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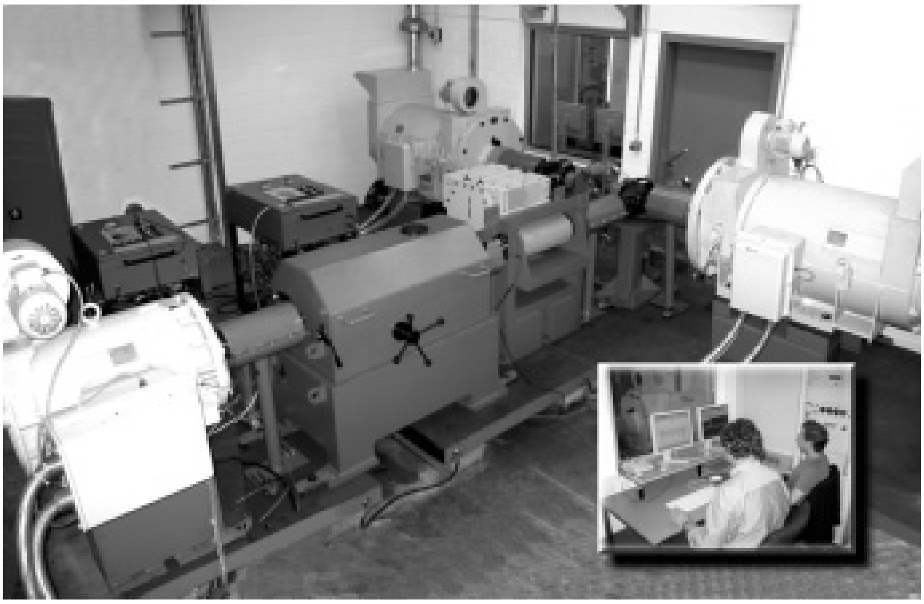
**Hardware-in-the-Loop-Prüfstands-
technik – Antriebsstrangprüfstand
für Doppelkupplungssysteme**

Hardware-in-the-Loop Test Bench Technology

Drive Train Test Bench for Dual Clutch Systems



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The rig testing and adjustment of a new wet-running dual clutch system both as an individual part and in combination with the vehicle transmission have made it necessary to develop special hardware and software concepts. This contribution by ZF Sachs AG and GIF-Gesellschaft für Industrieforschung mbH is a test bench that permits comprehensive testing of these dual clutch systems.

1 Introduction

Shortened development times and new simulation technologies make both a comprehensive interface expansion of the test bench automation and an expansion of the test bench hardware necessary for the adjustment and testing of drive train components on dynamic drive train test benches. In cooperation between ZF Sachs and GIF, a modern and flexible test bench was developed based on the existing technology on which both system components as well as entire dual clutch systems can be tested. The core components of the dual clutch transmission are the dual clutch and its actuators, **Figure 1** Dual clutch system. The dual clutch transfers the torque independently to two transmission input shafts of the dual clutch transmission. The first clutch drives the odd gears and the second clutch the even ones. A regulated pressure and torque overlapping between the clutches allow the realisation of a gear ratio change free of tensile force interruption. The actuation and the cooling of the dual clutch in connection with the control, driving and safety functionality stored in the control device ensure optimal power transmission in every situation. Detailed reports on the technology of the dual clutch transmission and its market chances were given in [1, 2, 3, 4].

2 Basis for the Dual Clutch Test Bench

The following standardised test bench concept was selected as the basis for the dual clutch test bench, **Table**

All e-machines are equipped with highly dynamic GIF torque/rotation speed measurement flanges. The torque-related torsion of the measured object made of special low-hysteresis steel is recorded with a strain gauge and converted into electrical voltage signals. Parallel to the torque measurement, the rotation speed is also measured with a high resolution. The test bench automation is realised with the fully real-time-capable and freely programmable automation system PDES (GIF). The configuration includes analogue and digital inputs and outputs definable without limitations. All channels are updated at a rate of 100 Hz. Selected channels are available with a summated scanning rate of up to 20 kHz.

A CAN controller and structures for PID and fuzzy logic controllers are also integrated. The regulation of the asynchronous machines is performed via the operating modes of speed regulation and torque regulation. By entering vehicle-specific values, such as the vehicle mass or cw value, PDES calculates control values for the drive units according to the driving resistance equation, making possible the additional regulation type road load simulation.

2 Basis for the Dual Clutch Test Bench

Table: Technical data of e-machines

Drive machine: Dynas3-360B	
Output	360 kW
Max. speed	10,000 rpm
Max. torque / overload	750/900 Nm
Angular momentum	0.6 kgm²
Load machine: 2x Dynas 210G	
Output	210 kW
Max. speed	2.500 rpm
Max. torque / overload	4,000/4,800 Nm
Angular momentum	12.2 kgm²

3 New Test Bench Components

The basis test bench was significantly expanded for complete testing of system components such as the dual clutch, actuators, control software or the entire dual clutch system with and without transmission.

