
Development of Direct Push Clutch Control during Honda Formula One Third Era

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ABSTRACT

One main development topic for the Formula One third era clutch was the direct push clutch (DPC), which was developed in order to increase the accuracy of transfer torque.

Conventional pull clutch position control could not readily stabilize the amount of torque transfer during standing starts, and therefore pressure control of the DPC was used in order to stabilize the clamp load. The non-linear characteristics of the hardware posed some issues with the hydraulic pressure response. However, these issues were addressed by control, and as a result response that had no issues in practical terms was able to be assured and the method was successfully deployed in racing.

1. Introduction

In the standing start range, the main focus of development has been to drastically curb wheel spin at the initial stage by enhancing the accuracy of clutch transfer torque estimation and raising the performance of the partial clutch engagement start. For clutches with the conventional structure, both the clamp load and the coefficient of friction μ were indeterminate factors, making it a considerable challenge to estimate torque. The DPC with its control of clutch transfer torque by means of hydraulic pressure was developed in 2005, but the hardware and the control were integrated as one, so that assuring the requisite pressure control performance became an important subject for development as had been experienced in the case of the gear box development. This paper introduces the DPC pressure control system.

2. Development Goals

In the development of DPC, the adoption of a device that uses hydraulic pressure to determine the clamp load increased the accuracy of estimation of transfer torque. However, the relationship between the hydraulic pressure and the length the piston travels in the action from the fully disengaged state to the bite point where pressure

against the disk begins is different from that from the bite point to full engagement. As a result, pressure controllability became an issue. Controllability was also diminished by the hydraulic pressure vibration resulting from sticking and slipping of the piston that occur when the hydraulic pressure is raised from the fully disengaged state. In standing starts, speedy and accurate delivery of the amount of torque that results in the tires exercising the maximum gripping force is sought. The clutch response and convergence that will transfer the necessary torque are important, and the following objectives were defined regarding the controllability of the hydraulic pressure:

- (1) Hydraulic pressure response of 30 ms or less up to the target value
- (2) Hydraulic pressure overshoot of 1 bar or less

3. Overview of the DPC

Figure 1 shows the DPC configuration. The force applied to the piston is conveyed to the pusher in a lever structure with the fulcrum ring as the fulcrum and the pressure plate as the point of action. Thus the clamp load is transferred to the clutch disk.

Consequently, the DPC differs from the conventional pull clutch in that the clamp load can be directly controlled using hydraulic pressure.

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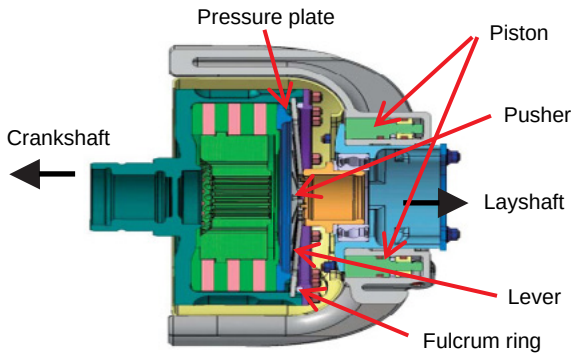


Fig. 1 Configuration of direct push clutch

4. Establishing Pressure Controllability of the DPC

4.1. Issues in Pressure Controllability of the DPC

Figure 2 shows the DPC stroke and hydraulic pressure characteristics as well as the clutch state, which are factors diminishing its pressure controllability.

In Fig. 2, the area (A) extends from the state of full clutch disengagement to the bite point where the clutch begins to engage. The amount of actuator movement is large relative to the amount of change in the hydraulic pressure.

When the wear of the clutch disk progresses, the distance that the pusher moves from the fully disengaged position until it hits the pressure plate grows longer. The area (A) in the figure expands to become (A').

An area like this became a dead zone when under pressure control, interfering with the response, and not only did it diminish the effectiveness of gearshift, standing start, anti-stall, and other such types of control that require rapid clutch control, but it was unable to satisfy the limit on response time (50 ms) before reaching the target value as defined under FIA regulations. Therefore, this was very likely to result in a violation of the regulations.

In order to address these issues and achieve the target value explained earlier, the following types of measures were taken with regard to DPC pressure control.

