Electronic Engine Management
And
Calibration
User Manual

1 Introduction

This manual is intended to provide a brief overview on engine tuning, a detailed description of the Reata Engineering Graphical User Interface (GUI), and ECU wiring information. Readers that are new to engine tuning should find the first chapters informative and are advised to read through them. Experienced tuners can go to the GUI and wiring chapters immediately.

2 ECU basics

The Engine Control Unit is used to control the operation of internal combustion engines. Typically this involves the control of fuel quantity and spark timing as well as other ancillary controls. The ECU is a microprocessor based electronic circuit that is capable of executing its code at very high speeds and thus able to monitor and control the engine to crank angle resolution.

The ECU operates off look-up tables to determine the appropriate value of fuel quantity and spark timing. The look-up tables would usually be determined through experiment on the same engine.

2.1 ECU, Sensing

The ECU requires knowledge on the engine status in regards to its crank angle, engine rpm, engine load (determined through Manifold Absolute Pressure or Throttle Position Sensor), coolant temperature, air temperature, Exhaust Oxygen (Lambda) sensor etc. The sensors used are not unique and vary due to make and year of production. However some general description on the sensors can be drawn.

Crank and Cam Sensors

The function of the crank and cam sensors is to provide knowledge of angular position and speed of the engine to the ECU. The ECU requires knowledge of angular position of the engine crank so that spark and fuel are generated at the desired crank angle. (details of the different crank and cam sensor configurations can be found in Appendix 5.4 ‘General Engine Settings, Overview’)

Usually these sensors are inductive type, two wire (or three wire) and operate on the principle that a voltage is generated in a coil when iron (a tooth) goes past the sensor at some speed. Other types of position sensing is sometimes used such as optical triggering or hall effect (hall effect requires use of magnets).

Manifold Absolute Pressure (MAP)

The MAP sensor is used to provide intake manifold pressure measurement which can be used as an engine load indicator. Sometimes this is also referred to as Manifold Air Pressure, however the use of the word Absolute is more descriptive as it has to be appreciated that the pressure being measured is not gauge but absolute. Note that gauge pressure refers to pressure quantity above atmospheric pressure. Ambient pressure is 100kPa (14.7 psi) in an absolute scale and not zero. MAP sensors are typically three wire (ground, signal and supply) and vary in their pressure measuring range depending on application. Naturally aspirated engines typically utilise 100kPa sensors while turbocharged (or supercharged) engines utilize 200kPa or 300kPa sensors.

Throttle Position Sensor (TPS)

Usually a potentiometer directly connected to throttle body’s butterfly shaft. The overall electrical resistance of the potentiometer can vary from one sensor to another. However the overall resistance has practically no effect on the throttle position measurement. The ECU reads the voltage at the wiper which is a function of the orientation (angular position) of the shaft.

Coolant and Air temperature

The coolant and air temperature sensors are usually thermistors. Thermistors are resistors whose resistance changes with temperature. Used in conjunction with a pull-up resistor, the thermistors and pull-up resistor make a potential divider whose voltage output depends on temperature. The voltage is read by the ECU to provide temperature measurement. The thermistor has two electrical terminals and therefore two connections to the harness, however sometimes the coolant temperature sensor has one side of the thermistor grounded to the engine and hence the sensor will have only one electrical terminal.

Oxygen (Lambda) sensor

This sensor has seen a lot of evolution over the years. The fundamental principle is based on the production of a voltage by zirconium dioxide element when exposed to fresh air and exhaust gas. The most basic sensor is the one-wire sensor. The single wire provides a voltage that changes in relation to exhaust oxygen. The output signal of the single wire sensor referenced to chassis ground. The two-wire sensor provides two electrical connections one for ground and the other for signal. Therefore the two-wire has better signal quality compared to the one-wire (note that the single wire's ground connection to the chassis is through the possibly rusted exhaust system). Oxygen sensors require an operational temperature above 300˚C to function properly. The three-wire senor has an embedded heater that heats up the sensor quickly on start-up thus enabling a much faster knowledge of exhaust oxygen. In a three-wire sensor, usually two wires are for the heater (typically two white wires) and the third is signal (referenced to chassis ground). A four-wire sensor has two wires for heater (typically two white wires) and the other two wires are signal and signal ground. One, two, three and four wire sensors provide a voltage ranging from zero to 1Volt. A voltage of approximately 0.45 volts indicates stoichiometric condition, voltages lower than 0.45 imply lean combustion while voltages higher than 0.45 imply rich combustion. The measured voltage cannot provide knowledge on the Air to Fuel Ratio AFR but only knowledge whether rich or lean. Five-wire sensors do provide a voltage that provides knowledge on the AFR. Five-wire sensors are also referred to as wide- band sensors. Wide band sensors have signal conditioning circuitry and provide a linearized voltage output with AFR.

2.2 ECU, Electronic Control

The ECU controls the engine through fuel injection and spark timing. For spark ignition engines, the quantity of fuel required is in direct proportion to the quantity of air inhaled by the engine. The mass of Air to mass of Fuel ratio (AFR) for ideal operation is stoichiometric. When a three way catalytic converter is used in production vehicles, the AFR is cycled (through closed loop control) between rich and lean in order for the catalyst to be able to perform both oxidizing and reduction reactions. In racing applications the AFR is typically maintained rich (that is AFR smaller than AFR stoichiometric) because this produces more power and is safer for the engine.

2.2.1 Fuel Injection

Spark ignition engines operate at AFR close to stoichiometric. The quantity of fuel required to obtain the required AFR is controlled by the amount of time the injector is left open, and is referred to here as Duration Of Injection (DOI). The DOI required at any condition depends mostly on Volumetric Efficiency which in turn is very dependent on engine rpm. The DOI required is also dependent on engine load which is determined through the MAP or TPS sensors. It is noted here that the logical consumption of much more fuel at higher rpm is due to the fact that the DOI applicable is injected every revolution (or every other revolution). Fuel injectors are very quick-acting on-off valves capable of being cycled (that is opened and closed) in the order of a millisecond. Injectors are available in a variety of flow rates and are also divided into low impedance and high impedance injectors depending on their electrical resistance. Peak-and–hold drivers can drive both low impedance and high impedance injectors while saturation drivers can drive high impedance injectors only.

2.2.2 Spark Generation

The timing of the spark is critical for optimal engine operation. Typically spark timing has to be advanced with increasing engine rpm. This is due to the fact that spark has to be generated in an earlier crank angle if the flame front is to travel across the combustion chamber at higher rpm while still fully combusting all gases just several degrees after top dead centre. The optimal spark timing is also dependent on engine load. Lighter engine loads require more advanced spark due to a slower moving flame in lower density combustion gases. In older mechanical systems this spark advance at low engine loads was achieved by the vacuum advance system. Various types of spark generation and delivery are available, namely, one coil with distributor, a coil every two cylinders (wasted spark) and an individual coil for each cylinder. The spark, as with the older contact breaker setup (make and break) is generated by the switching-off of current to the coil. This is so because the coil (inductor) cannot allow the magnetic flux to vanish immediately and therefore a high voltage is produced which is capable of producing an electrical discharge across the spark plug gap. The Capacitive Discharge Ignition (CDI) delivers a quantity of electricity to the coil at a very high voltage on the primary side of the coil (can be 300V). This high voltage in CDI systems charges the coil a lot faster and leaves enough time to recharge and spark the plugs more than once per engine cycle (multi spark).

3 Using the ECU

The ECU is an electronic circuit using state of the art microprocessor, memory, signal conditioning and power transistors. The wiring diagram should be well followed before connecting power to the system. Damage to the ECU can be done if wiring is not correct or not following the wiring suggestions. This applies most of all to making sure that ECU pins that are supposed to be connected to power are correctly connected to the relevant power, while pins that are not supposed to be supplied with power aren't connected to power. It is also worthwhile mentioning that high voltage spikes (around 350V) are generated by the spark plug coils even on the low voltage side (that is ECU side). These high voltage spikes are properly handled by the coil drivers but should not be connected to any other ECU pins other than the coil drivers.

Before using the ECU, the wiring strategy must be developed. The attached wiring diagram should be used as the basis of the strategy, with modifications as necessary for the particular user application such as fuses, starting, charging and other ancillary circuits.

3.1 Usual Wiring Information and Commonalities

ECU's are powered from battery voltage, nominally 12V. The battery voltage is not actually 12V all the time as during cranking voltage will surely drop, while during charging voltage would be around 13.8V. The spark plug coils, injectors, oxygen sensor heater, relays, dashboard indicator lights and other ancillaries will typically run off 12V supply. The ECU internal electronics will typically run at lower voltage. This voltage was 5V until recently and now is 3.3V. Sensors will also typically be powered by a lower voltage, typically 5V, however some sensors do get powered by the battery 12V. Sensor signals are typically between 0 and 5V, one exception is the two wire inductive pickup (used for crank and cam sensors) whose output voltage increases from less than a volt at low rpm but can reach as high as 20V depending on application. Due to the fact that ECU electronics and power electronics have a common ground but a different high side voltage as described above, switching of the power circuits by the ECU electronics is achieved by closing or opening the connection of the power circuits to ground. That is, coils and injectors would have a continuous 12V supply (battery voltage), the ECU would then turn on the coils and injections by supplying a ground connection to them. Turning-off of the power is achieved by breaking the connection to ground. Such a strategy was also used in the past on mechanical contact breakers systems. At this stage it is appropriate to note that due to the fact that all current from coils, injectors and other power circuits flows into the ECU through the low voltage side (ECU side) of these power consumers, the ground current flowing out of the ECU is very high when compared to the much smaller current flowing into the ECU from the battery positive supply to power the ECU electronics. This fact needs to be appreciated to recognize why there are typically many more ground connections compared to the 12V positive supply connections. It is advised that all these ground connections are connected so that there is ample current handling capability.

Another word on grounds, different types of grounds are cited, namely battery ground and analogue ground. Battery ground is the ground that is directly connected to battery, its main feature is its huge current carrying capacity, the current flowing from coils and injectors would be routed to this ground inside the ECU. The analogue ground is the ground that is used by analogue sensors, analogue meaning voltage that can vary continuously between ground and supply voltage. Examples of analogue sensors are TPS, MAP and temperature sensors. The voltage output of these sensors varies in direct proportion to the measured parameter. Therefore the ground voltage level of these sensors has to be very stable otherwise a slight shift in the voltage level of the ground would be erroneously translated into a change in the measured parameter value. It should be noted that battery ground would have discrete shifts in ground voltage level due to the turning on and off of coils and injectors and turning on and off of other digital electronics. A filter to cancel these shifts in ground level is typically employed to produce a clean analogue ground. The supply voltage to the analogue sensors (typically 5V) would also be a clean voltage, that is it would also be without any voltage shifts due to switching. Appreciating the differences between these ground and supplies is important so that connections are made to the appropriate terminals and not just by whatever happens to seem the easiest physical connection on the vehicle.

Heat dissipation: Electronic circuits do need to get cooled and cannot operate at high temperatures. The ECU heats up in part due to the microcontroller and associated electronics but mostly due to the power transistors associated with switching on and off of the coils, injectors and other auxiliaries. The reason behind the heat generated by power transistors is due to the fact that when switched on, the power transistors would have a voltage drop across them say of 0.8V. Therefore if a coil draws 5Amps in saturation, it would translate in 4W (P=IV, P=5*0.8=4) of heat generated in the transistor that has to be dissipated into the surroundings. Therefore ECU’s typically have there case that functions as a heat sink for the internal electronics. To make sure the heat sinking is effective, the ECU should be mounted in a relatively cool location and if possible have air current or mounted to heat sinking (and cold) metal parts.

3.2 Engine Calibration

In this section on engine calibration a strategy is described to map an engine even if no knowledge of injector DOI is known beforehand. Simple calculations of injection duration are suggested to provide a baseline fuel table from which the engine could be started, and then fuel tables are fine tuned by experiment. Similar baseline numbers for ignition timing are given. Experimental dynamometer testing would then usually be the next logical step to determine spark/fuel hooks, MBT timing and whether to inject onto open or closed intake valves.

Since the fuel quantities for a new application might be significantly different from other applications which the end user might have encountered, the look-up tables must be generated from a clean sheet. A simple process for generating fuel tables will be described herein.

3.2.1 Getting started with a new engine

This manual describes a process used to calibrate the settings for an engine which is new to the end user. It is assumed that at this point an engine and programmable ECU would have already been committed. The calibration process here is described by giving reference and going through the process as used for calibrating a 600cc Honda motorcycle engine. A simple and systematic process of establishing and building the spark and fuel tables and testing of the engine is described. The first priority would be to establish the baseline fuel table and ignition table with which to start and run the engine.

Engine Details

To get started, some basic engine parameters must be known. For the Honda F4i engine used in this study, some of the fundamental engine parameters are summarized in Table 1 below:

Engine Type	**F4i**
Bore	**67.0 mm**
Stroke	**42.5 mm**

Engine Displacement	**599 cc**
Compression Ratio	**12:1**
Firing Order	**1-2-4-3**
Idle speed	**1300rpm**

Table 1 Honda CBR600 F4i Parameters [Honda User's Manual]

3.2.2 Injection Table

Before starting the engine, some initial calculations need to be performed to establish a preliminary fuel look-up table. The approach is to calculate how much fuel would be necessary for stoichiometric combustion in each cylinder, assuming that each cylinder is filled with air at atmospheric pressure (100% volumetric efficiency). The fuel quantity for idle conditions is then calculated for an expected typical MAP value at idle.

For one cylinder of 150cc filled with air (only) at 100kPa and 20℃ (293K), using the Ideal Gas Law we have

$$Mass\ of\ \ air = m_a = \frac{PV}{RT} = \frac{100\times10^3\,Pa\cdot150\times10^{-6}\,m^3}{287\,\frac{J}{kg\cdot K}\cdot293K}$$

$$= 1.78\times10^{-4}\,kg$$

Next, if the stoichiometric air-to-fuel ratio is 14.5, then the mass of fuel required per cylinder per cycle would be,

$$Mass\ of\ \ fuel = m_f = \frac{m_a}{AFR} = \frac{1.78\times10^{-4}\,kg}{14.5}$$

$$= 1.23\times10^{-5}\,kg$$

For gasoline of Specific Gravity of 0.75 [Heywood, Internal Combustion Engine Fundamentals]

$$Volume\ of\ \ fuel = V_f = \frac{1.23\times10^{-5}\,kg}{0.735\,\frac{kg}{l}}$$

$$= 1.64\times10^{-5}\,l$$

$$= 0.0164ml$$

Figure 1 Injector Flow Test

As an example the flow test from the Honda 600F4i stock injectors is detailed. The flow rate was measured by pulsing the injectors for 8ms, while counting the number of injection events, and measuring the total volume of fuel collected in a graduated cylinder. Table 2 shows the fuel injector calibration measurements. A fuel flow bench feature is implemented in the Reata ECU specifically for this kind of test (in GUI: Diagnostics, Fuel, Flow test). The average volume for the injectors was 0.0280 ml per 8 ms pulse.

Injector #	Fuel Press [psi]	Volume [ml]	Pulse Count	Flow [ml /8 ms]
1 run 1	50	77	2719	0.0283
1 run 2	50	78	2749	0.0284
2 run 1	50	78.5	2827	0.0278
2 run 2	50	78	2790	0.0280
3 run 1	50	79	2867	0.0275
3 run 2	50	79	2877	0.0275
4 run 1	50	77	2732	0.0282
4 run 2	50	78	2758	0.0283

Table 2 Fuel Injector Experimental Data

Experiments on other injectors showed that the fuel flow rate is approximately linear with injector open time, that is, the actual time that the injector needle is open. It was determined that the time to open the Honda injectors was 0.2 to 0.5ms. This is the time required to activate the solenoid and open the injector, before any fuel is released. The actual injection open time would be (8 – 0.5) ms, but the small difference was not important here as the purpose is to just establish a baseline from which to begin dynamometer testing. Assuming then a linear relationship, the pulse time required for stoichiometric combustion can be calculated as:

$$\frac{8}{0.0280} = \frac{x}{0.0164}$$

So, for this case, the injection duration, x, would be about 4.7 ms. This calculation presumed a cylinder filled with air at 100kPa, which relates to wide open throttle (WOT), 100% volumetric efficiency. At idle most engines would run close to 40kPa, which considering the Ideal Gas Law would imply that there would be close to 40% of the mass of air at WOT. Therefore we would need 40% of the 4.7ms, that is 1.9ms at idle.

For the first engine trials being described here, we did not have an idea of how the volumetric efficiency changes with rpm. Therefore, our initial fuel table was only a function of load. That is, our fuel injection duration was 4.7ms at WOT for all speeds, and 1.9ms at zero throttle for all speeds. The intermediate throttle positions were linearly interpolated between these end values. The initial fuel table is shown in Figure 1, which is in the form of a wedge. It is not dependent on speed, simply 1.9ms at zero throttle and 4.7ms at WOT.

