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SEQUENTIAL GEARBOX SHIFTING FOR A HYBRID VEHICLE

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Abstract: *CVT efficiency over a large range of car operation has been one of the most important impediments to its promotion in hybrid car development. A way to keep a good "mechanical" efficiency is sequential gearbox shifting, co - related to a fine adjustment of ratio selection. The paper is focused over on the design of the shifting actuation in the case of a medium size car equipped with a four speeds manual gearbox in-house designed and tested*

Keywords: vehicle, automatic shifting, actuator, shifting strategy, centrifugal clutch.

INTRODUCTION

One of the most known combinations in hybrid design is the use of a CVT included in transmission chain. The efficiency of a CVT strongly decreases with the vehicle charge and transmission ratio increasing (figure 1), i.e. at the large engine torque, the 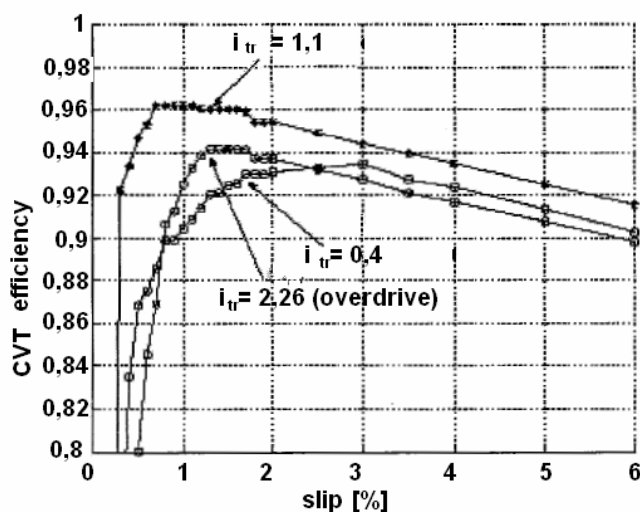efficiency decreases from 0.96 to 0.92. By contrast, with a medium value of efficiency of 0.98 for a standard mechanical gearbox, it seems to be beneficial to keep a classical mechanical transmission, but to superpose it's electronically control (regarding optimal ratio). The main advantages of a mechanical gearbox are the minimal weight and packaging, the simplest design, and consequently, the lowest costs. The disadvantages are related to a short time of energy stream interruption and poor comfort.

Figure 1 - CVT efficiency versus its slipping

A feasible way to maintain the overall efficiency is the use of manual transmission robotizing, taking into account the possibility of shifting periods shortening, which in turn, is dependent of actuators response. Figure 2 shows the differences between three types of transmission, regarding the smoothness quality during car acceleration: manual, automatic and CVT (Continuously Variable Transmission). The shifting smoothness consists in car longitudinal acceleration response, so the smaller acceleration variation, the better car comfort and longer life of transmission components.

