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Simulation of a pressure regulated press system for steplessly variable pulley transmissions

Steplessly variable pulley transmissions are possible systems for continuously variable transmissions in tractors. Great potential for an increase in total working efficiency lies in the optimising of the press and conversion hydraulics. A new pressure regulated system was investigated with the aid of computer simulation. The focal point lay in the realisation very quick reactions for the availability of pressure for the press system when sudden changes in torque take place, a situation common in tractor operation. For further investigations, a real time simulation system was evolved with which, alongside data recording at the test stand, a rapid and efficient development of regulating strategies is possible.

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Continuously variable tractor transmissions have, in the meantime, found their place in the market with highly developed examples. From 2001, alongside Fendt and Case/Steyr [1], John Deere and Deutz-Fahr also offer hydrostatic power-split transmissions. Chain converters appear interesting, above all, because of their very high mechanical efficiency. So far, their power limits are not sufficient for large tractors, but these can be steadily increased [2]. Within a project financed by the German Research Society (SFB 365), new concepts for the hydraulics of a steplessly variable pulley transmission were investigated with the aim of improving total transmission efficiency.

Pressure-regulated press system

A chain converter comprises two conical disc components between which torque is transmitted via chain kept in position by friction. To avoid slippage of the chain and therefore damaging of the converter [3], an oil pressure proportional to the torque must be present in both press system cylinders. For a change in conversion, the pressure is additionally increased.

Whilst the versions currently produced in series (e.g. Audi Multitronic [2]) are dependant on a constant oil volume flow for immediate availability of pressure, in a newly developed, pressure-regulated and energy-efficient system [4] the advantages of the constant flow systems (high dynamic, rapid stillstand displacement) have been retained. A simpler construction has been achieved: a displacement pump, a 3-way pressure regulating valve, and a new type of torque sensor [4] for each plate component. The oil pressure on the press cylinder is regulated over variable displacement pump and pressure regulating valve according to the moment electronically measured by the torque sensor, whereas with the known P.I.V. constant flow system the pressure comes from a moment-dependant throttling. In case of greater positive torque gradients where pressure build-up takes places too slowly through the inertia of valve and pumps, the torque sensor very quickly determines the required pressure. This is done completely mechanically according to the P.I.V. principle (so-called "pump effect") retained for this purpose.

Simulation of the press hydraulics

The basic requirement of simulation is that its dynamics offer an exact as possible reproduction of the reality. In the construction of a complex system the individual components are firstly modelled and verified through measurement. The total system is then built-up from the developed models. The modular structure means that individual elements can easily be replaced for the investigation of various concept variations, and for further optimisation.

Applied for the simulation was the software MATLAB/Simulink with the hydraulic extension Hydraulik Blockset. Alongside the torque sensor the pressure regulating valve with its basic functions was also simulated.

As proof of the model's simulation value it was compared with calculated values measured on the test stand. The structure represents half of the new press system: a variable displacement pump, a pressure regulating valve and torque sensor.

The response to a surge of desired value is an important criterium for the valve (*fig. 1*). With a rise in pressure the first milliseconds are decisive because the rapid availability of the required pressure is necessary for the damage-free operation of the chain converter [4].

A further basic characteristic is the effect and length of time of pumping. To investigate the time aspect, the stress loading is suddenly increased whilst a desired pressure is constantly applied at the pressure regulating valve. Through the pump function of the torque sensor, the oil pressure rises and is higher than the desired pressure at the valve because the desired value calculation has a built-in delay. The pressure regulating valve now – undesirably – attempts to reduce the pressure to the adjusted desired value.

