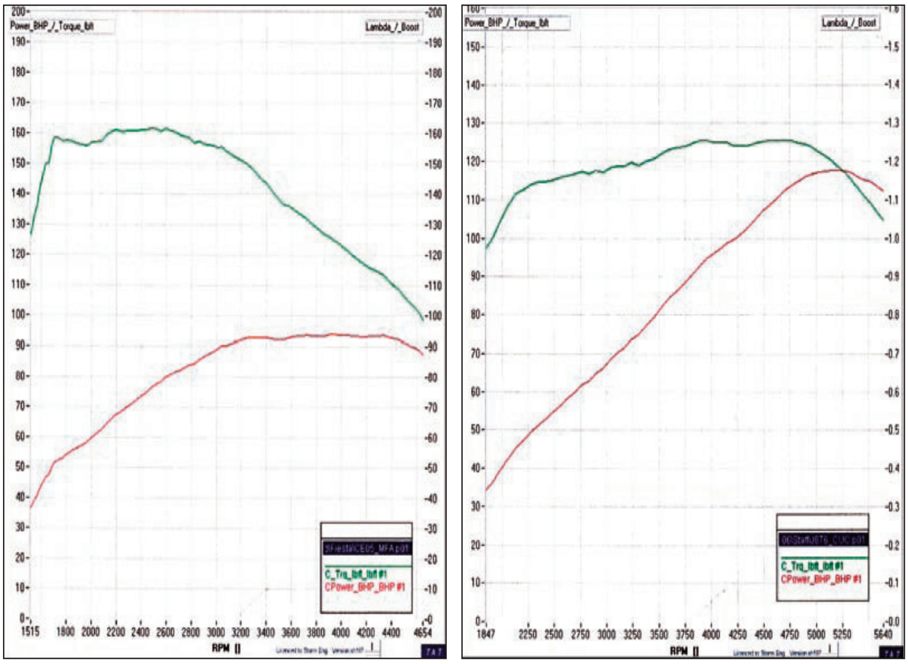
Torque and Power part 2

In the March issue of Autobiz, part one of this Tech Tip explained the differences and relationship between torque and power. In this second installment, the Institute of the Motor Industry (IMI) sets out to further examine the nature of torque and power in diesel and petrol engines and to shed some light on what remapping is and what it can do.

Petrol and diesel engines have always had very different properties. Diesel is renowned for good, low end torque and petrol for high revving, quick acceleration. With modern designs, these differences have become less obvious. The rough running diesel has been mostly cured by high pressure common-rail injection and the refinement of the petrol engine's valve timing mechanism, has improved power output and flexibility. Here, we will look at the two engines in terms of torque signatures and how engine performance can be improved in both. There are fundamental differences between petrol and diesel engines, which give them very different torque curves.



A typical torque (green) and horsepower (red) curve for a diesel engine, on left, and a petrol engine, on the right.

The most obvious difference is maximum torque. The diesel engine produces maximum torque at around 2000rpm, whereas the petrol engine does this at over 4000rpm. This gives a very different driving experience and performance. The initial surge in a diesel is followed by a sharp reduction in engine torque, which encourages the driver into a gear change. The petrol engine, by contrast, produces a relatively flat torque curve, which gives a continuous long pull feel to its acceleration. So why is this?

The diesel engine has higher peak and average combustion pressures and this means that the piston/crank assembly has to be more substantial and therefore heavier, which limits the maximum speed of the engine. Speed is also limited by a slower combustion process. Petrol engines are lighter and with lower cylinder pressures. They produce less torque but gain their superior power by producing it faster. Modern design allows engines to breathe effectively, even at high engine speeds.

The power/torque graph above is from a naturally aspirated Honda 2 litre type R. As you can see, the torque curve is long and relatively flat, due, among other things, to variable valve lift and timing.

