Development of Traction Control Systems for Formula One

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ABSTRACT

Efforts have been made toward the development of traction control that controls the amount of tire slip at a level that exceeds the abilities of Formula One drivers and enhances turning acceleration performance, and the development of overrun control that is intended to prevent rear tire lockup by using engine torque when the brakes are being applied. Numerous control systems have been applied in racing based on modern control theories, including high-precision engine speed control and wheel speed feedback control, which is extremely challenging in Formula One, where driving at the limit is the norm.

Launch control, which is control applied in the start of a race, has also realized complete direct control of clutch transfer torque. Development has proceeded on start assist systems that can enhance start performance with reliable repeatability while continuing to satisfy regulations even after prohibition of automatic clutch control. The direct push clutch and other new technologies have been actively adopted.

1. Introduction

Traction control was extremely important to Formula One activities of the third era, which started with the Australian Grand Prix in 2000.

The Federation Internationale de l’Automobile (FIA) had basically prohibited traction control until the Spanish Grand Prix in 2001. The FIA changed its stance at that time, completely lifted the ban, and development of traction control started.

Vehicle dynamic performance continued to evolve even while restrictions were subsequently placed on tire performance. In this context, the optimal control of traction and the maximum employment of tire capabilities occupied crucial positions in the evolution of vehicle dynamic performance.

In 2008, the FIA unified control specifications by making it obligatory to install a common electronic control unit (ECU). Even after control systems that could be used as driver aids were completely eliminated, there was continuing high demand for control systems to make it easier for drivers to manage torque during cornering.

Given these circumstances, development of traction control continued largely throughout the period of third-era activity.

This article describes the history and development technology of various systems, including traction control (TC) in the acceleration range, the development of methods for setting traction that were implemented by throttle pedal input after TC was prohibited, overrun control (OC) in the deceleration range, launch control (LC) that enables fully automatic launching with the press of a single button in the launch range, and the race start system (RS) presupposing manual clutch operation that was developed after 2004 when LC was prohibited.

2. Development Goals

The purpose of traction control in Formula One racing is to assist the drivers so that they can drive the car as fast as possible with repeatability. It is necessary with racing cars in general, however, not only to bring out their performance limits, but also to sustain that unstable state. With mass-production vehicles, it is a requirement of similar control systems that, for safety reasons, they keep the vehicle inside the limit range. This difference in what the two types of system are intended to achieve is also the difference in the performance they are required to produce.

Formula One cars and mass-production vehicles also differ greatly in the hardware that is subjected to control. Formula One cars are, of course, light in weight, in the 600 kg range, and their drivetrains are built to have the lowest possible rotational inertia. Meanwhile, they have engine power, braking power, and tire grip force that are several times greater, as absolute values, than in mass-production vehicles.

For the above two reasons, Formula One cars have

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much more sophisticated traction control than mass-production vehicles. They demand highly precise, highly responsive systems. Generally speaking, bringing out the performance limits of a vehicle will mean making the most of the performance of its tires, which are the only points of contact with the ground. Control of Formula One power plant systems is no exception in this. While effectively transferring the limited engine power to the tires, it must never exceed the tires' limits. The control methods used can be generally classified into two types: one is the method for directly controlling wheel torque, and the other is the method for controlling the amount of tire slip. Another, indirect method for accomplishing this is to control just the engine torque or the engine speed. Drivetrain components have rotational inertia, backlash, and twist. Strictly speaking, therefore, control by wheel criteria and control by engine criteria are different, and the various methods are employed according to the application, the degree of ease or otherwise of control, and the advantages or disadvantages involved.

Figure 1 shows the history of the three systems introduced below. Figure 2 shows a configuration diagram of the control systems.

2.1. Aims of Traction Control (TC)

The aims of TC in Formula One cars are to control traction at a level surpassing the skill of the driver and to limit the amount of tire slip appropriately so as to enhance straight-line acceleration performance and turning acceleration performance. The TC system is none other than engine power control, but what it is ultimately intended to control is the amount of tire slip.

The degree of challenge represented by control, given the precision required in achieving the desired amount of slip and response, depends on the delay in generating torque by the engine, which serves as the actuator, and the existence of torque transfer delay due to backlash and twist in the component parts of the drivetrain, which is situated between the engine and the tires. TC is further required to assure robust performance with respect to disturbances from rough road surfaces, curbs, and the like.

2.2. Aims of Overrun Control (OC)

OC in Formula One cars is a system for control of engine torque during braking in order to prevent rear tire lockup and to optimize the amount of tire slip.

Active brake balance control and antilock braking system (ABS) implemented by braking systems are forbidden in Formula One racing. However, the enormous tire grip force and the maximum deceleration of as much as 5 G realized by carbon brakes result in a large amount of front and rear load shift, so that the optimum front and rear brake force balance changes from moment to moment. OC does more than simply adjust the engine braking force. When circumstances make it necessary, even during braking, it produces torque all the way to the drive side so that front and rear brake force distribution are optimized while producing performance that, although limited to the rear tires, is intended to be similar to ABS.

