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Modelling and Simulation of Electromechanical Actuators for a Dual Clutch Transmission

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Summary

The fundamental issue of this study is that the electromechanical pump is independent from the engine and the electric motor only operates the pump when necessary. From this point of view, it is called on-demand hydraulic actuators. The pump system improves energy efficiency by reducing unnecessary pump operation, and it is an effective component for the wet clutch actuator which has a higher torque capacity. This paper describes the simulation and modelling for electromechanical actuators based on a lumped parameter approach. The performance simulator was developed using Amesim software and the proposed pump system was applied to the powertrain model as a dual clutch actuator. The simulator can evaluate how much the on-demand pump system reduces energy consumption than the conventional system.

Keywords: on-demand pump system, electromechanical actuators, dual clutch transmission, energy efficiency, lumped parameter approach, performance simulator

1 Introduction

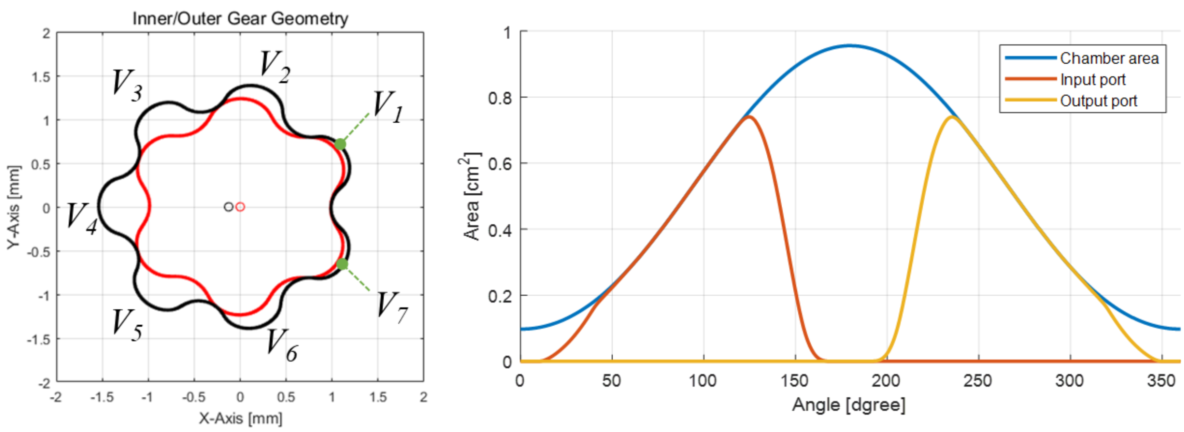
The prevailing discipline notes that a manual transmission has low fuel consumption along with driving enjoyment and sportiness. On the other hand, an automatic transmission offers high convenience without interruption in traction at the hands of the driver. Broadly speaking, the dual clutch transmission (DCT) achieves the advantages of two transmissions. The DCT selects gears automatically for the driver to shift gears easily and it gives the driver convenience while in driving mode. The dual clutch connects propulsive power directly to wheel and it has high efficiency. For the DCT, its actuation system is also considered important for transmission efficiency and performance. In this case, a conventional hydraulic actuation system uses a mechanical oil pump (MOP) driven by the engine. When an engine is utilized at a high speed with a low demand pump, this results in excess pump drive accompanied by some unnecessary energy losses [1]. On the other hand, an electrically driven pump supplies hydraulic flow on-demand and then it is independent of the engine operation. This process is advantageous to the driver, and it can reduce the energy loss. The pump is also suited for use in an energy efficient hybrid electric vehicle because the engine starts and stops repeatedly as it follows the normal process of working [2].

Of course, some automotive manufacturers have developed the actuation system with the electrically driven pump. In this case, Volkswagen [3] produced the model DQ200, which is a seven-speed and dry DCT. Additionally, Audi also introduced the model DL382 seven-speed and wet DCT. It has gas pressure accumulator without a pressure sensor. In the same vein, Fiat Powertrain Technologies (FTP) [4] manufactured C635, a six-speed and dry DCT, developed jointly by Magneti Marelli and BorgWarner. The hydraulic accumulator to maintain the operating pressure and the pressure and flow valves control the clutches for gear shift. Evidently, Getrag [2] presented 7DCT300, a seven-speed and wet DCT. It is connected to the cylinders of clutches directly for the on-demand actuation. We focus on this model because it is simple to reduce components although its control is difficult.