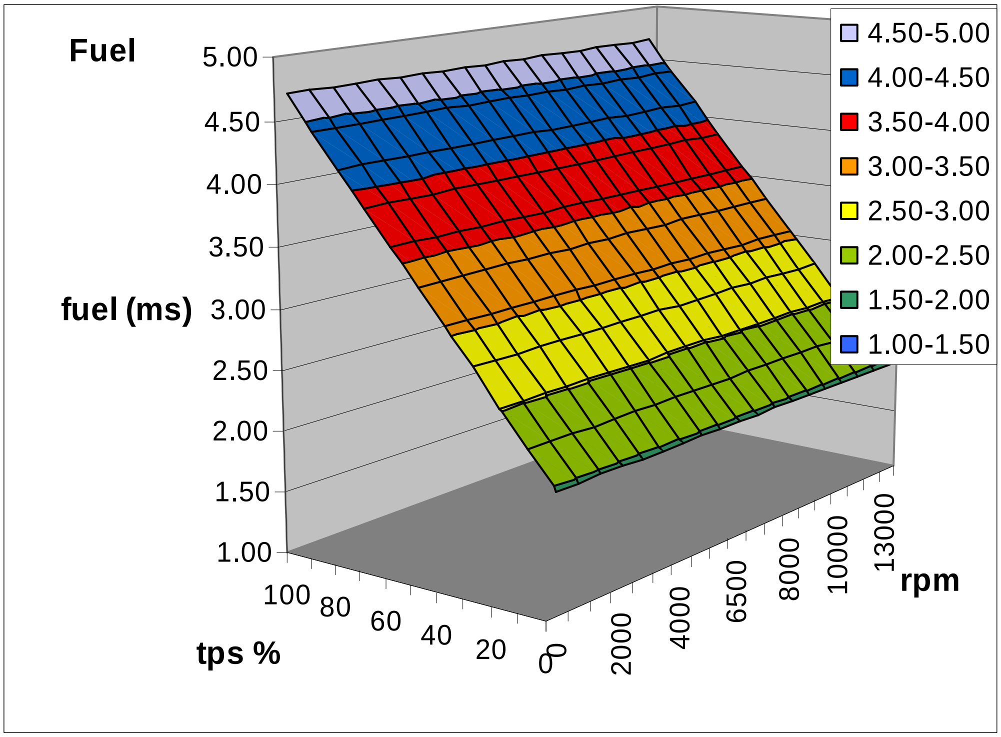

Figure 2 Initial Fuel Table

The load parameter shown in Figure 2 is TPS, however the calculations were based on a load condition described by MAP in kPa. This equivalence in description of no-load as 40kPa in a MAP based table and 0% in a TPS based table is fine. The same applies to full load condition, where this is described by 100kPa in a MAP based table (naturally aspirated) and 100% TPS in TPS based table. However the linear relationship, described by the slope of Figure 2 is only really applicable to a MAP based table. The MAP value produced at a specific TPS opening, it not constant with engine rpm and this would effect the fuel requirement. Nonetheless Figure 2 is a valid initial table from where the engine can be started.

3.2.3 Ignition Table

The Honda Service Manual states that the spark advance is thirteen degrees before TDC at idle. Thirty degrees advance at high rpm is quite normal for engines; hence the initial table was set to have 13°
 advance at idle (1300rpm) and 30° advance at 6000 rpm. It is also quite common for racing engines not to have any load offset to timing i.e. no vacuum advance. Hence the initial ignition table was setup to be only a function of speed. Refer to Figure 3.

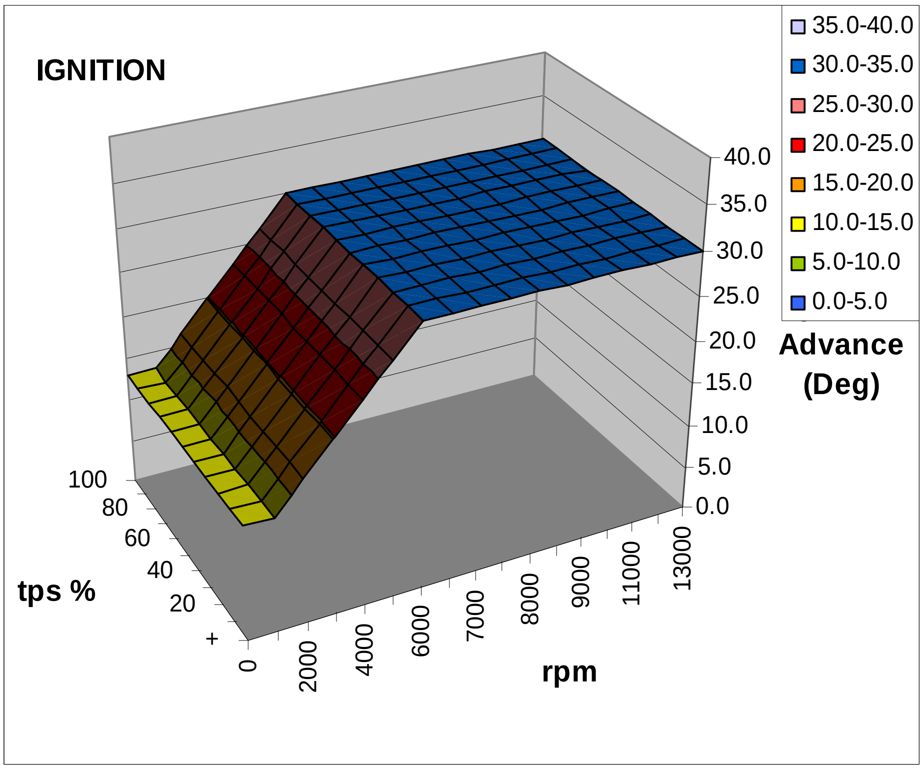

Figure 3 Initial Ignition Table

3.2.4 Starting and Coolant Temperature Compensation

It is very well known and accepted that some extra fuel would be required to start a cold engine. In carburettor systems the choke, be it manual or automatic, would help in starting a cold engine. In electronic fuel injection systems, this extra quantity of fuel is attributed to two causes: starting

compensation, that is if engine was not rotating and is then sensed to start rotating (cranking) a quantity of extra fuel is injected; and coolant temperature compensation, another quantity of extra fuel is injected depending on the engine coolant temperature. Typical values of starting compensation can range from 150% to 200% and would be applied for the first 10 turns or so. In the Reata Engineering ECU and GUI, these percentages are multipliers not additions, that is 200% would mean that double the quantity of fuel is injected. Typical values of coolant compensation is 170% at 10°C that tapers off to 100% at 70°C, that is 70% extra fuel when the engine is at 10°C. These two compensations would both act together (and definitely also act with other compensations such as air temperature compensation etc), therefore if the engine is started at 10°c, is would get 340% for the first 10 turns.
Having set these baseline values for fuel injection, ignition values, starting and coolant compensations, the engine should crank and start. However new users should keep reading through the manual before actual attempts at wiring and cranking the engine are attempted as there are many more aspects of the ECU that need to be understood and followed.

3.2.5 Dynamometer testing

After starting the engine, the engine would then preferably be coupled to an engine dynamometer for testing. The ECU allows choice of the load parameter between either TPS or MAP. Naturally aspirated racing applications would typically be tuned with TPS as the load parameter. The load parameter would probably be MAP for naturally-aspirated engines which are not targeted for racing. Turbocharged applications would typically be tuned with MAP as the load parameter. The look-up tables are in the form of a Load parameter (either TPS or MAP) versus the engine RPM. Optimal ignition timing and fuel injection duration would then be determined at all available speed discretizations in the table at WOT, and several more at part throttle. TPS was used as the load parameter in the example of the Honda 600cc F4i engine since this is a direct input in the dynamometer setup, i.e. the Load location within the look-up tables was set by adjusting the TPS manually. Engine speed was then set by manipulating the dynamometer loading. Ignition and Fuel hooks as determined experimentally. Figure 4 shown the spark hooks for the restricted Honda 600 engine. These ignition hooks show the expected trends, that is the MBT timing is higher at higher rpm. The MBT timing is high also where the volumetric efficiency is poor (this relates to vacuum advance, that is when cylinder is lightly filled, advance has to be larger). Volumetric efficiency can be measured from measurements of the mass air flow using automotive mass flow sensors, laboratory grade laminar flow element, or critical flow orifices. In the Reata Engineering ECU, the load-cell voltage can be read into the GUI thus providing a real–time torque measurement. The torque measurement can be logged and further analysed and plotted against ignition timing and/or injection quantity using Excel®.

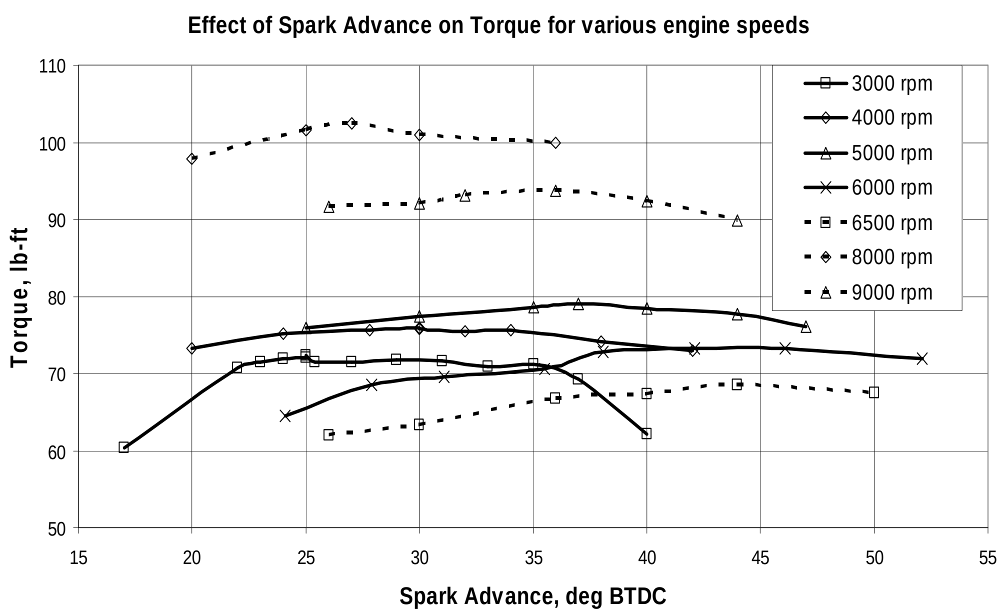

Figure 4 Spark Advance Hooks at WOT

Additional tests can be conducted to determine the best timing for start of fuel injection. For the Honda F4i engine being described, best performance was measured with fuel injected onto open valves, versus closed valves. It was found that injection onto open valves gave 6% more torque at the point of worst volumetric efficiency (6500rpm). This was a worthwhile improvement given the fact that it did not involve any extra hardware. Note that this can only be done if the fuel injection strategy is sequential, that is ECU is knowledgeable of each cylinder's strokes. Sequential operation requires a cam signal into the ECU to reset and synchronize the four stroke cycle, sequential operation is described in Appendix 5.4 'General Engine Settings, Overview'.

3.2.5.1 Compensations

After dynamometer calibration is finalized, some additional tests would still need to be done to determine the necessary amounts of compensations. The compensations that need to be determined are: coolant temperature compensation, air temperature compensation and throttle pump. During dynamometer testing it is important to have the engine in known and stable operating conditions of coolant and air temperature. These temperatures would be the basis from where compensation is applied. That is if coolant temperature during dynamometer tests was stable between 90 and 100^{o}C then the coolant compensation table would have to be 100% at the 90 and 100°C region and higher values than 100% at colder temperature. At hotter coolant temperatures it would be logical to have less than 100% due to the fact that the air induced into the cylinder would be hotter, hence less dense and consequently requiring less fuel. However it is usual not to lower the coolant compensation value below 100% above the baseline operating temperature in order to help in cooling the engine and keep away from possible knocking. Coolant compensation should be adjusted so that while warming up, the engine would operate adequately with an AFR close to the desired value.

Air temperature compensation would also be applied below and above the baseline air temperature maintained during dynamometer testing. For naturally aspirated engines a fairly constant air temperature during dynamometer testing can be achieved by ducting air into the engine from outside the test cell. For the baseline temperature maintained during testing the air temperature compensation would be 100%. At colder air temperature the density of the air would be bigger and hence a larger quantity of fuel can be injected. On the other hand, at hotter air temperatures the air density is less and hence less fuel can be injected. Due to the fact that it would not be quite easy to experimentally vary the inlet air temperature by fairly large amounts, the best way to calculate the required amount of compensation is through theory using the Ideal Gas Law. Refer to Appendix 5.3 'Air Temperature Compensation on Fuel' for the derivation and quantification of air temperature compensation.

In turbocharged applications the air temperature (usually measured downstream of the turbocharger) depends heavily on the turbo operating condition, that is boost pressure and rpm. Hence in turbo applications the baseline air temperature is suggested to be taken in the region of preferred operation of the engine, that is the region in which the car is intended to be driven. Such a temperature would typically be higher than atmospheric conditions, say 50°C and depends on application, especially boost pressure and intercooler size.

The throttle pump compensation injects additional fuel when the accelerator pedal is depressed quickly. The electronic throttle pump facility in ECU's mimics the mechanical throttle (or accelerator) pump but gives a much higher modification capability. The quantity of extra fuel required will vary from application to application and would have to be finally tweaked during driving. The compensations, including the equations on which the throttle pump compensation are calculated, are discussed further in section 4.2.5 'Fuel Compensation'.

4 GUI

The Reata Engineering GUI is a Windows® based software and has pull down menus that are very typical to Windows® based applications. The pull down menus in the Reata Engineering GUI are detailed in this manual in the same order of appearance in the pull down menus: staring from left to right and then top down. This simple and structured sequence of description of the menus is intended to make access to descriptions in this manual easier.

If an ECU is connected and communicating with the computer, then the GUI will load the Engine Settings File from the ECU. The execution of GUI without a communicating ECU will prompt a request for the loading of an Engine Settings File from disk. The entries in the pull down menu can be greyed out, this happens if the ECU is not communicating and the particular pull down menu entry cannot function.

4.1 File

This tab provides management of the Files associated with the ECU. These files have an extension .esf which stands for **e**ngine **s**ettings **f**ile. It is important to appreciate that there are four locations where these settings can reside namely: disk, GUI, ECU memory and ECU flash. ECU has both memory and flash. The ECU displays, executes and saves the settings that are in memory not in flash. The settings that are stored in flash are only as backup and must first be loaded to memory to be displayed, executed or saved. Management of the flash is detailed in section 4.3 subsections Store Parameters in Flash and Restore Parameters from Flash.

Open Configuration

The Open Configuration tab allows the opening of a saved settings file from disk. If an ECU is connected to the PC and communicating with the GUI, using the Open Configuration will only load the GUI with the settings from the specified file on disk, the ECU will still have the settings it had before.

Save Configuration

The Save Configuration tab saves the current engine settings present in the GUI to disk. Note that the save feature saves the settings in the GUI and not the settings in the ECU (if the ECU settings are to be saved they first must be downloaded from ECU into GUI).

Download Configuration from ECU

The Download Configuration from ECU allows downloading of the engine settings **from** the ECU **to** the GUI on the computer. Note that this tab does not save the settings to file it only downloads the settings from ECU so that ECU and GUI are using the same settings.

Upload Configuration to ECU

The Upload Configuration to ECU allows uploading of the engine settings **from** the GUI **to** the ECU. Once this is done the previous settings in the ECU will be overwritten, however the settings in flash would remain as they were.

It should be a habit to save important settings to a file on disk to avoid unintentional overwriting of settings.

Comm Port Settings

The Comm port, short for communication, is the serial RS232 port through which the ECU and computer communicate. The most common connector associated with the RS232 is the 9 pin connector. Recent generation laptops do not have this type of connector and a USB to RS232 converter has to be employed.

Comm Port Number: set this to the desired port number, different computers might not have the same numbers of ports. The com port is selected using a combo box from the available ports.

Baud Rate: the communicating speed between the ECU and computer. This value is typically 57600.

Data Bits: the number of data bits in the serial communication word. Typically set to8.

Stop Bits: the number of stop bits in the serial communication word. Typically set to 1.

Parity: whether or not a parity bit is used, and if used whether odd or even parity is used in the serial communication word. Available entries are: Even; Mark; None; Odd; Space. Typically set to None.

Sampling Interval: the amount of milliseconds that the GUI allows to pass between communications with the ECU. This period is the refresh period with which the GUI obtains data from the ECU and hence is the refresh period that engine sensor data is refreshed on the computer screen. It is also the period between the data logging lines in the online logs that are automatically generated by the GUI when an ECU is communicating with the GUI. More on online logs in the ‘Logs Setup’ section. The typical value for this interval is 100 milliseconds, however if radio transmitters or other potentially slow setup is used, the interval should be increased until stable communication is established, say 300 milliseconds.

4.2 Edit

Editing of engine settings is effected through this pull down menu. The settings screens have two buttons on the right hand side namely: Done and Cancel. The function of by these buttons is as follows.

Done: if the changes effected are good and they are desired to stay in the GUI, press Done. This only registers the values in the GUI, the ECU will still have the values prior to any modification.

Cancel: if the changes effected are not worth keeping, press Cancel and they will be discarded. The values prior to opening the particular settings interface will be re-established in the GUI.

4.2.1 General Engine Configuration

The General Engine Settings are divided into four tabs: **Mechanical Setup**, **Ignition Setup**, **Injection Setup** and **Limits and Alarms**.

4.2.1.1 Mechanical Setup

In this tab the details of mechanically related settings need to be set. An overview with related diagrams explaining the various cases an end user will encounter is given in Appendix 5.4 'General Engine Settings, Overview'.

Number of Cylinders

Set the appropriate number of cylinders in the engine.

Relevance: always

Range: 1 to 8

Firing Order

Set the firing order of the engine. Note that the ignition and injector cables are connected ignition 1 to cylinder 1, ignition 2 to cylinder 2, ignition 3 to cylinder 3 and so on and same applies to injectors. That is the firing order is taken care of by the ECU and hence needs to be set in the GUI.

Relevance: always

Range: 1 to 'Number of Cylinders'

Number of teeth on Crank sprocket

The number of teeth on crank sprocket including any missing ones is entered here. If there are missing teeth on the crank sprocket then this entry should specify the number of existent teeth plus the imaginary number of teeth on the crank sprocket if the sprocket were to have a constant pitch equal to the pitch between two existing teeth. The ECU handles sprockets with equally spaced teeth. Any missing teeth are considered as if they are there for determining if teeth are equally spaced or not. If no crank sprocket, for example a cam sprocket is installed, the value of 0 should be entered.

Relevance: relevant only if a crank sensor is fitted otherwise this entry should be zero.

Range: 0 to 200

Number of missing teeth on Crank sprocket

Set the number of missing teeth on crank sprocket. If there are no missing teeth on crank, set to 0.

Relevance: relevant only if ‘Teeth On Crank Sprocket’ is greater than two.

