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Backflowing oil to save propulsion energy

Conventionally designed hydraulic drives in an open circuit have the disadvantage that the energy used by the actuator under pulling loads is no longer available to the system. The system presented here, which is capable of regeneration, is shown as a technique which nevertheless allows this energy to be recovered. In this system, the oil backflow is directed to a hydrostatic variable displacement motor which delivers its torque to the drive shaft of the hydraulic pump and thus reduces the total energy consumption of the system. Depending on the situation, the immediate use of the energy or its storage can be more efficient.

Keywords:
Regenerative hydraulics, recuperation, energy recovering.

Abstract
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In principle, four different translational or rotational types of burden can occur in an actuator. This 4-quadrant operation is shown in **Figure 1**. In cases 1 and 4, a pushing load prevails, which means that the load acts against the desired direction of motion of the actuator. In cases 2 and 3, the load pulls in the same direction as the desired direction of motion. In this case, it is theoretically possible to recover and recirculate energy because the level of potential or kinetic energy is reduced. Otherwise, the energy enters the system in the form of heat, which must be dissipated by appropriate cooling systems.

State of the art

Numerous current developments in both stationary and mobile hydraulics are pursuing the goal of improving the total efficiency of a hydraulic system by recovering the power delivered by an actuator.

However, energy recovery is not easy to realize in the hydraulic systems commonly used today. In order to be able to control the speed of the actuator to be lowered or decelerated, the outlet side must be slightly throttled and the energy to be delivered by the actuator must be converted into heat. This causes high losses because 100% of the energy delivered by the actuator must be dissipated in the throttle in the form of heat and is hence no longer available to the system.

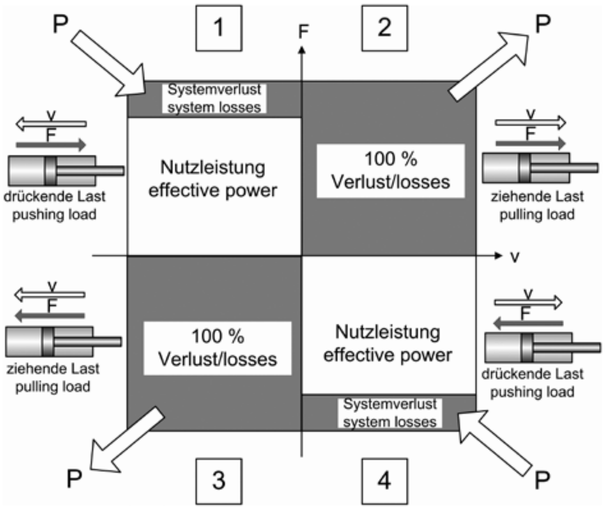
Design of the hydraulic drive

The hydraulic energy recovery system was first designed in a simulation at the University of Braunschweig. The project is supported by the Deutsche Forschungsgemeinschaft (DFG).

This system is equipped with three 3/3 directional valves V_A, V_B, and V_{Reg} for every actuator (of which only one is shown (1)). In addition to the pump (2), the system features a hydrostatic variable displacement motor (3), which is termed regeneration motor below, as well as another pump/motor unit (4) with a hydraulic reservoir for energy storage.

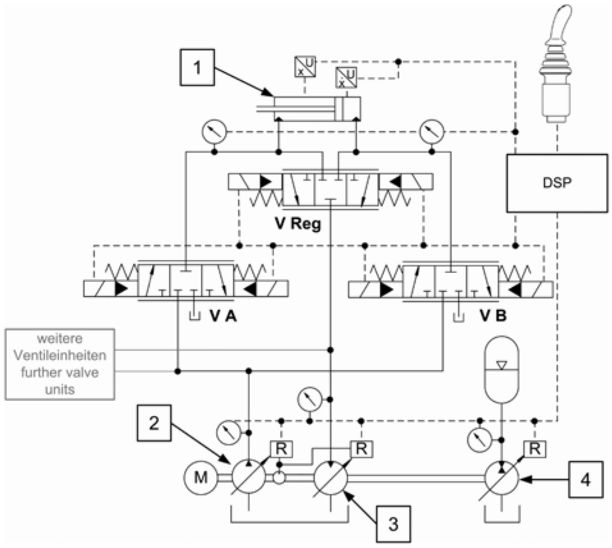
In order to be able to control lowering speed under pulling

Fig. 1



Losses of conventional hydraulic systems

Fig. 2



Design of the hydraulic drive with a regenerative function

loads, the outgoing volume flow must be limited. This can be achieved by throttling (no energy recovery) or controlled power absorption by the regeneration motor. For this purpose, its absorption volume is varied by an open-loop sum flow control system.

In the simplest case, the control logic for two actuators is designed according to the pattern shown in **Table 1**. Since identical recirculation pressure levels are required for this sum flow control on the outlet side if the actuators are exposed to different pulling loads, additional valve control is also necessary in this system. The volume flow which leaves the actuator exposed to higher pulling load is throttled by the valve V_{Reg} up to a point where pressure in the recirculation pipe is at the level of the recirculation pressure of the actuator under smaller pulling load.