4.2. Substance of DPC Pressure Control

4.2.1. Variable P-term gain, variable low-pass filter

In order to achieve the enhanced hydraulic pressure response described earlier, the variable P-term gain and variable low-pass filter (LPF) shown in the conceptual diagram in Fig. 3 were employed. This gain and LPF cutoff frequency are hydraulic pressure variables, and the aim was to raise the P-term and LPF cutoff frequency in transient states of the low-response area in the dead zone in order to achieve better hydraulic pressure response.

4.2.2. Simple state predictive P-term control

With variable P-term gain and LPF, the switching hydraulic pressure for the gain and cutoff frequency

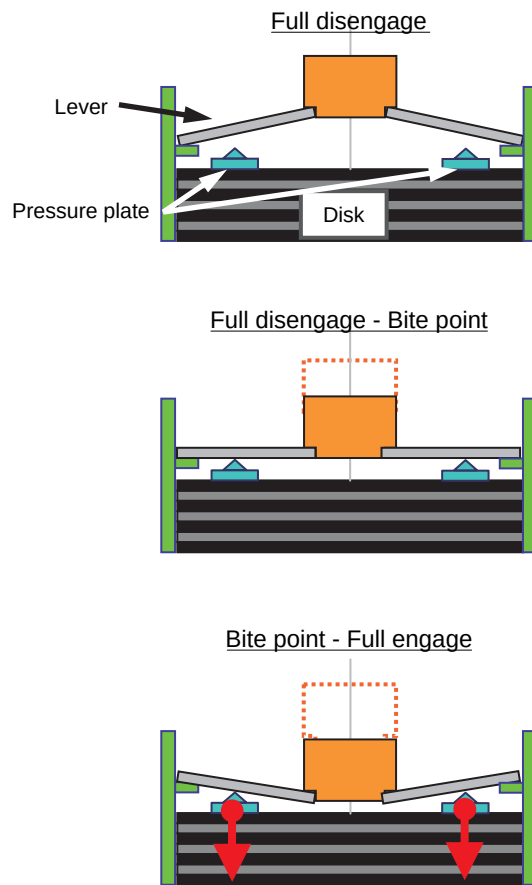
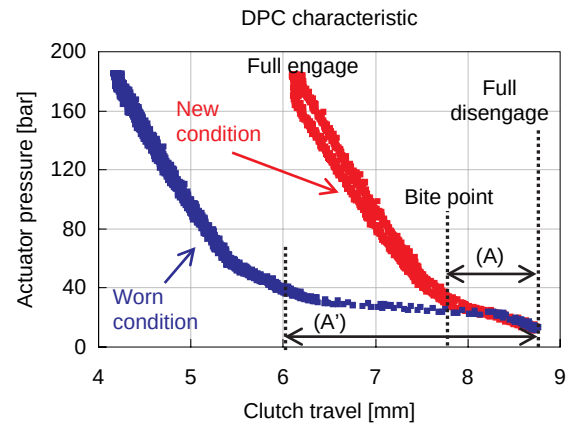


Fig. 2 DPC pressure-stroke characteristic

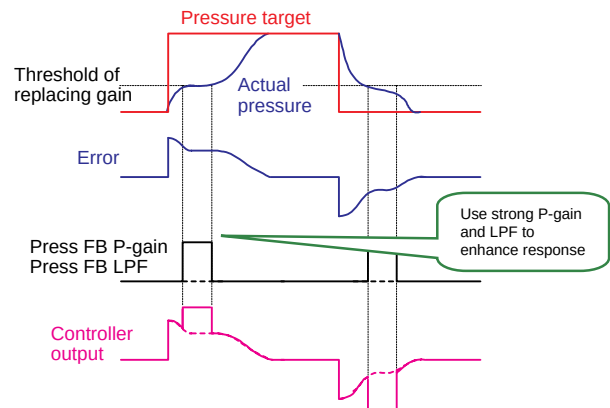


Fig. 3 Image of variable P control

depends on the hydraulic pressure in the dead zone. As explained earlier, the hydraulic pressure in the dead zone changes according to the wear of the clutch, and robustness could not be assured by variable control alone.

Therefore, the hydraulic pressure that follows after the time of non-response by hydraulic pressure (waste time) was estimated from the slope. Predictive control was implemented as shown below in order to use this predicted value as feedback to raise the P-term gain while reducing overshooting. Figure 4 shows the conceptual diagram.