In this respect, a gerotor pump is suitable for the on-demand actuation. The gerotor derived from generated rotor is a positive displacement pump. Many researchers have researched gerotor modeling. The Rundo *et al.* study [5, 6] have analyzed a gerotor oil pump for more than a decade. They proposed the first lumped parameter model of a gerotor, and its simulation was based on Amesim [7], a software for the modeling and analysis of multi-domain systems. Recently, other researchers have also developed their own models [8-10]. A lumped parameter model simplifies complicated gerotor dynamics with equivalent physic and hydraulic elements. However, the on-demand actuation systems applied to transmissions have few analyses based on the hydraulic simulations. This paper presents modeling and simulation of the pump applied to dual clutch transmission. A gerotor lumped parameter model is developed using pump geometry. Through the performance simulation for the vehicle equipped by the proposed actuation system, the energy consumption is evaluated further in this study.

2 Pump geometry

An on-demand and electromechanical pump is a gerotor, which is equipped with an electric motor. It consists of inner and outer rotors. The inner rotor has less one gear teeth than the outer rotor. The axes of both rotors have offset properties and each rotor rotates on their respective axes. The geometry of the two rotors divides the dynamically changing chambers between their gears. The chamber variation can be represented for one complete cycle, because the feature repeats in that instance. For this reason, when the inner rotor rotates through only the one cycle angle, it is measured and divided by the number of the outer teeth [8]. Because the gerotor thickness is constant, the chamber between the gears of rotor convert to a measurement of an area. Each area changes and the relative area with inlet and outlet port are formulated in a rotation, and then a lumped parameter model is developed. There are chamber areas of the unit gerotor components, and the openings area of inlet and outlet ports. In this case, the gerotor geometry calculations affects its performance. Figure 1 (a) and (b) show the inner and outer gear geometry and the chamber, inlet and outlet flow areas, respectively. The areas are calculated while gears rotating, based on the MATLAB code. We use the code in [11] modified for the calculation.



(a) Inner and outer gear geometry (b) chamber, inlet and outlet flow areas

Figure 1: Calculated gear geometry and flow areas

3 Lumped parameter models

It is difficult to simulate the powertrain with pump actuator system under complex conditions because the simulation time is long and requires a lot of computation power when using CFD analysis tool. A lumped parameter model can simulate and iterate fast and easily in that case, where the other sub-models approximate the behaviour of the original system under assumptions. Figure 2 shows the lumped parameter model of gerotor.

The equivalent hydraulic model is a single chamber for the n-th control volume V_n. The number, n is the same as the outer gear number. The model substitutes the chamber variation with a view of the simple hydraulic cylinders. In the case of the geometry results, the translation of the single hydraulic cylinder functions as an area change between the gears of the rotor. If the cylinder cross section area is considered a unit of value, then the cylinder displacement functions as each chamber of the gerotor. There is relative data to the lumped parameter model, as the following:

$$\begin{aligned}\text{Gerotor chamber} &= \text{Gerotor area} \times \text{Gerotor thickness} \\ &= \text{Cylinder cross section area} \times \text{Cylinder displacement} \qquad (1)\end{aligned}$$

All inlet flows are connected in this model. Likewise, all outlet flows are also connected. The n-th teeth leakage is connected to the next teeth leakage. In this diagram below, each chamber has a plate leakage connected to the tank. In this case, the target gerotor has seven-gear outer rotor.

4 Performances

We simulate a powertrain model for the actuator performance. Although power losses for DCTs, of course, occur [12], this paper considers genernal losses, not detailed loss models. Before evaluation of the energy consumption, the unloading test for the gerotor is first simulated. The gerotor pump rotates at 3000 rpm and the results gives a notation of its pressure ripple. There is the number equivalent to 7 times of pressure fluctuation cycle per rotation, shown in Figure 3. For the powertrain model simulation, we simplified the actuator model as an ideal pump with an orifice. Figure 3 shows that the simplified pump is similar to the gerotor pump developed. It is applied to the powertrain model.