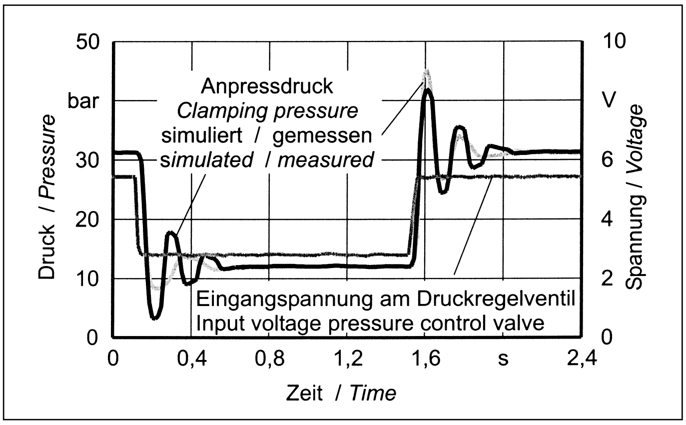

Fig. 1: Step response of pressure control valve

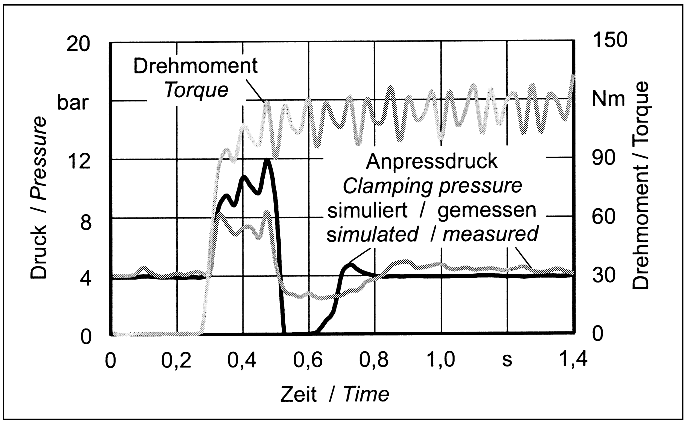

Fig. 2: Time characteristics of pump effect of the new torque sensor

Through valve inertia, however, the pressure remains torque-proportional for around 40 ms. As long as the torque sensor continues to pump the pressure perseveres at a somewhat lower level (*fig. 2*) because the valve opens in the direction tank. Through its design, the torque sensor can only pump for a limited time, subsequently the pressure drops rapidly because the pressure regulating valve continues to reduce pressure in tank direction. The result here indicates the period of time in which, at the most, the pressure regulating valve and the pump must have taken to raise the oil pressure.

The next step is represented by the linking of torque measurement on the new torque sensor and the relaying of this value to the pressure regulating valve. The torque determination is optimised on the basis of earlier trials [4] and especially the disturbing lag in desired value relay is reduced. In the trial, the pressure is adjusted according to the abruptly-increased torque via the pressure regulating valve (*fig. 3*). At the beginning of the torque surge the torque sensor supports the pressure increase until the pressure regulating valve sets the pressure.

During the pump function, a too large torque is recorded. Because of this, the over-reactions are strongly defined. The effect is strengthened by the behaviour of the pressure regulating valve with desired surges (fig.1).

Simulation in real time

Alongside classic simulation there is also the possibility of interactive data exchange with the surroundings. When one speaks of "hardware on the loop" this means control equipment is allied with the simulated surroundings. On the contrary, "rapid control prototyping" means the simulation of the regulator on the PC which communicates with a real test stand [5]. Calculations in the simulation program must, therefore, take place in real time, i.e., within the same period of time as the actual event. At the Chair for Agricultural Machinery, the simulation program MATLAB/Simulink is used for this with the extension Real-Time Workshop and Real-Time Windows Target applied.

For the first step in the determination of the torque at the torque sensor, a Rapid Control Prototyping System is realised. All measurement data is recorded and shown. At the same time, the sensor signal in the appropriate torque and the equivalent desired pressure is calculated. Through giving the tension-pressure characteristic field, the desired tension directly on the pressure regulating valve is produced. This method allows the processing of data without large efforts in programming of a controlling equipment and speeds up the precise and efficient development of new regulators or controlling equipment. With the collected information a controlling appliance is programmed and this now calculates the desired pressure.

Next step will be the conception and simulation of a regulating strategy for the press and conversion regulation of the entire hydraulic circuit.

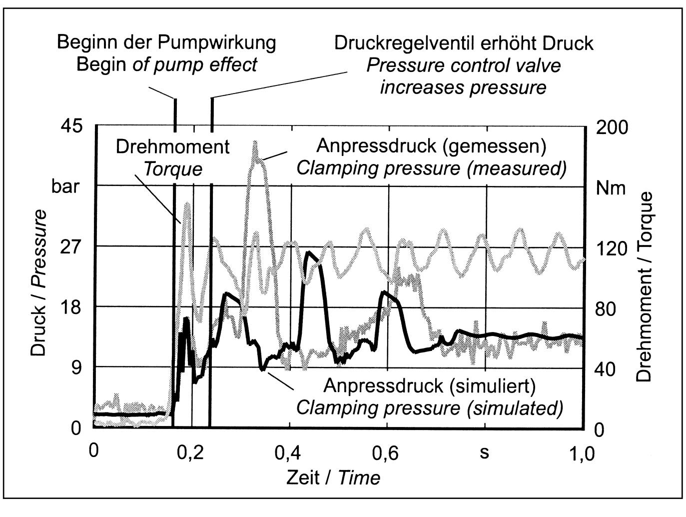

Fig. 3: Raise of oil pressure by an abruptly increase of torque, caused by pressure control valve and torque sensor

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