Optimization of hydraulic drives for parabolic troughs

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Abstract

HAWE Hydraulik SE, Munich, engineers and manufactures hydraulic drives (CSP-drives) for parabolic trough plants consisting of a compact power pack, directional and control valves, over-center valves, two cylinders and the fittings/hoses for connecting these components. Optional, but this is depending on the system and the control philosophy, also a hydraulic accumulator.

An optimized hydraulic drive for a parabolic trough field makes the power plant operator profit from savings at components, higher system efficiency, lower operational energy supply needs, less time spent on commissioning and first start-up, lower maintenance effort and increased life span of the drive and finally also savings on peripheral and safety devices. Many of shown proposals are even combining two or more of above mentioned advantages.

KEYWORDS: CSP, parabolic trough, hydraulic drives

Hydraulic systems are the ideal choice for driving the parabolic trough of a solar thermal power plant. The size and weight of the troughs are such that the advantages of a hydraulic solution can be utilized to the full, namely its ability to apply a large force with precision within a small space requirement exactly when it is needed. However, the development of hydraulic drives is not yet finally completed.

1. Savings at components

1.1. Cylinders with smaller dimensions working at higher pressure

A radial piston pump effortlessly generates an operating pressure of up to 700 bar. Taking advantage of this feature the usual operating pressure for drive cylinders of 150…200 bar (limits of an external gear pump) can be increased to 350 bar. Based on identical forces, the size and weight of the cylinders can be decreased. At the same time the procurement costs for the cylinders are reduced. An operating pressure of 350 bar is also a practical size for the reason that standard cylinders and the other system components are also designed for similar max. pressures. Increasing pressures higher than this which would entail increased costs.

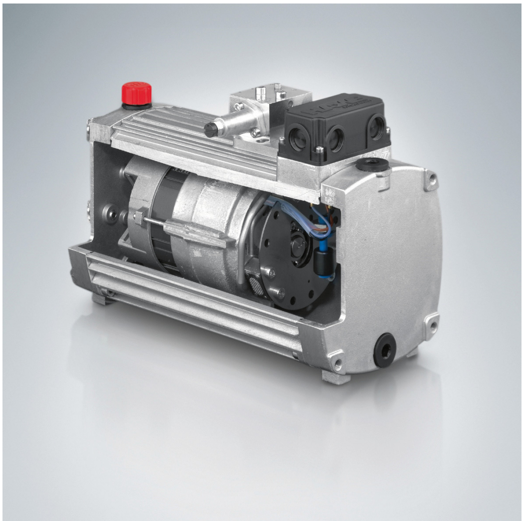

Figure 1: Power pack with immersed motor, radial piston pump, modular tank design

1.2. Modular tank design

A modular tank design with precisely adjustable size allow the compact power pack to be matched exactly to the oil volume actually required for the application. This is realized by using a small base tank element with the motor/pump unit and several extensions. Without this wide variety of size graduations, this can easily amount to three or more liters of unnecessary oil per tank. In the case of power plants with 1,000 drive pylons, every wasted liter for the initial filling and every oil change at maintenance after that can add considerably to the costs. This is an unnecessary expenditure that is not incurred with a correctly sized tank.

2. Higher system efficiency

2.1. Continuous tracking

State-of-the-art tracking is done step by step. Approximately every 10 sec the power pack is started and the trough follows the suns path on the horizon keeping the line focus of the mirrors on the absorber tube with the heat transmission fluid. This 1 sec ON/ 10 sec OFF philosophy requires that the positioning of the focus is set some 0,01° in advance and readjusting with some 0,01° delay to the sun. Otherwise the number of activations of the power pack would become too high in too short time and the requested lifetime of the drive of 20 years would not be achieved. Doing this the focus will not always be at the optimal position at the absorber tube, but more in an acceptable tolerance band. Continuous tracking can avoid this disadvantage. The challenge here is to design a proportional valve which can control a flow of 0,05…0,1 l/min as these are values necessary for existing trough designs. Such a valve ensures an accurate positioning of the trough all the time, increases the system efficiency and reduces in combination with an accumulator charging operation the ON/OFFs of the power pack dramatically.

2.2. 2-pole and 6-pole winding on one motor

The motor of the power pack can be implemented as a double motor. A 2-pole and a 6-pole winding are mounted together on one common rotor. This means that two volume flows with a ratio of 3:1 can be implemented easily and at low cost with only one pump. This has the advantage that the optimum setting can be made for tracking of the trough (small volume flow with low electric power over 10…12h per day) as well as for moving the trough in the evenings to the stowing/starting position for the next morning (large volume flow for fastest possible motion for approximately 15min per day). No compromise has to be found between these two requirements nor cost-adding, additional components have to be applied into the system