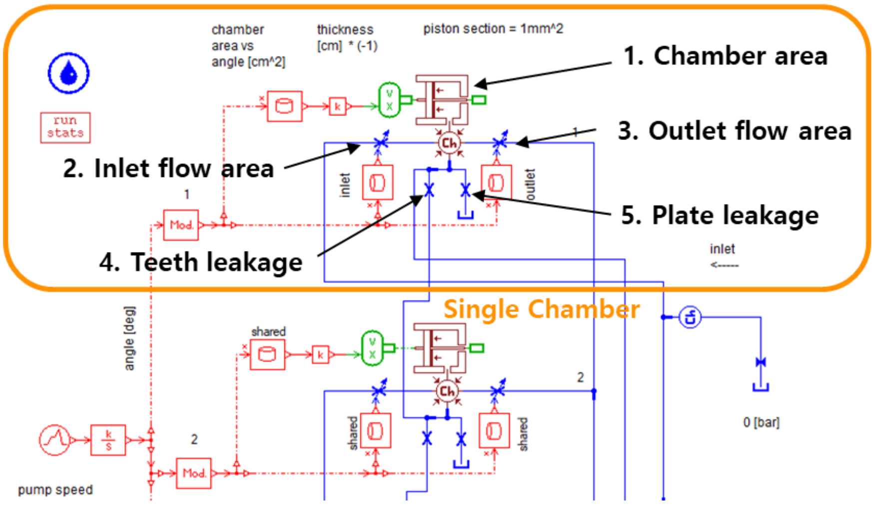


Figure 2: Lumped parameter model for single chamber components

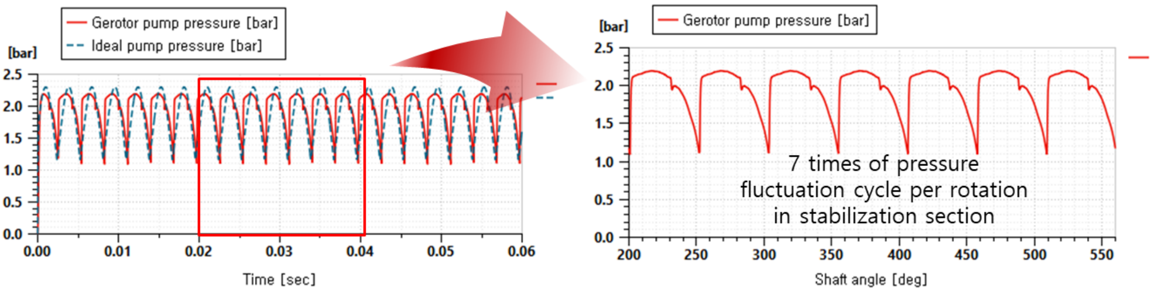


Figure 3: Simulation result of pressure in the unload experiment

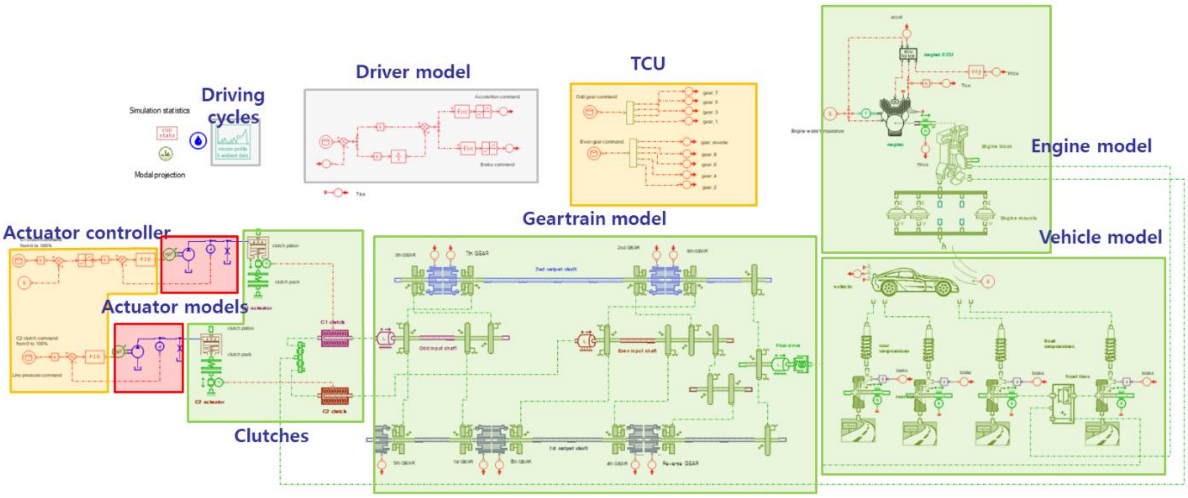


Figure 4: The target powertrain model with the proposed actuator

Next, the energy consumption of MOP and gerotor pump are compared. Except from the actuator system, the powertrain model is the same. The powertrain model is developed in Figure 4. It consists of an engine, vehicle geartrain, driver, clutches, actuator models, actuator controller, driving cycle, and transmission control unit (TCU). The vehicles with the two different actuator systems drive on the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) cycle. The pump powers are significantly different as shown in Figure 5. The gerotor pump actuates a dual clutch and sustains pressure for the clutch engagement. The MOP is connected to the engine and then the pump power is determined by the engine speed. When the engine speeds up, the pump also increases speed and the power is higher than the demanded power for the clutch actuation. In