Better Braking – Energy Saving Concept for Cylinder Drives with Large Masses

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Abstract

Energy saving is currently one of the major trends for drive technology. This applies to the automotive industry as well as to mobile and industrial applications. Intensive research on alternative drive concepts is done not only in the automotive industry but in mobile and stationary hydraulic systems, too.

For hydraulic drive systems enhanced solutions such as variable speed controlled pump drives were developed. These systems provide only the required volume flow and pressure level and avoid throttle losses.

Another approach is only to rethink about the dimensions of the cylinder drives. If a single rod cylinder has to move large masses dynamically the required cylinder diameter is sized by the resulted acceleration and deceleration force.

Within this paper a new drive concept is presented that uses an additional circuit to realise significantly higher deceleration without overloading the cylinder. It allows at the same cycle time the use of cylinders with smaller piston diameters. This reduces the needed pressure level at the same volume flow and the needed hydraulic energy input.

KEYWORDS: energy saving, energy efficiency, cylinder drives, large masses

1. Introduction

Machines with cyclical movements (e.g. transport functions) usually have the same speed and force requirements in extend and retraction direction. In order to achieve shortest cycle times, the drives are accelerated and decelerated as quickly as possible.

For high accelerations and decelerations high forces are required. In particular, the braking of large masses with hydraulic cylinders must be viewed critically. The braking pressure depends only on desired deceleration force and the active braking area of the cylinder. In contrast to the acceleration, where the maximum system pressure acts on the cylinder areas, during deceleration the pressure can be boosted to a multiple of the system pressure.

If as usual a single rod cylinder is used for symmetric motion the maximum load on the cylinder occurs when braking with the annulus area. The required piston diameter of the cylinder is calculated from the desired deceleration force, from the rod diameter and the maximum pressure rating of the cylinder. The lower limit of the rod diameter is given by the maximum allowable buckling.

The maximum brake pressure does not depend solely on the maximum allowable operating pressure of the cylinder but also on the maximum operating pressures of the needed additional components such as tubes, pipes, fittings and pressure relief valves which are stressed by the brake pressure, too. These standard components are not available for all pressures ranges and special designs lead to high costs.

The ideal system would be a cylinder with variable areas. This drive system could be dynamically adapted to the current load case. The pressure losses would be minimised and an overload of the components could be effectively prevented /1/.

Approaches to area-variable cylinders like the 4 area cylinder are more complex. Especially regarding life time the variety of needed seals in the systems is required to think critically.

2. Presentation of the new solution

Looking on a cyclic motion of mass without additional load forces (e.g. transportation movement) the required power can be divided into its individual components (see **figure 1**).