A modern way to solve the energy stream interruption is a double clutch activity (figure 3), co-related to pre-selected gears operation: the range of 1-st, 3-th and 5-th ratios are controlled through a clutch (or through a dedicated side of the clutch disk) and the other ratios, 2-th, 4-th and 6-th are controlled through another clutch (or through the alternate side of the clutch disk). The electronic controller ensure a progressive reduction of friction in the clutch which controls the abandoned ratio, concomitant with a progressive friction increasing between the clutch pieces which control the next ratio. Another aspect imposed by the customer's requests is the improvement in the field of vehicle acceleration response after gear shifting, sensed as a comfort quality parameter (figure 4).
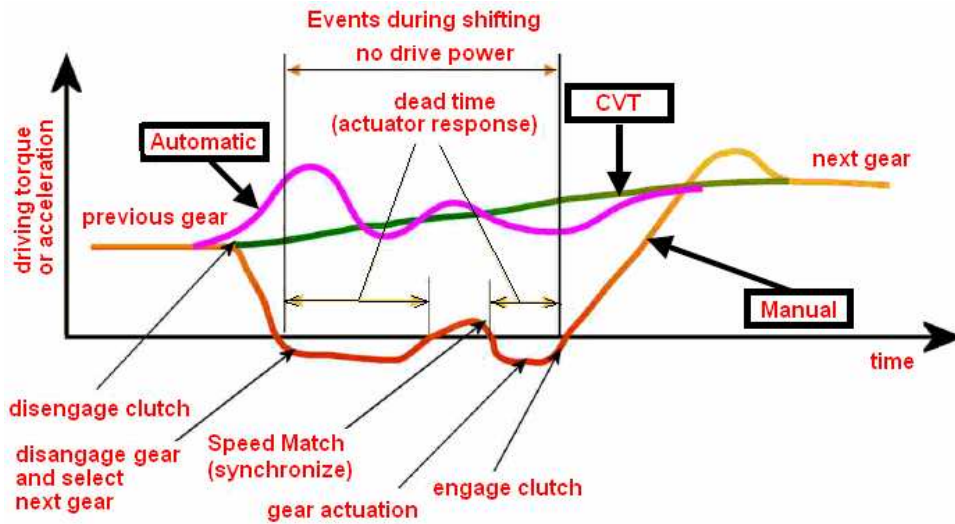
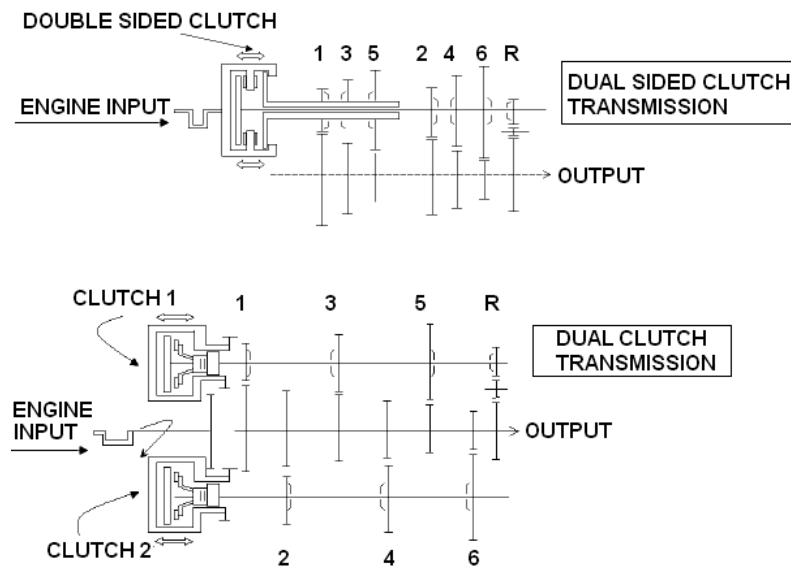**Figure 2 - Car acceleration during shifting process, for three types of transmission**

