

F2006SC31

ESTIMATION PROCEDURE OF INCREASING THE SPEED OF GEAR SHIFT IN SPORTS CARS AT THE DESIGN STAGE

Dudnikov, Andrey*
South Ural State University, Russia

KEYWORDS – gearshift, gearbox, gearshift time, transmission.

ABSTRACT – They make high demands of gear-boxes for sports cars: short gearshift time; gearshift with minimal interruption of power flow (or without interruption at all); ability to stand peak overloads; significant degree of safety and reliability; optimal transmission ratio. In this paper a formula for determination of gearshift time is derived. Its components take account of form factor of the vehicle, psychomotor data and professionalism of the driver. In this paper different gearbox constructions have been rated by the time of gearshift. They are automated manual gearbox, twin-clutch gearbox and new kinematic scheme of gearbox which provides gearshift for 0.1 seconds.

TECHNICAL PAPER

1. INTRODUCTION

In existing transport machines changing towing force on driving-wheel is carried out by changing gear ratio in transmission mechanism. With all this going on in gear-shift process of race cars and cross-country vehicles there is a problem of interruption of power flow and significant losses of time for gear-shift process. The major task of improving fixed-ratio gear-boxes and its control systems is decreasing of acceleration time and shortening of gear-shift time. They make high demands of gear-boxes for sports cars:

- short gear-shift time;
- gear shift with minimal interruption of power flow (or without interruption at all);
- ability to stand peak overloads;
- significant degree reliability;
- optimal transmission ratio.

Basing on the researches we could come into conclusion that fixed-ratio gear-boxes have ability to transfer high torque at the same time having compact design and high reliability. The main drawback is considerable time periods of gear-shift which are caused by necessity of matching circumferential speed of joining elements. Increasing of gear-shift time is a result of synchronizer work. It includes declutching and breaking off power flow during the gear-shift time.

Estimation of gear-shift time can be based on the following parameters:

- vehicle speed;
- torque data from gearbox output shaft;
- gearbox design;
- gear shift mechanism design;
- reaction and skills of the driver.

Total shift time is sum of all these parameters.

2. GEARSHIFT TIME COMPONENTS

Let's look at the gear-shift process on the basis of stated parameters. In general gear-shift time includes the following components:

- time of driver's reaction;
- time of clutch operation;
- time of gearshift mechanism operation;
- time based on gearbox design.

In that case gear-shift time can be represented as a formula:

$$t_{shift} = t_{reaction} + t_{clutch} + t_{gsmech} + t_{gbox}$$

Where $t_{reaction}$ is the time of driver's reaction; t_{clutch} stands for the time of clutch operation; t_{gsmech} is the time of gear-shift mechanism operation; t_{gbox} is the time which is based on gearbox design.

Let's view all the components of the formula in detail.

2.1. Time of driver's reaction

Time of driver's reaction ($t_{reaction}$) – it's the system of psychomotor actions of the driver.

Driver's reaction time it's the time within the interval of signal appearance and the beginning of response. This time is defined by:

- quickness of receptor's irritation and transferring impulse to sensory center;
- quickness of signal processing in central nervous system (conversion, identification);
- quickness of making decision of signal response;
- quickness of transferring signal for action through efferent fiber;
- quickness of irritation growth in actuator (muscle) and overcoming the self-inertia of corresponding body part.

In that way driver's reaction time includes sensory and motor components.

Sensory component consists of searching and cognitive eye movements, fixation and distinction of control objects.

Motor component consists of action system for realization of made decision. Driver moves his foot on to the clutch pedal, moves his hand from the steering wheel to the gear-change lever then he presses the clutch pedal and shifts to neutral. After that he shifts to gear, releases the clutch pedal and moves his hand back to the steering wheel at the same time receiving the action effectiveness information. Motor component of the time of reaction depends on lightness of muscle irritation, and also on what is self-inertia (that is weight) of different body parts. That is why time of reaction of different body parts differs.

In many cases we need not just simply reaction for signal but estimation of the situation. This essentially leads to increasing time of reaction due to "delay". That is time that needed for signal processing, its identification and making decision of expediency one or another response.

Because of that we can emphasize the *central component* which consist of the following elements:

- realization of necessity of gear-shift (situation);
- active simulation of situation evolvement;
- search for similar situation in memory;

– aim of action formation.

There is no correspondence between the time of simple reaction and the time of “delay”. This gives grounds to consider “delay” as independent figure which is not connected with sensory and motor component of the reaction time.

