Previous attempts at wedge clutches in automatic transmissions often failed because of unpleasant shift jerking. Researchers from Shanghai Jiao Tong University are working on solving this problem through a precisely controlled electric motor. The validation is based on hardware and software tools by dSPACE.

The current trend in the automotive industry of electrifying the drivetrain sometimes also touches the transmission system. For example, in automatic transmissions, electric actuators could be capable of replacing conventional hydraulic clutches. One reason is that electric actuators are usually more compact and lighter than hydraulic actuators, another is that they do not need a permanently-running combustion engine to sustain the built-up forces. Because this can save a significant amount of fuel, researchers at the Shanghai Jiao Tong University (SJTU) recently evaluated an electrically driven wedge clutch.

A Challenging Transition

The wedge mechanism is driven between a rotating clutch plate and a fixed counter bearing (figure 1). The further the electric motor drives the wedge, the tighter the clutch plate is pressed against its counterpart. With a constant wedge angle, however, a critical point is eventually reached at which the ratio between the drive force of the electric servomotor and the friction force on the clutch plate is enormous. This means that even a small actuating force can suddenly cause a very large normal force on the clutch plates. In the transmission output torque, this sudden transition between “sliding” and full traction translates into a distinct jerk that

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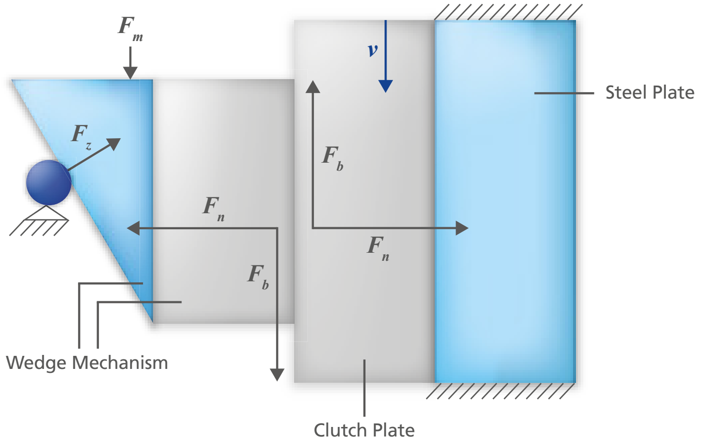
Figure 1: Force analysis on a simplified depiction of the wedge clutch mechanism. Even a small actuating force F_m can cause a very large normal force F_n on the clutch plates, translating into a distinct jerk that would seriously affect ride comfort.



Smooth and e-fficient

Electric wedge clutch for smoother shifts

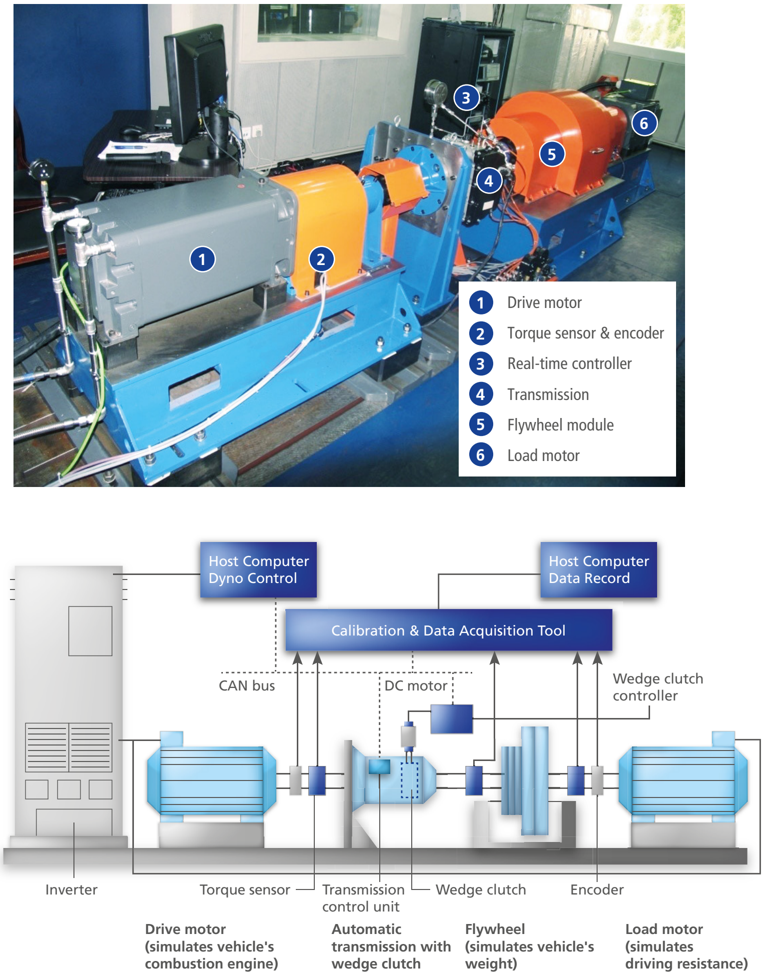


Figure 2: The dynamometer test rig emulates a mid-class passenger car for the effective validation of the wedge clutch system.

would seriously affect ride comfort and thus destroy the chances of the wedge clutch going into series.

