# Engine Testing Overview

# Engine Testing Topics

To develop your understanding of why engine testing is done.

To look at particular testing requirements and methods.

- Test cell design and instrumentation operation
- How the internal combustion engine works
- Engine testing
- Turbo~charging, variable vane geometry applications
- Exhaust gas emissions, combustion analysis
- Performance and validation testing
- Instrumentation, temperature, pressure and flow
- Fuel, ignition and emission loops leading to mapping and calibration.
- Test cell procedures and safety issues.

# Engine testing 'acronyms' used in automotive industry

- DVT — Design Validation Testing
- OCT — Oil consumption test
- TDC — Top dead centre
- BDC — Bottom dead centre
- LPP — Location of peak pressure
- BSFC — Brake \Specific Fuel Consumption
- BMEP — Brake Mean Effective Pressure
- MBT — Minimum spark, best torque
- MBTL — MBT retarded to clear detonation
- TLA — Top limit advance
- BLA — Bottom Limit advance
- AFR — Air Fuel Ratio

# Definition of terms

- Crank angle- the measure of rotation based on the engine movement- one complete revolution = 360 degrees crank angle.
- Stoichiometric-a mixture(typically air and fuel) where the reacting components are present in proportions to react fully.
- Four stroke engine-an engine with a power stroke on alternate cycles-as opposed to a two stroke engine
- Misfire(petrol only)-an event where the combustion event does not take place or where a flame builds and is prematurely extinguished.
- Lean limit- the highest air-fuel ratio at which the engine will run with a certain level of misfire.
- Knock-the detonation of the ’end gas’ in the cylinder under high load, or high pressure conditions.

# Why an engine needs a test?

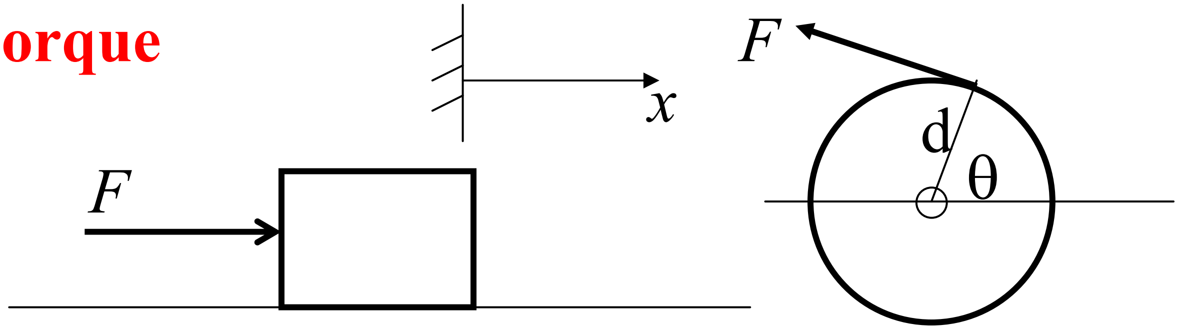
To find out performance before mass production and fitting it into a vehicle.

To improve the design and configuration, to integrate new materials and technology

Historically, the test basically was to find out the power and fuel consumption, also to test effectiveness of cooling, vibration and noise, lubrication, controllability, etc.

Modern regulations force engines to reduce harmful emission and comply stringent regulations, therefore, test is getting more and more sophisticated.

# Power and Torque




| | Force (N) | Work (J) | Power (W) |
|---|---|---|---|
| **Translational:** | $F = m\dfrac{d^2x}{dt^2}$ | $W = Fx$ | $P = \dfrac{dW}{dt} = F\dfrac{dx}{dt}$ |
| **Rotational:** | $T = J\dfrac{d^2\theta}{dt^2}$ | $W = T\theta$ | $P = \dfrac{dW}{dt} = T\dfrac{d\theta}{dt}$ |

- **Engine Torque**
  - The fundamental output of the engine
  - Usually expressed in Nm or BMEP
  - Torque is measured by a dynamometer or an ‘in-line’ device
  - BMEP is the accepted figure used to compare the performance of engines of differing capacities.

## BMEP not just use HP

BMEP - Brake Mean Effective Pressure - average effective pressure of all stroke cycles. (whether they are Two or Four Cycles).

$$BMEP \times swept\_volume = T \times 2\pi$$

$$BMEP = \frac{T \times 2\pi}{swept\_volume} = \frac{\left(\dfrac{\dfrac{P}{RPM \times 2\pi}}{60}\right) \times 2\pi}{swept\_volume} = \frac{60P}{swept\_volume \times RPM} \qquad (Pa)$$

BMEP is a function of temperature of the gases in the cylinder.
To increase the temperature needs to burn more fuel or to increase burning efficiency.
Torque is a function of BMEP and displacement.

A high BMEP and a low rpm, or a low BMEP and a high rpm, can equal the same power. Larger valves, ports, pipes, compression, etc. all can increase the volumetric efficiency of the engine. The most effective is to increase the number of cylinders. The more efficient it is, the higher the BMEP.
Pressure increases by compression alone can increase pumping losses, and in the amount of heat lost to the surrounding parts.

**Two cycle engines:**
**BMEP = ( HP * 6500 ) / ( L * RPM )     (psi)**
*2-cycles require only one half of 4-cycle BMEP to produce the same power at the same rpm.*

**Four cycle engines:**
**BMEP = ( HP * 13000 ) / ( L * RPM )    (psi)**

***L*** *= Swept volume in Liters.*

Examples:
**1**) 2-cycle, one cylinder 80cc with 20 HP at 11500rpm
BMEP=20 x 6500/0.08/11500=141
**2**) 4-cycle, one cylinder 500cc with 30 HP at 7500rpm
BMEP=30 x 13000/0.5/7500=104
**3**) 2-cycle, four cylinder 750cc with 160 HP at 8250 rpm.
BMEP=160x 6500/0.75/8250=168
**4**) 4-cycle, eight cylinder 5736cc (V8) with 350 HP at 5000 rpm
BMEP=350 x 13000/0.573/5000=158
**5)** 2-cycle, two cylinder GP 250cc with 90 HP at 11750 rpm
BMEP=90 x 6500/0.25/11750=199 (units?)

# Basic Instrumentation for Engine Test

- Power/torque measurement - dynamometers
- Engine speed measurement
- Air flow rate measurement
- Fuel flow rate measurement

# Test Equipment and Instruments

- **Emission equipment**
- **Thermocouples**
- **Pressure transducers (in cylinder measurement)**
- **Turbine flow meters**
- **Smoke measurement**
- **Fuel measurement**
- **Blow-by measurement** (blow-by: gas past the rings into the crankcase)
- **Air flow measurement**

# Dynamometers

Types

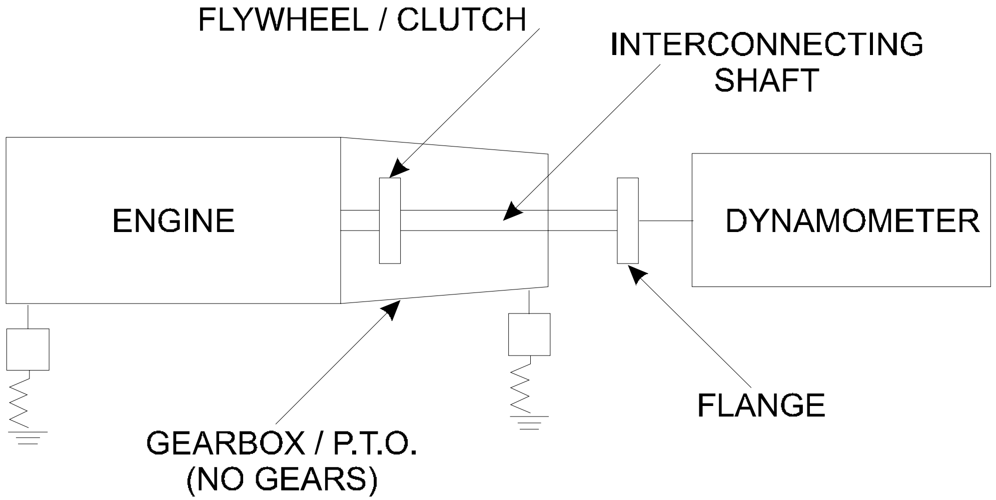
- Water dynamometer
- DC dynamometer
- AC dynamometer
- Eddy current dynamometer

A dynamometer must be capable to allowing the engine to develop torque at different engine speeds

Functions

- Resist the rotation of the engine shaft - load control
- Control engine speed
- Load measurement, normally engine torque
- Start, motoring and stop engine

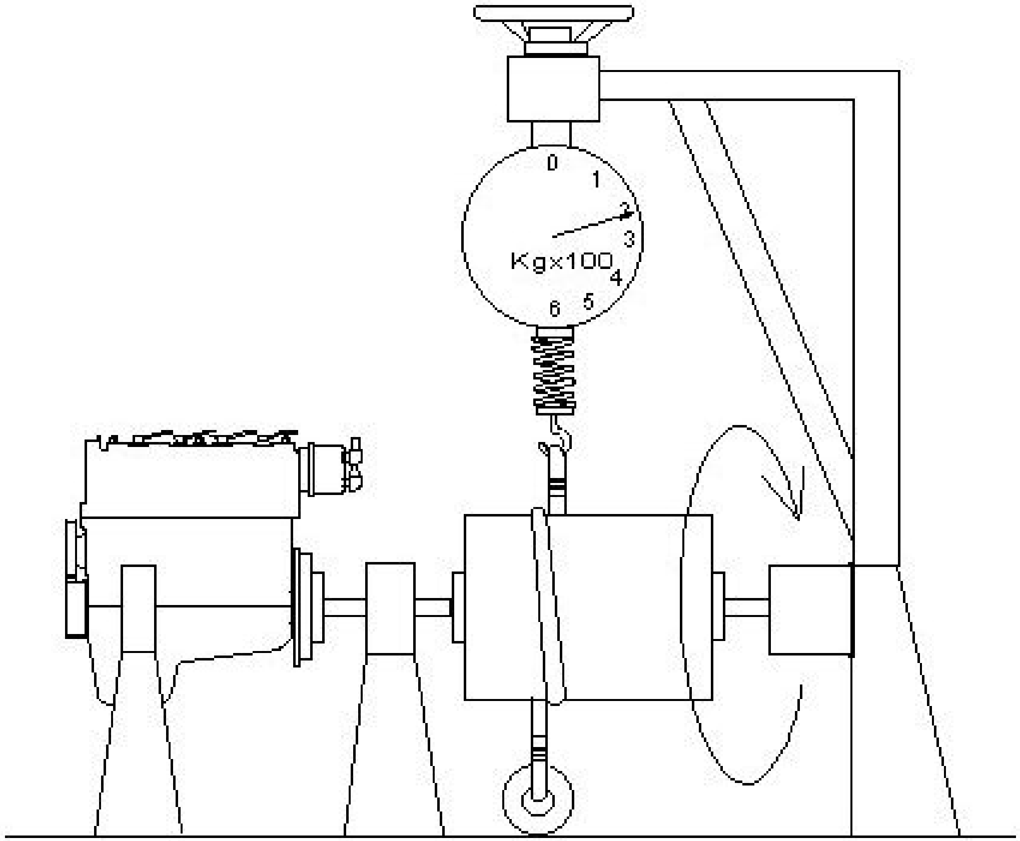
# Dynamometer - Torque meter or power meter



# Dynamometer testing

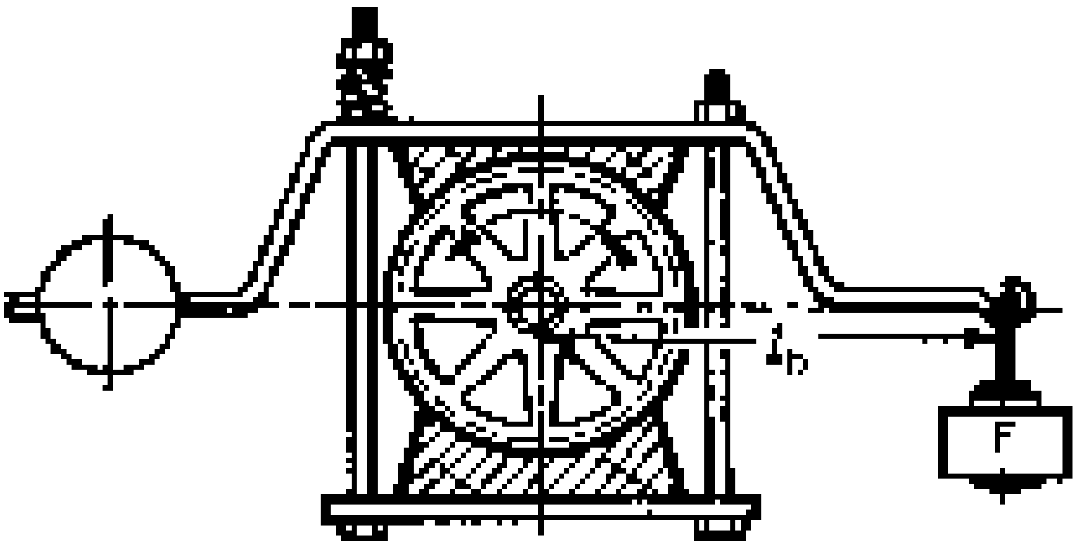
- Dynamometer testing of heat engines started long before Mr Otto made the internal combustion engine popular.
- Engineers in the early 1700's with the new steam powered reciprocating engines needed a means of measuring power, in order to further develop their engines.

