Application of a new test procedure for mechanical testing of hydraulic fluids

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ABSTRACT

This paper describes a friction and wear test in a newly developed test machine, which was developed at the TU Hamburg-Harburg to investigate the lubricating capability of hydraulic fluids. The aim of the development of the new test procedure is a better representation of the tribological contacts and effects in fluid power machinery.

The investigation of the lubrication capabilities of hydraulic fluids using a line contact showed, that a distinction between different fluids regarding their lubrication capabilities can be made, using friction-, wear- and erosion tests (galling). The high reproducibility of the boundary conditions during different tests was achieved by steady design modifications of the test rig and the development of a computer program for fully-automatic control of the test procedure.

The developed test machine fulfils the requirements of a simple test procedure and simply shape of test specimen, which could be produced from principally every type of material and production machines, existing in every company that produce fluid power components.

1 INTRODUCTION

A very important feature of a hydraulic fluid is its potential to separate the surfaces of a loaded tribo-contact, and by this to reduce friction and wear in this contact. The most reliable test to investigate the lubricating capability of a hydraulic fluid is the field test, i.e. the application of the fluid under typical operating conditions and for typical operating periods. For many reasons field tests are time consuming and costly, and the operating condition of different applications typically will be very different so that results from one application might not be transferable to another application. This situation leads to the necessity for fluid producers as well as for the producers of hydrostatic machinery to test their product in a laboratory test before they go for a field test. It should be clear that laboratory tests are only helpful if they reproduce the situation in the tribo-contact of the real machine to a high extend.

The Institute for Konstruktionstechnik (Engineering Design) of the Technical University Hamburg-Harburg has developed a new test procedure and a test machine to investigate the lubricating capability of hydraulic fluids. In future this test possibly can replace the vane pump test according to DIN 51389 /DIN51389/. The aim of the project was to find a test procedure which reproduces the totality of wear relevant tribological effects in hydrostatic machinery as good as possible, using simply shaped test specimen and a test machine, which allows an easy measurement of the mechanical parameters to derive from these friction and wear.

Test procedures can be classified according to DIN 50322 in 6 categories (see Fig. 1) from test in real systems under real operating condition (category I) to model tests with simple test specimen (category VI).

One of the standards to investigate the “mechanic” performance of a hydraulic fluid with a tight connection to hydraulics is based on the special design of the vane pump, the test is to a high extend influenced by production and assembly tolerances of the pump, materials used and surface treatments of the parts. It is well known that the results of tests with the vane pump differ from test stand to test stand and that the tests are cost intensive and time consuming as well.

Other tests with simple test arrangements are reliable and deliver reproducible results in areas for which they were developed; an example for this is the FZG-test /DIN51354/ for gears and, with some restriction, the test in the four ball test machine for bearings /DIN51350/. Results with these tests can not easily be transferred to hydrostatic machinery because the tribological situations in the sliding and rolling contacts in hydrostatic machines are different from the tribological situations in these tests.

