Tribological study of material combinations for continuous control valves used in water hydraulics

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EXTENDED ABSTRACT

Reduction of oil usage and its almost daily increasing price is directing world development in the field of hydraulic fluids towards alternative sources. One possible alternative source is water, which is environmentally acceptable, low-cost and nonflammable. Several hydraulic components for acceptable high pressures using this fluid have already been developed and are available on the market [1, 2, 3 and 4]. In the field of hydraulic valves the ball- or poppet-seat type of valves are usually available on the market at designer's or customer's disposal [1 and 2]. But this type of valve is badly suited for continuous regulation functions, especially for continuous and fine flow regulation. Other weak points of such valves are their large dimensions and quite complicated construction [2].

Taking into consideration the body accessible information about water power-control hydraulics, we have designed a new hydraulic test rig to investigate the tribological and hydraulic behaviour of such systems under pressures up to 150 bar and flows up to 30 L/min. With this aim we have designed a model proportional 4/3 directional continuous acting spool type sliding valve, which serves as a testing specimen. Tribological properties and static as well as dynamic behaviour can be investigated using this model by employing various components of different materials and using a variety of testing conditions. Figure 1 shows simplification of the test rig. The most important components are: water reservoir (Fig. 1, pos. 1), standard Danfoss axial piston pump, type PAH 25 (Fig.1, pos.4), with flow rate near 35 lpm, electrical motor with flexible coupling (Fig.1, pos. 2 and pos.3), pressure relief valve with setting of 150 bar (Fig. 1, pos. 5). The pump delivers water to the proportional 4/3 directional control valve – the specimen (Fig. 1, pos. 6). The specimen controls a double-acting through-rod hydraulic cylinder (Fig. 1, pos. 7). We simulate loading and provide pressure in water hydraulic circuit on two ways. First, when we do long-term life cycling tests, we use oil-hydraulic double-acting through-rod hydraulic cylinder (Fig. 1, pos. 8A). In this case we set various pressures with double oil-throttles (Fig. 1, pos. 9). On the other hand, translator-moving mass (Fig. 1, pos. 8B) is used for short-term dynamic tests. Pressure measurement is provided by pressure sensors (Fig. 1, pos. 10). Stroke of a control spool in specimen is measured by linear displacement sensor (Fig. 1, pos. 11) and stroke of hydraulic cylinder by other linear displacement sensor (Fig. 1, pos. 12).

The main, observed parts of the specimen are spool (Fig. 2, pos. 1) and sleeve (Fig. 2, pos. 2). The spool and the sleeve are observed tribological pair. The spool is inserted into the sleeve and it is inserted into the housing (Fig. 2, pos. 6). The two proportional solenoids, one on the right (Fig. 2, pos. 3) and one on the left (Fig. 2, pos. 4) side of the spool, control it continuously. This two solenoids and a linear variable displacement transducer (LVDT) (Fig. 2, pos. 5) are carried out for closed-loop regulation of the spool movement.

