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Vehicle Technology

Engine Mapping and
Control

- Introduction
- Requirements – what does an ECU system control?
 - What is a map?
 - Load sites and interpolation
- Fuelling
 - Basics
 - Injection sequencing
 - Fuel presentation
 - Closed Loop System
- Ignition Timing
 - Basics
 - Modern implementation

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- Basic Mapping
 - Basic Mapping Procedure
 - Dyno vs Rolling Road
- Compensations
 - Cranking Enrichment
 - Acceleration Fuelling
 - Cold-start compensation
- Conclusions

Contents

Introduction

- Mapping??
- At any given speed or load point, the engine needs a given amount of fuel to achieve a given air/fuel (λ) ratio
- In the olden days, car ignition was controlled by a distributor (dizzy)
- Fuelling was controlled by one or more carburettors (carbs)
- These were set up and tuned by men with beards.....
- Both were essentially mechanical systems

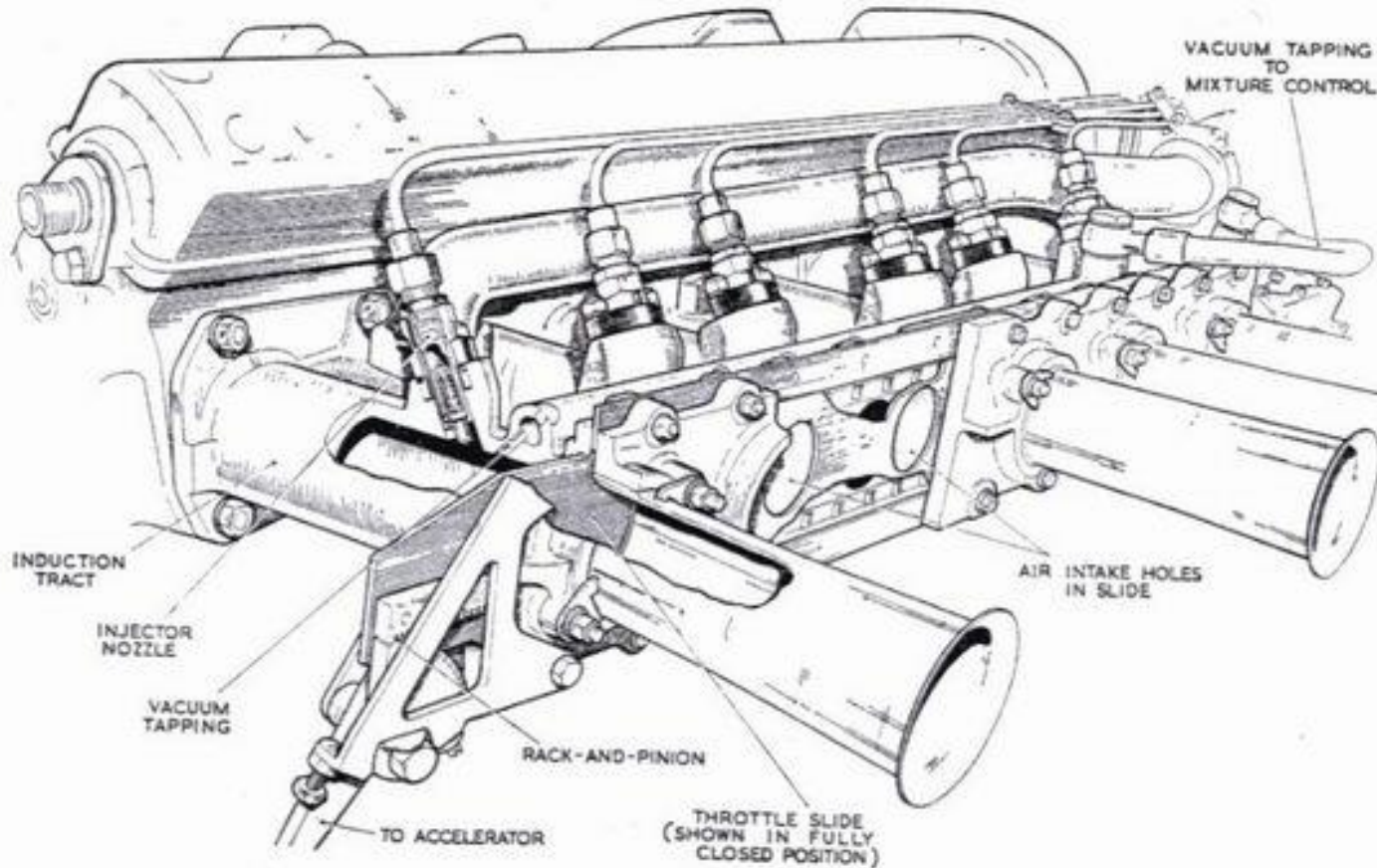


Introduction

- Mechanical systems can become unreliable and go out of tune
- They can be viewed as complex and hard to set up....
- Early injection systems were mechanical
 - 1950's Jaguar and Mercedes racing cars
 - 1970's Lucas mechanical system used by Triumph
 - 1980's Bosch Jetronic – large increase in usage of injection systems (GTi, XRI???)
- Gradual development into today's fully electronic ECU systems to control fuelling and ignition timing