Range: 0 to ‘Teeth On Crank Sprocket’-1

Last non-missing tooth on Crank sprocket

Assigning numbers to the teeth as they would go by the crank sensor, input the number assigned to the last tooth before the gap due to the missing teeth arrives. The numbering sequence starts by assigning 1 to the first tooth that goes by the sensor after TDC. Refer to notes about how to determine this entry in Appendix 5.4 ‘General Engine Settings, Overview’.

Relevance: relevant only if ‘Number of missing teeth on Crank sprocket’ is greater than zero

Range: 1 to ‘Teeth On Crank Sprocket’

Number of teeth on Cam sprocket

The number of teeth on cam sprocket including any missing ones is entered here. If there are missing teeth on the cam sprocket then this entry should specify the number of existent teeth plus the imaginary number of teeth on the cam sprocket if the sprocket were to have a constant pitch equal to the pitch between two existing teeth. The ECU handles sprockets with equally spaced teeth. Any missing teeth are considered as if they are there for determining if teeth are equally spaced or not. If no cam sprocket, for example a crank sprocket with missing teeth is installed, the value of 0 should be entered.

Relevance: relevant only if a cam sensor is fitted otherwise this entry should be zero.

Range: 0 to 200

Number of missing teeth on Cam sprocket

Set the number of missing teeth on cam sprocket. If there are no missing teeth on cam, for example just one tooth on cam, set to 0.

Relevance: relevant only if ‘Teeth On Cam Sprocket’ is greater than Number of Cylinders.

Range: 0 to ‘Teeth On Cam Sprocket’ -1

Last non-missing tooth on Cam sprocket

Assigning numbers to the teeth as they would go by the cam sensor, input the number assigned to the last tooth before the gap due to the missing teeth arrives. The numbering sequence starts by assigning 1 to the first tooth that goes by the sensor after TDC. Refer to notes about how to determine this entry in Appendix 5.4 ‘General Engine Settings, Overview’.

Relevance: relevant only if ‘Number of missing teeth on Cam sprocket’ is greater than zero

Range: 0 to ‘Teeth On Cam Sprocket’

Crank tooth at Cam Sensor

Specifies the number assigned to the tooth on the crank sprocket which goes by the crank sensor after the cam tooth lines up with the cam sensor. See notes in Appendix 5.4 ‘General Engine Settings, Overview’. on how to assign this entry.

Relevance: relevant only if ‘Teeth On Crank Sprocket’ is greater than zero and ‘Teeth On Cam Sprocket’ is equal to one.

Range: 0 to ‘Teeth On Crank Sprocket’*2

Sprocket correction angle

Specifies, in **crank angle degrees**, the amount of offset which has to be applied so that zero degrees correspond to exact Top Dead Centre of piston number one. Refer to notes about how to determine this entry in Appendix 5.4 ‘General Engine Settings, Overview’. This angle can be changed on the fly through the use of the ADJUST button adjacent to the value.

Relevance: always

Range: if crank sprocket is present 0 to (360/ ‘Teeth On Crank Sprocket’) or else if only cam sprocket is present 0 to (180/ ‘Teeth On Cam Sprocket’)

Missing teeth ratio

To determine the occurrence of missing teeth, the ECU calculates the ratio of time elapsed between current tooth and previous tooth divided by the time elapsed between the previous tooth and the one prior to it divided by the number of missing teeth plus one. That is for any number of missing teeth, and perfectly stable engine speed, this value is 100%. However a value of 60% is advised so that ECU detects the missing tooth even in unsteady RPM. Note, for one missing tooth and perfectly stable engine operation the lower value is 50% while for two missing teeth the lower value is 33%.

Relevance: relevant only when ‘Number of missing teeth on Crank sprocket’ is greater than zero or ‘Number of missing teeth on Cam sprocket’ is greater than zero.

Range: 0% to 100%

Number of strokes for RPM average

Specifies the number of piston strokes which are used in determining the average RPM. Using a larger value for this entry will reduce the tachometer oscillation. Suggested to use value of 1 as a starter.

Relevance: always

Range: 1 to 4

Cylinder correction angle

Specifies, in crank angle degrees, the amount of offset for each individual cylinder which has to be applied, in addition to the ‘Sprocket correction angle’, which should be applied in order that the zero degrees correspond to TDC for the particular cylinder. In normal cases these entries would be zero for an inline engine.

Relevance: always

Range: -90 to 90

Load Parameter

This combo box specifies the sensor used as load parameter. Normally this is either MAP or TPS but can be chosen to be any other analogue input, for example MAF. Refer to relevant discussion in the ECU Basics and Engine Calibration sections.

Relevance: always

Missing Tooth Algorithm

Specifies the algorithm, simple or complex, which is used to determine a missing tooth. Determination of the missing tooth occurrence is determined as by the algorithm explained in the Missing teeth ratio subsection above is termed **Simple**. The **Complex** algorithm compares the current elapsed time to the time that occurred a stroke earlier. This algorithm is intended to take care of slowing down and speeding up of the crank due to compression and power pulses especially during starting.

Relevance: relevant only when ‘Number of missing teeth on Crank sprocket’ is greater than zero.

Crank Triggering Edge

Specifies the edge, rising or falling, at which the crank input is triggered. This applicable for both two and three wire sensors.

Relevance: when ‘Teeth On Crank Sprocket’ is greater than zero

Crank Sensor ON Voltage

Specified the voltage at which the teeth signal is considered to have gone to the ON position so that a rising edge will occur.

Relevance: when ‘Teeth On Crank Sprocket’ is greater than zero.

Crank Sensor OFF Voltage

Specified the voltage at which the teeth signal is considered to have gone to the OFF position so that a falling edge will occur.

Relevance: when ‘Teeth On Crank Sprocket’ is greater than zero.

Cam Triggering Edge

Specifies the edge, rising or falling, at which the cam input is triggered. This applicable for both two and three wire sensors.

Relevance: when ‘Teeth On Cam Sprocket’ is greater than zero

Cam Sensor ON Voltage

Specified the voltage at which the teeth signal is considered to have gone to the ON position so that a rising edge will occur.

Relevance: when ‘Teeth On Cam Sprocket’ is greater than zero.

Crank Sensor OFF Voltage

Specified the voltage at which the teeth signal is considered to have gone to the OFF position so that a falling edge will occur.

Relevance: when ‘Teeth On Cam Sprocket’ is greater than zero.

The above six parameters would be expected to a have an offset in ignition and injection timing if wrongly set. This offset would probably vary with rpm as the width of the crank pulse is not necessarily a fixed number of crank angle degrees. This understanding of whether the hardware being used provides a trigger that is consistent with the rising or falling edge has to be available. The Crank/Cam oscilloscope view (explained in section 4.5.5) can help in the determination of the correct values for these parameters.

4.2.1.2 Ignition Setup

Number of coils

Specifies the number of coils fitted on the system

Relevance: always

Range: 1 to ‘number of cylinders’

Coil dwell time

Specifies the time in milliseconds for which the coil is kept on before it is switched off so that the spark occurs. It is noted that spark occurs when current is turned off. The selection of this dwell time depends on the time that is required for the coil to saturate. If a very long time is specified useless electrical energy is consumed, coil unnecessary heating, and ignition events might overlap at high speeds. Typical value 4 milliseconds.

Relevance: always

Range: 0 to 60

Number of sparks

Specifies the number of sparks which occur in one firing cycle.

Relevance: relevant only on multi-spark systems, specifically CDI systems as these can charge up the coil extremely fast. (not supported with the current hardware)

Range: 0 to 255

Sparks off angle

Specifies the angle, after TDC, at which sparks will be switched off irrespective of the number of sparks which have already occurred.

Range: 0 to 180

Relevance: relevant only on multi-spark systems (not supported with the current hardware)

Spark delay

Specifies the time in microseconds that pass between the switching off of the coil and the occurrence of the spark. This is a hardware related time mostly a function of the ECU hardware and software, however there is also a dependency on the coil used. A typical value is 180 microseconds. If wrongly set, a bad value in this setting can cause drifting of the ignition event, however the rising/falling setting of the crank/cam signal is much bigger cause for drift.

Relevance: always

Range: 0 to 60000

Spark Output Pins

Specifies the connector pins which will be used for Spark Outputs i.e that will be connected to the low voltage side of the ignition coils. Normally the Spark pins, S1,S2,S3….., would be used for spark.

Relevance: always

Range: Selection from combo.

4.2.1.3 Injection Setup

Number of Primary Injectors

Specifies the number of injectors fitted on the system

Relevance: always

Range: 1 to ‘number of cylinders’

Primary Injector Output Pins

Specifies the connector pins which will be used for primary injectors outputs i.e that will be connected to the primary injectors. Normally the Fuel pins, F1,F2,F3….., would be used for fuel.

Relevance: always

Range: Selection from combo.

Primary Injector delay

Specifies the time in milliseconds that pass between the switching on of the injector and the injector to start injecting fuel. The dead-time of the injector is part of this time. Similar to ‘Spark Delay’ above. The effect of some drift on injection event is however much less important than spark drift and hence this values can be left 0.

Relevance: always

Range: 0 to 60

Number of Secondary Injectors

Specifies the number of secondary injectors fitted on the system

Relevance: always

Range: 1 to ‘number of cylinders’

Secondary Injector Output Pins

Specifies the connector pins which will be used for secondary injectors outputs i.e that will be connected to the secondary injectors.

Relevance: always

Range: Selection from combo.

Secondary Injector delay

Specifies the time in milliseconds that pass between the switching on of the injector and the injector to start injecting fuel. The dead-time of the injector is part of this time. Similar to Primary injector delay above, and similarly the effect of some drift on injection event is much less important than spark drift and hence this values can be left 0.

Relevance: always

Range: 0 to 60

Injection angle

Specifies the angle, in crank angle degrees, to which the injection event is referred. If the 'Injection angle at' is set to 'Start' then this entry specifies the crank angle at which the injector is switched on. If the 'Injection angle at' is set to 'End' then this entry specifies the crank angle at which the injector is switched off.

Relevance: always

Range: This entry can be between –360° and +360° fo r sequential operation. Noting that zero is at TDC when the valves are overlapping. For non sequential operation this entry can be between -180° to +180°. Sequential is described in Appendix 5.4 'General Engine Settings, Overview.

Injection angle at

Either start or end of the injection duration can be chosen to provide angular reference of the injection event with respect to engine crank angle. Refer also to description on the specification of the 'Injection Angle' that will follow in the Injection Setup tab.

Relevance: always

Number of Strokes for injection

Specifies the number of strokes which must elapse between successive injection events. This feature can be used with single point injection systems in order to even out the fuel delivery to each of the cylinders. For example, on a four cylinder engine with single point injection, injecting fuel every 3 strokes will tend to even out delivery to all cylinders in the long term.

Relevance: always

Range: 1 to 4

Max Percentage Duty Cycle

Specifies, as a percentage of one full cycle, the maximum duration for which the injector can stay open. The injector has a dead-time which is needed to open and close. If the duration of the injection starts to approach the duration of one whole cycle, then the injector will not be opening for the duration that it is intended to. When this limit is approached it should be considered to either fit larger injectors of install secondary injectors. Further details in appendix section 5.1 Maximum value of DOI for engine

Relevance: always

Range: 0 to 100

Primary injector flow rate

Specifies the flow rate in pounds per hour (lb/hr) for the primary injectors. This value should be obtained either from the manufacturer of the injectors or by performing the injector flow test as described in section 3.2.2.

Relevance: when number of secondary injectors is not zero

Range: 0 to 600

Secondary injector flow rate

Specifies, the flow rate in pounds per hour (lb/hr) for the secondary injectors. This value should be obtained either from the manufacturer of the injectors or by performing the injector flow test as described in section 3.2.2.

Relevance: when number of secondary injectors is not zero

Range: 0 to 600

Time for Fuel Pump On at boot

Specifies, in seconds, the duration for which the pump is kept on when the ECU is switched on. When the ECU is switched on the fuel pump is energized so that when the engine is started the fuel pressure is already available.

Relevance: always

Range: 0 to 60

Fuel tank running time

This is useful in cars with fuel tanks without gauges or with irregular shaped tanks for which level gauges might not mean much. The ECU keeps a counter of the quantity of fuel being consumed, by summing the total time of all injection events. The Fuel tank running time is an empirical (obtained through experiments) value which specifies the amount when a full tank of fuel has been consumed.

Relevance: when an output pin is used as a fuel gauge.

Range: 0 to 65536

Accumulated button

When this button is pressed the current value of the fuel consumed is copied to the 'Fuel tank running time' entry. This can be used so that when a full tank is known to have been consumed, the full fuel tank is taken to be the accumulated value.

Relevance: when an output pin is used as a fuel gauge.

Range: N/A

Fuel Pump Output Pin

Specifies the connector pins which will be used for the fuel pump.

Relevance: always

Range: Selection from combo.

4.2.1.4 Limits and Alarms

Cut Rev Limit

Set this value according to the engine's capability. Both spark and fuel are cut if the rpm are sensed to go above the 'Cut Rev Limit'.

Relevance: always

Range: 0 to 20000

Tachometer Output Pin

Specifies the connector pin which will be used for connection to a tachometer. A pulse occurs with every spark event.

Relevance: always

Range: Selection from combo.

4.2.2 Ignition Table

The ignition table provides the capability to change the ignition values (spark advance) for the whole operating range of the engine. The ignition table is setup with rows representing the different engine rpm points, while columns represent the different load points. The load parameter can be selected to be either TPS or MAP (or other) from the General Engine Settings. The discretization of the rpm can be changed by right clicking on any rpm entry, three possibilities will appear Edit RPM Value, Insert RPM Row and Delete RPM Row, refer to Figure 5 Setting RPM entries in Tables. Use these options to modify the RPM values representing the rows as desired. Note that the bottom RPM row value is the RPM value that is used as the highest RPM on the tachometer displayed on the screen. It is also important to specify this number higher than the Rev Limiter so that the ECU will have valid ignition and injection values beyond the Rev Limiter value. The RPM values representing the rows will be consistent throughout the settings tables, that is changes effected from the Ignition Table will also be effected in the Injection Table, a reminder to this effect appears to remind the user of such an automatic change in the other table.

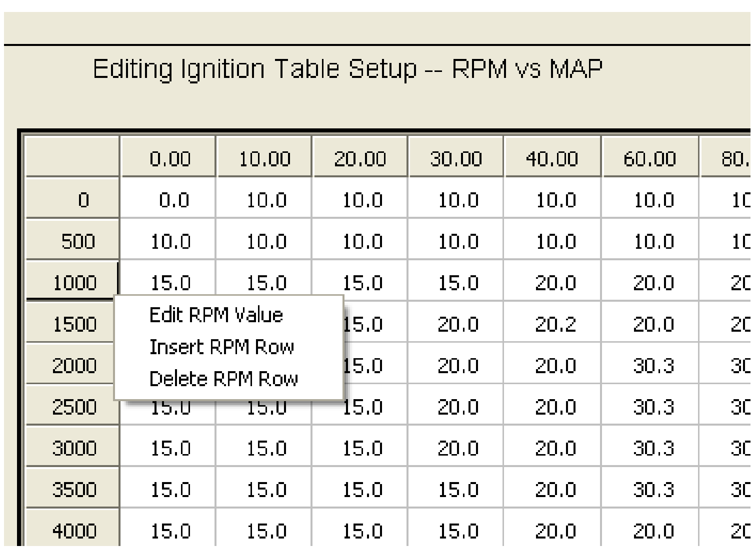

Figure 5 Setting RPM entries in Tables

Similarly the load entries can be changed by right clicking on the load entry, refer to Figure 6 Setting the Load Parameter entries. The changes effected in the load entries will also be applied to the injection table and a reminder appears to this effect when exiting the ignition table editing.

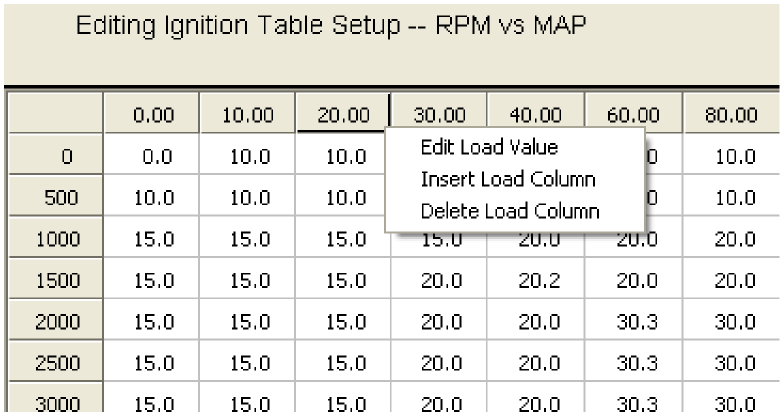

Figure 6 Setting the Load Parameter entries in Tables

The ignition values in the table can be changed by left clicking on them and typing the desired value. If mathematical manipulating of the values is required, it is suggested that the whole table or the desired part is copied by highlighting it and then pressing CTRL+C to copy it and then paste in Excel® where the mathematical manipulation can be effected. Pasting back of many cells into the ignition table can be easily effected by left clicking on the upper left corner of the desired area and pressing CTRL+V. If contours of the values are desired, it is suggested to paste the table in the Excel® sheet ReataTablesView.xls provided on the website.

4.2.3 Injection Table

The same editing capabilities as for the Ignition Table are available for the Injection Table, therefore it is not necessary to repeat description.

4.2.4 Sensor Conversion

The sensor signals are acquired by the ECU as analogue signals that are converted into actual parameters such as temperature by the ECU. The Reata Engineering ECU enables the user to work with any sensor by setting up a conversion table from voltage to the measured parameter.

A sensor can be connected to any analogue input pin. The analogue input pins are pins marked **A01** to **A22**.

A01, **A02**, **A03** and **A04** are inputs which are not amplified. These are normally used for TPS, MAP, coolant temp and air Temp.

A05 and **A06** are single ended inputs which can be assigned with an amplification.