- Mechanics: Test trestle, coaxial shaft connection, belt drive
- Hydraulics: Hydraulic system
- Test bench automation: Software and hardware expansion
- Control: Rapid prototyping system dSpace

These expansions are described in detail below.

3.1 Mechanics

The dual clutch test trestle shown on the title page and in **Figure 2** serves for mounting of the dual clutch and, in terms of function, forms the bell housing with crankshaft flange and transmission input shaft. It consists of a height-adjustable housing, various bearings, hydraulic and electrical connections and sensors. The middle bearing can be moved axially. The drive bearing consists of the two transmission input shafts and the oil supply for clutch actuation and cooling.

To be able to load both clutches at the same time yet independently of each other as with an overlapping clutch, a newly developed coaxial shaft connection and a belt drive with hollow shaft are connected to the shafts of the drive bearing, Figure 5. The torque of clutch 1 is transmitted from the inner shaft through the hollow shaft of the flat belt drive over a closed rear axle differential and finally to the drive machine. The torque of clutch 2 is transmitted over the outer shaft of the coaxial system and over the belt drive to a closed rear axle differential and finally to the other drive machine. The coaxial shaft outputs for the independent operation of the two clutches can be blocked via an adapter so that operation with only one drive is possible.

3.2 Hydraulic System

The heatable mobile hydraulic system, Figure 4 and Figure 5, supplies the regulated actuation pressure and the cooling oil flow for the dual clutch. The separation of the circuits prevents them from influencing each other. The set values can be set either directly on the system via an integrated PLC or by an external control. In this case, the hydraulic system is controlled by the test bench automation, for which additional analogue and digital inputs and outputs are integrated into the PDES.

3.3 Rapid Prototyping System dSpace

The tool set Matlab/Simulink/Stateflow is used by ZF Sachs AG for development of the system functionality of the dual clutch transmissions. Among other features, it allows early inspection of the system functionality in the simulation environment. However, this process cannot replace the testing and further development on real components. Through the selection of a rapid prototyping system from the company dSpace for controlling the components on test benches and in prototype vehicles, the newly developed functions of the simulation environment can be ported directly to the test bench environment so that they can be tested and further developed there and adapted for use in a vehicle. Depending on the availability and goals, both individual functions for clutch and transmission control as well as the complete functionality of a transmission control can be implemented. For this reason, the dSpace system described here is also referred as a clutch/transmission control (KGS).

A high performance dSpace system possessing the following interfaces was developed for the test bench to guarantee the greatest possible flexibility for future test tasks.

- 64 AD channels
- 32 DA channels
- 128 digital inputs/outputs
- 4 CAN controllers
- 20 frequency outputs (e.g. PWM)
- 20 frequency inputs
- 5 incremental sensor inputs.

In addition to controlling of the dual clutch transmission, the data collection and the coupling with other test bench components, such as the hydraulic systems and the test bench automation, also take place via the interfaces. This connection is described in more detail in the following section.

The system - designed in 19" plug-in format - is integrated together with an operating PC into a rolling cart. It is specially designed for the drive chain test bench described here, but can also be operated as a stand-alone system on other test benches. For this purpose, some of the interfaces listed above are connected to a connection panel.

3.4 Connection of the Rapid Prototyping System to the Test Bench Automation PDES

The PDES software developed by GIF is used for the test bench automation. Through the creation of control programs in a macro-capable, high-level language and real-time task management, it is possible to realise flexible I/O operations with this system, even with third party hardware.

The connection between the test bench automation and the clutch/drive control realised in this project is depected in Figure 5 and Figure 7. The connection takes place via numerous analogue and digital interfaces as well as via a CAN bus interface, [5]. In order to achieve high flexibility and low signal run times, nearly all available analogue and digital measurement signals are received by both systems in parallel. Set values are also specified via analogue interfaces from the clutch/transmission control to PDES, for instance to specify a rotation speed or torque requirement for the asynchronous machines, **Figure 3**.

For safety reasons, hard-wired digital signals are used for release and emergency stop functionality. In addition, mutual monitoring is performed by two watchdog signals via the CAN interface. Important measurement and status values from the actuators that are only available in the clutch/transmission control are also sent to PDES via the CAN interface. These signals are recorded by the test bench automation and monitored in the framework of the global safety concept. In the event of an error, PDES initiates appropriate safety measures, such as a regulated braking of the asynchronous machines or deactivation of the frequency converter system. In special configurations, such as vehicle/road simulation, PDES generates signals of control equipment that is not present, such as the engine and ABS controllers, which are required for the transmission simulation.

