Konrad Steindorff and Hans-Heinrich Harms, Brunswick

Valve-controlled hydraulic drive with a regenerative function

A worldwide increase in energy costs, tightened emission regulations, and the protection of resources require more energy-saving drive systems also for mobile machines. In the valve control systems which are mainly used to drive these machines, the oil backflow is throttled for motion control under pulling loads so that the delivered power is converted into heat and can therefore no longer be used. In this contribution, a system is presented which is intended to allow the oil backflow to be regenerated.

Dipl.-Ing. Konrad Steindorff is a scientist working at the Institute of Agricultural Machinery and Fluid Power of the Technische Universität Braunschweig/Germany (director: Prof. Dr.-Ing. Dr. h.c. H.-H. Harms), Langer Kamp 19a, D-38106 Braunschweig; e-mail: *k.steindorff@tu-bs.de.*

Keywords

Valve control, energy recuperation, mobile hydraulic systems

Literature

Books are marked by •

[1] • *Rahmfeld, R.*: Development and Control of Energy Saving Hydraulic Servo Drives for Mobile Systems. Dissertation, Universität Duisburg. Fortschritt-Berichte VDI, Reihe 12, Nr. 527, VDI-Verlag, Düsseldorf, 2002

[2] • *Holländer, C.*: Untersuchungen zur Beurteilung und Optimierung von Baggerhydrauliksystemen. Dissertation, Technische Universität Braunschweig. Fortschritt- Berichte VDI, Reihe 1, Nr. 307, VDI-Verlag, Düsseldorf, 1998

Numerous developments in both stationary and mobile hydraulics are pursuing the goal of improving the overall efficiency of a hydraulic system by recuperating the power delivered by a consumer or by reducing the losses.

In excavators, the slewing gear is often operated in a closed hydraulic cycle with displacement control. This arrangement provides the possibility of feeding power back onto the diesel engine shaft via the pump while slewing motion is being slowed down. The application of this principle in the entire hydraulic drive requires displacement control for every hydraulic motor. Therefore, a variable displacement unit designed for maximum power is required for every motor, which causes the need for highly sophisticated and expensive installations [1]. In addition, different inflow and outflow volumes lead to problems if differential cylinders are used.

Description of the hydraulic regeneration concept

The hydraulic system shown schematically in *Figure 1* in an exemplary manner with a cylinder as a consumer provides the possibility of regenerative operation. At the design stage shown in *Figure 1*, initial investigations are intended to show how much power can be fed back to the hydraulic motor and the pump shaft if pulling loads are applied to the cylinder. In principle, four different types of (translatory or rotatory) loads can occur in a consumer. These cases are also shown in *Figure 1*.

In cases 1 and 4, a pressing load prevails, which means that the load acts against the desired direction of motion of the consumer. In cases 2 and 3, a pulling load acts in the same direction as the desired direction of motion. As a result, the volume flow which leaves the cylinder must be throttled in a conventional hydraulic system in order to avoid an undesired acceleration of the cylinder. This causes significant losses because the energy built up before must be dissipated and is therefore no longer available for the system. These cases can also be applied to rotatory consumers. If a rotating consumer must be slowed down, the inertia of the consumer acts as a pulling load, and energy must be dissipated.

In the two cases 2 and 3, the hydraulic system examined here allows regenerative operation to be realized. This is intended to be realized by extending a conventional system to include an additional proportional valve V_{Reg} and another variable hydraulic unit, which gives off its torque to the shaft of the hydraulic pump. Moreover, inflow and outflow must be able to be controlled separately in this system. If the system senses that a pulling load is applied (e.g. in case 2), valve V_B, which would otherwise throttle the oil outflow to the tank, is closed, and V_{Reg} is opened. Thus, the oil outflow is directed to the hydraulic motor. Therefore, the load on the pump is reduced because the output shaft is coupled to the pump shaft.

The adjustable motor and pump units transform the hydraulic power recuperated from the consumer. The motor-pump arrangement shown is a hydrostatic transformer with a dissolved design. This enables a small volume flow under high pressure to be converted into a large volume flow under low pressure (and vice versa), which is needed because the required pump volume flow does not necessarily equal the backflow volume.

Since, however, the load on the pump is low in any case if pulling loads are applied, mainly systems with several consumers are considered at this design stage. In another step, the possibility of intermediate energy storage is intended to be examined so that efficient regeneration with one single consumer becomes possible.

In the case of multiple consumer operation, the power recuperated from the consumer under pulling load can be supplied to another consumer which needs power at the same time. This is illustrated below using an excavator with all consumers including the slewing gear in an open circuit as an example. In a typical work cycle shown in *Figure 3*, an excavator loads material from the ground onto a vehicle. During this cycle, the machine must carry out a cyclical slewing

