Compact and Efficient Implementation of a Pressurized Tank Line

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Abstract

Hydraulic hybrid systems, that are able to recuperate energy, require a pressurized tank to ensure the back flow ability. Usually, the pump suction port cannot be connected directly to the elevated pressure. Thus both, ambient pressure tank and pressurized tank are required with auxiliary components. This note presents a concept, where the pump rotary shaft seal is replaced to withstand the elevated pressure in order to get rid of the ambient pressure tank. Successful implementation of the concept encourages to further apply it.

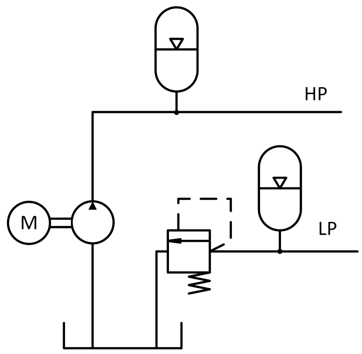

Figure 1: Pressurized tank concept with pressure relief valve in LP line

1 Introduction

Among other engineering fields, energy efficiency of hydraulic actuation needs to be increasingly considered. Hydraulic hybrid technology provides one possibility to reduce the energy loss in hydraulic circuits. The main advantage of hybrid systems are the ability to recuperate energy from actuators, typically into hydraulic accumulator, and use it afterwards to reduce the loading of the prime mover. While recuperating, the actuator pushes oil towards high pressure line (HP line), and thus needs substitute oil flow from the tank line. This is reverse direction compared to typical situation, and therefore, a new requirement is set to the tank line: it should be low pressure source (LP line) rather than unpressurized tank line.

Perhaps, the simplest way to implement LP line is to place a low pressure accumulator into tank line and assemble a pressure relief valve between the ambient pressure tank and the accumulator as presented in Fig. 1. This circuit can be built with standard components and have been used e.g. in [1]. However, the relief valve loses energy of $Q_{\mathrm{LP}} \cdot p_{\mathrm{LP}}$, where Q_{LP} depicts the LP line flow rate, which equals the pump flow rate on average, and p_{LP} depicts the pressure of the LP line; therefore, other solutions are required for the best energy efficiency. Another presented solution is to use closed circuit pump, which allows using of elevated pressure at suction port, and therefore, the relief valve in the low pressure line can be omitted [2]. As a drawback, this solution requires ambient pressure tank for the leak flow of the pump, because the pressure limit of the pump housing likely makes it impossible to connect it to the LP line. Consequently, an auxiliary pump is required to pump the leaked oil volume back to the main circuit. Therefore, this solution neither is regarded to be adequate.

This note presents a solution to create a single pump unit which involves HP and LP lines, both capable of providing oil flow to a hydraulic hybrid system. Some alternatives are discussed and the selected candidate is then dimensioned and implemented as the pressure source for a hybrid actuator presented in [1].

2 Design alternatives

In order to design a single pump system, providing HP and LP lines, the pump should not have an external leakage line. Or if it has, it should be connected to the pump suction line, thus making it to correspond with the pumps without leakage line. In both cases, the pump housing will be exerted to the LP line pressure, which is typically in the range of 1 MPa to ensure the back flow ability. That might become a problem since typically the housing pressure is not allowed to exceed 0.3 MPa absolute pressure. The housing pressure of pumps, or to put it more exactly, the difference between the housing pressure and ambient pressure is mainly limited by the strength of the pump cover and by the pressure rating of the rotary shaft seal. From these two, the latter one dominates in most cases. To overcome this issue, there are two main concepts; to increase the pressure level outside the pump cover in order to reduce the pressure difference over the pump housing, or to increase the pressure rating of the rotary shaft seal by replacing it. Both of these concepts have many implementation alternatives. Some of them are presented in Fig. 2 in simplified manner.

The circuits a) and b) in Fig. 2 depict the alternatives where the pressure outside of the pump is elevated by placing the pump inside the LP accumulator. The challenge in this concept is the need to transfer the power for the pump through the accumulator wall. In the circuit a) the power is transferred in mechanical form by a magnetic coupling. In the circuit b) it is transferred in electrical form through a pressure sealed bushing. The common drawback of these two alternatives, at least in prototype phase, is the complexity of the structure when the pump is placed inside the accumulator. In addition, the magnetic coupling in the circuit a) requires some extra space which increases the size of the complete system. The power lead-through is more compact in circuit b), however, the motor which can be immersed in oil might not be a standard component. Corresponding compact pump units where the electric motor and pump are im-

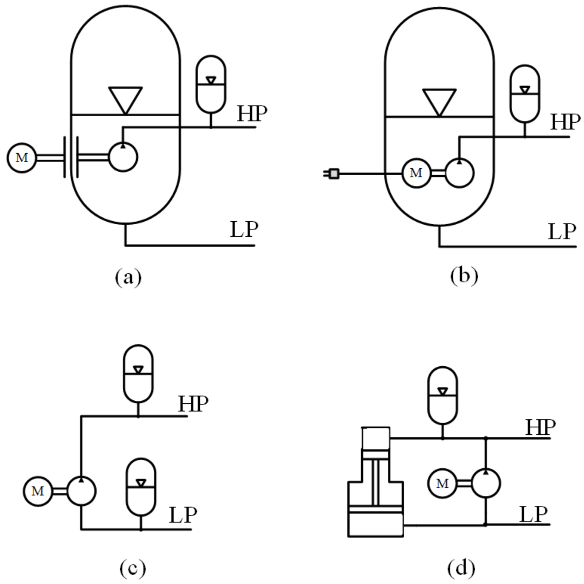

Figure 2: Four different implementation alternatives of pressurized tank without a pressure relief valve in LP line

mersed in oil inside the tank can be found in the market; however, the tank of them probably cannot be pressurized.