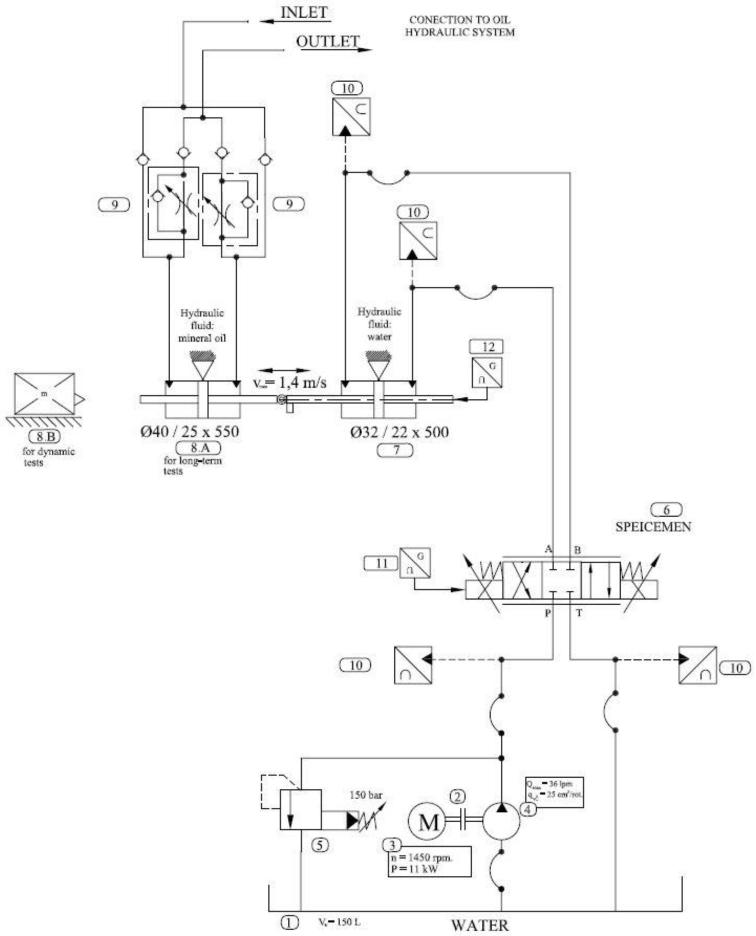


Figure 1: Simplification of hydraulic circuit of water PCH test rig

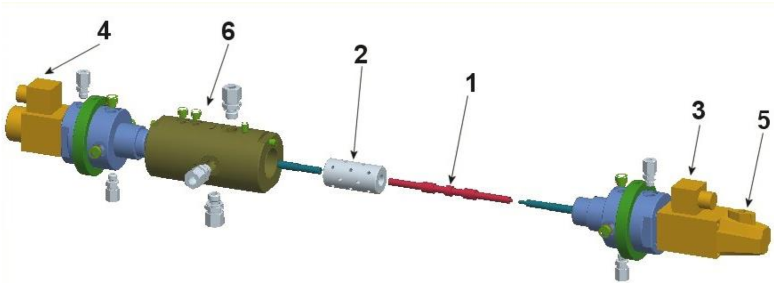
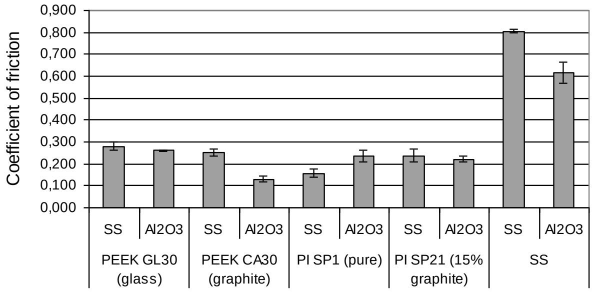


Figure 2: Specimen, functional prototype of the proportional 4/3 directional sliding control valve

In order to investigate the change in hydraulic parameters, in particular wear resistance and useful life in selected hydraulic tests for different possible material combinations, model tribological tests were performed to make an initial or preliminary selection. Generally, stainless steel (SS) is the most typical and in-expensive material already used in several hydraulic parts and was thus reasonably the first-choice material. Other potential groups of materials include ceramics and polymers. Since ceramic materials are very costly and also have a low fracture toughness, they were not considered as the most suitable materials for the real-scale tests through which we would like to compare materials in the later stages of this research. Therefore, they were not included as the "studied" material (disk) in the first screening tribological tests; however, a ceramic was used at least as a counter-material, i.e. pin, which should also give us some indication of the tribological properties of the selected couples. We selected those that can be used in water for a longer time-span [5 - 7] and gave some promising tribological results in the past, and which are also easily commercially available and suggested by world-wide known producers. Thus, we selected two different types of materials from two groups of polymeric materials, i.e. polyetheretherketone (PEEK) and polyimide (PI). A commercially available PEEK (Victrex Europa GmbH, Germany) containing 30 % of carbon (CA30) and 30 % of glass (GL) fibers were used. Polyimides (Vespel) from DupontTM without any addition (SP1) and containing 15% of graphite fibres were also tested. Pin materials were SS (X105CrMo17), obtained from Aubert&Duval and hardened to 55 Hrc, and alumina ceramic balls (99.7 % purity, 10 mm diameter) from Hightech Ceram. In total, 4 types of polymeric materials and stainless steel were selected as disc materials, while pins were of the same stainless steel and alumina ceramics. Tests were performed in a pin-on-disc apparatus (CSEM, Switzerland) with uni-directional sliding between the disc and the pin. The relative sliding velocity was 0.1 m/s and a load of 1N was applied, which corresponded to 40-70 MPa of initial contact pressure, depending on the material pair. In the open literature [5 - 7], data are available for some selected polymeric materials at lower pressures, but our goal was to investigate the higher-end load-region of those materials. Tests were run for 370 m of total sliding distance. All the tests were performed in a cup with distilled water at around 21^{o}C, i.e. at room temperature conditions. These conditions correspond to a boundary lubrication regime, where hydrodynamic effects are negligible and the tribological performance depends primarily on surface and interface phenomena. Friction was monitored during the test and wear loss of the disc materials was subsequently calculated. The first empirical friction and wear results are presented in Figures 3.a and 3.b, respectively. At present, detailed surface analyses, which would allow determination of wear and friction mechanisms and confident interpretation of the results, are still in progress.



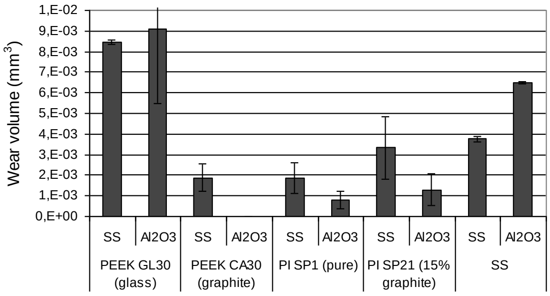


Figure 3.a: *Coefficient of friction* and 3.b: *Wear loss* for selected material pairs (disc against two pin materials is shown)

CONCLUSIONS

- The lowest friction was obtained for the PEEK CA30/Al_2O_3 contact. Another interesting low-friction pair appeared to be PI SP1/SS because of its easily applicable and low-cost material combination.
- The lowest wear was obtained in the PEEK CA30/Al_2O_3 contact, in accordance with the lowest friction found for this material pair.

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