Improving petrol engine performance

There was a time when what goes on under the bonnet was well understood not only by the professional mechanic, but by enthusiastic amateurs. With a fairly basic toolkit, a weekend project could reap a large improvement in an engine's performance. Currently, due to the computerisation of the engine and stringent legislation, would-be petrolheads are often limited to cosmetic changes. Real gains in engine performance can only be achieved by quite involved engineering and ECM reprogramming, but it must still pass its NCT emissions test. This limits the modification to improvements in volumetric efficiency.

Volumetric efficiency

If a piston moves slowly from top to bottom with the inlet valve open, we would expect the cylinder to be full of charge at atmospheric pressure, or 100% volumetric efficiency. As the engine speed increases, the time available to fill the cylinder is reduced. At 6000 rpm, a typical induction stroke takes 1/200 of a second, and this reduces the volumetric efficiency. Pressure charging can produce volumetric efficiencies over 100%. Engine designers take into consideration every aspect of the way the air moves into the engine, but the resulting design will be a compromise of power, driveability and reliability. This gives the engine modifier room to manoeuvre. There are many options, but ultimately the ECM is king. Unmodified naturally aspirated engines will benefit little from a remap, but the power output of pressure-charged engines can be improved by up to 30%. With modifications to valve gear and manifolds, more substantial increases in power can be achieved.

So what is remapping?

The engine ECM is a computer and works in a different time frame to us! Millions of decisions can be made every second, so a decision about how much fuel to inject, or when to ignite it, even at 10,000rpm, is done with plenty of time to spare. The ECM uses a set of instructions and data look-up tables to do its job. Basic look-up tables are fuel and ignition, but there are many more for coolant temp, map, boost, etc. The look-up tables maps can be displayed graphically, which produces a contoured three dimensional map of the data, thus the term mapping. Remapping is done by altering the data in the fuel and ignition look-up tables to take advantage of the extra air provided by changes in boost pressure control and other modifications that provide more air.

Remember that whenever the vehicle is fitted with a catalytic converter and O2 sensor, the air/fuel ratio (AFR) will need to remain at 14.7:1. Removing the catalytic converter on any vehicle manufactured after January 1993, will cause it to fail its emissions test. Initially, remapping needs to be done using a chassis dynamometer, but once a working map is made, it should fit every standard engine of the same specification. For off-road performance vehicles, bespoke mapping is needed. A dynamometer and either a wide band oxygen sensor, or a gas analyser, are essential to take advantage of the modifications to the engine and to get optimum performance and reliability. Without the catalytic converter and no worries about emission tests, the AFR can be altered. This will give further improvements in torque and power (obviously with great detriment to fuel economy and the environment). The catalytic converter can only work properly if the AFR is very close to 14.7:1. This gives the lowest emissions and fuel consumption. However, for optimum power, a rich mixture of around 12.5:1 is used. This mixture also runs cooler and is therefore a safer air AFR for performance engines.

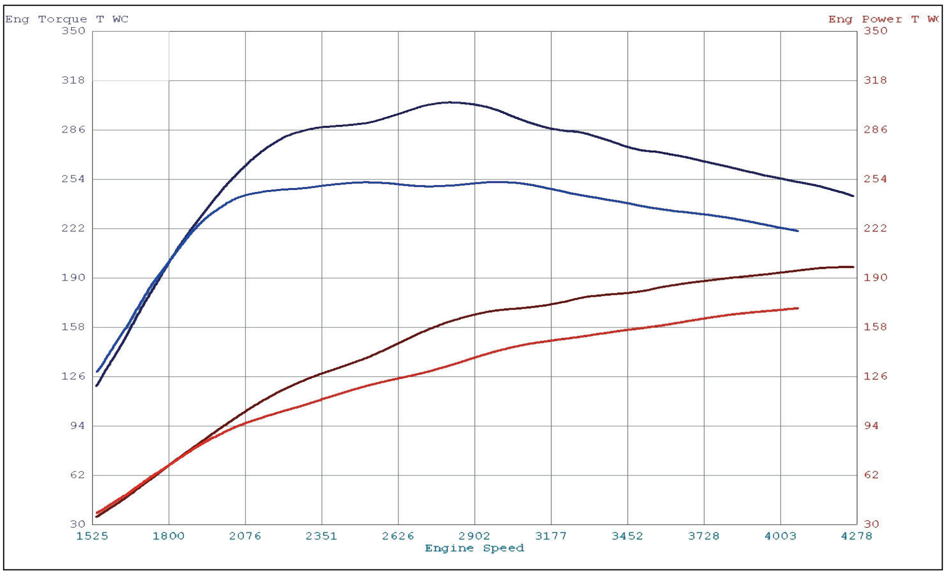
There are many diesel engine performance enhancing companies which make claims of substantially improved power output and reduced fuel consumption. It can be done in two ways: Digital plug-in interface or mapping. A digital plug-in box fits between the harness and the ECM. Signals from the sensors are modified before they get to the ECU. This effectively fools the engine's ECM into injecting more fuel. Re-mapping involves accessing the ECM's maps though a K line or CAN-bus line on the 16 pin diagnostic socket and changing the maps. Increasing the amount of fuel injected, is usually achieved by increasing the injector rail pressure under maximum load. Remapping companies may claim that this can be done, because diesel engines run with air fuel ratios that are weak. In a diesel engine there is always more oxygen in the cylinder than is needed by the fuel. This helps ensure the most complete combustion possible and reduces the emission of particulates. By increasing the amount of fuel injected, some of this excess air is used to provide more torque. The results can be quite startling.