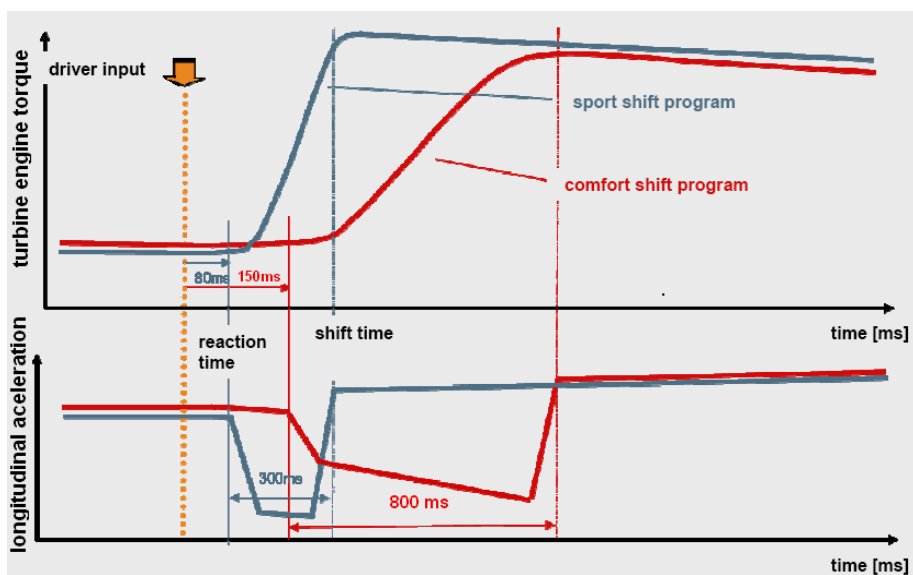

Figure 3 - Two types of dual clutch activity

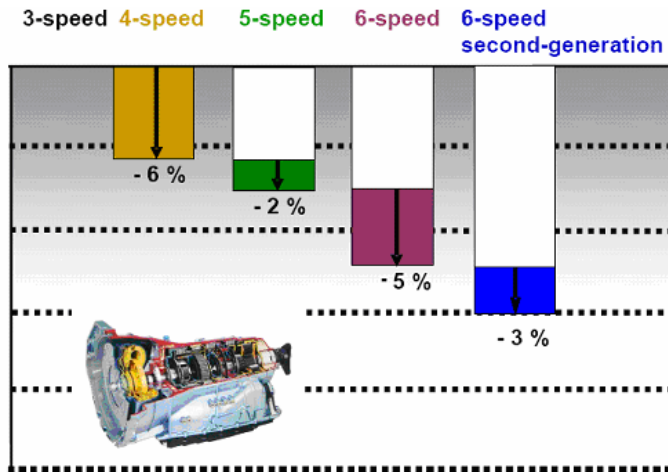**Figure 4 - The difference between sport and comfort shift program**

Figure 5 - Fuel reduction potential by means of the transmission's ratios number increasing

Figure 6 - The principle of centrifugal clutch

It is necessary to underline the importance of the number of gearbox increasing over the fuel economic behaviour (figure 5). If a fuel reduction of 6% corresponds to the promotion of 4 - speed despite 3 - gears gearbox, the last 6 - speed gearbox generation realizes 16% reduction compared to the basic 3 - speed gearbox.

THE DESIGN

The work in such complex task implies a corresponding big volume of conception, testing, adjustment activity and calibration, due to the need to ensure the best 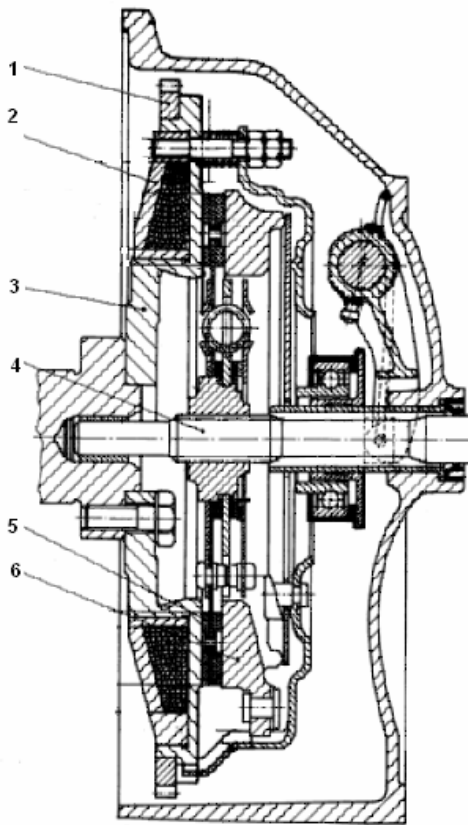co-relation between engine load control device, concomitant to clutch slipping control during shifting and to the gearbox actuation. Another important task consists in solving the problem of the optimal speed choosing, so it seems to distinguish between two directions: to decide when the shifting have to start and it's sense (up or down); and to solve the shortest shifting period without lack of synchronization. Moreover, it is desirable from many points of view, to keep the basically design of clutch, gearbox and fuel delivery device command, in order to realize the lowest investments costs, the minimal complexity and overall car's mass increasing.