A07, **A08**, **A09**, **A10**, **A11**, **A12**, **A13**, **A14**, **A15**, **A16**, **A17**, **A18** are inputs which can be used as single ended as well as differential inputs. These pins, in both configurations, can be assigned with an amplification depending on their setup. These inputs, taken in pairs, can be used to connect to thermocouples.

A19 is hard-wired as cam sensor.

A20 is hard-wired as crank sensor.

A21 and **A22** are for future use and will be assigned to knock sensors.

Add

Choosing this entry in the Sensor Conversion pull-down menu will enable the user to create a senor entry and connect it to an input pin.

When a new sensor is created the new entry will be shown in the 'Sensor Conversion' pull-down menu. The user can enter and edit the desired sensor by clicking on the appropriate entry in the menu.

Delete

A combo box is displayed from which the user can select the sensor input that he wants to delete.

Edit

By clicking on any of the sensor conversion entries shown in the sensor conversion pull-down menu the user can enter the edit dialogue for the relevant sensor.

The dialogue consists of:

Sensor Name: The name to be given to this particular sensor.

Units: The units of measurement for this particular sensor.

Filter is a number between 1 and 16 which is used to filter out noise that may be present on the signal input. A value of 1 means that no filter is applied. A value between 2 and 16 means that the signal will be smoothed out. The bigger the value the smoother the signal but also the slower the response.

Input pin This combo box specifies the connector pins which will be used for this sensor. Any pin which is already used is greyed out.

Amplification this combo box specified the amplification which will be used with this sensor. Only the appropriate amplifications will be available according the pin chosen.

Thermocouple if this input is to be used as a thermocouple the type should be chosen here, otherwise 'Not thermocouple' should be selected.

Input If the selected pin can be set as differential, a radio button will be shown so that the input can either be set to single-ended or differential.

Sensor Conversion Table

The sensor conversion table can be generated using the ECU in **CALIBRATE** mode. This feature facilitates the generation of the conversion table. The right mouse button should be used on the left 'Voltage' column to edit, insert and delete rows. Refer to Figure 7 Setting the Voltage entries in Sensor Conversion These right mouse button options are identical to those provided for editing the ignition and injection tables.

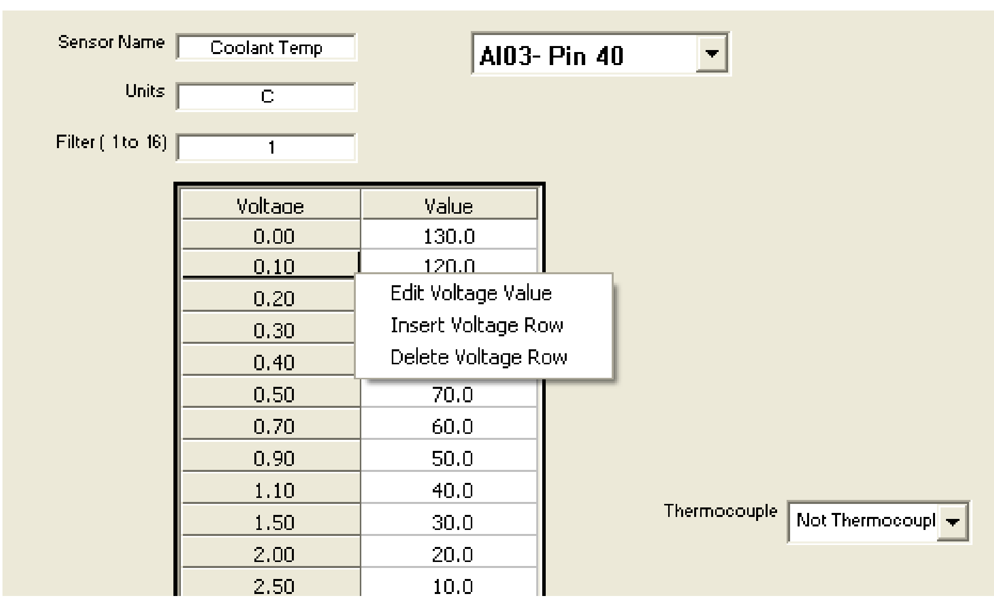

Figure 7 Setting the Voltage entries in Sensor Conversion

An Excel® sheet with an example of the test measurements and conversion of a thermistor sensor is made available on the web site. This Excel sheet should be of help as thermistors are logarithmic in nature and the use of the appropriate logarithmic equation makes the conversion table a lot better.

4.2.4.1 Throttle Position

Since the throttle position sensor is usually a linear sensor the extremities of the sensor travel are usually enough for the conversion table. It is important to note that if the TPS is mechanically moved in relation to the throttle butterfly shaft, the calibration may be lost and would necessitate recalibration of the fuel and possibly ignition tables. The suggested calibration procedure is to fully close the throttle, fully retracting any idle screw, try to make the throttle plate rest against the throttle body, then read the voltage input into the ECU using the CALIBRATE button. Set the value for this voltage to 2 or 3 percent. Next open the throttle fully, set this as 95 to 97 %. Then set zero volts to 0% and 5volts to 100%. Such a method would make sure that even if due to noise a voltage lower than the fully closed voltage enters the ECU, the ECU will never get confused and interpret that as a percentage lower than zero. Same thinking applies to the 100% position.

4.2.4.2 Manifold Absolute Pressure

In order to run the calibration a method of pulling a vacuum say down to 30kPa is required. If the engine application is turbocharged the MAP sensor would also have to be calibrated to 200kPa or 300kPa depending on the boost level. A manual vacuum pump with a vacuum pressure gauge is probably the best method for the calibration below atmospheric pressure. The atmospheric pressure needs to be measured by means of a barometer to give a reference value to which the vacuum and gauge pressures are subtracted and added respectively. In the case a barometer is not available, 100kPa can be used as a ball-park value or the atmospheric pressure obtained from a weather station report. Once again it is advised to set the zero volt and five volt calibration points to MAP values even if these voltages are never reached during calibration. Plotting of the calibration in Excel® is suggested as MAP sensors are usually of a linear nature and hence plotting and passing a linear trend-line through the measurements should make the calibration curve neater. If the trend-line is plotted, extend it to zero volts and five volts and use these as the extreme values for the look-up table. If Excel® cannot be used, the same procedure can be made manually on graph paper or perform mental determination of adequate 0V and 5V MAP values. A calibration sheet for a MAP sensor is available on the website to facilitate understanding of this procedure. It is also wise to appreciate that the ignition and injection tables should have a column for the lowest and highest possible MAP value in the MAP conversion table. This would make sure that even if a voltage outside usual operation is received by the ECU this still results in a quantifiable value of ignition and injection.

4.2.4.3 Coolant Temperature

Coolant temperature sensors are typically thermistors. The calibration experiment can be easily done by starting with iced water and raising its temperature up to boiling. A thermometer or thermocouple is required to be able to determine the temperature of the water. The water ice mix has to be quite high on ice and crushed ice is better than one big lump of ice. Stirring throughout the calibration is advised to have a uniform temperature throughout, calibration every 20°C or so is suggested, heating slowly to go from one point to the next, and stop heating to read measurements and allow stirring to reach a uniform temperature. The GUI interface can be used during the calibration to facilitate the experiment. Temperatures below 0°Celcius and above 100°Celcius are difficult to obtain and hence a proper extrapolation method for the thermistor curve should be employed. Thermistor characteristics are modelled by the Steinhart equation and this model should be adopted for proper interpolation and extrapolation. Since characteristic is not linear, points every 10°C are suggested to be provided in the look-up table. Please refer to the downloadable Excel Sheet detailing an example of a coolant sensor calibration. It is also noted that since the thermistor is not the only resistor in the sensing system, it is suggested to know and account for the other resistors in the network to obtain the most accurate look-up table. A proper choice of the pull-up resister is required to provide a full range of measurements from below 0°C to above 100°C, for a thermistor having a resistance of around 2500Ohms at 20°C a 470Ohm pull-up resistor is suggested. The Reata ECU is designed to have the pull-up resistor connected externally so that the best match resistor can be used for any sensor. Further more when an externally powered sensor is tapped (coolant sensor connected to stock dashboard) the pull-up resistor should not be connected.

4.2.4.4 Air Temperature

Air temperature sensing is typically done by thermistors. The same methodology of the coolant sensor applies. It is noted that the resistance (at room temperature) of the air temperature sensor might be very different than the resistance (at room temperature) of the coolant temperature sensor and hence might require a pull-up resister with a different resistance than that for the coolant sensor. Calibration of the air temperature sensor can be effected from close to freezing to 80°C or higher quite easily. An air temperature close to freezing can be obtained by putting the sensor in the fridge or freezer or in an ice filled container. Stirring of the air should be effected to make sure that a uniform temperature is established between the air temperature sensor and the thermometer or thermocouple being used to make a valid temperature measurement. Hot temperatures can be obtained using a hair dryer and varying heating or fan control or the distance away from the sensor. Once again the use of the Steinhart equation is advised and an example of a calibration sheet can be found on the website to facilitate the process.

4.2.4.5 Lambda

Lambda or O_2 sensors that are not wide band are not linear and provide a voltage of around 450milliVolts around stoichiometric operation. When using these types of sensors one cannot interpret much how rich or lean the combustion is. Effectively a one to one look-up table is implemented for the lambda sensor and the raw voltage being measured is what is shown as the sensor output.

4.2.4.6 Wide Band Lambda

The wide band lambda sensor manual would usually provide calibration data to convert from voltage to AFR. Insert this calibration in the settings interface by first generating the required voltage levels in the left hand column by using the right mouse button. Alternatively the look-up table can be inserted in a text editor such as Notepad®.

4.2.4.7 Mass Air Flow

The mass air flow sensor calibration is quite involved and probably a look-up table provided by others is the most feasible way. If a look-up table is provided by others, the values can be manually inputted by generating the appropriate voltage values in the left hand corner first and then typing the corresponding MAF value in the right hand column. Another effective method to make changes to the settings file is by opening the desired Engine Settings File in a text editor such as Notepad® and cutting and pasting the necessary look-up tables there. A calibration curve in Excel® is provided to have a characteristic of a popular hot and cold wire type MAF sensor.

The complexity of calibration of a MAF sensor comes from the fact that another calibrated MAF sensor and an air flow pulling capability has to be available. The MAF sensor used for calibration can be yet another automotive sensor or a laboratory grade sensor such as a laminar air flow sensor. The flow through the MAF sensor should be pulled and not pushed due to fact that the turbulence generated by the fan or blower if used to push will effect the MAF reading in a way that is not easily modelled and accounted for. Hence air should be pulled through the MAF sensor to be in a similar manner as that used on the engine and in such a pulling manner is not effected by turbulence. It is also noted that flow characteristics of the piping (for example elbows or corrugations) immediately upstream of the MAF sensor can effect its calibration. Downstream piping configurations have a much lower effect.

4.2.4.8 Torque

Load-cell output, even when amplified are typically linear, therefore two test points are usually enough. The calibration would be as you would do for the load-cell readout on the dynamometer. Typically disconnect load-cell mechanically to be perfectly sure it is not loaded, read this voltage using the

CALIBRATE button and type zero as the torque value. Reconnect the load-cell mechanically and load it with the known calibration masses, once again read the voltage and type the torque value to which these masses correspond.

4.2.5 Fuel Compensation

The fuel quantities specified in the injection table relate to specific operating conditions, namely steady state engine operation, known and stable air and coolant temperatures. Departures from these conditions require that the ECU adjusts the fuel quantity to maintain adequate engine operation. Compensations are discussed in 3.2 ‘Engine Calibration’ in section on ‘Compensations’. All compensation values are multiplied to the injection value obtained from the table in a “cumulative” (but actually multiplication not addition as the word cumulative might imply).

All compensation can be enabled or disabled during ‘dyno mode’. This can be done by selecting the desired button when in the editing dialogue for the compensation.

4.2.5.1 Starting

The starting compensation is in the form of extra percentage of fuel over a number of turns. The percentage is a multiplication not an addition, that is if 150% is specified, and the injection table value gives 3ms, then the delivered value is 4.5ms. The extra amount of fuel is injected for the specified number of turns from when engine is sensed to start rotating (cranking).

4.2.5.2 Throttle Pump

Extra fuel is injected to aid in accelerating the engine when TPS is sensed to increase abruptly. A higher setting of the Compensation on Current TPS value results in a larger quantity of fuel being added. A lower setting of the Compensation on Past TPS value results in a larger quantity of fuel being added. This is because it is the difference between these two settings together with the difference of the current and past TPS values that is used to quantify the extra amount of fuel, the larger the difference the more extra fuel. The equations used to quantify the throttle pump compensation quantity is :

$TPSChange = TPSPositionNow - TPSPositionOld$

If $TPSChange$ is negative, then $TPSChange = 0$

Else $TPSChange = TPSChange$

$$TPSPumpComp = \frac{(TPSChange \times CompCurrentTPS) + (TPSPumpCompPast \times TPSPumpCompOld)}{100}$$

If $TPSPumpComp > ClampingValue$, then $TPSPumpComp = ClampingValue$

Else $TPSPumpComp = TPSPumpComp$

$TPSPumpCompOld = TPSPumpComp$

$TPSPositionOld = TPSPositionNow$

A clamping value is set to that it is assured that while enough extra fuel is injected, multiple and fast depressions of the accelerator do not end up flooding the engine.

The importance of the Throttle Pump compensation is mostly important at low speeds. The RPM limit setting is the RPM under which Throttle Pump compensation is applied while above this RPM limit no Throttle Pump compensation is applied.

4.2.5.3 <u>Coolant Temperature</u>

The coolant temperature compensation is a percentage that is multiplied to the injection value obtained from the injection table. Any number of temperature entries with the corresponding compensation can be set using the usual right mouse button on the temperature column to edit the temperature column entries and typing the %compensation in the right column. 170% (meaning 70% extra fuel) at 10°C going to 100% at 70°C are typical coolant compensation values.

4.2.5.4 <u>Air Temperature</u>

Editing of the Air Temperature compensation table is similar to the Coolant Compensation table. It is noted here that the 100% value is centred on the air temperature at which dyno testing is performed. Air Temperature compensation is also discussed in the Compensation section of the Using the ECU chapter and the derivation and calculation involved are given in the appendix 5.3 ‘Air Temperature Compensation on Fuel’.

4.2.6 Spark Compensation

Spark compensation is set in these tables. Typically these values would be obtained from experience or following suggestions by others as the experimental determination might be difficult.

4.2.6.1 Air Temperature

The amount of spark advance or retard is set hear as a function of air temperature

4.2.7 Idle RPM Control

Motor Wait Time

Stepper motors move only one step at a time. The processor issues the pulse so that the motor will move one step. If the processor issues these pulses too fast the motor might end up not moving fast enough and so might loose some of the pulses and so moving less steps than it should.

The Motor Wait Time is the time in milliseconds in which the motor is assumed to have moved one step. The processor waits for this time to elapse before giving another step. This value should be determined empirically because it depends a lot on the motor and the load which it is driving.

Motor On Time

This is the time in milliseconds for which a pulse is applied to the motor. Normally this would be equal to the Motor Wait Time but could be made less if the load is light so that the motor can dissipate less energy.

Maximum Step Constant

This value together with the Step Constant explained below and the error in RPM is used to calculate the number of steps issued to the stepper motor.

$$NumberOfSteps = \frac{RPMerror \times StepConstant}{MaxStepConstant}$$

Example, if RPM is 640, desired Idle RPM is 700, Max Step constant is 1000 and the Step Constant is 50, then

$$NumberOfSteps = \frac{(700 - 640) \times 50}{1000} = \frac{60 \times 50}{1000} = 3$$

Maximum Steps Motor Can Move

This entry set the number of steps that will open the bypass fully. Continuing to turn the motor further will cause no effect to the control system

Minimum Active RPM

The minimum engine RPM above which the ECU will not try to control the RPM. This ensures that the idle speed control does not open when engine is stopped or being started. By setting this value to a value greater than the Cut Rev Limit, the idle speed control function will be deactivated.

Idle RPM when Cold

A colder engine would usually require a slightly higher idle speed for stable operation. The setpoint RPM for a cold engine is set in the Idle RPM when Cold.

Typical value: 1200

Idle RPM when Hot

When engine temperature reaches normal operating condition the idle rpm can be maintained slightly lower than when cold. The setpoint for a hot engine is set in the Idle RPM when Cold.

Typical value: 800

Cold Temperature

The ECU transitions from Hot RPM setpoint to Cold RPM setpoint if the engine coolant temperature is sensed to be below the Cold Temperature setting. Two temperatures, and not just one, are required to define this transition so that Idle setpoint does not oscillate between the Cold and Hot setpoint due to coolant temperature reading oscillating slightly above and below the setting temperature.

Typical value: 45

Hot Temperature

The ECU transitions from the Cold RPM setpoint to Hot RPM setpoint if the engine coolant temperature is sensed to be above the Hot Temperature setting.

Typical value: 80

Allowed Error

The Allowed Error defines the band of RPM above and below the setpoint in which the engine is allowed to operate. For example, if the idle RPM set point is 700, and the Allowed Error is 50, then the Idle RPM Control scheme will be satisfied and not issue any bypass air modifications if engine RPM is between 650 and 750 rpm.

Typical value: 50

Step Constant

The aggressiveness (gain) of the control scheme is set by the Step Constant. The bigger the Step Constant the more the bypass will be actuated for a given error in RPM. Very high gain is known to cause oscillations in control schemes, therefore adjust this value with care.

Typical value: 50

Sampling Period

The Idle RPM Control scheme reads engine RPM, performs its calculations and issues its command to the idle speed control motor every so many milliseconds as specified in the Sampling Period.

