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Recuperation on a transmission test bench

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Abstract.

This article presents a recuperation concept for an industrial gearbox test bench. The concept of hydraulic testbench was realized in the past already, the fully automated system is a new technology. Here the concept is presented witch combines to the hydraulic circuitry and the control technology implementation.

Keywords. Recuperation, Gear Box, Multiple variable control, efficiency optimization, Open Source control software

1. INTRODUCTION

The test bench presented here is a combination of classic industrial hydraulics and modern control technology. The test bench has been developed as a research and development test bench. It offers a very high degree of flexibility both in the design of test sequences and in the selection of test specimens for industrial and mobile gearboxes as well as drivetrains or hydraulic motors. The basic concept can be seen in Figure 1.

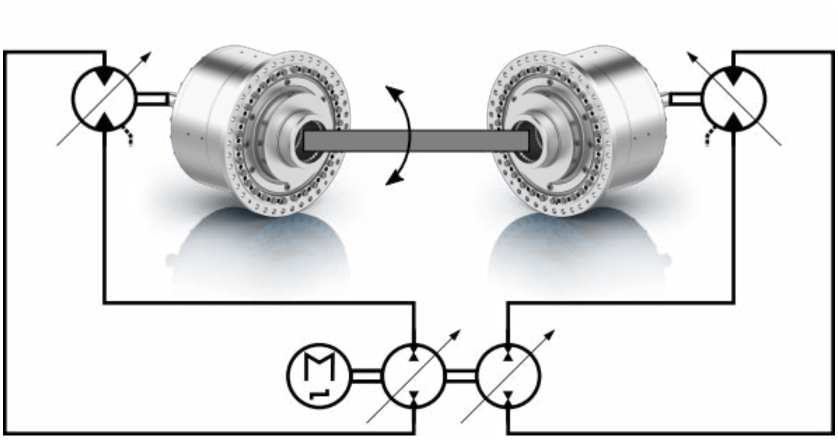

Figure 1: Figure 1: Concept of the Test Bench

An asynchronous motor operated by a frequency converter drives two identical A4V pumps that are installed in tandem. Type A6V hydraulic motors are installed on the test gearboxes. The two test gearboxes are braced against each other, with one gearbox operating as a speed-controlled drive and the second gearbox as a torque-controlled brake.

The test bench allows tests to be carried out on a variety of different purposes. Its main tasks are:

- Investigation of thermal behavior
- Identifying mechanical efficiency
- Investigation of wear and fatigue behavior
- Measuring vibrations and noise
- Testing new materials, manufacturing processes, and lubricants
- Testing gearboxes, hydrailic motors or complete drive trains

2. TEST BENCH DESIGN

When designing the test bench, the focus was on energy efficiency and flexibility in addition to suitability for the planned test specimens. For this reason, automation does not rely on ready-made solutions from component manufacturers, but rather on an open source solution. The EtherLab [1] project offers numerous functions that are used here.

The selection of hydraulic components is based on the performance data of the gearboxes. Typical input speeds of 1500 to 2500 RPM are required, which are then also applied to the output of the test setup due to the back-to-back arrangement. The torques can exceed 3000Nm and the transmitted power can range up to 600kW. With a gearbox efficiency of around 97,5% each, this results in a maximum waste heat output of about 60 kW.

These key data were used for the design of the pumps, motors, and gearbox cooling system [2]. Figure 2 shows the entire test bench; the soundproof enclosure and the hydraulic container are not shown.

Since this is a research and development test bench, the hydraulic connection options are designed to be very flexible. Figures 3 to 5 show three examples of frequently used arrangements. For large test specimens, the two built-in main pumps can be operated in parallel, see figure 3. However, two load tests can also be run simultaneously on smaller gearboxes, figure 4. Free-running tests with no load can be performed on up to four test specimens simultaneously, figure 5. Mixed operation between the operating modes is also possible.

All auxiliary functions, such as control oil pressure supply, filtration, temperature control, housing flushing, and feed and flushing functions, are implemented via separate systems. These systems are working independently of the main pumps.

The feeding of the closed hydraulic circuits is temperature-controlled in order to minimize the demand for feed oil. For this purpose, oil is taken from the low-pressure section [3] via a proportional throttle, and the pressure-controlled feed oil supply pushes fresh oil through accordingly.