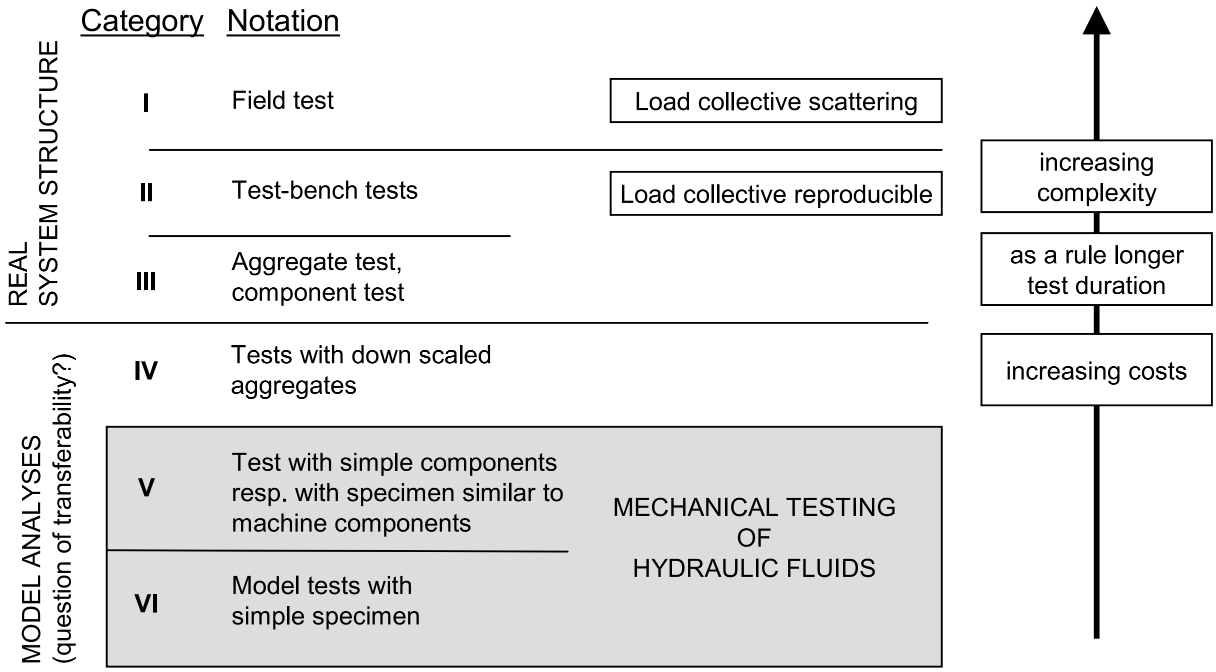

Figure 1: Overview of the categories of wear testing (DIN 50322)

To ensure a precise reproduction of the test procedure a new control software was developed using the software package DASYLAB. The control software controls speeds and changes of speed, pressure to load the tribo-contact and changes of that pressure both versus time and for different types of tests. By this the influence of the test personal has been significantly reduced. The only influence the test person has now is when mounting the test specimen on the shaft and the vane holder, were design changes have let to a very precise adjustment of the specimen without the necessity of extremely accurate work during assembly.

The load conditions of the tribo-systems within a hydrostatic machine (contact pressure, type of relative movement) and – velocity and destructor and the properties of the contact partners define the parameters in the contact zone (temperature and geometry) which have the main impact on friction coefficient, critical load and wear performance of the tribo-system. The test procedure and test machine which was by systematic approach developed in research projects DGMK 514 and 514-1 / Kes99/, Kes01/ fulfils the requirements stated above, as the test machine reproduces typical and critical tribological situation with the parameter values covering a wide scope of tribo-contacts in hydrostatic machinery (see as well /Kes00/, Fel04/).

2 PRINCIPAL ARANGEMENT OF THE TEST APPARATUS

The aim of the development of a new test procedure was to achieve

- reproducible quantitative test results with high accuracy,
- simple test specimen, which do not require special manufacturing technologies,
- a test procedure which can be automated and
- low energy consumption, small volume of test fluid and short test time.

A detailed analysis of the tribo-contacts in hydrostatic machines was the base for a specification for this new test procedure and machine. Using design methodology and systematic design approach a test principal was found, which is shown in Fig. 2. The arrangement of the test apparatus allows the investigation of line contact and and area contact. During the research project it was found, that the line contact is the more interesting one and generates data which allow to classify lubricating capabilities of different fluids; this is the reason why the majority of the tests was only using data from the line contact.

To quantify the lubricating capability of a hydraulic fluid the following parameters are used:

- $p_{HD,crit}$ critical pressure which leads to adhesive material removal ("galling"),
- $\mu_{Ex,average}$ average friction coefficient in the line contact,
- V_{line} wear volume of the test specimen vane

The accuracy and the reproducibility of these parameters define to a high extend how good the tested fluids can be classified as low, medium and high lubricating fluids. Exact measurements of the mechanical parameters as speed, torque and pressure,