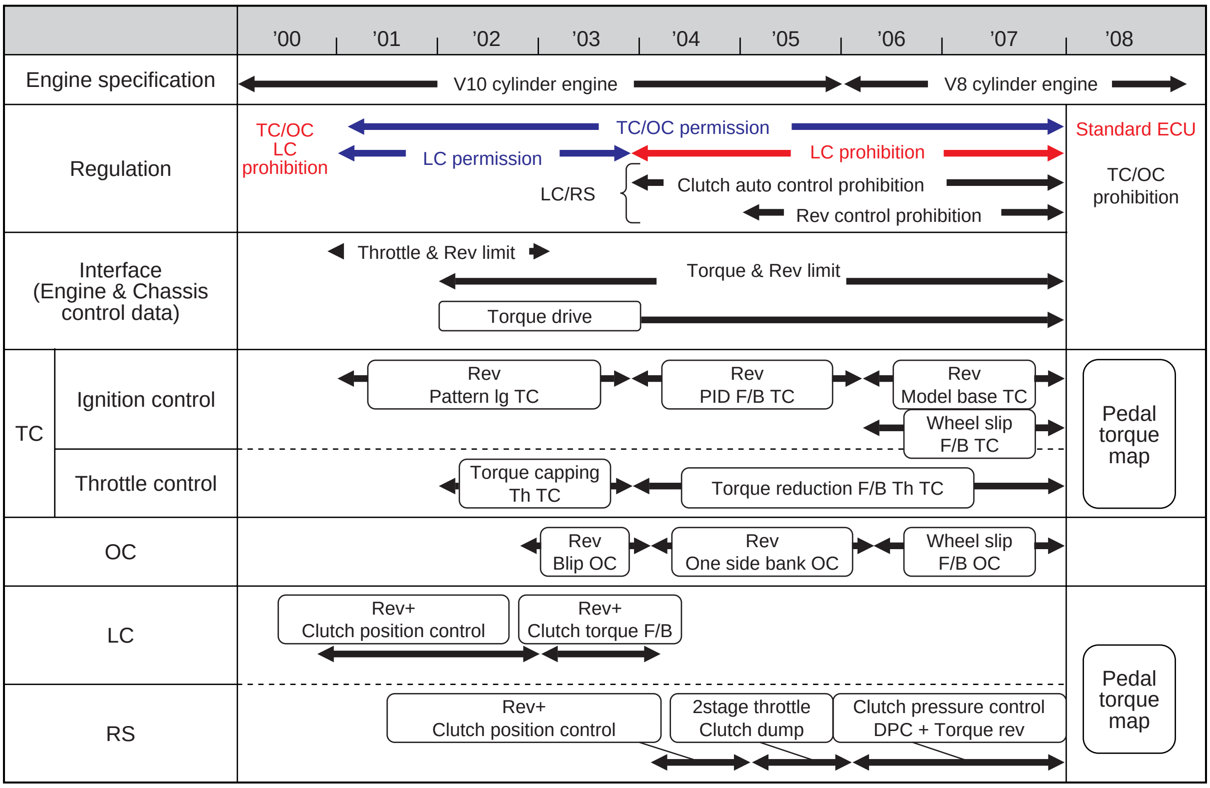

Fig. 1 History of control system development

The result is that drivers can feel safe about pressing down hard on the brake pedal even under conditions with bumps or other such disturbances. When turning in to a corner, the amount of rear tire slip can be limited so as to obtain an oversteering reduction effect.

OC has many of its challenging aspects of control in common with TC. One major difference, however, is that the primary causal source of tire slip is the braking force, while the role played by engine torque is just a fraction of that. Consequently, the margin of control available to OC is necessarily limited.

2.3. Aims of Launch Control (LC) and the Race Start System (RS)

LC is a system that automatically implements Formula One race starting by integrated control of engine torque, engine speed, and clutch engagement amount. If drivers activate the system according to a determined procedure, all that remains is for them to push a single button. LC then appropriately controls the amount of rear tire slip and realizes the maximum acceleration from zero to 100 km/h. (LC was prohibited by Formula One regulations in 2004.)

On the other hand, RS could be termed the driver's manual race start assistance system that followed the prohibition of LC. Development of standing start control within the range permitted by regulations also took place following the prohibition of LC, and this has been a battle of wits among the teams and with the FIA since 2004. The aim of RS is to realize the best standing start performance, with repeatability, by arranging it so that the driver only has to follow a predetermined standing start procedure (throttle pedal operation, clutch paddle operation) to have the proper settings for engine and clutch control be selected by engineers to match with the coefficient of friction µ between the road surface and the tires, as well as with the meteorological conditions.

The two challenges that LC and RS face in common can be summarized as control of clutch transfer torque with a high level of precision and response, and cooperative control of the engine and clutch.

3. Development of Traction Control (TC)

In 2001, the use of TC was explicitly permitted in the regulations, and it was used in racing from that point to 2007. In 2008, TC again came under complete prohibition when the FIA instituted the requirement for a common ECU. This section describes the development of TC together with the measures used to enhance drivability following the prohibition of TC.

3.1. TC Development

TC development for third-era Formula One activities can generally be classified under one or the other of the following two headings:

