

Gear-Shift Strategy for a Clutchless Automated Manual Transmission in Battery Electric Vehicles

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ABSTRACT

The battery electric vehicles (BEVs) equipped with automated manual transmission (AMT) can realize gear-shift automatically and show many advantages in terms of reduction of fuel consumption and improvement of driving comfort and shifting quality. This paper focuses on the gear-shift control strategy for a clutchless AMT in a battery electric bus. Compared with the traditional ICE vehicles, the studied battery electric bus has the different powertrain structure, which consequently requires a different gear-shift strategy. First, the so-called clutchless AMT means that the clutch usually used in the conventional AMT vehicles is removed. Second, the synchronizer within the transmission is omitted and that means only the sleeves are employed to accomplish engagement of gears. In order to find the key factors that affect gear-shift operation of AMT in battery electric bus, the several gear-shift phases including "Gear Release", "Synchronization", and "Gear Engagement" are modeled. The analyses show that the gear-shift operation of clutchless AMT requires the motor with the capabilities of fast mode-switching (between torque output, speed control and free mode) and high-precise speed regulation. The corresponding gear-shift control strategy based on the previous modeling and analyzing is designed in this paper. Finally, the on-road test results are investigated and the conclusion is drawn.

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INTRODUCTION

Compared with conventional vehicles, the electric vehicles (EVs) with the advantages of high efficiency, energy saving, low noise, and low/zero emissions, can effectively solve the issues that caused by traditional vehicles, such as the environmental pollution and energy shortages. Therefore, the world regarded the development of EVs as the direction of the automobile industry [1]. One the promising application of EVs is the battery electric bus. The relevant data showed that the traditional vehicle emission accounts for 60% of urban air pollution in China, while of which more than 40% is caused by the city bus emission [2]. Hence, the development of battery electric bus has great potential to solve urban environmental problems.

The AMT is based on the traditional manual gearbox, which has the advantages of low cost, good inheritance and easy manufacture. The battery electric bus equipped with AMT can realize gear-shift automatically, reducing the bus driver fatigue, increasing passenger comfort, and improving economy. This paper focuses on the study of gear-shift control strategy for a clutchless AMT in battery electric bus. First, a clutchless AMT solution, which removes the clutch between motor and transmission and has no synchronizer in the transmission, is introduced. The advantages of this layout are analyzed then. Second, the factors that affect the shift quality are discussed through the modeling of gear-shift process. Next, a gear-shift control strategy mainly based on the speed difference synchronization is designed. Finally, the on-road test results are analyzed, and the conclusion is drawn.

CLUTCHLESS AMT FOR BATTERY ELECTRIC BUS

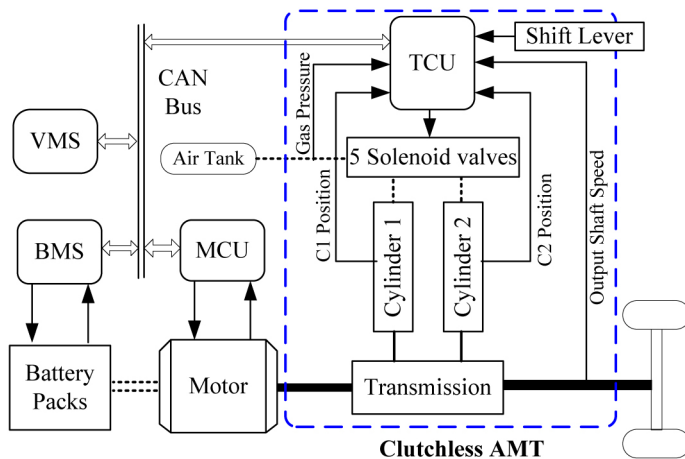


Figure 1. Powertrain structure of battery electric bus

The figure 1 shows the powertrain structure of battery electric bus. The electric motor is the power source of the whole vehicle, which is fed by the battery packs that stored the chemical energy. The vehicle is jointly controlled by the multi-controller, including VMS (vehicle management system), TCU (transmission control unit), MCU (motor control unit) and BMS (battery management system) etc. All of these controllers are connected via CAN bus.