# Primitive: Rope break dynamometer

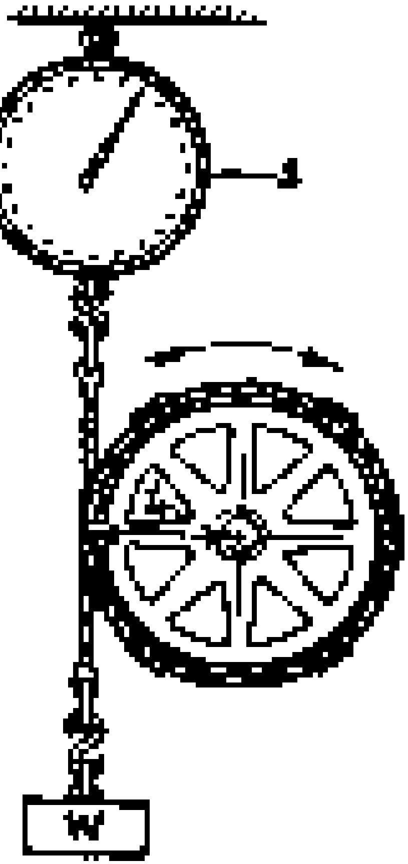


# Friction Brake

Early systems were very primitive, a person was required to pour water on the blocks to prevent them from burning!

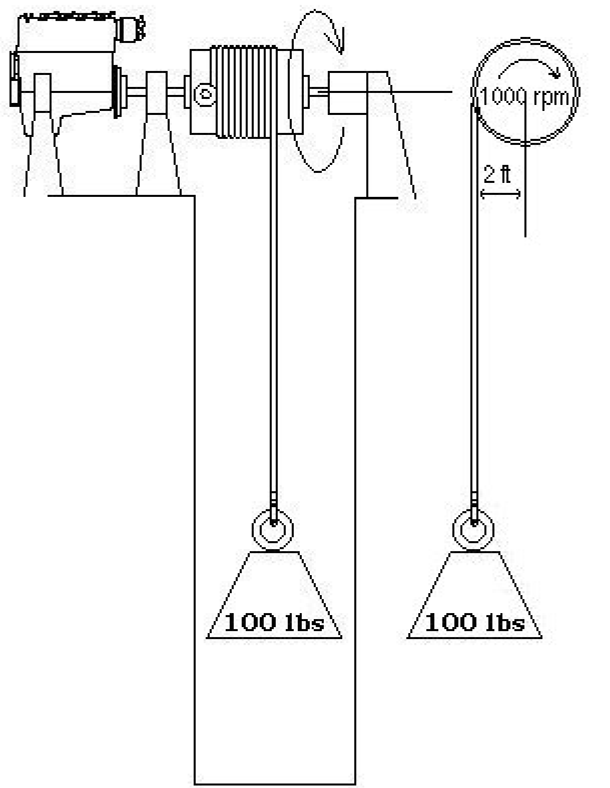


# Friction Brake



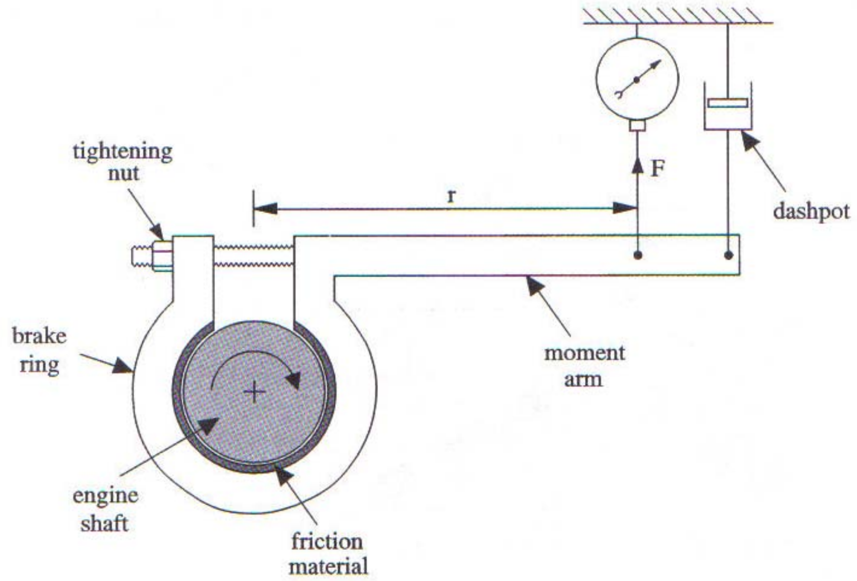

The advent of accurate spring balances in the mid 1800's gave rise to a more universal and advanced dynamometer.

# Power measurement




$$P = T\omega = 2\pi \frac{RPM}{60} Wr$$

# Torque measurement

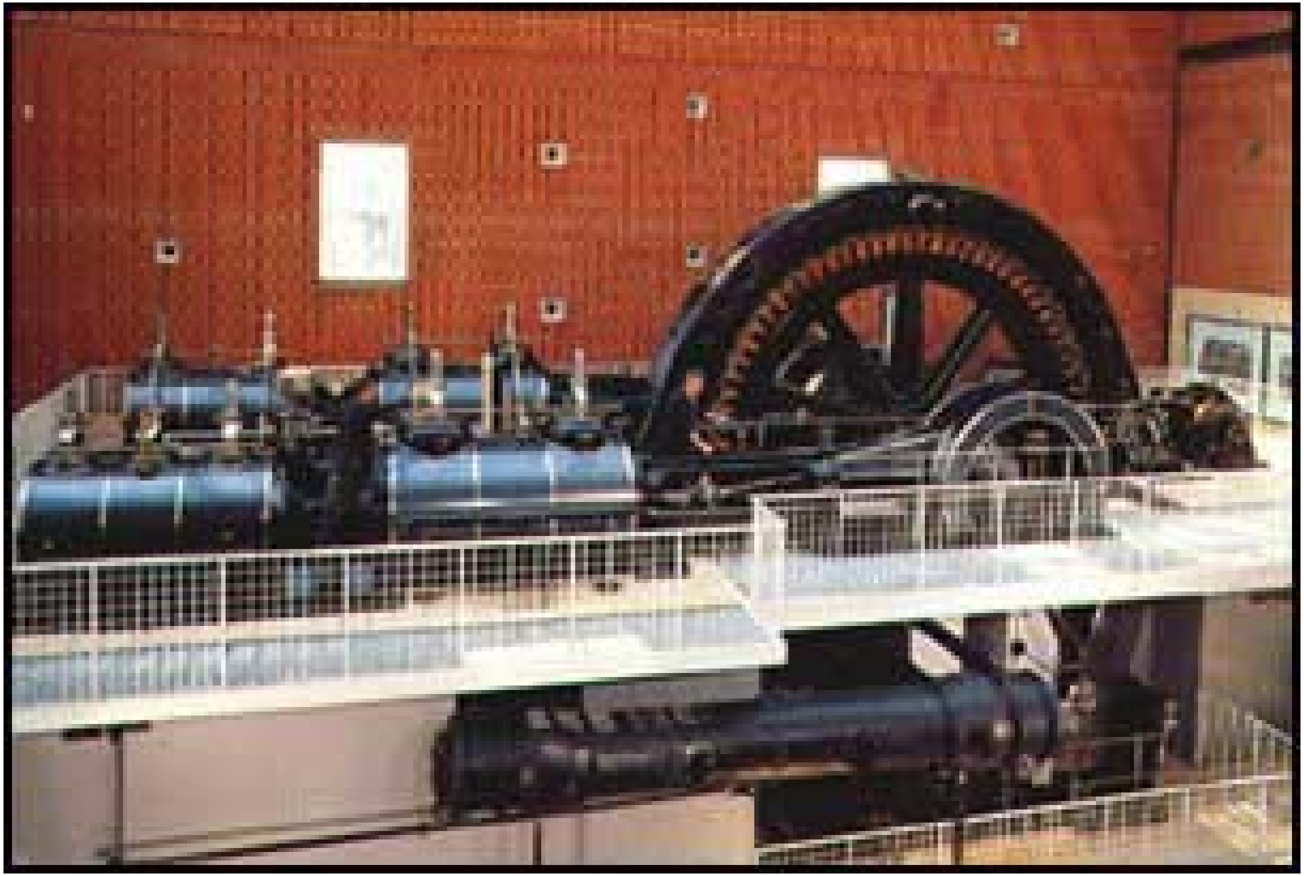


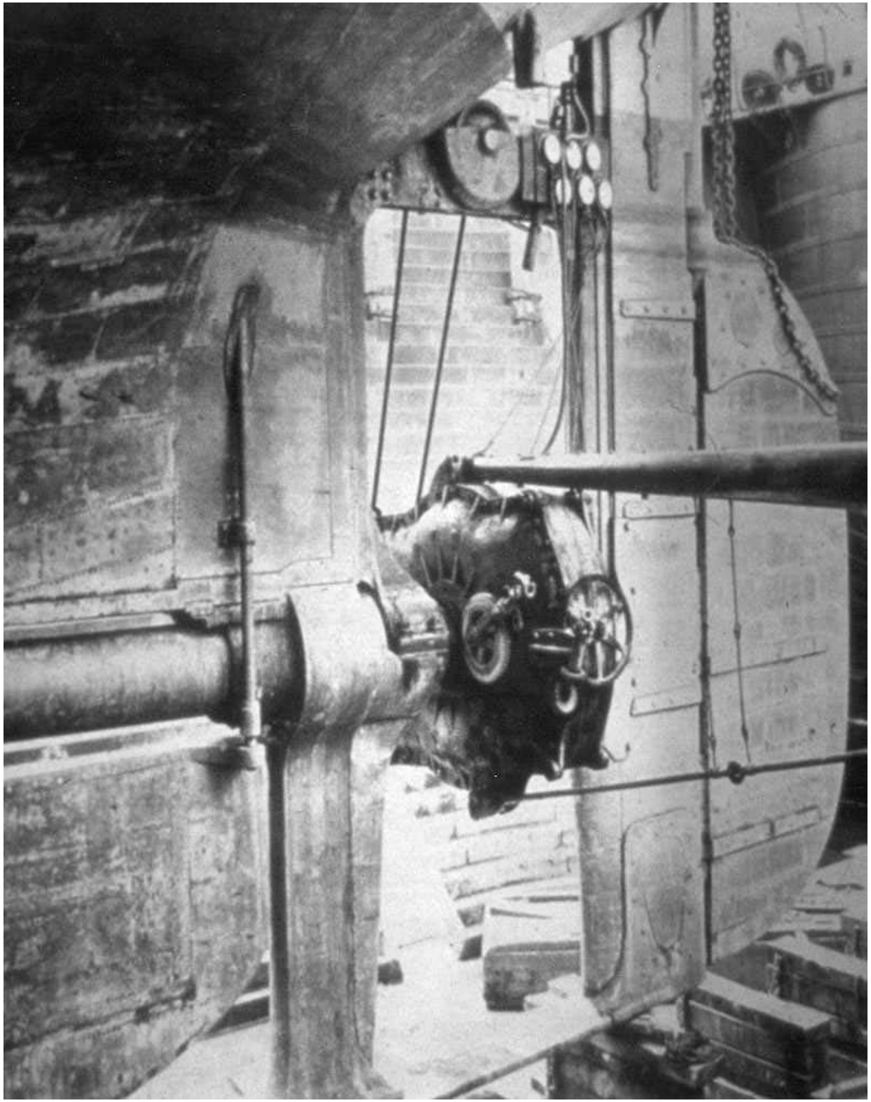

torque = restraining force × radius of moment arm
(T) (F) (r)

power = torque × angular speed
(P) (T) ( ω )

angular speed = 2 π × engine speed
( ω ) (N – rev/s)