So then driver’s reaction time ($t_{reaction}$) can be presented as:

$$t_{reaction} = t_{sensory} + t_{motor} + t_{central}$$

Where $t_{sensory}$ is the time of sensory reaction; t_{motor} – motor reaction time; $t_{central}$ – central “delay” time.

2.2. Time of clutch operation

Time of clutch operation depends first of all on its constructive parameters and on clutch drive design. In general the time of clutch operation can be presented as:

$$t_{clutch} = t_{disengage} + t_{engage}$$

Where $t_{disengage}$ – disengagement time; t_{engage} – engagement time.

Disengagement time can be split onto the following parts:

$$t_{disengage} = t_{freetravel} + t_{workingstroke}$$

Where $t_{freetravel}$ – time of the clutch pedal free travel; $t_{workingstroke}$ – time of the clutch pedal movement up to the driving and driven disks disconnection and reaching minimally allowable clutch torque by the terms of gear-shift.

Engagement time which consists of two periods can be presented as:

$$t_{engage} = t_{Ieng.period} + t_{IIeng.period}$$

Where $t_{Ieng.period}$ – time of the 1st engagement period (from the beginning of clutch plates touch up to reaching clutch torque which is equal to drag torque of driven disk from the direction of driving wheel); $t_{IIeng.period}$ – time of the 2nd engagement period – it is time from the end of the 1st engagement period to total connection of driving and driven disks when its angular velocity is equal and disk slipping is stopped.

Duration of the 2nd engagement period and amount of $t_{IIeng.period}$ can be defined by permissible dynamics growth of transmitted torque and by driven clutch disk rotary acceleration and therefore by acceleration of the vehicle.

Thus, *time of clutch operation* can be presented as:

$$t_{clutch} = t_{freetravel} + t_{workingstroke} + t_{Ieng.period} + t_{IIeng.period}$$

An amount $t_{IIeng.period}$ depends on constructive parameters of clutch drive and of clutch design. Thus, engagement time increase when there is hydraulic drive of clutch. This was done for transmission load impact reduction.

Within the interval of disengagement end engagement time the powertrain “engine –driving wheel” is torn up.

Powertrain breakup it is a part of gear-shift process when transmission is off. That is driving and driven parts of clutch and gearbox do not interact with each other.

Duration of power flow breakup depends on constructive parameters of gearbox and gearshift mechanism. There are gearboxes in which interruption of power flow brought to zero or there is no interruption at all (automated manual gearboxes, twin-clutch gearboxes).

2.3. Time of gearshift mechanism operation

Time of gearshift mechanism operation can be presented as:

$$t_{gsmech} = t_{off} + t_{neutral} + t_{on}$$

Where t_{off} – time of moving gearshift lever to neutral; $t_{neutral}$ – movement time of gearshift lever until the beginning of synchronizer work; t_{on} – time of movement gearshift lever when shifting to gear after synchronization.

2.4. Time based on gearbox design

Time based on gearbox design:

$$t_{gbox} = t_{synch}$$

where t_{synch} – synchronization time of driven and driving pinions.

For different gearbox constructions time of gearshift mechanism operation and time based on gearbox design can differ. Thus, in automated manual gearboxes where gearshift happened by means of cam clutch synchronization time equals to zero. In twin-clutch gearboxes both synchronization time and time of gearshift mechanism operation can equals to zero since by the time of gearshift all the gears are in required positions.

Summarizing foregoing, time of gearshift depends on two factors and could be divided into:

1. Gearbox and its constructive elements design. Here we can add such parameters as the time of clutch operation, time of gearshift mechanism operation and time based on gearbox design.
2. Psychomotor characteristics and skills of the driver. There is time of driver's reaction, time of the clutch pedal free travel, time of the gearshift lever movement.

Improving gearbox design we could reduce to zero synchronization time, dismiss operation and time of disengagement and hence engagement of the clutch. And also decrease driver's reaction time by for instance changing gearshift operation mechanism.

Shift control time in inertia-mass systems can be defined by inertia characteristics of the system – mass or moment of inertia and also by efforts which is put on shifting elements. To decrease shift control time it is efficiently to use forces and its torques while gear works. In the limit gearshift operation can be done due to internal force factors. In that way gearshift control will bring to locking and unlocking of shifting elements (1).

Let's look up the gearshift process in different gearboxes, applied in race cars.