The car's prototype able to support a classic manual transmission to be self commanded, it was selected a Romanian car type Dacia 1300, equipped with an Otto engine of 1,3 liter displacement with carburretor, 4 forward speed gearbox and a single disk clutch.

The dedicated robot of automatic gear shifting is a complex one, because it is necessary to act at the level of throttle valve (progressively closing during clutch disengagement and opening during clutch engagement). At the finish of the clutch disengagement starting gearbox actuating (with two dedicated actuators), in a manner which implies clutch engagement after new ratio engagement. This requirement derives from a driver activity replacement by shifting automatism. Normally, the actuators are four: one for throttle valve, one for the clutch and two for gearbox.

Clutch actuating

A major problem is to obtain a perfect clutch slipping during car start clutch engagement during car movement start), the other clutch operations being very simple. Because of a lack of experience of our team in electronic devices design, it was tested a centrifugal clutch based an innovative idea.

The clutch was modified in a manner to be disengaged in "normal stage" (the engine being out of order), its engagement starting after a minimum value of engine speed of approximately 1000 rpm. Figure 6 shows the principle of this type of clutch operation. In order to maintain the basic transmission components, the centrifugal clutch was based on the original car clutch, adding some special pieces. It is easy to observe how the flywheel 3 was modified on their left side where was

realized an inner space (with the help of a conical disc 2. This inner space is filled with a calculated mass of some bearing balls of 2 mm dia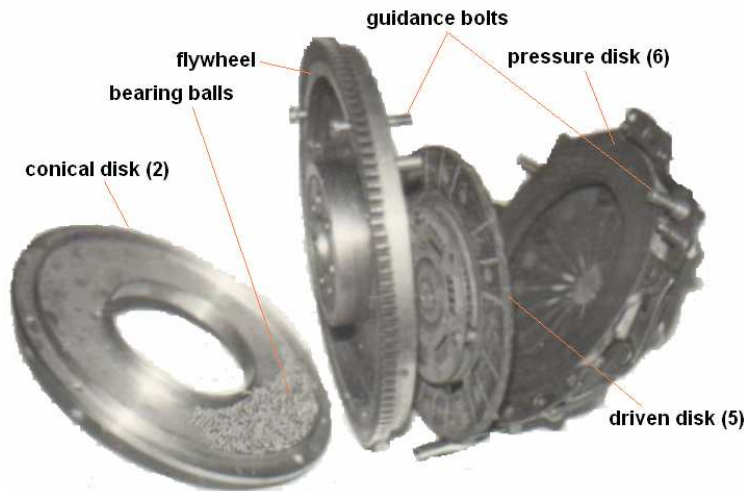meter. The contact between flywheel and part 2 can be ensued (at the engine speed below 1000 rev/min) by means of bolts and dedicated retaining springs, but after 1000 rev/min, the centrifugal forces acting over the bearing balls will push them in radial direction. Therefore, they will develop an axial resultant axial force, progressively increasing with engine speed; the pressure disk 6 will be pulled onto flywheel. This phenomenon realizes a smooth clutch engagement (the derived disk 5 starts to rotate and to drive torque to the gearbox). This clutch design keeps the possibility of external actuation. Two dedicated limiting transducers of the clutch lever transmit signals to the Electronic Central Unit (ECU), corresponding to full engagement and full disengagement of the clutch.

