TESZTPAD KÖRMÖS KAPCSOLÓS AUTOMATIZÁLT SEBESSÉGVÁLTÓHOZ

TEST RIG FOR AUTOMATED TRANSMISSION WITH DOG CLUTCHES

Ayham Aljawabrah, PhD student, aaljawabrah@edu.bme.hu
Dr. László Lovas, associate professor, lovas.laszlo@kjk.bme.hu
BME Department of Railway Vehicles and Vehicle System Analysis

ABSTRACT. In recent years, the dog teeth clutch had a more important role over the traditional synchronizers as a coupling element. Although it has a simple geometry, the correct operation of a dog teeth clutch requires a very fine operating algorithm for successful engagement. Developing such an algorithm requires careful experimental testing. This paper describes the test rig in our department.

1. INTRODUCTION

In vehicle gearboxes, the conventional coupling elements such as the synchronizers and multi-surface friction clutch (MSFC) use the friction principle to achieve successful gearshift, to create power transmission between the input and output elements. The task of the friction is to reduce the rotational speed difference. The dog clutch as a coupling element has a high potential to reduce fuel consumption compared to the conventional coupling elements [1, 2].

Recent developments of automated manual transmission (AMT) are focused both on mass and size reduction, which leaves little space within the gearbox casing. Dog teeth clutch has been replacing the synchromesh because it provides quicker shifting time, a simpler structure, and has lower cost [3, 4] as well as fewer space requirements. Unlike in the case of the traditional synchronizers, the speed synchronization mechanism – the friction mechanism - is removed from the dog clutch, so the speed synchronization problem has to be investigated to achieve successful engagement.

The overall efficiency of electric vehicles (EVs) can be improved by applying multi-speed gearboxes in the transmission chain [16]. Some papers discuss clutchless AMTs used in battery electric vehicles (BEV) where the friction cone is removed from the synchronizer, and the speed synchronization is achieved by electric motor control [5, 6].

Before addressing the previous researches conducted in this field, let us briefly consider the dog teeth clutch geometry. A dog clutch, Figure 1, is a coupling used to transmit power. It consists of two parts having complementary geometry. These complementary shapes are referred to as dog teeth. Teeth can be present either on the circumference of a cylinder and referred to as radial type (spline clutch), or on the circular surface of the cylinder, referred to as axial type (face clutch). In this paper, only face dog tooth clutches are considered. However, the described method can be applied independently of the place of the geometry.

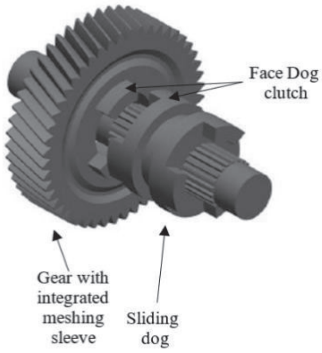


Figure 1 Face dog clutch

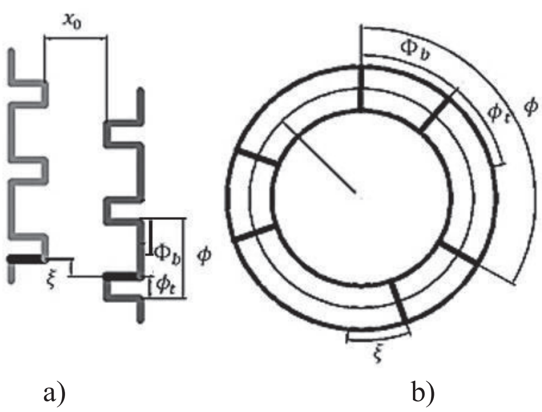


Figure 2 Dog teeth Clutch Geometry

The dog geometry is shown in Figure 2a. At the beginning of the shifting, the sliding sleeve and the shifted gear have an axial gap x_0 and initial relative angular position ξ between the marked teeth. Figure 2b shows further parameters. Here the circular teeth are represented in linear shape for easier understanding. The sliding dog can slide axially with a speed v_0, while it has relative angular rotation with respect to the target gear. The relative angular rotation is called the mismatch speed $\Delta\omega_0$. The engagement of the complementary geometries is eased with an angular backlash Φ_b. The dog clutch had an angular pitch ϕ and tooth thickness ϕ_t

2. DISCUSSION

To the author's knowledge, Laird [7] was the first to study experimentally the shifting characteristics for the radial and face dog clutch. He claimed that in contrast to the radial dog clutch, the face dog clutch engagement time decreases with the increase in the mismatch speed and it is independent of the engine torque. Moreover, face dog clutches mostly engaged at the first attempt. The study was conducted on a standard Land Rover diesel engine and gearbox driveline shown in Figure 3. The gearbox had four forward speeds, and the clutch and synchronizer cones were removed from the gearbox. The 3rd and 4th gears had identical radial dog clutches while the 2nd gear had a similar one with fewer teeth numbers. Moreover, to investigate the axial dog clutches, an alternative face dog clutch was installed for the 3rd gear. A solenoid valve was used to control the hydraulic cylinders that drove the gear selecting forks.