3. SPORTS CARS GEARBOX CONSTRUCTIONS

3.1 Automated mechanical gearboxes

Automated mechanical gearboxes it is gearboxes where traditional mechanical-link shifting mechanism replaced by an electronic clutch and a high-pressure hydraulic shift actuator (2). The main feature of automated mechanical gearboxes is total lack of synchronizing elements. Lack of synchronizing elements caused by its demerits such as low speed of gearshift and short life cycle in gearshift high loads conditions (“rough shift”). There are also only spur gears in such kind of gearboxes.

Lack of synchronizing elements became possible because of master clutch construction. There are cams on pinion butt by which pinion engage with shaft. In this case it's possible to shift gears with partial declutching or even without disengagement of clutch at all. In such constructions load impacts fall on cams and on gear teeth. Performance of cams and relative stability to load impacts was reached due to reduction of step pitch which entails increasing the number of gears to six-seven, decreasing inertia moment of the engine (applying light-weight forced engines with small displacement), decreasing inertia moment of engine flywheel (switching to double-disk clutch with high working properties of materials), wheels, total decreasing of inertia mass (flyweight of the vehicle) etc. Above-listed call forth using of automated mechanical gearboxes in race cars.

For quick drive gearshift is implemented by flicking the large paddles mounted at the steering column and behind the steering wheel. One paddle for upshift and another for downshift. This helps shorten time when the driver moves his hand from the steering wheel to the gear-change lever and back.

The distinctive feature of this kind of gearboxes is how well it integrate clutch action and gearshift together. Within milliseconds since the driver press the gearshift paddle, the computer ease the electronic throttle, then disengage the electronic clutch, and then signal the hydraulic actuator to shift to another gear – all these actions are taken progressively and smoothly.

During hard acceleration, upshift will be made at over 8,000 rpm and the whole process takes as little as 0.15 sec. This is why that gearbox has no performance loss compare with the standard manual. In reality, it might be even quicker than a manual car during cornering, because the driver no longer need to take care of clutch and throttle, nor wasting time to travel his hand from steering wheel to gear lever mounted on central tunnel.

3.2. Twin-clutch gearboxes

Twin-clutch gearboxes like automated manual gearboxes can operate as a semi-automatic, there the driver changes gears via buttons, paddles or conventional shifter. There is also a full automatic mode, where computer determines which gear to be selected. Unlike conventional gearboxes Direct-Shift Gearbox (DSG) uses two clutches – one clutch connects to the odd gears (1st, 3rd and 5th) while another clutch connects to even gears (2nd, 4th and 6th). This enables it to shift far smoother and faster than conventional gearbox.

Twin-clutch gearbox allows shifting practically without interruption of power flow due to twin-clutch construction. Twin-clutch allows shifting gears with partial overlap.

Pre-selection of gears quicken the shift a lot. Upshift takes just 8ms, 10 times quicker than BMW SMG II which is the fastest automated mechanical gearbox currently available. Downshift is less impressive, because the gearbox need to wait for the throttle blip to match gearbox speed with engine speed. Change down a gear therefore takes 600ms. Changing down a few gears could be more complicated. The most complicated is from 6th to 2nd (both are controlled by the same clutch while the distance between the two gears is the longest). It needs to change to 5th (controlled by another clutch) temporarily before 2nd is selected. This takes 900ms. Among other disadvantages of DSG it is impossibility to stand peak torques. At peak overloads twin-clutch can simply fall out (2).

