Pump Actuator Based Control of a Clutch System

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Abstract

Typically a clutch brake combination (CBC) is actuated by a hydraulic unit consisting of a pump and a valve system. By operating the valves different pressure levels can be generated, which determine the transmittable torque. The rated power of the pump is considerably high, consuming a lot of energy even when no work is done. If a system requires additionally the availability of multiple possible pressure levels, the system gets very complex. Furthermore at the attachment of the system the valveadjustment takes a big manual expenditure of human labor.

A flexible adaptation and the elimination of disturbances would be excellent for modulating the torque. Additionally the reduction of the energy consumption becomes more important today.

Therefore the standard hydraulic pump is replaced by the pump actuator, which essentially consists of a variable speed driven hydraulic pump. This generates superior control possibilities over a standard hydraulic system and allows a great reduction of the energy consumption, better control possibilities for the complete system, as well as new methods of fault diagnostics.

KEYWORDS: servo controlled pump actuator, pressure control, clutch brake combination

1. Conventional control of a CBC

The control consists of a hydraulic power unit, a series of valves, orifices and accumulators. The pump in the hydraulic unit is permanently working at nominal speed. Depending on the status of the valves the system is pressurized fully, partially or not at all. The system doesn't adapt itself on changing conditions, like rising temperatures or wear of the friction linings. The consequences of these inflexible conditions are inconstant clutch- and brake times or overshooting in the pressure characteristics. Furthermore a complete disassembly of the CBC is required to check the wear of the friction linings, causing expensive downtimes of the complete machine.

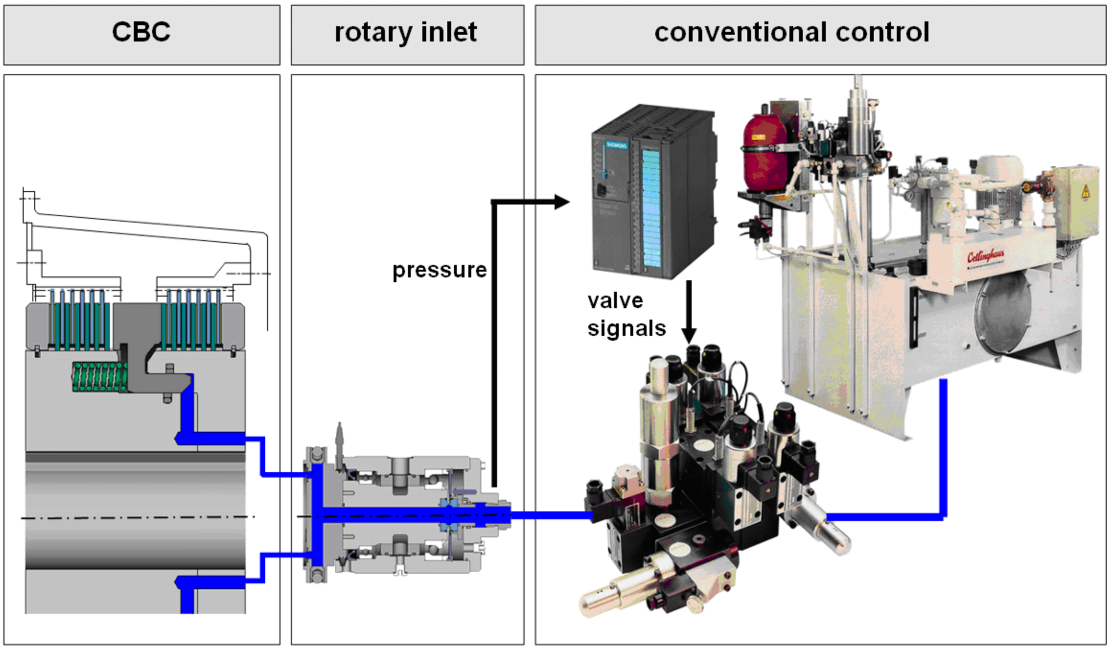

Figure 1: Conventional control of a CBC

2. Pump actuator based control of a CBC

In this case the CBC is pressurized by a variable speed driven hydraulic pump. Different pressure levels can be realized by changing the pump speed. The pressure control eliminates disturbances like rising temperatures or wear of the friction linings. In case of emergency the integrated press safety valve (PSV) ensures the secured state of the system by bypassing the hydraulic oil back into the tank.