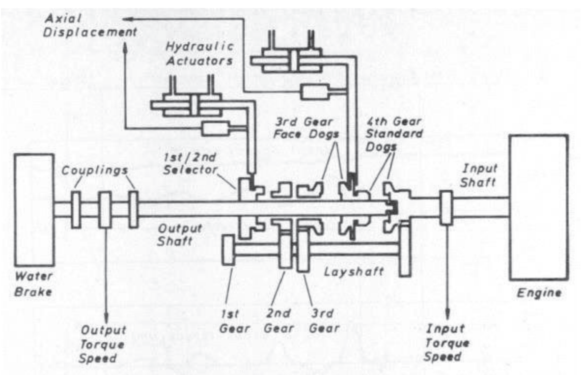


Figure 3 Test rig developed by Laird[7]

The input and output angular speeds and torques were measured by a telemetry system. The axial movement of the solenoid was measured by two displacement transducers. The Cardan shaft transmit the power to a Heenan and Froude dynamometer. All transducer elements were connected to a Hewlett Packard digital computer for data post-processing and analysis.

Later on, Bóka in his work optimized the shifting process of dog teeth clutches utilized in heavy-duty automated manual transmission (AMT), and developed a shifting control algorithm [8]. He firstly described an external synchronization strategy for AMT used in heavy-duty commercial vehicles [9]. Then, he used the notion of engagement probability to find a certain successful engagement region depending on the initial mismatch speed [10]. Finally, he applied an electro-pneumatic transmission brake on the gearbox countershaft to set the required small mismatch speed [11].

To test the developed algorithm, he used a test rig shown in Figure 4. It included a 12-speed heavy-duty automated gearbox with all gearbox actuators providing full functionality. The rig contained input and output speed sensors, and a gearbox countershaft brake chamber pressure sensor. Two 3-phase asynchronous electric motors were driving the input and output shafts.

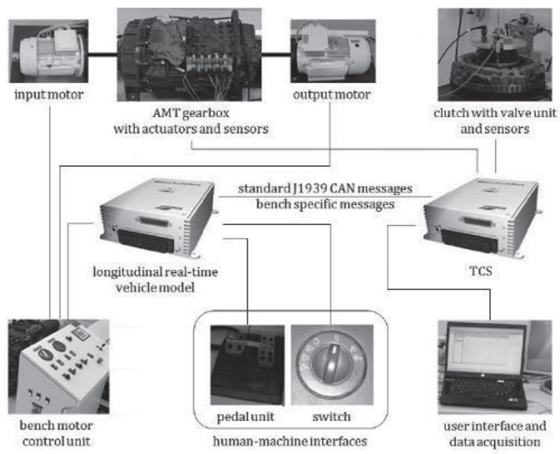


Figure 4 Test rig used by Bóka [8]

The control architecture was based on two real-time computing ECUs, where one was running a detailed real-time full vehicle model and the other one was running the transmission control software (TCS). The functionality of the ECU was limited to processing the sensor signals and driving the solenoid valves. The virtual vehicle was controlled through a human-machine interface, the pedal unit, and the switch that was used to select drive, neutral or reverse mode. The TCS controlled the gearbox and the clutch based on the signals received from the vehicle model in the forms of standard J1939 CAN messages.

This test rig modeled a real truck powertrain without the output inertia since the output inertia is very large and it was not possible to include it in the test rig.

Duan [12] developed an analytical dynamic model for the dog clutch and validated the simulation results with the measurements obtained from the dynamometer. Echtler [2] analyzed the saving potential for a newly developed shifting element to replace MSFC in automatic transmission (AT). He utilized a 9-speed AT and electric motor as a test rig to compare the fuel consumption between MSFC and TorqueLINE, the new shifting element. In the following paper, Mileti [13] analyzed the performance of six dog clutch design variants used in TorqueLINE. The authors created a multibody simulation using SIMPACK and applied different axial speed and mismatch speed to find the successful engagement area then he validated the results with the experimental test rig.

We have seen that different layouts of test rig were developed, but the test rig should be able to mimic the powertrain layout under consideration. Most of the developed test rigs share three main components: the electric motor, gearbox, and inertia part.