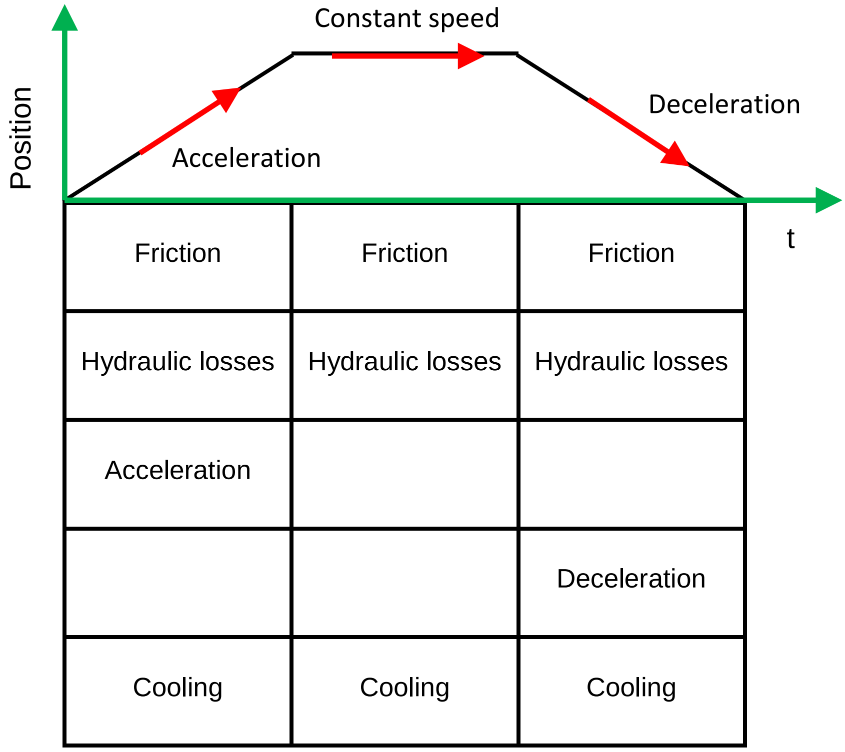

Figure 1: Overview of different power components

During a move with a constant speed the drive has to apply power for friction as well as for hydraulic losses. Only during the acceleration phase it has to supply the power for acceleration in addition. During the braking phase of a valve-controlled drive the braking power is completely converted into heat at the valve which results in additional cooling power for downstream components.

The new drive system takes over the idea of a hybrid drive system. The operating principle is well known from the automotive industry. In hybrid passenger vehicles, the combustion engine at higher power requirement is supported by an electric drive. This allows the use of smaller engines (downsizing). The needed electrical power for the electric drive is recaptured during braking and stored in batteries.

This principle can be adapted to the hydraulics by building a drive system consisting of two hydraulic cylinders. The drive cylinder is supported during the acceleration and deceleration phase by a secondary cylinder connected in parallel. This acceleration and brake cylinder supports the drive cylinder only during acceleration and braking. It allows reducing the diameter of the drive cylinder as the combustion engine of a hybrid vehicle can be sized smaller. The hydraulic power for the additional cylinder is recaptured during the braking process. The kinetic energy of the moving mass is stored into an accumulator and can be used for the next acceleration.

In the new system the different power components presented in **figure 2** can be distributed to the two subsystems. Subsystem1 applies only the power for the friction and hydraulic losses during the constant travel and subsystem2 provides the necessary additional acceleration and deceleration power. Due to the fact that the kinetic energy is not dissipated into heat but recaptured into an accumulator the cooling power is reduced too.