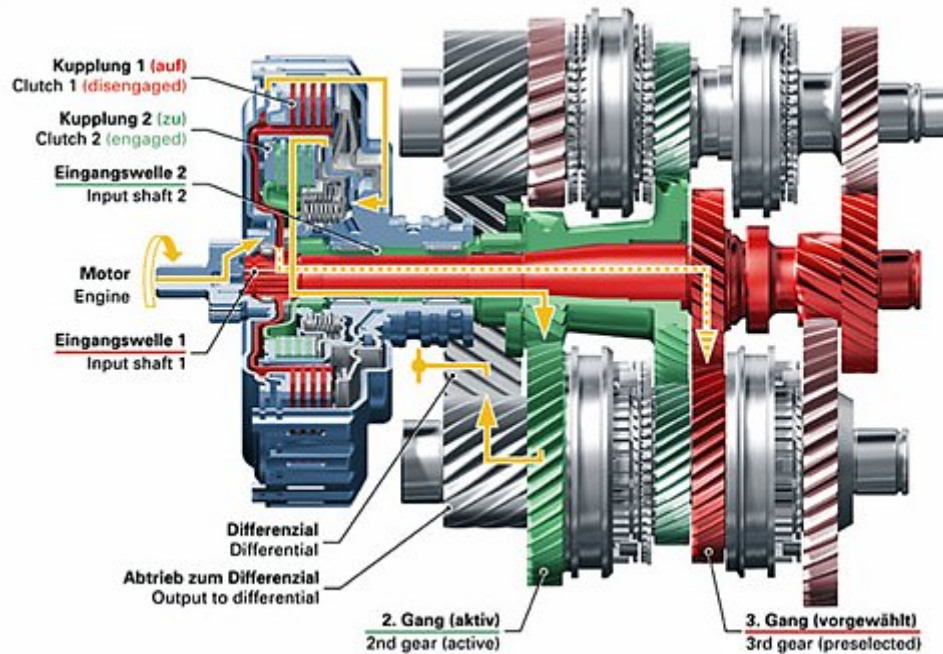


Fig.1 Twin-Clutch Gearbox DSG.

4. NEW GEARBOX KINEMATIC SCHEME

In gearbox classification we can add the new gearbox with so called shift by changing gear axle base. This gearbox was designed in South Ural State University at the Automotive Department.

There are following benefits of this type of gearboxes:

- high efficiency of gearshift (gearshift happens without synchronization of the speed of rotation);
- practically uninterrupted power flow while shifting;
- possibility of gearshift automatization using internal force factors;
- gearshift without declutching;
- low price due to lack of high-priced electronic control systems;
- lack of synchronizing elements.

Each speed in multiple-shaped gearbox contains drive and driven shafts with fitted-on gears and intermediate gears freely fitted on curvilinear axle for rotation and equipped with stop. Curvilinear axle is secured in gearbox for turning around axis of drive or driven shaft. Intermediate gears are installed on axle with angular shift, being in constant meshing either with gears of drive shaft or gears of driven shaft. At gear-shifting, common axle of intermediate gears of shifted-in and shifted-out speeds is unlocked and rotated around axis of gearbox shaft with gear of which intermediate gears are in constant meshing. Intermediate gear of shifted-out speed is brought out of meshing with gear of other shaft, and gear of shifted-in speed is brought synchronously into meshing with gear of other shaft for complete engagement of corresponding speed, after which axle of intermediate gears is locked. To select direction of change-over, engine of vehicle is changed over for traction or braking conditions (3).

Cinematic scheme of two-stage module is shown on figure 2.

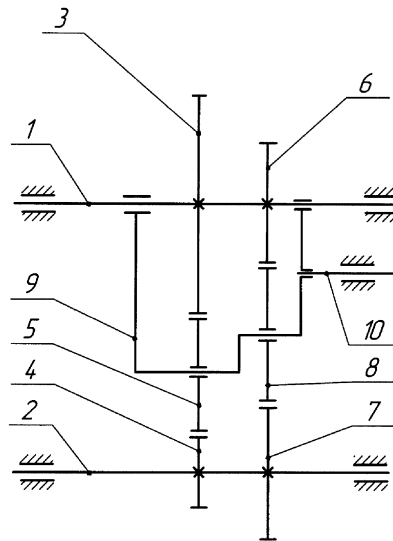


Fig. 2 Cinematic Scheme of Two-Stage Module of Gearbox
With Gearshift by Changing Axle Base.

1, 2 – drive and driven shaft; 3, 4, 6, 7 – gears of drive and driven shaft;
5, 8 – intermediate gears; 9 – curvilinear axle; 10 – stop.

The functional model of new gearbox with gearshift by changing axle base was designed and produced at the Automotive Department of South Ural State University. Its ride tests proved performance and high dynamic properties of that gearbox for sports driving mode of vehicle. Gearshift was made without declutching. Unavoidable high loads (in such gearshift speed) which take place in any gearbox didn't reach maximum permissible value. Model of gearbox maintained efficiency of gearing due to gear work through entire contact line and because of surplus degree of freedom (which occurred due to unstop curvilinear axis) and because of zero torque.

Today there is a current task of engineering of gearbox construction with gearshift by changing axle base for race car to get new technical characteristics by the time of gearshift and dynamics characteristics of the vehicle.

REFERENCES

- (1) G.D. Dragunov, A.G. Dudnikov, "Advisability and Forthcoming Efficiency of Increasing Gearshift Time in Race Cars", XXVI Russian School for Science and Technology Problems, June 2006
- (2) http://www.autozine.org/technical_school/, "Transmission", 2006
- (3) G.D. Dragunov, "Method of and Device for Shifting Gears in Multiple-Speed Gearbox", Patent for Invention, RU 2268162 C1, January 2004