Hydrostatic transmission design - Closed-loop circuit for boat carriers

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Abstract: This article presents a design study whose goal is to propose a hydrostatic transmission applied on a remote-controlled boat carrier. Considering the customer input, the machine has to be able to transport a 40-ton boat within a flat shipyard for maintenance purposes. Once the study is completed, Poclain Hydraulics has to provide a complete range of hydraulic products able to ensure an efficient and safe transport solution.

Mounted on 8 solid-tire directional wheels, 10 meters long and 3 meters wide, the carrier is supposed to move at a very low speed when loaded in order to safely place the boat to a precise location. However, to run long distances all along the shipyard, it has to be able to reach 12 km/h unloaded. Because of the heavy payload, acceleration and braking phases have to be particularly taken into consideration, so that no damage is caused due to the inertia of the load. Accurate proportional control at a very low speed is the key point of this application that state of the art Poclain pump and high torque hydraulic motors can ensure.

The final goal is to get a safe, flexible and user-friendly machine which will be able to be used by the final customer at any time, using a simple remote control interface. According to the movement instruction sent by the user, the electronic controller has to pilot the pump on its own, depending on load and speed values, to ensure an optimal cycle time without damaging the components or causing injuries.

Keywords: boat carrier, hydraulic transmission design, closed-loop circuit

Figure 1. *Boat moving solutions*

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1 Situation

Times to times in marinas, boats have to be taken out from the water in order to be moved to a maintenance or storage area. There are several kinds of equipment to perform such an operation: cranes, trailers, on slipways winches, self--propelled carriers, etc.

One of the most flexible solutions is to use a remote-controlled self--propelled carrier that can carry the boat to any location, without any additional towing equipment.

Figure 2. *Self- propelled boat carrier*

2 Input data

The machine has to be able to carry a 40-tons boat from a point A to a point B within the marina, in safe conditions, for the user as well as for the load.

This implies:
- a smooth proportional control from 0 to max speed, forward and reverse,
- the ability to run at very low speed at constant torque during critical maneuver phases,
- a strong starting torque to be able to move the load on slopes,
- an efficient load control in braking phases to prevent the machine from accelerating,
- a strong an reliable static brake for parking and emergency situations,
- the possibility to run at higher speed without load to save time,
- a reliable control device paired with an ergonomic remote-controlled user interface.

To match these requirements, especially in terms of torque at low speed, a closed-loop hydrostatic transmission for sure remains the best solution in terms of performances and components integration. Poclain Hydraulics is able to supply a complete range of products including high-torque/low speed motors, closed-loop pump, valves, and electronic control unit.

Machine data:
- 9 tons empty, 50 tons loaded,
- 10 m long, 3 m wide,
- 8 laden directional wheels, 4 powered wheels,
- 4 km/h max speed with load, 12 km/h w/o load,
- 5 % slope capability,
- 30 kW engine.

Figure 3. *Self-propelled boat carrier*

3 Hydraulic components sizing

Motors

Using a direct drive transmission with high-torque/low speed hydraulic enhances the mechanical efficiency of the machine, by avoiding friction losses generated by a gearbox. This type of motor is also much easier to integrate into the wheels, improving the required space for the drive components.

Considering the weight of the machine, the number of powered wheels, and the driving conditions, a sizing calculation gives a displacement value of around 1000 cc/motor, to be able to move the machine in any required condition. Wheels should spin up to 25 rpm with load, and 60 rpm unloaded. According to the duty-cycle of the machine, a 350 bars working pressure range is a good compromise between components life-time and size, even if the Poclain MS motor can work up to 450 bars.

The MS hydraulic motor from Poclain hydraulics fulfills all requirements in terms of size (from 170 to 15.000 cc), speed, and functions.

Indeed, it can be equipped with a wheel shaft for direct assembly on the wheel, a static multi-disc negative brake, and a dual-speed control spool, used to divide the displacement of the motor by 2, in order to

multiply the rotation speed of the motor by 2 for the same flow.