Validation on a Test Bench

By using an optimal control of the electric actuator, researchers at SJTU are working on preventing exactly that problem, making it possible for the wedge clutch to smoothly engage and disengage at lower torques and with low power losses. To quickly, accurately and precisely validate the feasibility of this kind of control, and thus the wedge clutch, on their dynamometer test bench, the engineers used MicroAutoBox II from dSPACE together with a PID (proportional-integral-derivative) controller. The controller's task is to control the fluctuations of the normal force on the clutch plates within a few milliseconds, thereby optimizing the switching behavior.

Simulating a Mid-Class Car

For the input value, the PID controller uses the deviation between the predetermined desired and actual normal force on the clutch plate. This deviation is the basis for controlling the voltage of the DC-powered servomotor as an output variable. Together with the rotation angle, the voltage is implemented as a corresponding load torque on the wedge clutch. The wedge clutch is built into the transmission bell housing in the center of SJTU's dynamometer test bench (figure 2). On the drive side, a fast-response electric motor emulates car combustion engines with cylinder capacities of up to 1.6 liters and torques of up to 297 Nm at about 6500 rpm. On the output side, there is a flywheel, which simulates the inertial mass of a mid-class car, and a load motor for reproducing different driving resistances.

Adaptive PID Controllers in Action

By using the PID controller in a closed loop, slip differences between the clutch plates of the drive side and the output side were reduced to a minimum in a short time so the gears could switch smoothly. Because conventional PID controllers produce unstable results under complex driving conditions and varying system parameters, the researchers at SJTU used adaptive PID controllers with operating-point-dependent parameter control

> "Our researchers were impressed by the seamless integration of dSPACE's tools. This gave them the chance to concentrate completely on developing the algorithms."
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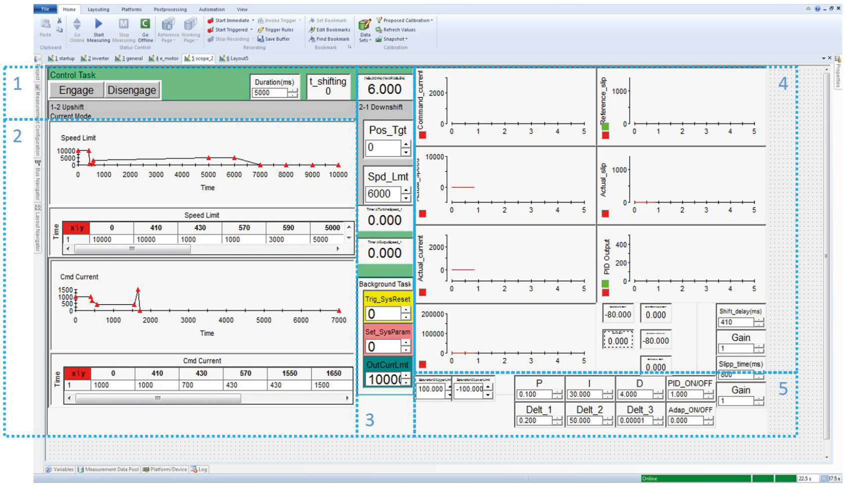
> *Jian Yao, Shanghai Jiao Tong University*



1) Switching control signals for clutch engagement and disengagement

2) Calibrating the DC motor's actuation signals for
- Actuating clutch travel
- Providing the normal force

3) Setting the initial values for
- DC motor control limits
- Communication parameters
- Sampling frequency
- System initialization

4) Displaying
- Slipping errors between clutch plates
- DC motor current
- Rotary speed and angle
- Control outputs

5) Setting initial values for
- PID control parameters
- Adaptive gain

Figure 3: ControlDesk Next Generation helped the SJTU researchers create a rich user interface for monitoring and managing signals in their test environment.

in order to control the real servo-motor on the test bench.

Tests Like Under Real Driving Conditions

The researchers develop the control concepts in MATLAB®/Simulink® and compile and execute them on a dSPACE MicroAutoBox II during the tests. The results showed that the PID controller exhibits a robust performance and complies with all of the reference characteristics when the system parameters and driving conditions are changed, making it possible to control the transmission as under real driving conditions. In addition to benefitting from MicroAutoBox, whose numerous I/O interfaces were easy to integrate, the SJTU test bench also profited from dSPACE's experimentation and visualization software, ControlDesk® Next Generation.

Comprehensive Test Instrumentation

With the numerous instruments in ControlDesk, the researchers at SJTU created a rich user interface for monitoring and managing the signals in their test environment (figure 3). They were therefore able to perform tasks such as calibrating the control signals for the DC motor or setting the important initial values and parameters of the PID controller on the computer screen, to name just a few examples. In addition, they reproduced and analyzed all the important signals in detail, from the slip errors between the clutch plates, to the current, speed and angle of the DC motor, to various control outputs.

Paving the Way for Future Tests

Above all, the researchers at SJTU were particularly impressed by the seamless connection between the dSPACE tools and MATLAB/Simulink. This coupling gave them complete trust in the compact and robust hardware system, letting them concentrate on algorithm development. Because of their positive experiences, they are planning further tests to complete the developed control algorithms and develop the actual controller for their promising wedge clutch. Their future development activities plan to include further dSPACE tools such as the production code generator TargetLink® or a hardware-in-the-loop (HIL) simulator. ■

Jian Yao,
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