Typical value: 100 milliseconds

Minimum TPS

Idle RPM Control is only allowed below this level of TPS, meaning the engine is really meant to be idling because throttle is completely closed. This setting is very important in not allowing the Idle Control scheme to operate when engine is being used on engine brake. If this Minimum TPS setting is too high, say more than 15%, the Idle RPM Control scheme will try to lower the RPM by closing the bypass valve, at this point it will not actually be doing any effect as all the combustion air would pass through the throttle since it would be at say 10% open. However, when engine is taken off engine brake, and

throttle is closed, the bypass would be far too closed to allow enough air for combustion and engine would stall.
Typical Value: 5% to 8%

4.2.8 Logs Setup

The ECU generates data logs that are recorded in the ECU's memory. The data logs can be read at a later date or time into the communicating PC through the GUI by means of the Get Logs command in the LOGS pull-down menu.

The parameters that the ECU has knowledge of are listed in the window on the left and the user selects the ones required to be logged by clicking the '**>>**' button.

When the '**>>**' button a new line is added on the right part of the dialogue. This line has a sampling interval entry which defaults to 100ms.

The most basic method is to select a common sampling interval for all parameters, for example 100 milliseconds. If the data storage capacity is required to be maximized to lengthen the logging time, the sampling interval for the different parameters can be set according to the nature of the parameter. For example, coolant temperature should not be changing rapidly and therefore sampling at one or two second intervals should be enough. It is advised that slower sampling rates are chosen as integral multiples of the fast sampling rate, that is choose 100ms and 800ms not 100ms and 750ms. Such a integral multiple system will facilitate the data logging viewing in Excel® and does not compromise any accuracy.

To remove a parameter form being logged click on the '**<<**' button.

The ECU also generates another set of logs when communicating to the PC, these logs are called the on-line logs. This name is due to the fact that these logs are generated when the ECU in on-line with the GUI. The on-line data logs are automatically saved to the PC without any intervention from the user. These logs can be found in the logs subdirectory and are named by datetimeonline.log. The parameters stored in the on-line logs are the parameters which the GUI shows on the screen and a header row is provided to indicate the column data. The sampling interval for the on-line logs is set by the sampling interval setting for the Comm Port in the File pull-down menu.

4.2.9 Launch Control

Launch Control is provided to assist in acceleration from a stand still. Launch control works by maintaining engine operation in a good rpm range and also tries to limit the amount of slip that occurs between tires and road. The underlying principle of how this strategy is adopted in the Reata Engineering ECU is the following. From standstill and with launch control enabled the driver will depress the clutch completely and insert first gear. Then the driver will press accelerator all the way. If no launch control is activated the engine would go to the Cut Rev Limit. However with launch control activated the engine would rev up only to Start Line RPM which is a value well below the Cut Rev Limit RPM and an RPM value were the engine would already have a good torque and the torque from this point on should not experience and dips. Therefore the driver would be at the start line with the engine revving at the Start Line RPM, then he would release clutch completely, the tires would obviously spin and slip as the engine imposed revolutions on the tires that are far bigger than the speed the car can attain instantaneously. The ECU would sense that the launch event has started due to the fact that the ECU would sense the undriven wheels starting to rotate. The ECU holds the engine revving at the Start Line RPM until the speed of the driven wheels, sensed by the ECU, is within the desired slip ratio from the wheel speed if there is no slip (no slip speed obtained from the undriven wheels). When the driven wheels go into that allowable region of slip, the ECU will progressively increase the Rev Limiting value until the car reaches the Switch Off Speed at which point the Rev Limit value will become the Cut Rev Limit as specified in General Engine Configuration.

Indication that Launch Control is selected is provided through the flashing of the Shift Down Indicator on the dashboard.

Start Line RPM

The Start Line RPM specifies the RPM at which the engine is chosen to be kept whilst waiting for the green light. This value should be chosen with knowledge of the engine's torque characteristics with rpm. The engine is maintained at the Start Line RPM very much like a rev limiter, that is by shutting downs of both ignition and injection.

Number of Undriven Wheels

Specify the number of undriven wheels that are instrumented with wheel speed pickups.

Number of Teeth on Undriven Wheels

Specify the number of teeth, or other occurrences that will occur every revolution of the undriven wheels.

Diameter of Undriven Wheels

Specify the diameter in meters of the undriven wheel.

Number of Driven Wheels

Specify the number of driven wheels that are instrumented with wheel speed pickups. If the Number of Driven Wheels is set to zero, the ECU will calculate the driven wheel speed based on the specified Engine to Wheel Ratio underneath (assuming no slip in clutch).

Number of Teeth on Driven Wheels

Specify the number of teeth, or other occurrences that will occur every revolution of the driven wheels. This setting is irrelevant if the Number of Driven Wheels is set to zero.

Diameter of Driven Wheels

Specify the diameter in meters of the driven wheel.

Engine to Wheel Ratio

Specify the ratio of turns the engine would have to rotate for the driven wheels to rotate by one revolution. If the Number of Driven Wheels is not zero, the value of the Engine to Wheel Ratio would not be used by the ECU

Allowed Slip when Dry

Specify the allowed slip say 5%. Trials need to be performed to obtain optimal value.

Allowed Slip When Wet

Specify the allowed slip say 10%. Trials need to be performed to obtain optimal value.

Switch Off Speed

This road speed should be determined by calculating what speed the car would be at when launch control should be switched off. The corresponding engine speed should be less than the Cut Rev Limit specified in General Engine Settings.

Sampling Interval

The Launch Control scheme reads engine RPM, wheel speed, performs its calculations and issues its command to limit engine RPM every so many milliseconds as specified in the Sampling Period.

Typical value: 100 milliseconds

4.2.10 Digital Inputs

In this interface the digital inputs connected to the Digital Input pins can be set up. Digital inputs are pulled high, the switch shorts the input to ground.

The window on the left of the dialogue shows all the functions which are supported by the ECU. When one such function is selected the '**>>**' button is enabled. When the '**>>**' button is clicked a new row for the selected function is created. This row consists of five columns:

- **Function name** which is the same that was in the left window.
- **Debounce time** is the time, in microseconds, for which the signal has to be present in order to be taken as active. If the signal is low for a duration less than the debounce time it is not considered. This will solve problems when a push button is pressed manually and causes a lot of chatter.
- **Activation time.** In some cases it would be needed that an input is kept on for a number of seconds in order to be taken into consideration. This ensures that the switch was intentionally triggered and not accidentally hit.

- **Input pin.** This combo box presents the input pins that can be used for the input. If an input pin is already used the pin is greyed out.
- **Inverted.** This thick box determines if the input should be treated as inverted.

To remove a digital input the '**<<**' button corresponding to the input should be clicked.

4.2.11 Gauge View Setup

By using this interface the user can determine the gauges that will be displayed on the screen as well as their positioning.

This dialogue consists of three tabs: Gauges, Fuel compensations, Spark Compensations, LED's.

The window on the left of the dialogue shows the functions available for which a gauge can be created. When on such function is selected the '**>>**' button is enabled. When the '**>>**' button is clicked a new row for the selected function is created. This row consists of four columns:

- **Function name** which is the same that was in the left window.
- **Gauge type.** This combo box gives a selection between the available types of gauges.
- **Column** where the gauge will be displayed.
- **Row** where the gauge will be displayed.

To remove a switch output the '**<<**' button corresponding to the input should be clicked.

On the Gauge tab gauges for values calculated on the values of other gauges can be created by pressing the '**Add Calculated'** button. Example Power is calculated from RPM and Torque. When pressing this button a new dialogue is opened where the user can define the Calculated Gauge.

- The dialogue consists of the gauge name
- The gauge units

- The minimum for the gauge
- The maximum for the gauge
- The formula to be used for the calculation of the gauge value.

The formula is built by double clicking on the variable. The variable name will be copied to the formula window. Then add the necessary arithmetic sign by typing in the edit window. Any other variable can be chosen to complete the formula.

To remove a gauge the ‘**<<**’ button corresponding to it should be clicked.

The range shown on the gauge is that which is specified in the calibration of the input on which the gauge works.

The Fuel compensations, Spark Compensations and LED setup tabs have a layout similar to the Gauge Setup

4.2.12 Switch outputs

In this interface the Switch Output pins can be set up.

The window on the left of the dialogue show the functions available for which switch outputs can be set up. When one such function is selected the ‘**>>**’ button is enabled. Then the ‘**>>**’ button is clicked a new row for the selected function is created. This row consists of five columns:

- **Function name** which is the same that was in the left window.
- **Switch Name** which will be associated with this output.
- **On-Value.** The value of the relevant function for which the output will switch ON
- **Off-Value.** The value of the relevant function for which the output will switch OFF
- **Output pin.** This combo box presents the output pins that can be used for the output. If an output pin is already used the pin is greyed out.

To remove a switch output the ‘<<’ button corresponding to the input should be clicked.

4.2.13 Closed loop Lambda

Using this interface the ECU can be set up to function in closed loop mode. In this mode the ECU continuously monitors the exhaust gases through the lambda sensor and adjusts the fuel duration so that the mixture would eventually converge to a pre-determined one. The closed loop lambda would be useful in normal day to day running as it learns form ambient, fuel quality, driving style and other conditions which are not taken care of by the pre-calibrated parameters.

Close loop lambda would not be suggested for racing applications since in racing the torque and power are of the outmost importance while emissions and fuel economy are given secondary importance.

The closed loop lambda algorithm was set up so that it can work with a narrow band lambda sensor which is much cheaper and readily available than a wide band sensor. A narrow band sensor would also be more robust than a wide band one.

The Closed loop Lambda interface consists of three tabs: Target Table, Parameters Setup and Fuel Compensation Setup.

4.2.13.1 Target Table

In this fist tab the whole function of the closed loop lambda can be enabled or disabled. The sensor for Lambda input is also selected from a combo containing all the analogue inputs.

The table itself contained the target values for each cell in the RPM versus load table. The values entered in this table are the value for the individual cell to which the resulting lambda value shall converge. Could be that for some range of cells the mixture is preferred to be a bit rich and in others a leaner mixture is preferred. There might be some cells which would not need to be improved (for example the cells in the idling region). These cells shall be assigned a value of zero.

Parameters Setup

- **Number of turns for averaging.** The number of turns for which conditions must remain within limits in order for the computation to be performed. If the conditions are not stable for a reasonably long period then the sample is not considered to be reliable.
- **Number of turns to discard**. The number of turns which for which conditions remaining within limits before the sample starts to be

collected. This will allow for any latency that the lambda sensor might have.

- **Lambda no correction region**. When a complete sample is gathered the number of instances which result richer than desired for this cell is computed as percentages of the whole sample. If the computed value is greater than the higher bound then the corrected fuel for that cell is decreased by one step. If the computed value is less than the lower bound then the corrected fuel for that cell is increased by one step. If the computed value is within these bounds then no more adjustments are performed.

- **Percentage clamping bounds.** The corrected value for each cell is clamped by these limits. The limits are computed as the percentage of the value in the Injection table.
- **Correction step.** The value in milliseconds which is added or subtracted to the relevant cell in the corrected fuel table.

- **Percentage Bounds for RPM inside cell.** The value of the RPM should be inside these limits in order for the condition to be used for computation. 0% means that the RPM should be exactly the middle of the cell, while 100% means that the RPM can be the whole range inside the cell.

- **Percentage Bounds for Load inside cell.** The value of the load should be inside these limits in order for the condition to be used for computation. 0% means that the load should be exactly the middle of the cell, while 100% means that the load can be the whole range inside the cell.

Fuel Compensations Setup

The condition for computation can only be valid if the amounts of compensations are within a certain range. If there is a very high amount of fuel due to compensations then the situation cannot be considered for a computation. The percentage amount of compensation that can be allowed for computation can be defined in this tab

- **Percentage bounds for overall compensation.** The overall compensation is the multiplication of all compensation values which are active at a certain time. This entry defines the bounds for the overall compensation. The condition is not considered as usable if the overall compensation is outside of these bounds.

- **Percentage bounds for 'ABC' compensation.** There is one such entry for every fuel compensation ('ABC') that is defined. As for the overall compensation the bounds can be set for each individual compensation. The condition is not considered as usable if the individual compensation is outside of these bounds.

4.2.14 Tables in Dyno Mode

The Reata Engineering ECU has a powerful interface to adjust the Ignition and Injection tables on the fly while dynoing the engine. The Tables in Dyno Mode interface turns off interpolation. No interpolation means that the Ignition and Injection values are determined from the closest cell in both RPM and Load. Compensations are turned on or off according to the setting for each individual compensation. Normally compensations will be turned off during dyno testing. No compensations means than none of the temperature or other compensations are active, that is even if engine is still cold it will not get any extra fuel. It is important that no interpolation and no compensations are applied so that the values obtained experimentally are the baseline values that are to be stored in the tables. However in some cases it might be desirable that an individual compensation is enabled during dyno mode. A case in point is when testing a turbo charged engine. If the air temperature cannot be kept constant then the air temperature compensation has to be enabled since the temperature will vary considerably and would need the compensation to keep the correct mixture.

The values shown in the table change from Ignition to Injection depending on the last excursion of the mouse in the right hand side of the screen. If the mouse hovers in the 'Spark Advance' area the table will be Yellow and the Ignition values are shown. If the mouse hovers in the 'Injection Duration' area the table will be Green and the Injection values are shown. The active table will remain the same even if the mouse goes out of the right hand side and into the table area.

The values in the table can be changed in the following ways.

1. If the cell is clicked, the value can be typed directly into the cell.
2. The value of the cell were the engine is operating can be changed by dragging on the sliders for Ignition or Injection on the right hand side.
3. If the mouse is clicked anywhere on the sliders the value where the mouse is clicked on the slider is immediately used.
4. A sweep of the value can be done automatically. This is very helpful for spark hooks where the spark would be swept over an entire operating range and analysis afterwards determines MBT.

It is important to realize that engine should be operating in a fixed cell for the system to be used effectively and in a fast manner. The dynamometer control is what can make this possible or not. If the Load parameter is TPS, the dynamometer speed control is the only control loop required because the Load parameter will not vary as long as the TPS is not changed by the user. However if MAP is the Load parameter, a control loop to maintain fixed MAP has to be employed, this would have to act on the throttle and possibly the waste gate for a boosted system. Therefore a more elaborate system would be required for dynoing with MAP as the load parameter. Therefore TPS as the load parameter should be an easier starting point for new users.

The on-line logs can be opened in Excel® and the plots can be used to reveal the desired injection quantity and also draw spark hooks from which MBT is determined.

4.3 Action

Update Date and Time

The ECU has an internal clock that is used for the logs generated and recorded within the ECU. The date and time of the ECU's internal clock can be changed through this interface. The internal clock does not automatically update to daylight saving time.

Store Parameters in Flash

The settings in all the tables can be stored to flash memory using this option.

Restore Parameters from Flash

The settings are read from flash and set into ECU memory using this option. It is noted that the ECU utilises the settings in memory and not flash to run the engine. The flash is only a backup memory.

Kill Engine

The engine can be killed (stopped) using this option.

4.4 View

Currently this view pull-down menu gives access to view the parameters associated with the closed loop lambda feature.

View Closed Loop Lambda Table

Using this interface the current state of the Closed loop Lambda can be visualised and the Corrected fuel table can be reset.

On entry the first screen will display the presently active corrected fuel table.

Five buttons are available with following functions:

Reset Correction Cells: The corrected fuel table is copied from the original Injection table

Get Corrected Fuel: Displays the Corrected Fuel table which is the table which is being used in place of the original Injection table

Get Visited Cell: Displays the number of times that each cell has been revised.

Get Increased Cells: Displays the number of times each cell has been incremented.

Get Decreased Cells: Displays the number of times each cell has been decremented.

4.5 Diagnostics

This pull-down menu gives access to Morse and operational tests for both spark and fuel. The fuel flow-bench feature is achieved through the use of the operational test on fuel.

4.5.1 Spark

Morse Test

The Morse test can be applied on the engine to check if engine RPM or power will go down when one cylinder is deactivated. Such a test can help diagnose faults with individual; cylinders.

Operational Test

The spark plugs can be made to spark without cranking the engine to test that all electrical hardware is functional. This feature is very useful in pre-starting checks. The Enable Hot Outputs Override cable needs to be grounded to have this feature operational, refer to wiring diagram. It is worthwhile noting that the ECU has hardware and software safety disable of ignition and injection when engine is not rotating. This is mostly to safeguard against flooding of cylinders with fuel. It is therefore important not to forget the Hot Output Override Enabled after the diagnostic check is performed because this will be rendering the safety feature useless. Coil on time is set in milliseconds, a 4 to 10millisecond coil on time is typical. Frequency is in Hertz, that is if frequency is set to 10, the plug will spark 10 times a second. The counter keep record of the number of sparks performed. The maximum frequency that can be used reliably is 50Hz.

4.5.2 Fuel

Morse Test

As with spark a Morse test can be applied for fault finding.

Flow Test

The injectors can be flow tested to establish their flow rate. Injectors can also be flow tested to check their proper operation and to check for variation within a batch of injectors. The injector DOI can be varied along with the pulsating frequency. A counter keeps track of the number of times the injector has been opened. The counter keeps a count of the number of times the chosen set of injectors are open as a group. That is if injectors 1 and 2 are selected with a frequency of 10Hz and pulsed for one second, the counter will show 10 not 20. To have adequate accuracy in the measured flow rate a measuring cylinder should be used with a 1cc accuracy and a volume of between 90cc and 100cc collected for each test.

4.5.3 Enter Dyno Mode

When dyno mode is entered, the ECU issues ignition and injection values directly from the tables by selecting the closest cell in terms of engine RPM and Load. Therefore no interpolation is applied neither due to RPM nor load. Furthermore only the compensations which are enabled for dyno mode are applied. This Enter Dyno Mode feature is mostly intended to validate the table as is without any tweaking of values especially during calibration.

4.5.4 Exit Dyno Mode

ECU returns to normal operation thereby applying interpolation on RPM and load between cells and also applying the appropriate compensations.
When the ECU is switched on it will revert to dyno mode OFF, no matter the state it was before switching off.