Dividing the displacement of the motor by 2 to run twice as fast will consequently divide the available torque by 2. This is not an issue since the high speed is required for an empty machine only. This function allows using a smaller pump, because the 2nd gear of the hydraulic motor does not require a lot of flow: the motor's displacement adapts to the working situation.

The dual-displacement control spool is simply actuated by a small 3-ways solenoid valve located on the machine.

Figure 4. *Poclain Hydraulics MS motor*

Closed-loop Pump

The pump has to be able to supply a proportional oil flow to the hydraulic motors, in order to ensure a safe and smooth control of the machine, whatever the load. According to the number of motors that have to be supplied, the rotation speed range of the engine, and the working pressure, a calculation indicates that a 52 cc pump is necessary for the machine to reach the desired speed.

Figure 5. *Powered front wheels*

The PM50 brand new axial piston pump from Poclain Hydraulics gathers all necessary functions thanks to its very wide range of controls and options. One of the advantages of this pump is to include additional hydraulic functions such as circuit flushing, which will not require any dedicated flushing valve somewhere else in the circuit.

The electric proportional control version fits the best the customer need because of its easy integration into the machine's electric system, managed by a remote-control. Moreover, the auxiliary mounting pad behind the pump can receive the open-loop pumps used for the auxiliary components of the machine.

The closed-loop feature of this pump is a great advantage in terms of load control during braking phases. Indeed, due to the high inertia of the load, the machine tends to accelerate if it runs down a slope, even if the control signal remains constant. The return line from the motors to the pump that characterizes a closed-loop circuit will neutralize this acceleration by using the resisting torque of the engine to slow down the machine.

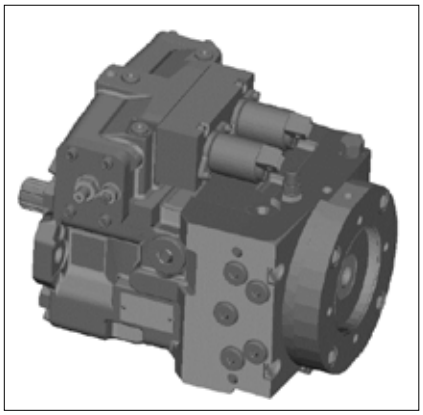

Figure 6. *Poclain Hydraulics PM50 closed-loop pump*

Disposing of a "return line" from the motor to the pump allows the pump to brake the motor by maintaining a back pressure behind it. The flow is not free to increase without opposing any resistance to the motor. It is regulated by the pump. During a deceleration sequence, the more the motor tends to accelerate because of the high inertia of the load, the more the pressure will increase in the return line.

As long as the displacement of the pump remains constant, the flow will not increase. It will remain the same, and consequently, the speed of the motor will be under control.

This characteristic allows a very easy and safe control of the load, by preventing the machine from accelerating when the engine speed and pump control signal are constant. It does not require any additional component.

About cooling, different solution can be applied to maintain the temperature at an acceptable level. Very large tank, or very large cooler (air/oil, water/oil), auxiliary cooling circuit, exchange valves... All of them have a different impact on the compactness of the machine, the dissipated heat, the efficiency of the cooling, the cost, etc...

An efficient and space-effective way to cool down the circuit is to combine several options on a lower scale: medium-sized tank, medium-sized air/oil exchanger, and oil-shuttle valves to take some hot oil off from the circuit and send it directly to the cooler. The missing oil is compensated by the charge pump which sends some fresh oil from the tank. Another advantage of the PM50 is to integrate this function.

Electronic control unit (ECU)

The ECU controls all the components of the hydrostatic transmission. It is the interface between the remote-control and the hydraulic components. In addition to this role, it has to be able to diagnose and protect the machine and the user from any defect.

