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Research paper

Shift strategy of a new continuously variable transmission based wheel loader

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ABSTRACT

Most wheel loaders are generally equipped with hydraulic mechanical automatic transmission (AT) including a low-efficiency torque converter, leading to a poor fuel economy. Hence, in this study, a new hydraulic mechanical power reflux transmission (HMPRT) substitutes the torque converter to improve the wheel loader efficiency. The operating mode of wheel loaders is complex and variable, demanding a frequent shift in the working condition. Therefore, it is critical for a loader with an HMPRT to formulate an appropriate shift strategy. Herein, first, the principle and basic characteristics of an HMPRT are analysed. The speed ratio and efficiency of the complete system is significantly affected by the torque converter. Therefore, the speed ratio of the torque converter is considered for formulating the shift strategy. In this work, a feasible shift strategy is proposed based on the working feature of wheel loaders and characteristics of an HMPRT. Finally, the simulation model of a loader with an HMPRT is established to verify the effectiveness of the above proposed shift strategy under pure acceleration and V-pattern working conditions.

1. Introduction

The wheel loader is considered to be one of the most versatile construction equipment machines, which is widely used in the construction of infrastructure [1]. To meet the adaptability to various loads, the loader generally uses hydraulic-mechanical drive mode, such as traditional AT. A torque converter is a critical power transmission mechanism, which plays the role of an energy converter in hydraulic drive [2]. The torque converter causes power loss leading to low transmission efficiency [3,4]. Presently, the hydraulic transmission efficiency is improved mainly by optimizing the design of the blade, and using multi-element working wheel, and adding the numbers of gears in the engineering machinery [5–9]. The form of power reflux by hydraulic torque converter provides an alternative solution to the problem of low efficiency transmission and impact vibration of a roadheader [10]. In view of the complex working conditions of a wheel loader, a gearshift device is added to the transmission in this study, thereby forming a hydraulic mechanical power reflux transmission (HMPRT).

HMPRT is a new type of transmission system that replaces the torque converter in an AT. The torque converter no longer plays the role of transmitting the output power from the engine in the HMPRT system but is coupled with the planetary mechanism to achieve the function of speed ratio regulation. Compared with traditional AT, an HMPRT system improves the system efficiency and widens the range of speed ratio based on maintaining the advantages of the low-speed high-torque characteristics. Therefore, the torque converter does not require locking to avoid low transmission efficiency, and further, the

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HMPRT system can achieve a continuously variable speed ratio within the range of speed ratio adjustment. The speed ratio and efficiency characteristic curves of the HMPRT system will be introduced in the following sections.

To adapt to the regular and severe changes in working conditions, a wheel loader needs to shift gears frequently in order to meet the operational needs [1]. Therefore, the formulation of a shift schedule is one of the important research directions for the loader with HMPRT, which directly affects the economy, power, and comfort performance of a vehicle [11,12].

The power reflux transmission without a gearshift device does not involve the shift process, and hence it has never been involved in gear shift research before. The related literature has not been found yet. Therefore, it is necessary to develop a shift control strategy for HMPRT. The shift schedule of an automatic mechanical transmission (AMT) vehicle generally adopts two parameters namely, vehicle velocity and throttle opening. The velocity indicates the vehicle status, whereas the throttle opening reflects the intention of the driver [13]. An AT vehicle uses two parameters to establish the dynamic shift rule. Aiming at the problem of insufficient power in the case of a traction curve disjoint, the point with the maximum slope on the acceleration curve is chosen as the shift point, which is ahead of original point. [14]. There are some problems of unexpected and frequent gearshift under certain operating conditions of a vehicle with dual clutch transmission (DCT). The throttle opening and vehicle speed are chosen as shift control parameters, based on the PID fuzzy control algorithm, and different correction coefficients are provided in the process of upshift and downshift [15,16]. A two-parameter shift schedule is widely adopted, and the throttle opening and vehicle (or engine) velocity are typically selected as parameters. To solve the inadequacy of using two parameters, a three-parameter gear-shift schedule was proposed. A terrain coefficient, which includes the road grade and rolling resistance coefficient, was added for improving the fuel economy of the vehicle [17]. A generalized load concept that can comprehensively reflect the driving condition information was proposed for an AT vehicle [18].

Gearshift characteristics are generally determined by the relationship between the acceleration or traction, and velocity for different throttle openings [13,14].The shift schedule design for the HMPRT system cannot be similar to that of AMT system, whose gear-shift points are calculated and uniquely determined by the speed and acceleration under a certain throttle opening [19]. However, the speed and acceleration of an HMPRT system cannot be determined only at a certain gear in the gearshift device. The HMPRT's shift points also cannot be determined in a similar manner as that of AT's because the torque converter of traditional AT requires locking. Therefore, the shift schedule of AT can be classified into two cases based on the locking of the torque converter: when the torque converter is not locked, the shift points are the intersection points of the acceleration curves under a hydraulic condition, and when the torque converter is locked, the shift points are the intersection points of the acceleration curves under a mechanical condition [20,21]. The torque converter of an HMPRT system is not locked in the entire process of speed ratio regulation, and significantly affects the system ratio and efficiency. Therefore, the selected shift points and parameters of HMPRT are different from those of AT.

Owing to the particularity of the structure and speed ratio characteristics, an HMPRT shift schedule is essentially different from that of the conventional AT. Consequently, this study focuses on the method for proposing an appropriate shift schedule for HMPRT to combine its characteristics.

2. Structure and characteristics' analysis of HMPRT

2.1. Structure of HMPRT

An HMPRT system mainly consists of a gearshift device, a torque converter, and a planetary gear mechanism. The structure of an HMPRT system is shown in Fig. 1. The fixed-ratio gear is connected to the carrier. The pump impeller of the torque converter is connected to the sun gear, and the turbine is connected to the input shaft of the transmission system. The gear ring is attached to the gearshift device.

The engine power flows through the fixed-ratio gear from the input shaft of the HMPRT to the planet carrier. A majority of the power is transmitted to the gearshift device by using the power split characteristics of the planetary gear train. The purpose of connecting the gearshift device is to expand the range of the speed ratio. From the sun gear, the remaining power is passed to the torque converter and then returned to the input shaft of the engine via the turbine. Consequently, the fixed-ratio gear, planet carrier, planetary gear, sun gear, and torque converter form a power reflux path.

The torque converter is located reversely between the sun gear and input shaft to sharply reduce the power loss. Additionally, HMPRT realizes a stepless speed variation in the entire process by using the torque converter continuously to adjust the speed and transform the gear of the gearshift device.

2.2. Basic characteristics

The ratio and efficiency characteristics are important indices of HMPRT. The mathematical analysis lays a good foundation for determining its shift schedule.