



# Transmission control for power-shift agricultural tractors: Design and end-of-line automatic tuning

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## ABSTRACT

This paper addresses the analysis and design of the transmission control system for a high-power power-shift agricultural tractor. Specifically, all the criticalities involved with the correct management of both single clutch and double clutch gear shifts are investigated, and a control system capable of providing good shifting performance in all operating conditions is proposed. Further, to comply with components tolerances and spreads in the production line, an automatic procedure for the end-of-line tuning of the transmission control system is proposed to objectively classify the quality of the gear shift and automatically optimize it. The suitability of the proposed approach is thoroughly tested on an instrumented vehicle.

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## 1. Introduction and motivation

Agricultural vehicles have to cope with working conditions which are more complex and demanding than those experienced by other ground vehicles, [10]. In fact, agricultural vehicles are essentially designed to work at low speed while providing large traction forces. Moreover, their ease of moving on uneven soil makes them suitable also for heavy trailers transportation. To ensure the maximum flexibility of use at each speed and to exploit the maximum engine power available in all working conditions, nowadays agricultural vehicles are often equipped with a so-called *power-shift* transmission. This kind of transmission has a large number of gears available (typically from 9 to 30) and it allows to perform a gearshift with no (or at least with a minimum) loss of power from the engine to the driving wheels.

Usually, a power-shift transmission is characterized by the presence of two or more (depending from the number of gears and the overall mechanical architecture of the gearbox) wet clutches connected to an hydraulic circuit, whose pressure can be regulated by a proportional solenoid valve. Considering the large number of gears available and the fact that to achieve an optimal gear shift it is necessary to correctly manage several control variables, this kind of transmission needs to be properly controlled.

The design of such a control system is not a trivial task. In the scientific literature, some works dealing with power-shift or dual

clutch transmissions control for ground vehicles are available, see e.g., [3–8,15], but very little has been done on specific solutions for agricultural tractors. This is mainly due to the fact that agricultural vehicles have very specific performance specifications due to the very broad range of working conditions and variability of the vehicle load, which make the gear shift optimal performance definition different from that of ground vehicles. As a matter of fact, the main constraints are the repeatability of the manoeuvre and the comfort of the driver on all working grounds, which vary from asphalt roads to rough off-road terrains. Also the load distribution in tractors is much different than for other vehicles, due to the fact that it might be due to either front or rear additional loads due to the various working instruments that need to be employed for different tasks. Finally, note also that the variation of the operating conditions is most often non measurable via on-board sensors, and thus asks for robust and easily tunable gear shift controllers. These facts make the problem of ensuring an optimal and repeatable gear shift on an agricultural tractor a very challenging task.

To design an effective transmission control system, first of all the most significant variables which influence the gear shift quality must be identified, see e.g., [2,16]. Further, the gear shift control system has to optimally manage the trade-off among the following conflicting requirements:

- (i) yield comfortable gear shifts;
- (ii) guarantee that no loss of power to the driving wheels occurs during gear shifts;
- (iii) cause a minimum wear and tear of mechanical components over the life of the vehicle transmission.

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