Introduction



Lucas Mechanical Fuel Injection

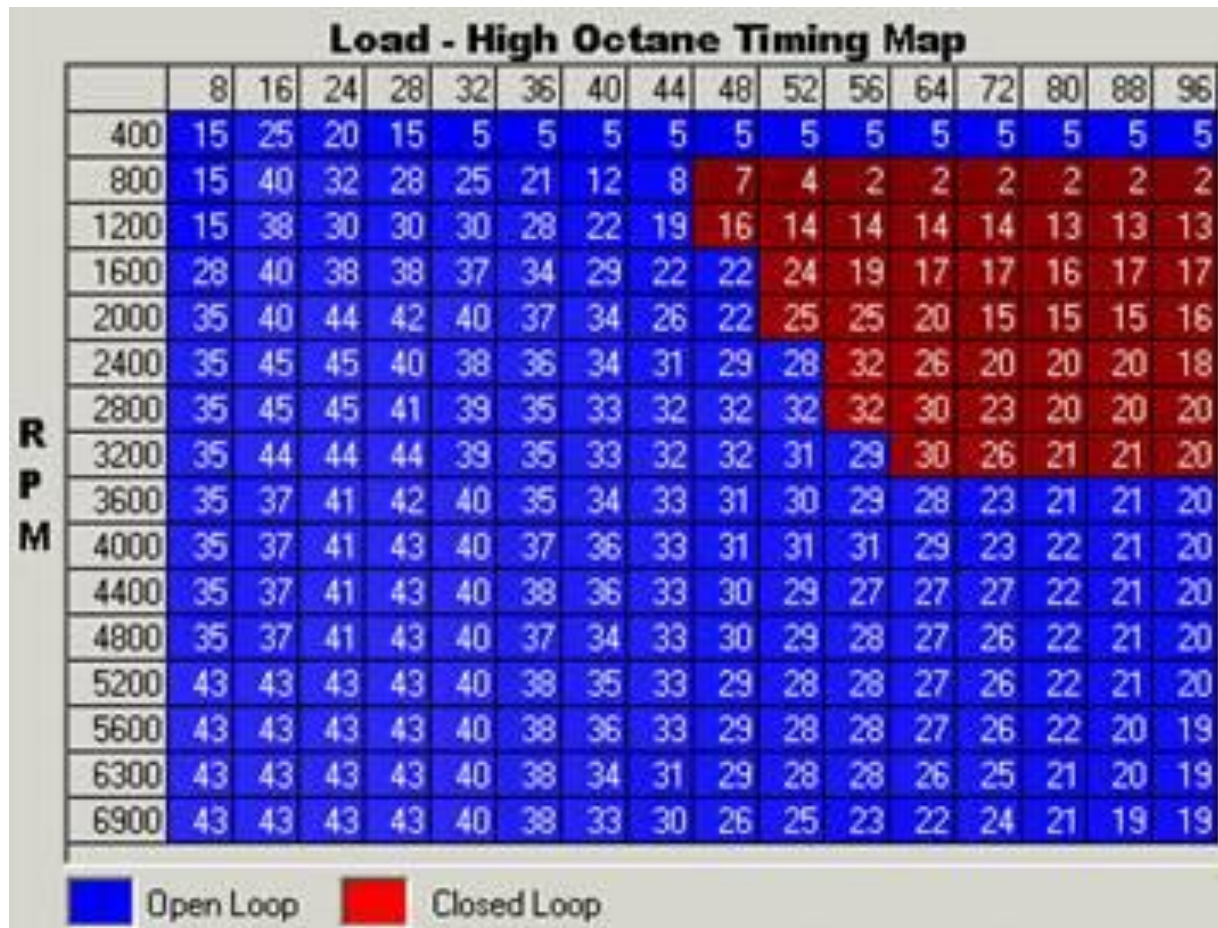
Requirements

- Need to determine amount of fuel and ignition timing
 - Depending on engine speed and load
- Three different methods of determining engine load
 - Mass Air Flow (MAF) sensor
 - In theory, if you know the amount of air going in to the engine, then you know how much fuel you need to achieve a given lambda value
 - But carry over etc.....
 - Moving flap meters, Hot Wire, Bubble Meters
 - Manifold Air Pressure (MAP) sensor
 - Pressure (below ambient) in manifold relates directly to air flow into engine
 - Throttle Position Sensor (TPS)
 - Widely used in racing as believed to give better throttle response