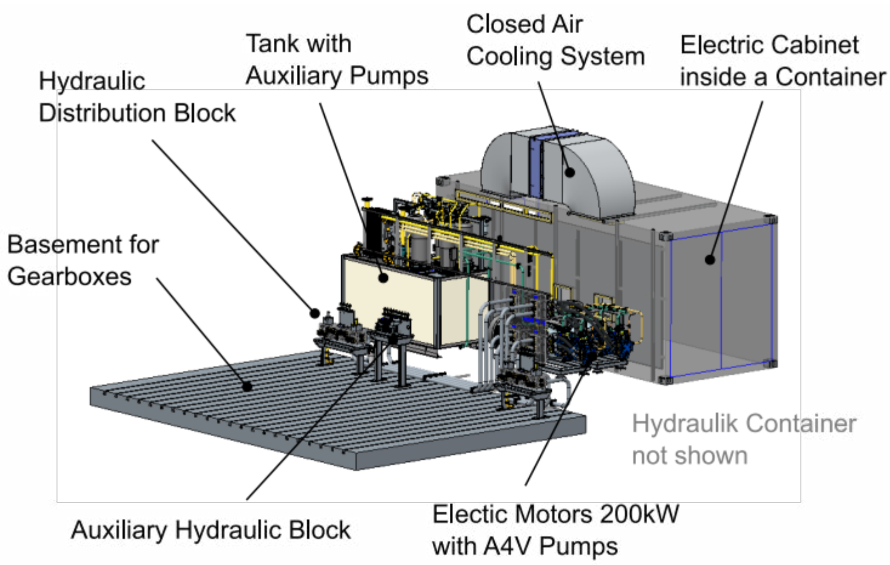

Figure 2: Test Bench Overview without Specimen

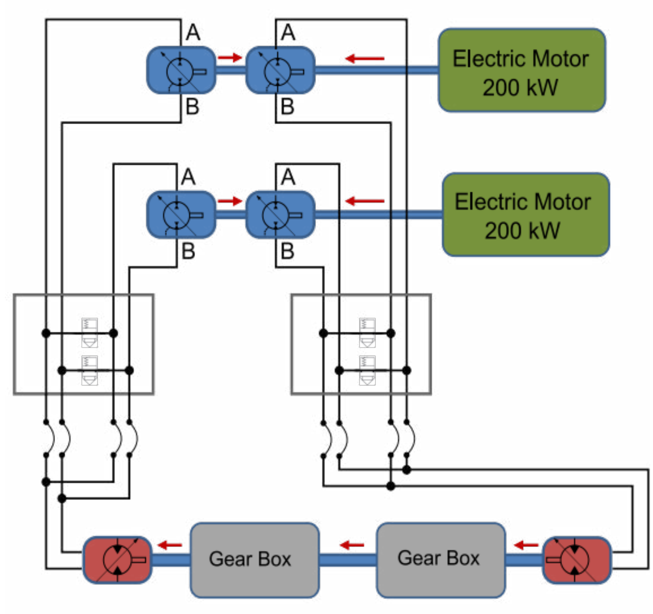

Figure 3: Parallel Pumps operating for big Specimen

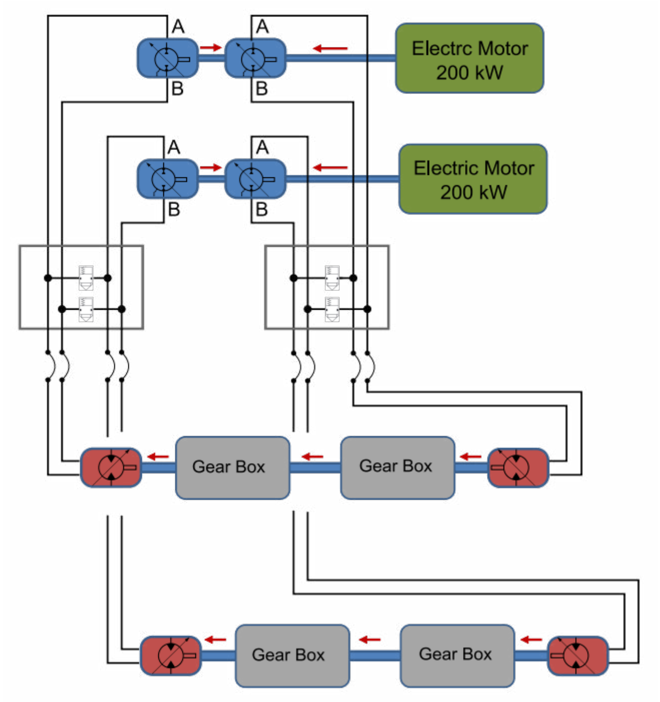

Figure 4: Configuration for two Tests at the same Time

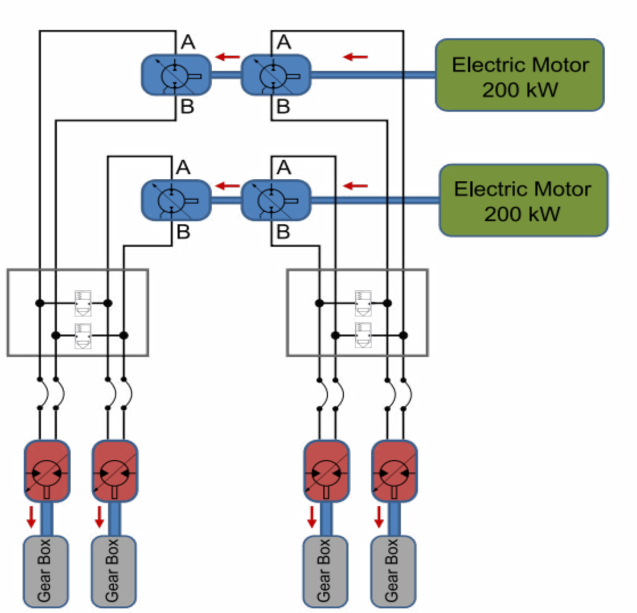

Figure 5: Multiple Specimen in free running Mode

3. Efficiency of a Test bench

What is the efficiency of a test bench in which all of the energy used is ultimately dissipated as heat? For the test bench implemented here, the definition shown in the image was chosen in order to implement an optimization strategy.

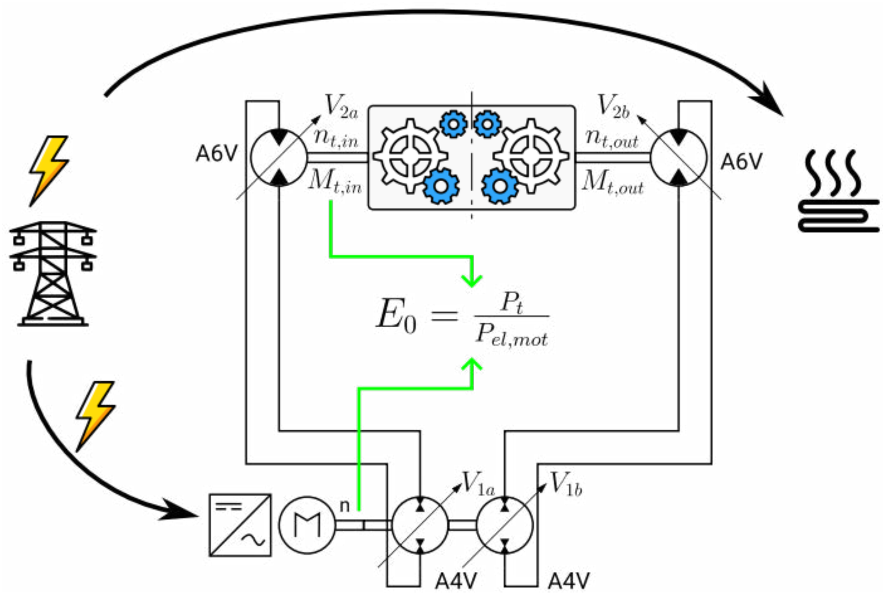

Figure 6: Definition of Efficiency at the Test Bench

Efficiency is defined as the ratio between benefit and effort and is defined here as the ratio between the mechanical input power in the test specimen and the active power used in the electric pump drive.

$$E_0 = \frac{\eta_{A4Va}\eta_{A6Va}}{1-\eta_{geara}\eta_{gearb}\eta_{A6Vb}\eta_{A4Vb}\eta_{A4Va}\eta_{A6Va}} \quad (1)$$

Since many hydraulic adjustment units operate in series in this test bench, each individual efficiency level has a very strong influence on the overall efficiency. The overall efficiency can be determined using the equation 1 and is in the order of magnitude of 1,5. This means that the power flow through the gearboxes can be about one and a half times greater than the electrical power input. If the components are not operated at their optimum operating point, the overall efficiency drops significantly. A deterioration of around 2% in a single component reduces the overall efficiency by around 10%.

4. CONTROL SYSTEM

The entire automation of the test bench, including all auxiliary systems, is implemented using the open source tool kit EtherLab®. EtherCAT® is used as the fieldbus system, which easily allows sampling rates better than 1 kHz, even for large systems. As shown in the figure, the control system for the main functions is cascaded.