To control the permanent magnet synchronous motor, a servo converter is used. This servo converter provides the necessary power via the power amplifier. The implemented controller calculates a control voltage out of the specified torque. This torque is calculated with an algorithm placed on an external embedded PC, which communicates via data bus with servo controller.

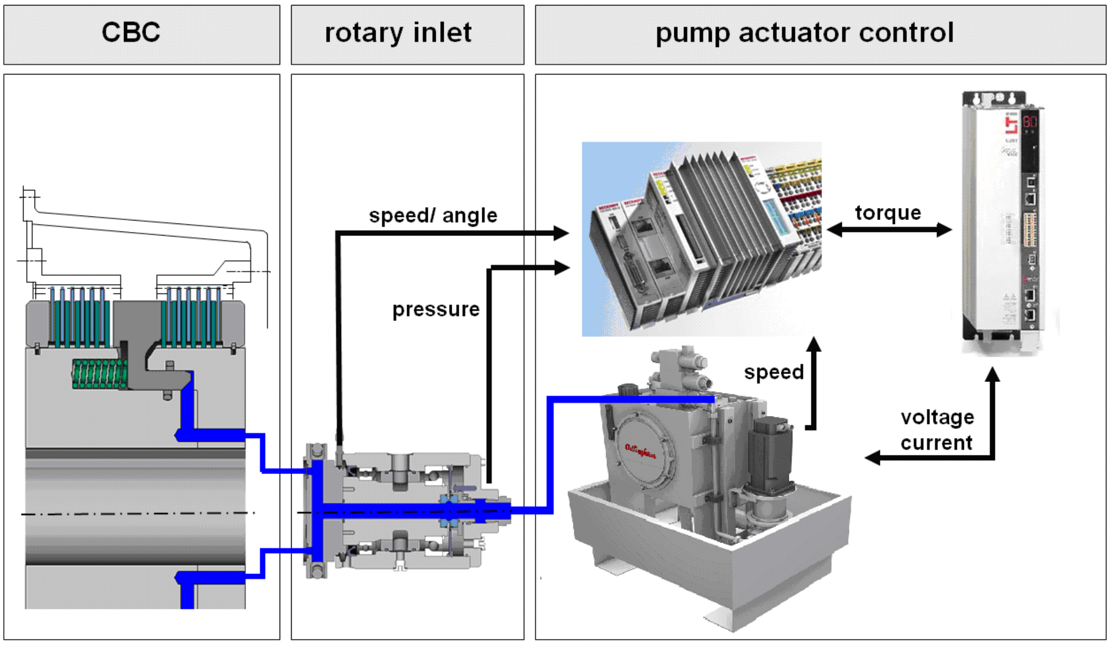

Figure 2: Pump actuator based control of a CBC

3. Construction of the clutch-brake combination

The CBC transmits the torque and velocity from the input shaft to the output shaft via a frictional connection. **Figure 3** shows the mechanical construction of the CBC.