Figure 7 - Photography of centrifugal clutch assembly

The clutch actuator is a vacuum type one, realized by means of a modified servo brake device (figure 8). This device ensures the requested clutch disengagement force in a short period of 0.3…0.5 seconds. It actuate at the level of external clutch lever (at the same "points" as in the case of manual actuation).
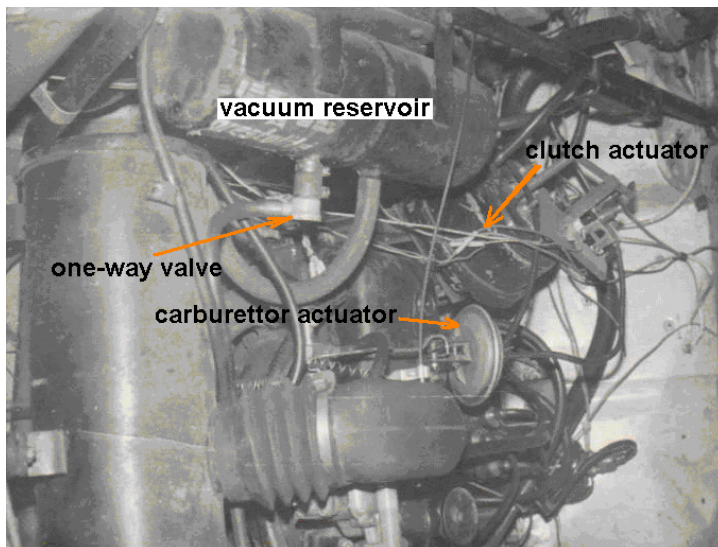

Figure 8 - Photography of engine compartment showing the arrangement of clutch actuating device

Gearbox actuation
Regarding the requirements of a correct shifting operation and the possibilities of the robot to accomplish with these needs, it is important to un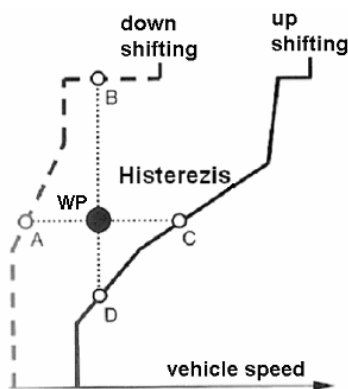derline some aspects related to a hysteretic behaviour of electrical actuation. This behaviour is a beneficial one; the dedicated ECU becomes simpler. Figure 9 shows a typical shifting characteristic curve, which is plotted on a scale of accelerator pedal position versus car speed. The gas pedal is the single wish-input device and so, the accelerator pedal simply informs the ECU how fast the driver wants to accelerate. The characteristic in figure 9 consists of two curves, one for shifting up and one for shifting down. The "desired hysteretic" has to be created into the design of the shifting strategy to prevent constant shifting up and down if the driver chose to be driving near a shifting point. The understanding of these two curves can be easily realised if a simple example is made. First, it has to fix what happens from the WP, the "working point" or just simply a typical operating point. If the driver does not change the accelerator pedal position, the shifting state stays on a horizontal line (AC line). If a frontal wind bowls, the

Figure 9 – Shifting characteristic curve

speed of the car will drop off. Eventually point A will be reached on the down shifting curve, so the car will downshift. If, on the other hand, the car starts to go a downhill, point C will be reached and the transmission will shift into a higher gear.

Considering a vertical movement on this shifting characteristic (as a consequence of a sudden change in the driver's wish without a change in speed), i.e. for example, if the driver wanted to pass a vehicle suddenly, he would step on the gas pedal and reach point B. The car would downshift to achieve quick acceleration. Inversely, if the driver suddenly lets up on the gas pedal, point D will be reached, and the car will up-shift to reduce engine RPMs for less engine braking and more economical operation.

There is such a pair of curves for each gear change. The shifting strategy being electronically controlled, these shifting characteristics can be postponed (pushed to the right on the speed axis) for sportier operation or shifted to the left for more economical vehicle operation.

