A COMPARISON OF TWO ENGINES ECU

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Abstract

The modern vehicles are becoming more and more complex and contain many systems among these is the internal combustion engine which is the heart of the vehicle. Modern engines are controlled by dedicated Electronic Control Unit (ECU) which acts as the mastermind of the engine. The control unit (ECU) receives readings from sensors and takes actions through actuators; the operation of the ECU is regulated by embedded models called MAPs which are stored in the ECU memory.

The use of identical internal combustion engine to drive several vehicle classes is becoming more and more common in automotive industry, such approach allows for production flexibility and reduces production cost as well. In the present study, two vehicles operating with the same engine are selected; the MAPs stored within the two control units (ECUs) have been analysed and compared. The several changes done in ECU MAPs allowed for: steady idle, better acceleration performance, more responsive turbocharging and better fuel utilization with a higher power output.

Keywords: Engine management, common rail, ECU, MAP

1. Introduction

Engine power is a very important specification for any internal combustion engine, it depends on several variables including the amount of fuel injected, the timing of injection, etc. In the past, the engine variables were controlled by means of mechanical components, nowadays with the huge advance in technology and electronics, most control is being implemented within Electronic Control Units (ECU). The ECU is an embedded electronic device [1] that controls a series of actuators on an internal combustion engine (e.g. fuel injector) to ensure optimal engine performance. It does this by reading signals coming from sensors placed at various parts within the engine bay (e.g. engine speed sensor), interpreting the data using multidimensional performance lookup tables (called MAPs), and adjusting the engine actuators accordingly.

The fuel injection system has the major role to control the engine's performance, the ECU uses input information (e.g. engine speed and load) to extract the appropriate injector time from the MAPs and then fires the injector for this length of time. The ECU uses Pulse Width Modulation (PWM) to control the amount of fuel that exits the injector and goes into the cylinder. The ECU must not only control the fuel Injected Quantity (IQ) but also must control the time the fuel is injected into the cylinder to achieve the optimum time that produce the best explosion (power).

However, there are times when the engine is not running under the ideal conditions and it is at these times that other vital feedback is required to allow the ECU to run the engine properly. Generally, under these conditions the ECU makes adjustments or (corrections) to the fuel Injected Quantity (IQ) according to what it knows about the prevailing conditions.

The fuel Injected Quantity (IQ) must be limited for two main reasons: enough air must be available (smoke limit) and smooth engine power must be produced to safe guard the power train (torque limit).

2. Case study

The present study is based on a comparison of two ECUs used to operate two identical engines; this will be accomplished by investigating two identical TDI engines manufactured by the same company, however, equipped with two different ECUs to increase engine power. The engines are 1600 16v TDI, both engines have the same mechanical components but different output power, the first engine (Engine A) have 90 hp, while the second engine (Engine B) have 105 hp. The MAPs stored in each ECU are directly extracted by the On-Board Diagnostics (OBD) plug using the KESS v2 device, see Figure 1. The WinOLS software is used to read/view the MAPs and compare them.

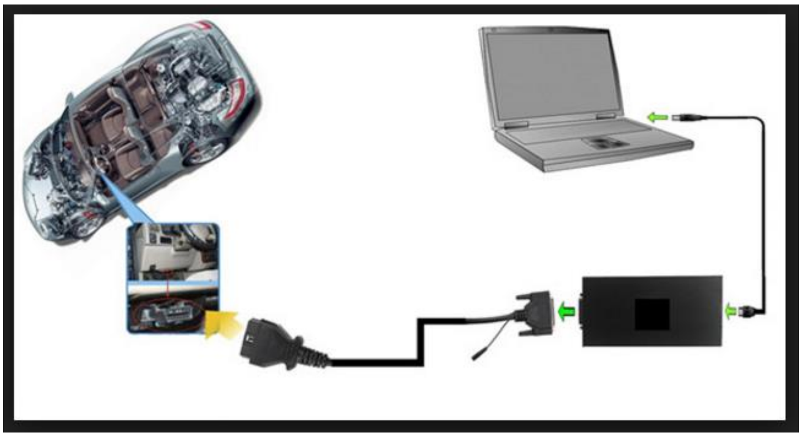

Figure 1: ECU data extraction using KESS v2 device

3. Results and Discussion

After reading and comparing the sixteen MAPs stored in each ECU, it was found that the change occurred only in six MAPs as will be discussed below.