For such an application, which is not particularly complex in terms of software and number of functions, Poclain Hydraulics provides a *SmartDrive™ Easy Plus* ECU using a free-of-charge software gathering all functions that are required for most of standard machines:

- proportional pump control,
- dual speed management,
- CAN-Bus engine control,

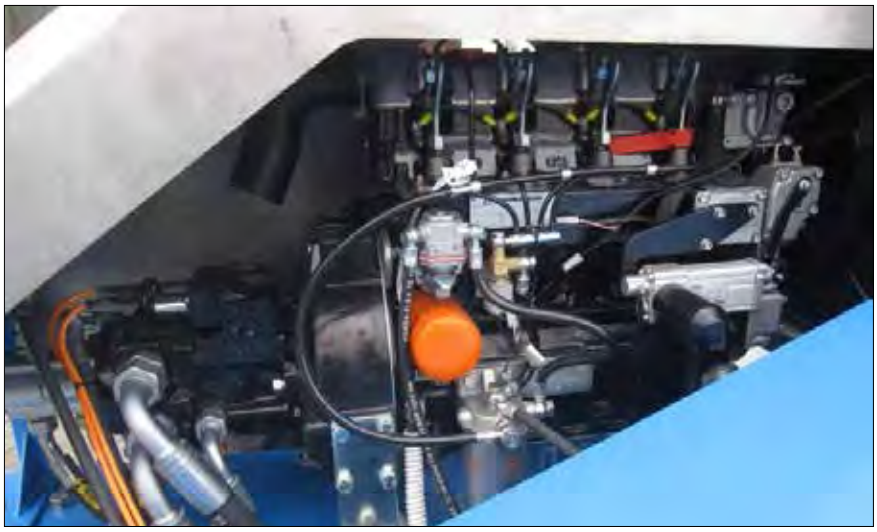

Figure 7. *PM50 pump mounted on the engine*

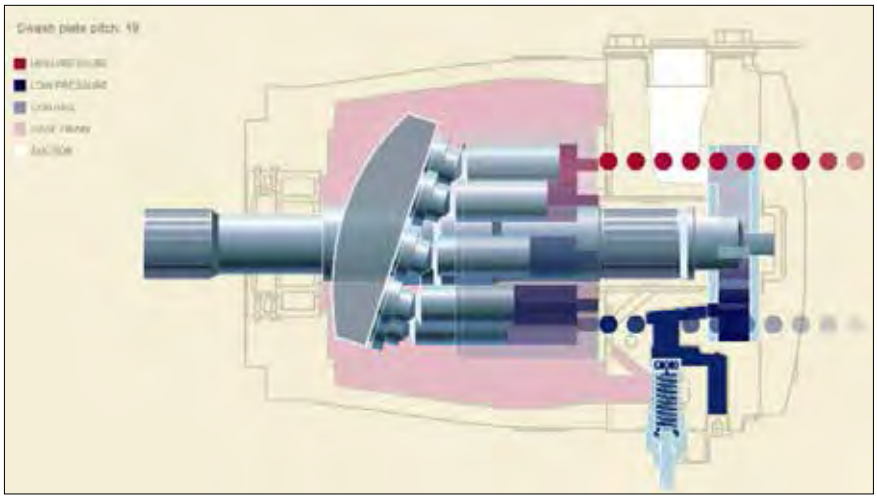

Figure 8. *Closed-loop pump working principle*

Figure 9. *SmartDrive™ Easy Plus ECU*

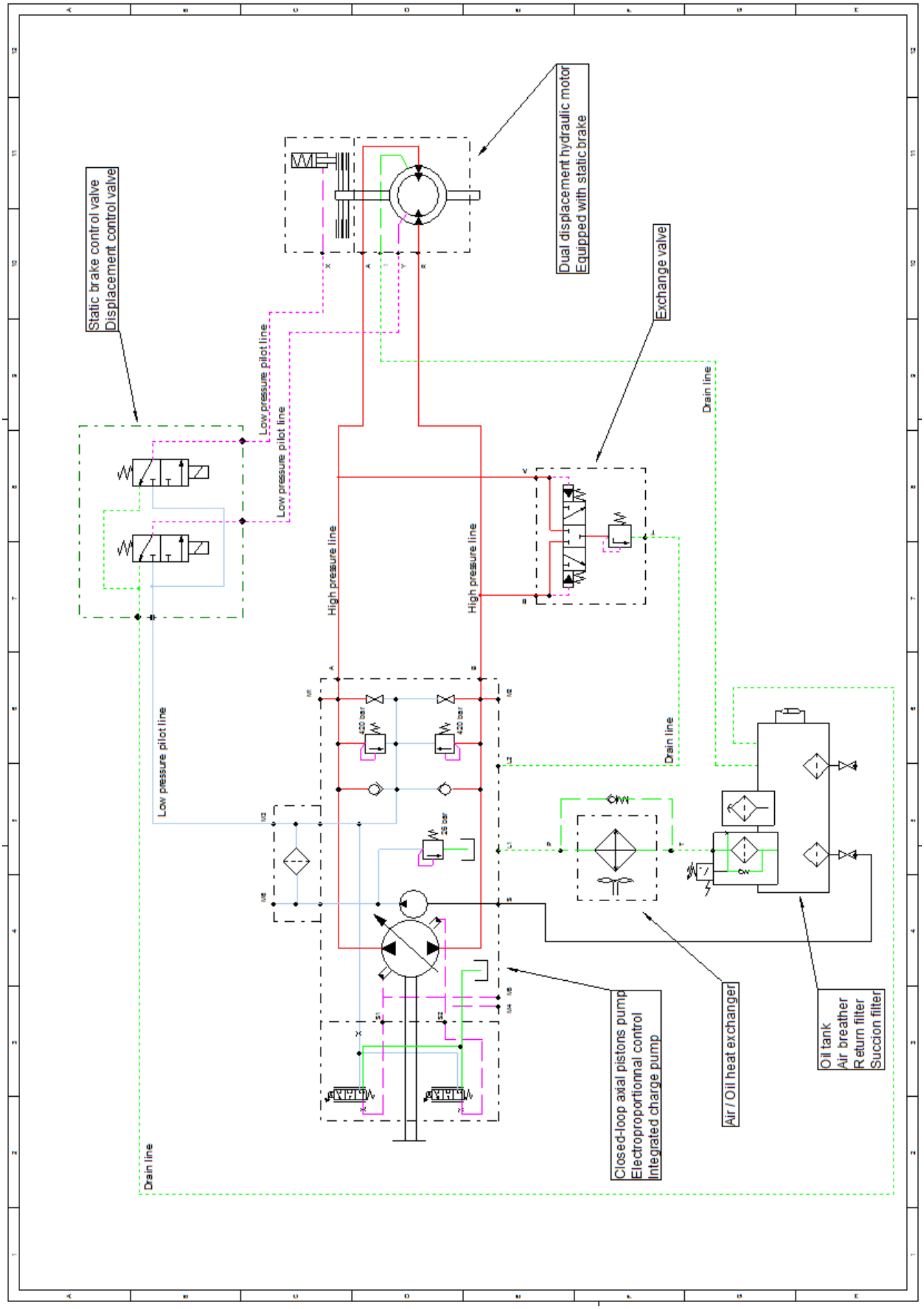

Figure 10. *Theoretical hydraulic schematic of a closed-loop circuit*

- driving modes management,
- braking management,
- on board diagnostic,
- safety mode in case of defect,
- external interferences protection,
- all parameters customization,
- ...

According to the control information sent by the remote-control, the ECU controls the pump and the valves accordingly, permanently monitoring the consistency of all signals. If an error is detected, safety sequences are automatically triggered to stop the machine in safe conditions.

4 Radial pistons motor in closed loop: basics

Charge function

A permanent charge flow coming from the charge pump located inside of the main pump compensates the leakages in the circuit and maintains a permanent charge pressure in the circuit. Thanks to this pressure, all pistons remain in contact with the circular cam.

Main flow

The variable flow coming from the main pump supplies only a certain quantity of piston chambers. Consequently, these "high pressurized pistons" tend to go out of the cylinder bloc. Due to the geometry of the lobe located above the rollers (slope), the motor spins by a few degrees.