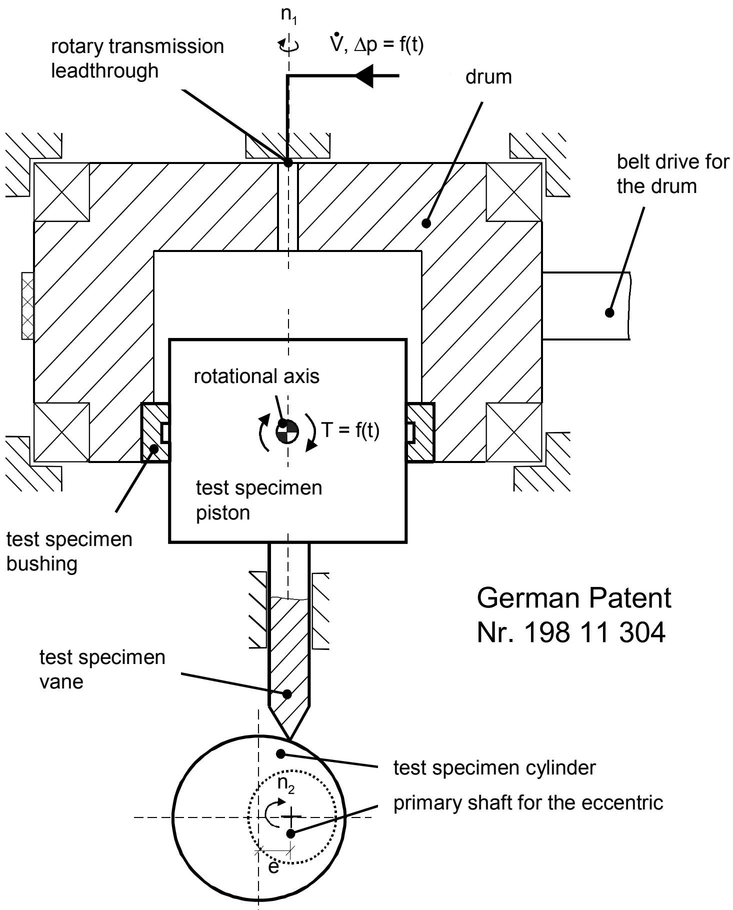

Figure 2: Principal arangement of the test apparatus

the possibility to calculate contact forces having friction in guiding devices and bearings in the calculation and a sophisticated method to measure and calculate the wear volume at the vane are the basis to achieve adequate results.
During the research project a number of design changes have been made with the test machine to improve the accuracy and reproducibility of the measurements.

3 DESIGN OPTIMISATION OF THE MPH TEST RIG

In the primary design of the test rig the vane was guided in a sliding contact and by measuring pressure above the piston and force applied to the vane it could be seen that friction forces in the guide caused an uncertainty in the vane force, which had a negative influence on the accuracy of the friction coefficient calculation. Therefore the vane

