REGENERATIVE BRAKING SYSTEM FOR THE CAR

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The design research in this paper is a case study of application of regenerative braking system to the Dzire car and improvements in regenerative braking system for the fixed output generation for the particular position of the acceleration pedal. In the regenerative system, the output of the vehicle is combined with the motoring output of the pump/motor and the engine to supply an amount of fuel corresponding to the position of the acceleration pedal, to drive the wheels at the starting. The research question addressed in this paper is the solution to the disadvantage of the existing regenerating system. i.e., sum of the outputs of the engine and the motor cannot be fixed because the output of the motor is varied due to the variation of the inner pressure of the accumulator even when the acceleration pedal position is fixed.

To address the above problem we proposed a modified hydraulic layout and we did a case study on Maruti Swift Dzire Diesel engine and proposed five solutions which are used to control the fixed output for the fixed position of the accelerator pedal. The solutions are optimized using the decision matrix and the results are satisfactory.

Keywords: T/M-Transmission, PTO-Power Take Off, LVDT-Linear Variable Differential Transducer, MPFI-Multi Point Fuel Injection System, SAE-Society of Automotive Engineers.

1. INTRODUCTION

In the conventional vehicles part of kinetic energy is dissipated mainly as heat in the braking system. Regenerative braking system is used to capture this heat energy and converts it to the hydraulic energy which is utilized in accelerating the car. The accumulated energy is utilized for starting and accelerating the car. This system consists of a transmission (T/M), a PTO output shaft, a pump/motor, a hydraulic oil circuit, an electromagnetic clutch, an accumulator, and a control unit.

Only about 15% of the energy from the engine output is used to move the car down the road. The rest of the energy is lost to engine and driveline inefficiencies and idling. Out of 100% energy available at engine, 62% was wasted due to engine losses, 12% for the standby losses and 9% for the driveline and friction losses. If we consider the braking losses, around 5.8% of total kinetic energy was wasted during the braking. So there should be a system to capture the kinetic energy lost during decelerating the vehicle.

1.1. Case Study on Dzire Car

The quest for increasing the efficiency of an internal combustion engine has been going on since the invention of this reliable workhorse of the automotive world. In recent times, much attention has focused on achieving this goal by regeneration of energy from braking. In the present case study on Dzire car it is focused to regenerate the energy lost during decelerating the vehicle. In addition to the above, various method shave been discussed to achieve a fixed combination of output from regenerative system and engine for the particular accelerator pedal position.

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1.1.1. Theoretical braking energy calculations

Experiments with engines very often involve an energy balance on the engine. Energy is supplied to the engine as a chemical energy of the fuel and leaves as energy in the cooling water, exhaust, brake work and extraneous heat transfer, which is often termed 'heat loss'. But, this usage is misleading as heat is energy in transit and the First Law of Thermodynamics states that energy is conserved. The heat transfer to the braking is found from the KE lost during braking.

1.1.2. Assumptions

1. Five numbers of passengers with weight as 72 kg/person was considered.
2. Luggage weight was treated as 100 kg.
3. Petrol weight was treated as 43 kg.
4. The vehicle speed comes to zero when the driver applies the brake.
5. Number of braking was considered to be more between 40–60 kmph.
6. Number of braking was considered to be more in city traffic compared to the highway.
7. Energy wasted in braking was considered as 5% of the total fuel energy (taken from SAE (Society of Automotive Engineers).

1.1.3. Dzire Diesel engine (Model-1115Zdi):

Mass calculations:

Weight of the vehicle	$= 1115\,\text{kg}$
Passengers weight	$= 5 * 72 = 360\,\text{kg}$
Luggage weight	$= 100\,\text{kg}$
Diesel weight	$= 43$ litre (Considered as 1 ltr = 1 kg)
Total weight of the vehicle	$= 1115 + 360 + 100 + 43 = 1618\,\text{kg}$

Illustrative example for finding the KE lost during braking

The kinetic energy is converted into heat in the brakes. For example the loss in KE in Braking the car which is going at 20 km/s and weighing 1000 kg is

$$\text{Loss in KE} = (1/2\,m\,v^2)$$
$$= 0.5 \times 1000 \times 20 \times 20$$
$$= 200000\,\text{J}\ (200\,\text{kJ})$$

1.1.4. Input energy calculations:

The calorific value or heating value of diesel fuel is approximately 45 mJ/kg.

