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An investigation into the finding
optimum ignition timing angle for a SI
engine.

Research Methods and Projects
M6X02206

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1. Abstract.

1.1 This report has been written to outline the primary test aim of increasing engine efficiency at a given load site whereby the test engine produces its peak torque, by carrying out a Mean Best Torque test at a given manifold pressure which will vary ignition timing from 0°TDC to 40°BTDC in 2-degree intervals to find the optimum ignition angle for the given load site, however the injection on-time will not be altered. The secondary test aim will be to reduce exhaust gas emission levels at this given load site by achieving MBT, which will be measured using a 5-gas analyser and the results compared to that of the standard car. The test will be carried out on a Maha MSR 500 dynamometer which will be equipped with a wideband lambda probe which will insure the AFR is within safe limits.

1.2 This report has been written to explain the testing procedure and theory behind increasing engine efficiency. The report will explain both tests aims which are to achieve the most effective spark ignition point for a given RPM and load, and to reduce exhaust emissions at the given RPM and load. The spark ignition point will be changed from 0-40 degree's spark angle in 2-degree intervals, and the data plotted. The vehicle will be tested on a machine whereby the car can be driven under load in a controlled environment. The exhaust emissions will be measured on a device where it will allow 5 gases to be sampled at once during the test, and the results plotted. Once the data has been gathered there will be analysis on the data whereby the initial project aims can be evaluated against and the effectiveness of the proposed methods critically reviewed.

2. Contents page.

2.1

<u>Page number.</u>	<u>Description</u>
1	Cover page
2	Abstract, introduction
3 - 4	Literature review
5	Preliminary test methodology/Results
5 - 6	Final test methodology
6	References
6 - 7	Bibliography
7 - 8	Appendices

3. Introduction.

3.1 This seminar paper has been written to outline the aims of the proposed project idea. During this paper there will be outlines of current secondary research methods and proposed test methodology. There will be a brief methodology of the preliminary testing that has been undertaken, as well as the results from the test.

- 3.2 The primary aim of the project is to identify the point at which the test car will produce the highest torque output for the least amount of ignition timing, also known as MBT or Maximum Brake Torque. J Heywood, 1988 describes MBT as a condition whereby the maximum torque is produced for the least amount of ignition timing, this also allows the greatest torque to be produced for the least amount of brake specific fuel consumption, therefore allowing the engine to operate more efficiently.
- 3.3 The secondary aim of the project is to have a reduction in exhaust gas emissions at given load sights by finding the MBT point as stated above, the exhaust gas emissions that will be targeted for reduction will be disclosed in the literature review.

4. Literature Review.

4.1 Secondary research must be undertaken prior to the live testing, in order to fully understand the methodology and testing procedures. As stated in the introduction, the primary aim of the test was to identify the point at which MBT occurs. As disclosed in paragraph 3.2, J Heywood, 1988 describes MBT as the point at which the maximum brake torque can be achieved for the least amount of ignition timing angle in CA° before top dead centre. MBT timing is a strategy used in aftermarket or “standalone” ECU tuning often used in fast road cars or race cars to calculate the optimum timing angle to be used in different load sites providing the ECU can support such a feature.

4.2 The dynamometer use was a Maha MSR 500 which is a 4WD single roller dynamometer, which offers accurate output measurements and a large amount of external measuring probes to be used in one machine. The external measuring devices will be the dynamometers built in lambda probe and engine speed reference probe.

4.3 The instillation and tuning procedure of the new ECU will follow closely to that of R, Mollna Valle 2004, whereby the test discloses the general tuning procedure that can be widely applied to all spark ignition engines. However, the test plan will be modified as the tuning procedure will only influence a given manifold pressure at 4000rpm where peak torque is produced and not influence the full scope of load sites as the aim of this test differs from that by R, Mollna Valle 2004.

4.4 From reading M Gogos et al, 2009 report titled “influence of ignition timing on the exhaust emissions of a ford escort fuelled by various ethanol and petrol mixtures”, the conclusion that was made of over advanced ignition timing resulting in increased NO_x emissions, whereas HC and CO emissions were reduced. The conclusion outlined a possible prediction to be made for this test, i.e. increased timing would result in increased NO_x outputs. However, this was with E50 fuel which is a 50/50 ethanol and petrol mix, the influence of ethanol on NO_x production will not be a factor in this test and may provide different results.