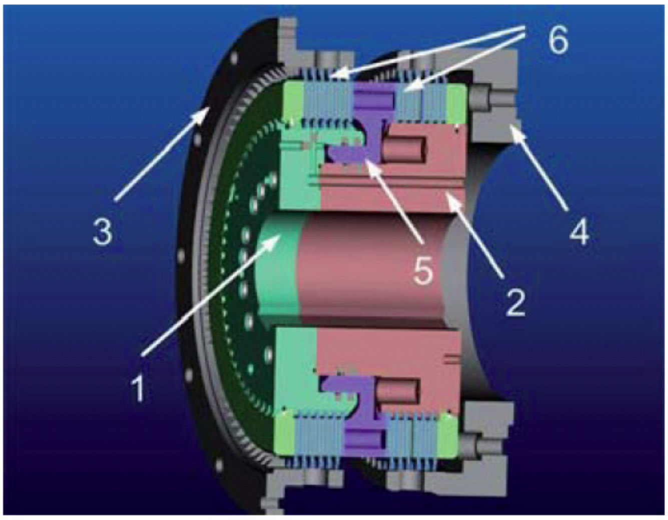

Figure 3: Construction of the CBC

The inner part (1 and 2) is connected to the drive shaft. The outer part (3) on the left side is fitted to the fixed flange of the body. The right outer part (4) of the body is connected to the rotating drive unit; the cylinder with the piston (5) inside is filled with oil to engage the clutch by pressing the plates (6). If there is no pressure in the cylinder, the brake is engaged by spring force. In case of black out of the control the brake is activated automatically, which is described as inherently safe. The time to switch from brake to clutch is called filling time, whereas the time to action from clutch to brake is called emptying time.

4. Structure of the pump actuator

This pump actuator consists of two main parts, a permanent magnet synchronous motor with a flanged internal gear pump and a hydraulic tank. In the hydraulic tank, the hydraulic fluid for actuating a clutch brake combination (CBC) is provided. In case of emergency a press safety valve (PSV) ensures the secured state of the system by bypassing the hydraulic oil back into the tank. Furthermore in order to prevent excessive over pressure a pressure relief valve (PLV) is provided in the system.

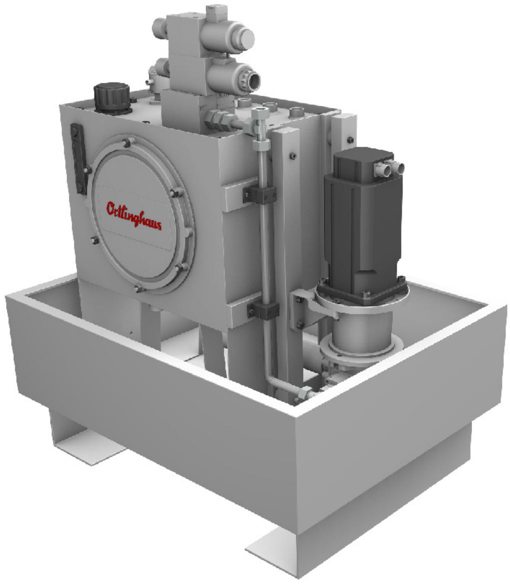

Figure 4: Pump actuator

5. Systems analysis

An idealized hydraulic system has a linear relationship between the pump speed and the generated pressure. In the real system, there are a variety of disturbances, such as compressibility of the oil, air inclusions, elasticity's of hoses and seals, temperature changes, wear of the friction and nonlinear behaviour of the springs in the CBC. The control has to be able to handle these disturbances. **Figure 5** shows an example of the influence of temperature changes on the coupling process with a standard valve control. The pressure progression is diagrammed with the green characteristic. At time t_{fs} a clutch process is required. It is followed by the filling time t_f where the piston inside the CBC moves from the brake plates to the clutch plates. By reaching the clutch plates at t_{ss} the next phase t_s starts with the synchronization of the speed. After synchronization at t_{cs} the angle (red curve) rises linear with a constant synchronous speed of the input and output shaft (blue curve).