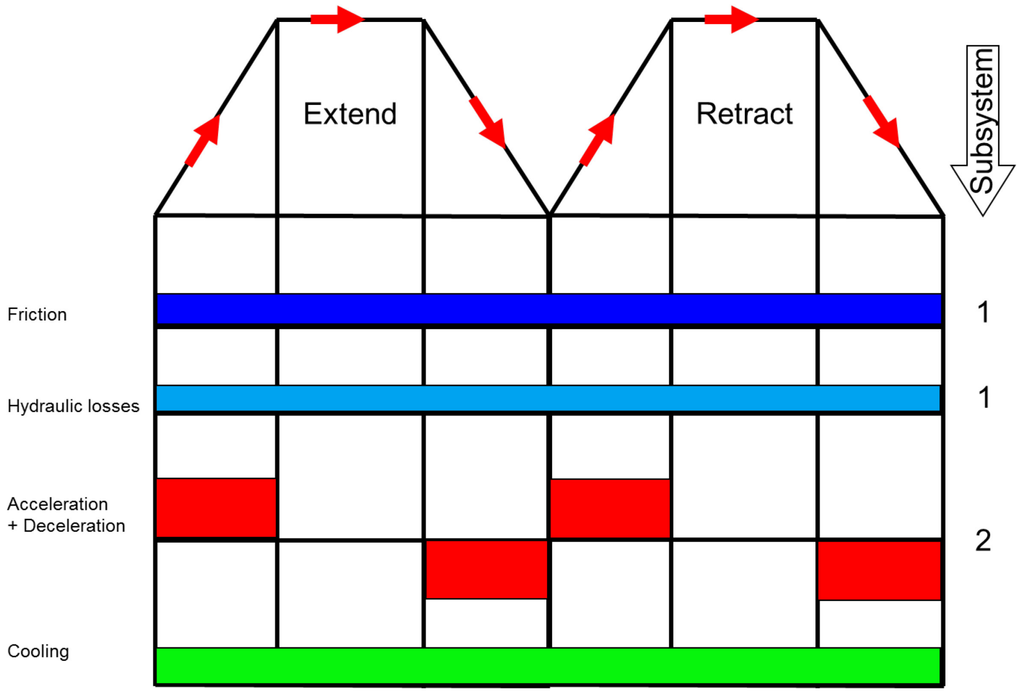

Figure 2: Distribution of drive power between the two drive subsystems

Particular in cyclic working drives with short cycle times (e.g. injection moulding machines, blow moulding, die casting, etc.) the expected savings are especially high.

In the next two sections both subsystems are presented separately.

2.1. Drive System for constant speed

Machines with cyclical movements mostly have the same speed and force requirements in extension and retraction direction. Friction forces of guiding systems and of the cylinders itself are of the same absolute value and apply always in opposite direction to the movement.

Because of their symmetrical design double cylinders are the first choice for applications with symmetric movements. Due to the required double overall length this solution is not suitable.

Figure 3 shows an alternative circuit for a single rod cylinder which allows nearly symmetrical drive performance and is suitable for the subsystem1. This A-regeneration circuit feeds the draining oil from the rod side back into the bottom during extend side when moving in extended direction via a control edge /2/.

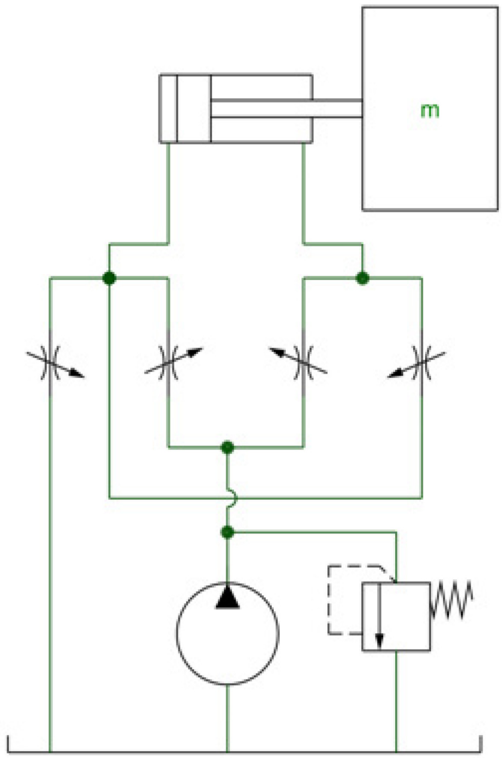

Figure 3: A-regeneration circuit for the same speed extent and retract direction

2.2. Braking and acceleration system

In the braking phase the rod side is connected to an accumulator. The braking characteristic of the subsystem2 is defined by the gas spring of the accumulator.

To accelerate the drive in extend direction the accumulator has to be connected to the bottom side of the cylinder. Because two independent cylinders are used the stored energy can be used even if the accumulator pressure drops below system pressure.

During the constant travel the subsystem2 is towed by the subsystem1. The cylinder takes the entire required amount of oil out of the tank line. The tank line should be pressurized by a few bar to avoid cavitation.

Another alternative to sucking the entire amount of oil from the tank line is again a regeneration circuit (**figure 4**). The drain oil from the rod side is fed into the bore side. With this concept the cylinders must suck only half of the needed oil volume out of the tank line. In addition the breaking pressure for extend and retract movement is on the same level due to this circuit. Therefore only one accumulator with fixed gas pressure can be used for both directions.