Requirements

- Engine speed usually measured with an electronic sensor reading a trigger disk

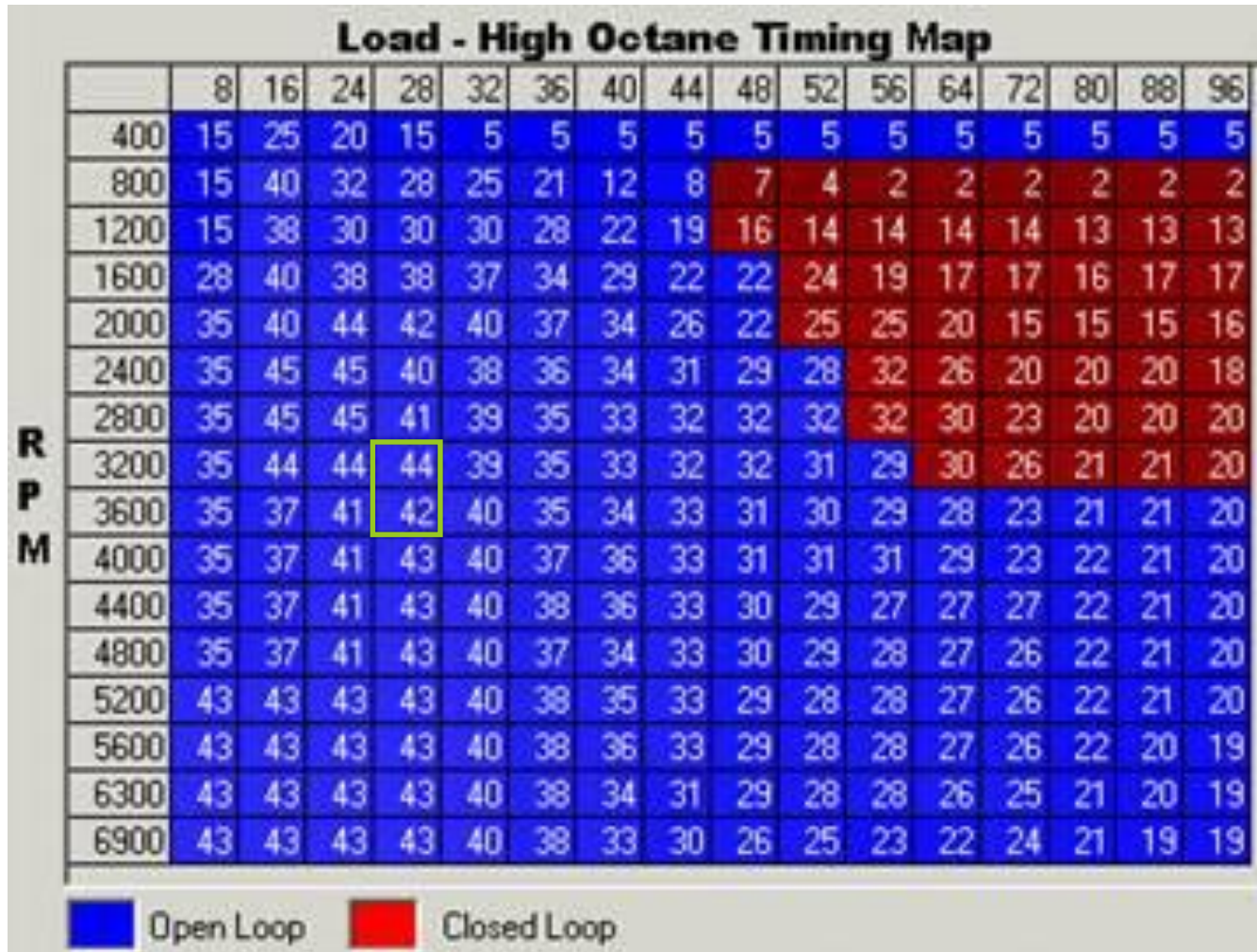


Load Sites

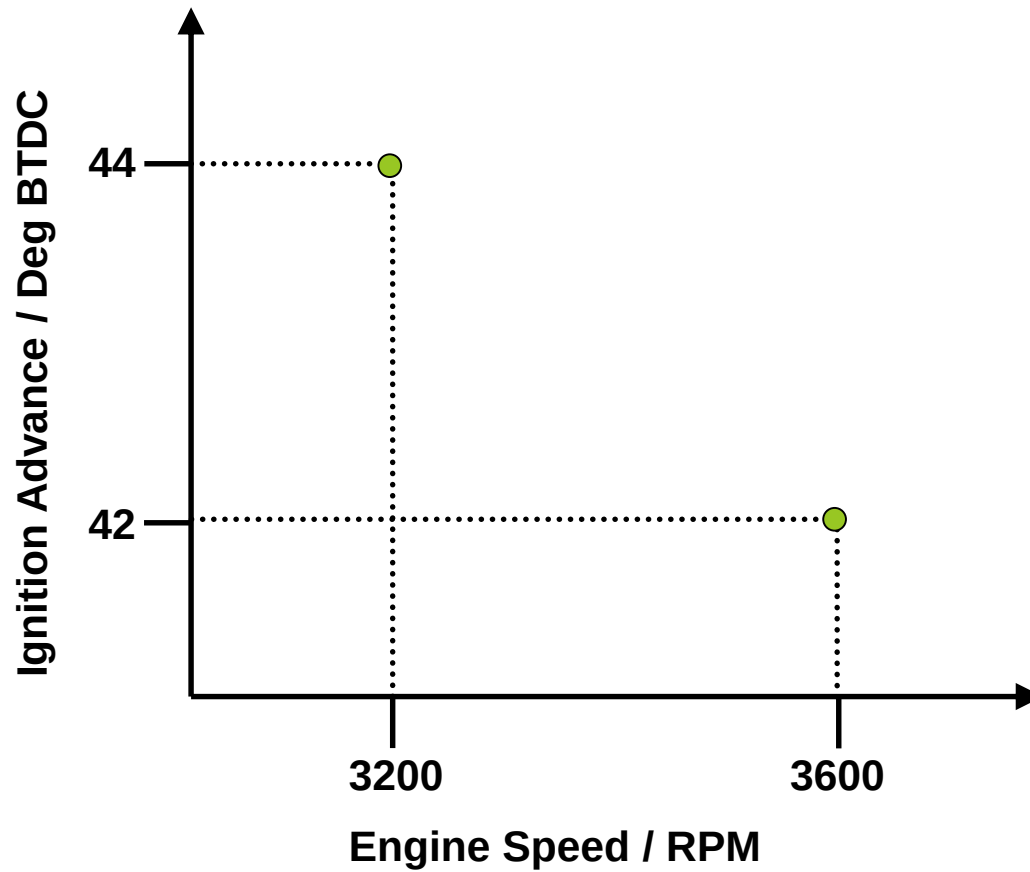
- Ignition and fuelling timing is then determined by creating a map
- Discreet points in RPM and Load ranges
- This acts as a lookup table for ECU to determine required timing/fuelling based on information from RPM and MAF/MAP/TPS sensors
- But between points? i.e. engine runs at 3520rpm and we only have points in table at 3200 and 3600rpm?
- ECU smoothly interpolates between points (actually in 2 dimensions)