This aspect regarding hysteretic behaviour is a supplementary one, the most important aspect being the hardware device design, which usually comprises electric motor, one for "selection", another for "coupling".

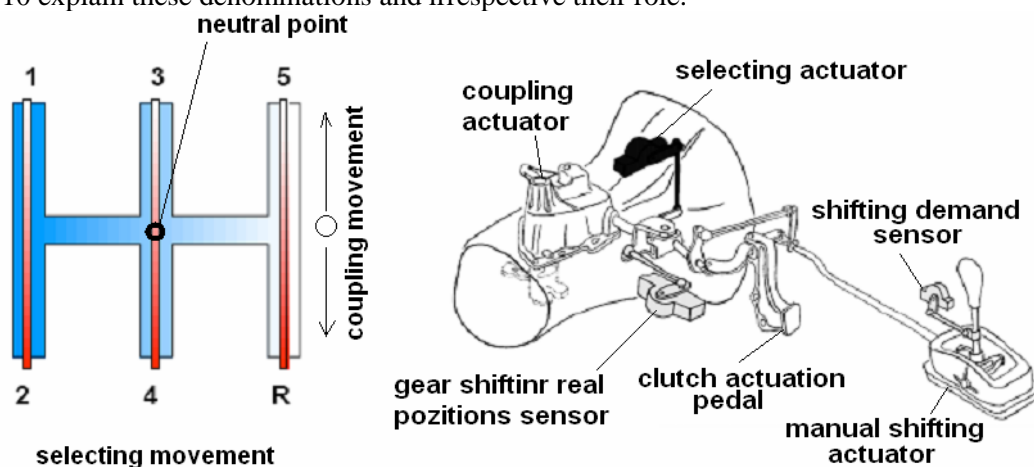Figure 10 explain these denominations and irrespective their role.

Figure 10 - The explanations in the field of gearbox actuation

The shifting strategy is based on the balance between driving strategy, driving functions, better transmission control, better transmission actuation (schema in figure 11).
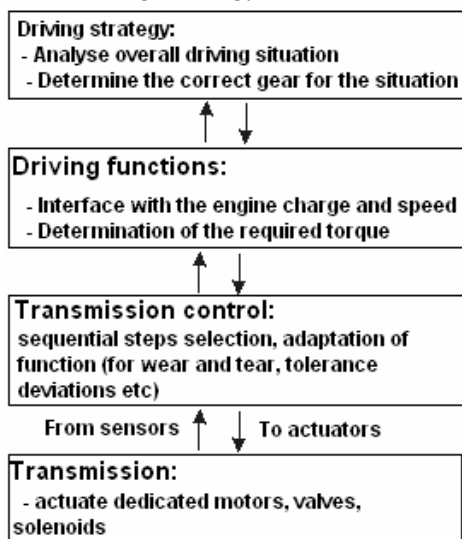

Figure 11 - Overview of transmission control

The gearbox shifting request two shifting lever movement: a rotational one, named selecting movement and another coupling movement. By means of selecting movement one of three shift rails is chosen, let's say the first/second one, but the shifting is finished by coupling movement of the shifting lever, when the shift rail is pushed into desired direction (of the second gear, for example). Each movement has to be realised with a dedicated actuation devices, usually based on an electric motor coupled to a screw/nut reductor (or a worm/worm gear one). In our prototype of robotization we used a screw/nut redactor for selecting actuator and in series mounted worm/worm gear whit screw/nut reductor.

