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[F] PhD Extended Abstract Form *(Please select the Calibri 10 typeface)*

Power Shift Operations in Multi-Group Transmissions for Standard Tractors

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Extended Abstract

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1. Chapter – Introduction

Tractors are multi-functional working machines that are used with several different implements in several different applications. For each application, the engine torque and speed have to be adopted by the transmission to generate the required pulling force and to provide the correct working speed. Beginning with simple transmissions, the development focuses on increasing the number of ratios and on continuous improvements of the gearshift quality to reach quick, efficient and comfortable gearshifts with little torque interruption. Currently, continuously variable power split transmissions (CVT) represent the state of the art in transmission design. Their smooth ratio changes represent the benchmark in terms of drivetrain comfort. However, the worldwide market share of partial and full power shift transmissions (PST) is still high, due to slightly higher efficiencies, lower production costs and in some markets, a higher expected durability.

2. Chapter – Fundamentals and State of the Art

Full PST, that offer a high number of gears, are based on a “grouped” transmission design, to reduce assembly space and cost (Figure 1). Within this PhD thesis, transmissions that offer two groups are called two-group transmissions, whereas transmissions with more than two groups are called multi-group transmissions. The multi-group transmission design requires gearshifts that cover ratio changes within one, two or several groups (Figure 1). The basic power shift operation within one group, including one engaging and one releasing clutch, is called a one-swap gearshift. If gearshifts cover two groups, they are called two-swap gearshifts and so on. Ideally, each involved group of a gearshift offers a different ratio step. The group offering the biggest ratio step defines the shift direction of the overall gearshift. Therefore, it is called the main step, whereas the ratio steps of the other groups are called minor steps.

If multi-swaps are performed under load, the application of gearshift parameters is challenging and may lead to jerks during the gearshifts. Scientific pulling force measurements of full PST show that current multi-swaps offer torque interruptions of about 50 % during a period of one second, compared to the applied pulling force. Moreover, in a new developed full PST with three groups, one gear is unused to prevent a three-swap at low driving speeds. With respect to the smooth ratio changes of modern CVT, it turns out that investigating and improving the gearshift comfort of multi-swaps in PST is of high importance.

By analyzing existing publications and research papers, it appears that the highest effort to optimize the gearshift quality of power shifts is spend in the automotive and in the commercial vehicle sector. Within these sectors, many investigations and current developments exist to measure the gearshift quality and to optimize the gearshift quality by fully automatic gearshift parameter application processes. However, the focus is on one-swap and quite seldom on two-swap power shifts. Multi-swap power shifts are not focused, as the only occur in full PST within the agricultural sector.

With regard to two-swap power shifts, the analysis shows that the transmission output torque will drop down significantly during the torque transfer of the gearshift. Moreover, a two-group transmission will offer different gearshift behavior, if the main step is located in the first group instead of locating in the second group. Finally, the focus during the parameter application process is to define the timing between the individual gearshifts of the two groups.

For multi-swap gearshifts, there are no comparable, general applicable investigations known, even though the number of

possible transmission designs and group arrangements increases with the number of groups of the transmission. However, it is mentioned that the main problem of multi-swap power shifts are the internal synchronization and the torque transfer of the internal speed and torque steps, as they are very high, compared to the steps of the direct gearshift.

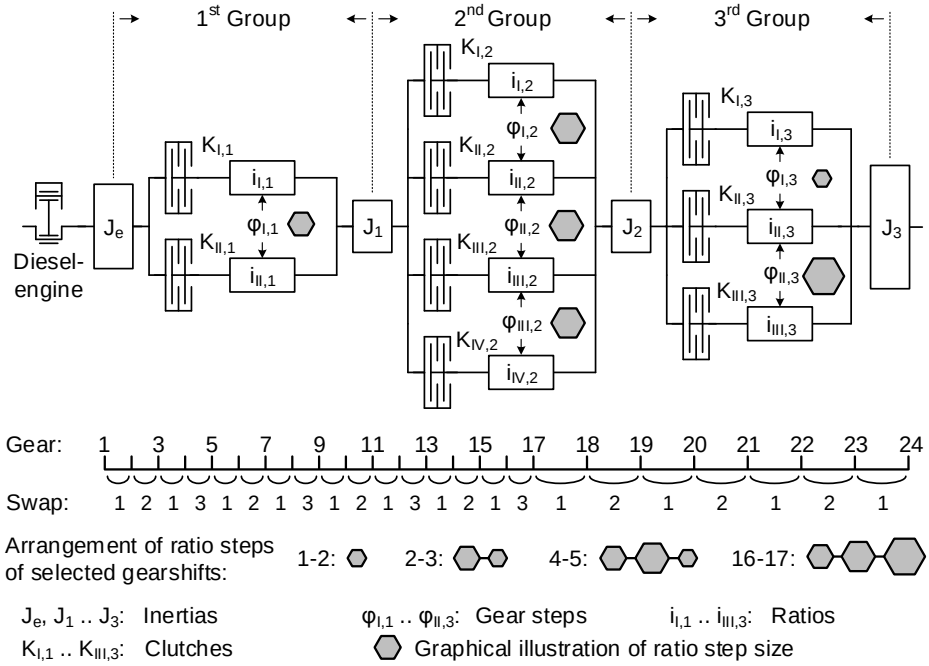

Figure 1: Transmission design and arrangement of ratio steps of an exemplary multi-group transmission