4.5.5 Crank/Cam oscilloscope view

This interface allows the user to verify the correct operation of the Cam and Crank sensors. It resembles the screen of a digital oscilloscope where the waveform produced by the crank and cam sensor can be viewed. The signal voltage is represented in the vertical direction while the time is represented on the horizontal axis.
It should be noted that this feature can only be used while cranking by using the starter motor. Ideally the sparking plugs should be removed so that the

engine will turn faster with less stress on the starter motor. In any case the engine will not start while the ECU is in this mode.

This interface offers also a number of options to better view the signals.

1. The **Crank** and **Cam** checkboxes determine which signal will be displayed. If both are checked then both signals are displayed.
2. **Timebase** as in the case of normal oscilloscopes the timebase is the time interval between any two vertical grid lines on the display. The time base can be selected to adjust for better viewing of the waveform.
3. **Operation Trigger/ Roll** In triggered operation the signal is displayed only when it passes the triggering voltage point. In roll operation the signal is displayed continuously as it occurred. Sometimes it is good to operate in the roll mode in order to be sure that the signal is present. Then for better analysis triggered operation can be selected.
4. **Trace** selects which signal is used for triggering if both signals are enabled. If only one signal is enabled then the selected signal is used for triggering.
5. **Edge** determines the direction of the signal which will cause the triggering. If positive edge is selected a trigger will occur when the signal crosses the trigger voltage while increasing. If negative edge trigger is selected the trigger will occur when the signal while decreasing. An edge is determined by crossing voltage level specified in **Voltage** below.
6. **Activity** determines if the display is continuously updated or if only a single shot is captured. Sometimes it is convenient to study a single shot without the disturbance of subsequent changes in the waveform.
7. **Voltage** is the triggering voltage.
8. **Position** is the location on the time axis which will be visualised as the triggering point. The value is a percentage of the full screen. 100% is on the left most while 0% is the right most.

Figure 8 Oscilloscope View Dialogue

4.6 Logs

When enabled the logs are continuously written to memory. If the memory is filled up then the logs wrap to the beginning of the memory space overwriting the old values. When the ECU is switched on, the logs, if enabled, will continue to be written at the location that was next to be written when the ECU was switched off. The Logs can be set for the Edit pull-down menu as discussed in section 4.2.8 Logs Setup.

Reset Logs

When the logs are reset the contents of the logs is zeroed.

Disable Logs

When the logs are disabled no more data is written to the logs memory and the size is frozen. However the contents is still available for download

Enable Logs

When Logs are enabled the data starts to be written to the logs memory. If the logs were previously reset then the first data is written to location zero. If the logs were previously disabled then the first data will written to the next location.

Download Logs

All the data written to the logs memory since the logs were last reset will be downloaded.

5 Appendix

5.1 Maximum value of DOI for engine

The quantity of fuel that needs to be delivered for one cylinder needs to be delivered in the available time before the 4 stroke cycle repeats again. The higher the rpm the shorter the time it takes the engine to come back and repeat the cycle. Therefore the higher the rpm the lower is the available time for the injector to deliver its required quantity of fuel. For example at 6000rpm, the cam would rotate at 3000rpm and the intake stroke would therefore repeat at 3000 times per second for each cylinder. 3000rpm happen in one minute, therefore by simple proportion, in one second the cam rotates 50 times. Hence the time it takes for the cam to rotate one revolution is 1sec divided by 50 times, equals 0.020 seconds, that is 20 ms.

If the engine were rotating at 12000rpm the time it takes the camshaft to rotate one revolution would be half of 20ms, that is 10ms.

However the time that the injector should be made to open (DOI) should not approach this calculated time it takes the cam to rotate one revolution. The DOI should typically be not larger than say 85% of the maximum available time. This is so because the injector should have enough time to close and be surely closed. If the injector is made to open for say 95% of the maximum available time, the closed time might be so small that the injector does not actually close but remains open the whole time. If this happens, one would not be controlling the injector because while 95% were requested, it would be giving 100%. Hence to be totally sure that injector is maintained under control, the safety value of say 85% it typically used.

This maximum time available dictates the flow rate or size of the injector. Therefore if the injector is being selected for a particular application, it should be selected so that at maximum rpm of the engine it can flow the anticipated amount of fuel in at least 85% of the available time. It is also worth noting that if the 85% of the available time is approached, the injector would remain open for nearly the whole four strokes and in such a condition there would not be any capability of selecting whether to inject on open or closed valve. If for example the injection is required to be on an open valve, then the DOI has to be not larger than around 35% of the maximum available time.

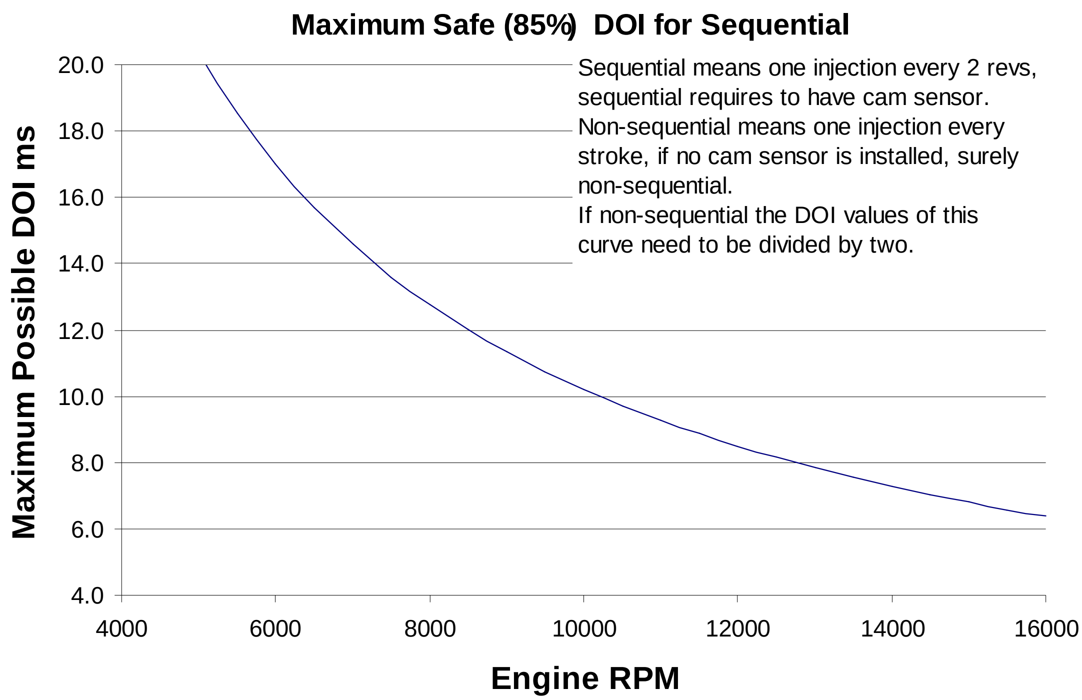

Figure 9 Maximum Injector DOI as a function of engine RPM, sequential & 85% factor

rpm	Max DOI ms (sequential, 1 inj /2 Rev)	Max Safe DOI ms (85%) (Sequential)	Max Safe DOI ms (85%) 1 inj / 1 Rev (non-sequential)
6000	20.0	17.0	8.5
8000	15.0	12.8	6.4
10000	12.0	10.2	5.1
12000	10.0	8.5	4.3
14000	8.6	7.3	3.6

Table 3 Maximum Injector DOI as a function of engine maximum RPM

5.2 Idle Speed Control without Idle Speed Control Motor

A typical Formula SAE engine does not have an idle speed control motor, which is a widespread method of idle speed control. A description of how idle speed can be effectively controlled by means of spark timing is discussed.

For a typical Formula SAE engine, for example a Honda 600cc F4i engine, idle speed conditions relate to rpm in the range of 1500rpm and very small TPS. In this region of the Ignition table, the ignition timing table was adjusted to achieve speed control. At 1500rpm, our choice of idle speed, the ignition timing was set to the value at which the engine runs well, say 15° BTDC. At higher rpm, say 2000, a purposely low value of ignition timing was used, say 10° BTDC while at lower rpm, 1000rpm, a higher ignition timing value was specified, 20° BTDC. This ignition strategy slowed down the engine if it tried to idle too fast, but aided the engine if it tried to idle too low. Refer to Figure 10 Idle Speed Control Strategy, without idle speed control motor This system works very well and was capable of properly maintaining engine to idle from cold start to fully warmed-up conditions. It is important to realise that this strategy can only really slow down the engine through 'non-optimal' ignition timing. Sufficient air flow through the throttle body must be available for the engine to run. That is, if throttle body is closed way too much that not enough air can flow to maintain engine at 1500rpm, no value of ignition would be able to make the engine run at 1500rpm. In effect this scheme requires that more air is available to the engine than that required for 1500rpm, say it would need enough air to be able to operated the engine even at 2000rpm, this is usually set through the throttle stop screw.

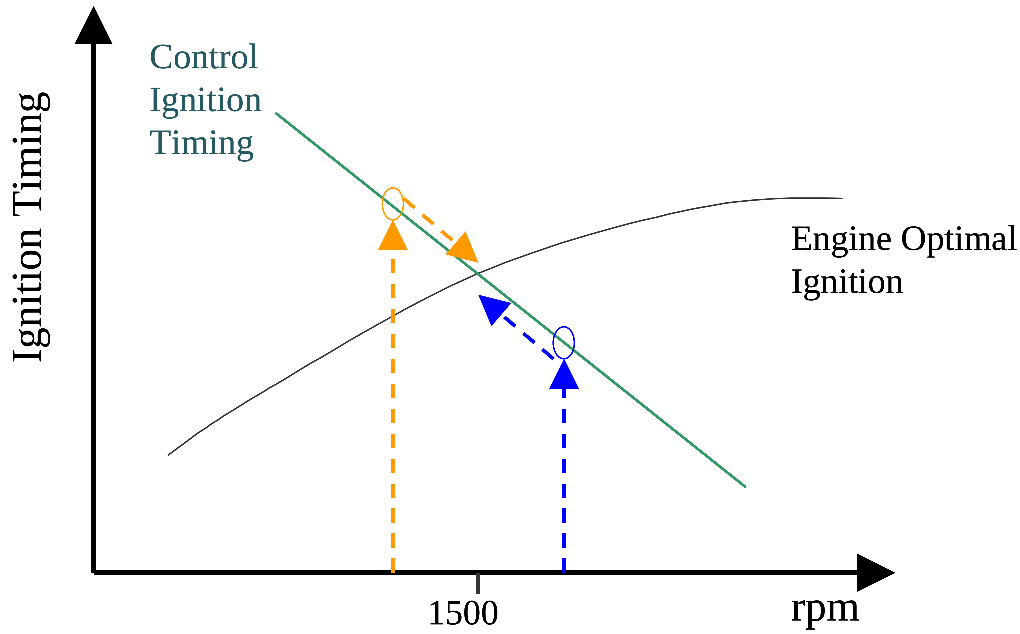

Figure 10 Idle Speed Control Strategy, without idle speed control motor

During warm-up, engine controllers typically employ coolant temperature compensation that enriches the fuel strategy because of a fuel deposition on walls and denser air charge (due to less heating of the air in the manifold and intake port). The idle speed control strategy described above presumes that the coolant temperature compensation is active, and does not replace the need for coolant temperature compensation.

5.3 Air Temperature Compensation on Fuel

A fuel injection compensation scheme can be generated by calculating the quantity of mass of air at the temperatures above and below the baseline air temperature maintained during engine testing.

Ideal Gas Law $pV = mRT$

Therefore $m = \frac{pV}{RT}$

If the condition during engine testing is referred to by subscript 1, then we have

$$m_1 = \frac{p_1 V_1}{RT_1}$$

If subscript 2 is used to denote the condition which is at a temperature T_2 not equal to T_1 the baseline temperature, we have

$$m_2 = \frac{p_2 V_2}{R T_2}$$

Now if we are interested in a correction table with respect to temperature, we will only allow the temperature to be different. The correction will then be applied to the same pressure, that is the same MAP value. The correction will also be applied for the same volume, that is this correction will apply to the same cylinder volume not a larger or smaller engine. Therefore

$$p_2 = p_1 \quad ; \quad V_2 = V_1$$

Then diving m_2 by m_1 we get

$$\frac{m_2}{m_1} = \frac{T_1}{T_2}$$

That is the ratio of mass of air is inversely proportional to temperature, which is anticipated, that is a hotter temperature results in a smaller mass of air for the same pressure and volume. It is noted that the Ideal Gas Law is based on the absolute Kelvin temperature scale not degrees Celsius. The temperature in Kelvin is the temperature in Celsius plus 273.

As an example, if baseline temperature during testing was 20°C (293K) and we want to generate the correction factor for 30°C (303K), we have correction factor given by

$$\frac{m_2}{m_1} = \frac{T_1}{T_2} = \frac{293}{303} = 0.967$$, that is 96.7 %.

As an other example, if baseline temperature during testing was 20°C (293K) and we want to generate the correction factor for 10°C (283K), we have correction factor given by

$$\frac{m_2}{m_1} = \frac{T_1}{T_2} = \frac{293}{283} = 1.035$$, that is 103.5 %.

As yet another example, if in a turbo application the baseline is 55°C (328K) and we want to generate the correction factor for 45°C (318K), we have the correction factor given by

$$\frac{m_2}{m_1} = \frac{T_1}{T_2} = \frac{328}{318} = 1.031$$, that is 103.1 %.

It is noted that the values for 10 degree colder is not the same for the baseline values of 20°C and 55°C.

The correction factor based on this methodology for baseline temperatures of 20°C and 55°C follow and could be adopted in the Air temperature correction table of the GUI. However, it is noted that in racing applications, it might not be worthwhile to reduce fuel above the baseline temperature as keeping 100% fuel would help in lowering temperatures.

Naturally Aspirated engine application

	Celsius	Kelvin	Correction Factor
	-20	253	115.8
	-15	258	113.6
	-10	263	111.4
	-5	268	109.3
	0	273	107.3
	5	278	105.4
	10	283	103.5
	15	288	101.7
Baseline	**20**	**293**	**100.0**
	25	298	98.3
	30	303	96.7
	35	308	95.1
	40	313	93.6
	45	318	92.1
	50	323	90.7

Figure 11 Air Temperature Compensation, 20°C Baseline Temperature

Turbocharged engine application

	Celsius	Kelvin	Correction Factor
	-20	253	129.6
	-15	258	127.1
	-10	263	124.7
	-5	268	122.4
	0	273	120.1
	5	278	118.0
	10	283	115.9
	15	288	113.9
	20	293	111.9
	25	298	110.1
	30	303	108.3
	35	308	106.5
	40	313	104.8
	45	318	103.1
	50	323	101.5
Baseline	**55**	**328**	**100.0**
	60	333	98.5
	65	338	97.0
	70	343	95.6
	75	348	94.3
	80	353	92.9
	85	358	91.6
	90	363	90.4

Figure 12 Air Temperature Compensation, 55°C Baseline Temperature

5.4 General Engine Settings, Overview

The cylinders are numbered 1, 2, 3 … 'number of cylinders'.
The firing order is determined in the 'General Engine Settings', 'Mechanical Setup' tab.

Using the Diagnostic tools from the menu make sure that all injectors and spark-plugs are operating correctly and that their numbering is correct.

5.4.1 Static setting

Through the settings of crank and cam sprocket details, the ECU will adopt different operational strategies. Sequential typically means that the ECU is knowledgeable of the 4 different strokes by each cylinder. This would necessitate cam sensor knowledge. In a sequential injection system, the fuel injector would open once every 2 crank revolutions. In a sequential ignition system, the spark would fire only once every 2 crank revolutions. The different situations of crank and cam sensors handled by the ECU are described in the following four cases. Cases 1 and 3 offer the possibility of sequential operation. The ignition and injection might be set to operate on different strategies. For example, the injection might be set to operate sequential while ignition operates on wasted spark. This is set by specifying 'number of injectors' equal to 'number of cylinders' while specifying the 'number of coils' as half the 'number of cylinders'.

5.4.1.1 Case 1 No missing teeth on crank and one cam tooth

Engines with no missing teeth on crank sprocket and one cam tooth

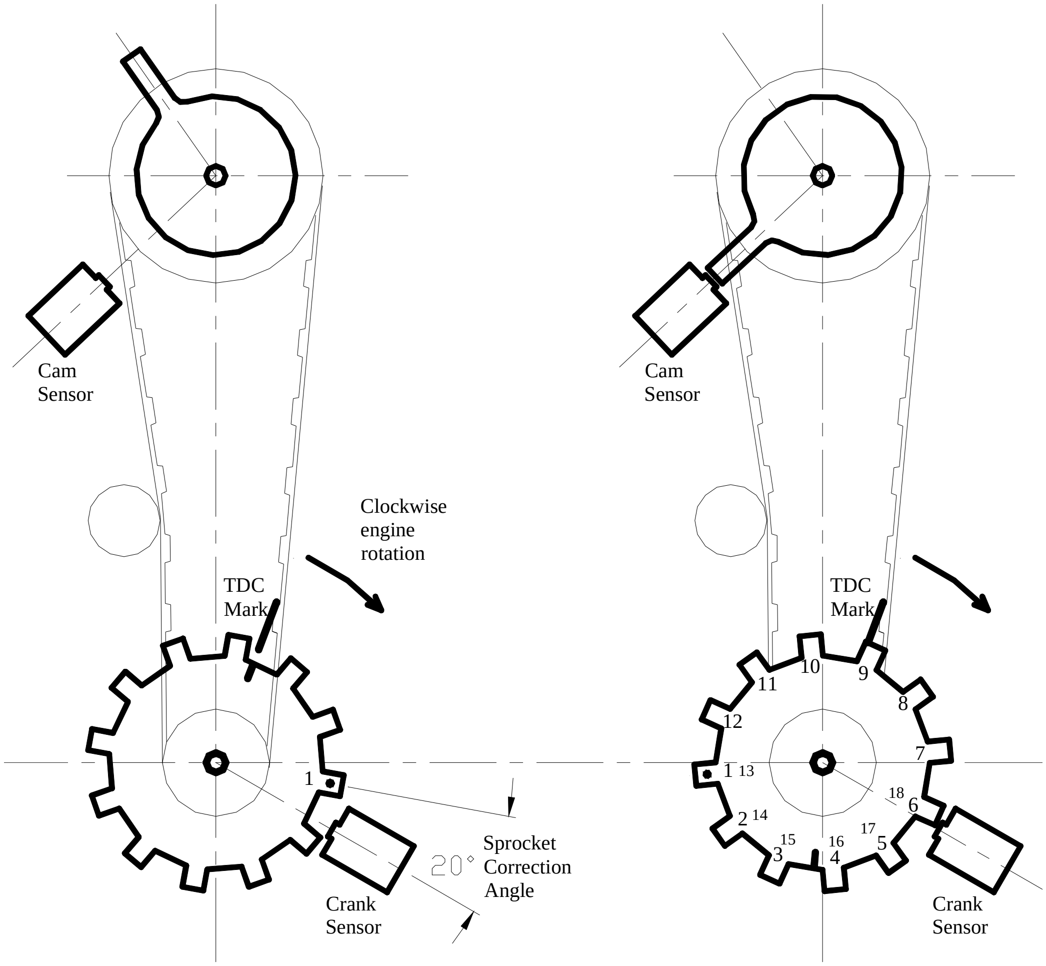

Figure 13 Case 1, Left: Determination of Sprocket Correction Angle and Tooth No 1,

Right: Determination of Tooth at Cam Sensor

Start turning the crank slowly in the direction of rotation until the engine is positioned with the cylinder No. 1 at TDC and firing i.e. with all valves closed. This position is depicted on the left side of Figure 13. This is the Zero Crank Angle datum position for the engine. All events that happen are with respect to this position.   During this procedure of gathering information on crank and cam angular position, it must be clear that all measurements should be made relative to the sensors and not to the timing marks.