# Late 19th Century steam engine





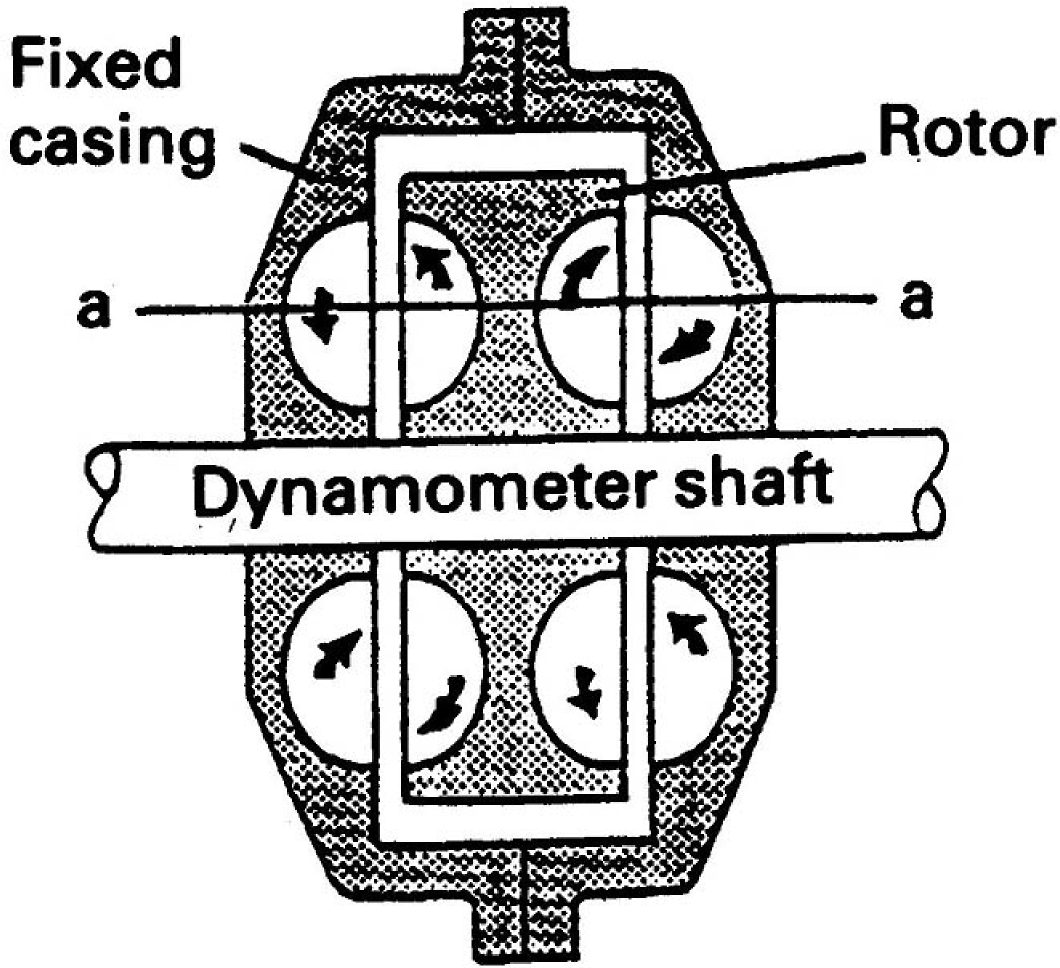
William Froude designed this dynamometer to test the engines of HMS Conquest. The unit was submerged in order to provide cooling capacity for the absorbed power. Handles located on the stern of the shi operated complex bevel gears and opened and closed the sluice gates. An arrangement of levers read the torque on a spring balance on the quay and a mechanical mechanism the speed.

These were coupled to a rotating dru which produced a speed vs load chart. The area under the graph being the power.

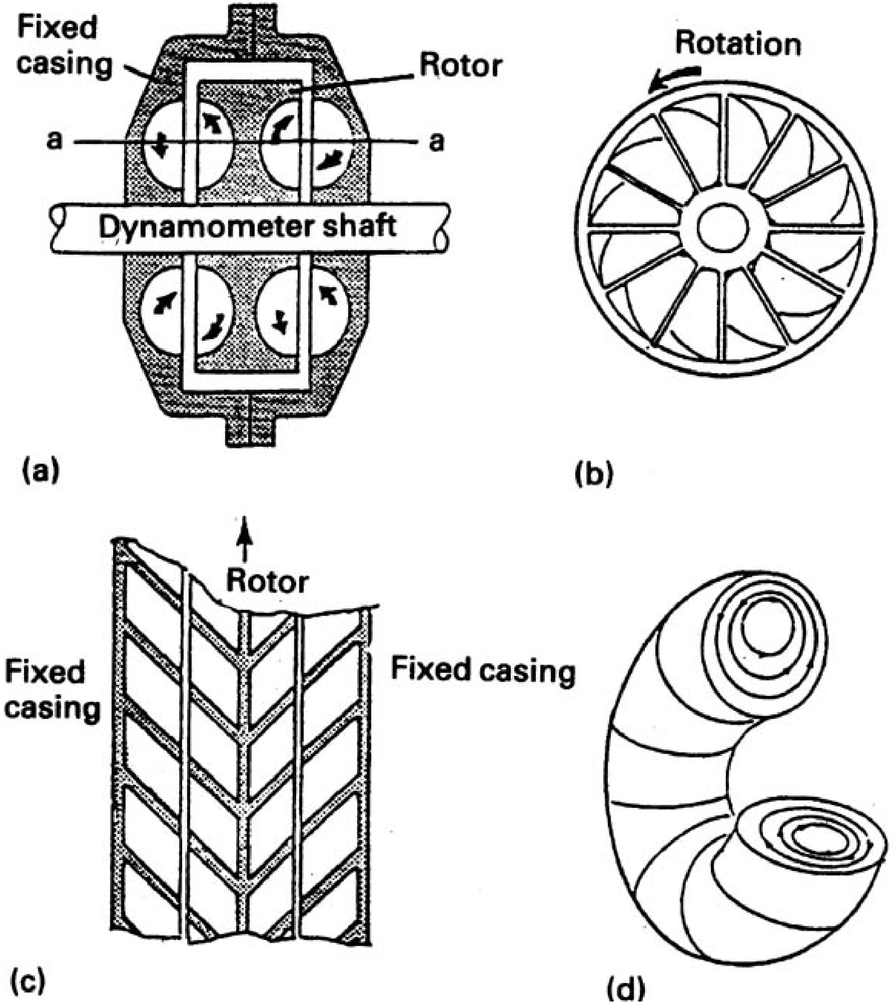
William Froude died after the HMS conquest dynamometer tests.

He was undertaking sea trials off the African coast and he is buried in Cape town. His son Richard, and financial backer associate Henersley Heenan formed the company Heenan & Froude in Trafford Park Manchester in 1881

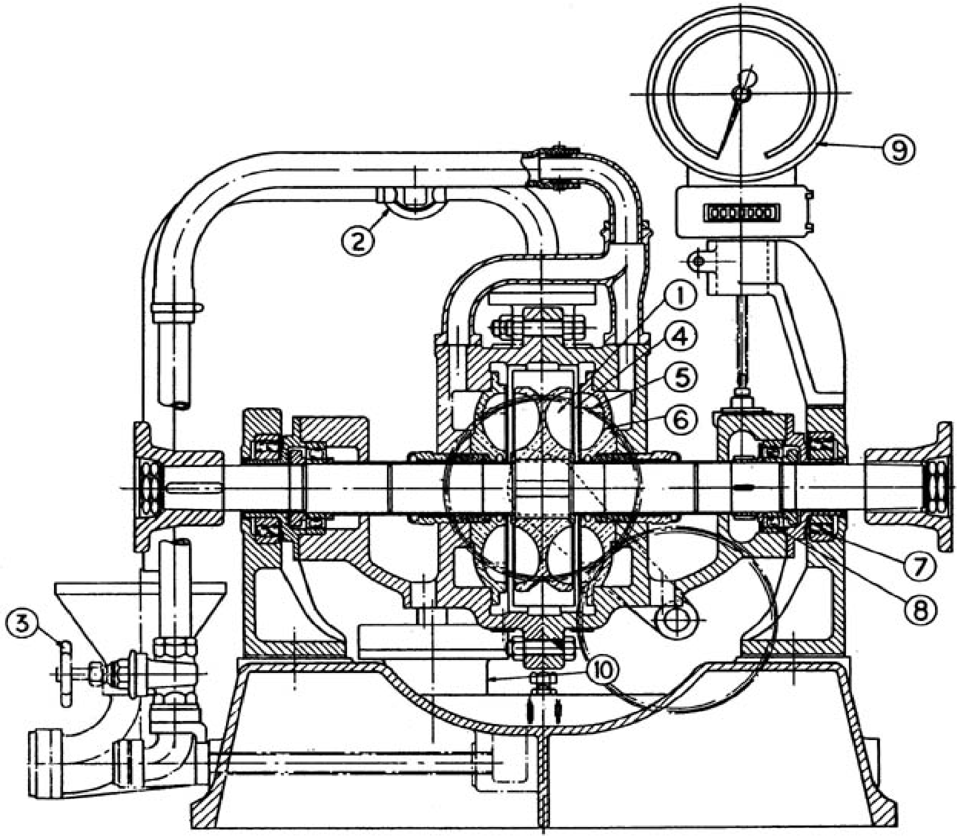
# Parts of the basic hydraulic dynamometer



# Parts of the basic hydraulic dynamometer



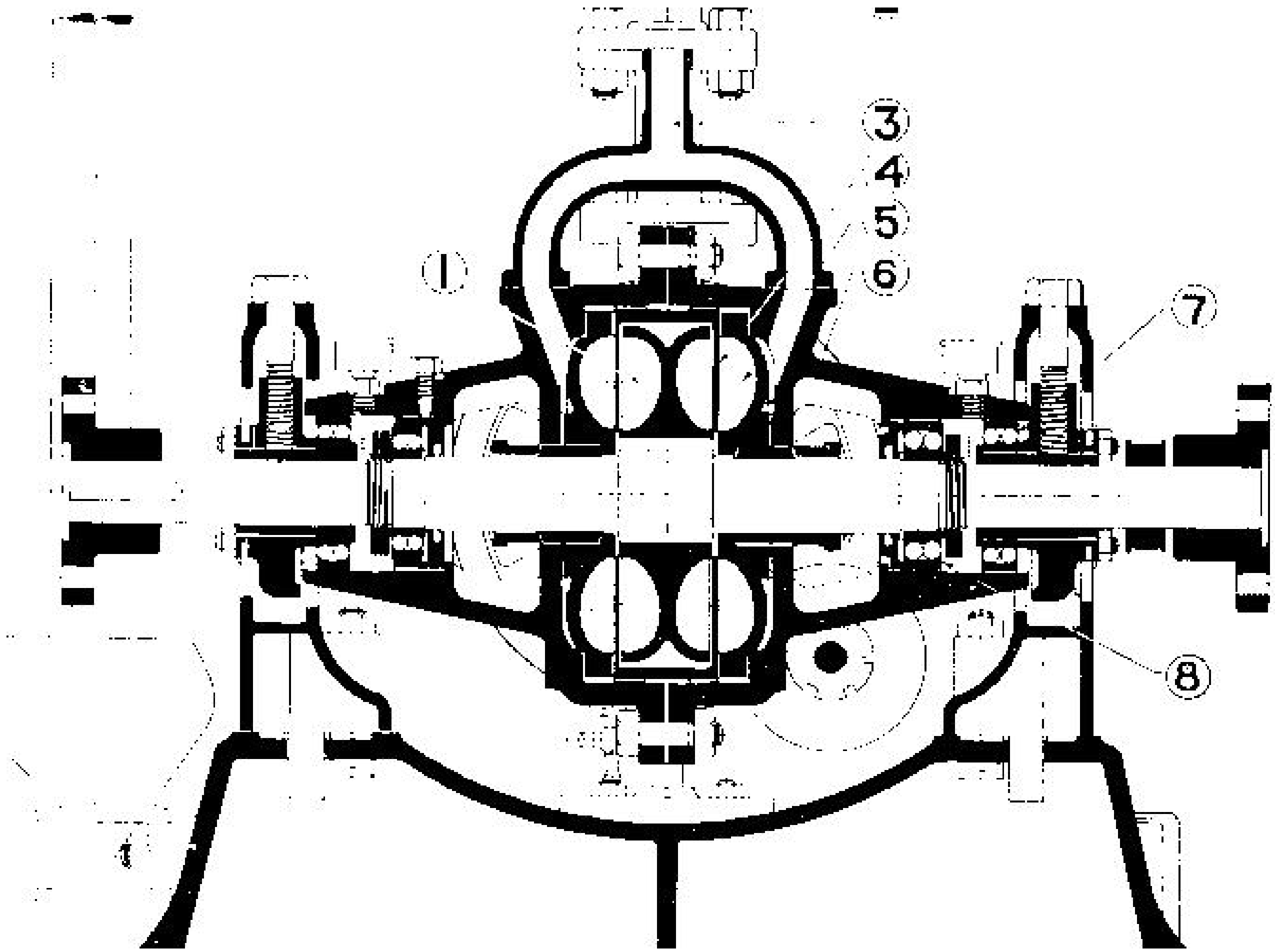
# Froude Dynamometer




Typical cross-section through casing of Froude dynamometer, type DPX

(1) Rotor
(2) Water outlet valve
(3) Water inlet valve
(4) Sluice plates for load control
(5) Water inlet holes in vanes
(6) Casing liners
(7) Casing trunnion bearing
(8) Shaft bearing
(9) Tachometer