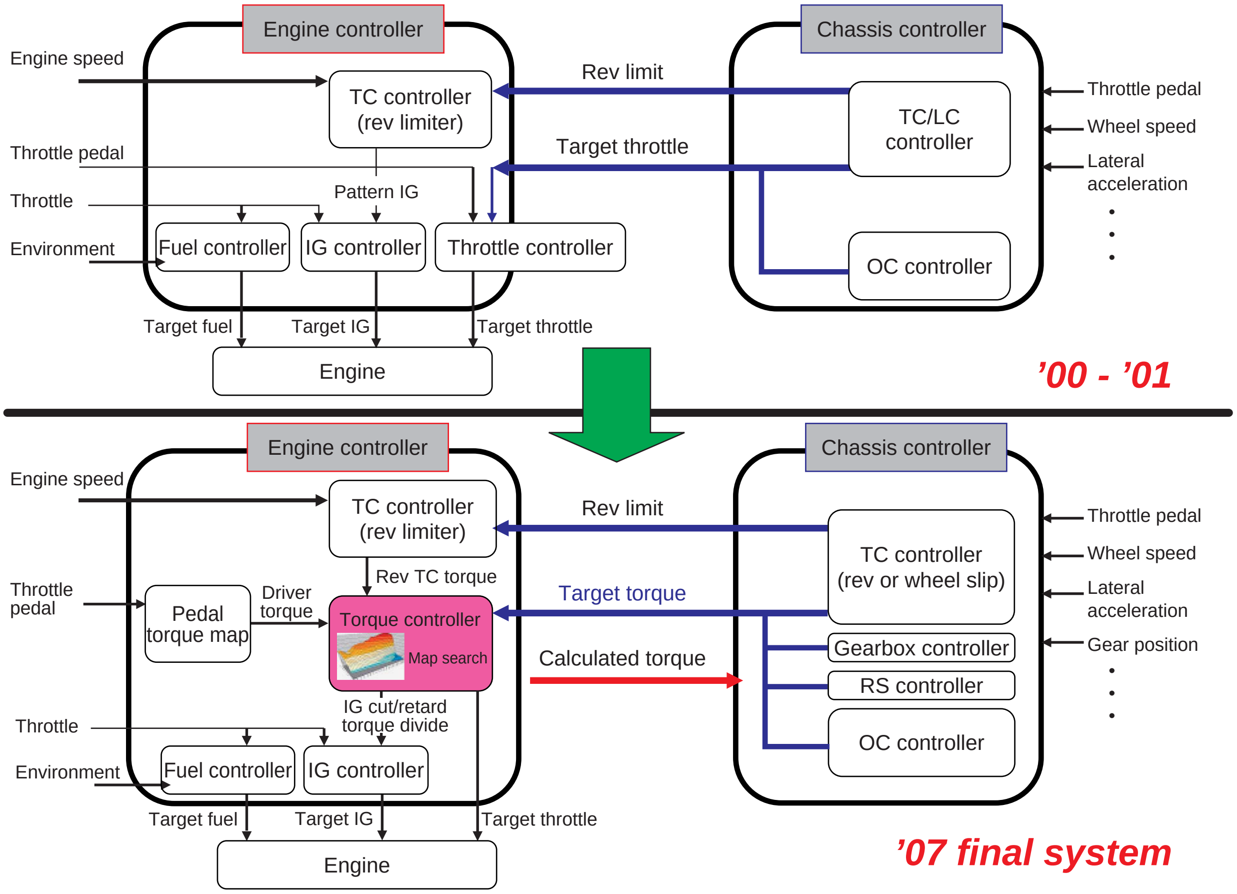

Fig. 2 Configuration of control system

- Trackability of target tire slip
- Determination of target tire slip that yields maximum acceleration performance

At the initial stage of development, the target tire slip was not very trackable, and some instances were observed of factors that disrupted vehicle behavior. Such factors included insufficient toughness with regard to disturbances such as rough road surfaces and curbs, and inadequate control due to insufficient consideration of the transfer properties involved from the engine target torque to the tire traction force. The TC development effort in the beginning and middle periods of the third era sought to resolve these matters primarily by enhancing the trackability of target tire slip, and development work focused on a controller for this purpose.

3.1.1. Enhancement of trackability of target tire slip

Methods for controlling tire slip include direct methods of using actual slip as a feedback parameter for target tire slip, and indirect methods of calculating a target engine speed from the target tire slip and reduction ratio, and then using the engine speed as a feedback (F/B) parameter (Fig. 3).

The engine speed control TC (Rev TC) that had been in use from the start of the third era corresponds to the latter method. The controller of those days used the deviation from the target engine speed as a basis for specifying a predetermined ignition pattern [Pattern Ignition (IG)]. It did not implement control using the engine torque. In the subsequent course of creating various different drivetrain control systems, engine torque was taken as the common parameter, and consolidating it in the torque interface led to enhanced precision of the control system and expansion of the degrees of freedom (introduction of torque drive system).

Rev TC subsequently had the convergence and torque linearity enhanced by the adoption of PID F/B control. The further application of modern control theory that takes engine characteristics into account enhanced convergence still more, while the optimization of the torque control amount also heightened toughness with respect to disturbance.

Figure 4 shows the actual track data for Rev TC. It can be seen how the target tire slip is tracked by controlling the engine speed. Rev TC has the advantages of not being susceptible to system delays, and of fast response. On the other hand, it does not allow independent control using rear left or rear right tire slip, and has disadvantages coping with curbs and the like.

In parallel with development of the Rev TC, development of wheel slip feedback TC (W/S F/B TC) also took place. This is a method of control that uses the tire slip as an F/B parameter. This allows traction control to use only favorable side of rear wheels or both during cornering, and it increases flexibility of the settings. It has a robustness with regard to the input of disturbances from the road surface that was established in advance through simulations, and it also enabled limitation of excessive torque reductions.

Figure 5 shows the actual track data for W/S F/B TC. The wheel torque is subject to finely tuned control with respect to changing load on the rear tires (rear inner and outer tire Fz), and the tire slip is retained in the TC slip target value.

In the third era, the above two control methods (Rev F/B TC and W/S F/B TC) were employed differently according to the circumstances. Rev TC was mainly employed with low speed gear (in racing starts and when building up speed coming out of a low speed corner) or on wet road surfaces, when the traction is large against reaction force from road surface and the F/B system requires high response and high resolution. W/S F/B TC, which allows more flexible control, was employed mainly for driving in middle and high speed gears and under conditions when disturbances such as curbs could have an influence.

Important points of TC F/B systems include not only the consideration of system delay and robustness with respect to disturbances, but also the fact that, in the interest of drivability, it limits excessive ignition control fluctuations that ignore the will of the driver, and that, in the interest of fuel economy, it limits the amount of fuel injected. Throttle TC (Th TC) implements control

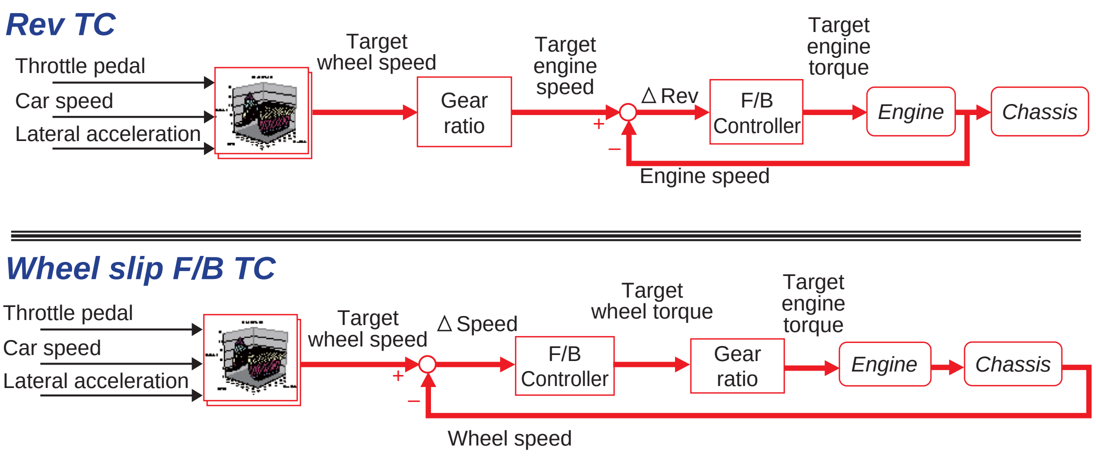

Fig. 3 Feedback control system in TC

for the above purposes. It continued to make enhancements following from Torque capping Th TC, which was close to the sequence control employed in initial development, and ultimately was able to employ control by a torque reduction F/B system that realized a fuel economy increase of approximately 3% and ignition control that provides a stable, small amount of fuel injection even during the input of disturbances.