The first tooth that will pass in front of the crank sensor is tooth number 1. Mark it with a sharpie.

Slowly rotate the engine in the direction of rotation until the centre line of the first tooth (the one marked as tooth number one) lines up with the centre line of the crank sensor. The angle rotated should be declared as the **Sprocket**

Correction Angle. For the setup shown in Figure 13, the Sprocket Correction Angle is 20°.

Continue rotating the engine (while counting teeth) until the cam tooth is aligned with the cam sensor (the sensor will trigger when it is in the middle of the tooth metal). This position is depicted on the right side of Figure 13. The number of the tooth that will pass in front of the crank sensor next should be declared as the Crank Tooth at Cam Sensor. Note that it might happen that you have to rotate more than one whole crank revolution in order to align the cam tooth to its sensor. In such a case the Crank Tooth at Cam Sensor is greater than the number of teeth on the crank sprocket. In the setup shown in Figure 13, the Crank Tooth at Cam Sensor is 18.

Declare the **Teeth on Cam Sprocket** as 1.

Declare the **Number of Missing Teeth on Crank Sprocket** as zero (0).

Example Case 1: referring to setup shown in Figure 13

The **Teeth on Crank Sprocket** is 12.

The **Number of Missing Teeth on Crank Sprocket** is zero (0).

The **Last non-missing tooth on Crank sprocket** is zero (0).

The **Teeth on Cam Sprocket** is 1.

The **Number of Missing Teeth on Cam Sprocket** is zero (0).

The **Last non-missing tooth on Cam sprocket** is zero (0).

The **Crank tooth at Cam Sensor** is 18.

The **Sprocket Correction Angle** is 20.

5.4.1.2 Case 2 Missing teeth on crank and no cam sprocket

Engines with missing teeth on crank sprocket and no cam sprocket.

Start turning the crank slowly in the direction of rotation until the engine is positioned with the cylinder No. 1 at TDC. This is the Zero Crank Angle datum position for the engine. All events that happen are with respect to this position. During this procedure of gathering information on crank and cam angular position, it must be clear that all measurements should be made relative to the sensors and not to the timing marks.

It is advisable to have the ignition occur in a region with no missing teeth, that is if the sensor is pointing to a sector of missing teeth during the ignition it is best to change the sensor position relative to the sprocket. In fact this should be checked for the ignition occurrences for the other cylinders as well.

Condition A when crank sensor points at a sector with no missing teeth

The first tooth that will pass in front of the crank sensor is tooth number 1. Mark it with a sharpie.

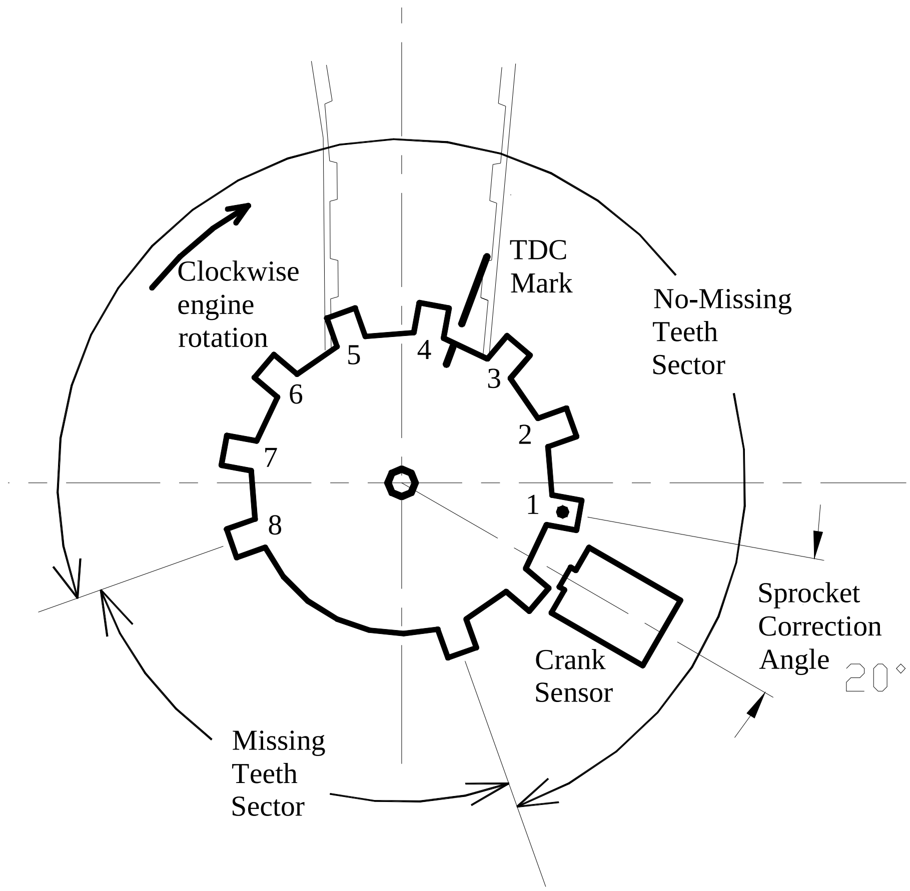

Figure 14 Case 2A, Determination of Sprocket Correction Angle and Last Non-Missing Tooth on Crank Sprocket

Slowly rotate the engine in the direction of rotation until the centre line of the first tooth (the one marked as tooth number one) lines up with the centre line of the crank sensor. The angle rotated should be declared as the **Sprocket Correction Angle.**

Continue counting from this tooth (the one just assigned as tooth number one) and opposite to engine rotation to determine and declare the **Last Non-Missing Tooth on Crank Sprocket.**

Example Case 2A: referring to setup shown in Figure 14

The **Teeth on Crank Sprocket** is 12. (this includes the 2 missing teeth)

The **Number of Missing Teeth on Crank Sprocket** is 2.

The **Last non-missing tooth on Crank sprocket** is 8.

The **Teeth on Cam Sprocket** is zero (0).

The **Number of Missing Teeth on Cam Sprocket** is zero (0).

The **Last non-missing tooth on Cam sprocket** is zero (0).

The **Crank tooth at Cam Sensor** is zero (0).

The **Sprocket Correction Angle** is 20°.

Condition B when crank sensor points inside the sector containing the missing teeth

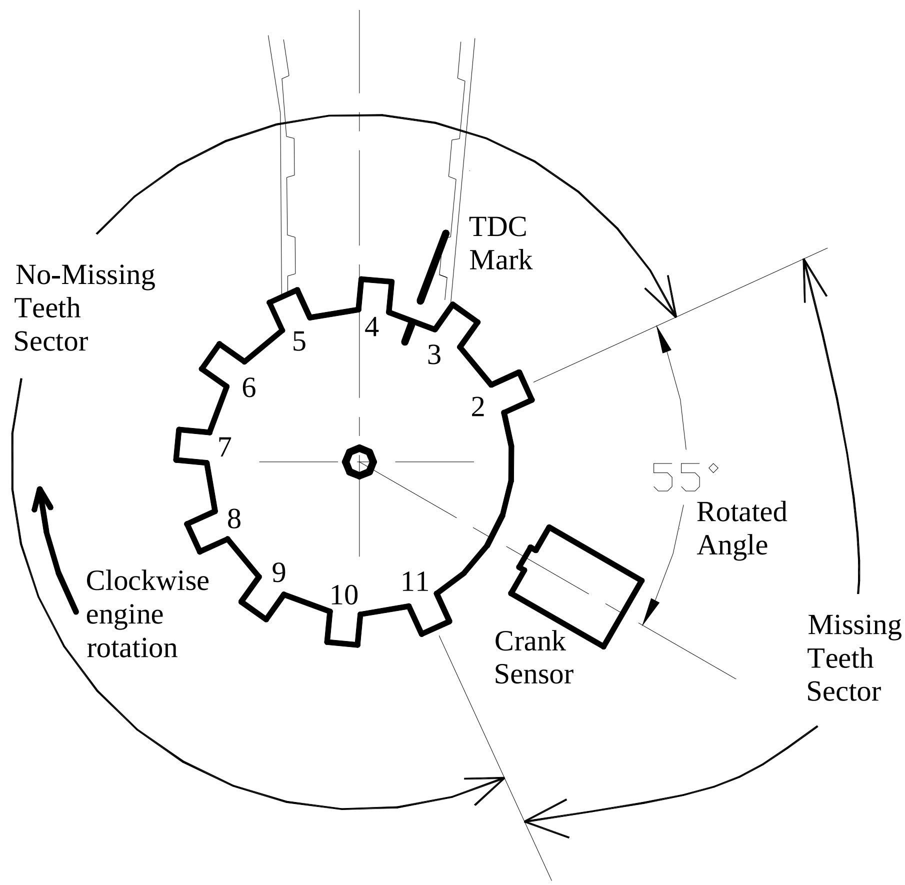

Figure 15 Case 2B, Determination of Sprocket Correction Angle and Last Non-Missing Tooth on Crank Sprocket

Slowly rotate the engine in the direction of rotation until the centre line of the first existing tooth (the one after the gap generated by the missing teeth) lines up with the centre line of the crank sensor. Measure the Rotated Angle. Now divide the Rotated Angle by the Angle Between Two Non-Missing Teeth. Truncate this value, that is if answer is 2.675 then Truncated Answer is 2, if answer is 0.8456, then Truncated Answer is 0. The first existing tooth that is now lined up to the crank sensor should be assigned as tooth number

(Truncated Answer +1). Continue counting from this tooth (the one just assigned {Truncated Answer +1}) and opposite to engine rotation to determine and declare the **Last Non-Missing Tooth on Crank Sprocket**. The **Sprocket Correction Angle** should be declared as
(Rotated Angle – {Truncated Answer* Angle Between Two Non-Missing Teeth}), i.e. the declared Sprocket Correction Angle is to an imaginary closest tooth.

Declare the **Number of Missing Teeth on Crank Sprocket**.

Example Case 2B: referring to setup shown in Figure 15
The Teeth on Crank Sprocket is 12. (this includes the 2 missing teeth)
The Number of Missing Teeth on Crank Sprocket is 2.
The Last non-missing tooth on Crank sprocket is 11.
The Teeth on Cam Sprocket is zero (0).
The Number of Missing Teeth on Cam Sprocket is zero (0).
The Last non-missing tooth on Cam sprocket is zero (0).
The Crank tooth at Cam Sensor is zero (0).
The Sprocket Correction Angle is calculated in following manner.
Rotated Angle =55. Since there are 12 teeth on Crank Sprocket (including the missing), the Angle Between Two Non-Missing Teeth =360/12=30. Division of the Rotated Angle by the Angle Between Two Non-Missing Teeth =55/30=1.833. Therefore the Truncated Answer is 1 (note this is not the rounded value). Hence the first existing tooth (the one after the gap generated by the missing teeth) is assigned number = Truncated Answer + 1= 1+1=2. Sprocket Correction Angle is calculated by (Rotated Angle – {Truncated Answer* Angle Between Two Non-Missing Teeth}) = (55 –{1 * 30} =55 – 30 = 25.

5.4.1.3 Case 3 No crank sprocket and with missing teeth on cam sprocket

Engines with no crank sprocket and with missing teeth on cam sprocket.

Start turning the crank slowly in the direction of rotation until the engine is positioned with the cylinder No. 1 at TDC and firing i.e. with all valves closed. This is the Zero Crank Angle datum position for the engine. All events that happen are with respect to this position. During this procedure of gathering information on cam angular position, it must be clear that all measurements should be made relative to the sensor and not to the timing marks.

It is advisable to have the ignition occur in a region with no missing teeth, that is if the sensor is pointing to a sector of missing teeth during the ignition it is best to change the sensor position relative to the sprocket. In fact this should be checked for the ignition occurrences for the other cylinders as well.

Condition A when cam sensor points at a sector with no missing teeth

The first tooth that will pass in front of the cam sensor is tooth number 1. Mark it with a sharpie.

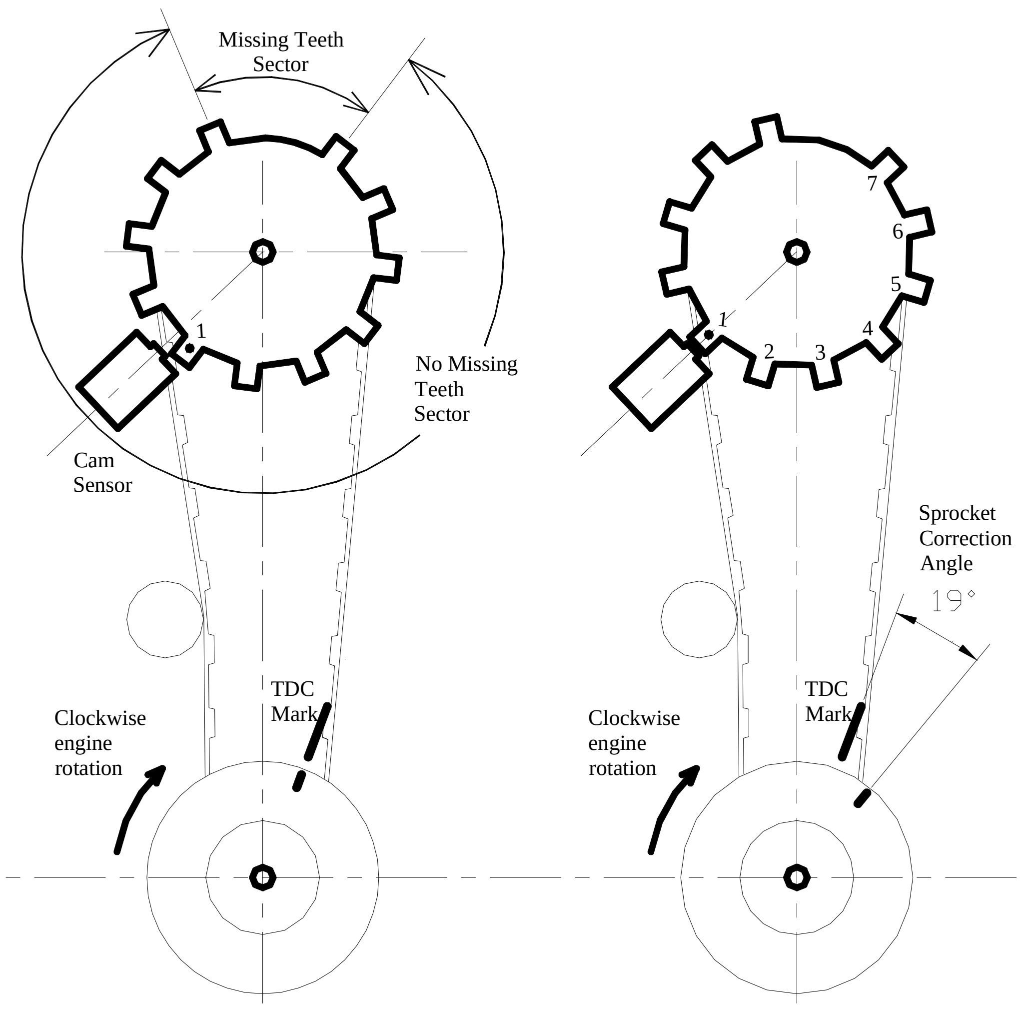

Figure 16 Case 3A, Determination of Sprocket Correction Angle and Last Non-Missing Tooth on Cam Sprocket

Slowly rotate the engine in the direction of rotation until the centre line of the first tooth (the one marked as tooth number one) lines up with the centre line of the cam sensor. The angle rotated by the CRANK should be declared as the **Sprocket Correction Angle.**

Continue counting from this tooth (the one just assigned as tooth number one) and opposite to engine rotation to determine and declare the **Last Non-Missing Tooth on Cam Sprocket.**

Example Case 3A: referring to setup shown in Figure 16

The **Teeth on Crank Sprocket** is zero (0).

The **Number of Missing Teeth on Crank Sprocket** is zero (0).

The **Last non-missing tooth on Crank sprocket** is zero (0).

The **Teeth on Cam Sprocket** is 12. (this includes the 1 missing tooth)

The **Number of Missing Teeth on Cam Sprocket** is 1.

The **Last non-missing tooth on Cam sprocket** is 7.

The **Crank tooth at Cam Sensor** is zero (0).

The **Sprocket Correction Angle** is 19°.

