Counterbalance valve: An engineering approach

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September the 17th, 2014

Abstract

In this article a practical approach of the graduation project of A.G. de Groof will be given. The relative short formula, which makes very easy to check the stability of a counterbalance valve , will be explained and the way it should be handled is shown. To make sure that the reader is familiar with the working of the counterbalance valve, this is explained in the first section.

There is more to the stability of counterbalance valves as might seem at first. That is why this article will show simple formulas for checking stability in several situations. After that the parameters are explained in detail. But at first the working of a counterbalance valve is shown.

In figure 1 a system is shown where a counterbalance valve is used. Characteristic for such a system is a negative load: The load and the movement of the cylinder are in the same direction, which can cause that the load drives the actuator instead of the other way around.

The counterbalance valve makes sure that the bottom side of the cylinder in figure 1 has a pressure to hold the load on the cylinder. This means that the cylinder does not 'fall'. That is why this valve may not be chosen too large, but a too small valve will limit the speed of the operation or cause high pressure.

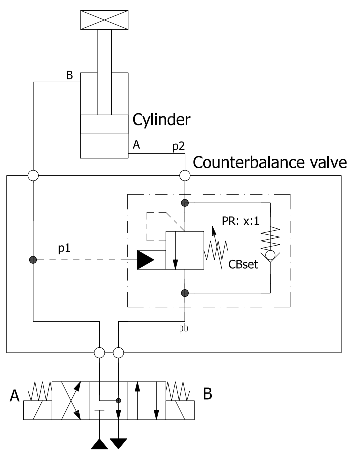

Figure 1: An overview of a system with a counterbalance valve with the rod mounted upwards

1 Stability

In [1] a simple criterion can predict the instability correctly on three real cases. The criterion is based on a third order equation and is simplified to a small criterion. This criterion gives an indication when a system is stable or unstable. The criterion focuses only on the hydraulic system. The mechanical stiffness of the system is neglected in the criterion. The criterion can be used for four standard scenarios. In the next sections each scenario will be explained.

1.1 Counterbalance valve with the rod facing up

Figure 1 shows a hydraulic circuit where the cylinder is mounted vertically with the rod up. The counterbalance valve is mounted on the bottom side of the cylinder. The mass wants to speed up the cylinder rod and piston, but will be limited by the oil mass and the back pressure created by the counterbalance valve. The criterion used for checking the stability of the system for this configuration is.

$$\frac{G_{relief}\,C_{ha}}{Chb} > \frac{G_{pilot}}{Cr} \tag{1}$$

1.2 Counterbalance valve with a rod facing down

Figure 2 shows a hydraulic circuit where the cylinder rod is mounted downwards. The counterbalance valve is mounted on the rod side of the cylinder. The mass wants to speed up and pull out the cylinder rod and piston, but will be counteracted by the oil mass and the back pressure created by the counterbalance valve.

The acceleration of the mass is neglected in the criterion. The difference with the criterion where the cylinder rod is mounted up is that the denominators are switched to the other side.The criterion for this configuration is found:

$$\frac{G_{relief}\,C_{ha}}{C_r} > \frac{G_{pilot}}{C_{hb}} \qquad (2)$$

1.3 Counterbalance valve with a hydraulic motor

Figure 3 shows a circuit with a hydraulic motor as actuator. The model used for the cylinder can be applied for rotation drives. Normally for rotation drives the second law of Newton is rewritten to a rotation law. For this model the second law of Newton is used and the input variable will be chosen that the cylinder model will act as a motor. The motor will be simulated like a linear cylinder with a very small area ratio (≈ 1). The