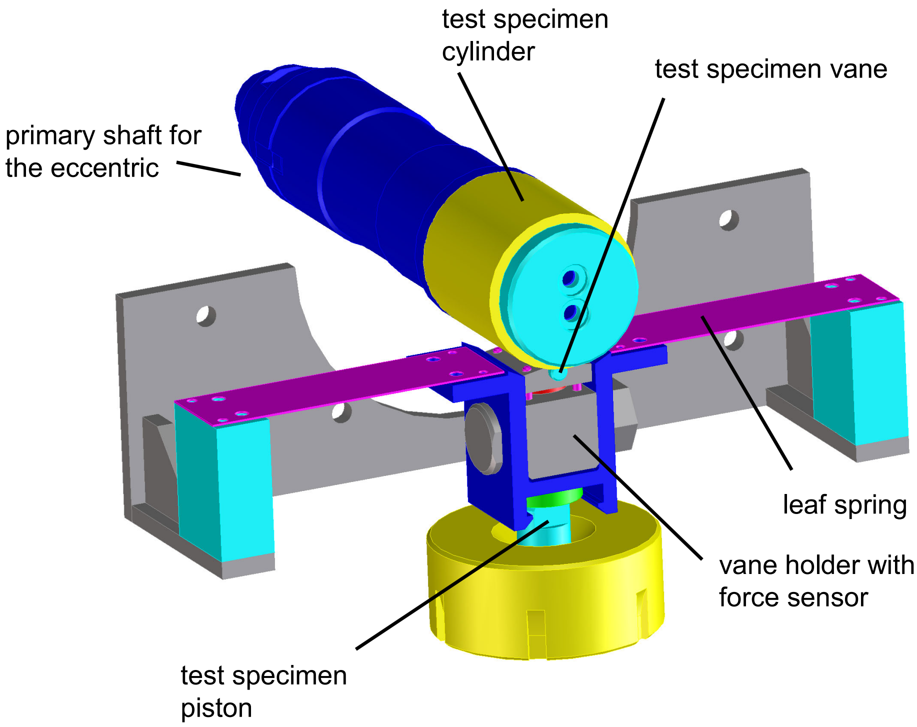

Figure 3: 3D-CAD-model of the main components inside the MPH test rig

holder is now guided by 2 leaf springs. Friction forces between piston and bushing are small as the bushing rotates around the piston and there is no side load on the piston.

4 COMPLETET TEST SERIES – LINE CONTACT

Within the project mineral oil based hydraulic fluids of HL- and HLP-type and synthetic esters of HEES-types were tested. Main task was to demonstrate different lubricating capabilities of these types of fluids as they should be expected for the different types. The most important point was to demonstrate that the results of multiple tests with the same fluid are in a narrow range, i.e. show small deviations from an average value.
This paper reports about the test results for seven different types of hydraulic fluids, one fluid of HEES-type, four fluids of type HLP and two fluids of type HL. All fluids had corrosion and anti-aging additives, the HEES-type and the HLP-type fluids were equipped with ep- and aw-additive packets in different concentrations.

4.1 Test conditions

To define the optimal test conditions for the short term and long term test (short term test is the test for critical load, long term test is the test for friction coefficient and wear volume) a big number of tests were done. During these tests it was found that the starting process for the test is of significant influence on the results of the tests.

4.1.1 Start procedure

The parameters of the starting procedure have to be such that initial damages of the test specimen are avoided and a controlled running inn of the line contact is archived. An automation of this starting procedure lead to a significant improvement of the following tests.

4.1.2 Accelerated test procedure

Short term tests are used to find the critical $p_{HD,crit}$, which is the pressure when spontaneous and intensive adhesive material transfer between the sliding services starts galling. The pressure on the piston produces a critical pressure within the tribo-contact at which the lubricating film between the contacting services disappears and mixed friction changes to friction of solids. Figure 4 shows the development of the test parameters versus time for a typical short term test.

4.1.3 Endurance test procedure

The endurance test is used to find the fluids specific work friction coefficient of the line contact and the volume loss of the test specimen vane.
The level of the critical pressure found in the short term test leads to the load for the long term test. Load means the average pressure on the piston which is held constant during the hole test to produce a constant force in the line contact between vane and cylinder.