this case, it has the feature of unnecessary losses. However, the proposed gerotor pump uses only on-demand states when the electric motor rotates. Its energy consumption reduces by 96.5%, compared to the MOP.

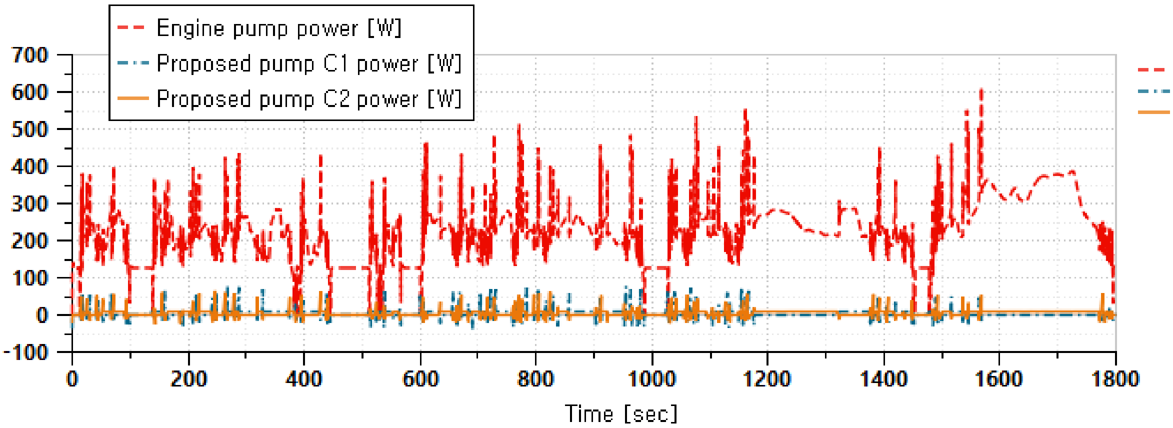


Figure 5: Comparison of the conventional MOP power with the proposed pump power (WLTP cycle)

5 Conclusions

This paper proposed a simulation model for dual clutch actuators with the on-demand pump. Through the use of gerotor geometry, the chamber areas for the lumped parameter model were calculated. The gerotor model developed as the clutch actuators was combined with the powertrain model. In this case, the powertrain model with the MOP and the proposed actuator were evaluated on their energy consumption. The proposed resulted in the energy reduction rather than the system with the MOP. Above all, the gerotor design and control parameters can affect drivability and efficiency performances for the driver. In the future, we will analyse which parameters are important to the performances through the simulation environments developed in this paper.

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