Motion Control of a Hydraulic Parallel-Link Servomechanism with
Three Degrees of Freedom on a Plane

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This paper presents a motion control for hydraulic parallel-link servomechanism with three degrees of freedom on a plane. We proposed two methods which are based on the preview control system theory; 1) Conventional displacement preview control system and 2) Multipreview control system. The systems control both the profile-tracing path and the vibration in acceleration waveform of the end effector. The objective of two methods is to minimize profile-tracing error and to suppress the noise vibration in acceleration waveform of the end effector. The characteristics and performance of the proposed methods are verified through simulations.

1. Electrohydraulic parallel-link servomechanism with three
degrees of freedom on a plane

The geometrical equation is express as

\[ y(t) = x(t) - l_1 \cos \theta(t) \]

\[ y_2(t) = x(t) - l_2 \cos \theta(t) \]

\[ y_3(t) = x(t) + l_3 \cos \theta(t) \]

The relationship between the piston velocity \( \dot{y} \) and the end effector velocity \( \dot{X}_e \) is approximated by

\[ \dot{y}(t) = A(X_G, \theta(t)) \dot{X}_e(t) \]

where \( A(X_G, \theta(t)) \) is Jacobian matrix.

The equation of motion of the end effector is expressed as

\[ \frac{d^2}{dt^2} X_G(t) = A(X_G, \theta(t)) f(t) \]

2. Optimal control system

Define the performance index \( J \) of the error system as

\[ J = \sum_{k=0}^{\infty} \left[ X_G^2(k) + \Delta u^2(k) - \sum_{j=1}^{\infty} F_j(k) \Delta u(k+j) \right] \]

3. Conventional displacement preview control system

The control input \( \Delta u(k) \) can be expressed as

\[ \Delta u(k) = F_0 + F_1 X_G(k) + \sum_{j=1}^{\infty} F_j(k) \Delta u(k+j) \]

4. Multipreview control system
The control input $\Delta u(k)$ can be expressed as

$$\Delta u(k) = F_{e1} \Delta x(k) + F_{e2} \Delta x(k) + F_{e3} \Delta x(k) + F_{e4} \Delta u(k-1) +$$

$$\sum_{j=1}^{n} F_{e1j} \Delta x(k+j) + \sum_{j=1}^{n} F_{e2j} \Delta x(k+j) + \sum_{j=1}^{n} F_{e3j} \Delta u(k+j).$$  \hspace{1cm} (6)

5. Simulation

To show the characteristics of the preview control systems, we use MATLAB and SIMULINK programs to simulate the motion of the systems. Circular path with $r_0 = 0$ are used as test patterns. From Eq.(4) the preview step number is chosen as $M_R = 100$. $Q$ and $H$ are chosen as follows

Case I (Conventional displacement preview controller)

$$Q = diag(0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01)$$

$$H = diag(1,1,1)$$

Case II (Multipreview controller)

$$Q = diag(0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01)$$

$$H = diag(1,1,1)$$

6. Discussion

1. Element of error $e$ has the most effect on trajectory error, as shown in Figure 5 and Figure 6.
2. Element of cylinder force $f$ is very sensitive to trajectory and vibration in acceleration waveform, as shown in Figure 7.
3. Element of velocity error $\dot{e}$ has small effect on acceleration waveform but more effect to trajectory, as shown in Figure 9.
4. Element of acceleration error $\ddot{e}$ has more effect on acceleration waveform than on trajectory error.

7. Conclusion

The characteristics of the weighting factor $Q$ of conventional displacement preview control system and multipreview control system for control of both the profile-tracing path and the vibration in acceleration are discussed by using the simulation.