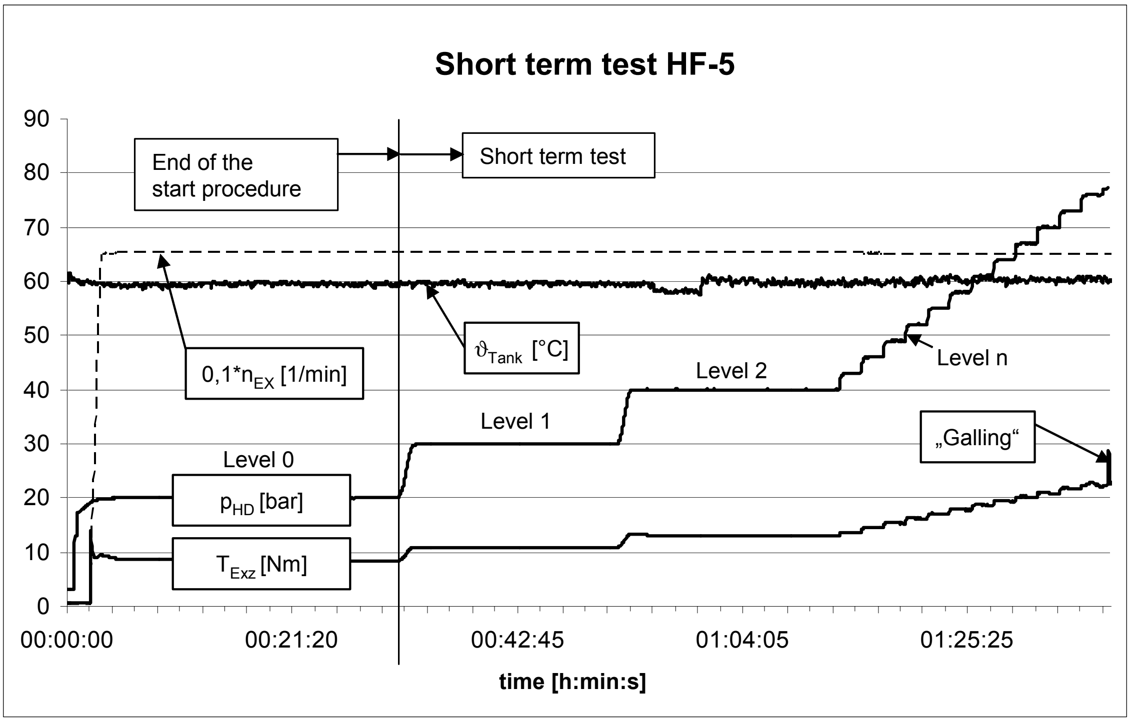

Figure 4: Typical regime of operational parameters in the accelerated test phase

4.2 Test results

Table 1 gives information about the absolute values of the tests of a typical test range. Is it important to see that the critical pressure and the average friction coefficient of three test runs are more or less close to an average value while the volume loss of the vane shows bigger deviations for different tests with the same fluid under the exact same conditions. It can also be seen that there is a certain correspondence between critical load, average friction coefficient and volume loss. On the other hand the table shows, that to achieve a certain and measurable loss, different load levels had to be applied for the different fluids, which means, that a direct, straight forward classification of the fluids can not bee based only on the values of table 1. Therefore a different presentation of the results has been developed, which is shown in Fig. 5. The figure shows the isometric presentation of a results base. In this figure the ellipsoids represent the limits of the measured values for the different fluids; all values are referred to the HF-1 fluid as a reference.

Hydraulic fluid	Class	$p_{HD,krit}[bar]$	$\mu_{Exz,mittel}[-]$	$V_{Linie}[mm^3]$
HF-1	HL	60	0,060	0,0589
load level 1		60	0,056	0,0620
		57	0,062	0,0419
HF-2	HL	47	0,055	0,0155
load level 1		42	0,055	0,0225
		41	0,058	0,0400
HF-3	HLP	62	0,063	0,0176
load level 1		67	0,058	0,0202
		61	0,063	0,0245
HF-4	HLP	86	0,070	0,0409
load level 2		88	0,064	0,0230
HF-5	HLP	73	0,074	0,099
load level 2		77	0,068	0,0837
HF-6	HEES	120	0,037	0.0092
load level 3		106	0,038	0.0022

Table 1: Results of typical test series with different load levels

Figure 6 and 7 which show projections of Fig. 5 showing two axes of the three dimensional diagram of figure 5 demonstrate clearly that the measurement with the MPH-test-rig allow a clear differentiation of not only fluids of different classes but also of fluids within a class.