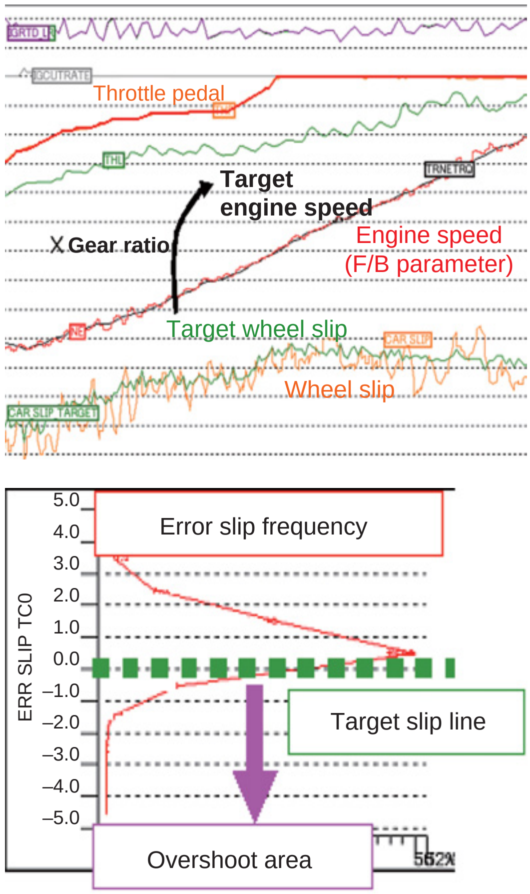

Fig. 4 Rev TC track data

3.1.2. Calculation of target tire slip

Enhancement of feedback control systems came to assure stable trackability of target slip, and TC development shifted to ascertaining optimal target slip. Starting in the summer of 2006, attempts were made to use the car model and tire model in the ECU together with data from the various types of sensors to estimate the vehicle state quantities, and then to calculate target slip through an integrated control that also included diff control (electronic limited-slip differential gear control). The method that was finally adopted, however, was to store multiple maps of target slip based on driver throttle pedal positions and vehicle lateral G forces.

The above methods adopted from the beginning of the third era had the advantage of enabling settings that responded to the feelings of drivers and reflected their will. On the other hand, it is crucial to be able to determine the settings that are appropriate for the corners, road surface, and tire conditions of each individual circuit, and that further support the skills and predilections of the driver. The challenges with respect to the time and labor involved and the method’s adaptability were never fully resolved.

3.2. Development Following TC Prohibition

The change of regulations in 2008 placed control of overall vehicle systems, including the engine and gearbox, in the ECU manufactured by McLaren Electronic Systems, which would become the common FIA ECU. TC and OC were prohibited. As a result, lack of traction during cornering and poor drivability emerged as issues. It therefore became necessary to enhance both hardware and software aspects of the systems.

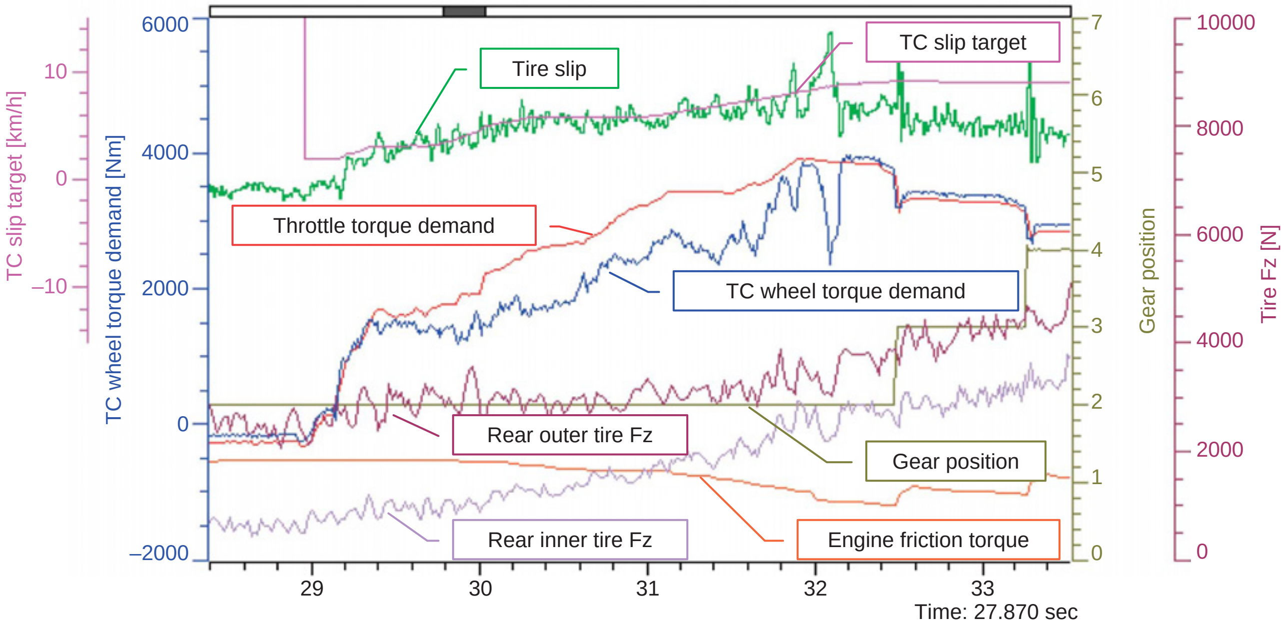

Fig. 5 Wheel slip feedback TC track data

Development of powertrain systems proceeded with a focus on torque accuracy. The reason for doing so was that when TC was in effect, torque values other than high magnitude torque errors were absorbed by the feedback system so that weaknesses tended not to come out in the open. The prohibition of TC, however, heightened the requirement for torque accuracy, including transient engine torque characteristics.

Furthermore, the method for defining the target torque against the throttle pedal could not depend only on driver feeling. It became necessary to establish setup methods to substitute for TC.

3.2.1. Torque accuracy

Important points for the powertrain from the perspective of drivability include:

(1) Ability to predict the driving torque of throttle pedal operation by the driver;
(2) Linear torque characteristics of pedal operation; and
(3) High torque response.

Maintaining the vehicle stability limit during a turn when any one of these factors is missing becomes a challenge. With regard to items (2) and (3), solutions are likely to differ according to driver characteristics and predilections.