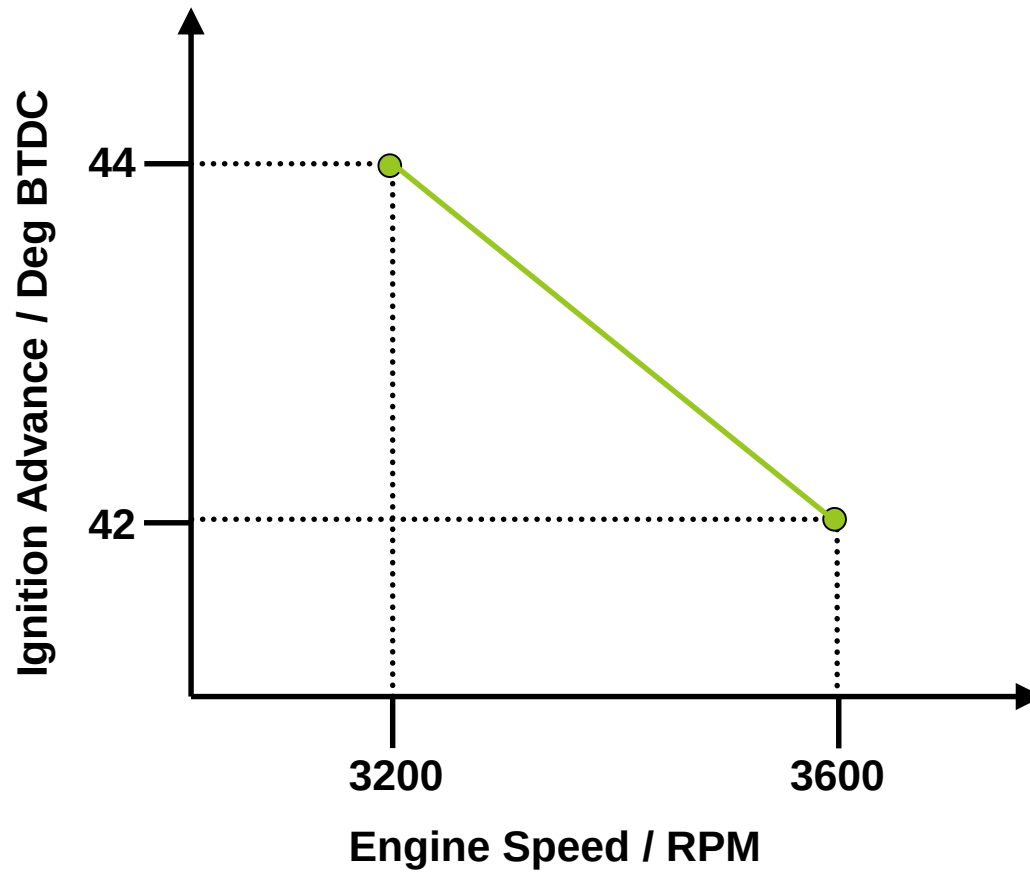
Load Sites



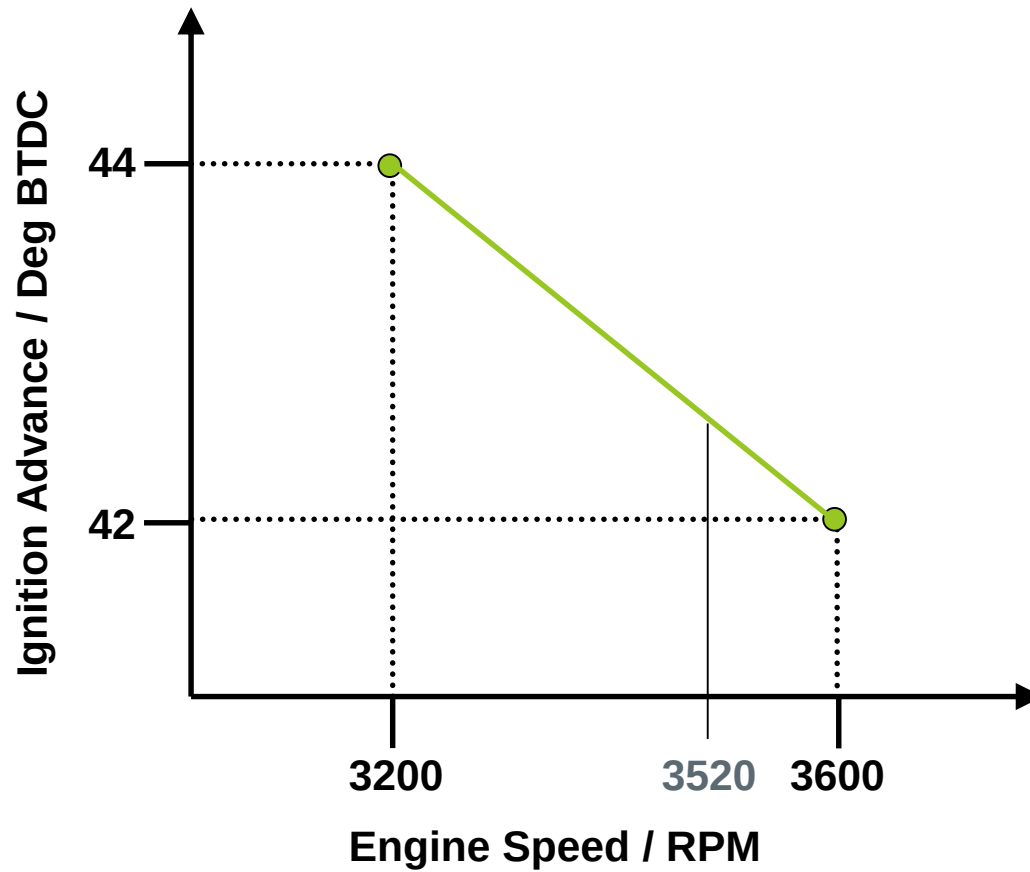
1D Interpolation



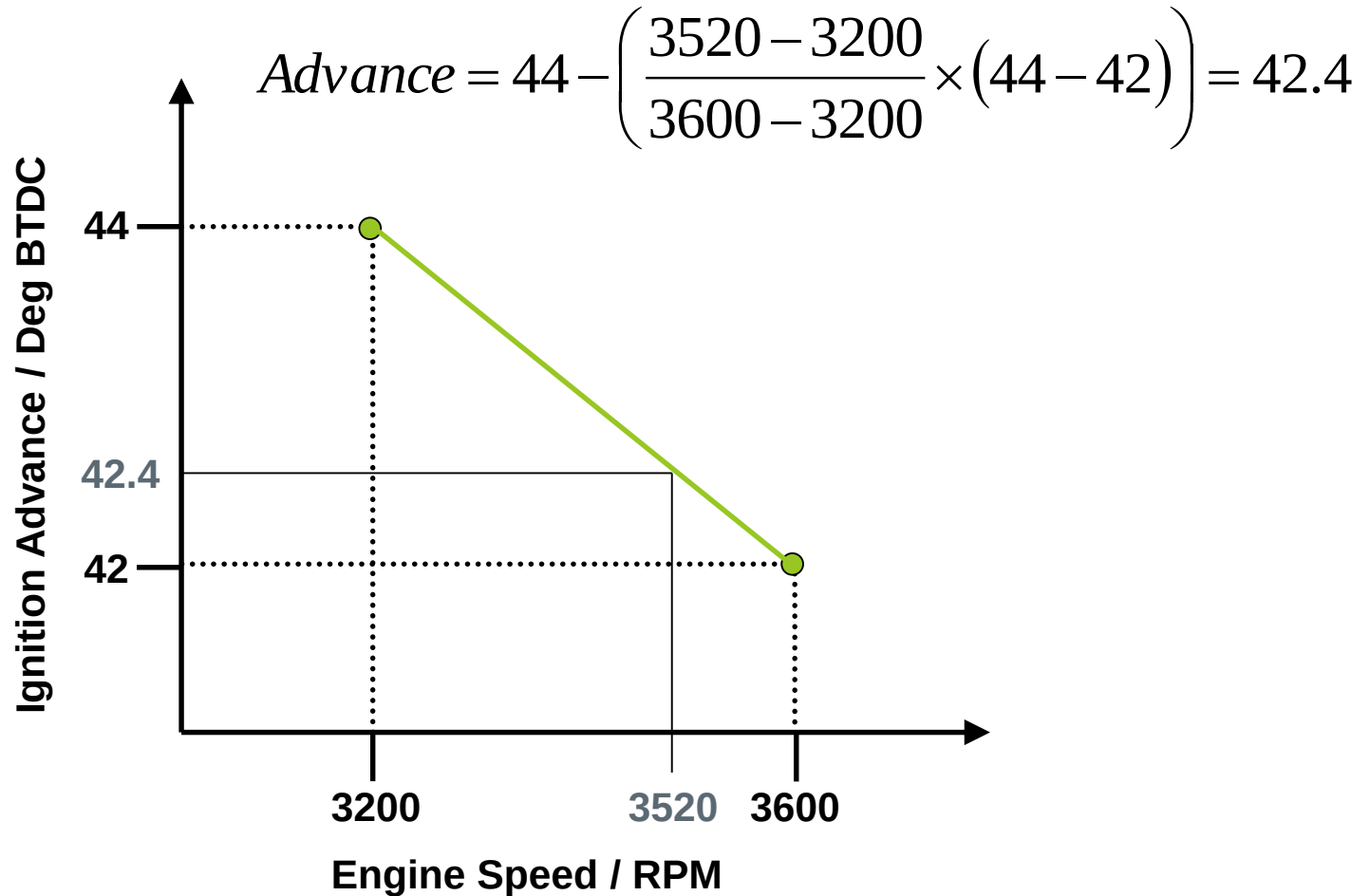
1D Interpolation



1D Interpolation

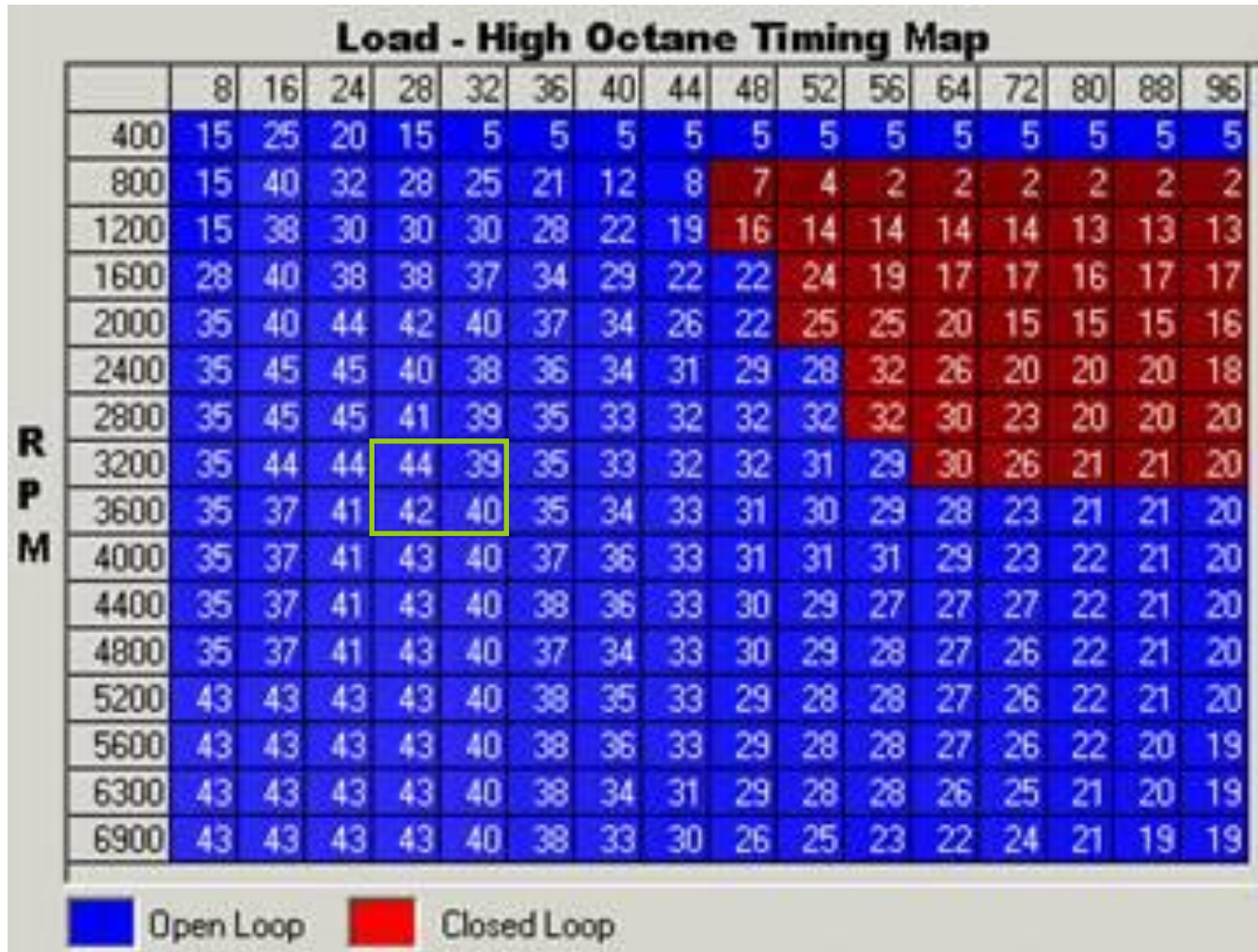


1D Interpolation

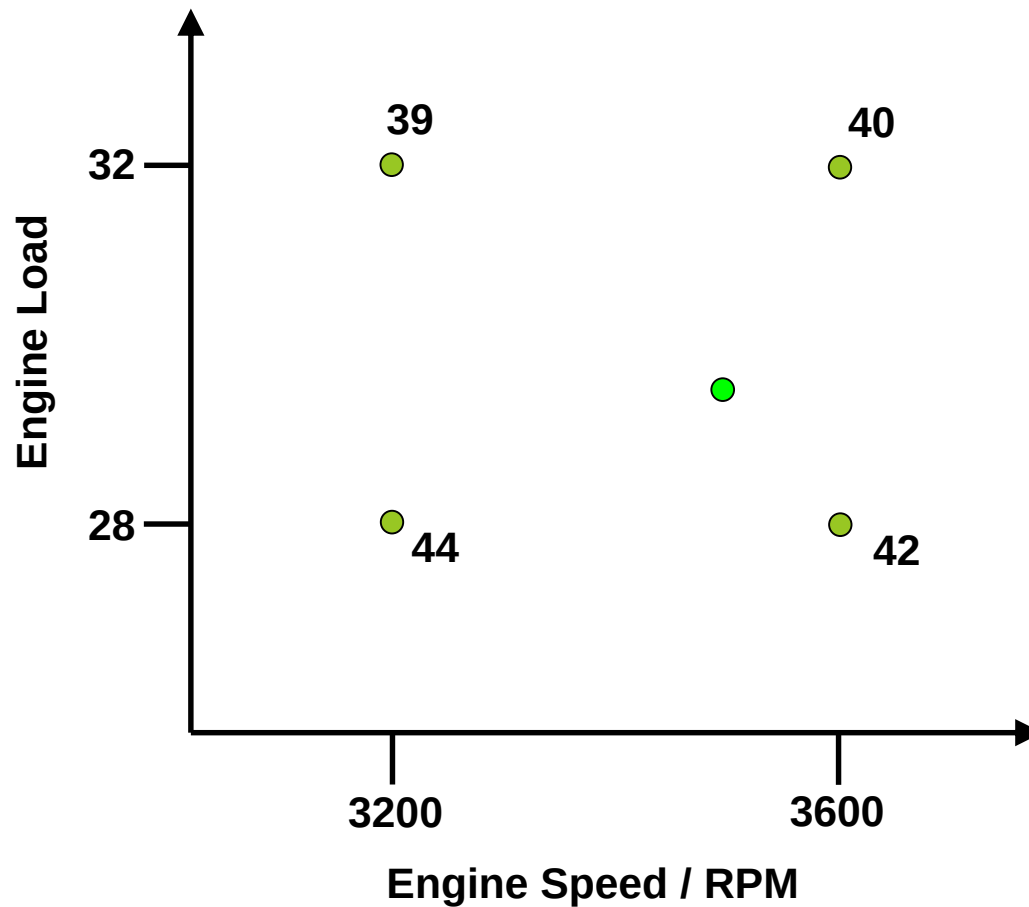




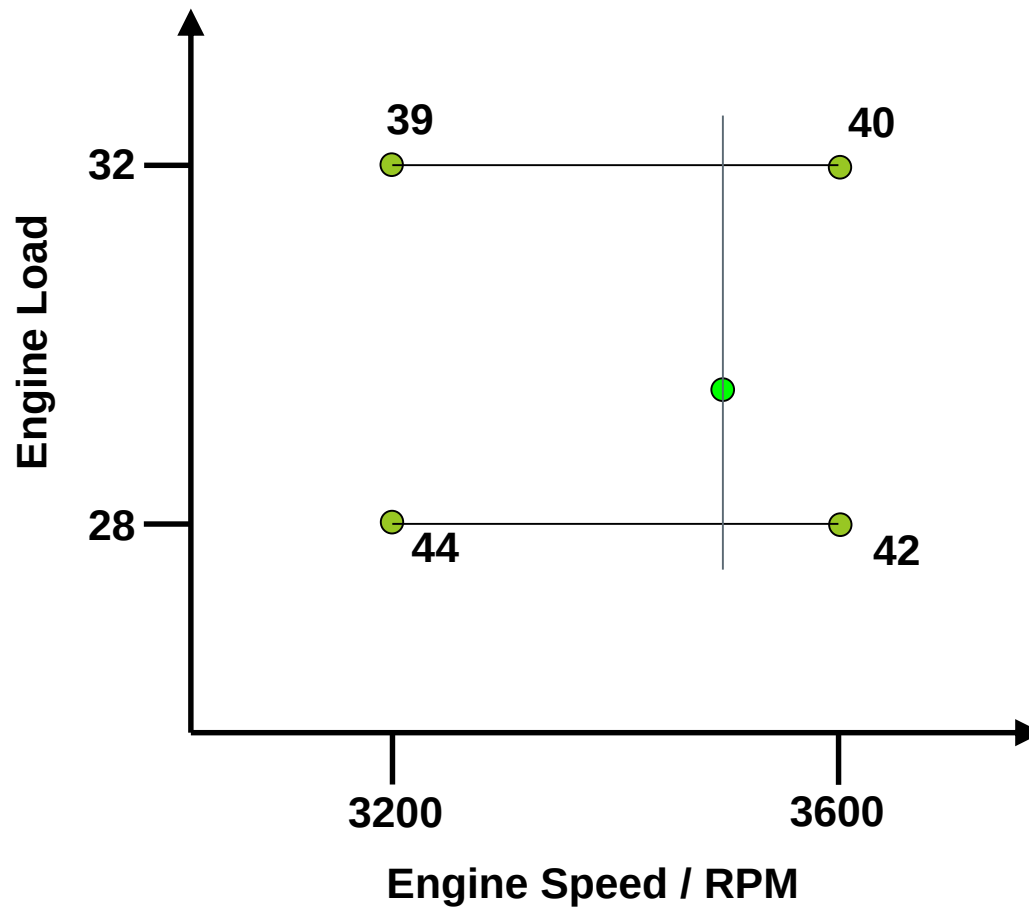
