

A Calibration Optimizer Tool for Torque Estimation of K0 Clutch in Hybrid Automatic Transmissions

Vicente Cuapio Espino, Akshay Bichkar, and Joycer D. Osorio
 Ford Motor Company

ABSTRACT

Software development for automotive application requires several iterations in order to tune parameters and strategy logic to operate accordingly with optimal performance. Thus, in this paper we present an optimizer method and tool used to tune calibration parameters related to torque estimation for a hybrid automatic transmission application. This optimizer aims to minimize the time invested during the software calibration and software development phases that could take significant time in order to cover the different driving conditions under which a hybrid automatic transmission can operate. For this reason, an optimization function based on the Nelder-Mead simplex algorithm using Matlab software helps to find optimized calibration values based on a cost function (square sum error minimization). This work will present a K0 clutch in a hybrid automatic transmission run under several operating conditions, and the method with which the optimizer aids the parameter calibration process in order to converge to the optimal values. This process also helps in the software development process to identify and include control strategy changes. The simulation environment that will be presented in this paper is based on Simulink/Stateflow Model Based Design (MBD) under Matlab platform. In this environment, the calibration parameters and strategy logic will be loaded to run desktop tests, optimization and further validation. Finally, a quantitative comparison among calibration methods (i.e. with and without the optimization algorithm) will be presented and how this could impact vehicle development processes in terms of test time optimization.

CITATION: Cuapio Espino, V., Bichkar, A., and Osorio, J., "A Calibration Optimizer Tool for Torque Estimation of K0 Clutch in Hybrid Automatic Transmissions," *SAE Int. J. Commer. Veh.* 10(1):2017, doi:10.4271/2017-01-0603.

1. INTRODUCTION

Calibrating an automatic transmission can be a very demanding task and time consuming, mainly, because several parameters need to be tuned in order to reach the desired drivability level without compromising fuel economy and/or power delivery. For OEM's, the calibration process represents a big effort, since tight schedules and urgent milestones require prompt solution deployment to avoid interruptions in the vehicle program development. These implications need to be considered at the high general level, since at the end vehicle manufacturing is an important business worldwide. On the other hand, at the field engineering work, the correct parameter definition requires a deep knowledge of the hardware operation and a profound understanding of control theory. Thus, this work aids the calibration process with the implementation of an automated optimization tool, as opposed to manual tweaking, to ease the process of parameter tuning for a specific automatic transmission controls feature.

The optimization method presented in this paper is based on the Nelder-Mead simplex algorithm to improve torque capacity estimation for the K0 clutch (disconnect clutch) control feature applied to hybrid automatic transmissions. Also, the optimizer eases the calibration process for automatic transmissions thanks to the time reduction to calculate the optimal parameters in order to minimize the torque estimation vs. torque calculation error.

Optimization processes have been proposed by several researchers in areas related to improvement of the transmission operation control and for sub-feature operation improvements. Reference [1] proposed the implementation of non-dominated sorting genetic algorithm-II (NSGA-II) to have a novel improve shift scheduling lines strategy in order to calculate optimal theoretical value of energy consumed per unit distance (EPD). The method is implemented in an electric vehicle power-pack in order to maximize the efficiency (i.e. energy usage during vehicle operation). Genetic algorithms are quite good to perform optimization task such as energy minimization, which is the goal of [1] by implementing NSGA-II to optimize the shift strategy for traction and regeneration mode during vehicle operation. The NSGA-II achieved an optimization of 1.21% than manual tuning shift points. Another research work, implemented in a hydro-mechanical continuously variable transmission (HMCVT) [2] proposed a shift scheduling strategy based on the physical parameters involved as engine rotating speed, load torque, pressure and speed valve flow rate, and shift time. For details about the operation modes evaluated please refer to [2], at the end of which is demonstrated how for different operations it is possible to optimize shift strategy based on the physical parameters and shift time variation. Reference [2] details the operation of HMCVT and the parameter dependency to define shift scheduling, and a model of this system is evaluated in a simulation environment. In [3] the author compares two algorithms: non-recursive identification Levins g-Marquardt method and a

recursive identification method, to estimate an extended characteristic map, where the torque characteristic and the normalized friction coefficient is combined. This combination includes information about the clutch slip in the clutch torque characteristic. This characteristic map predicts the clutch torque based on the clutch actuator signals and clutch slip. The author implemented the algorithms in a wet clutch for dual clutch transmission (DCT) application and found that both algorithms are able to identify characteristic maps and a reduction in the error between the reference and predicted clutch torque. This should result in a better performance during the clutch slip because of the better prediction of the clutch torque.

In this paper, the main goal is to implement an optimizer tool to obtain the optimal values of main parameters that calculate the clutch torque capacity. Matlab/Simulink environment is used for the optimizer development and simulation and validation phases. The K0 control feature is modeled here with its corresponding calibration inputs (i.e. to emulate the complete transmission calibration) in order to respond to the different conditions under which the transmission operates.