Engine development sought to enhance the air intake and the exhaust and fuel systems. This yielded enhancement of combustion stability under low load (under rich air/fuel ratio conditions), limited variation in transient throttle opening and closing, and promoted enhancement of torque response and torque repeatability. Map measurements of various kinds made with a view to combustion stability as well as data settings made with consideration of usage conditions on the circuit also contributed to increased torque accuracy and enhanced drivability.

3.2.2. Definition of target torque

With feedback control for TC being prohibited, the setting of target torque for the throttle pedal becomes an item with significant effects on drivability. Drivers operate the throttle pedal to control the amount of tire slip when coming back up to speed out of a corner, and one thing that is crucial at this point, in addition to assuring the resolution and linearity of the driving torque against throttle pedal operation, is implementing torque reduction when excessive slipping occurs. During the 2008 season, the settings were optimized in light of the traction utilization ranges on the low-speed corners at every circuit in order to realize all of the factors noted above. At that time, circuit simulations were also carried out in advance in order to heighten the efficiency of the process leading to optimization.

3.3. Establishment of Evaluation Items and Test Bench Evaluation Methods

The ability to quantitatively analyze the influences that power plant torque behavior and vehicle settings have on TC controllability and drivability is a matter of importance in performing every kind of development. Evaluation items were therefore examined together with methods of test bench evaluation.

Since the project was frozen in mid-development, some parts of activities such as evaluation of the stability of a vehicle as a whole that relied on driver comments still remained. In powertrain evaluation, however, and particularly in evaluation of torque response characteristics and accuracy, quantitative benchmarks and test methods can be established. Benchmarks and methods can be checked in advance before running on the circuit, and front-loaded development can now be implemented.

4. Development of Overrun Control (OC)

4.1. Engine Rev Control OC

The development of OC began at the suggestion of a Honda team member in the autumn of 2001, during the BAR-Honda period. It became a full-fledged development item in 2002, and progressed to the point of being adopted for use in racing.

This was initially a system to control the handover of the lower engine speed limit (the opposite of the rev limit), in accordance with the feed forward throttle position demand and tire slip limit, from the chassis control unit (Pi-Sigma MCU) to the engine control unit (ATHENA ECU). From the autumn of 2002, as with TC, the throttle position demand handed over between the MCU and ECU was replaced by torque demand. Subsequently, there were requests from the drivers for engine braking and antilock performance, which are mutually contradictory, and in 2003, throttle torque demand was switched over to an on-demand system (Blip OC) that responded to engine speed deviation.

Up to the start of 2006, however, the drivers complained of a pushing feeling and other issues in the OC caused by a phase delay in the control. Its use was therefore limited. Changes went on being made in methods of setting target values, and further tuning continued, but the rear tire antilocking performance that was the real purpose of OC remained incomplete.

4.2. Wheel Slip Feedback OC

Wheel slip feedback TC was adopted for racing at the beginning of 2006, and after several races, a completely identical control algorithm was also applied to OC. This was not conventional engine speed control, but instead allowed the use of rear wheel speed as a source for direct feedback. Consequently, it allowed fast, finely calibrated control of engine torque with respect to disturbances from the road surface, fluctuations in brake torque, and other such factors.

Figure 6 shows a view of control in OC. The OC wheel torque demand will have risen and prevented lockup of the rear tires long before the tire slip amount reaches the limit slip amount (OC slip target), and when the slip comes under control, the torque goes down (each torque value is benchmarked to the wheel torque). The throttle is opened according to the OC torque demand with an added torque margin. This enhanced the antilock performance and received favorable comment from the drivers.

This new OC was based on wheel torque control, and therefore was easily capable of adjusting the engine braking torque simply by feed forward control. Since the necessary amount of engine braking differs according to the driving style, it is basically intended to provide an amount suited to the driver's predilections. However, considering that it tends not to be affected by changes in the gear ratio, as well as its utility in eliminating stepped changes in torque during gear shifts, it was decided to implement control by a map of wheel torque demand relative to car speed. The value given to simplicity and ease of tuning in the Formula One context was another reason for this choice. The data from the 41-second point to the vicinity of the 41.4-second point in Fig. 6 shows this OC feed forward torque demand in operation.

During braking, the engine would fire at a higher frequency, so that the rise in exhaust temperature in the exhaust pipes was initially an issue in development. This was addressed by firing only one bank when torque was adequate to the demand, and using the left and right banks in alternation every time engine braking was used.

The use of an FIA-common ECU became obligatory in the regulations starting in 2008, and TC and OC were prohibited. Driver complaints, however, centered more on their being unable to use OC than TC. This is because controlling engine torque during braking of the kind applied in OC is challenging even with the skills possessed by Formula One drivers.

5. Development of Launch Control (LC) and the Race Start System (RS)

As of the end of 2008, it was thought that the RS control method using the FIA-common ECU would continue to be used by ex-Honda Racing Formula One Team even in 2009 and beyond. The discussion here, therefore, will be limited to the LC of 2003 and earlier, and the RS used after it up to 2007.

5.1. Clutch Position Control LC

The development of LC started in 2001, the same year that the ban on TC was lifted. Up to 2002, one issue faced in LC was the controllability of the initial tire slip from immediately after the standing start (launch) until the clutch is fully engaged. This was because position control of the pull clutch of that time resulted in large changes in clamp load due to the amount of disk wear and thermal expansion that would occur even if the clutch were held at the same position in a partially engaged state. The changing clamp load meant that the transfer torque would become unstable. Originally, such changing factors should have been absorbed by the tire slip feedback control portion of the system, but the processing cycle of systems at that time was too slow to provide adequate compensation capacity.

5.2. Clutch Torque Control LC

In 2003, in order to resolve the above issues, a non-contact magnetostrictive torque sensor was installed on the input shaft located between the clutch and the gearbox, and a system for direct feedback control of clutch transfer torque was developed. This clutch torque control had practically no delay compared with TC controlling engines that experience a torque generation delay time of 10 msec or more. It therefore provided an edge in tire slip control.