# Cross section of an early Froude dynamometer



# Water Dynamometer

- Friction type – water as friction medium between the shaft and stationary parts
- Passive: Can’t be used to motor the engine
- Slow to altering the resistance offered to the shaft rotation (several seconds)

## DC Dyno

- Comprise a DC generator. The strength of the electromagnetic field within the generator, coupling its rotating and stationary parts, can be adjusted to vary the resistance to the engine shaft rotation.
- Dyno also can be used as an electric motor.
- The resisting torque can be adjusted rapidly and can be controlled by computer.
- The speed can't be changed rapidly due to high inertia parts.

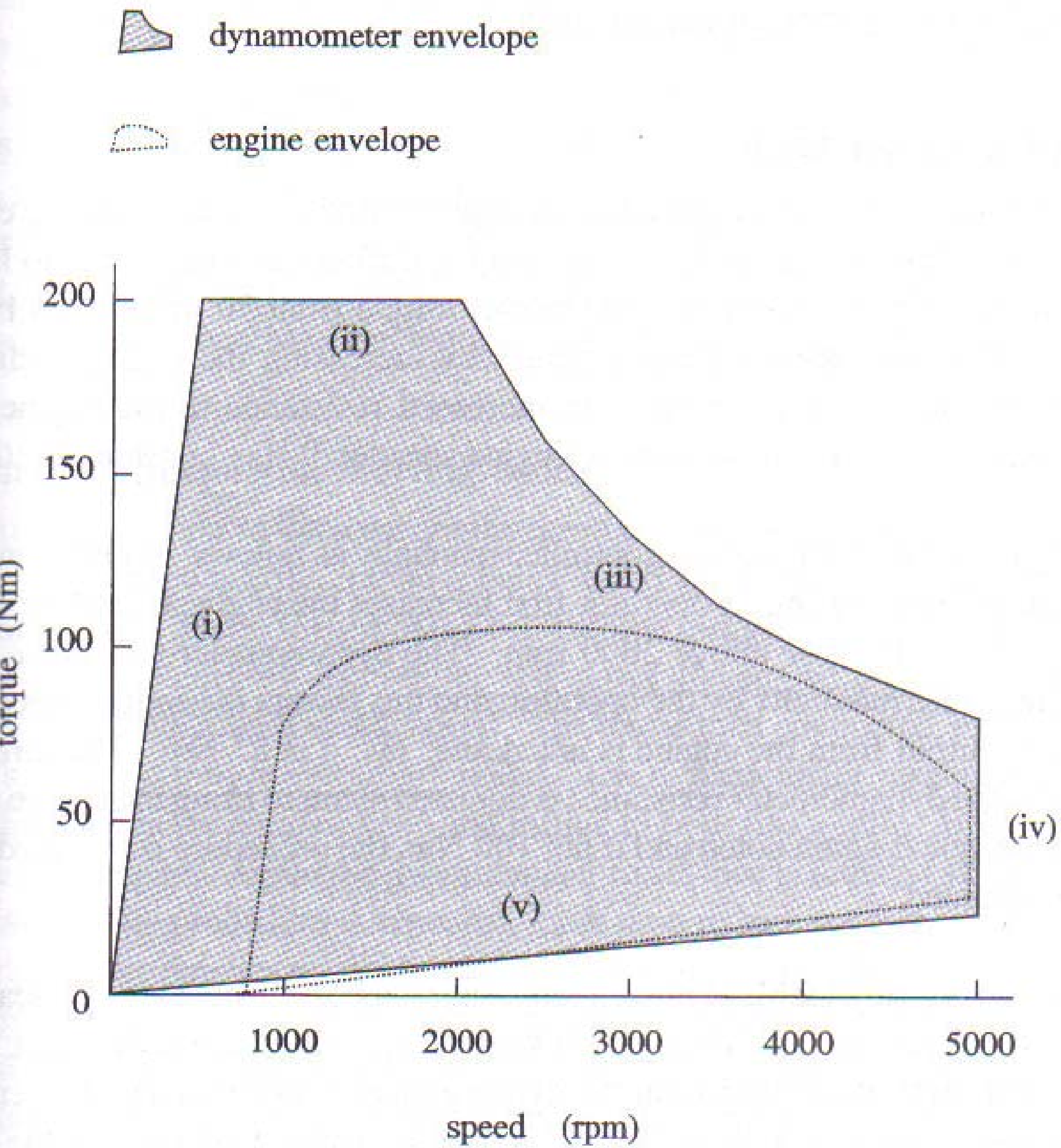
## AC Dyno

- AC generator, also can be work as a motor
- Fast torque change, but slow speed change
- The AC dynamometer can , on average, operate at 25 to 30% higher speeds then DC units for a given speed / power rating.
- AC units are generally more expensive then DC units as the control / drive system is more complicated

# Eddy Current Dyno

- Fast speed and torque changes, also can be controlled by computer
- But cannot  be used as a motor for motoring engine
- Water cooling

# Dyno Operating Envelope




(i) Torque line at low speed

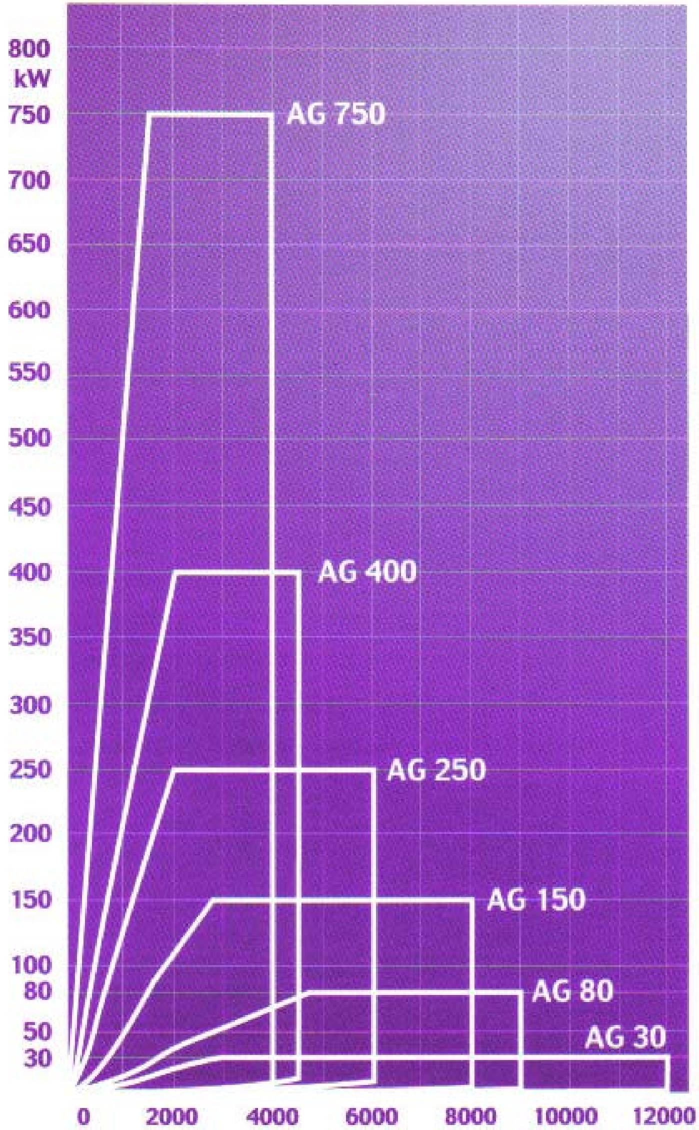
(ii) Max torque line

(iii) Max power line

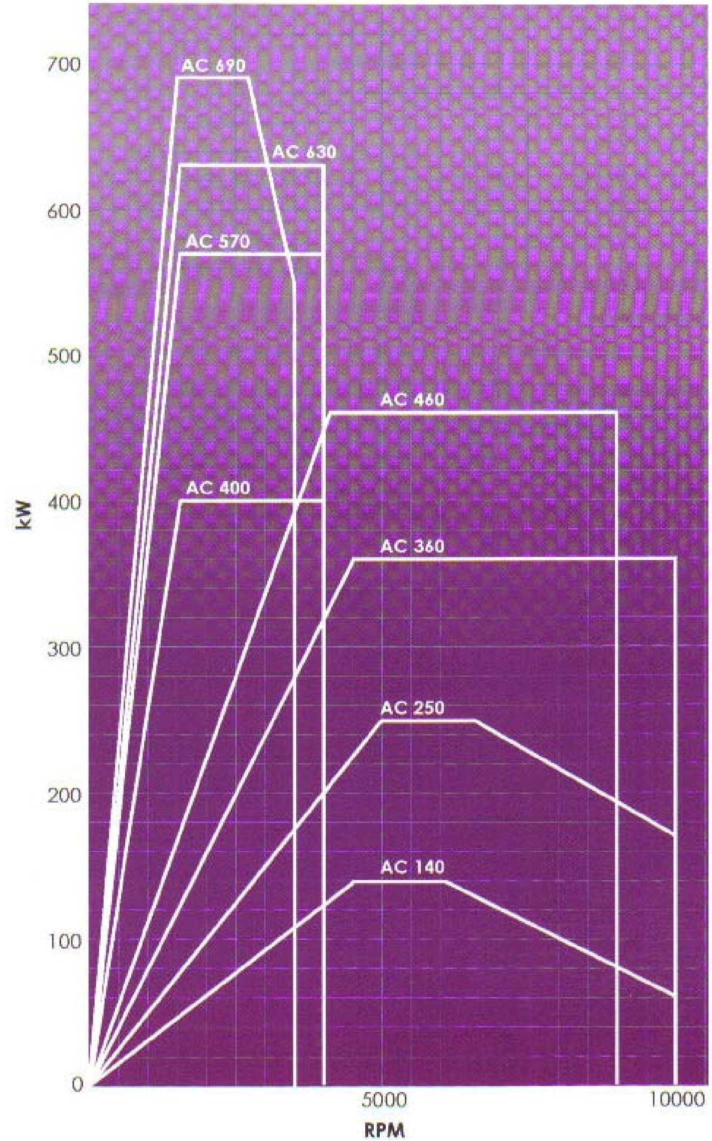
(iv) Max speed line

(v) Residual torque line, arising from bearing friction, aerodynamics resistance within the dyno