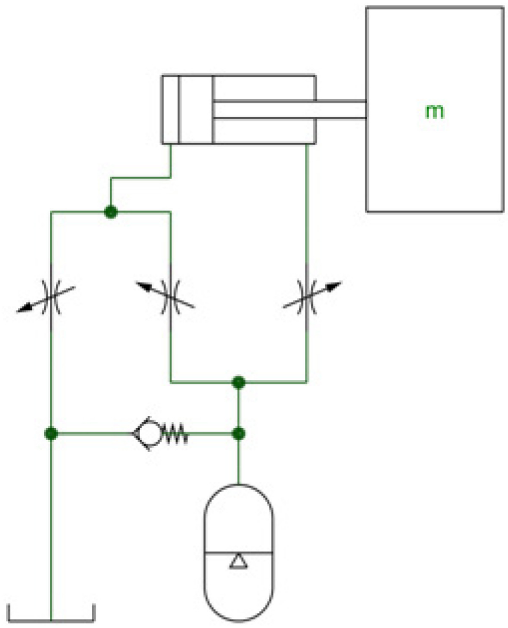

Figure 4: Subsystem2

To move the system in retract direction the accumulator is attached to the rod side of the cylinder and the cycle works vice versa.

2.3. Complete system

Figure 5 shows the complete drive system. All control edges are built as proportional directional control valves. The complete system consists only of well proved components.

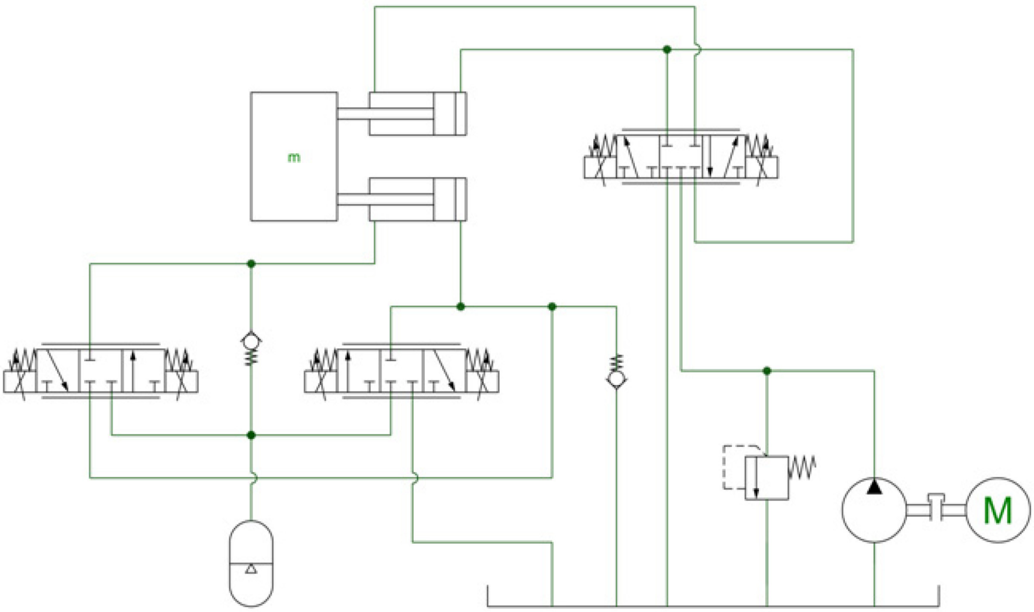

Figure 5: Hydraulic circuit of the complete system

Since no spontaneous failure of the accumulator is to be expected, the system is as safe as a standard sized close loop controlled drive. If wear occurs at the seal of the accumulator, it can be easily detected by a pressure monitoring.

3. Test rig

To proof the idea of the new drive concept a test stand shown in **figure 6** was built at the smallest possible scale. Therefore two cylinders (25mm bore, 18mm rod diameter and 500mm length) and moving a mass of 500kg were chosen.

