**Research Question: \_\_\_\_\_Develop a Dual Clutch Transmission (DCT) for a future formula SAE car.**

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|  | **Source/Evidence/Data #1** | **Source #2** | **Source #3** | **Source #4** | **Source #5** |
| **Citation** | [1] | [2] | [3] | [4] | [5] |
| **Purpose** | Provides an analysis of the shifting process of dual clutch transmissions | Provides analysis of drag torque in a two speed DCT. | Estimate the torque transmitted to each clutch in a DCT | Estimate torque transmitted to each clutch for ground vehicles with DCT | To improve the shift quality of a DCT using data driven predictive control technique. |
| **Why is the study necessary?** | The purpose is to “improve the DCT shift quality.” Variation of torque affects the powertrain system. “accurate clutch torque control” is therefore important for DCT | Limited studies performed on the powertrain losses of a transmission. Even less studies performed of both the gear box and clutch losses together. | Improves control of the clutch during shifting to prolong transmission life. | Improve fuel efficiency of DCT by improving gear shifting performance.  | Clutch slippage during the inertia phase affects the shifting quality. Improving the quality and efficiency of the shifting would make shifting without traction interruption possible and make the DCT as efficient as a manual transmission. |
| **Methods** | Performed both simulation with Matlab and an experiment.Analysis of shifting process:* Step 1: off-going clutch torque rapidly reduced, on-coming gradually increased
* Step 2: on-coming further ramps up, off-going reduces even more (when zero, finishes torque phase, enters inertia phase).
* Step 3: on-coming clutch torque increases to target torque
* Synchronization of angular velocities, torque recovers to normal output
 | Testing performed using an electric vehicle powertrain with a two-speed DCT .Measured input and output speed and torque and oil temperature of DCT case.Test rig operated at stable conditions (gear, speed, motor torque, and oil temp) for at least two minutes. Both experiment and simulation were performed | Experiment conducted using a Hyundai Elantra with the transmission replaced with a DCT.Test involved up and down shift of gears. Driveline speeds obtained from experiment compared to simulations.Simulation performed using a traditional driveline model with clutch torque expressed using 3 different methods:* 1st method required damper torque and other clutch torque, used when only 1 clutch slips
* 2nd, uses transfer shaft torque, used when sensors attached to transfer shafts, used for validation
* 3rd, uses output shaft torque, validation when output shaft torque sensor is available
 | Three observer systems used to observe torque on each clutch * Model reference PI: estimates output shaft torque, based on model of driveline with predefined parameters.
* Unknown input observer: Estimates combined clutch torque.
* Individual Transfer Shaft model based observer: identifies clutch torque by modeling angular deflection from torsion.
 | Constructed a virtual model of a six speed DCT using AMESim.* Clutches modeled with a friction model that describes the torque in both slipping and sticking states
* Gear modeled with fixed gear ratios with losses due to teeth friction considered.
* Losses to teeth friction considered in differential gear box
* Aerodynamic force of vehicle calculated
* Parameters of model are measured while others determined with other identification methods.

Simulation of DCT to determine efficiency of shifting gears both up and down. |
| **Results** | * Clutch 1 starts slipping and clutch 2 engages at designed speed. Engine torque adjusted adequately by throttle to control engine speed.
* Impact of shift testing less than 8 m/s3 for simulation.
* For experiment: impact of shift testing less than 10 m/s3
 | * DCT average efficiency 95% for both gears although second gear was slightly higher
* Drag torque gradually increased after reaching critical speed
* Windage losses possible affected test results, although they are minor
* “DCT efficiency increases with input torque”
 | Due to difficulty of installing torque measuring devices, clutch torque estimations were not compared to measured clutch torques. Quantitatively compared to output shaft torques.Clutch torques and output shaft torques for both experiment and simulation were close. | Clutch torque validated by converting estimated torque into output shaft torque.Accurate determination of clutch torques allows for necessary amount of actuation to prevent the clutch slipping.Torque estimations using observer models are reasonably accurate with measured torques. | Simulation results:* Controller performance verified.
* At beginning of shift solenoid has fluctuations but then becomes smoother
* Transmission output torque did not show abrupt changes during inertia phase.

Experimental Results:* Experimental results are close to simulation results.
* Designed controller meets demand for performance
* Slight deviation shows controller speed needs improvement
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| **Discussion/Conclusion** | Both simulation and experimental results agree. Results show that proposed strategies satisfy requirements for shifting gears | Both experimental and simulation results agree reasonably. “Drag torque is dominated by viscous shear in wet clutch and differential gear churning and windage losses.”This experiment can be applied to other wet clutch transmissions. | Proposed modeling method for DCT clutch torques. Allows for development of clutch actuators with better efficiency and precision. | Model observer gives accurate estimations of torque and are verified with experiments. Provides ability to accurately determine clutch torques, monitor backward torque, and output shaft torque. | Theoretical analysis of stability of transmission needed. Real world testing of DCT needed in the future. |
| **How can this help my senior project?** | This will help with the controls for shifting the transmission. | Will help determine if the use of wet clutch is needed and design a transmission while considering the losses from drag torque. | This source may help model a DCT by using the simpler method. | Source may help design a DCT and take into account the torque the transmission will see. | May help to improve the shifting of a DCT for the project. Source provides numerous equation to aid in the design of DCT. |

[1] Y. Liu, D. Qin, H. Jiang, and Y. Zhang, "Shift control strategy and experimental validation for dry dual clutch transmissions," *Mechanism and Machine Theory,* vol. 75, pp. 41-53, 5// 2014.

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[3] J. J. Oh, S. B. Choi, and J. Kim, "Driveline modeling and estimation of individual clutch torque during gear shifts for dual clutch transmission," *Mechatronics,* vol. 24, pp. 449-463, 8// 2014.

[4] J. J. Oh and S. B. Choi, "Real-Time Estimation of Transmitted Torque on Each Clutch for Ground Vehicles With Dual Clutch Transmission," *Mechatronics, IEEE/ASME Transactions on,* vol. 20, pp. 24-36, 2015.

[5] L. Xiaohui, C. Hong, G. Bingzhao, Z. Zhenwei, and J. Weiwei, "Data-Driven Predictive Gearshift Control for Dual-Clutch Transmissions and FPGA Implementation," *Industrial Electronics, IEEE Transactions on,* vol. 62, pp. 599-610, 2015.