4.5 Reading “Spark timing and fuel injection strategy for combustion stability on HEV powertrain” by Hyungseuk Ohn, 2010 the applications of the proposed test method was realised, as the use in series HEV powertrain vehicles would be a prime application of the projects primary aim. Where the generator for the series hybrid system operates at peak

torque for the use of the vehicle; the optimisation of ignition timing would result in the engine generator being more efficient at the corresponding load site. The application of the primary project aim could be used in generators that run at a fixed engine speed for the entirety of their use.

4.5 The selected methods for validating the tests are as follows: Repeated tests, Mathematical predictions using excel. Firstly, during the live testing each test will be repeated 3 times to eliminate anomalous results. Each of the 3 results will be used to create a mean value from which will be used for creating graphs and analysis. Secondly, an excel spreadsheet will be created that will allow optimum ignition angle to be calculated using mathematical equations. From here, the live data results will be compared to that of the excel sheet to aid in validating the test.

4.6 The car selected for testing was a Vw Lupo, which has a 1.0 litre 4-cylinder SOHC 8 valve engine. From the preliminary tests the power output was found to be 42.3bhp at 4900rpm, and a peak torque value of 92.4Nm at 4000rpm. The Vw Lupo that was chosen had the catalytic converter removed and a performance air filter fitted, therefore the baseline emission data will not be representative of a standard car.

4.7 As later discussed in paragraph 7.2 the influence that the viscosity of the lubricants within the engine and gearbox had on the vehicle's outputs. The Material Safety Data Sheet or paraphrased as "MSDS", for both engine and gearbox lubricants shows that both oils significantly drop in viscosity through temperature changes from 40 degrees Celsius to 100 degrees Celsius, the full report can be found in the bibliography section 9.7 and 9.8. The graphs showing the viscosity changes can be found in the appendices section under figure 5.

4.8 The programmable ECU chosen for the test was the Mtech V3 ECU, this ECU was chosen as it supports all the modifications required during this test. The Mtech V3 ECU will have the following inputs from the vehicle: Engine speed reference from Crankshaft/Camshaft position sensor, Manifold pressure reference from built in pressure sensor in the ECU, Throttle position sensor signal that will allow the ECU to calculate load, Intake Air temperature signal. The ECU will have control of the following outputs: Injection on-time, ignition timing and the fuel pump. The simplicity of the chosen controller allows the setup time for the car to be kept to a minimal, and the changes it makes to the car to be more predictable. However, due to the ECU being aftermarket, the base fuelling must be adjusted to be the same as when the preliminary testing was carried out to insure the fuelling does not affect the results.

4.9 Alternative methods to increase engine efficiency are: Increased compression ratio, forced induction, variable valve timing, increased volumetric efficiency of the cylinder head. However, the issue with these methods is that they require additional modifications to the vehicle and can lead to an increase of certain exhaust emissions. The justification for the proposed test methodology comes from the simplicity of the test and the equipment needed, and the necessity to get the most energy transferred from the fuel to useful work.

5. Preliminary Test Methodology.

5.1 The preliminary test objective was to carry out power, torque and lambda to use as a baseline to aid in comparison later. The test apparatus used was as follows: Engine speed reference and an external lambda sensor, the Maha MSR 500 dynamometer was equipped with test probes which allowed for the measurements to be taken with minimal external equipment. Once the car was safely secured, the measuring equipment was fitted. The measuring equipment fitted was an engine speed reference probe which would detect when the ECU fired one of the spark plugs, and after setting the dynamometer up for a 4-cylinder engine, an engine speed signal can be generated.

5.2 The second piece of measuring equipment was the Maha MSR 500 wideband lambda probe, which was fitted to the exhaust tip, to allow the current fuelling strategy to be measured. The decision was made to use just the two measuring devices for the preliminary tests as they are used for a comparative baseline, and the two measuring devices used were key and would be used again during the main testing session. The test car as stated in the literature review was setup on the dynamometer and WOT tests were carried out in 4th gear. From here, the data was collected to aid in the selecting the test sites for the final testing.

6. Preliminary Results.

6.1 Figure 1 shows the baseline power measurement both at the wheels and the calculated power at the crankshaft, noting how the peak power was greater and at a higher engine speed at the crankshaft compared to that of the wheel power. The peak power output at the wheels was 42.3bhp at 4900rpm, meanwhile in figure 2 the peak torque output was 92.4Nm at 4000 rpm.