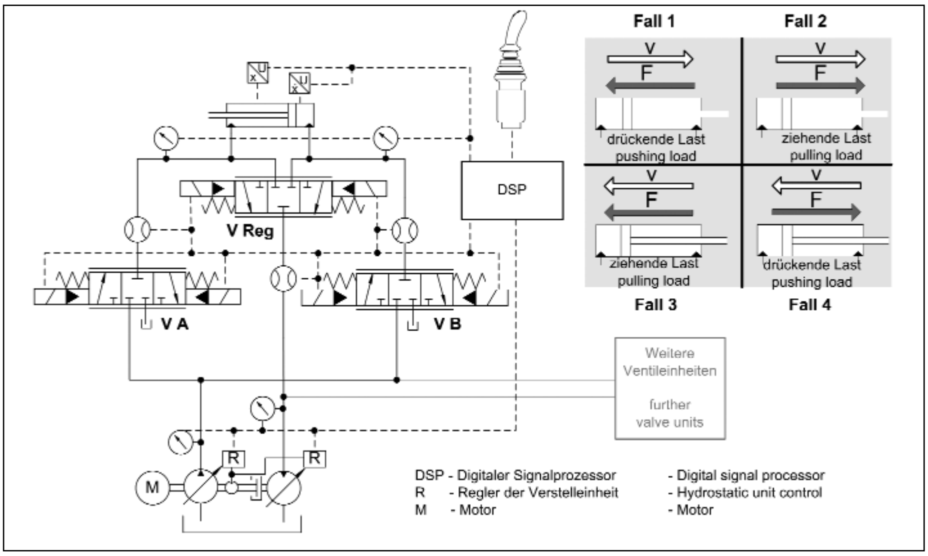

Fig. 1: Diagram of the hydraulic drive with regeneration function and possible loading conditions

motion and several lifting movements. While a lifting motion with the aid of the boom is being carried out, the slewing movement of the turntable must be slowed down. In this case, mass inertia acts as a pulling load on the turntable. The energy regenerated by this system can be used to support the lifting motion of the boom and thus to reduce the load on the diesel engine, which ultimately saves fuel. Thus, the energy of any other translatory or rotatory consumer can be regenerated. A similar cycle is shown in *Figure 2*. This diagram illustrates that the slowing-down process of the turntable and the lifting of the boom coincide temporally as do the opening of the bucket and the lowering of the boom.

In this concept, the sensors and the control strategy used are very important. For any consumer, the individual loading condition (pulling or pressing) must be known at any time. Based on these conditions and the requirements of the operator, the set volume flow to the consumers must be controlled using the swivel angle of the pump and the valve openings. If the loading condition is suitable for regeneration, the swivel angle of the regenerative hydrostatic unit must additionally be controlled such that the rotational speed of the hydrostatic unit and the pump would be the same due to the available oil flow from the regenerated consumer. In order to prevent the consumer from running at a higher speed under pulling load, the regeneration valve is adjusted such that it provides a certain minimum pressure on the inflow side so that the consumer is always under slight pressure and the dynamics of the system are not impaired under changing loads.

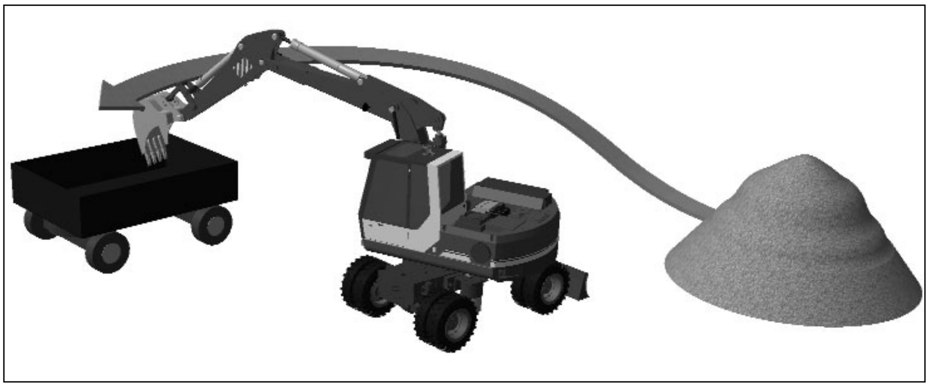

Fig. 3: Typical motion sequence of an excavator: rotary drive braking, boom lifting

Summary

In this contribution, a system was presented which allows built-up potential or kinetic energy to be regenerated if pulling loads act on a hydraulic consumer. This concept is based on a hydraulic system in an open circuit, which requires the control edges of the inlet and the outlet to be controlled separately. An additional variable hydrostatic unit recuperates the energy of the oil backflow.

With the aid of an adapted control strategy, the system promises significant energy savings while requiring only a few additional components because only one additional hydrostatic unit is needed regardless of the number of consumers. As part of a project promoted by the German Research Foundation (DFG), a simulation model of this system is currently being built at the Institute of Agricultural Machinery and Fluid Power. This model is intended to allow the energy savings potential provided by this system to be estimated and evaluated.

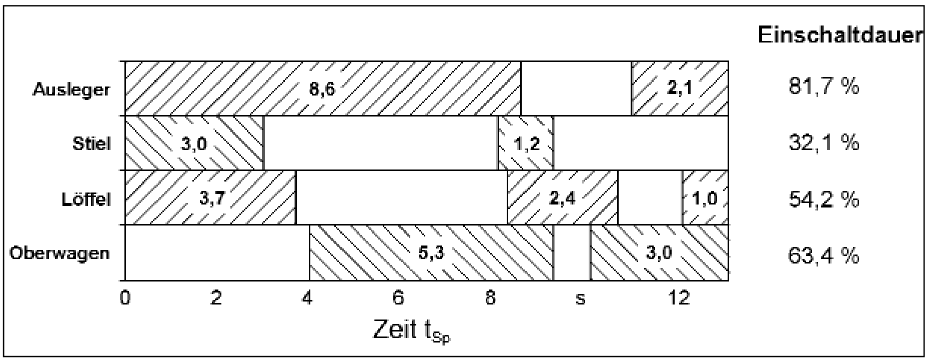

Fig. 2: Power-on time of an exemplary excavator duty cycle [2]