# Dyno Operating Envelope




Froude Eddy Current Dyno capacity Chart

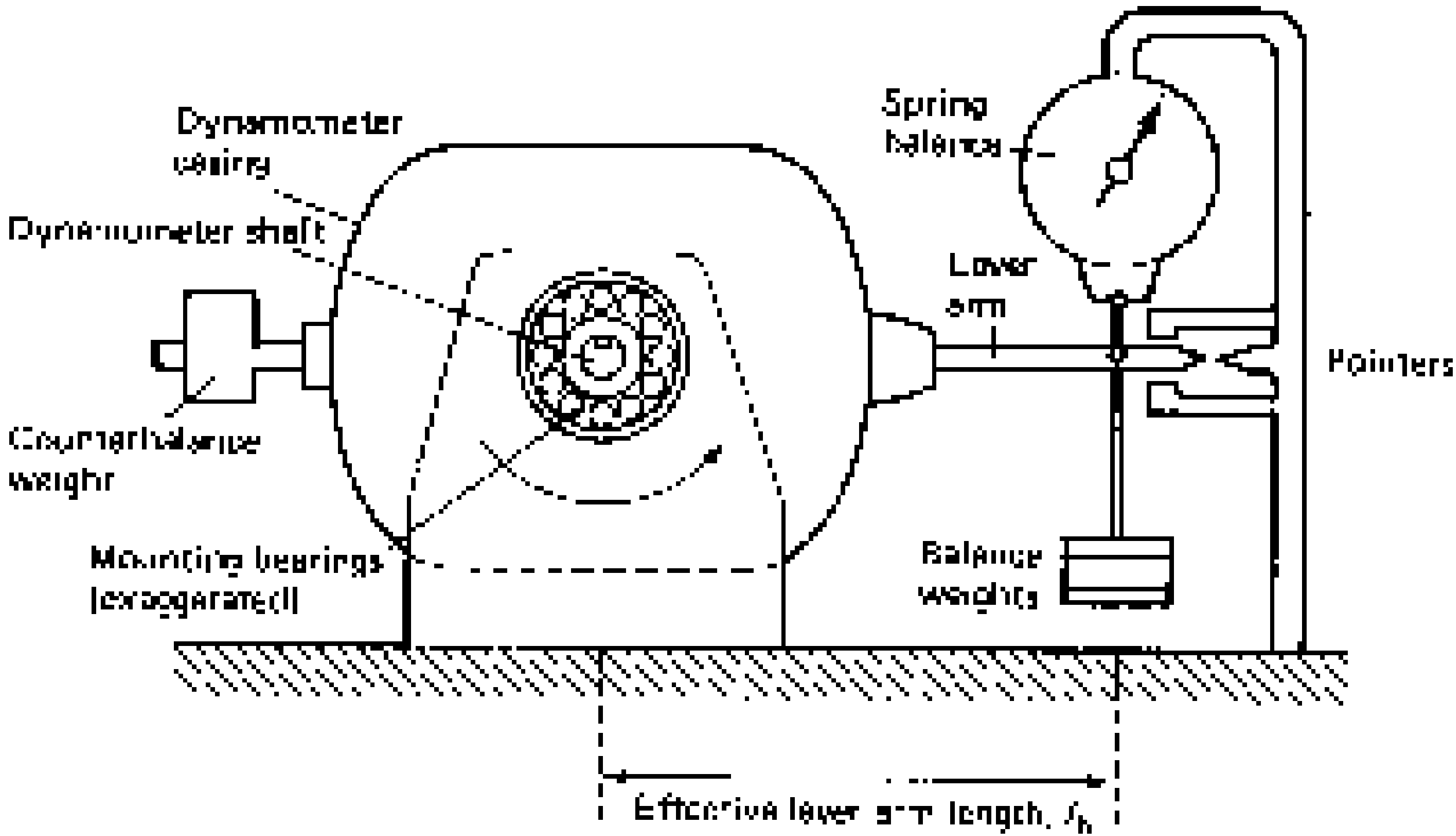



Froude AC Dyno capacity Chart

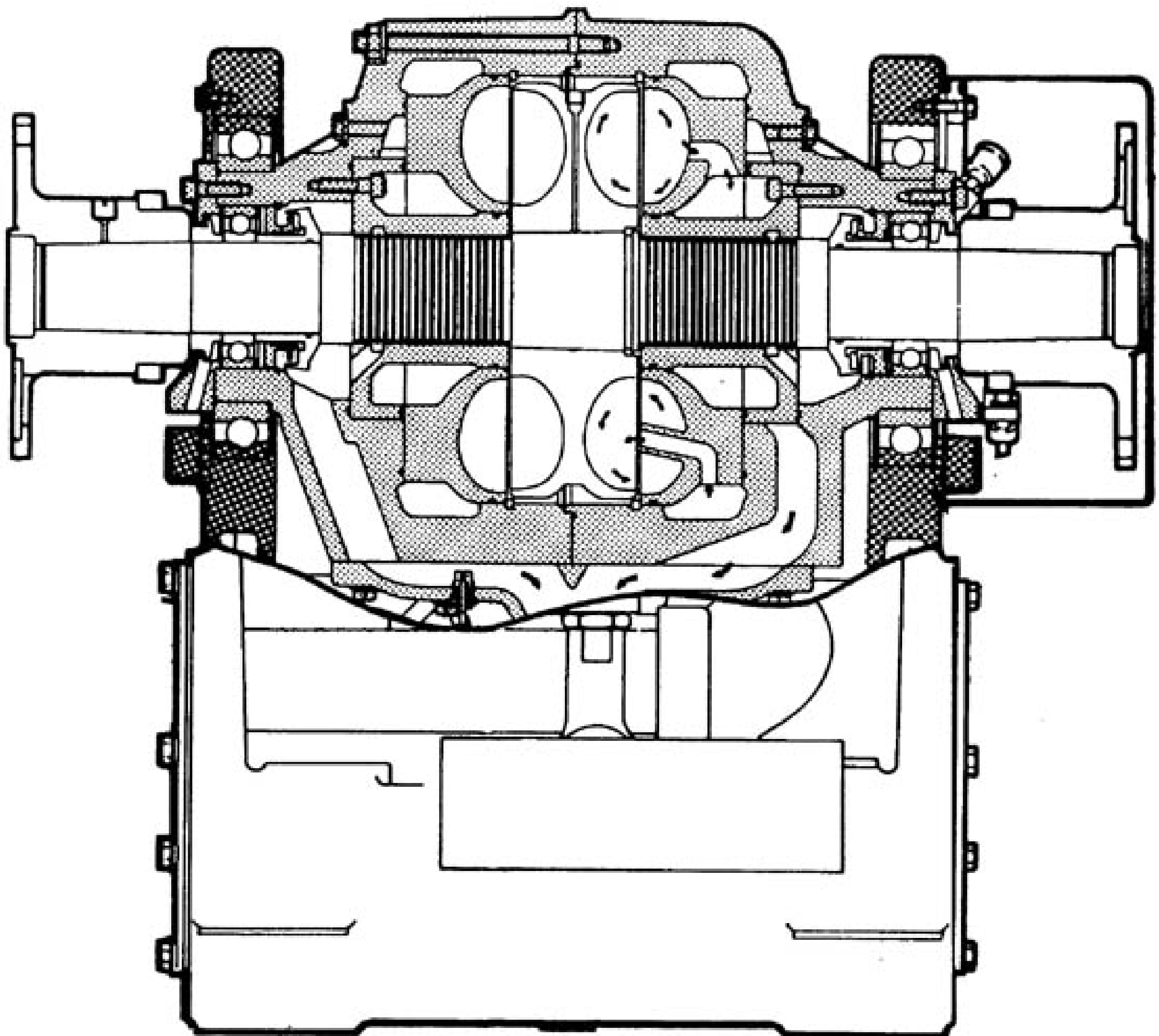
# Dyno Operating Modes

- Constant engine speed
- Constant torque
- Constant throttle opening or fuelling (Full load)