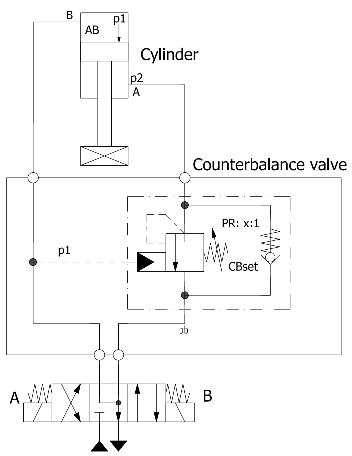

Figure 2: System overview with the rod mounted downwards

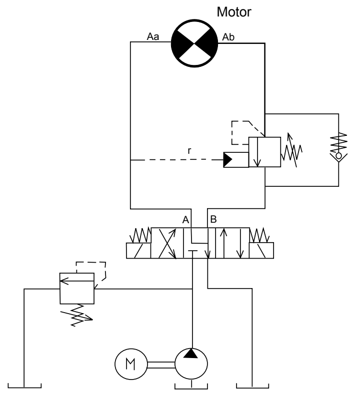

Figure 3: System overview with a motor

small difference in ratio is the internal and external leakage of the motor.

The counterbalance valves are used in a rotation drive to prevent overrunning of the load. An overrunning situation can cause cavitation and, most important, the load is not under control. The criterion for a counterbalance valve with a rotating actuator is.

$$\frac{G_{relief}\,C_{ha}}{C_r} > \frac{G_{pilot}}{C_{hb}} \qquad (3)$$

1.4 Cylinder with a load control valve

Figure 4 shows a hydraulic circuit with a load control valve. The criterion can also be simplified further and can be applied to load control valves. The advantage of a load control valve versus a counter balance valve is that the piston stroke is larger, which means that the piston can modulate the flow much more accurate. Often a load control valve also has larger control area, which also increases the stability. The longer piston also has benefits on the damping.

The load control valve works in steady state as a check valve and it has theoretically no leakage, while a counterbalance valve has some leakage. The opening of the valve depends on the orifice configuration. Load control valves are load independent. Because a load control valve is load independent the term G_{relief} can be neglected. The criterion for a load control valve states for Figure 4 (rod mounted upwards):

$$\frac{k_1\, C_r\, C_{hb}}{C_{ha}} > G_{pilot} \tag{4}$$

If the rod is pointing downwards then the criterion is:

$$\frac{k_1\, C_{hb}}{C_{ha}} > G_{pilot} \tag{5}$$

2 Definition of the used parameters

The parameters are shown in the table below.

Explanation of the variables	
A_b	Area of the bottom of cylinder
C_{ha}	Capacitance of A line
C_{hb}	Capacitance of B line
C_r	Area ratio of cylinder
G_{pilot}	Gradient of pilot function
G_{relief}	Gradient of relief function
k_1	Gain parameter
m	Mass of the piston, rod and mass

2.1 G_{pilot}

The G_{pilot} describes the opening characteristic depended of the pilot pressure.

$$G_{pilot} = \frac{dQ_{through\ counterbalance\ valve}}{dp_{pilot}} \tag{6}$$

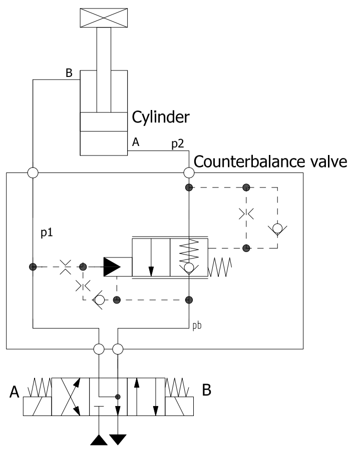

Figure 4: An overview of a system with a load control valve

The smaller the G_{pilot} term, the better for stability. This means that the smaller the rate of change in flow with a small rate of change of pressure is good for the stability. That means a large pressure drop over the valve is good for the stability, which is consistent with the introduction of this article. If the pilot pressure opens the counterbalance valve too much, the actuator will loose pressure and the load can fall, leading to unstable behavior of the counterbalance valve.