3. Less energy consumption

3.1. Over-center valve with pilot ratio 1:∞

The over-center valve plays an extremely important role in the hydraulic system. Usually it is used for the accurate positioning and keeping the trough in its position and at the same time it acts as a safety element in case of excessively high wind loads. However, as both cases have conflicting requirements in terms of the size of the oil volume flow, HAWE Hydraulik has separated these two functions on component base. This not only increases the safety of the power plant, but also helps reduce the energy consumption of the hydraulic system. The opening characteristic and flow range of the doubleacting over-center valve of 3 l/min and lower has been adopted to the required conditions at solar thermal power plants. This provides a highly responsive method of extending and retracting the hydraulic cylinders with high positioning accuracy. The geometrical pilot ratio is 1:∞. Regardless of the load, the release pressure can thus be set to a constant value of 20 bar or less. Even if additional forces act on the cylinders due to oscillations during tracking of the trough collector, their speed of motion remains unchanged and positional accuracy is maintained. The release pressure remains below that of standard commercial over-center valves and impacts positively on the necessary working pressure level and consequently on the energy consumption of the system as a whole.

3.2. Adopted size of motor/pump assembly

The arrangement of the hydraulic components also plays an important role for the optimum drive. The company uses radial piston pumps for generating the hydraulic energy since these offer a higher efficiency than external gear pumps. The pump is built onto the motor shaft without coupling in order to eliminate energy losses and rule out the risk of coupling wear at this point. Finally, the compact power pack lives up to its name since motor and pump are both accommodated in the housing which at the same time also acts as the oil tank (oil-immerged design). This keeps the dimensions of the power pack comparatively small. The larger cooling capacity of the hydraulic fluid also makes it possible to use a motor with a considerably smaller rated power and dimensions than an air-cooled standard motor. This also reduces energy losses at each starting of the power pack. The specific construction of the radial piston pump from individual pump elements avoids overdimensioning and allows it to be matched precisely to the required flow rate without the need to keep to a limited number of pump sizes. The size of the drive motor is matched to the needs of the pump in order to prevent unnecessary power consumption at this point

4. Less time effort for comissioning and first start-up

4.1. All components on one pallet

The logistics for installation on the power plant site are considerably facilitated if the complete drive is delivered on a single pallet. HAWE Hydraulik has developed a special wooden enclosure for this in order to prevent the two cylinders with the hydraulic unit from being damaged during transport. Each pylon is assigned a separate pallet accordingly. Even the proper lifting device for the cylinders, to avoid mishandling, is included.

4.2. Power pack assembled onto one of the cylinders

The compact power pack with the control valves is mounted directly on one cylinder and already connected by tubes to the ports of this cylinder. This means that the only work that has to be carried out on site is connecting two hoses to the over-center valve on the other cylinder, without the need for any complicated piping on site. That considerably facilitates the installation of the cylinders in the pylon and reduces the risk of mistakes in assembly. The power pack and the cylinders are delivered prefilled with oil.

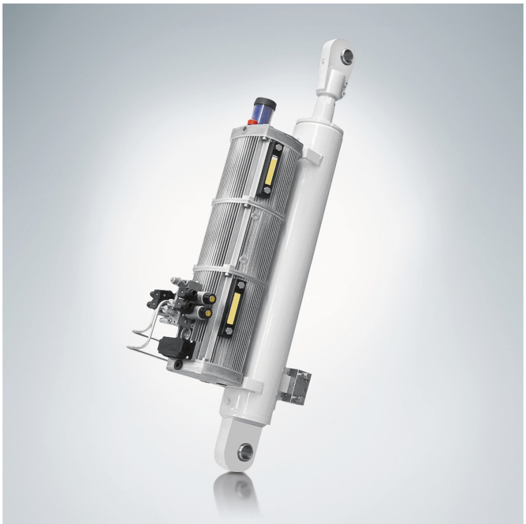

Figure 2: Power pack assembled on tracking cylinder

5. Less maintenance effort and increased life span of the drive

5.1. Accumulator charging operation

Incorporating a hydraulic accumulator in the drive system increases a lot the life span of the motor/pump assembly. Then it has to be switched on only for charging the accumulator (approx. once every 20 min) which is significantly less than when used for tracking steps each 10 sec. If the hydraulic energy from the accumulator is used for trough tracking, the pump does not need to operate in this phase and its motor does not use any power.

5.2. Optimized surface protection

A look at the surfaces of the individual components highlights further potential for optimization. The surfaces are treated with zinc-nickel. The corrosion resistance of such surfaces has been positively confirmed in a salt spray test (NSS) over a period of 720 hours in compliance with DIN EN ISO 9227. The components are fit for continuous use in environments with high air humidity and salt content. Problems such as occur with painting in accordance with DIN EN ISO 12944 do not arise in the first place. For example, moving parts such as a hand lever or the manual emergency actuators could not be painted completely unless they were actuated during painting. Inaccessible places or large areas could have different thicknesses of paint. Weathering effects are more quickly apparent at these places. Not least, there is a danger that the paintwork will be damaged during installation of the drive in the pylon and scratched off paint particles resulting from careless work could find their way into the hydraulic system and cause faults. Finally, the paint layer will be interrupted and possibly scratched if spare parts with separate surface coating are installed at a later time. For these reasons, zinc-nickel surfaces are a trouble-free and more cost-efficient choice in the long term.