2D Interpolation



2D Interpolation



2D Interpolation

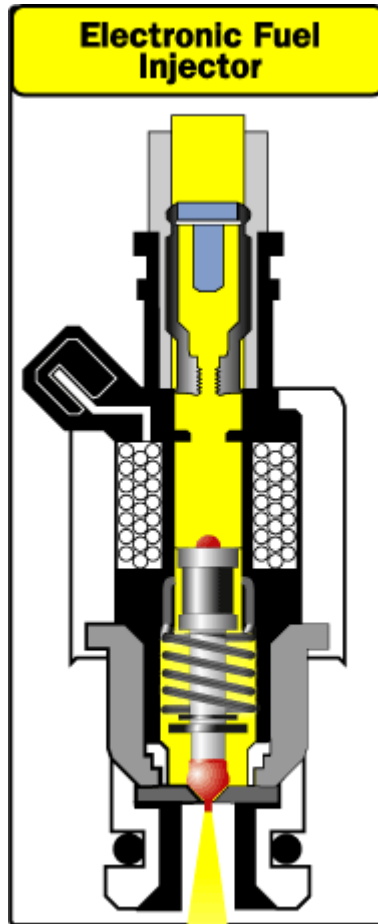


Basic Fuelling

- More air = more fuel required
- Aiming for a given air/fuel (lambda ratio) λ
 - Stoichiometric (i.e. just enough air to burn all fuel) $\lambda = 1$
 - Rich (i.e. a map optimised for power) $\lambda < 1$ (typically 0.9)
 - Lean (i.e. a more economical map) $\lambda > 1$
- Electronic injection uses a solenoid injector
 - Basically a valve which lets pressurised fuel spray into the inlet port whilst it is open
 - Opens in response to a signal pulse from ECU
 - Injector flows fuel at a certain flow rate
 - Thus, the longer the pulse from the ECU, the more fuel is injected