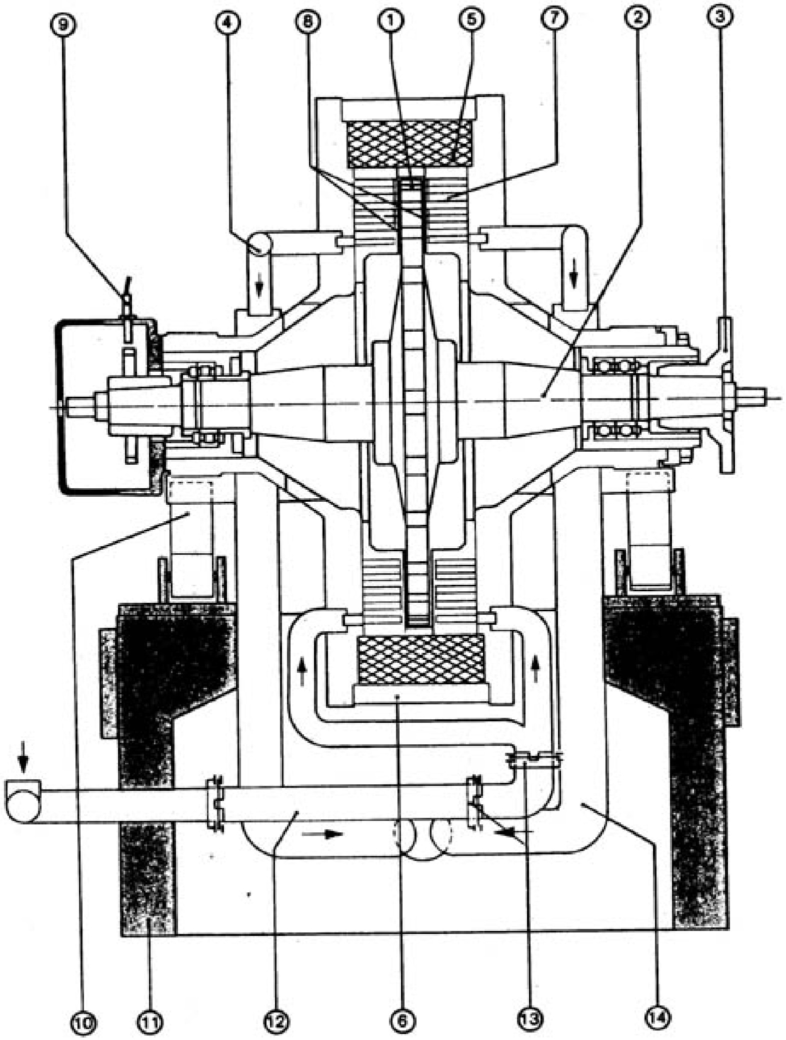
# Typical dynamometer



## Variable fill Schenk U series



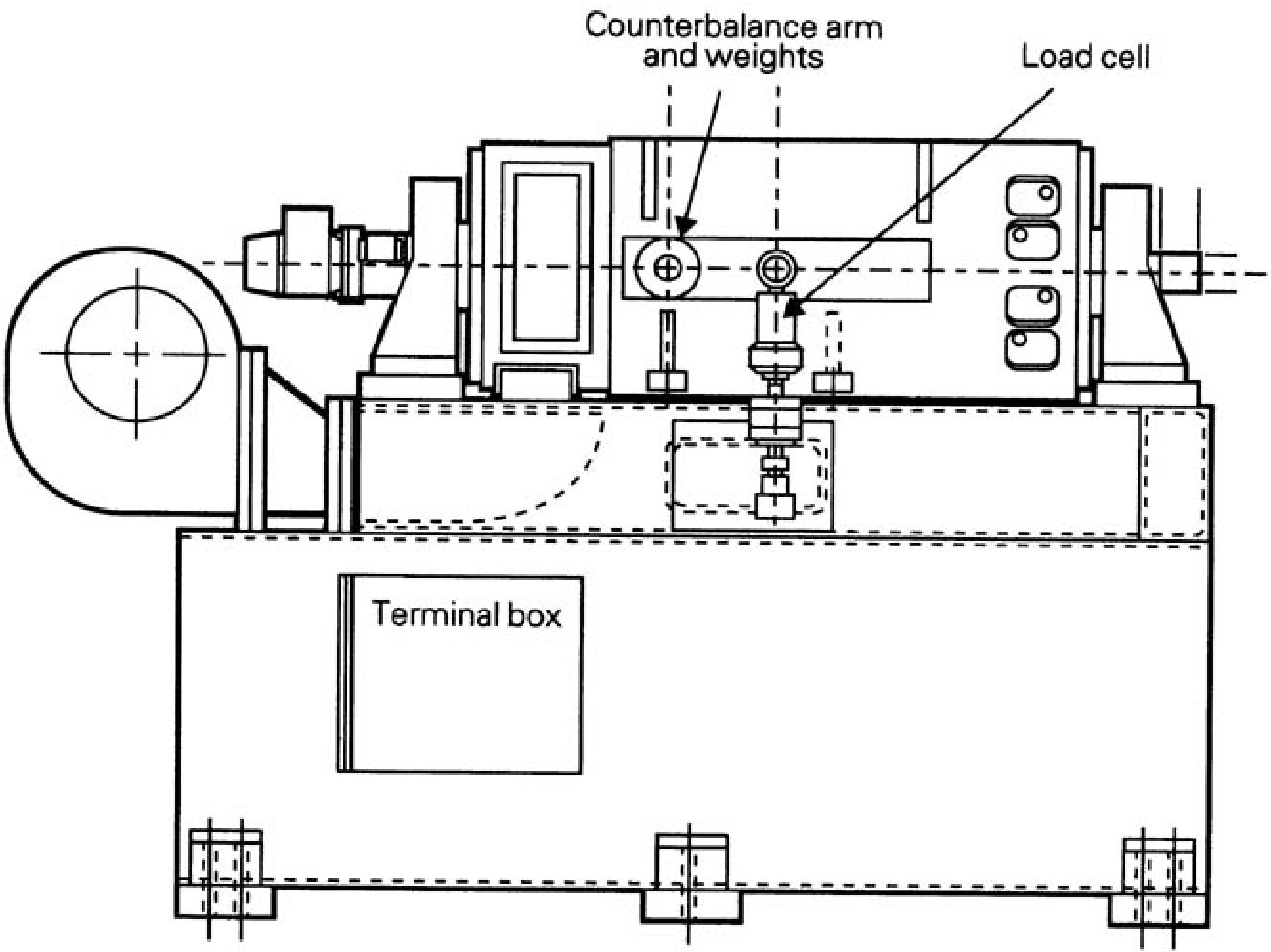
# Eddy current

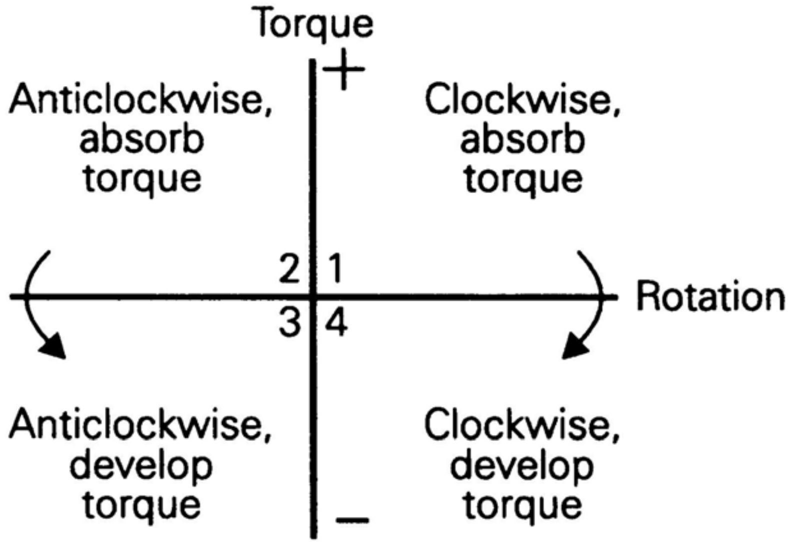



Eddy current dynamometer. 1 Rotor, 2 rotor shaft, 3 coupling flange, 4 water outlet with thermostat, 5 excitation coil, 6 dynamometer housing, 7 cooling chamber, 8 air gap, 9 speed pick-up, 10 flexure support, 11 base, 12 water inlet, 13 joint, 14 water outlet pipe.

# Example of an eddy current dynamometer

# DC ~ AC Generator

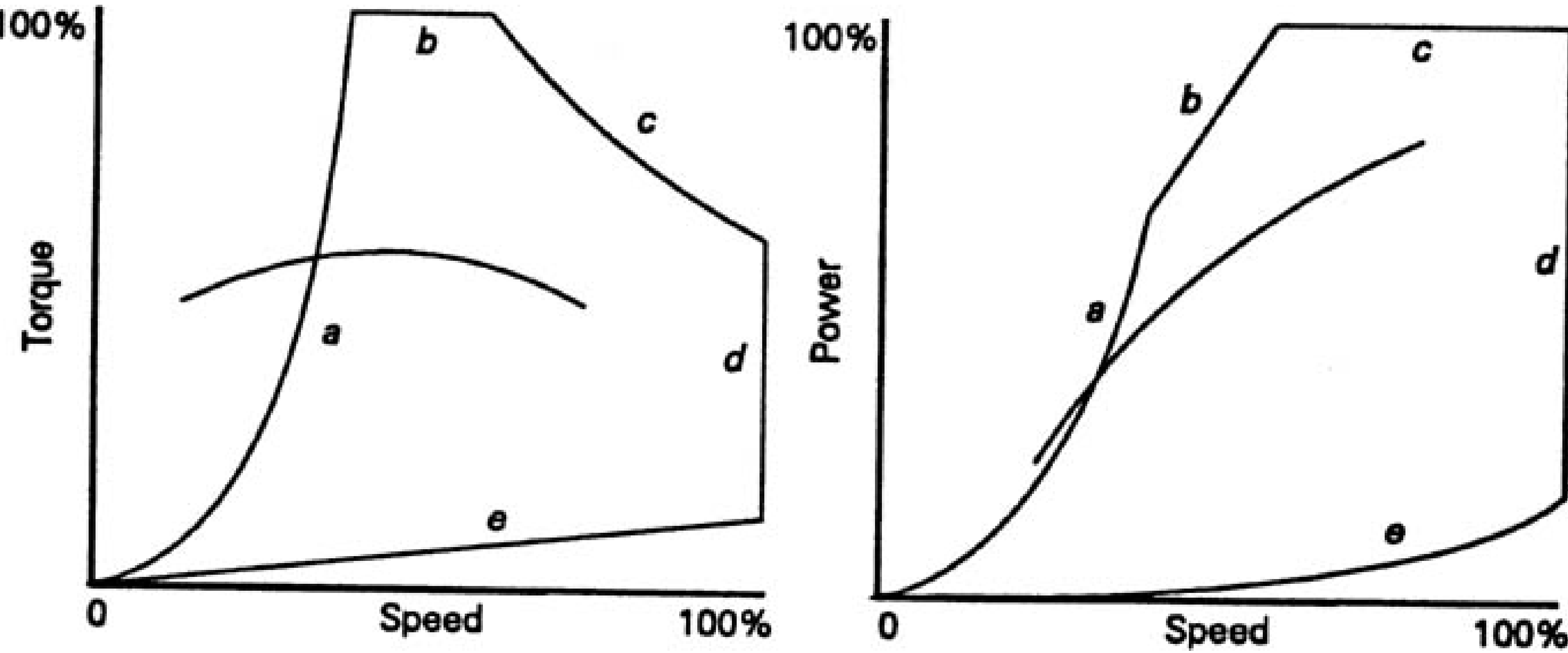





Operating quadrants

| Type of machine | Quadrant |
| --- | --- |
| • Hydraulic sluice plate | • 1 or 2 |
| • Variable fill hydraulic | • 1 or 2 |
| • Hydrostatic | • 1,2,3,4 |
| • DC electrical | • 1,2,3,4 |
| • AC Electrical | • 1,2,3,4 |
| • Eddy current | • 1 & 2 |
| • Friction Brake | • 1 & 2 |

# Hydraulic Dyno operating curve



# Hydraulic dyno~ Quadrant 1 or 2

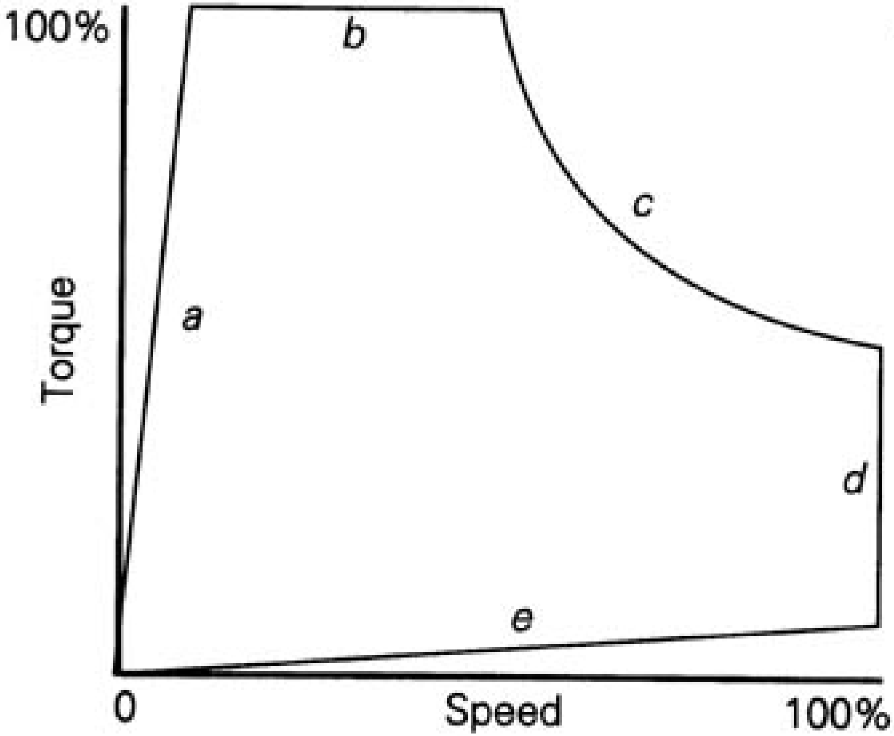
- Full of water. Torque increases with the square of the speed. No torque at zero rev/min

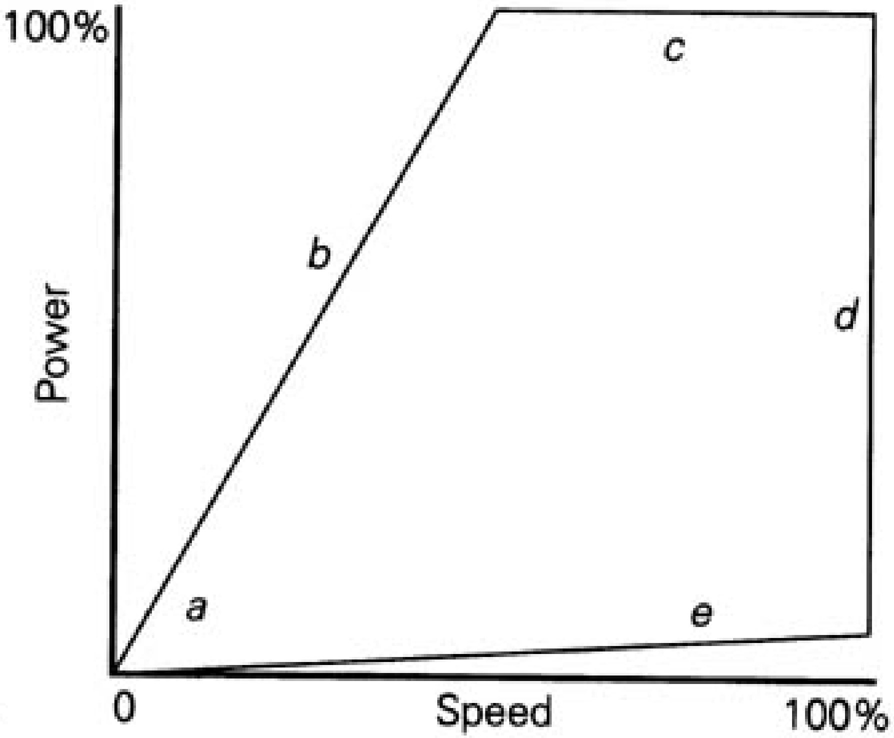
- Performance is limited by shaft torque

- Performance is limited by maximum permitted power which is a function of cooling, water through put and permitted rate of temperature rise

