How to Synchronize Hydraulic Cylinders

Brendan Casey
Marian Tumarkin
How to Synchronize Hydraulic Cylinders

Copyright © 2006 Brendan Casey & Marian Tumarkin

All rights reserved. No part of this electronic book may be reproduced or transmitted in any form or by any means, electronic, mechanical, photocopying, and recording or otherwise, without the prior, written permission of the publisher.

The contents of this book reflect the author’s views acquired through his experience in the field under discussion. The information in this document is distributed on an “As is” basis, without warranty. Every effort was made to render this book free from error and omission. However, the author, publisher, editor, their employees or agents disclaim liability for any injury, loss, or damage to any person or body or organization acting or refraining from action as a result of material in this book, whether or not such injury loss or damage is in any way due to any negligent act or omission, breach of duty, or default on the part of the author, publisher, editor or their employees or agents.

First published in 2006 by
HydraulicSupermarket.com
PO Box 1029
West Perth WA 6872
Australia
Email: info@HydraulicSupermarket.com
Web: http://www.hydraulicsupermarket.com/books

About the Authors

Brendan Casey is the founder of HydraulicSupermarket.com and the best-selling author of ‘Insider Secrets to Hydraulics’ the most comprehensive guide to reducing hydraulic equipment operating costs ever published. A fluid power expert with an MBA, he has more than 18 years experience in the design, maintenance and repair of mobile and industrial hydraulic equipment.

Dr Marian Tumarkin has over 35 years of experience in the field of Fluid Power with a Ph.D. from the National Academy of Science in Moscow. He is an accomplished scholar in the field with over 50 published papers and 10 patents to his name.

A highly experienced Fluid Power engineer, Marian has designed electro-hydraulic systems for Russian and Australian Air Forces, Australian and American automotive industries, as well as developing special purpose machines. In this role, he was responsible for concept design and problem solving, calculations and component selection, system testing and troubleshooting.

Marian has extensive teaching experience both in Europe and Australia, delivering basic and advanced Fluid Power subjects to undergraduate and post-graduate students as well as engineers and technicians.
ACTUATOR SYNCHRONIZATION

The problem of synchronizing hydraulic actuators arises in many applications, where the synchronous operation of multiple actuators under load has important performance implications.

To simplify analysis, consider synchronization of two lifting cylinders. Note that all descriptions below are applicable for any number and any type of actuators.

If load on the lifting platform is non-symmetrical, the lifting distance for the cylinders (1) and (2) will be different because of difference in flow rates $Q_1$ and $Q_2$ (and accordingly in speeds $V_1$ and $V_2$) – Fig. 2.23.

To address the issue, consider the influence of different cylinder extension speeds on the horizontal position of the platform – Fig. 2.24.

Simple calculation gives:

$$V_1 - V_2 = \Delta V; \quad \tan \alpha = \frac{\Delta S}{L}$$

$$\Delta S = V_1 \times t - V_2 \times t$$

$$t = \frac{S}{V} \quad \Rightarrow \quad \tan \alpha = \frac{S}{V} \times \frac{\Delta V}{L}$$

Let $L = S = 1$ m (3 ft). Then:

$$\alpha = \tan^{-1} \frac{\Delta V}{V} \quad \Rightarrow \quad \begin{array}{|c|c|}
| \Delta V / V | \alpha \\
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>5.7^\circ</td>
</tr>
<tr>
<td>5%</td>
<td>2.9^\circ</td>
</tr>
<tr>
<td>1%</td>
<td>0.6^\circ</td>
</tr>
</tbody>
</table>
\end{array}$$

Keeping in mind the possible platform deflection for different speed accuracy, shown in the above table, consider possible solutions.
SOLUTION 1 – FLOW DIVIDER VALVE

Flow dividers are used to split the flow from a single source into two equal flow rates for two actuators – Fig. 2.25.

Flow divider (3) includes a spool (4), which automatically changes the opening slots to compensate for the difference in pressures \( p_1 \) and \( p_2 \). These pressures act on the opposite sides of the spool (4) through the drillings in the spool in such way that an increase in pressure \( p_1 \) would reduce the slot (increase resistance) for flow \( Q_2 \). Accordingly, increase of the pressure \( p_2 \) would increase resistance for flow \( Q_1 \). Therefore, pressure \( p \) at the inlet of the valve is equal to the highest outlet pressure plus pressure drop across the open slot. This means that the pressure drop on the metered side can be large, and this creates excessive heat.