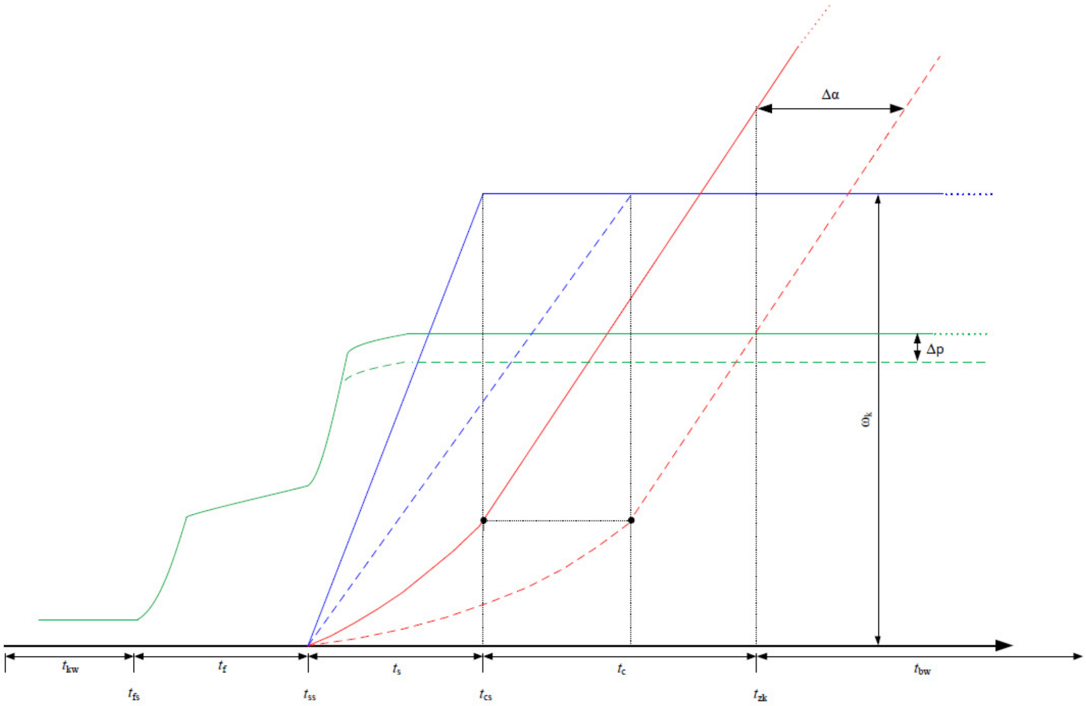

Figure 5: Effect of temperature on the engaging process

The dashed curves show the pressure, speed and angle at a higher oil temperature. Due to the lower viscosity a higher leakage occurs at the seal gaps and the pressure relief valve, causing a lower pressure level in the CBC system. That results in a lower press capacity of the clutch plates, causing an extension of the synchronization time. By using a pressure closed loop controlled system these and other variation of the system parameters can be eliminated.

6. Structure of the control

The pressure characteristic is highly nonlinear, caused by the springs with the two block positions at the clutch and the brake position.

The developed system is a closed loop control cascade using a torque, a speed and a pressure controller. With this control cascade it is possible to pressurize the CBC with any pressure level within the system limits. **Figure 6** shows the control structure of the whole system.

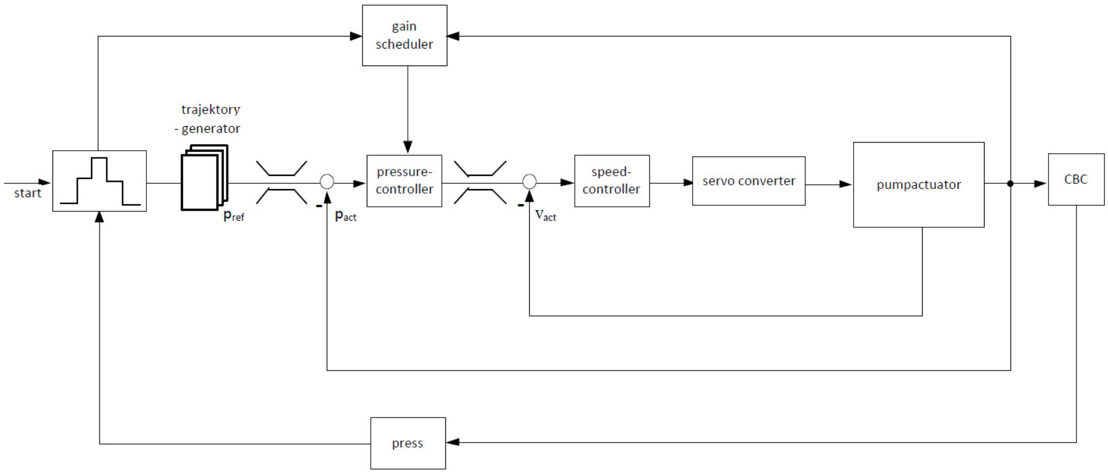

Figure 6: Technical design of the control

The integrated pressure sensor in the hydraulic part continuously provides the actual pressure value. The difference between the reference pressure and the actual pressure value describes the pressure control deviation. Based on this deviation the pressure controller calculates a reference speed, followed by the speed controller that computes a reference torque for the servo converter.