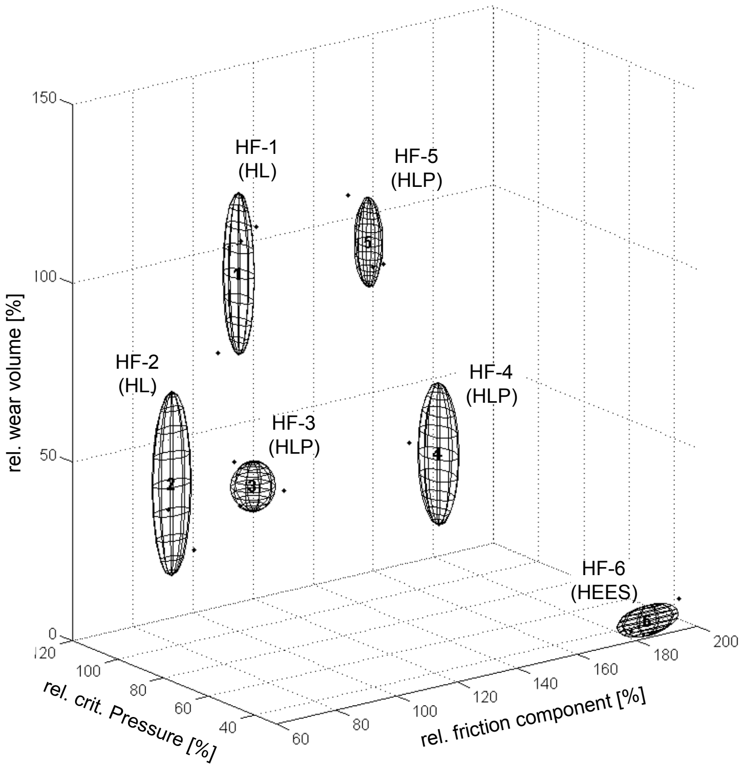

Figure 5: Isometric representation of the result parameter

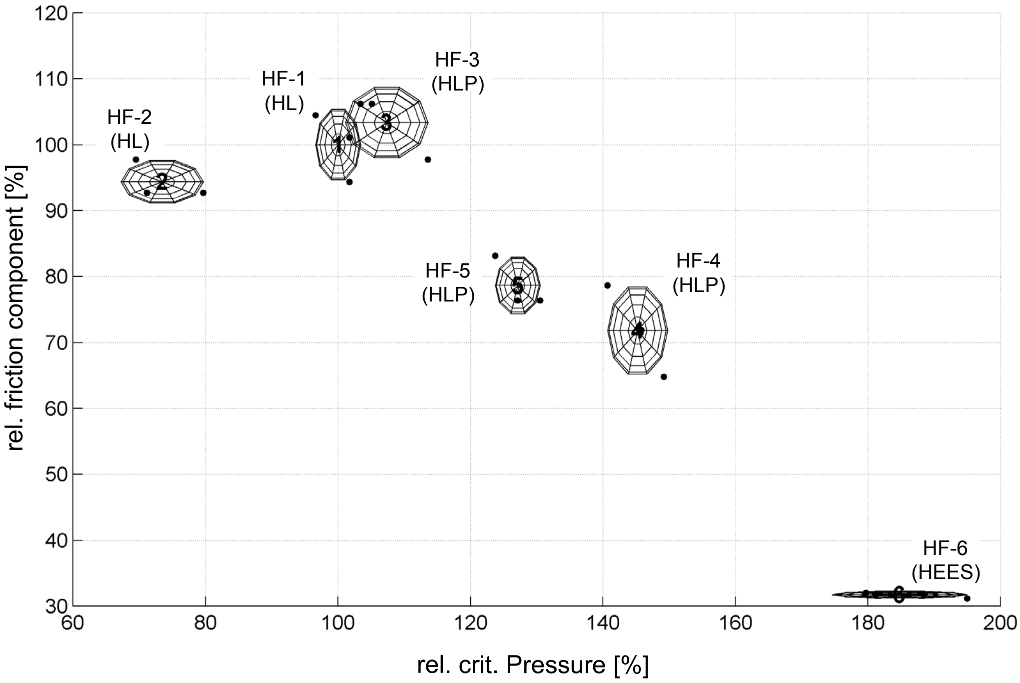

Figure 6: Projection of the result parameter (xy-plane)