The realization of direct control of transfer torque brought the capability to produce feed forward torque matched to the coefficient of friction μ between the road surface and the tire at the starting instant. Once the vehicle started moving, it could switch over to slip feedback control for the rear tires, and the amount of tire slip could be controlled so as to maximize acceleration. In order to accomplish this switchover as quickly as possible, a dedicated arithmetic processing unit was

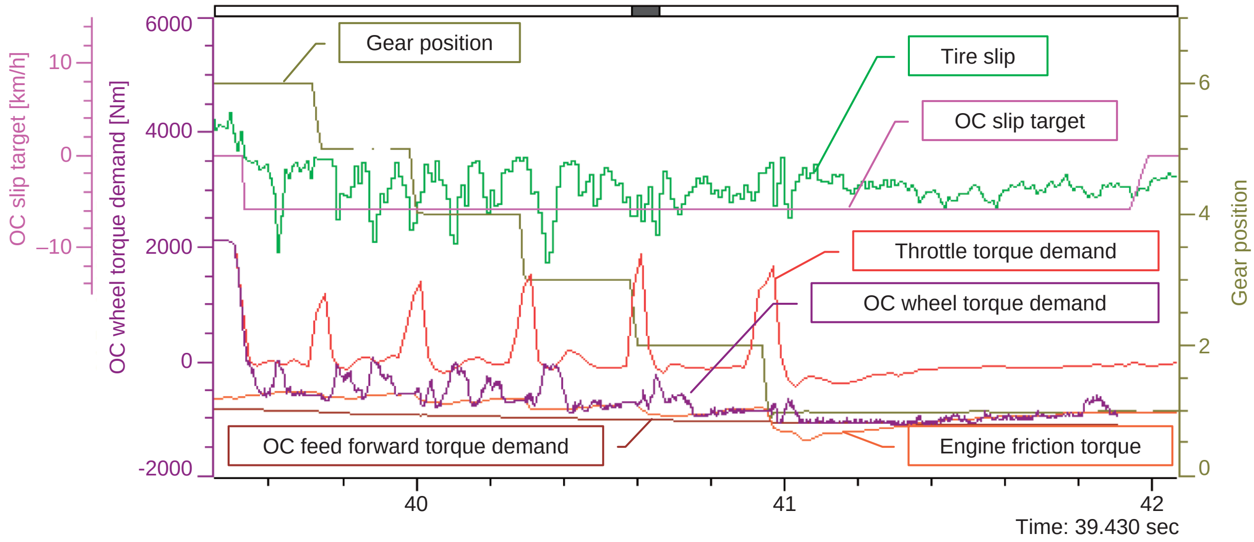

Fig. 6 Wheel slip feedback OC track data

installed to detect extremely low wheel speeds. This was done because slip control of tires when they are beginning to roll was a major contributing factor to victory from the start of a race.

With LC, the speed of the driver's reflexes also makes a significant contribution. Actual measurements were therefore made of the brake release system, button operation, paddle operation, and other such systems for each driver, and the pattern with the smallest delay was adopted. In the case of an outstanding driver, there is a reaction time of less than 0.2 second from seeing the starting signal to taking action on the controls. If the driver fails to start, then a Formula One car with acceleration performance taking it from zero to 100 km/h in under three seconds does not, in practical terms, allow for recovery even with an outstanding control system.

Another factor that determines the results of a Formula One race start is tire temperature management. The traction performance of a tire becomes optimal in the vicinity of 80-90°C, as no doubt every team was aware, and very few teams were able to manage this in an actual race start at that time. BAR-Honda finally managed to apply a tire surface temperature sensor in racing from the time of the British Grand Prix in 2003. This showed for the first time how abnormally low their tire temperatures were on the starting grid, and the team was having to play catch-up on this and related operational matters. When road surface conditions were good and tire temperatures were optimal, LC had a very real punch that could provide acceleration from zero to 100 km/h in under 2.6 seconds, and BAR-Honda was probably ahead of the others in this regard. There were other teams, however, that took the lead with a rearward weight distribution package, which was advantageous in starts, or with their knowhow on using tires, and it was regrettable that the BAR-Honda team's starting performance did not raise the team's overall strength into the top rank.

5.3. Partial Clutch Engagement RS with Pull Clutch Position Control

In 2004, the FIA entered on a program of eliminating driver aid systems, starting with the immediate prohibition of LC. The regulations required clutch control to move the clutch to a target position, or to exert a target pressure on the clutch, determined by the driver's manual operation. It was too great a challenge to explicitly state the position with regard to TC in the regulations, and so TC operation following full clutch engagement was still permitted. BAR-Honda sought to simplify the driver's clutch operations by devising a special clutch paddle map, as shown in Fig. 7, and combining it with a double paddle system in which clutch paddles were attached on either side of the reverse face of the steering wheel, as shown in Fig. 8, so that they would be in standby at different positions and would be released at different times.

The paddle on the disengagement side of the two paddles would serve as the actual paddle demand value. Therefore, the portions marked with heavier lines in Fig. 8 are the actual clutch position demands. According to this procedure, the driver shifts from the fully disengaged state to that of partial clutch engagement, and then to full engagement, enabling a sequence of operations that could be carried out rapidly and accurately. In a state of partial clutch engagement, there will be a fixed target torque in accordance with the horizontal parts of the paddle map. This makes use of the fact that at the extremely low speed in the initial phase of acceleration, the maximum driving torque of a Formula One car is close to being a certain fixed value (Fig. 10).

The ECU was equipped in advance with various internal paddle maps on which the horizontal portions represented several different torque target values. The final selection of the map to be used for the actual race start was determined several tens of seconds before the start by a control engineer who was standing by in the pit, and the driver was instructed by radio. It was done this way because the start was practiced on the actual grid at the beginning of the formation lap, and the coefficient of friction μ between the road surface and the tires was estimated from telemetry data.

Regardless of ingenious measures of this kind, the system of that time, whereby a pull clutch was subjected to position control, did not manage to realize transfer torque for the launch as intended. This situation persisted, caused by the state of disk wear, changing temperatures, and the like, much as was the case with the issues faced by LC up to 2002.