Input energy = mass of fuel* calorific value

Energy available per 1 kg of diesel fuel=1*45=45*10^3 kJ.

Energy wasted in braking =0.05*45*10^3=2.25 mJ

1.1.5. Case study at city and highway traffic

We have considered the traffic at highways and in the city to find the available braking energy at different speeds.

CASE1: Chennai to Madurai (highway cruising)
Distance = 450 km.
Number of signals + zigzag road =330.
During the journey, the total number of application of brake will be 330.
Refer the Table 1 for the highway cruising calculations.
CASE2: Tambaram to Sriperambudur (city cruising)
Distance = 50 km.
Number of signals + zigzag roads =300.
During the journey, total number of application of brake will be 300.
Refer the Table 2 for the city cruising calculations.

Table 1.

Vehicle weight (Kg)	Vehicle speed (kmph)	Vehicle speed (km/s)	Kinetic energy(kJ)	No. of application of brake	Total energy lost(kJ)
1618	10	0.002777778	0.006242284	20	0.124845679
1618	20	0.005555556	0.024969136	20	0.499382716
1618	30	0.008333333	0.056180556	20	1.123611111
1618	40	0.011111111	0.099876543	30	2.996296296
1618	50	0.013888889	0.156057099	40	6.242283951
1618	60	0.016666667	0.224722222	30	6.741666667
1618	70	0.019444444	0.305871914	40	12.23487654
1618	80	0.022222222	0.399506173	35	13.98271605
1618	90	0.025000000	0.505625000	35	17.69687500
1618	100	0.027777778	0.624228395	24	14.98148148
1618	110	0.030555556	0.755316358	13	9.819112654
1618	120	0.033333333	0.898888889	13	11.68555556
1618	130	0.036111111	1.054945988	2	2.109891975
1618	140	0.038888889	1.223487654	4	4.893950617
1618	150	0.041666667	1.404513889	4	5.618055556
		Total energy wasted			110.6180555

Table 2.

Vehicle weight (Kg)	Vehicle speed (kmph)	Vehicle speed (km/s)	Kinetic energy (kJ)	No. of application of brake	Total energy lost (kJ)
1618	10	0.002777778	0.006242284	50	0.312114198
1618	20	0.005555556	0.024969136	60	1.498148148
1618	30	0.008333333	0.056180556	80	4.494444444
1618	40	0.011111111	0.099876543	50	4.99382716
1618	50	0.013888889	0.156057099	30	4.681712963
1618	60	0.016666667	0.224722222	30	6.741666667
		Total energy wasted			23.34567678

1.1.6. Description about the hydraulic circuit

Main components of circuit are transmission (T/M), PTO output shaft, pump/motor, hydraulic oil circuit, electromagnetic clutch, and accumulator and control unit. Out of two types of regenerative systems(electric and hydraulic regenerative systems) which can be used for capturing lost energy in a regenerative braking system hydraulic system are superior due to its high power density, cost-effective, efficient and/or durable energy storage system for the vehicle. The role of the each part has been explained in the different operation modes of the hydraulic system layouts. See the reference Figure 1 — Layout of the hydraulic system.

Control system layout:

The control unit controls the electromagnetic clutch and operates the pump/motor in response to the running condition of the car. For this unit as a pump, the torque of the wheels during the decelerating mode serves to accumulate the operating oil into the accumulator through PTO unit, thereby to capture the kinetic energy. For this unit as a motor, the operating oil accumulated in the accumulator serves to generate starting/accelerating torque to drive the wheels through the PTO unit. See the reference Figure 2_Control system layout.

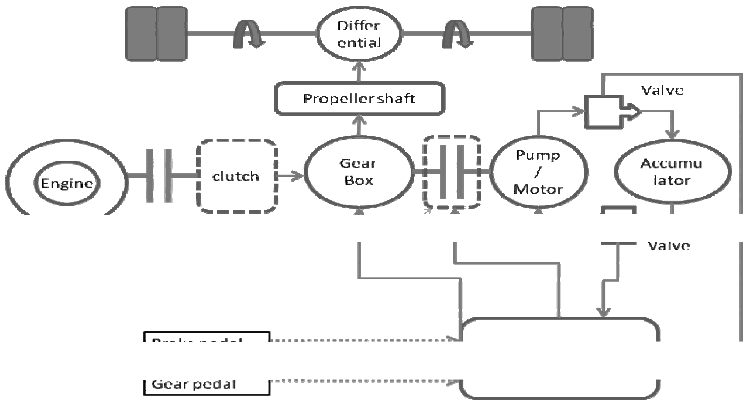


Figure 1.