The circuits c) and d) in Fig. 2 depict the other alternative where the rotary shaft seal is replaced with a high pressure version. These circuits require the pump housing to withstand the LP pressure. The circuit c) might be the simplest implementation where the ambient pressure tank is replaced by a standard accumulator. The circuit d) exploits a boost trap type pressurized tank which is known from aeroplane hydraulics.

3 Implementation

The circuit c) was selected for implementation. The aim is to power a hydraulic hybrid actuator with the unit. The hybrid actuator includes a high pressure accumulator, and therefore, that is not needed in the pump unit. Also, the pressure relief valve for safety function is integrated in the actuator. The hybrid actuator requires the HP pressure to be between 13.5 and 15 MPa. Thus, continuous pumping is not needed. In contrast, it is possible to maintain the pressure in the allowed range by cyclic use of

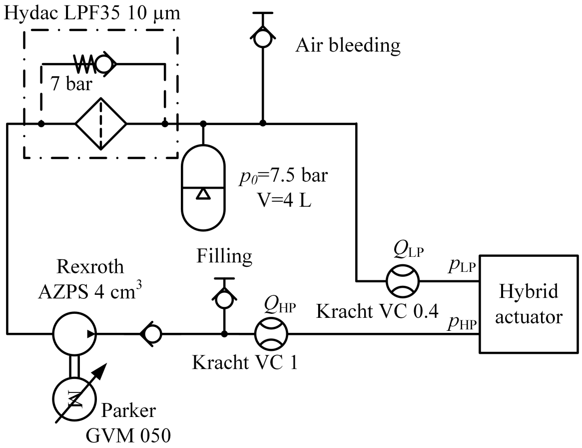

Figure 3: Hydraulic circuit diagram of the test setup. The hybrid actuator includes a HP accumulator.

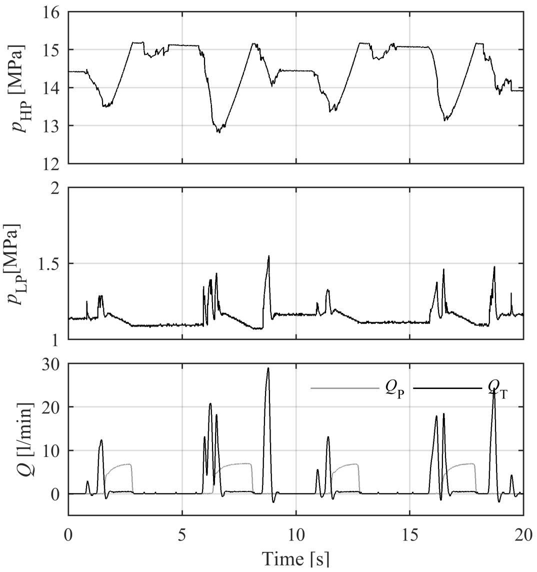

Figure 4: Measured pressures and flow rates

the pump.

The main dimensioning problem was the low pressure accumulator. It was dimensioned by analyzing the maximum difference in oil volume in the hybrid actuator and the pressure limits of the LP line. The pump was dimensioned to provide at least 7 l/min flow rate. The resulting components and the circuit can be seen in Fig 3.

The hydraulic circuit without an ambient pressure tank rises some concerns; cooling and deaeration, which are typically the additional tasks of a tank. However, better energy efficiency of the hybrid systems reduce the need for cooling. In this case, the natural cooling capacity of system was found adequate. Since the system is closed, the air was assumed not to become a problem if the system filling is conducted carefully. To facilitate the deaeration, the LP accumulator was assembled up side down.

The core of the implementation was the change of the rotary shaft seal to withstand the LP line pressure. A local seal provider suggested two seal alternatives; a high pressure version of standard seal made of NBR rubber (pressure rating 1 MPa), and a custom made seal from teflon-carbon material (pressure rating 1.5 MPa). The latter one was selected owing to the higher pressure rating, despite a small concern about leak tightness.

The built system was successfully tested with the hybrid actuator. The system was initially filled up to pressure of 1.5 MPa. At this initial stage, the HP accumulator was empty. After the system start, it was charged up to 15 MPa, yielding the pressure of LP accumulator to drop down to 1 MPa. The system pressures and flow rates are shown in Fig 4. The flow rate of the LP line is occasionally negative, thus representing the recuperating state. The selected rotary shaft seal was not completely leak tight as concerned, since some drops of oil leaked out during the tests.

4 Conclusions

A pressurized tank line (HP line) was implemented without a need of pressure relief valve and ambient pressure tank by replacing the rotary shaft seal of the pump with a high pressure version. The implementation was straight forward; nothing unexpected arose. The solution significantly reduces losses of the HP line and makes the system more compact compared to former solution of placing a pressure relief valve into tank line. However, another rotary shaft seal is required for complete leak tightness.

Funding

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References

[1] Huova M, Aalto A, Linjama M et al. Digital hydraulic multi-pressure actuator–the concept, simulation study and first experimental results. *International Journal of Fluid Power* 2017; 18(3): 141–152.

[2] Verkoyen T, Schmitz J, Vatheuer N et al. Retrofittable hydraulic hybrid system for road vehicles. In *Efficiency through Fluid Power: 7th International Fluid Power Conference (7th IFK), Aachen*. pp. 433–444.