2.2 G_{relief}

The G_{relief} term describes the opening behavior of the valve depended on the load pressure.

$$G_{relief} = \frac{dQ_{through\ counterbalance\ valve}}{dp_{relief}} \tag{7}$$

The larger the G_{relief} term the more benefit it has for the stability. The larger the rate of change in flow rate with a small rate of change of pressure is good for the stability. This means that a small change in the actuator pressure opens or closes the counterbalance valve, so the counterbalance valve modulates the flow, preventing the unstable behavior.

2.3 Capacitance

The capacitance is the ability of a volume to store energy. Hydraulic capacitance is determined by dividing the total fluid volume of a pressure-containing envelope by the fluid bulk modulus. Pipe lengths and diameters, cylinder sizes, among others, all contribute to a circuit's capacitance. In turn, this capacitance affects the rate at which pressure can change in a given situation. A large capacitance on the side of the actuator in which the load also pushes (in figure 1 the B-side) has a negative effect on stability, because the response time of the counterbalance valve to modulate the flow is effected negatively. A large capacitance on the other side (so the side connected to the pilot area) has a positive effect, because it prevents the pressure in that area to drop very fast and close the valve due to a dropping pilot pressure, which can lead to unstable behavior.

2.4 Area ratio

A hydraulic cylinder with a high area ratio is good for the stability when the cylinder is installed with the rod downwards. A large area ratio means a hydraulic cylinder with a large piston diameter combined with a large rod diameter.

2.5 Gain parameter

The gain parameter k_1 is defined as the change of flow through the (proportional) directional valve due to a pressure change over the directional valve.

$$k_1 = \frac{dQ_{through\ directional\ valve}}{dp_{over\ directional\ valve}} \tag{8}$$

A large change in flow is beneficial for the stability, because it compensates the pressure drop in the pressure line.

2.6 How to check the stability

The criterion states that the term on the left must be larger than the term on the right. If this condition is met, than the hydraulic system is theoretically stable. The most important system parameters are the G_{pilot} and the G_{relief}. If machine stability problems exist, change to a valve with a lower Pilot Ratio (G_{pilot}) or higher Relief Ratio (G_{relief}) or combination of both.

3 Selecting a counterbalance valve

3.1 Sizing

A counterbalance valve is pressure dependent and not flow dependent. A large enough pressure drop over the valve is required to control the load. If a counterbalance valve is oversized, the restriction is reduced and so is the stability. It is better to slightly undersize a counterbalance than oversize the valve. The main task of a counterbalance valve is creating a pressure drop. Pressure drop curves are available for each manufacturer, use these when sizing a counterbalance valve. Sizing these valves too small will however effect the speed of operation.

3.2 Pilot ratio

The pilot ratio of a counterbalance valve can be categorized in two types: A high pilot ratio and a low pilot ratio. Mind that for load control valves the orifices also influence the behavior.

High pilot ratio For a counterbalance valve with a high pilot ratio, a smaller pilot pressure is needed to open the valve. It allows load lowering with a reduced pilot pressure. A counterbalance valve with a high pilot ratio improves the dynamics of the system but it reduces the stability for a negative load. It is used for fast machine operation and systems with a constant load. Also there is less energy lost because there is less pilot pressure needed to open the valve.

Low pilot ratio For a counterbalance valve with a low pilot ratio, more pilot pressure is needed to open the valve than a valve with a high ratio. More power is needed to open the valve. A lower pilot ratio increases the stability and permits a smooth control of motion. It is applied when large changes of load lead to large pressure differences during lowering.

4 Recommendations

The results of this model have been proven for three cases, each with a stable and unstable situation. These results are based on the criterion in section 1.1. It is now possible to apply the rewritten criterion in section 1.2 , 1.3 and 1.4 on other cases . If more data about the characteristics of valves is available, then a program can be made to estimate the stability. This program can give an indication when a system is stable or unstable. The characteristics of the valves can be found through testing, so it will require a test setup. This helps engineers to select a correct counterbalance valve without having to go through all the theory time after time.

References

[1] A.G. de Groof. Instability of counterbalance valves. *Hogeschool Rotterdam*, 2014.