Figure 12 presents the design of the coupling actuator, fixed on the gearbox cover 1. The shifting lever is moved for "coupling" by means of the screw 5 (part of the screw/nut reductor), in series mounted with worm gear 6 and worm 12. The worm 12 is processed on the rotor axle of the electric motor. To solve the problem of synchronizing process-avoiding wear increasing, two elastic disks are used with the goal to realize electric motor supply if a big actuating torque is happened. The screw nut

5 press one the rubber disk 8 and the disk 10 push the micro switch (L_1 or L_2). These micro switches interrupt the current to the electric motor (for a short time, until the synchronization is solved) and after pushing resistance over the screw 5 decreases.
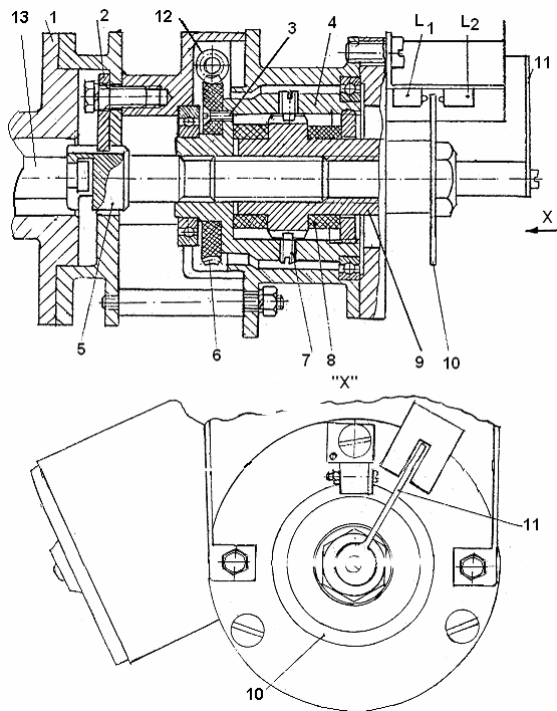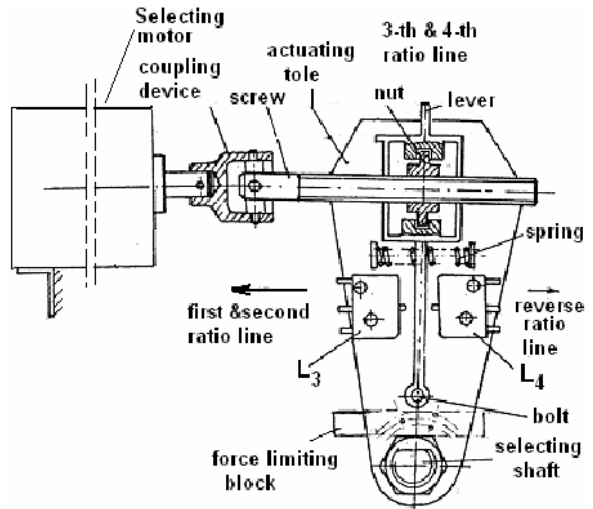

Figure 13 shows the selecting actuator which solves the problem of rotating resistance through a similar arrangement based on elastic elements (springs) and micro switches. Figure 14 is photography of the actuating gearbox assembly, which includes
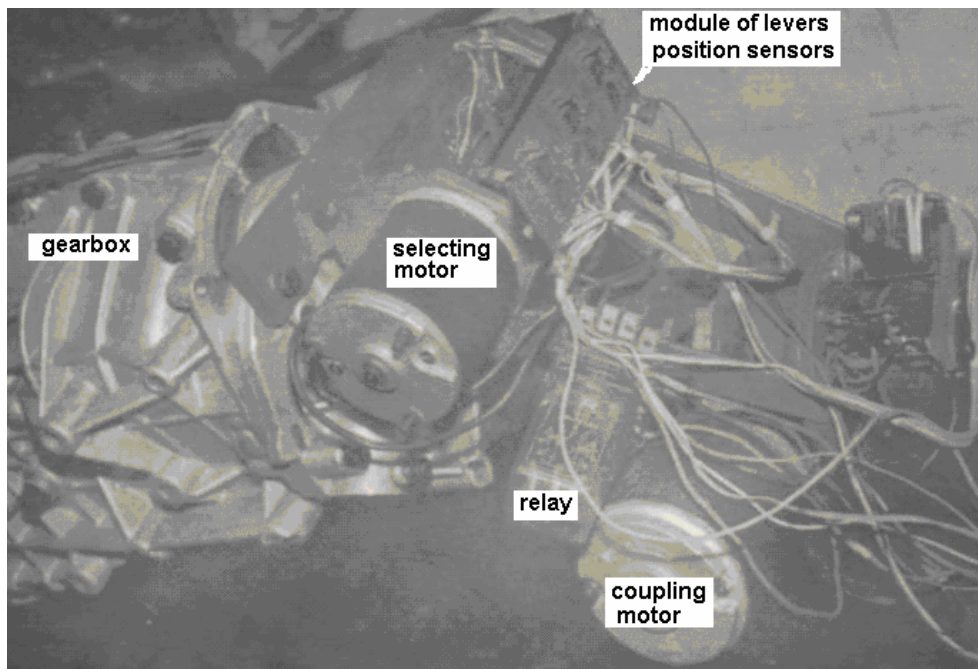
Figure 13 - Selecting actuation design