- (1) The time of non-response by hydraulic pressure is defined as the specified time. The hydraulic pressure following the specified time is estimated from the slope of the current hydraulic pressure.
- (2) The amount of operation is calculated according to the difference between the predicted value and the target value.
- (3) If the predicted value is greater than the target and the current value is smaller than the target, then the difference is considered to be zero and the amount of operation zero.
- (4) If the predicted value is greater than the target and the current value is also greater than the target, then the amount of operation is calculated according to whichever has the least difference relative to the target.

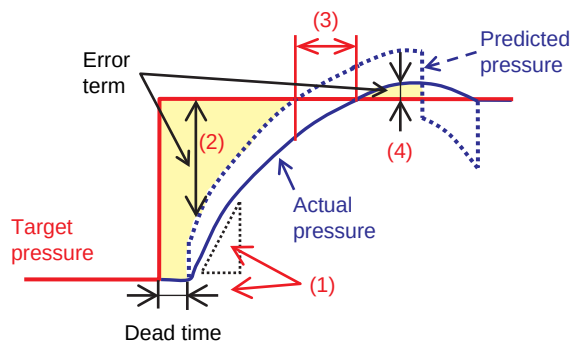


Fig. 4 Predictive P-term control

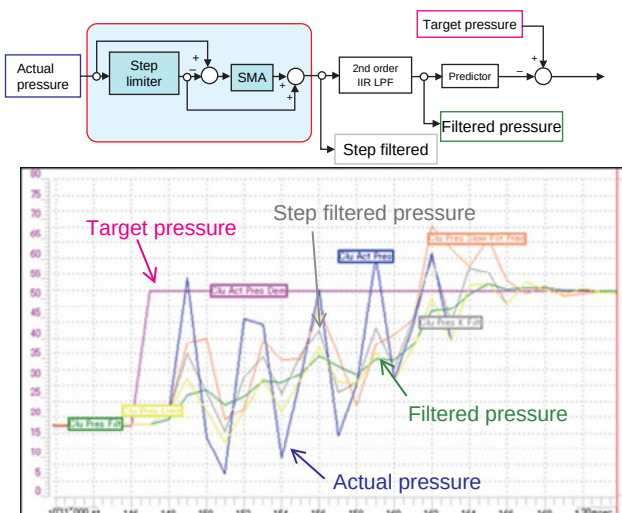


Fig. 5 Step limit moving average

4.2.3. Step limit moving average

Limits were imposed on the size of the steps in actual clutch pressure, taking the effective response frequency of the actual hardware into account. This limited the delay and resulted in the occurrence of significant damping to occur. This damped the vibration generated by sticking and slipping of the piston. Figure 5 shows the conceptual diagram.

4.2.4. Additive I-term control

Overshooting and undershooting were determined by the deviation from the target value and the slope of the hydraulic pressure, and the I-term was converted into a step form to increase the convergence. Figure 6 shows the conceptual diagram.

The filter value discussed earlier is fed back to the integral control. When this filter value deviates from the target value by more than a certain figure and the slope remains small for a set period of time, it is determined to be overshooting. The I-term is then reduced regardless of the feedback so that convergence with the target value will occur more quickly.