- Minimum torque = minimum permitted water flow

# Eddy Current operating curve

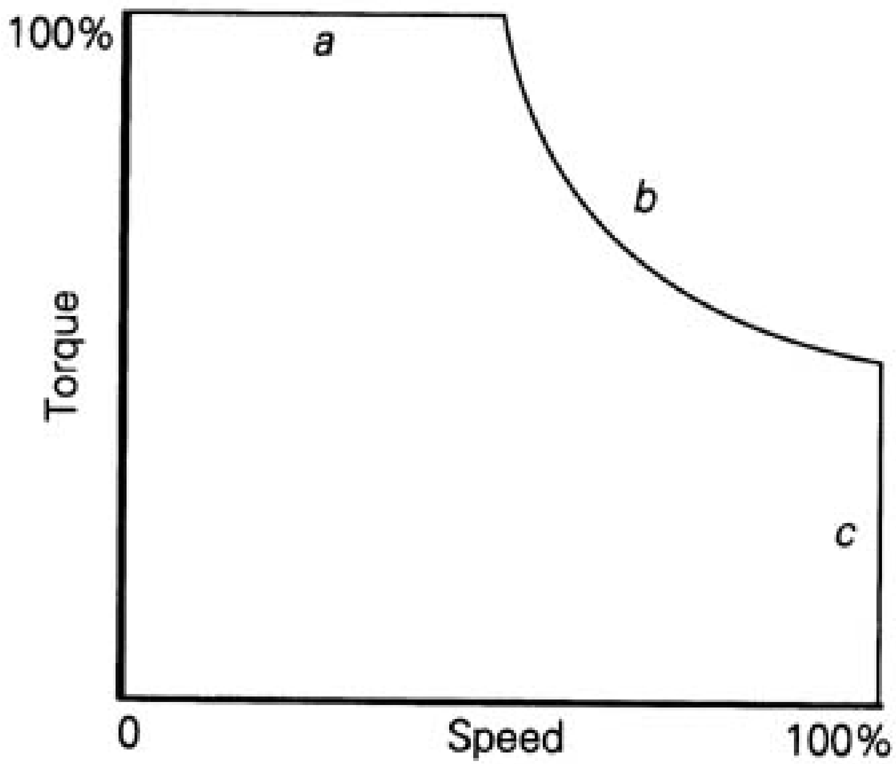


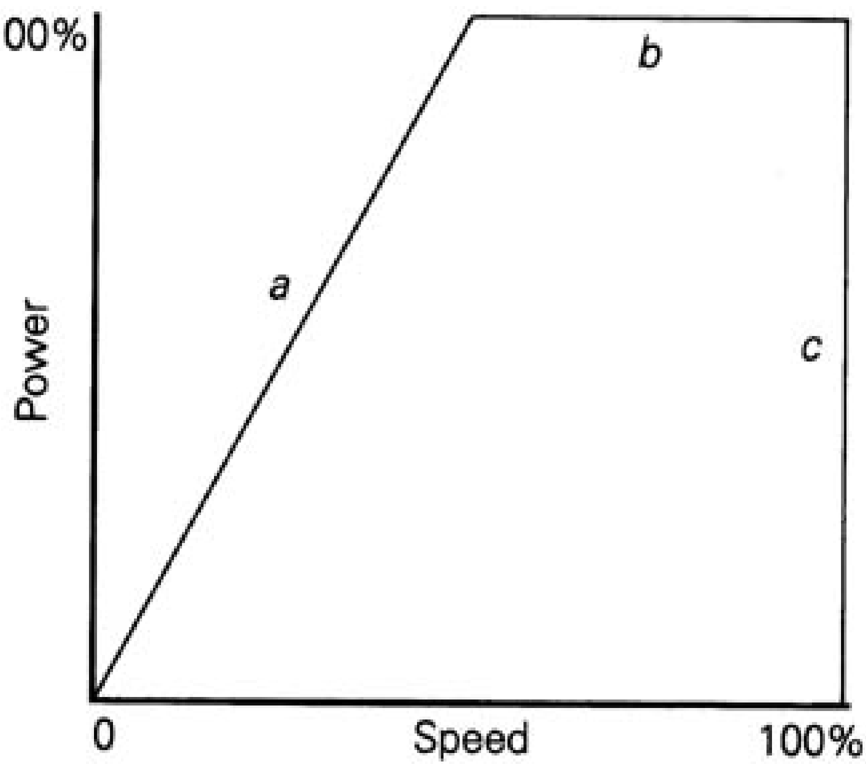



## Eddy current dyno

- Low speed torque corresponding to maximum permitted excitation
- Performance limited by maximum permitted shaft torque
- Performance limited by maximum permitted power which is a function of cooling water through put and max permitted temperature rise
- Maximum permitted speed
- Minimum torque corresponding to residual magnetisation , wind-age and friction

# AC~DC Operating curve

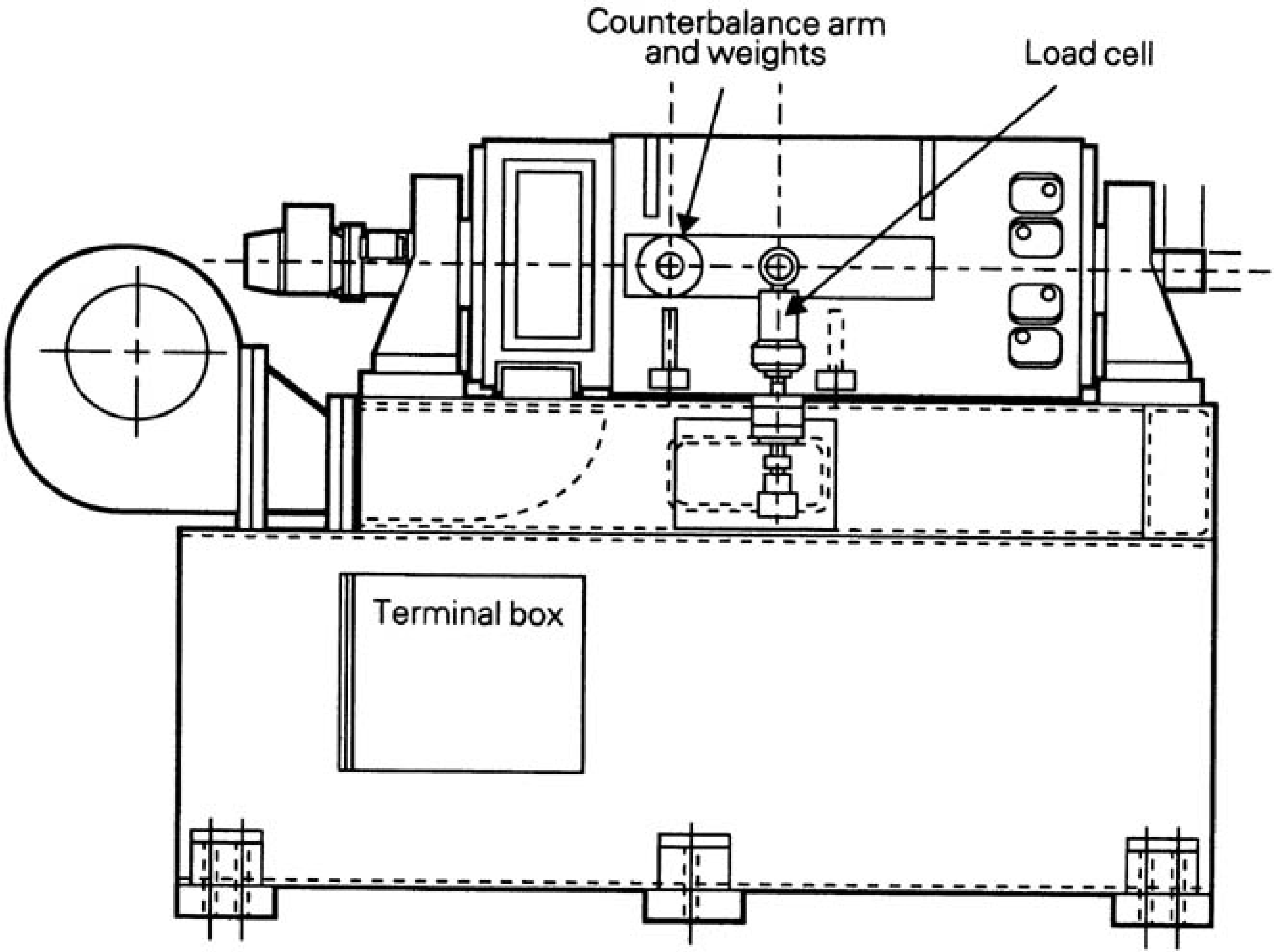


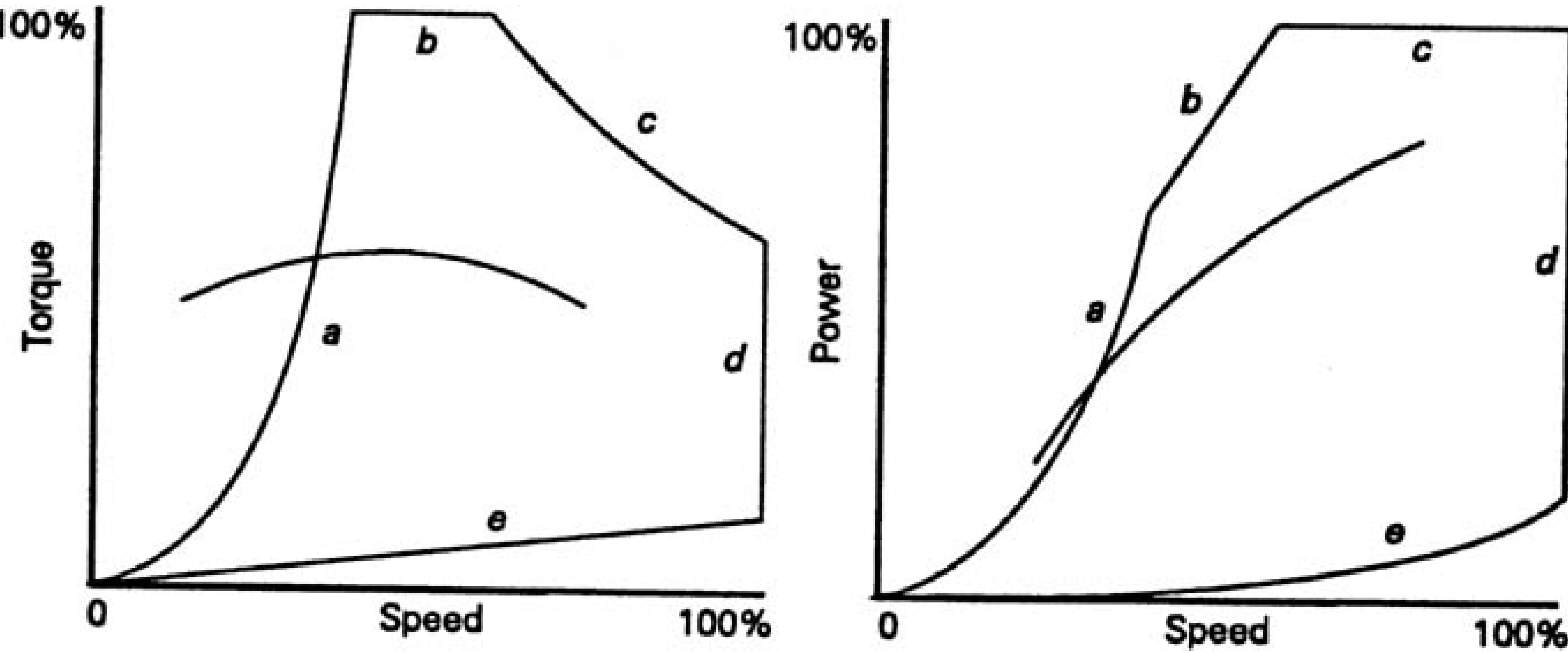
# DC or AC Electrical dyno

- Constant torque corresponding to maximum current and excitation
- Performance limited by maximum permitted power out put of the machine
- Maximum permitted speed
- NB Quadrants, 1,2,3 & 4