AP Injector 1 Map A

Inlet Air Pressure (% of max)

Estimated RPM (% of 65536 x 12,500)	46.9	40.6	34.4	28.1	26.6	25.0	23.4	21.9	20.3	18.8	18.0	17.2	16.4	15.6	14.8	14.1	12.5	10.9	9.4	7.8	6.2	4.7	3.1	2.3	1.6	0.8	0.0
586	26	28	30	34	37	39	42	47	50	53	55	58	61	63	64	66	69	71	75	81	86	99	111	118	124	138	162
684	26	28	30	33	35	38	40	45	48	51	53	56	58	60	62	64	66	68	73	79	83	97	108	116	123	136	162
781	26	28	30	32	34	36	39	43	46	50	52	54	56	59	61	62	65	67	72	78	82	95	106	113	120	134	162
879	26	28	30	32	34	36	39	42	46	49	53	56	58	60	62	65	67	67	72	78	83	93	104	110	118	130	158
977	24	26	28	32	34	36	38	42	45	49	52	55	57	59	61	64	66	67	73	78	83	91	100	104	110	126	154
1074	22	24	26	30	32	36	39	41	43	48	51	53	56	58	61	64	67	69	73	78	82	88	96	100	108	122	150
1172	20	22	24	28	30	36	40	42	44	46	49	54	57	59	62	64	66	67	72	75	78	86	94	100	108	120	150
1270	18	20	22	26	28	37	41	43	45	48	50	52	56	58	60	63	64	66	70	73	75	80	92	97	106	120	148
1367	16	18	20	24	26	38	41	42	44	47	49	51	54	56	58	62	63	66	70	73	75	79	87	95	106	122	150
1465	16	18	22	26	28	37	40	41	43	46	48	50	52	55	58	61	62	66	72	75	77	81	86	95	108	126	158
1562	8	12	16	22	25	33	40	43	44	47	49	51	53	56	59	62	65	68	73	76	78	83	91	100	110	132	168
1758	8	12	16	22	25	33	38	42	44	46	48	50	54	57	60	63	66	70	75	77	78	89	101	110	124	150	187
1953	8	14	18	24	27	30	37	44	45	47	50	54	56	59	62	65	69	72	75	78	87	93	108	121	138	160	193
2148	8	14	18	26	29	32	39	48	52	54	57	60	62	64	67	70	73	75	78	83	92	98	113	130	148	169	191
2344	8	16	22	30	34	39	43	52	56	57	60	63	66	68	70	72	75	77	80	87	93	100	116	135	151	175	193
2539	8	18	30	35	38	40	44	51	56	58	61	64	68	70	72	74	76	78	79	84	93	102	118	138	153	173	192
2734	8	18	33	37	40	41	44	48	53	56	59	62	66	69	70	73	75	77	79	83	94	103	117	134	148	167	197
2930	10	26	34	39	41	42	46	49	53	56	59	62	66	68	71	73	76	78	80	87	97	106	116	132	144	172	208
3125	13	27	33	39	42	45	49	51	55	59	61	64	66	70	72	75	78	80	85	93	101	110	120	132	143	176	218
3320	21	29	35	40	44	47	52	54	57	62	64	66	69	72	75	77	80	85	95	109	113	119	127	139	150	185	224
3516	24	30	36	40	43	47	52	56	62	66	68	72	75	79	81	84	86	91	99	116	122	132	139	147	161	196	229
3711	26	34	39	41	44	48	53	58	67	70	74	77	80	83	86	88	91	95	102	120	132	138	145	154	167	202	235
3906	28	35	40	43	46	52	56	62	70	76	79	78	81	85	87	88	91	96	101	119	136	143	152	161	174	209	244
4297	31	35	41	44	48	55	61	66	74	78	79	81	83	84	87	89	94	96	102	110	128	134	144	154	168	200	234
4688	31	33	39	44	48	59	66	70	75	78	79	81	83	85	87	90	94	97	100	109	130	138	150	162	176	212	248