6.2 From the torque output data it was concluded that the final test session should be undertaken at 4000rpm. Further preliminary testing will be undertaken to establish the manifold pressure at which the tests will be undertaken, this is vital due to the Mtech v3 ECU requiring a manifold pressure input to calculate load and fuelling. Baseline exhaust gas emission testing must also be carried out to use as a reference for the final test to evaluate whether the proposed changes will have a positive effect on emissions output.

7. Final Test Methodology.

7.1 The final test will be undertaken at a given manifold pressure that is yet to be found as stated in paragraph 6.2, from here the ignition timing will be changed using the Mtech v3 ECU from 0°TDC to 40°BTDC in 2-degree intervals, and the resulting torque and emission figures will be recorded. The optimum timing angle or MBT figure will be highlighted, along with the point at which the targeted exhaust emission was at its least.

7.2 During both tests the following ambient conditions will be recorded: Ambient air temperature, Ambient air pressure, Humidity and Intake air temperature. These are all variables that could influence the final values, and therefore to increase validity to the results they must be controlled as closely as possible. One factor that was found in the

preliminary test that was not expected was the influence that gearbox/differential oil temperature had on the test cars outputs, as the gearbox/differential oil temperature increased with the amount of test runs the cars outputs increased due to the decreased viscosity of the oil. Therefore, to insure reliable results the car's gearbox and engine must both be up to operating temperature before recorded results can be obtained.

7.3 Due to the influence engine and gearbox oil temperature has on the vehicle's outputs, the measurements must be taken when the oils are between 80 and 100 degrees Celsius as shown in the MSDS report titled figure 5, during this temperature window the oils viscosity has halved and will reduce the effect on the cars output.

8. References.

8.1 Merkourios Gogos, Dimitrious Savvidis, John Triandafyllis – influence of ignition timing on the exhaust emissions of a ford escort fuelled by various ethanol and petrol mixtures 2009.

8.2 Ramon mollna valle, jose Eduardo mautone barros, jose Guilherme Coelho baeta, Fabricio jose Pacheco pujatti – mapping procedure applied to general engine management system for spark plug engines 2004.

8.3 Heywood, J. (1988). Internal combustion engine fundamentals. New York: McGraw-Hill.

8.4 Hyungseuk O, Seongeun Y, Kyoungdoug M (2009) Spark timing and fuel strategy for combustion stability on HEV powertrain.

9. Bibliography.

9.1 Merkourios Gogos, Dimitrious Savvidis, John Triandafyllis – influence of ignition timing on the exhaust emissions of a ford escort fuelled by various ethanol and petrol mixtures 2009.

9.2 Ramon mollna valle, jose Eduardo mautone barros, jose Guilherme Coelho baeta, Fabricio jose Pacheco pujatti – mapping procedure applied to general engine management system for spark plug engines 2004.

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9.4 Roussos G. Pagagiannakis, Dimitros C. Rakopoulos, constatine D. Rakopolous – theoretical study of the effects of timing on the performance and emissions of a light duty spark ignition engine running under either gasoline or ethanol or butanol fuel operating modes 2017.

9.5 Hyungseuk Ohn, Seongeun Yu, Kyoungdoug Min – Spark timing and fuel strategy for combustion stability on HEV powertrain 2009.

9.6 Takahiro Ishikawa, Shuhl Takahata, Hiroki Kudo, Takuya Izako, Takahiro Yamashita – A study of the factors determining knocking intensity based on high-speed observation of end-gas autoignition using an optically accessible engine 2018.

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9.8 msds.castrol.com (2004) linked - [https://msdspds.castrol.com/bpglis/FusionPDS.nsf/Files/1CD14DD79D0B77DD802579D10048C4F1/\\$File/BPXE-8SYFN5.pdf](https://msdspds.castrol.com/bpglis/FusionPDS.nsf/Files/1CD14DD79D0B77DD802579D10048C4F1/$File/BPXE-8SYFN5.pdf)