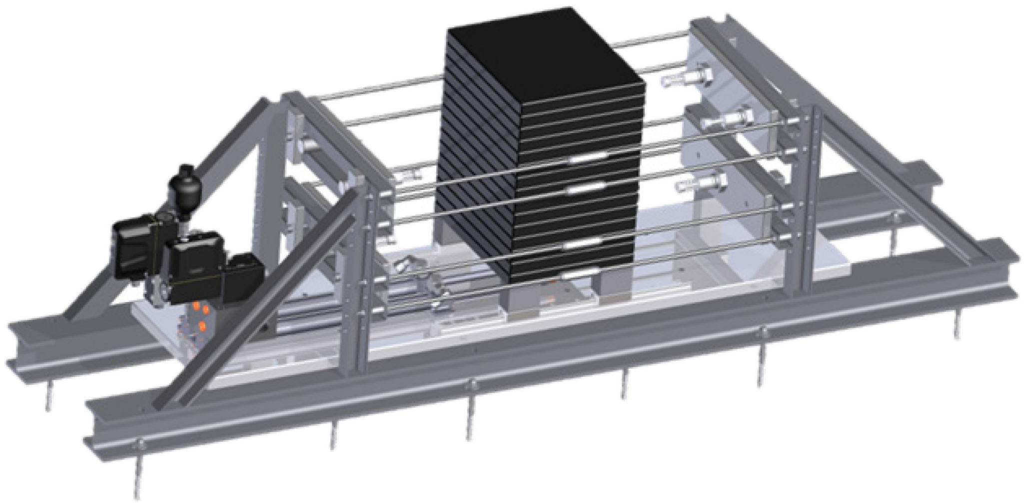

Figure 6: Test stand

3.1. Reference measurements – only subsystem1

To compare the old and the new system with each other a movement is defined which goes to the limits of the valve controlled system. Figure 7 shows the movement of one test stand cylinder with a maximum possible deceleration. The supply pressure of the system in this case is 160bar and the maximum speed is 1.2m/s.

In **figure 7**, the brake pressure in the extend direction (p_B) reaches the maximum working pressure of the cylinder of 210bar. During constant travel both cylinder pressures are on the same level. The maximum possible acceleration of the drive is achieved at system pressure of 160bar on the piston side and the valve is fully open.