4.3. Results

Figure 7 shows the pressure controller that was

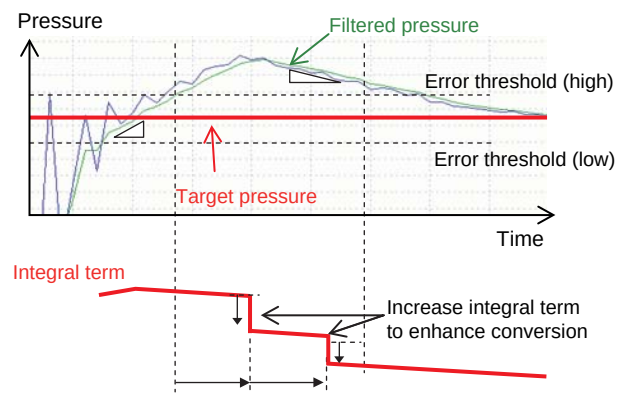


Fig. 6 Additive I-Term control

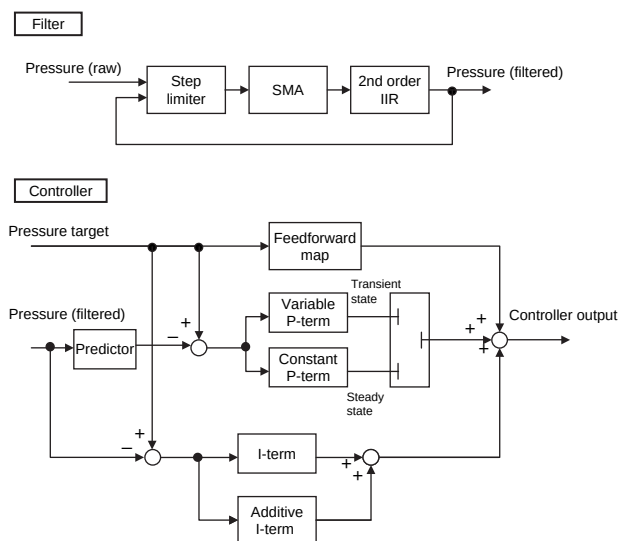
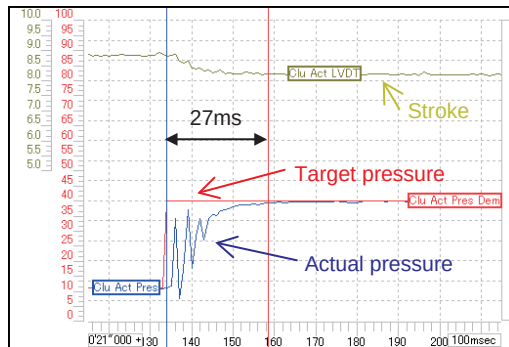


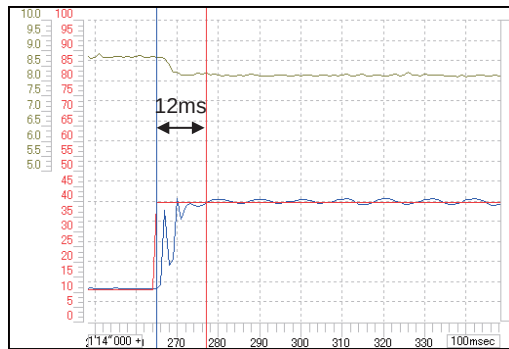
Fig. 7 Configuration of DPC pressure controller

ultimately realized.

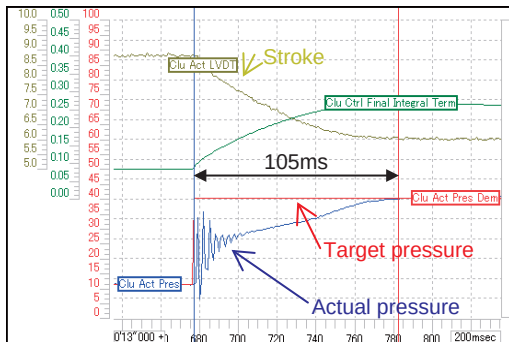
Figure 8 shows a comparison between standard PID control and the control described above. The comparison was carried out during step response assuming a standing start, when accuracy and speed of hydraulic pressure



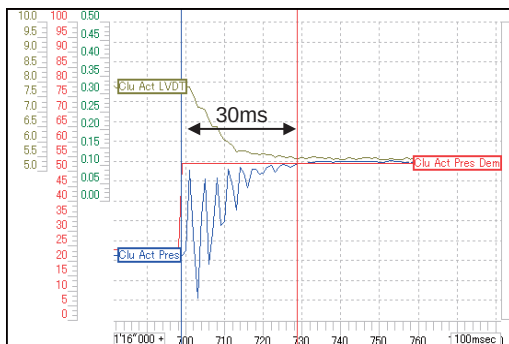
(a) Standard PID (no wear)



(b) New control (no wear)



(c) Standard PID (3.0 mm wear)



(d) New control (3.0 mm wear)

Fig. 8 Comparison of pressure control

response are required. Comparison was also carried out with 3.0 mm of clutch wear, which corresponds to the amount of wear from a single race, since response can be assumed to diminish when clutch wear results in an expanded dead zone.

The hydraulic pressure response time was successfully reduced, without overshooting, by 44% when there was no wear and by 71% when there was wear. Even when wear had occurred, the diminishment of standing start performance was kept to a minimum.

5. Conclusion

The establishment of pressure control of the DPC enabled an increase in the accuracy of clamp load (transfer torque) control.

The DPC was employed in racing from 2006, and the implementation of a partial clutch engagement start throughout the entirety of the standing start enabled realization of slip starts without any torque feedback control. This yielded the advantage of a maximum 0.46-second reduction in 0-100 km/h acceleration (an 11-m advantage in terms of distance).

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