Layout during braking

During the braking mode, the electromagnetic clutch is made on, while at the same time engine is declutched. The control unit controls the Pump/Motor unit to work as pump to store the braking energy in the accumulator. See the reference Figure 2_Braking system layout.

Layout during the acceleration

During the acceleration, if the inner pressure of the accumulator being sufficient, the control unit controls the pump/motor as a variable capacity type motor, the capacity of which is controlled by varying the displacement angle of the swash plate or shaft in response to the accelerator pedal positions. If the accumulator pressure is not enough to turn, vehicle will operate only on engine fuel. Here the swash plate position partially opens depending upon the requirement. See the reference Figure 2_Acceleration system layout.

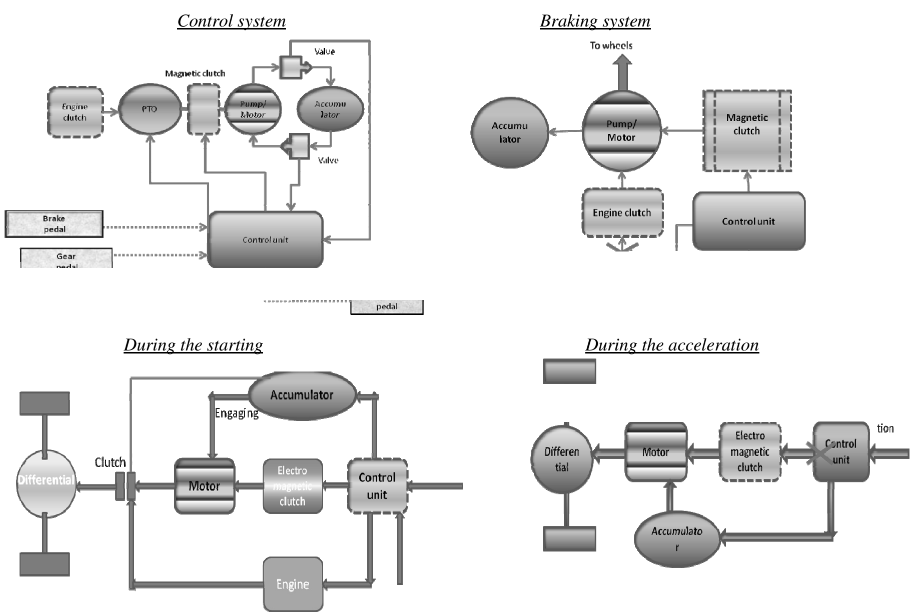
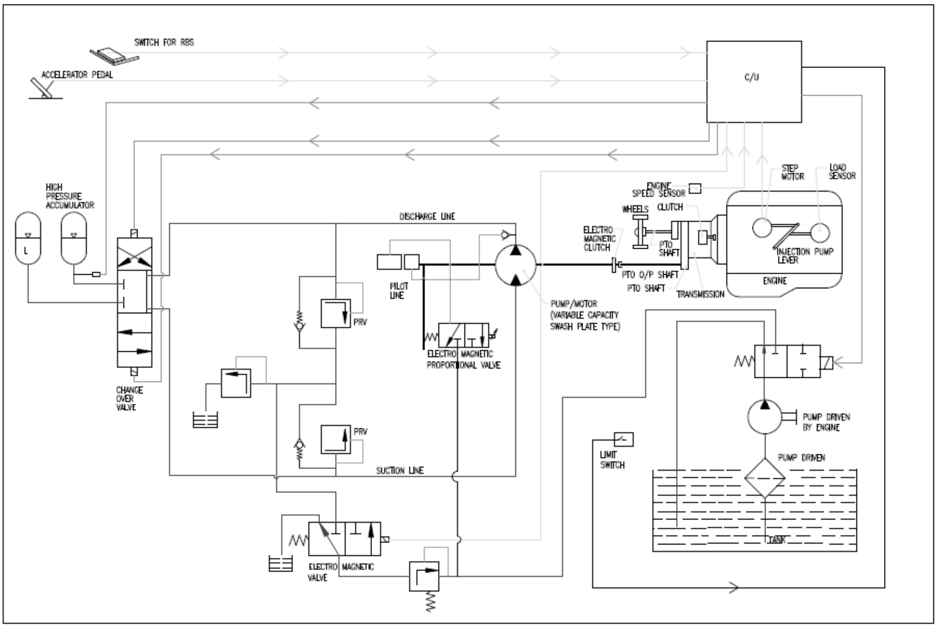