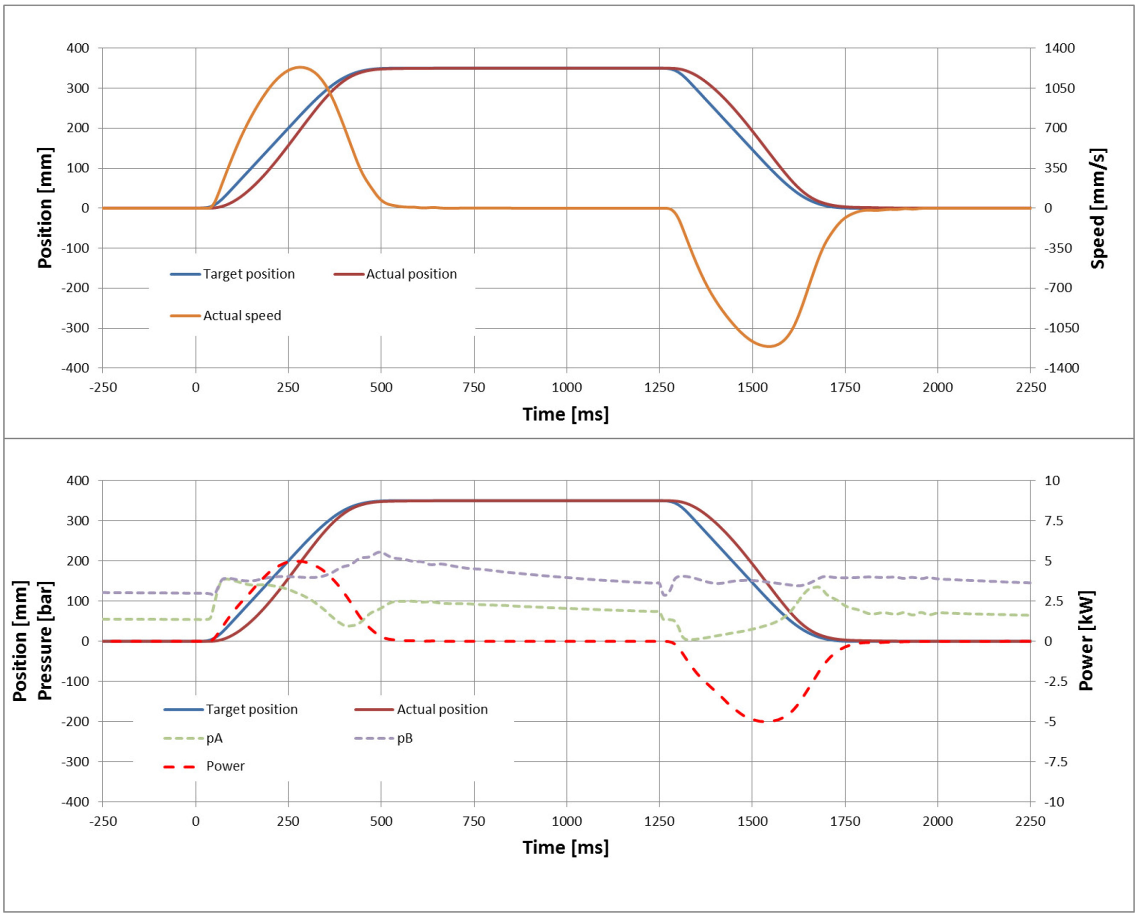

Figure 7: Reference cycle: one cylinder at system pressure 160bar

While the drive moves in retract direction the drive accelerates slower but does not reach the maximum working pressure during braking. The peak power for this movement is 5kW.

This movement is taken as a reference for the evaluation of the new drive system

3.2. Hydro-Twin system

Figure 8 shows that nearly same movement like in figure 7 can be achieved with the Hydro-Twin system but with a supply pressure of only 100bar.

In order to achieve maximum energy savings, the entire braking power is applied by the subsystem2. In the drive cylinder (subsystem1) during the braking phase no breaking pressure is built up and the cylinder pressure $p_{A\ subsystem1}$ and $p_{B\ subsystem1}$ remain on supply pressure level which is far below the maximum working pressure of the cylinder. Instead the complete kinetic energy is stored into the accumulator. In positive direction (extend) rod pressure $p_{B\ subsystem2}$ and in negative direction $p_{A\ subsystem2}$ increase to 120bar.

This energy is used to accelerate the subsystem2 in the opposite direction. The pressure curves $p_{A\ subsystem2}$ and $p_{B\ subsystem2}$ display the acceleration and the discharge of the accumulator. When moving with constant speed the bore and annulus side of the subsystem2 are nearly at tank pressure.

The peak power for this movement is at 2.5kW, hence half of the reference cycle.