5.4. Clutch Dump RS

A super-short first gear was introduced and RS was switched over to a clutch dump procedure, starting from the Japanese Grand Prix in the closing stage of 2004,

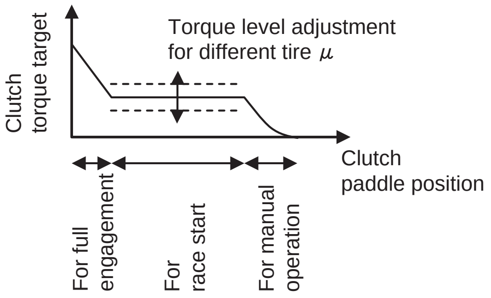

Fig. 7 Clutch paddle map

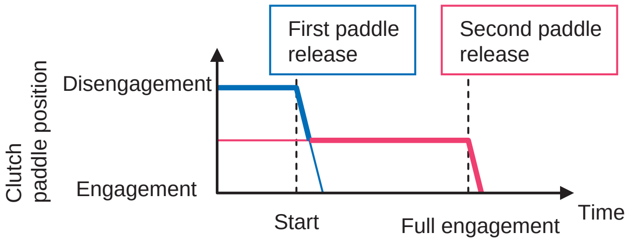

Fig. 8 Double paddle procedure

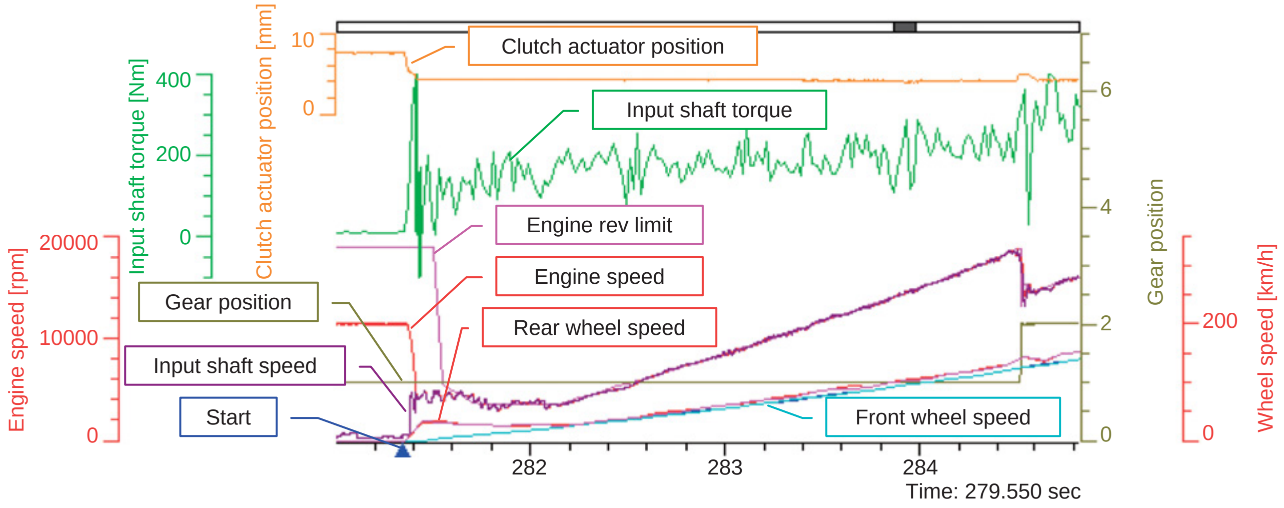

Fig. 9 Clutch dump RS track data (2005)

in order to resolve the weakness of pull clutch position control. This method involved holding the engine in ready state at the rather high speed of 11000 rpm or more, fully engaging the clutch when the clutch paddle was released immediately after racing starts, and thus forcing the wheel spin to be reduced by applying the engine rev limitation for extremely low speed, 5000 rpm or less. Figure 9 shows actual track data for clutch dump RS as it was in 2005.

Although the wheel spin prevents the initial acceleration from rising as high as when a partial clutch engagement start succeeds and there is no wheel spin, this method realized highly repeatable starts because the amount of wheel spin generated was the same every time. The only indeterminate factors in starting were the timing for release of the clutch paddle and the tire temperatures. There were primarily two challenging aspects of control. One was that the engine speed had to be kept at a low speed, even lower than its idling speed, even though for just one second or less, and satisfactory ignition conditions and hydraulic pressure had to be assured during that time. The other aspect was that the regulations specified that the target clutch position (or the hydraulic pressure) determined by the clutch paddle and the actual clutch position (or the hydraulic pressure) are allowed no more than a 50 msec delay. If full engagement occurs instantaneously according to the paddle demand, the shock torque generated in the drivetrain would have easily exceeded the maximum allowable torque for gearboxes of that time. That was why the clutch control was tuned with great care with the order of several milliseconds so that the maximum transfer torque could be reduced as much as possible within the allowed 50 msec time period.

There were no regulations relating to engine rev limit control in 2004, and drivers were permitted to keep their throttles wide open even before the start. In 2005, however, use of the rev limit while in the standby state was prohibited. BAR-Honda proposed an engine torque trimming map exclusively for use in starting and a two-stage method of pressing the throttle pedal, and continued the use of dump RS (Fig. 9) that realized controllability on a par with the real rev limit from the standby state to the standing start while seeking to simplify driver operations.

5.5. Partial Clutch Engagement RS with DPC Pressure Control

In 2006, the 3-L V10 engine used until then was prohibited, and the use of 2.4-L V8 engines was required. This meant that engine torque was diminished by 20% or more, so that the clutch dump system could effectively no longer be used. Figure 10 shows the relationship between torque in a V8 engine and the required torque calculated from the coefficient of friction μ between the road surface and the tires. The μ on a dry road surface ranges from 1.6 to about 1.9, so that in order to satisfy the relationship of Engine Torque > RS Required Torque, an engine speed of from 8000 to 9000 rpm or more is necessary. With the V10 engine, the relationship between required torque and engine torque was such that μ = 1.0, as shown in Fig. 10, allowing the dump system at 5000 rpm or slower. However, the V8 engine was required to provide torque at higher