Figure 2.

<u>*AutoCAD Hydraulic layout*</u>



CATIAV5 Hydraulic Pump/Motor forces

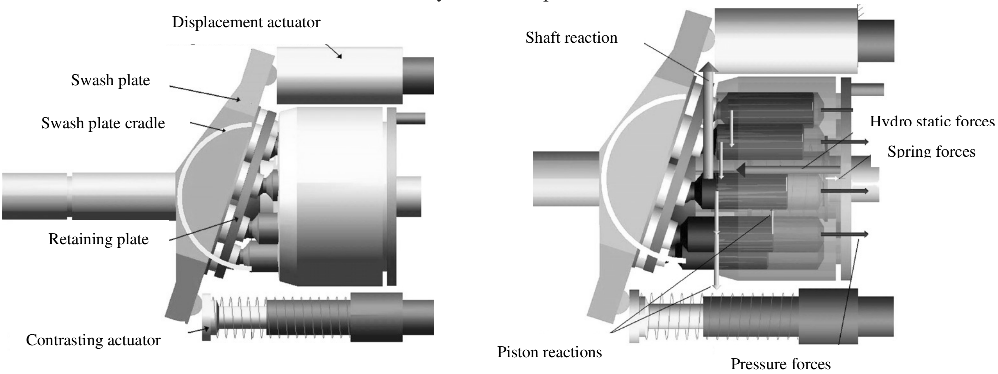


Figure 2. (*Continued*).

Control system layout during starting

During the starting, If the inner pressure of the accumulator being sufficient, the control unit controls the pump/motor as a variable capacity type motor, the capacity of which is controlled by varying the displacement angle of the swash plate or shaft in response to the accelerator pedal positions. If the accumulator pressure is not sufficient enough then the vehicle will operate solely on engine fuel. Here the swash plate position was fully opened. See the reference Figure 2_Starting system layout.

Hydraulic layout

Refer the Figure 2_ hydraulic circuit. It is the hydraulic layout to capture the braking energy during deceleration and to supply the accumulated energy during acceleration. To understand the Pump/Motor swash plate operation see the reference Figure 2_CATIAV5 Hydraulic Pump/Motor.

1.2. Analysis of the Fixed Output Generation

In the regenerative system, the output of the vehicle is combined with the motoring output of the pump/motor and the engine to supply an amount of fuel corresponding to the position of the acceleration pedal, to drive the wheels at the starting.

When the position of the acceleration pedal exceeds the predetermined value the control unit controls the pump/motor to serve as a motor in proportion to the pedal position where by the power generated by the motor is added to the drive line of the wheels.

Therefore it is disadvantageous that the sum of the outputs of the engine and the motor cannot fixed because the output of the motor is varied due to the variation of the inner pressure of the accumulator even when the acceleration pedal position is fixed.

1.3. Concept Generation

To solve the above problem we came up with different concepts that are generated by Intuitive method (Morphological analysis and Brain storming) of idea generation. Following concepts were generated to get the fixed output for the fixed pedal position

1.3.1. Spring controlled throttle valve mechanism

When the controller unit senses the information related to the deficiency in the accumulator, the LVDT (Linear Variable Differential Transducer) operated by the controller unit excited as per the deficiency which in turn pushes the spring to open the throttle valve to get more pressure difference in the carburetor. Disadvantage of this mechanism is more dead weight on the throttle valve because throttle valve is already controlled by the acceleration lever. See the reference Figure 3–Spring controlled mechanism.