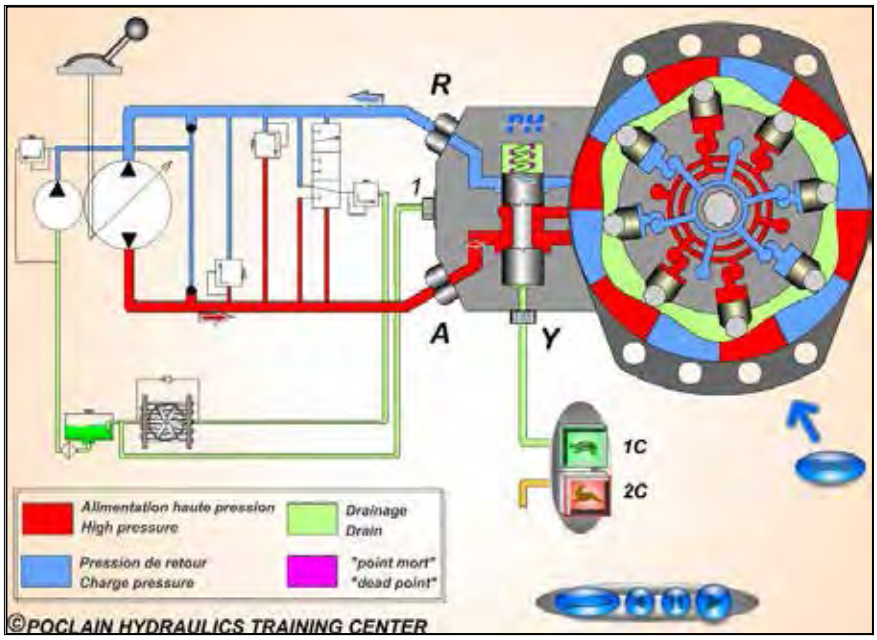

Figure 11. *Basic working principle of a radial pistons motor in closed*

This rotation will position another group of cylinders in front of the high-pressure supply, which will generate another rotation, etc... while the previous group is linked to the charge pressure.

5 Conclusion

The advantage of the closed loop circuit for such an application is to get many hydraulic functions using a very low number of components, and to make their integration easier. A simple hydraulic pump – motor combination can ensure many functions such as proportional speed control, braking, flushing, pressure limitation, power limitation, etc...

When these components are used in parallel with electronic control/monitoring systems like a SmartDrive™ ECU, the number of driving possibilities increases with many different configuration that are very simple to configure. The machine gets even safer thanks to the real time data monitoring, and the load carried more accurately.

Thanks to a wide a range of main-drive components (Pumps, Motors, Valves, ECUs), Poclain Hydraulics is able to provide all necessary products to equip such a machine and match the customer's requirements in terms of performances, integration, and lifetime.

Načrtovanje hidrostatičnega pogona vlačilca za čolne

Razširjeni povzetek: V prispevku je predstavljen projekt izvedbe hidrostatičnega pogona, namenjen za uporabo na večjih daljinsko vodenih vlačilcih za čolne. Vlačilec dolžine 10 m in širine 3 m, opremljen z osmimi kolesi, od tega so štiri gnana, mora naloženi čoln natančno in varno transportirati na določeno lokacijo v ladjedelnici ali v marini. Neobremenjen mora biti sposoben premagovati tudi večje razdalje v ladjedelnici, tudi s hitrostjo do 12 km/h. Velika okretnost vlačilca je zato naslednja pomembna zahteva, ki postavlja zelo visoke zahteve za njegov krmilni sistem.

Zaradi velikega bremena – čolni mase do 40 t – in njegove vztrajnosti v fazah pospeševanja in zaviranja je odločilnega pomena ustrezno zasnovan hidrostatični pogon vlačilca. Pri tem gre za hidravlični zaprti krogotok s proporcionalno regulacijo hitrosti, velikim zagonskim momentom, zanesljivim zavornim sistemom in zanesljivim ter fleksibilnim krmilnim sistemom. Omenjene zahteve je bilo moč doseči samo z uporabo ustreznih gradnikov. V prispevku je zato velik poudarek na tehnični rešitvi in izbranih komponentah, predvsem hidromotorja in hidravličnih črpalk, njunih značilnostih in posebnostih. Prav tako je predstavljeno elektronsko krmiljenje celotnega pogona z on-board diagnostiko

Ključne besede: vlačilec za čolne, hidrostatični pogon, zaprti krogotok