The existing angular momentum of the drive unit can be compensated by the frequency converter software for a better simulation of the real conditions. To do this, a desired angular momentum is entered into PDES, which is transmitted to the frequency converter software via CAN and serves as the basis for calculating the torque-generating current. The complete test sequence with accelerator pedal position, shifting information, if this is specified manually, and vehicle speed is stored in the test bench control program. The test sequence can be entered conveniently in advance via an Excel form created specially for the test bench. During the test operation, PDES evaluates the accelerator pedal position originating from the test sequence and the current drive rotation speed to calculate a resulting required torque via the engine performance characteristics stored in PDES; this required torque is used to regulate the drive unit. At the same time, the KGS ensures appropriate clutch actuation and cooling. In special driving situations, such as starting and shifting, the clutch/transmission control accesses the "engine management" as in a real vehicle and takes over control of the drive unit with regard to the regulation type and specification of set values.

4 Setup and Testing Examples

All system components or even entire systems can be tested on this test bench under real operating conditions in various setups. The respective configuration depends on the test goal and the development status of the system components.

4.1 Setup with One Drive Machine

During development of the fundamentals, the testing of individual system components without interaction with other components stands in the foreground. This includes the development of the dual clutch, the actuator components in connection with the dual clutch and also the development of regulating algorithms. An example setup for testing the torque capacity or the centrifugal force compensation is shown in **Figure 4**.

4.2 Setup for Transmission Simulation

To make the development of the entire dual clutch system independent of the availability and reliability of the transmission, a setup for transmission simulation is realised using two drive machines. For the individual testing of dual clutch systems, a test specimen mounting mechanism is required that allows rapid changing of the test specimen and also provides all relevant sensor signals, **Figure 5**. The test specimen is situated in an easily accessible, oil-tight test housing that functions as the bell housing. A hydraulic system is available for actuating the clutches and for their cooling oil supply. This can partially or fully take over the functions of the vehicle-side actuators. With this test setup, each drive machine, depending on which clutch is engaged, simulates the behaviour of a vehicle with regard to wheel friction and air friction resistance (road load simulation) in consideration of the current gearing ratio. During a simulated gear shift with the so-called overlapping transmission, a sliding change occurs between the drive machines. The measurement output in **Figure 6** shows a simulated transmission upshift with this setup. The three characteristic phases of gear engaging, overlapping and engine synchronisation can be recognised.

4.3 Setup with Dual Clutch Transmission

The last step is the testing of the entire system with the associated transmission, **Figure 7**. The transmission is installed on a transmission shield with corresponding bearing, **Figure 8**. The drive machine is connected to this. The load application takes place via the original drive shafts to the e-machines, with which the vehicle and the applicable vehicle resistances are simulated. The actuation of the clutches and the supply with cooling oil as well as the transmission actuators are handled in this configuration by vehicle hydraulics integrated into the transmission that are close to serial status and are controlled by the clutch/transmission control. The KGS is connected to the test bench automation via a CAN interface, as later in the vehicle. The remaining vehicle environment is also simulated in the test bench automation. The drive machine recreates the engine performance characteristics of the combustion engine, the drive machines work independent of the gearing ratio in the road load situation operating mode. This makes it possible to objectively test and adjust almost all functions, the entire functionality of the dual clutch transmission and the vibration behaviour. Endurance test runs can then be performed with the entire system so that only verification with final adjustment and vehicle endurance tests need to be performed during the subsequent vehicle tests. The measurement output **Figure 9** shows a start with the following transmission upshift. In this test, the operating mode of the drive unit is switched from torque regulation to speed regulation during the engine synchronisation phase.

5 Summary and Outlook

Based on the know-how of the clutch system manufacturer ZF Sachs and the experience of the engineering services provider GIF in the area of drive train testing, an optimal drive train test bench for the development of dual clutch components and systems was realised through the application of modern testing technology. The proven and flexible equipment of the company GIF forms the basis for this. This equipment was expanded with mechanical, hydraulic, electrical and electronic components for the testing of dual clutch systems. In addition, expansions to the test bench automation and the clutch-specific vehicle software were also realised. The performance, flexibility and reliability were verified in diverse tests, starting with a setup with one drive machine and continuing to the transmission simulation with two drive machines all the way to a setup with a complete transmission including transmission software close to serial status.

To date, extreme startup tests, adjustment of regulating algorithms and shift sequences and endurance testing in connection with a complete dual clutch transmission have been performed within the framework of a concrete development. The further development of the transmission software functionality ensures constant adaptation and expansion of the test bench particularly in the automation software and interfaces. The electro-mechanical development of this test bench will be characterised in the future primarily by the simulation of the combustion engine comformability with the drive machine and increasing of the maximum rotation speed of various test bench components up to 10,000 rpm.

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