5078	29	31	37	43	48	62	68	72	74	77	79	81	84	85	87	89	92	96	99	101	119	138	150	166	182	220	255
5469	27	29	34	42	46	59	67	69	71	74	77	79	80	82	83	85	87	89	91	95	104	117	148	160	174	218	255
5859	27	29	34	40	47	57	65	67	70	72	75	77	79	83	84	86	87	89	91	96	100	112	144	158	172	216	255
6250	25	27	32	38	46	55	62	66	69	71	75	76	80	83	86	88	90	91	93	96	100	111	124	152	164	214	255
6641	24	27	31	37	41	47	54	58	63	67	70	74	79	83	83	87	89	91	93	94	100	113	121	139	156	208	255
7031	24	26	28	34	38	42	48	54	59	63	66	69	71	76	80	83	86	89	92	95	101	110	117	135	150	208	255
7812	22	24	28	34	38	42	47	52	57	60	64	67	69	72	75	79	86	90	94	98	102	110	118	130	145	211	255
8789	22	24	26	32	36	40	44	49	54	59	62	64	67	69	73	78	86	90	95	101	109	115	118	129	143	224	255
9766	21	23	25	31	35	39	43	47	52	57	59	62	64	67	72	78	89	95	102	113	128	149	167	181	188	245	255
10742	20	22	24	30	34	38	41	44	49	54	57	59	62	64	71	78	91	103	115	132	156	190	214	226	239	255	255
11719	20	22	24	30	33	36	39	42	47	52	54	57	59	62	70	78	94	111	128	146	170	208	236	248	255	255	255

The ECM makes decisions about how to run the engine by looking up data from tables and acting according to these dynamic rules. Remapping is done by changing these values or adding a device that changes what the ECM sees to accomplish the same effect.



Remapping can boost the torque, blue, and horsepower, red. The lower set of each curve is before remapping.

Always entrust remapping to a reputable mechanic. Remapping has to be done carefully to avoid excessive emissions, especially in vehicles fitted with diesel particulate filters (DPF). The DPF removes carbon particulates (black smoke) and stores it. Sensors detect an accumulation of particulates and, when required, initiate a regeneration process which heats the filter to over 600C. The carbon is burnt off as CO2 and ash. The DPF can be problematic, especially if the regeneration is interrupted by short drive cycles.

Remapping and Euro standards

The implementation of Euro standards has had a large part to play in encouraging engine manufacturers to produce the quieter, cleaner diesel engines we enjoy today.

Modern vehicles which meet Euro 5 standards are fitted with sophisticated pre and/or after-treatment emission control systems. Without them, the engine struggles to meet these standards. Altering the map for more power is unlikely to improve emissions, but it should be noted, that a remapped engine will still have to pass any relevant emissions or smoke test, to pass the NCT.