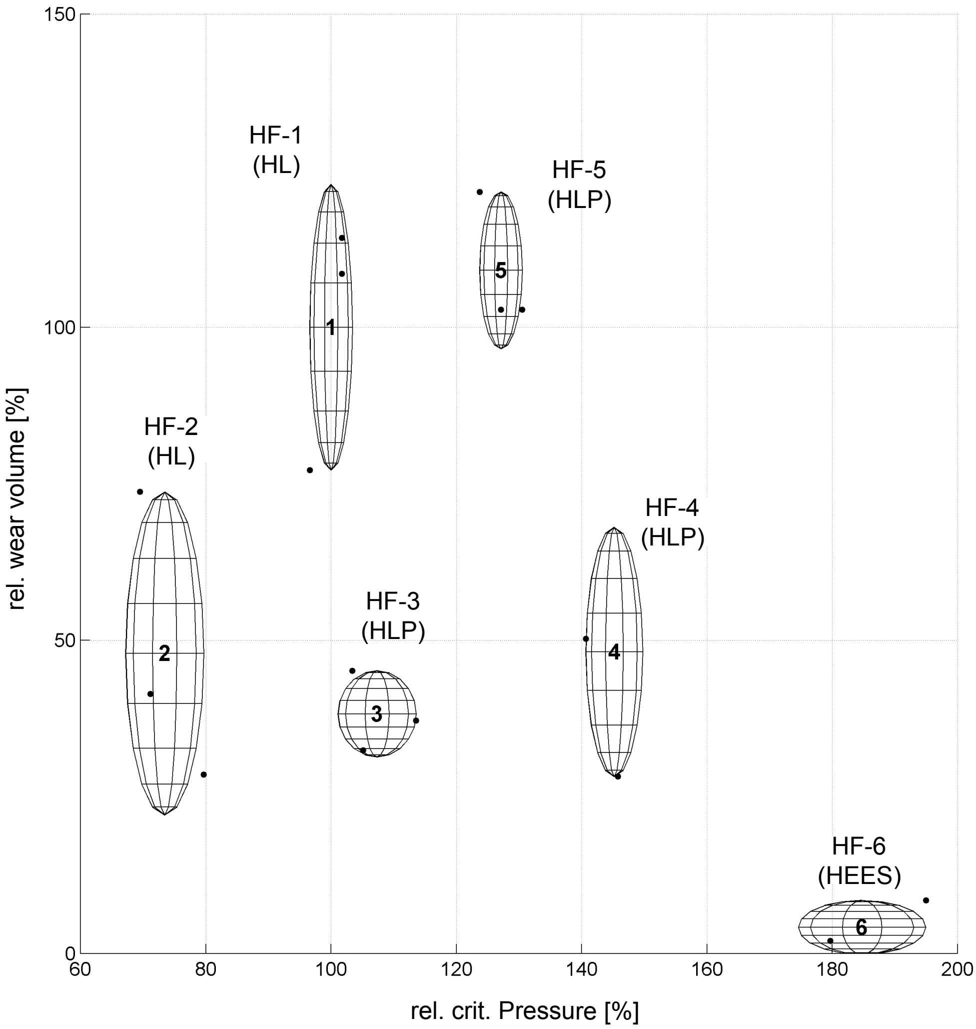

Figure 7: *Projection of the result parameter (yz-plane)*

CONCLUSION

The results of a high number of tests within the MPH-project have shown that it is possible to differentiate the lubricating capability of hydraulic fluids with the MPH-test rig. With the design improvement of the test rig and the development of a fully automatic test rig control the reproducibility of test results could be improved. Looking to recent tests with the actual test rig it could be seen, that the values for friction coefficient and critical pressure do not differ more than ± 10 % from the average. The wear volume shows bigger deviations within a test sample with a maximum of ± 20 % which possibly can be reduced by more accurate measurement techniques.

Reproducibility of test results was a major point for the MPH-project. The achieved accuracies must be seen in comparison to accuracies requirements of other tests which are used to test hydraulic fluids. The vane pump tests /DIN51389/ and also the FZG-test /DIN51354/ do not define a minimum number of test runs and a accuracies in the test results. According to the standards in both tests only one test run is necessary for a classification of a fluid. This leads to the conclusion that test results with the MPH-test-rig and –procedure may give better reliable data about the lubrication capability than other test procedures used assuming at minimum 3 test runs per fluid.

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