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Advanced shifting control of synchronizer mechanisms for clutchless automatic manual transmission in an electric vehicle

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ABSTRACT

On the basis of improving drivability and efficiency, an electric vehicle equipped with automatic manual transmission is a considerable framing. However, the conventional geared transmissions usually install automated clutch which require the hydraulic power in addition to the slippage in the clutch plate invoking some energy loss as well as wear. For this reason, a practical approach with respect to clutchless automatic manual transmission (CLAMT) and its gear-shifting control strategy for an electric vehicle was proposed by our research team. In order to determine the key factors affecting the gear-shifting operation of CLAMT, a dynamic model of the CLAMT driveline was developed and the dynamic characteristics of the transmission synchronizer during each gear-shifting phase were analyzed in this paper. The analysis indicates that the gear-shifting operation of CLAMT not only requires a power motor with the capability of rapid mode-switching and precise speed regulation, but also demands that the shift actuators have the ability of exact position adjustment and strong robustness against shift load variations. To realize rapid and accurate gear-shifting control, the key technique relating to the robust position control scheme for the gear-shifting actuators were described in detail and validated on a designed CLAMT test rig.

1. Introduction

Owing to the recent increase in fossil fuel prices and the introduction of stricter legislation for the reduction of exhaust emissions, hybrid electric vehicles (HEVs) and pure electric vehicles (EVs) have attracted worldwide attention and have been developed rapidly for launch into the market. Consequently, there has been a trend in the automotive industry leaning towards cleaner, more efficient, and more comfortable vehicles. In order to improve the efficiency of an electric driving system while also meeting the requirements of vehicle drivability, the power transmission unit plays an important role, whether it be for an HEV or EV. In particular, in lightweight EVs, such as the L6e category dictated by European Commission directives, the maximum power of a drive system, the total mass of a vehicle, and its maximum velocity must all be limited; therefore, it may not be easy to directly determine the appropriate motor power and speed ratings so as to conform to the performance requirements. By using a transmission, an EV can work at more efficient operating points and draw less power from the battery [1]. There are several types of transmissions and associated technologies that provide different levels of performance.

Nowadays, Automated Manual Transmission (AMT) has drawn the attention of car manufacturers since it may provide the benefits of both automatic and manual transmissions: the high efficiency, low cost, and low weight of manual transmission, and the smooth gearshift and convenience of automatic transmission. Furthermore, the AMT's controllability makes it a decent candidate for HEV or EV power transmission [2]. Inevitably, AMTs also have disadvantages, including the jerk generated during shifting, excessive wear in the clutch friction plates, and torque interruption during the shifting process.

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A number of research studies of AMT are mainly applicable to HEVs, and have focused on some intelligent control algorithms for the clutch, gearshift, engine, and even a coordinated control strategy based on the torque and speed so as to achieve acceptable shift performance. By utilizing the auxiliary dynamic action of the motor, the power source can be quickly controlled in the shifting process, and the shift quality can be improved for an HEV equipped with AMT. For instance, Lee et al. [3] proposed a gear-shifting control strategy for a parallel hybrid vehicle to reduce shift shock and shorten the shifting time through the speed control of an induction machine and a diesel engine. Liao et al. [4] studied the shifting process of an HEV system in which the motor was installed at the back of the clutch, and introduced a control strategy to reduce the synchronizing torque and the synchronization time by controlling the torque and speed of the engine and the motor.

Generally, because of the high inertia of the internal-combustion engine, a conventional AMT equipped for an internal-combustion engine (ICE) requires an electronically controlled clutch to isolate and engage the engine power for smooth gear changes. However, the gear ratio of transmission changes during the AMT shifting process such that the input shaft speed and the output shaft speed of the clutch will be different, resulting in the occurrence of a shift jerk. Generally, the method for reducing shift jerk is to extend the friction time of the clutch for traditional AMT vehicles, but this can increase the power restoration time and decrease the service life of the clutch. Therefore, a small number of studies have been undertaken to examine the feasibility of removing the clutch from the shift process. He et al. [5] proposed a control strategy control in which the torque and speed of the engine and electric machine are controlled in coordination with one another so as to achieve AMT shifting control for a plug-in HEV without a clutch. Zhong et al. [6] also used a control algorithm that combined the speed and torque engine control of an AMT powertrain to achieve shifting control without the use of a clutch. Yoon et al. [7] proposed a clutchless geared smart transmission (CGST) system using an electric motor, a planetary gear system, and a multiple-input gear-train for solving the wear problem due to the absence of a clutch.