The accuracy of flow divider valves is about 10%.

SOLUTION 2 – PRESSURE-COMPENSATED FLOW CONTROL VALVES

Independent adjustment of the pressure-compensated flow control valves allows setting to any synchronized speed. This arrangement requires manual fine tuning of two valves for any particular speed.

Accuracy of synchronization is about 5%.
SOLUTION 3 – MULTIPLE PUMPS

Internal leakage changes pump delivery as pressure changes. Therefore, the accuracy of speed control is about 5%. Two-pump arrangement does not provide the flexibility to change lifting speed – unless pump drive speed can be varied.

Fig. 2.27. Two-pump arrangement

SOLUTION 4 – DOUBLE-ROD CYLINDERS IN SERIES

The primary advantage of using cylinders in series is high volumetric efficiency. The amount of internal leakage in most cylinders approaches zero. This means that for any given motion on the cylinder (1), there is a known volume of liquid moving the cylinder (2) regardless of the load on each cylinder. Therefore, the accuracy of speed control is about 1%.

Main disadvantage – the pressure in the first cylinder will be twice that required by the load. This arrangement also requires extra space to accommodate the double rods.

Fig. 2.28. Hydraulic circuit with double-rod cylinders in series

SOLUTION 5 – SINGLE-ROD CYLINDERS IN SERIES

The system includes two cylinders plumbed in series, with bore and rod diameters sized such that annulus area of the cylinder (1) is equal to piston area of the cylinder (2).

It is difficult to manufacture the cylinders for this arrangement with high accuracy. Therefore, the accuracy of speed control is about 2%

Fig. 2.29. Hydraulic circuit with single-rod cylinders in series
SOLUTION 6. MASTER CYLINDER

As shown in Fig. 2.30, master cylinder (3) supplies equal flows for cylinders (1) and (2) independently of the load position.

Accuracy of synchronization is about 1%.

SOLUTION 7 – ROTARY FLOW DIVIDER

Another method of dividing one input flow into two equal output flows is by using a rotary flow divider. It consists of two hydraulic motors with equal displacements, connected together mechanically by a common shaft – Fig. 2.53. Because the motor sections turn at the same speed, output flow rates are equal. The pressure drop across each motor section is relatively small because no energy is delivered to the shafts, as is the usual case with a hydraulic motor.

Because of the small variation in the internal leakage of the motors, accuracy is about 10%.
SOLUTION 8 – SERVO CONTROL

Flow control valve (3) controls $Q_1$ and, therefore, the speed of cylinder (1) – Fig. 2.32. Follow-up electro-hydraulic control system controls $Q_2$ and, therefore, the speed of cylinder (2) – synchronized to speed of cylinder (1).

- 3 – Pressure compensated flow control valve
- 4 – Proportional valve
- 5 – Displacement transducer for cylinder (1)
- 6 – Displacement transducer for cylinder (2)

This arrangement gives an extremely accurate control of cylinder speed and position with an accuracy of better than 1%

Fig. 2.32. Closed-loop proportional control

Compared with pure hydraulic and mechanical approaches, electro-hydraulic synchronization provides a flexible alternative. With a closed-loop system, synchronization control strategies can be designed to handle uneven loading as well as uncertainties and external disturbances associated with the hydraulic system.

SUMMARY – ACTUATOR SYNCHRONIZATION METHODS

<table>
<thead>
<tr>
<th>Speed accuracy</th>
<th>Solution</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 %</td>
<td>1</td>
<td>Flow divider valve</td>
<td>Simple, cheap</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Rotary flow divider</td>
<td>Small power loss</td>
</tr>
<tr>
<td>5 %</td>
<td>2</td>
<td>PC flow control valves</td>
<td>Adjustable speed</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multiple pumps</td>
<td>Lack of flexibility</td>
</tr>
<tr>
<td>2 %</td>
<td>5</td>
<td>Single-rod cylinders in series</td>
<td>Special cylinder</td>
</tr>
<tr>
<td>1 %</td>
<td>4</td>
<td>Double-rod cylinders in series</td>
<td>Extra space Press. summation</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Master cylinder</td>
<td>Special extra cylinder</td>
</tr>
<tr>
<td>Better than 1 %</td>
<td>8</td>
<td>Servo control</td>
<td>Complex structure Expensive</td>
</tr>
</tbody>
</table>

Copyright © 2006 — www.HydraulicSupermarket.com
FURTHER READING

‘Advanced Hydraulic Control’ by Brendan Casey & Marian Tumarkin