10. Appendices.

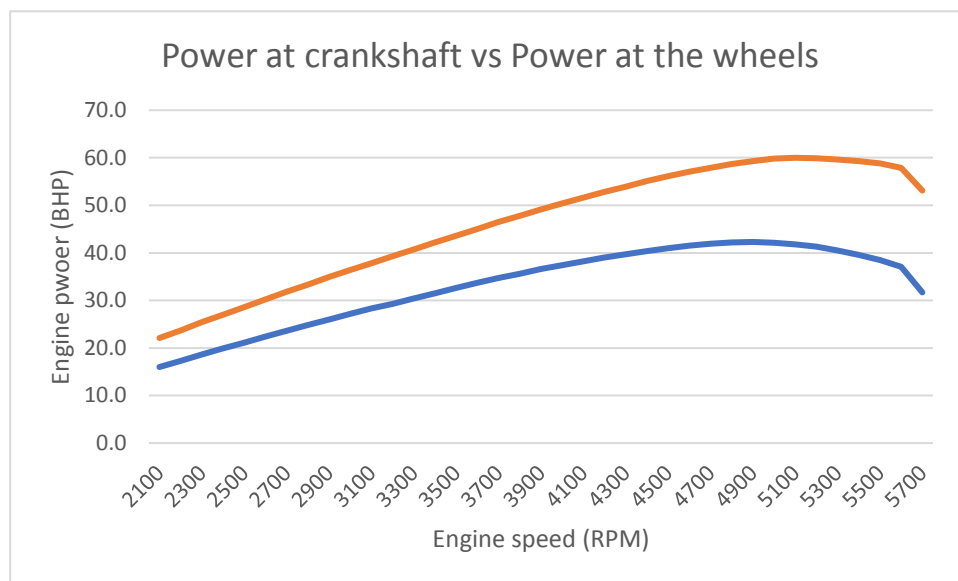


Figure 1.

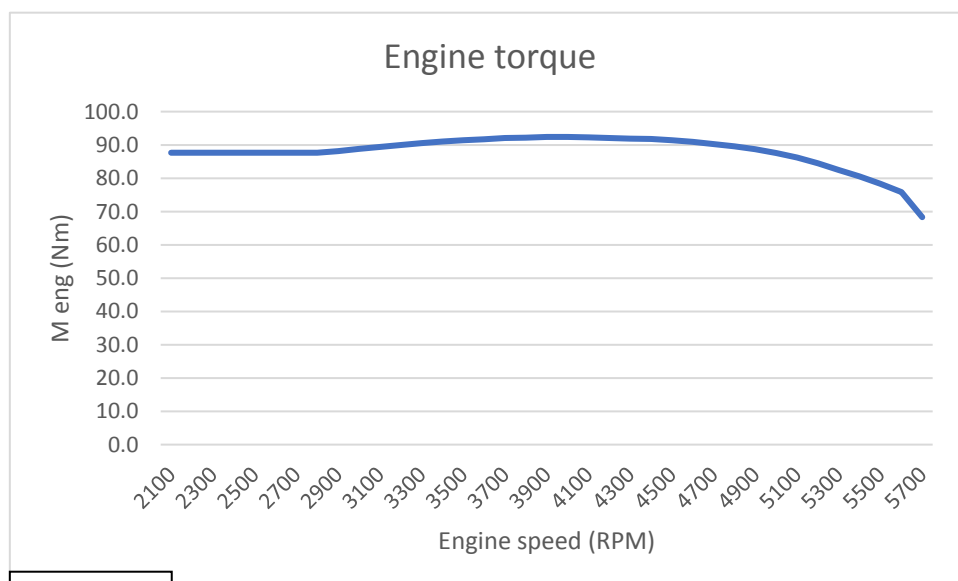


Figure 2.