3. Chapter – Aim and Methodic of the Thesis

By knowing that the group arrangement will influence two-swap power shifts, one can assume similar effects for multi-swap power shifts. This leads to the question how the transmission design, especially the arrangement of main steps and minor steps, will influence multi-swap power shifts. Another arising question is the optimal shift order of the main and minor steps. In addition, it is important to know how much the individual controllability of each clutch will contribute to comfort and efficiency improvements of the gearshift, because the application effort increases if the hydraulic pressure of each clutch needs to be applied individually. For simple power shifts, the centrifugal forces, acting on the hydraulic oil in the rotating clutch chamber, influence the controllability of the gearshift. For multi-swaps, the expected influence of centrifugal forces should be significantly higher than for simple power shifts, because of the higher internal speed changes during the power shift.

Following the example of the automotive sector, the above-mentioned questions are of fundamental importance to generate the aims for future-oriented, automatic gearshift optimization procedures. Therefore, the main research question of the PhD thesis is: *What are the special characteristics of multi-swaps compared to one- and two-swaps, and which requirements, impacts and recommendations result for the design of multi-group transmissions and their gearshift control systems?*

4. Chapter – Power Shift Operations in Multi-Group Transmission

Following the research question, the characteristics of multi-swap power shift operations are analyzed, based on simplified transmission models. The investigation focuses on three mainly different transmission designs out of the multitude of possible transmission designs for four-group transmissions. The three designs allow for the investigation of transmission design influences and for the investigation of shift order proposals to shift the main and minor steps of multi-swap power shifts.

The generally applicable results show, that transmissions, that offer the main step within the last group perform better for upshifts, whereas transmissions with the main step within the first group perform better for downshifts. However,

transmissions that offer the main step within the last group require less complexity of the transmission control system.

5. Chapter – Transmission and Simulation Model

By means of a real PST, the results are verified on a transmission test bench. The used four-group full PST with the main step in the last group is based on an existing partial PST (HEXAHSHIFT) for the CLAAS AXION 800 series. The dynamic behavior of the test bench and the transmission is validated by comparable measurements in a real tractor.

An additional simulation model allows investigating internal transmission effects. The simulation model is very detailed and its control interface fits directly to the interface of the real transmission control system. These approaches deliver good results for the analysis of the interaction of all clutches, the occurring centrifugal forces in the clutch chambers and the resulting power and energy losses during the multi-swap power shifts.

6. Chapter – Test and Simulation Results of Power Shifts

The test bench results confirm the developed theory of multi-swap power shifts. For example, they show that an optimal shift order for the main and minor steps exist. The results also confirm the fact that during the torque transfer, the transmission output torque reduces briefly, but drastically by the factor of the main step size, regardless of the shifting direction. This is why bigger main step sizes will reduce the power shift comfort.

The results also show that the characteristics of the clutches of the main step and the last transmission group have the biggest impact on the gearshift quality. At least these clutches should offer the possibility for torque modulation, e.g. by proportional hydraulic pressure modulation valves. One of the clutches of the main step transfers a torque value that is by the factor of the main step lower (e.g. by a factor of 2.85) than the transferred torque of the corresponding clutch, which reduces its controllability. To reach a good controllability still, both clutches should be compensated of hydraulic centrifugal forces, as indicated by the simulation results. Additionally, the simulation results show that the occurring power losses that are directly linked to the gearshift decrease the overall transmission efficiency by less than 0.5 %.

7. Chapter – Conclusions and Practical Benefit

Highly efficient, comfortable and quick gearshifts are some of the main goals during the development of future proven PST for tractors. Model based development as well as automatic application and fine-tuning of gearshift parameters are required methods to reach these goals. However, there are not many scientific investigations on the optimization of multi-swap power shifts known.

This PhD thesis provides theoretically and experimentally secured fundamentals for multi-swap power shifts. General applicable recommendations for the transmission design, the optimized shift order proposals, the knowledge about the contribution of individual clutch controllability to the overall gearshift quality, as well as efficiency results for multi-swap power shifts are presented. Nevertheless, the results show that multi-swap power shifts are physically in an inferior position than simple power shifts, with regard to gearshift quality, due to the main step size. Future developments should therefore focus on possibilities to compensate the output torque reduction due to the main step size.

Final remarks concerning the competition benchmarks and strength points

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- The PhD thesis provides a first systematic analysis of multi-swap power shifts to explain occurring effects and to develop general applicable descriptions and recommendations for multi-swaps.
- The mentioned recommendations support current design processes of multi-group PST as well as their shift control systems and provide target values for reachable gearshift quality.
- The simulation and test bench results support the developed recommendations and quantify occurring power losses of gearshifts.