1.3.2. Pin ball controlled throttle valve mechanism

When the controller unit senses the information related to the deficiency in the accumulator, the LVDT (linear variable differential transducer) operated by the controller unit excited as per the deficiency which in turn pushes the pin ball to open the throttle valve to get more pressure difference in the carburetor. Dead weight problem was avoided with this mechanism See the reference Figure 3–Pinball controlled mechanism.

1.3.3. Throttle pin controlled through LVDT via gearbox

Throttle pin is used to hold the throttle valve in the carburetor. When the controller unit senses the information related to the deficiency in the accumulator, the LVDT (linear variable differential transducer) operated by the controller unit excited by a gearbox as per the deficiency which in turn rotates the throttle pin to open the throttle valve to get more pressure difference in the carburetor. This is the more efficient way of controlling the output. See the reference Figure 3-throttle pin controlled through LVDT.

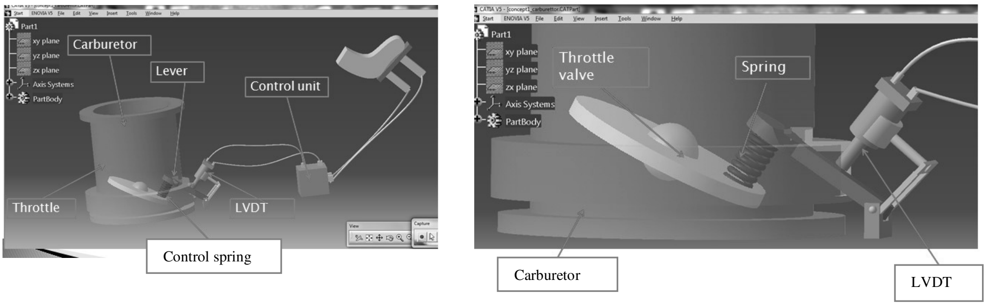
1.3.4. Throttle pin controlled by worm and worm wheel mechanism

Throttle pin is used to hold the throttle valve in the carburetor. When the controller unit senses the information related to the deficiency in the accumulator, the LVDT (linear variable differential transducer) operated by the controller unit excited by a worm and worm wheel as per the deficiency which in turn rotates the throttle pin to open the throttle valve to get more pressure difference in the carburetor. See the reference Figure 3–throttle pin controlled worm and worm wheel mechanism.

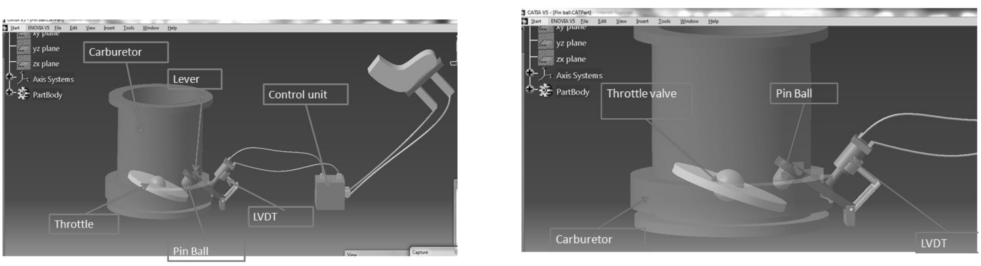
1.3.5. Pressure controlled through MPFI system

Presently most of the vehicles are using the MPFI, (Multi Point Fuel Injection system) to atomize the fuel and send to the inlet manifold of the engine. Here all the parts are controlled by CPU.

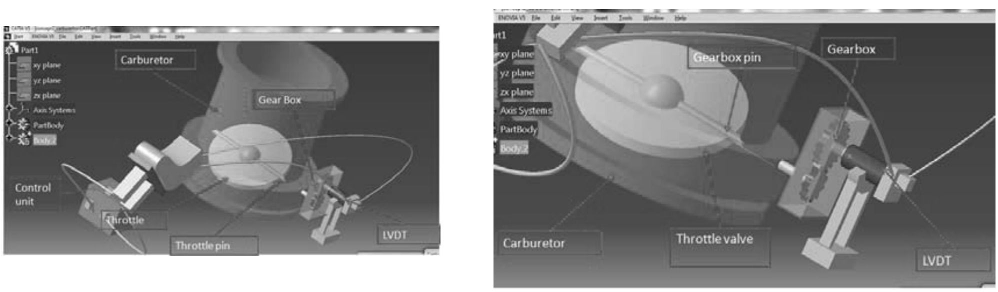
1. *Spring controlled throttle valve mechanism*