3.1 Driver Wish MAP

Table 1 provides the percentage differences between (Engine A) and (Engine B) MAP values calculated as the values of Engine B divided by the values for Engine A (i.e. IQ Engine B / IQ Engine A). The fuel Injection Quantity (IQ) output is increased up to 10% at the most usable power band (i.e. high pedal percentage request and high engine rpm); the reason for this increase is to allow for better acceleration performance in Engine B which makes the engine more responsive. However, the value given in the driver wish MAP is not final because the ECU contains other limiting MAPs that limit the fuel Injection Quantity (IQ): smoke limit and torque limit MAPs.

Table 1: Driver wish percentage difference between Engine B and Engine A

IQ percentage difference		Accelerator pedal (0 - 100)%							
		1%	**4%**	**10%**	**25%**	**37%**	**56%**	**80%**	**100%**
Engine rpm	**0**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	399	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	609	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	693	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	798	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	903	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1008	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1113	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1218	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1491	1.00	1.00	1.00	1.00	1.00	1.02	1.00	1.00
	1995	1.00	1.25	1.19	1.00	1.00	1.04	1.03	1.00
	2499	1.00	1.00	1.00	1.00	1.00	1.03	1.04	1.00
	3003	1.00	1.00	1.00	1.00	1.00	1.05	1.04	1.03
	3990	1.00	1.00	1.00	1.00	1.00	1.01	1.04	1.09
	4998	1.00	1.00	1.00	1.00	1.00	1.04	1.08	1.10
	5355	1.00	1.00	1.00	1.00	1.00	1.10	1.10	1.10

3.2 Smoke limit MAP

This MAP is going to limit the amount of fuel actually injected by looking at the actual amount of air going into the engine. It regulates the amount of black smoke (unburned fuel). The main change in smoke limit MAP (see Table 2) is focused in the low-medium air flow and engine rpm with a percentage increase up to 25%. This region covers engine operation during cranking and idling, therefore, Engine B is expected to have a rock steady idle, however, with emissions higher than Engine A.

3.3 Torque limit MAP

This MAP limits the fuel Injected Quantity (IQ) based on engine speed and atmospheric pressure. It is designed to protect the entire power train (from engine to tires) by limiting the actual beneficial power at given engine speed.

Since there is no point in having a higher IQ below 2000 rpm as their will not be enough air available; the main change in MAP values (see Table 3) is focused in the medium to high engine speed with a percentage increase up to 15%. This region covers engine operation during acceleration and cruising, therefore at a given engine speed, Engine B is expected to have a responsive power shift compared with slower power shift in Engine A

Table 2: Smoke limit percentage difference between Engine B and Engine A

IQ percentage difference		300	350	400	450	503	550	600	650	750	850	925
		Mass Air Flow, MAF (300 – 925) mg/stroke										
Engine rpm	861	1.10	1.09	1.12	1.08	1.06	1.02	1.00	1.00	1.00	1.00	1.00
	924	1.17	1.22	1.18	1.11	1.08	0.97	0.92	0.94	0.95	0.95	0.95
	1008	1.21	1.25	1.20	1.14	1.09	1.01	0.97	0.95	0.93	1.00	1.00
	1260	1.16	1.22	1.16	1.12	1.09	1.04	1.02	0.99	0.95	1.01	1.02
	1491	1.12	1.14	1.09	1.05	1.04	1.06	1.06	1.04	1.02	1.05	1.04
	1743	1.06	1.05	1.05	1.03	1.03	1.02	1.04	1.04	1.03	1.05	1.05
	1995	1.03	1.03	1.03	1.01	1.02	1.02	1.03	1.02	1.02	1.03	1.05
	2247	1.00	1.00	1.00	1.00	0.99	1.00	1.02	1.01	1.00	1.01	1.04
	2499	1.00	1.00	1.00	1.00	0.99	0.99	1.01	0.99	0.98	0.99	1.01
	2751	1.00	1.00	1.00	1.01	0.99	1.00	1.01	0.98	0.97	0.98	0.99
	3003	1.00	1.00	1.00	1.00	0.98	1.00	1.01	0.98	0.97	0.97	0.98
	3255	1.00	1.00	1.00	1.00	0.98	1.00	1.00	0.98	0.97	0.97	0.98
	3507	1.00	0.99	1.00	1.00	0.98	1.00	1.01	0.98	0.97	0.97	0.98
	3759	1.00	0.99	1.00	1.00	0.98	0.99	1.00	0.98	0.97	0.97	0.98
	4242	0.99	0.97	0.97	0.98	0.96	0.98	1.00	0.98	0.97	0.98	0.99
	5355	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.00	0.98	1.00	1.01

