COMPARISON OF DIFFERENT HYDRAULIC LINE CONCEPTS WHEN THE LOAD OSCILLATES

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ABSTRACT
There are some hydraulic actuators, which operates periodically. This led to a pulsating pressure in a hydraulic line. When a hydraulic actuator is placed at the tip of the crane, the hydraulic line consists of hoses because there are moving joints. The pulsating pressure decreases the reliability of the hydraulic hoses and fittings. It is possible to reduce the pressure oscillation by help of different dampers e.g. an accumulator or a T-pipe. This paper studies the properties of the T-pipe when the operating frequency of the actuator was quite low. The result was that the T-pipe works well even at the frequency 33Hz. The maximum working pressure of the hose is higher if the nominal size of the hose is smaller. When several small hoses are installed parallel those can be use even high oil flows. This way can be integrated the high working pressure and high oil flow. One benefit is that the hydraulic line, which is realised by several parallel installed small hoses, is more flexible than one big hose. These kinds of parallel hose systems were studied by calculating the maximum power level of different hose concepts with special interesting of price. Results show that two or several hose concept is cheapest at the power level over 100kW.

Keywords
T-pipe, parallel hydraulic lines

INTRODUCTION
The use of a hydraulic rock drill causes very certain problems to the hydraulic system. The rock drill produces pressure oscillation, which frequency is quite low (30-60Hz). In practise the rock drill is installed at the tip of the crane and the necessary hydraulic power must be transferred to the drill by hydraulic hoses. The pulsatile pressure, the long hydraulic hoses and high needed power level is a demanding combination.

Pressure oscillation can be reduced by different types of dampers. For such low frequencies an accumulator should be a good damper type. The accumulator is defined by calculating the nominal frequency of the accumulator [1, 2], which depends for instance on pressure, dimensions of the connection fitting and nominal size of the accumulator. However, there are problems (dimensioning, reliability) in using accumulator as a pressure damper [3].
The ECA-damper or the Helmholz resonator aren’t suitable for such low frequencies. The chamber volumes become too big in both cases [4]. A branched pipe, T-pipe, can be a useful damper in low frequencies even though the length of the pipe (or hose) becomes to quite long. The long hose is rather light and it is possible to hide among to the other hoses. One way to raise reliability is increase the nominal working pressure of the hoses. However, the higher nominal pressure level means also stiffer hoses; hoses lose their flexibility. The higher nominal pressure class means the bigger bent radius of the hose. Sometimes the inner diameters of the fittings are narrower in higher pressure level hose arrangements [5].

**DAMPEN WITH T-PIPE**

The rock drill causes several pressure ripples with different frequencies in the same time. In principle the rock drill is a mechanical controlled hydraulic cylinder. Figure 1 shows the pressure oscillation at the rock drill when the oil flow was about 80 l/min. The total length of the supply line was 20m (hose 1 L=15m D=1", hose 2 L=5m, D=3/4"). The used pressure sensor was Kistler A500 type 4065 pressure sensor and the measurement frequency was 50 kHz.

![Figure 1. Pressure oscillation at the rock drill.](image1)

In this time the length of the T-pipe becomes:

\[
\begin{align*}
\lambda &\quad\text{(speed of sound)} = 1100\frac{m}{s} \\
f &\quad\text{(frequency)} = 1200\text{Hz} \\
\Rightarrow \\
L_T &= \frac{1100}{4 \times 1200} m = 0.23m
\end{align*}
\]

The measurement was repeated with a 0.23m T-pipe and the result can be seen in figure 2. The T-pipe was installed as near the rock drill as possible. The difference is clear; high frequency oscillation is lower with the 0.23m T-pipe.

![Figure 2. Pressure oscillation with 0.23m T-pipe.](image2)

As mentioned before the operation frequency of the rock drill is about 33Hz. To be sure, that the T-hose is correct the measurement installation was changed. The rock drill was replaced with a servo valve when the installation was as the figure 3. In this case it was also possible to change the excitation frequency.

![Figure 3. The measurement installation.](image3)
In figure 4 is a pressure oscillation at a function of frequency. Oil flow was the same as using the rock drill (80l/min). The excitation oscillation was risen by a 2Hz step.

Next a 5 meter T-hose was installed to the system. The T-hose was near the servo valve and it branched away from the hydraulic main line. The measurement routine was otherwise the same as before (oil flow, control of servo valve etc). The T-hose had a significant effect to the frequency response. The best damping frequency is at the 55Hz, wherefrom the speed of sound is possible to calculate.

\[ a = 4 * L_T * f = 4 * 5 * 55 \frac{m}{s} = 1100 \frac{m}{s} \]  \hspace{1cm} (2)

When the speed of sound is known the T-hose is easy to dimension for the frequency 33Hz. Figure 6 shows the pressure response when the length of the T-hose was 8.3m. The best damping frequency is, as was expected, at a little bit over 30Hz.

Then the measurement installation was changed to original (rock drill in place of servo valve) and 8.3m T-hose was installed as in the last case.

When figure 7 is compared to figure 1 a clear influence is seen. The main pressure oscillation has been degreased about 40% and also the high frequency oscillation is much lower.