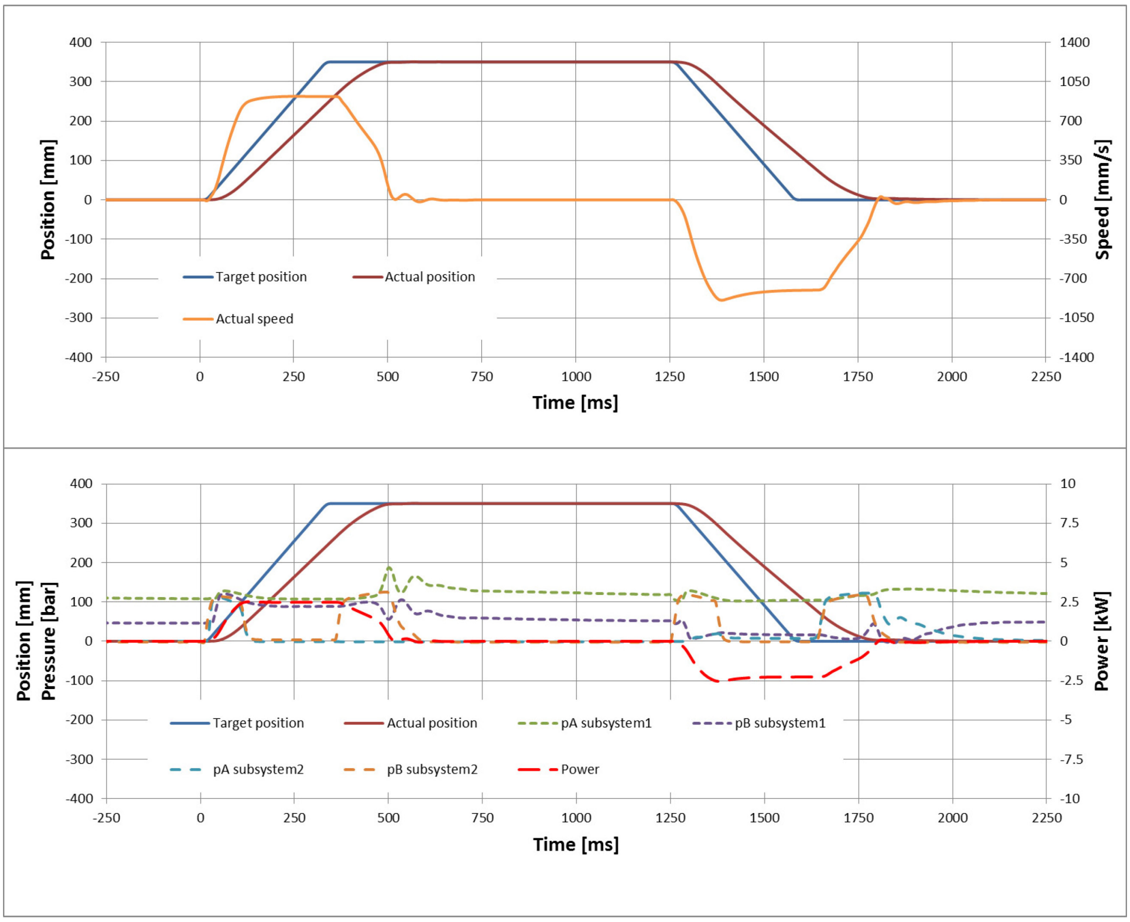

Figure 8: Energy saving cycle, system pressure 100bar

4. Conclusion

The new drive system allows re-using the braking energy at linear drives which is not possible with other existing energy-saving solutions. It also demonstrates the strength of hydraulics to store quick high power peaks effectively into accumulators. In order to achieve further energy savings the Hydro-Twin can be combined with speed controlled hydraulic pumps, too.

The presented test stand results show the energy saving potential of the Hydro-Twin system. A movement of a mass with the same dynamics requires only half the power. The savings on the cooling power due to the avoided throttle loss during braking are not taken into consideration here.

Figure 9: Design of full scale prototype

This concept works only when large masses are moving fast enough so that a lot of kinetic energy is available. Otherwise, there is not enough energy to be stored during the deceleration phase. Therefore, this concept is particularly capable for fast cyclic movements with large masses with high decelerations.

The next step in the development process is to build a first prototype for a real application. **Figure 9** shows the new design.

This time the diameters of both cylinders are chosen differently. At this application the diameter of the drive cylinder (subsystem1) size is reduced instead of the system pressure. The drive cylinder is no longer able to accelerate the mass to the required speed without the assistance of the second cylinder.

5. Literature

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