Table 3: Torque limit percentage difference between Engine B and Engine A

IQ percentage difference		Engine rpm (551– 2499 rpm)								
		551	1000	1250	1500	1750	1900	2016	2247	2499
Atmospheric Air Pressure (850 - 1000 mbar)	850	0.98	0.98	0.93	1.00	0.99	1.00	1.01	1.02	1.03
	900	0.98	0.98	0.93	1.00	0.99	1.03	1.03	1.04	1.04
	1000	0.98	0.98	0.93	1.00	0.99	1.03	1.03	1.04	1.04
		Engine rpm (2750– 4800 rpm)								
		2750	3000	3250	3500	3750	4000	4250	4500	4800
Atmospheric Air Pressure (850 - 1000 mbar)	850	1.05	1.06	1.08	1.10	1.13	1.15	1.10	1.10	1.03
	900	1.05	1.06	1.08	1.10	1.13	1.15	1.10	1.10	1.03
	1000	1.05	1.06	1.08	1.10	1.13	1.15	1.10	1.10	1.03

3.4 Turbocharger boost pressure MAP

The boost MAP determines the boost pressure based on fuel Injected Quantity (IQ) and engine speed. Most of the boost pressure changes (see Table 4) occur in the medium to high engine speed which is the area of interest for turbo charger operation (2000-4000 engine rpm). The percentage difference within this region is about 2%, however, this maximum boost pressure is always associated with the maximum fuel Injected Quantity (IQ). It is important to mention that the value given in the boost MAP is not final, since another MAPs control the amount of final pressure: boost pressure limit, and N75 duty cycle.

Table 4: Boost pressure percentage difference between Engine B and Engine A

Boost pressure percentage difference		IQ (0 - 45) mg/stroke								
		0	5	10	15	20	25	30	35	45
Engine rpm	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	21	1.00	1.00	0.99	1.00	1.01	1.00	1.00	1.00	1.00
	1008	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00
	1260	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94	0.86
	1500	1.00	1.00	1.01	1.00	1.00	1.01	0.98	0.97	0.92
	1750	1.00	1.00	1.02	1.02	1.02	1.01	0.99	0.98	0.95
	1900	1.00	1.00	1.03	1.02	1.02	1.01	0.99	0.98	0.97
	2000	1.00	1.00	1.03	1.03	1.02	1.01	0.99	0.99	0.97
	2247	1.00	1.00	1.03	1.03	1.02	1.01	0.99	0.99	0.97
	2499	1.00	1.00	1.02	1.02	1.02	1.01	0.99	0.99	0.98
	3500	1.01	1.00	1.00	1.01	1.01	1.00	1.00	1.01	0.99
	3750	1.01	1.00	1.00	1.01	1.02	1.02	1.00	1.01	0.99
	3990	1.01	1.01	1.01	1.00	1.02	1.02	1.01	1.01	1.00
	4250	1.03	1.01	1.02	1.00	1.02	1.02	1.01	1.00	1.01
	4494	1.00	1.02	1.02	1.00	1.02	1.02	1.01	1.00	1.04
	4746	0.96	1.02	1.02	1.00	1.02	1.02	1.02	1.03	1.05

3.5 Turbocharger boost pressure limit MAP

Boost pressure limit MAP determines the limiting value of the boost pressure when the atmospheric air pressure is different from ideal (ideal is taken as 1000 mbar). At low air pressure, the air is thinner so the turbocharger cannot compress enough air and will spin too fast as it tries, which will damage the turbocharger. Table 5 shows the percentage difference which indicates that Engine B allows slightly higher boost limit at middle to high rpm (up to 6%), so Engine B is slightly less turbo limiting. Therefore, it is expected to have better performance at turbo conditions.