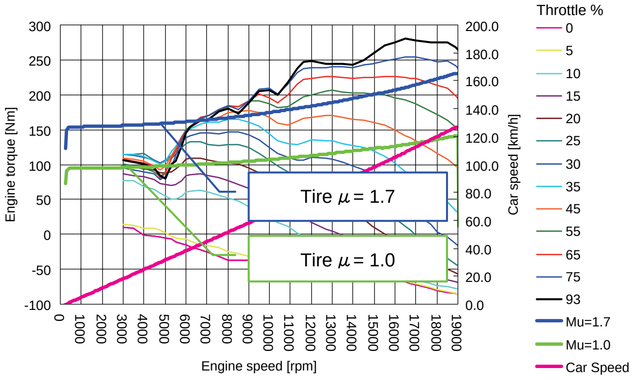

Fig. 10 V8 engine torque and required torque for RS

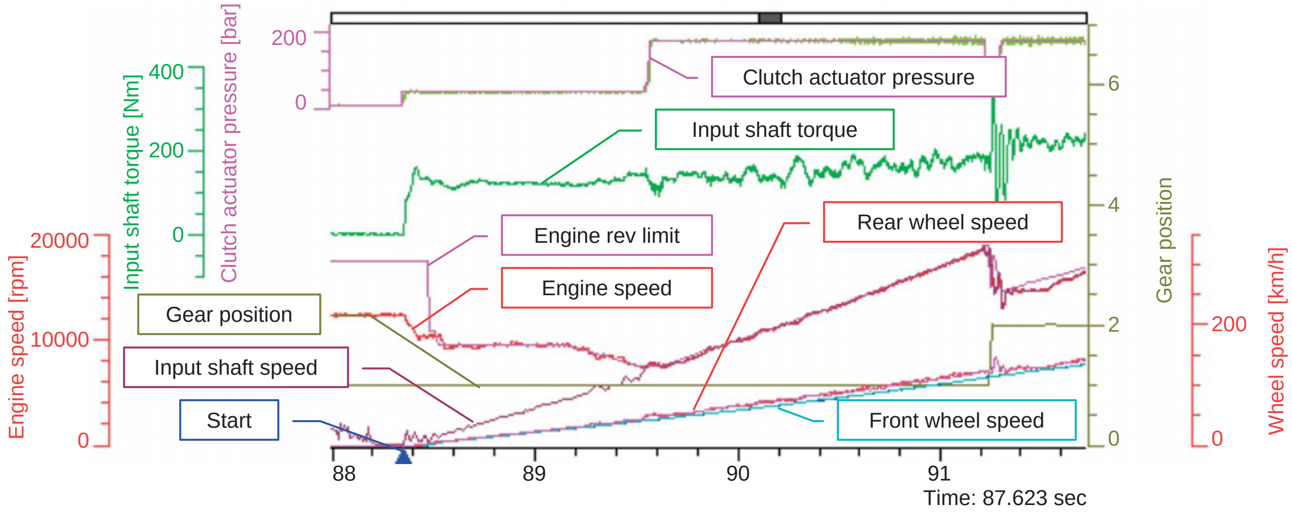

Fig. 11 Clutch partial engagement RS with DPC track data (2006)

engine speeds, also making it necessary to alter the RS strategy on the assumption that the double paddle system with partial clutch engagement would be back in use.

Honda’s unique, newly developed direct push clutch (DPC)(1) was adopted as a measure to enhance clutch torque controllability. This clutch resolved the issue of thermal expansion and wear state of the disk causing the clamp load to change, which was a weakness of the pull clutch. DPC used a system with a hydraulic actuator that pushed directly against the disk for the clutch connection. This succeeded in obtaining clamp load with generally linear characteristics with respect to the hydraulic pressure, and the transfer torque was stable. The clamp load was already known, so where race operations was estimating the tire μ as described earlier, now it also estimated the clutch disk μ, further enhancing the precision of paddle map selection in racing starts.

Torque/rev control was also introduced to combine torque control with the conventional rev control method of engine control. In this method, control of the absolute value of torque using the engine formed the primary means for control, and it would switch over to rev control only when the engine speed reached a specified upper or lower limit. The purposes were to stabilize clutch transfer torque by optimizing engine torque output, and to create conditions facilitating recovery from the wheel spin by holding torque at a minimum even when wheel spin occurred.

Figure 11 shows actual track data for partial clutch engagement RS by means of DPC pressure control. The double paddle method keeps DPC pressure (clutch actuator pressure) demand at a certain level, thus holding the transfer torque (input shaft torque) at a constant value as close as possible to an ideal value in the state of partial clutch engagement. This realizes an ideal standing start without causing wheel spin.

The development of this system up to 2007 generated knowhow that was applied wherever possible in the area of tuning in the FIA-common ECU that was made a requirement in 2008.

6. Formula One Control System Development Environment

When third-era Formula One activities got started, the focus was initially on testing in the actual vehicle, and the software development for control systems was also done by hand coding, working from specifications based on flowcharts. However, the project for development of Honda made chassis control systems, begun in 2002 to enhance development efficiency, was the start of a gradual shift to development based on the use of MATLAB Simulink and Stateflow, and from that point on, technology for autocoding was actively incorporated into the development effort. Development of software for control on the chassis side was gradually converted to autocoding with the LC in 2003, and in 2006, development of the chassis-side control unit was switched from Pi-Sigma MCU, which had been used up to that time, to the ATHENA system, which was made by Honda and used for engine control. With this, development on the chassis side was converted 100% to autocoding. Autocoding technology was incorporated on the engine side, as well, but ATHENA had already been employed continuously since 2000, and for that and other reasons, the use of autocoding did not progress beyond partial adoption for use on relatively new systems.

There were also advantages to the use of Simulink and Stateflow. Offline simulation was performed across a wide range on both the chassis and engine sides, from the debugging level to the development of new control algorithms, and the Hardware In the Loop Simulation (HILS) environment, which included a real ECU, was also actively employed. In fact, the LC and RS introduced from 2003, as well as the wheel slip feedback TC and OC introduced in 2006, were developed by simulation using a chassis model that included a drivetrain.

The development of third-era Formula One control systems sought to successfully develop systems with limited opportunities for testing in actual vehicles and to deploy them as quickly as possible in racing machines. Simulation technology can be said to have played a central role in this effort.

7. Conclusion

Throughout the third-era Formula One activities, there was an impetus to move beyond traction control that dealt simply with acceleration, and to incorporate traction control for limit ranges in a variety of different circumstances including deceleration and standing starts. This yielded results and many new insights in connection with (1) the adoption of torque drive system that converts throttle pedal input to engine torque demand, (2) the adoption of a torque interface with chassis control systems, (3) wheel slip control that directly controls wheel slip, (4) coordination with clutch control, and so on.

All this brought a keen awareness that not only the powertrain field, naturally enough, but also the chassis field and coordination with the driver were particularly important for traction control. It also became apparent that alternative testing approaches, to include virtual methods, were of importance in developing control systems for use under limit conditions that are not readily reproducible in the actual machine. It is to be hoped that the experience gained on these two points will also be put to active use in developing mass-production models.

Reference

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