While the above studies have focused on implementing clutchless driveline for vehicles or HEVs, little attention has been paid to pure EVs. However, the AMT employed in EVs can definitely operate without a clutch apparatus for the following reasons: First, the electric motor has a significantly smaller inertia than an ICE and has excellent low-speed control capability. Therefore, the vehicle can be launched by controlling the motor smoothly. Second, during gear shifting, the electric control unit (ECU) can quickly control the motor operation when the motor is switched between the torque mode and the speed mode. At this moment, the motor speed is controlled so as to be synchronous with the connected shaft of the MT. Then, the gear actuators can select when to finish the gear-shifting operations. Thus, a clutch is unnecessary. With regard to documentation on the topic of clutchless AMT devices for EVs, the majority of such material consists of patent articles and there are only a few technical notes investigating this subject. For instance, Liu et al. [8,9] carried out an AMT without clutch and synchronizer used in battery electric bus and introduced the corresponding gear-shifting operation procedure. Though these notes point out that the gear-shifting operation of clutchless AMT requires the power motor with the capabilities of fast mode-switching (between torque output, speed control and free mode) and high-precise speed regulation, the relating control methodology or technique is not discussed or analyzed in their articles. In addition, the removal of synchronizer component within the transmission would incur the risk about the circumstance of "kick tooth", even not engaging gear.

It is for this reason that the designed CLAMT of our research team still retains the synchronizer component within the transmission. The previous study [10,11] is focused on exploring the feasibility of a CLAMT adopted in an electric vehicle and proposes a gear-change control technique for a CLAMT, which includes identification of the model parameters, control of the synchronization speed during gear engagement, and basic motion control of the gear change actuator mechanism. In transmission control, the shift quality is one of the most significant considerations, and it is determined by shift time. During gear shifting, the output torque of the AMT driveline is interrupted temporarily. The torque interruption, which happens when the drive shaft gear moves towards the target gear and the transmission gear is disengaged, causes the driving comfort of the vehicle to deteriorate during gear shifting. Hence, it is important to shorten the interval of torque interruption and to accomplish the gear change in the minimum amount of time in order to improve the shift quality. According to the time analysis in the previous study [11], we can find that the expense time of the "speed synchronization" phase accounts for nearly 50% of the total time. Therefore, the capability of high-precise speed regulation is needed for the power motor to improve the gear-shifting quality. Thus, the previous study [11] had developed a synchronization speed control strategy for the CLAMT system to reduce the expense time of the synchronization phase. Furthermore, the

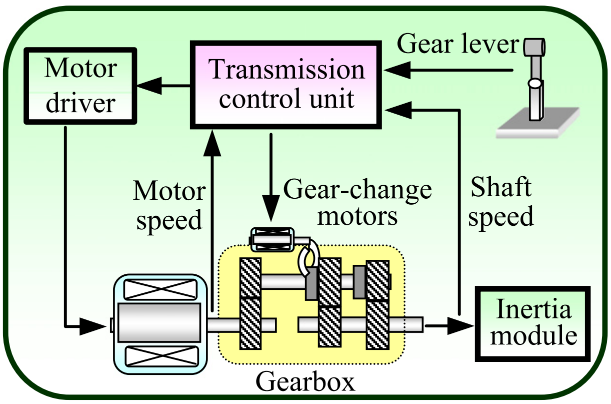

Fig. 1. Schematic of the clutchless AMT system for an EV.