Basic Fuelling



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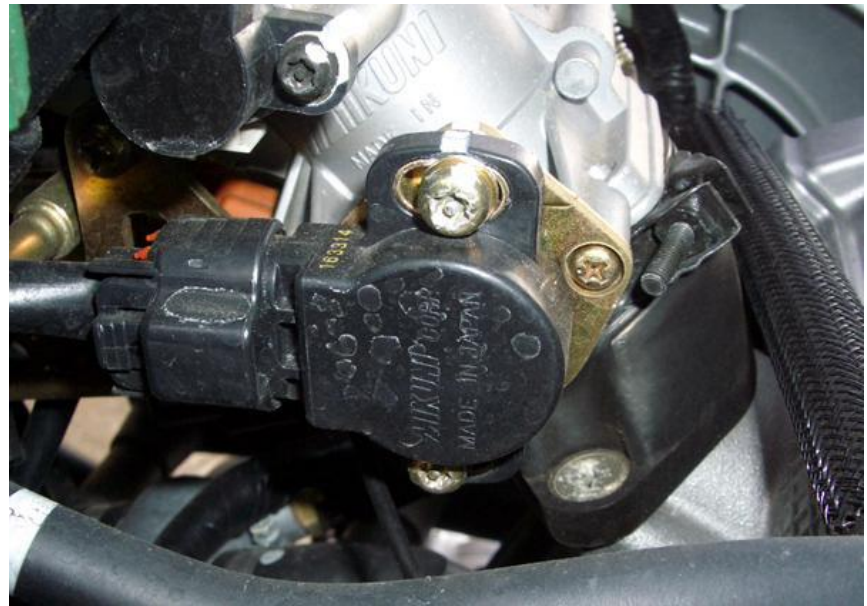


Basic Fuelling

- Main parameters
 - Engine rpm (from trigger wheel on cam or crank shaft)
 - Air flow (either directly from MAF or MAP sensor, or implied from TPS)
- Other parameters affecting the amount of air flowing into engine
 - Inlet air temperature
 - This can be compensated for by a temperature sensor measuring inlet air temp
 - Fixed correction applied for fuel based on air density
 - Engine (coolant) temperature
 - Equivalent to a choke on carburetted systems
 - More fuel needed until a cold engine has warmed up

Basic Fuelling

- Air pressure
 - Air is less dense at altitude than at sea level
 - Fixed compensation based on measurement from pressure sensor



Injector Sequencing

- In theory, carbs only supply fuel during induction stroke
- Batch Firing
 - All injectors fire twice per cycle (i.e. every 360° of crank rotation)
 - Thus the fuel for each cylinder is injected in two half quantities
 - Not related to inlet valve opening – thus if the valve is closed fuel remains in inlet tract until it is needed
 - Injectors do not need high flow capacities
 - Gives finer resolution (each “step” in software related to a smaller amount of fuel)
 - Not very efficient (some fuel can be injected and go straight to exhaust on overlap)
 - High exhaust emissions

Injector Sequencing

- Semi-sequential Firing
 - Injectors are paired on a 4 cylinder engine
 - i.e. two injectors fired every 720°
- Fully Sequential Firing
 - Injection every 180° but only one injector fired at a time
 - Thus, each cylinder only receives an injection once in the 4-stroke cycle
 - Individual fuelling for each cylinder
 - Timing of fuelling can be altered to avoid blow-through to exhaust
 - Less time to get fuel into cylinder, so larger injectors needed
 - Better fuel consumption and fewer emissions

Injector Sequencing

- Competition engines operate at high speed
- Thus, there is less time available for an injection event and the advantages of sequential injection are less apparent
- What is the solution?

Fuel Presentation

- It is desirable to break the fuel up into small droplets and mix it thoroughly with the air
- Also, vaporising the fuel will cool the air charge, making it more dense (and hence achieving more power). This can be achieved by aiming fuel at back of hot inlet valve
- Upstream injection
 - Places injector as far away from inlet valve as possible
 - Gives maximum time for fuel mixing and breaking into fine droplets
 - Gives maximum time for fuel to draw heat from inlet air
 - However, low rpm and small throttle opening gives less air flow and fuel can drop out of air stream and pool at lowest point of injection system

Fuel Presentation

- Reverse injection
 - Fire fuel into air-stream against direction of flow
 - Gives maximum “shear effect”
 - i.e. maximum breakup of fuel into droplets and good mixing
 - However, at low air flow rates, fuel can overcome air flow – fuel blows out into air box or filter
 - Can backfire through induction system
- Double Injectors
 - Practical solution
 - Only inner injectors aimed at inlet valve operate at low RPM
 - At high rpm both inner and outer injectors (placed as far as possible upstream in inlet system) operate



Fuel Presentation



Closed Loop System

- Lambda Sensor in exhaust system
 - Developed because Catalytic Converters need a close (and near to stoichiometric) control of the engine's lambda ratio operating point to allow them to function correctly
 - Sensor measured oxygen level in exhaust gases
 - Signal passes back to ECU so that the lambda ratio can be controlled continuously under range of operating conditions
 - Most OEM (Original Equipment Manufacturer) ECU's use narrow band lambda sensors, but WIDE BAND sensors are available to tell us what the lambda ratio is (rather than just if it's in spec or not as with narrow band)
 - These allow us to measure the lambda ratio when mapping
 - Some motorsport ECU's also include this (but you're usually controlling to a rich mixture!)