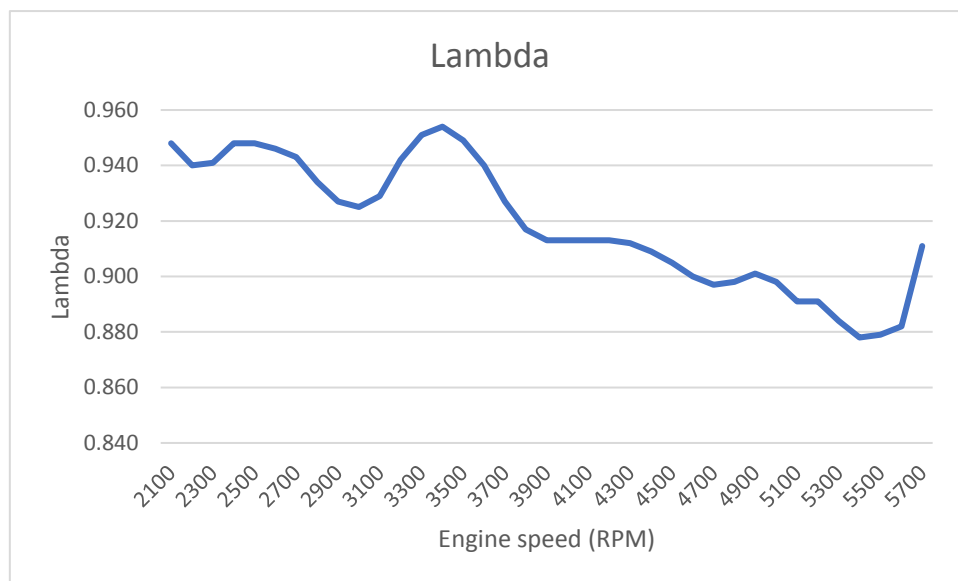


Figure 3.

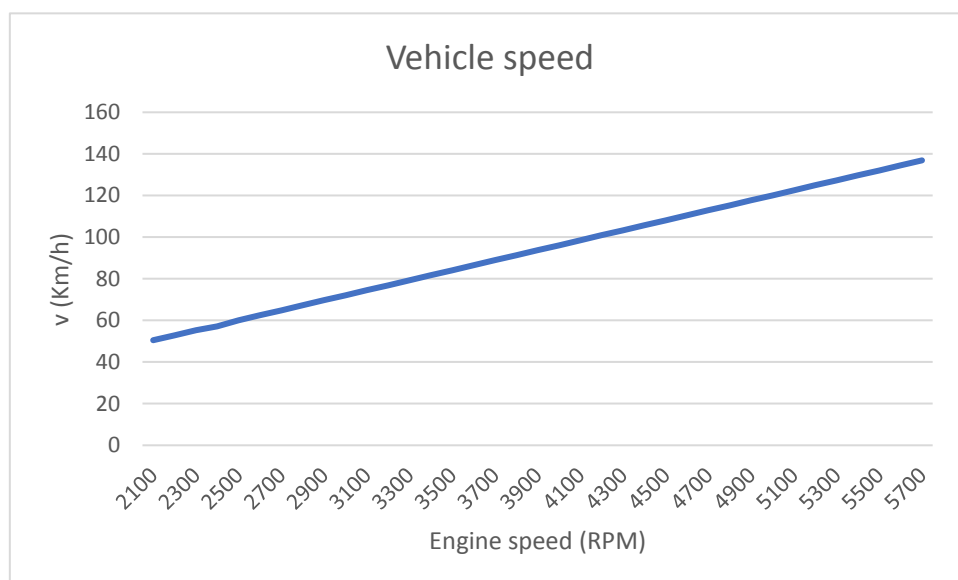


Figure 4.

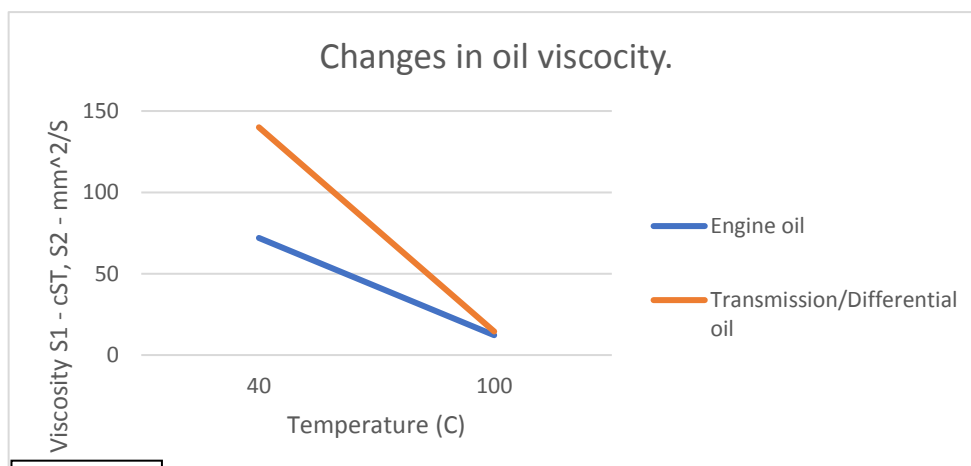


Figure 5.