Figure 12 - Coupling actuation design

general arrangement over the vehicle.

Figure 14 - Gearbox actuator arrangement

Figure 15 shown the structure of ECU, where there are revealed two sections, one dedicated to solve sequential steps of shifting (shifting logical section), and the other dedicated to establish the best point of shifting. The arrangement keep the manual command, but through buttons (from a console).
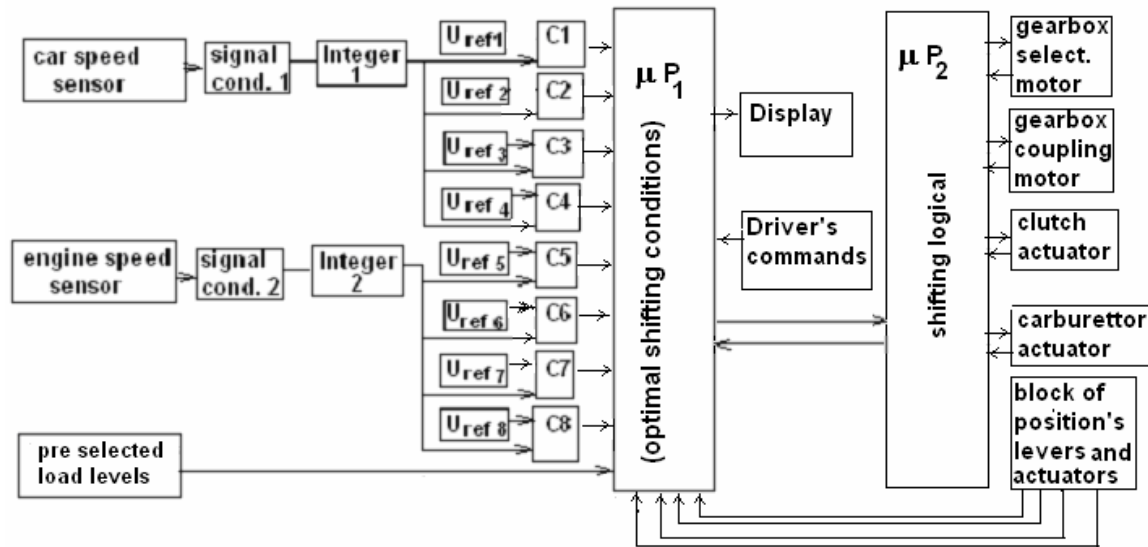
Figure 15 - The ECU structure

CONCLUSIONS

The results of the tests made with the Dacia 1300 car equipped with the described automatic gearbox shifting show a very good behaviour for all operation types. The fuel consumption over an urban trip within Pitesti city (made in both senses, direct and reverse), was better in automatic shifting version with a medium of 0,4 l/100 km than in manual shifting version.

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