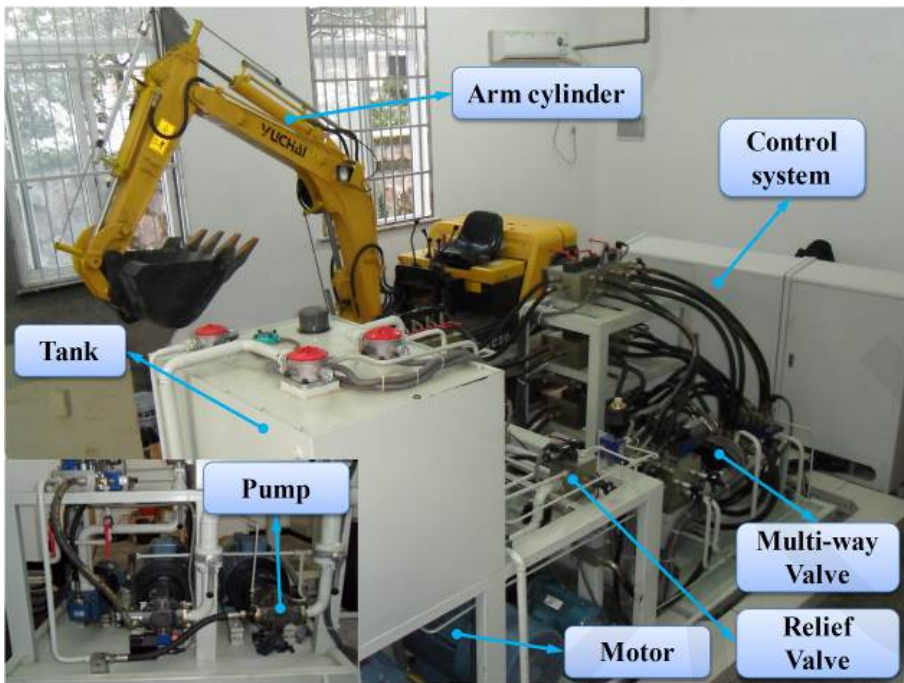
$$\eta_e = \frac{\Delta p_p}{p_p} = \frac{(A_1^3 + A_2^3) [A^2(x_{vp}) - A^2(x_v)] \Delta p_m}{A_1^3 A^2(x_{vp}) p_p}$$

● Analysis of stability and dynamic



- The system stability is proved by the Routh-Hurwitz criteria.
- The dynamic behavior is improved through the pole placement method.

Experimental tests



- The energy efficiency is improved by 3.2~6.8% by the proposed controller.
- Although the proposed controller obtains a smaller efficiency improvement than the maximum controller, its velocity is more consistent with that of the traditional controller.

Conclusion and future work

●Conclusion

- **A valve-based compensation method is proposed to reduce the pressure drop over the control valve and ensure the controllability, consisting of a static compensator and a dynamic compensator.**
- **The test results indicated that the energy efficiency were reduced by with the proposed controller, while the controllability was consistent with that of the traditional controller.**

●Future work

- **Future work will be focused on testing the effectiveness of the proposed controller in actual digging cycles.**

●Additional information can be found in:

Cheng M, Zhang J, Ding R. Pump-based compensation for dynamic improvement of the electrohydraulic flow matching system. IEEE Transactions on Industrial Electronics, 2016, DOI: 10.1109/TIE.2016. 2633478.