The pressure characteristic is divided into three nearly linear parts to handle the nonlinearity. The first part is between zero and the spring curve, where the brake is engaged. The second part is the whole spring characteristic while the piston of the CBC is located between the brake and the clutch. The third part is up to the maximum pressure where the clutch is engaged. To avoid an uncontrolled movement of the drivetrain during the changeover between brake and clutch (second part), the pressure controller is disabled and the pump is working at maximum speed. The other two parts can be controlled with the whole closed loop control cascade to ensure a dynamic pressure control. In theses two parts a small speed variation causes a high pressure variation. A gain scheduler handles the different requirements of the control. Furthermore the controller uses optimized control parameters in each part of the pressure characteristic.

Wear of the friction linings causes a shift in the position of the piston while engaging brake and clutch. The controller observes the delivery volume during the fill time by counting the revolutions of the pump continuously and adapts the control parameters automatically. Thus the diagnostic of the wear of the friction linings doesn't require a complete disassembly of the CBC anymore.

7. Saving energy by a process-specific control of the CBC

A major application area of hydraulically operated clutch brake combination is the eccentric press. The CBC transmits or disconnects the torque from the flywheel to the plunger of the press via a frictional connection. The product life of a press can be extended by accelerating and decelerating the plunger “softly”. A typical pressure characteristic of an eccentric press is shown in **Figure 7**. P1 characterizes the pressure level for engaging the clutch to synchronize the output shaft of the CBC softly. P2 represents the maximum pressure level with the maximum transmittable torque on the clutch which is used for the forming process.

At the pressure level P3 the brake of the CBC decelerates the plunger softly. P0 is the minimum pressure where the brake transmits the maximum torque. In Case of standstill of the plunger or in case of emergency this pressure is required.

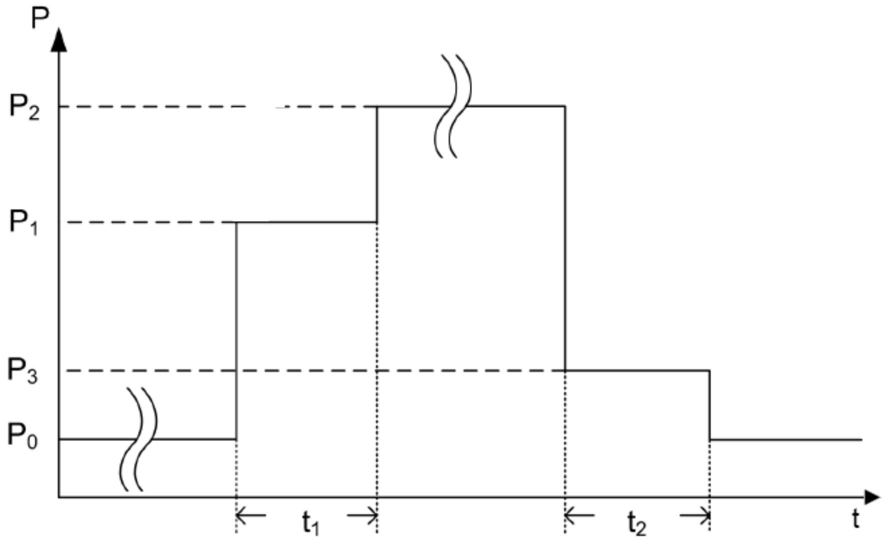

Figure 7: Conventional clutch-brake-cycle of an eccentric press

By controlling the CBC with the pump actuator it is possible to safe energy up to 80%. The maximum pressure is only required during the forming process. All the other time, when the CBC is engaged, the pump actuator generates an intermediate pressure level between P1 and P2 to ensure the synchronous speed of the input and the output shaft.