3. TEST RIG DESIGN

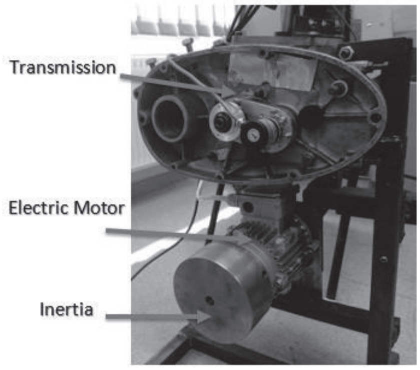
The current test rig at our department (Figure 5) consists of a 4-speed automated manual transmission, driving electric motor, and input inertia. The electric motor holding the inertia is connected through a toothed belt to the output shaft. Speed sensors are connected to the input shaft and the output shaft respectively.

The transmission shown in Figure 6 contains 4 speeds. As shown in Figure 6, the transmission contains four gear pairs, and four dog clutches, s1, s2, s3, and s4. Here, s1 and s4 are axial dog clutches while s2 and s3 are radial dog clutches, meaning shaft spline connection.

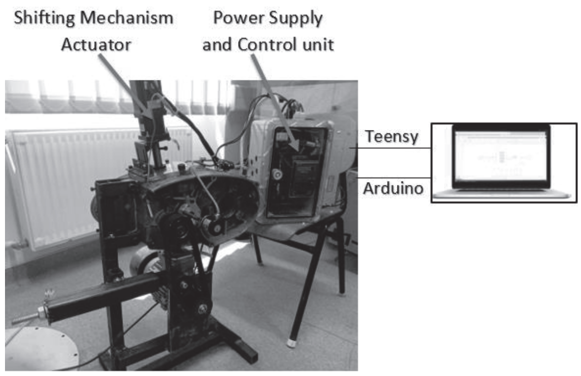
The shifting mechanism consists of a shifting motor, a cam disk, and two shifting forks. One fork is attached to the 2nd gear pair and the other one is attached to the 3rd gear pair.

The shifting motor receives the signal from the control unit. The control unit contains an Arduino and a Teensy board. The Teensy board reads the signals from the speed sensors while the Arduino is utilized to send the signal for the shifting motors. The control boards are connected to a MATLAB user interface through a universal serial bus (USB) connection. The shifting command can be sent to the Arduino from this user interface, and the measured data obtained from Teensy are also visualized here. The reason to utilize Teensy for speed measurements was the high data sampling rate that the simple Arduino board could not provide.

During experimental tests, the dog clutches were able to achieve successful engagement, but the output shaft velocity was changing too much due to the small inertia.

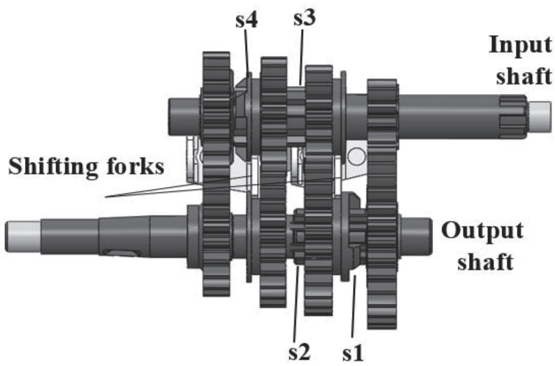


a)

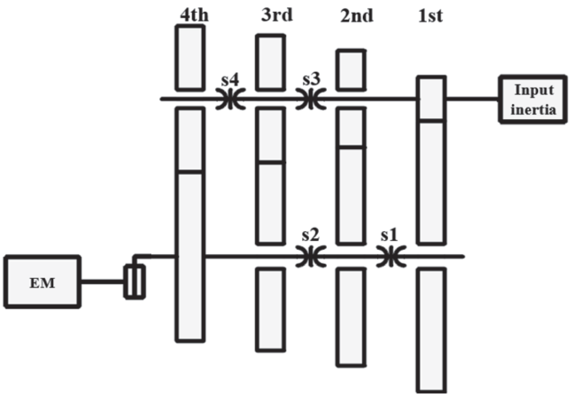


b)

Figure 5 Test rig: a) the main component, transmission, EM, and inertia b) the shifting mechanism actuator and the control unit



a)



b)

Figure 6 Test rig transmission: a) 3D model illustrating the main components, and b) the kinematic diagram

Thus, larger inertia is required. However, the current test rig has 5 kg inertia mass and its mounting system (the frame) is too small. This motivated us to launch the development of an improved, version 2 design, for further studies.

4. CONCLUSION

The dog teeth clutch has an emerging role over the traditional shifting elements from different aspects and it finds its way in transmissions installed in commercial and electric vehicles. The operation of the dog teeth clutches requires fine algorithms that need special test rigs for testing and validation. In this work, we aimed to present the first version of a new test rig that suits our research goals according to the available equipment and resources.

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