The use of the long T-hose requires that free air is exhausted from the T-hose. If there is free air in the hose it mistakes the calculation.
PARALLEL HYDRAULIC LINES

If the transferable hydraulic power is a really high, there are some problems in using hoses to the hydraulic line. When the power level is between 50-100kW there are several different hoses which are suitable for a necessary pressure and oil flow. If the needed hydraulic power is 150kW, the demands of the hose properties are high. The hose must endure for example 400bar pressure with nominal size 1" (\(v_{\text{max}}=7 \text{ m/s}, 213 \text{ l/min}\)). This kind of hose is very expensive and stiff (min. bend radius over 300mm). Figure 8 shows the price curve at a function of a maximum pressure level of the hose. The nominal sizes of the hoses are 1". The first hose (lowest pressure) has one steel wire braid reinforcement and the last has four spiral wire reinforcement.

On the other hand the pressure can be changed with nominal size of the hose at the figure 8. The price curve would be similar type; exponentially rising. A price curve indicates that if the pressure or oil flow raises the price raises much. The price curve of the hose supports the use of a low pressure and a small nominal size hose. Maximum pressures, minimum bend radius and prices of different hoses from one manufacturer have been collected to the table 1. Maximum oil flows have been calculated by using the maximum flow velocity 7\text{ m/s}. The maximum pressure multiply the maximum flow is the maximum power.

In figure 9 and 10 are prices of the hoses at the function of power. The hydraulic line has been realized with one or several parallel hoses. The principle is, that if the hydraulic power is too high for a one hose the hose arrangement is realized by two or several parallel hoses. The prices of the fittings and ferrules haven’t been included in the price. In principle the fittings and ferrules are very expensive at the big nominal sizes.

Figure 8. The price of the hose (FIM/m) at the function of maximum working pressure.

Table 1. Properties of the examinee hoses.

<table>
<thead>
<tr>
<th>Hose</th>
<th>Type</th>
<th>NS [inch]</th>
<th>(P_{\text{max}}) [bar]</th>
<th>(P_{\text{max}}) [kW]</th>
<th>(r_{\text{min}}) [mm]</th>
<th>Price [FIM/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 steel wire braid</td>
<td>½</td>
<td>310</td>
<td>27.5</td>
<td>140</td>
<td>97</td>
</tr>
<tr>
<td>2</td>
<td>As above</td>
<td>5/8</td>
<td>280</td>
<td>38.8</td>
<td>160</td>
<td>129</td>
</tr>
<tr>
<td>3</td>
<td>As above</td>
<td>¾</td>
<td>280</td>
<td>55.9</td>
<td>190</td>
<td>145</td>
</tr>
<tr>
<td>4</td>
<td>As above</td>
<td>1</td>
<td>225</td>
<td>79.8</td>
<td>240</td>
<td>202</td>
</tr>
<tr>
<td>5</td>
<td>3 steel wire braid</td>
<td>½</td>
<td>470</td>
<td>41.7</td>
<td>160</td>
<td>203</td>
</tr>
<tr>
<td>6</td>
<td>As above</td>
<td>¾</td>
<td>375</td>
<td>74.8</td>
<td>260</td>
<td>239</td>
</tr>
<tr>
<td>7</td>
<td>As above</td>
<td>1</td>
<td>310</td>
<td>110</td>
<td>310</td>
<td>289</td>
</tr>
<tr>
<td>8</td>
<td>As above</td>
<td>1 ¼</td>
<td>240</td>
<td>133</td>
<td>410</td>
<td>492</td>
</tr>
<tr>
<td>9</td>
<td>4 steel wire spiral</td>
<td>½</td>
<td>415</td>
<td>36.8</td>
<td>230</td>
<td>280</td>
</tr>
<tr>
<td>10</td>
<td>As above</td>
<td>¾</td>
<td>420</td>
<td>83.8</td>
<td>280</td>
<td>330</td>
</tr>
<tr>
<td>11</td>
<td>As above</td>
<td>1</td>
<td>380</td>
<td>134.8</td>
<td>340</td>
<td>394</td>
</tr>
<tr>
<td>12</td>
<td>As above</td>
<td>1 ¼</td>
<td>350</td>
<td>193.9</td>
<td>460</td>
<td>779</td>
</tr>
<tr>
<td>13</td>
<td>As above</td>
<td>2</td>
<td>290</td>
<td>231.4</td>
<td>560</td>
<td>1047</td>
</tr>
</tbody>
</table>
Figure 9. Prices of the hose arrangements (FIM/m) at the function of hydraulic power.

Figure 10. Prices of the hose arrangements (FIM/m) at the function of hydraulic power.
One hose concepts were cheapest at power levels 50 and 100kW actually two hose concept was almost same priced at power level 100kW with smaller bend radius. The hose arrangement, which was cheapest at power level 150kW, consists of two NS 1" hoses with the maximum working pressure 225bar. The price index of this hose arrangement was 404 and the price index of traditional one hose concept was 779 (NS 1 ¼, p_max=350bar). Two hose concept was about 50% cheaper compared to the one hose concept. The minimum bend radius was in addition about 50% smaller in two hose concept.

The situation was the same at power level 200kW. The cheapest hose arrangement was 2* 1" hose (p_max=310bar), which price index was 578. The price index of one hose system was 1047 (1 ½", p_max=290bar). The difference was the same class as at the 150kW level.

CONCLUSIONS

The damping capacity of the T-pipe has been tested at the low frequency (33Hz). The T-pipe has been used to damp also step responses. The hose arrangement, which consists of two or several parallel hydraulic hoses have been studied with the special interesting of price and maximum power level. According to this study the following conclusions can be made.

- The T-pipe works quite well although the frequency is low and pressure amplitude is uneven.
- The T-pipe damps little the vibrations of step excitation.
- When hydraulic power is over 100kW two or several parallel hoses can be cheaper and more flexible compared to the traditional one hose concept.

REFERENCES