8. Measurement results

Figure 8 shows the speed and the pressure characteristics in a clutch-brake cycle at an eccentric press. The magenta curve represents the reference pressure, the blue curve the actual pressure. The brown curve shows the speed of the output shaft and the green curve the speed of the input shaft. The filling time and the synchronization are completed within t=0.3s, whereupon at t=0.5s the controller generates the intermediate pressure of p=45bar. Just before the beginning of the forming process at t=1.2s the controller generates the maximum pressure of p=60bar. After the forming process at t=1.8s the intermediate pressure is approached to save energy. After a period of t=2.5s the braking process starts and ends at t=2.8s where the controller generates the minimum pressure of 4bar.

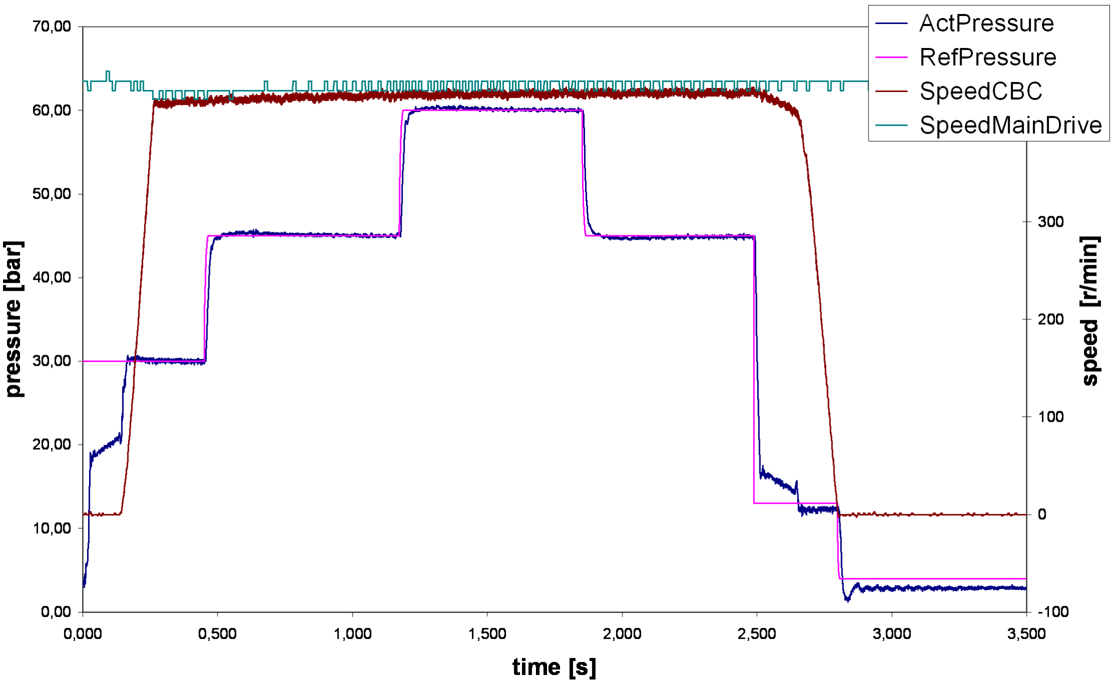

Figure 8: Pressure cycle with a controlled pump actuator

It is conceivable to control the synchronization by varying the reference pressure to increase the accuracy in the clutch and brake process.

9. Summary

In the paper a speed variable pump actuator with a specially designed closed loop pressure controller is figured out in order to actuate a highly nonlinear system. The designed control structure is able to fulfil all requirements which are made concerning dynamics and accuracy. A comprehensive system analysis has contributed to an optimal behaviour of the pressure control. The nonlinear characteristic of the hydraulics has been taken into account by providing different parameters depending on the reference pressure. The controller eliminates disturbances and is able to diagnose the wear of the friction linings. Also, the synchronization could be controlled by variation of the reference pressure. The example of an eccentric press shows the enormous energy saving potential of up to 80%.

10. Literature

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11. Nomenclature

t_{fs}	starting time filling sequence	s
t_f	filling time	s
t_{ss}	starting time synchronization	s
t_s	synchronization time	s
t_{cs}	starting time synchronous speed	s
p	pressure	N/mm^2
n	speed	1/s
t	time	s