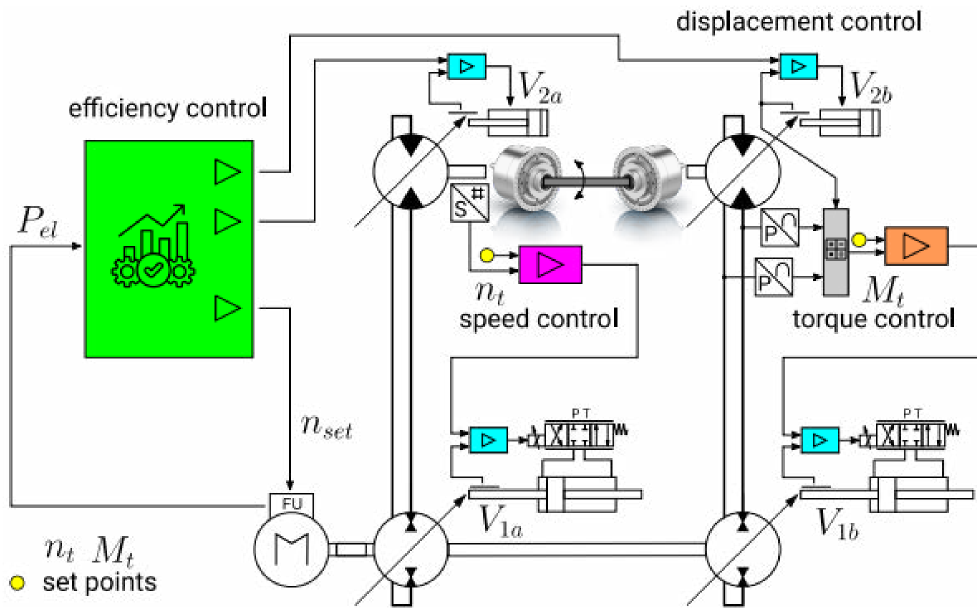

Figure 7: Structure of the Control System

All units with variable displacement have a subordinate swivel angle control loop [5]. The setpoints for this control loops are generated in the higher-level control loops for the input speed n_t and for the torque M_t.

The efficiency of displacement units is highly dependent on their operating points. The operating points are largely determined by the pressure, speed, and swivel angle. The general relationship [3] is shown in the figure 8. Looking at the basic efficiency curves helps to set a good starting configuration. On the drive side, the desired test speed at the gearbox input determines the ratio of the displacement volumes at a given drive speed of the electric motor.

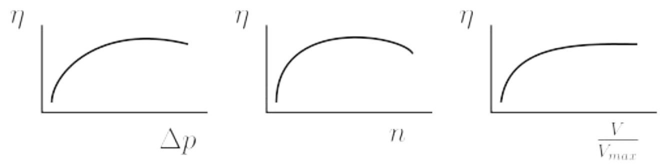

Figure 8: Efficiency and Operating Point

A mathematical description of these relationships, which are mostly determined experimentally, is only possible to a limited extent and is not useful due to the large number of different configurations. Instead, an evolutionary method is used here for the efficiency controller in order to achieve the most efficient overall operation.

Since the test runs last several hundred hours, there is enough time for optimization to implement a robust, i.e., slow algorithm. This algorithm uses small increments when changing the available control variables V2a, V2b, and n. Taking the operating limits into account, the speed of the drive is changed as long as the efficiency increases. The displacement volumes of motors V2a and V2b are then manipulated. The algorithm for increasing efficiency is activated by the operator during a test run and then runs automatically. The algorithm stops when no further improvement can be achieved by changing the control variables.

5. CONCLUSION

The test bench presented here combines the capabilities of classic hydrostatic drives with modern automation technology. The control concept with higher-level efficiency optimization and detailed improvements in the area of auxiliary functions has resulted in a system that is unique in this form.

It offers a high degree of flexibility in test design as well as a high degree of robustness through the use of high-quality components.

This investment in the Witten development site will help to secure expertise in industrial gear manufacturing in the long term and develop new technologies.

6. REFERENCES

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Biographies

Siegfried Rotthäuser

was born in Essen in early 1961 under the sign of Aquarius. After attending school and completing his military service, he studied general mechanical engineering at RWTH Aachen University from 1981 onwards and then worked as a research assistant at the IHP under Prof. Wolfgang Backe. After obtaining his doctorate, he founded the engineering firm IgH in 1993 together with Dr. Torsten Finke († 2025), where he continues to serve as managing director and board member within AXXERON Technologies.

Nico van de Sandt

born in Bocholt on December 8, 1971, studied mechanical engineering at RWTH Aachen University between 1993 and 1998 and then worked as a research assistant at the Institute for Machine Elements and Machine Design. He received his doctorate in 2004, specializing in rolling bearings and lubrication. From 2003, he held senior development positions in the gearbox industry. Since December 2015, he is head of R&D for gearboxes for mobile and industrial applications at ZF Industrieantriebe Witten GmbH.