Condition B when cam sensor points inside the sector containing the missing teeth

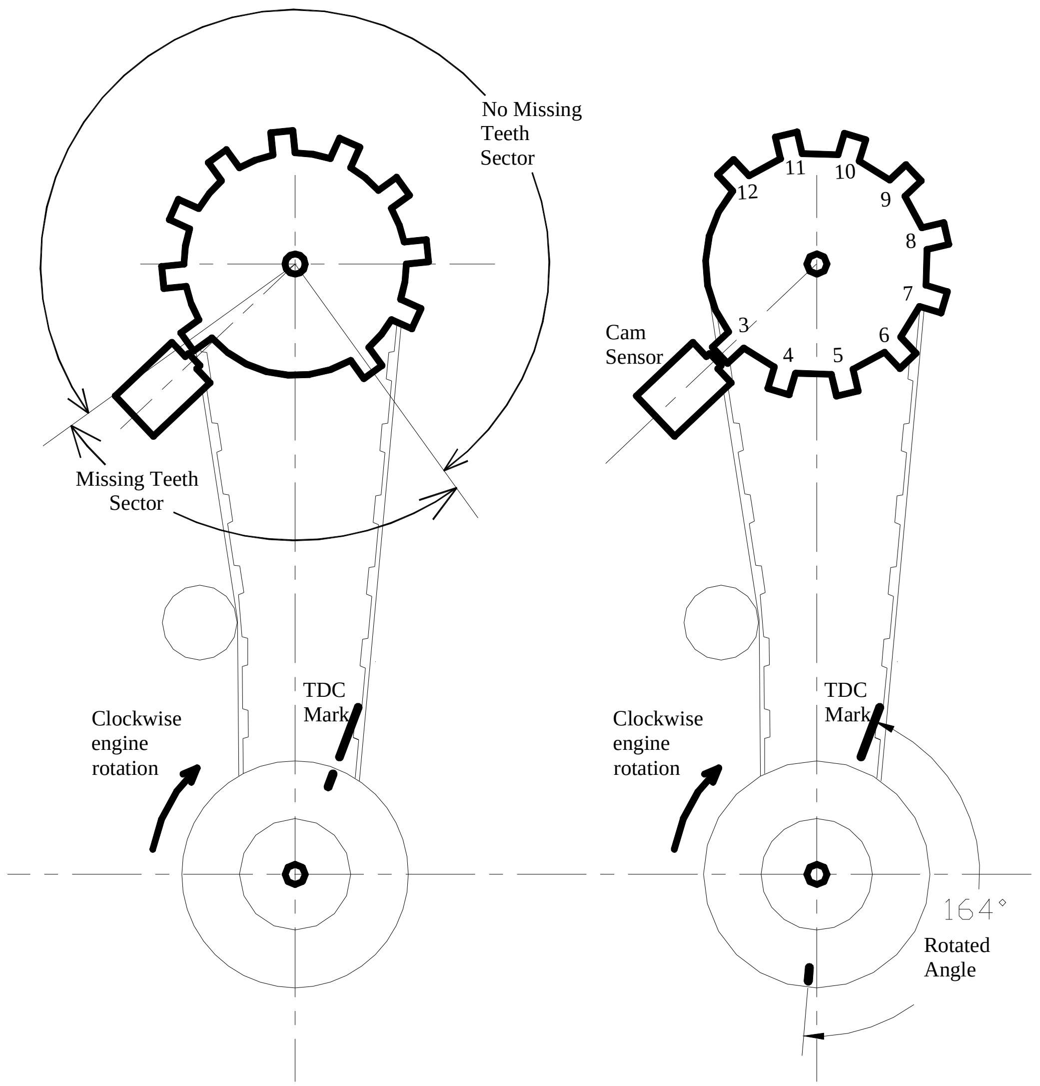

Figure 17 Case 3B, Determination of Sprocket Correction Angle and Last Non-Missing Tooth on Cam Sprocket

Slowly rotate the engine in the direction of rotation until the centre line of the first existing tooth (the one after the gap generated by the missing teeth) lines up with the centre line of the cam sensor. Measure the Rotated Angle by the CRANK. Now divide the Rotated Angle by twice the Angle Between Two Non-Missing Teeth. Truncate this value, that is if answer is 2.675 then Truncated Answer is 2, if answer is 0.8456, then Truncated Answer is 0. The first existing tooth that is now lined up to the cam sensor should be assigned

as tooth number {Truncated Answer +1}. Continue counting from this tooth (the one just assigned {Truncated Answer +1}) and opposite to engine rotation to determine and declare the **Last Non-Missing Tooth on Cam Sprocket**. The **Sprocket Correction Angle** should be declared as
{Rotated Angle – [Truncated Answer* 2*Angle Between Two Non-Missing Teeth]}, i.e. the declared Sprocket Correction Angle is to an imaginary closest tooth.
Example:

Declare the **Number of Missing Teeth on Cam Sprocket**.

Example Case 3B: referring to setup shown in Figure 17
The **Teeth on Crank Sprocket** is zero (0).
The **Number of Missing Teeth on Crank Sprocket** is zero (0).
The **Last non-missing tooth on Crank sprocket** is zero (0).
The **Teeth on Cam Sprocket** is 12. (this includes the 2 missing teeth)
The **Number of Missing Teeth on Cam Sprocket** is 2.
The **Last non-missing tooth on Cam sprocket** is 12.
The **Crank tooth at Cam Sensor** is zero (0).
The **Sprocket Correction Angle** is calculated in following manner.
Rotated Angle =164. Since there are 12 teeth on Cam Sprocket (including the missing), the Angle Between Two Non-Missing Teeth =360/12=30. Division of the Rotated Angle by twice the Angle Between Two Non-Missing Teeth =164/(30*2)= 164/60=2.733. Therefore the Truncated Answer is 2 (note this is not the rounded value). Hence the first existing tooth (the one after the gap generated by the missing teeth) is assigned number = Truncated Answer + 1= 2+1=3. **Sprocket Correction Angle** is calculated by (Rotated Angle – {Truncated Answer* 2*Angle Between Two Non-Missing Teeth}) = (164 –{2 * 2 * 30} =164 – 120 = 44.

5.4.1.4 Case 4 No crank sprocket and with distributor

Engines with no crank sprocket and number of teeth on cam equal to “Number of Cylinders” with distributor.

Start turning the crank slowly in the direction of rotation until the engine is positioned with the cylinder No. 1 at TDC. This is the Zero Crank Angle datum position for the engine. All events that happen are with respect to this position. During this procedure of gathering information on cam angular position, it must be clear that all measurements should be made relative to the sensor and not to the timing marks.

Rotate slowly the engine in the direction of rotation until the centre line of the first tooth lines up with the centre line of the cam sensor. The angle rotated by the CRANK should be declared as the **Sprocket Correction Angle.** The Sprocket Correction Angle is ideally between 160 and 70 degrees, normally this could be achieved by adjusting the distributor angle.

Note that during the spark event, which typically happens between 40^o to 10^o before TDC, the rotor arm has to be ALIGNED AND POINTING towards the proper high tension lead.

Declare the **Teeth on Crank Sprocket** as zero (0).

Declare the **Number of Missing Teeth on Crank Sprocket** as zero (0).

Declare the **Last non-missing tooth on Crank sprocket** as zero (0).

Declare the **Teeth on Cam Sprocket** equal to **Number of Cylinders**.

Declare the **Number of Missing Teeth on Cam Sprocket** as zero (0).

Declare the **Last non-missing tooth on Cam sprocket** as zero (0).

Declare the **Crank tooth at Cam Sensor** as zero (0).

Declare the **Sprocket Correction Angle** through its measurement.

5.4.2 Dynamic setting

Set the Ignition Table with zero advance for all RPM and load positions (or at least the low RPM and load). Disconnect the power from the fuel pump or disconnect the power to the injectors. With the plugs out of the head, crank the engine and with the timing light determine the advance at which the spark is happening. This should be zero, if not than the following methodology should be performed.

The ADJUST button next to the **Sprocket Correction Angle** edit box provides real time modification of the required settings.

The **Sprocket Correction Angle** fine tunes the zero position of the crank shaft. It can be thought of as a software adjustment of the position of the crank sensor.

- To **advance** the spark **increase** the **Sprocket Correction Angle**
- To **retard** the spark **decrease** the **Sprocket Correction Angle**

Case 1 Engines with no missing teeth on crank sprocket and one cam tooth

If the advance has to be corrected by more than 360/(**Number of teeth on Crank Sprocket**)

then the **Crank Tooth at Cam Sensor** has to be changed

- To advance the spark **increase** the **Crank Tooth at Cam Sensor**
- To retard the spark **decrease** the **Crank Tooth at Cam Sensor**

Case 2 Engines with missing teeth on crank sprocket and no cam sprocket

If the advance has to be corrected by more than 360/(**Number of teeth on Crank Sprocket**)

then the **Last non-missing Tooth on Crank Sprocket** has to be changed

- To advance the spark **increase** the **Last non-missing Tooth on Crank Sprocket**
- To retard the spark **decrease** the **Last non-missing Tooth on Crank Sprocket**

Case 3 Engines with no crank sprocket and with missing teeth on cam sprocket

If the advance has to be corrected by more than 180/(**Number of teeth on Cam Sprocket**)

then the **Last non-missing Tooth on Cam Sprocket** has to be changed

- To advance the spark **increase** the **Last non-missing Tooth on Cam Sprocket**
- To retard the spark **decrease** the **Last non-missing Tooth on Cam Sprocket**

Case 4 Engines with no crank sprocket and number of teeth on cam equal to "Number of Cylinders" with distributor

In this case with **Tooth on Cam Sprocket** = **Number of Cylinders**, there are no other parameters than can be changed other than the **Sprocket Correction Angle**. The rotor arm would be responsible for delivering the spark to the appropriate cylinder.

5.5 Fuel injection setup

The fuel injection time values in the fuel table are in milli seconds.

This value always refers to the time for which each injector is flowing. (the dead time or injection delay needs to be specified in the General Engine Settings .)

Note that for setups which **are** sequential (refer to 5.4.1 'Static setting' pg72), the millisecond value in the table is the flowing time of the injector for the four strokes, that is **two crank revolutions**. While for setups which **are not** sequential (refer to 5.4.1 'Static setting' pg72), the millisecond value in the table is the flowing time of the injector for **each crank revolution**. That is, for a non-sequential setup, the effective fuel time on a complete four stroke cycle for a cylinder will be twice the amount in the table.

5.6 Harness Wiring

Figure 18 Basic Harness Wiring Setup shows a typical basic setup for a four cylinder engine.

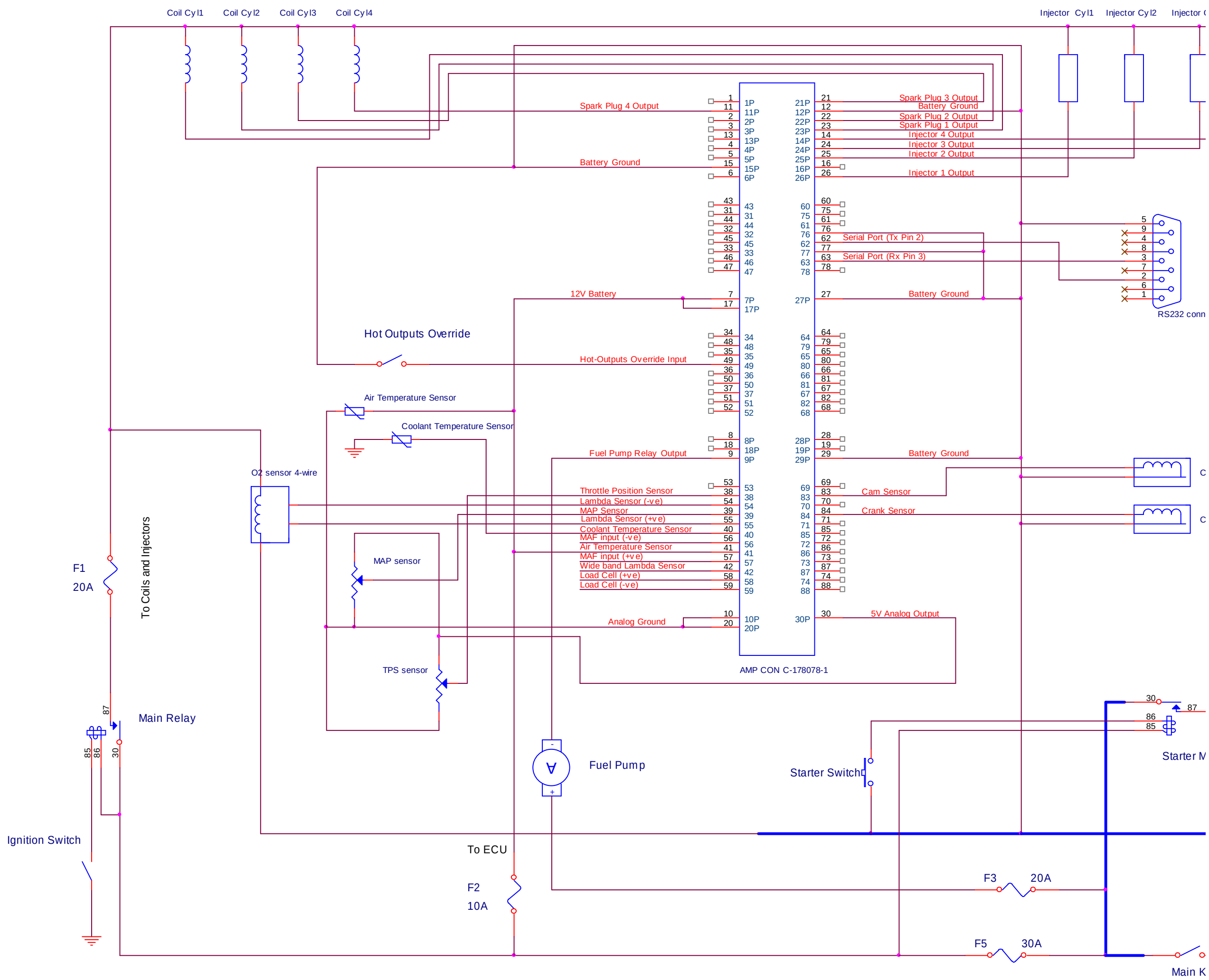

Figure 18 Basic Harness Wiring Setup

Figure 19 Wire Cross-sectional Area Namogram can be printed out and used to calculate the least gauge of wire needed for the given current, length and acceptable voltage drop.

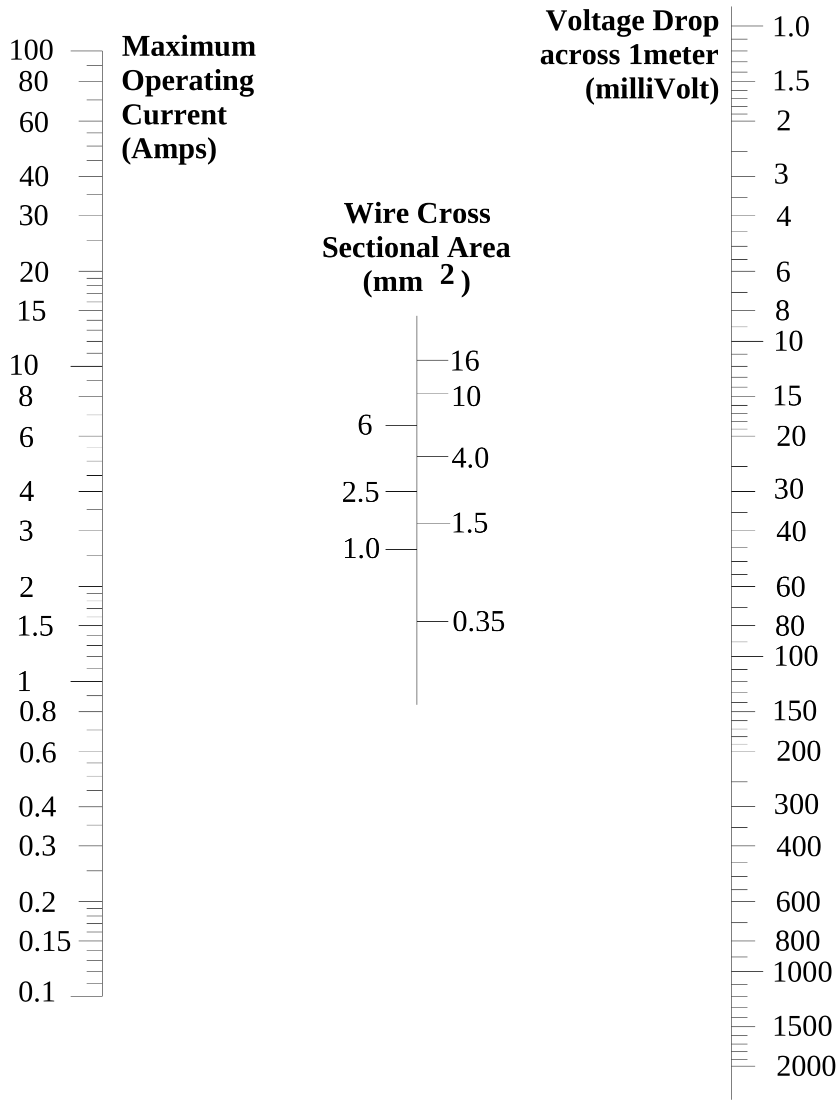

Figure 19 Wire Cross-sectional Area Namogram

6 Glossary

AFR	Air/Fuel Ratio
BBDC	Before Top Dead Centre
BDC	Bottom Dead Centre
BTDC	Before Top Dead Centre
DOI	Duration Of injection
ECU	Engine Control Unit
ESF	Engine Settings File
GUI	Graphic User Interface
MAP	Manifold Absolute Pressue
MBT	Minimum (spark advance for) Best Torque
SAE	Society of Automotive Engineers
TDC	Top Dead Centre
TPS	Throttle Position Sensor
WOT	Wide Open Throttle