Table 5: Boost pressure limit percentage difference between Engine B and Engine A

Boost pressure percentage difference		Engine rpm									
		1490	1743	1911	2247	2499	3003	3507	3990	4242	4494
Atmospheric Air Pressure	600	0.94	0.95	0.99	1.05	1.06	1.04	0.98	0.99	1.00	1.02
	650	0.94	0.95	1.00	1.05	1.06	1.04	0.98	0.98	0.99	1.00
	700	0.94	0.95	1.00	1.05	1.06	1.05	1.00	0.99	1.00	1.01
	750	0.94	0.95	1.00	1.05	1.06	1.05	1.00	1.01	1.02	1.04
	800	0.94	0.95	1.00	1.04	1.05	1.05	1.00	1.00	1.01	1.02
	850	0.96	0.97	1.00	1.04	1.05	1.05	1.01	1.01	1.02	1.03
	900	0.96	0.97	1.00	1.04	1.05	1.05	1.03	1.01	1.02	1.04
	950	0.96	0.97	1.00	1.03	1.04	1.04	1.04	1.04	1.05	1.06

3.6 Turbocharger N75 duty cycle MAP

N75 Solenoid valve is the electronic boost controller that the ECU uses to manage boost in the system. N75 duty cycle MAP is very critical since it prevent the turbocharger from explosion due to high pressure build up in turbocharger casing.

N75's duty cycle determines the boost duty; this is a value from 0% to 100%. When the N75 duty cycle is 0%, the waste gate actuator is opening 100% thus the exhaust gases are bypassed and no boost pressure is built. On the other hand, when N75 duty cycle is 100%, the waste gate actuator is completely closed thus all exhaust gases are directed toward the turbine to build up boost pressure.

The N75 duty cycle is normally set between 80-95% at idle such that the turbo is set to give the maximum boost since the exhaust gases flow is low. At higher engine rpm, the N75 duty cycle is normally set between 20-25% in order to protect the turbo from the high exhaust gases flow out from the engine. Table 6 presents the percentage difference between Engine B and Engine A, there is a little difference in N75 duty cycle below 1500 rpm as the turbocharger is not working even though it is set for maximum boost 80%. Over 1500 rpm, the differences become more evident, in general Engine B is set to provide more boost compared with Engine A; a maximum percentage increase of 36% is found (N75 duty cycle of 31.9% in Engine A to a duty cycle 43.4% in Engine B).

Table 6: N75 duty cycle percentage difference between Engine B and Engine A

N75 duty cycle percentage difference		IQ (0 - 58) mg/stroke												
		0	5	10	15	20	25	30	35	40	45	50	55	58
engine rpm	760	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	780	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1150	0.92	0.92	0.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1300	0.96	0.96	0.96	1.04	1.04	1.04	1.09	1.15	1.21	1.25	1.25	1.25	1.25
	1500	1.04	1.04	1.04	1.09	1.15	1.19	1.23	1.24	1.23	1.15	1.08	1.02	0.99
	1650	1.07	1.07	1.07	1.14	1.18	1.20	1.22	1.22	1.22	1.18	1.15	1.11	1.06
	1743	1.09	1.09	1.09	1.16	1.18	1.19	1.21	1.25	1.35	1.29	1.18	1.10	1.06
	1911	1.11	1.11	1.11	1.19	1.18	1.19	1.19	1.19	1.33	1.30	1.24	1.15	1.13
	2058	1.13	1.13	1.12	1.21	1.20	1.20	1.21	1.20	1.28	1.30	1.33	1.27	1.19
	2247	1.16	1.15	1.14	1.24	1.20	1.17	1.19	1.20	1.36	1.32	1.32	1.30	1.31
	2499	1.22	1.21	1.20	1.26	1.21	1.18	1.17	1.20	1.36	1.30	1.27	1.28	1.27
	3003	1.14	1.16	1.18	1.19	1.12	1.10	1.12	1.15	1.25	1.21	1.19	1.16	1.16
	3507	1.09	1.13	1.10	1.06	1.07	1.07	1.11	1.15	1.14	1.15	1.13	1.09	1.04
	3990	1.08	1.16	1.09	1.05	1.03	1.03	1.07	1.13	1.13	1.10	1.06	1.00	0.96
	4242	1.08	1.18	1.11	1.04	1.02	1.02	1.21	1.17	1.12	1.08	1.00	0.96	0.94

4. Conclusions

The ECU contains a set of MAPs that regulates the fuel Injected Quantity (IQ) and boost pressure. Some of the MAPs work as a lookup table while others work as a limiting condition. In the case study provided, the two engines ECUs are compared based on the stored MAPs within each ECUs. The several changes done in Engine B MAPs will allow for: steady idle, better acceleration performance, more responsive turbocharging and better fuel utilization with a higher power output.

References

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