5.3. Optimized IP-class protection

The IP Code, International Protection Marking, IEC standard 60529, sometimes also interpreted as Ingress Protection Marking classifies and rates the degree of protection provided against intrusion, dust, accidental contact, and water by mechanical casings and electrical enclosures. It is published by the International Electrotechnical Commission (IEC).

In the main effecting the power pack it is approved/certified with IP65 while the standard request is IP54 giving a higher safety for a long, trouble-free lifetime.

5.4. High ratio between working and permitted pressure

Since many components used for the trough drive are only operating in the medium of their permitted pressure range, it can be expected that they have an extremely long service life. E. g. the radial piston pump, designed for 700 bar, is usually working at 200 bar at this application.

6. Savings in peripheral devices

6.1. Immersed capacitors

The technology of reactive power compensation is well known and tested in the field of electrical engineering. However, there are economic and technical limits to reactive power compensation imposed by the costs and size of the capacitors needed and the fact that they heat up in operation. The oil-submerged construction also offers advantages in this respect. Since they are also oil-cooled, the capacitors can still be kept small and the power factor $\cos\phi$ of the motor can easily be increased to more than 0.90 without increasing the capacitors costs. This allows smaller cross-sections for the cabling of the power supply for the parabolic troughs in the field which results in cost savings.

6.2. Pure hydraulic controlled safety system

Depending on the system design, the accumulator can also play an important role in the event of faults (power failure) since in these situations the parabolic trough should be retracted from its present position in the opposite direction of motion to the sun, and the absorber removed from the point of focus. If the trough were to stay still in one position there would be a danger of the absorber tube with the liquid working medium becoming overheated and being destroyed. However, if the power supply is interrupted, the electronic control (SPS) and compact power pack cannot function. Without an independent power supply. A safety mechanism functioning purely by hydraulic means and without electrical energy can be integrated via the control valves in combination with a hydraulic accumulator. This ensures that the hydraulic flow direction is altered before the two pulse valves (detented 4/2-way seated valve with two solenoids) on the cylinders, and that the cylinders move the trough back, for example, by 10°. A considerable energy saving effect is obtained by using a solenoid with a power consumption of 8 instead of the usual 21 watts for the 2-way seat valve used for this which is permanently energized in normal operation.

7. Safety functions

7.1. End stroke safety valve

Many plant manufacturers wish to have an additional safety mechanism for protecting cylinder and pylon bearings and structure. In principle, the system controller stops the motion of the cylinders at the end stop when a cylinder is fully extended. If this were not so, one cylinder would be in a position to exert considerable force on the other cylinder due to leverage. As a result the bearing head of this extended cylinder or even the pylon bearing could be damaged. A mechanically actuated check valve integrated in the cylinder creates additional security independently of the electronic control system. It produces a hydraulic short circuit by automatically switching the hydraulic system to circulating mode, when one of the cylinders has reached the maximum travel position.

7.2. Over-center valves with separate pressure reliefs

The permissible volume flow of the separate pressure relief valve has been set in such a way as to take the trough safely out of the danger zone in case of overloading, in other words excessively high wind forces. A shallow characteristic curve for pressure/volume flow is important in order not to get any further pressure increase owing to oil flow through the valve which would result in generation of additional counterforces acting on the mechanical structure of the plant. Pressure limiting and over-center valves can be set independently of each other. The hystereses of both valves do not influence each other and therefore no longer need to be mutually taken into account. Both pressure values can be adjusted easily from the outside with a spindle and can be sealed if required. The maximum pressure is 450 bar which offers more than enough reserves for parabolic trough drives. Optional manual bypass valves facilitate installation and maintenance of the hydraulic cylinders.

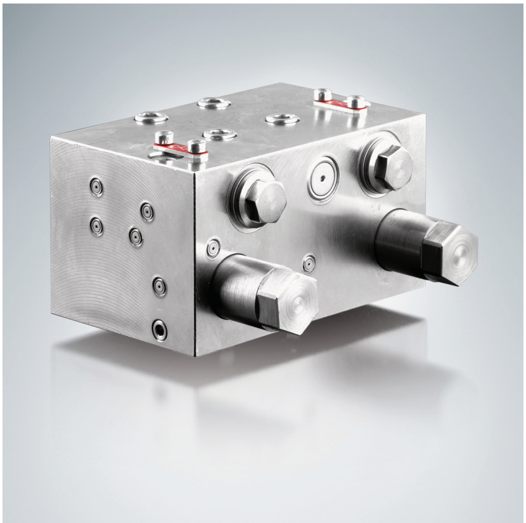

Figure 3: Overcenter valve with separate pressure reliefs