This paper is structured with an initial introduction where some background regarding recent researches in the optimization field for automatic transmission applications was presented. Section 2 is going to present the background of torque capacity estimation in a hydraulic clutch, the control model that is implemented to run the optimizer and the mathematical modelling, along with the data inputs to simulate the model. Section 3 goes deeper in the optimizer formulation and operation. Section 4 will explain the testing setup and the tests performed. Finally, Section 5 shows the conclusions of this research.

2. BACKGROUND, CONTROL MODEL & SIMULATION DATA

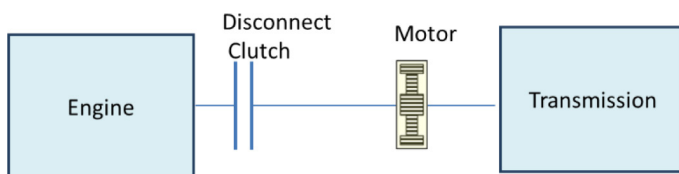


Figure 1. Hybrid vehicle architecture with K0 clutch (Disconnect Clutch).

This paper describes the optimization of the torque capacity estimation across the K0 clutch (Disconnect Clutch, DC). The physical location of the K0 clutch in a typical hybrid vehicle is shown in Figure 1. The K0 clutch is used to co-ordinate electric only vs. hybrid operation mode of the vehicle. When transitioning between these modes, the knowledge and co-ordination of torques between the engine, motor and road load / driver demand play an important role in disturbances introduced in the driveline. In order to have a smooth transition, it is essential to have an accurate estimate of the said torques. Also, for proper co-ordination of the torques produced by the actuators (engine, motor), it is essential to have a sufficiently accurate estimate of the torque capacity across the K0 clutch. Often times, for constraints such as cost, packaging, etc., it is not possible to include a torque transducer specifically for the K0 clutch. Thus, it is imperative to estimate the torque capacity of the clutch using other means.

Typically, in a wet hydraulic clutch, the estimate of the fluid pressure in the clutch piston serves as a usable surrogate to estimate the torque capacity across the clutch, as per the static relation in (eq1).

$$T_{DC} = K_{DC}(P_{apply} - P_{stroke}) \quad (1)$$

In (eq1), T_{dc} is the capacity across the K0 clutch, P_{apply} is the clutch apply pressure, P_{stroke} is the effective clutch stroke pressure (or kissing point) and K_{dc} is the effective gain of the clutch; and for apply pressures below the stroke level, the capacity equals 0. Note that the clutch apply pressure is not a statically constant term and changes dynamically, and has variation subject to the dynamics of the clutch, including characteristics such as boosting, clutch stroking, dynamic response, temperature dependence etc. These add to the variability in the dynamic relation between the pressure and torque capacity. Further, it is not always possible to have a pressure transducer to measure the instantaneous clutch apply pressure, for reasons similar to the torque transducer (cost, packaging etc.). Challenges such as these make the problem of clutch torque estimation a complex one. Modelling and clutch characterization help tackle some of the challenges posed.

Consider a sample pressure command applied to a typical hydraulic clutch, as shown in Figure 2. The actual apply pressure on the clutch would typically respond as shown in the same figure. In order to achieve the goal of using the apply pressure as a surrogate for torque capacity estimation (eq1), it is required to model the dynamic response between clutch command and actual. This model serves as a transfer function linking the static clutch capacity to the dynamic clutch capacity estimate (eq2).

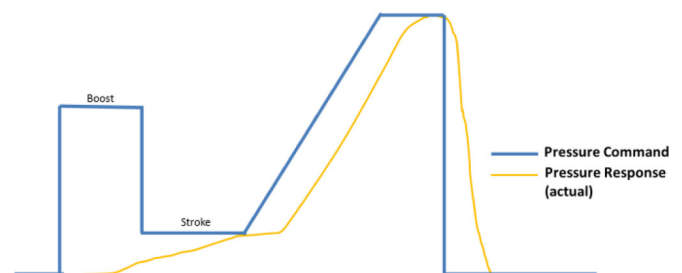


Figure 2. Typical hydraulic clutch actuation and response.

$$T_{DCdynamic} = T_{DCstatic} \rightarrow TransferFunction \quad (2)$$

The *TransferFunction* mentioned in (eq2) is in fact the transfer function for the actual apply pressure from the command pressure, which are mentioned in Figure 2. This can be approximated in the form of a model using a first order model with time constant τ , in conjunction with saturation and rate limits, as shown in Figure 3, where p_{cmd} is the command pressure and p_{act} is the actual apply pressure.

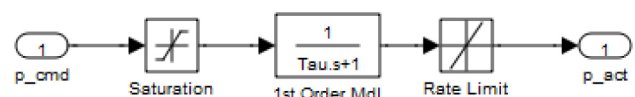


Figure 3. Model of clutch pressure for static to dynamic transfer function.