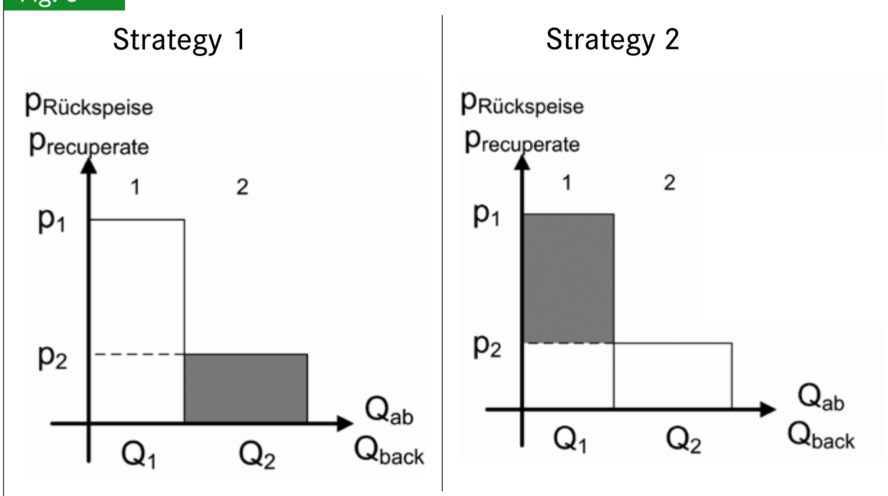
Operating strategies

In order to minimize total energy consumption, it is important to choose the right operating strategies for multiple-actuator operation. This requires some fundamental considerations:

In a system with two actuators, both actuators can be under pushing load. Energy recovery is not possible. If one actuator is under pulling load while the other one is exposed to pushing load, it is conceivable in principle to supply the energy released by the one actuator to the actuator under pushing load (regeneration). If both actuators are exposed to pulling loads, it is also theoretically possible to recover energy. However, this requires intermediate storage so that the energy is available for a later work process (recuperation). In order to be able to distinguish these cases, one must first determine the individual type of burden for every actuator according to the quadrants in **Figure 1**.

Then, the individual combination of load types must be established. If both actuators are exposed to pulling loads, it must first be clarified whether the capacity of the storage unit is sufficient for recuperation. If this is the case, the recuperation strategy which allows the largest quantity of energy to be recovered is determined and applied. The choice of strategy largely depends on the difference in the recirculation pressure level of the actuators under pulling load. **Figure 3** shows two actuators under different pulling loads. Since energy recovery requires that the recirculation pressure of both actuators

Fig. 3



Two actuators under pulling load with different recirculation pressure levels

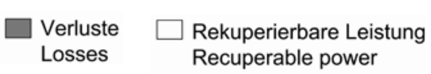
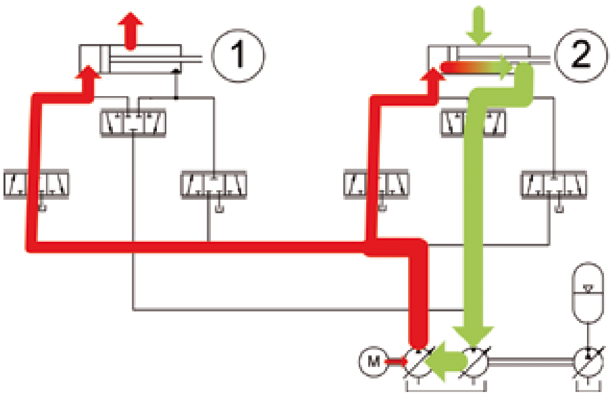


Table 1

Control logic of the regeneration hydrostat

Load status	Set volume flow of the regeneration hydrostat
Actuator 1 pushing or under no load	$Q_{Motor} = 0$
Actuator 2 pushing or under no load	
Actuator 1 pulling	$Q_{Motor} = Q_{back,1} + Q_{back,2}$
Actuator 2 pulling	
Actuator 1 pulling	$Q_{Motor} = Q_{back,1}$
Actuator 2 pushing or under no load	
Actuator 1 pushing or under no load	$Q_{Motor} = Q_{back,2}$
Actuator 2 pulling	

Fig. 4



Idle power problems in actuators under pulling and pushing load.

is at the same level, calculations must first be carried out in order to establish whether it is economically more efficient to throttle the actuator under higher load (1) to the level of the actuator under smaller load (2) or to opt for recirculation by only one actuator. For this purpose, the achievable power must be calculated. If only actuator 1 is recuperated **(strategy 1 in Figure 3)**, the power which can theoretically be gained can be calculated as follows:

$$P_1 = p_1 \cdot Q_1 \quad (1)$$

If both actuators are intended to recirculate energy, the pressure of actuator 1 must be throttled to pressure level p_2 **(strategy 2 in Figure 2)**. Thus, the power which can theoretically be gained from both recirculating actuators can be calculated as follows:

$$P_{common} = p_2 \cdot (Q_1 + Q_2) \quad (2)$$

This allows the appropriate strategy to be chosen.
If there is one actuator under pushing load and another one under pulling load additional problems occur. Since pressure at the inlet is determined by the load of the pushing actuator **(1 in Figure 4)**, the volume flow of the actuator under pulling load, which is used to fill the flow side **(2 in Figure 4)**, is delivered at the same pressure. As a result, hydraulic power is supplied to the actuator beyond the outside load, and an idle power flow is generated. Thus, the hydraulic power supplied to the actuator before is recirculated by the regeneration motor (minus the losses). In this case, however, the system must be designed for idle power flow.

Summary and outlook

The system presented here shows options for the recovery and recirculation of the energy to be delivered under pulling loads. For this purpose, in particular the operating strategies were considered because the choice of the appropriate operating strategy showed high energy savings potential especially if several actuators are present. In addition, the use of this system on a mobile machine promises even more possibilities of energy conservation because the recovered power is available at the engine output shaft. Thus, a comprehensive hybrid concept in which power can be shifted between the operating hydraulics and the traction drive seems conceivable in combination with a traction drive of any kind (hydraulic, mechanical, electric). For mobile applications the need for additional components and especially sensors can be regarded as critical.

Literature

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