Ignition Timing Basics

- We want the mixture to burn and expand (doing useful work and pushing piston down cylinder)
- If combustion takes too long, piston is already travelling down cylinder and less useful work can be done
- Many parameters affect when we want to ignite the charge
- Weaker mixtures take longer to burn
- More volume of charge (higher VE) in cylinder is more dense when compresses and burns faster
 - Thus part throttle (poor filling) generally needs more advanced ignition than full throttle conditions (better filling)
- Combustion takes a certain amount of time
 - Thus, at higher engine speeds we need to start this process earlier to ensure the gas expands and starts to do work when engine is around TDC
- Turbulence (and hence flame speed) also depends on engine speed

Modern Ignition Timing



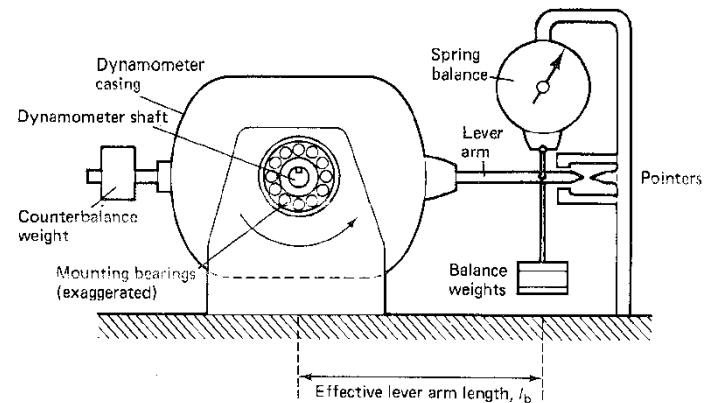
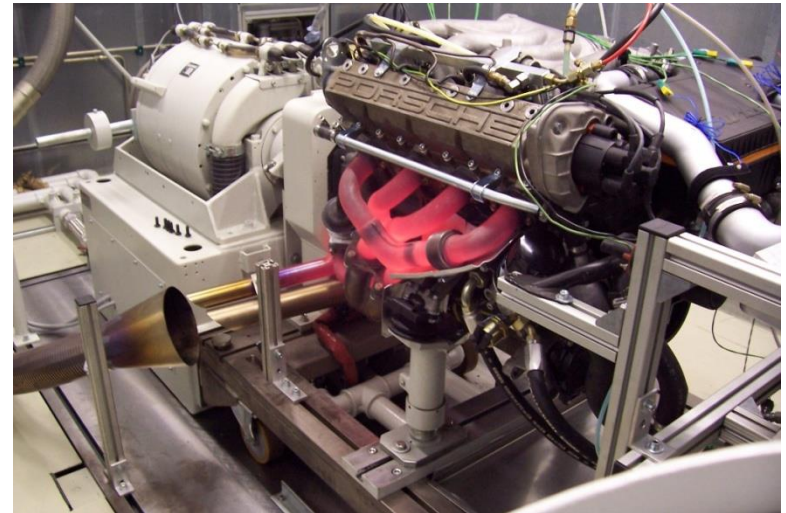
- Thus, ignition timing is a very complex subject!!!
- Electronically controlled ignition systems give maximum control over the spark timing
- Input is a trigger wheel which gives engine speed
- Missing tooth (or a cam sensor) gives position of engine within cycle
- Some form of load is also used (as per fuel mapping)
- This is much improved compared to a distributor

Basic Mapping Procedure

- Engine needs to be held at each load/speed site and the necessary fuel and ignition timing determined
- Rolling road or engine dynamometer
- Wide band lambda sensor and display shows the engine air/fuel conditions
- Ignition timing generally set approximately first based on previous experience and common sense
- Fuelling (and fine-tuning of ignition) then set based on power and lambda readings at each load site
- Aim for minimum best timing (more advance can lead to pinking)

Dyno / Rolling Road

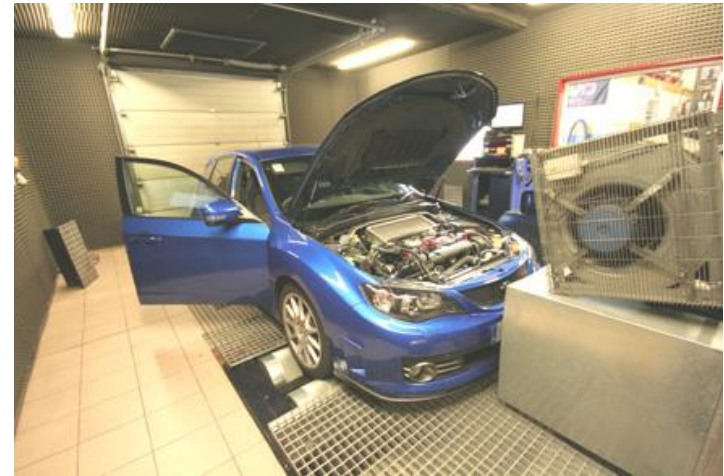
- Each has their advantages and disadvantages
- Engine dyno
 - Directly measures engine power at the flywheel
 - Can hold engine at load all day without overheating
 - Experimentation with inlet lengths etc
 - No use if you don't use the car's exhaust and silencer though!



Dyno / Rolling Road

■ Rolling road

- Has tyres and transmission in the way
- Modern eddy-current rolling roads can hold a car at speeds, and can compensate for transmission losses etc (run-down testing)
- Allows engine to be tested exactly as fitted in car
- Less opportunity for experimentation etc
- Overheating issues etc



Compensations

■ Cranking Enrichment

- Air speed at cranking is low (especially in race engines with big throttle bodies, inlet valves and race cams)
- Much of the injected fuel can drop out of the slow moving air stream
- Solution is to add extra fuel during cranking
- Often, a large amount of extra fuel is injected during first few seconds of cranking
- Enrichment decays after a few seconds
- Cold-starting can be hard to map (once engine runs it gets hot!!!)

Compensations

■ Acceleration Fuelling

- Snap throttle opening gives a sudden in-rush of air
- Air has flowed into engine before injection can be completed
- This gives a hesitation (or flat spot)
- Carburettors use a mechanical acceleration pump to avoid this
- Fuel injection systems need to compensate (and inject extra fuel) based on rate of throttle opening
 - Enrichment by a given amount for a given time
 - Can turn off acceleration enrichment over a certain rpm (engines accelerate more easily if they are already at high speeds)
 - Lightweight race engine with aluminium flywheel and throttle bodies will need less enrichment than a heavy V8 with stock plenum

Compensations

- Cold temperature compensation
 - Cranking compensation only in effect for the first few seconds of running an engine
 - “warm up enrichment”
 - Essentially a correction to the map in relation to coolant temperature
 - Can be a fuelling correction or an advance correction
 - Varies with coolant temperature

Conclusions

- Engine mapping is complex
- Essentially links fuelling and ignition timing to load and engine speed
- More accurate than older mechanical systems
- Includes compensations for temperatures, pressures and acceleration conditions
- Three strategies for injection sequencing
- Injector placement is critical
- Consult the experts!!!