The parts surrounded by dotted line show the structure of paper-studied clutchless AMT. It consists of electrical control components including TCU, sensors and solenoid valves, and the mechanical components including transmission, pistons and cylinders. The reason we call it the “clutchless AMT” is because the clutch usually used in traditional AMT vehicle is removed and the transmission is directly connected with the electric motor. In BEVs, due to the electric motor's characteristics of wide high-efficiency area and fast speed regulation and torque response capability [3], usually a 2 or 3 steps transmission or just a single reduction gear is needed to drive the vehicle. And in this paper, a 3-step transmission is used to meet the requirements of dynamics performance and mileage range [4]. The pneumatic actuators used in this paper consisted of five on/off solenoid valves, two cylinders, pistons and two angle sensors. The cylinder 1 performs the operations of engaging 2nd gear, engaging 3rd gear, and release gear to neutral position; the cylinder 2 performs the operations of engaging 1st gear and release gear to neutral position. It should be noted that the gear select operation in the conventional AMT is not needed during the gear-shift process of clutchless AMT.

ANALYSIS OF AMT STRUCTURE

Besides removing the clutch, the AMT in this solution also omitted the synchronizer within the transmission. The reasons and advantages are analyzed as following.

REMOVING CLUTCH

The clutch in traditional AMT is employed for vehicle launching and power cutting off during shifting. However, the AMT used in battery electric bus can remove the clutch [5]. This is because: (1) The electric motor has excellent low-speed control capability, so the vehicle can be launched by controlling motor smoothly; (2) TCU can quickly control the motor from torque output mode to free mode before releasing gear. And at this moment, the motor is not excited or its output torque is very small; it is equivalent of cutting off the power between motor and transmission. So the actuators can pick at this time to finish the gear release operation. For these reasons, the clutch is abolished in this paper. Moreover, this approach simplifies the structure of vehicle, reduces manufacturing cost and eliminates the need for clutch maintenance.

OMITTING SYNCHRONIZER

The function of synchronizer is to allow smooth engagement of gears during the gear engagement phase. On the one hand, the synchronizer makes the angular velocity completely equal between two engaging elements through friction torque produced by the friction elements; On the other hand, before the angular velocity of the two engaging elements achieves full equality, synchronizer generates the locking torque to prevent shift.

Nevertheless, due to the abolition of clutch in battery electric bus, one engaging element is connected to the motor and the other one is connected to the driveshaft directly. Inertia of the two parts are both great. If we still use the friction energy of two friction elements to achieve synchronization, the synchronizer will be worn quickly and seriously and the shift time will take a long period. Thus this solution canceled synchronizer and only employed sleeves to accomplish engagement of two gears. On this occasion, to engage two large inertia parts successfully and smoothly, two rotary elements should be in synchronous state as much as possible. This synchronous state is achieved by adjusting the speed of motor and that requires the motor with high-precise speed regulation ability [6].

MODELING AND ANALYSIS

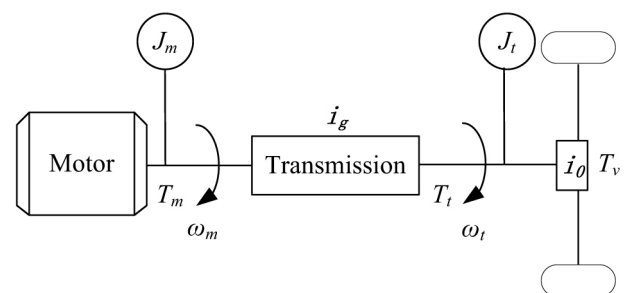


Figure 2. Model of powertrain system for battery electric bus