2. *Pin ball controlled throttle valve mechanism*



3. *Throttle pin controlled gearbox through LVDT*



4. *Throttle valve controlled by worm and worm wheel by LVDT*

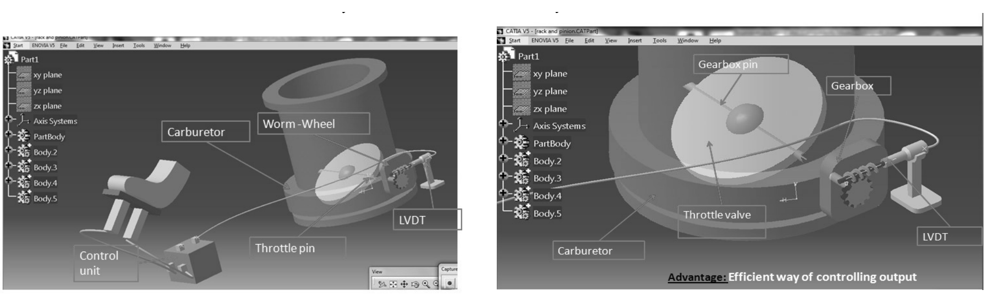
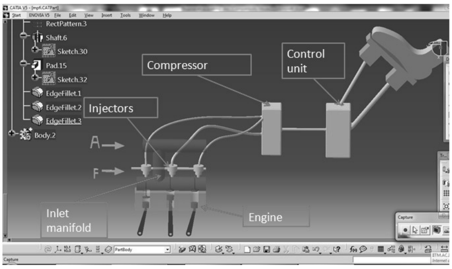


Figure 3.

5 Pressure controlled MPFI system



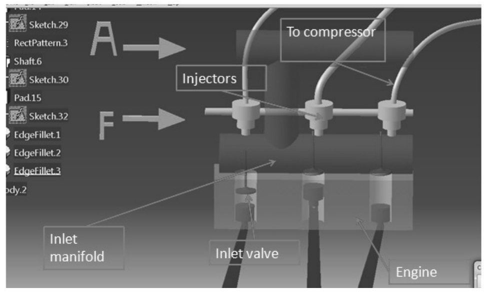


Figure 3. (*Continued*).

When the controller senses the information related to the deficiency in the accumulator the MPFI compressor will get input from the control unit to apply more pressure to the fuel injection injectors. Due to more pressure difference more fuel will be entering into the inlet manifold which in turn produces more output and the ratio of fixed output can be controlled. See the reference Figure 3–Pressure controlled MPFI system.

1.4. Evaluation of Concepts

Weighted decision matrix method was used to evaluate the concepts by defining the relative rating with respect to the customer requirements. See the reference Figure 4 — Evaluation using the decision matrix.

Reasons considered for MPFI system selection as best from decision matrix are

- Suitability to the present cars due to presence of electronically controlled MPFI system.
- Easy to adopt the MPFI system.
- Few modifications in the CPU to control the flow of fuel.
- Reduced manufacturing cost.

Decision matrix		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5	
Criteria	Wt.	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating
1	9	2	18	4	36	6	54	9	81	9	81
2	7	4	28	6	42	8	56	8	56	8	56
3	8	2	16	6	48	8	64	8	64	10	80
4	5	3	15	8	40	6	30	6	30	6	35
5	5	4	20	2	10	4	20	6	30	8	40
6	6	4	24	5	30	4	24	5	30	9	54
Total			**121**		**206**		**248**		**281**		**346**

❖Pressure controlled MPFI system

58

Figure 4.

1.5. Conclusion

- A regenerative braking system is an energy recovery mechanism that captures and converts the kinetic energy wasted during braking into a useful form of energy instead of dissipating it as heat as with a conventional brake.
- A hydraulic layout was generated to capture the braking energy and to supply the same for vehicle starting and cruising.
- This has been successfully implemented with the Dzire car analytically and 4.2% of the energy can be retrieved back to the useful work.
- In conventional method we can't get fixed output due to the variation of the inner pressure of the accumulator, even when the position of the acceleration pedal is fixed.
- Above problem was addressed with the five concepts out of which the MPFI controlled one was selected as the best.

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