# DC ~ AC Generator



# Hydraulic Dyno operating curve



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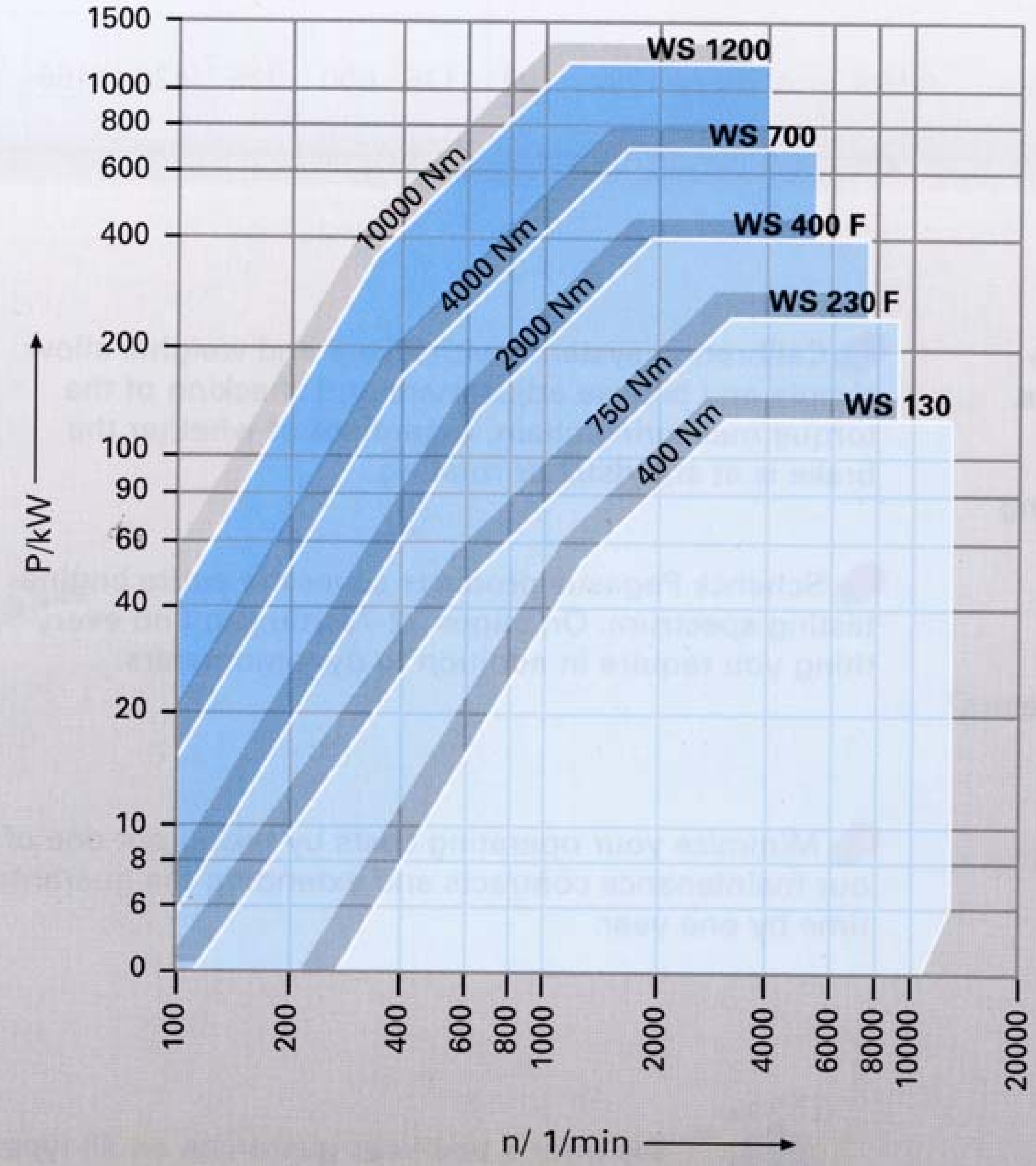
# Hook joint carden shaft



WS 1200
WS 700
WS 400 F
WS 230 F
WS 130
10000 Nm
4000 Nm
2000 Nm
750 Nm
400 Nm
P/kW
1500
1000
800
600
400
200
100
90
60
40
20
10
8
6
0
100
200
400
600
800
1000
2000
4000
6000
8000
10000
20000
n/ 1/min

# Engine Speed Measurement

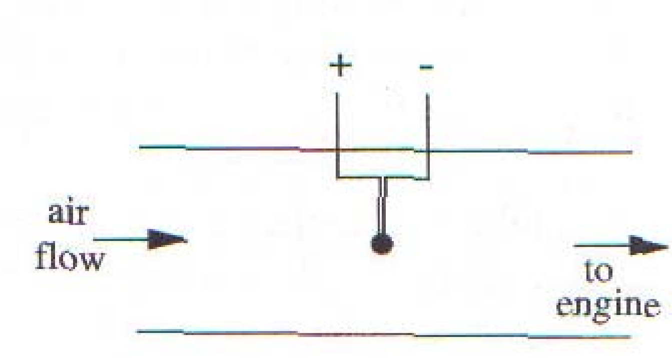
- Via ECU, on board speed sensor
- On test bed, normally through TDC sensor
- Shaft encoder

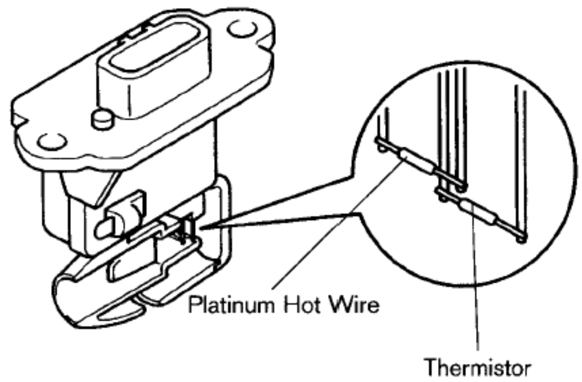
# Air Flow Rate Measurement

- Mass Air Flow-rate (MAF) sensor
- Various MAF measurement method on test bed
- Estimate MAF by exhaust gas analysis and fuel rate

# MAF Sensor Principle

- **One example – Hot Wire Flow Meter**




$$q = I^2 R \cong a + b(\rho V)^n$$

$$\dot{m} = \rho V A$$

$$I^2 R = A + B(\dot{m})^N$$

Q – heat loss rate from the hot wire

I – current flowing through the hot wire

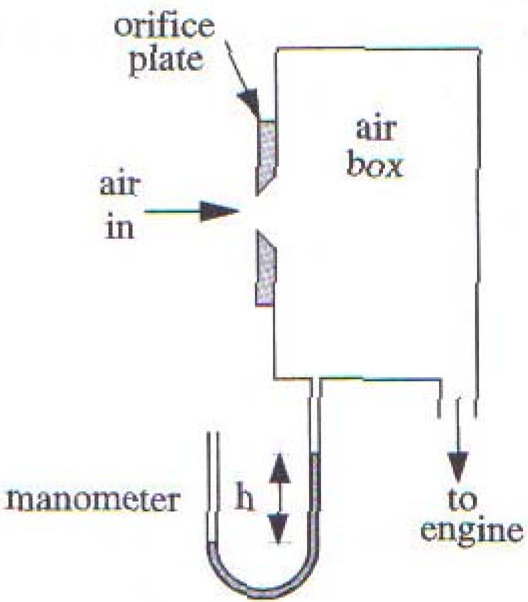
R – electrical resistance of the hot wire

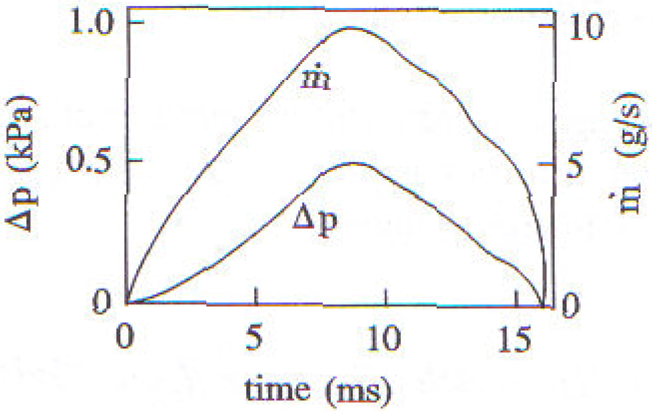
P – air density

V – air flow velocity past the wire

a, b, n – constants determined by calibration (A, B, N)

# Air Box with Sharp-Edged Orifice Plate




$$\dot{m} = C_d A\sqrt{2\rho\Delta P}$$

$$\Delta P = \rho_i gh$$

$$\rho = P_0 /(RT_0)$$

$C_d$ – orifice discharge coefficient

A – orifice area

$\Delta P$ – pressure drop = $\rho_i gh$

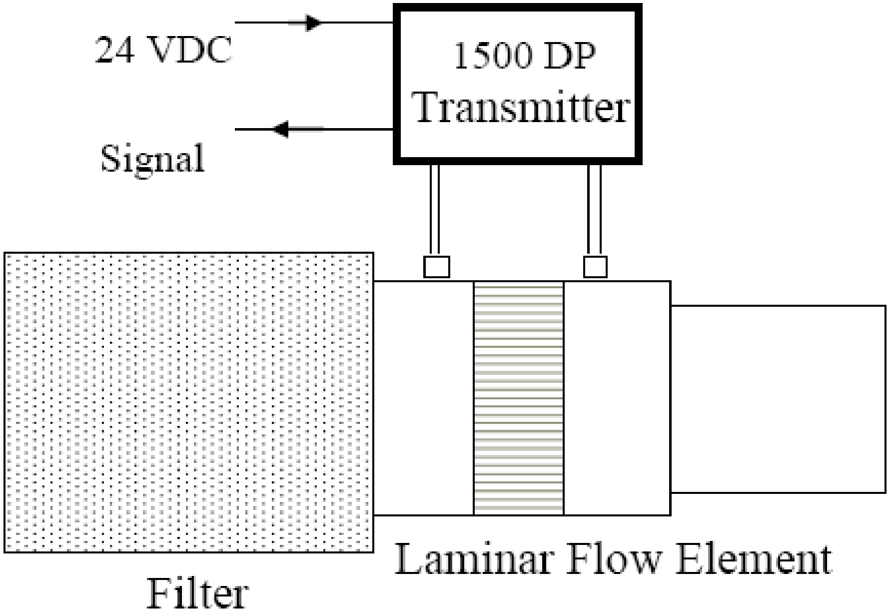
h – height difference in the manometer liquid column

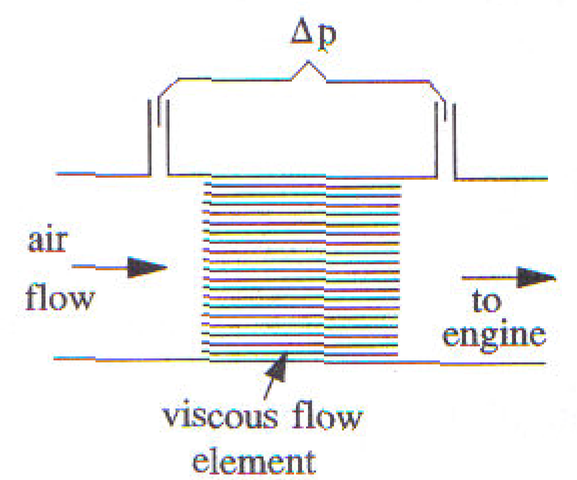
g – acceleration due to gravity (9.81 m/s$^2$)

$\rho_i$ – density of manometer liquid

$\rho$ – air density

# Viscous Flow Meter – Laminar Meter

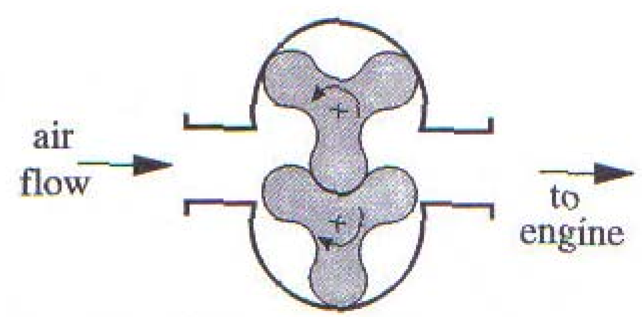



MAF = calibration factor X air density X P drop

- Typically, the small flow passage size is about $0.1mm^2$ and 70 mm long.

# Positive Displacement Flow Meter

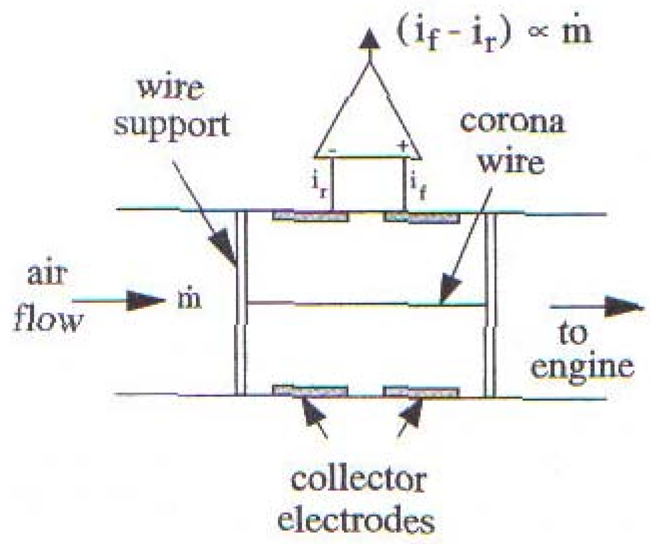



- Perhaps the most accurate method

$$\dot{m} = \rho_i V_d N = \frac{P_i}{RT_i} V_d N$$

$V_d$ – air volume displace/revolution

# Corona Discharge Flow Meter




**Lucas Dawe Corona Discharge Meter**

- Air is ionizated by 10kV high voltage
- Air flow rate is proportional to the ion current difference
- 1ms response; about 1% accuracy
- Forward and reverse measurement

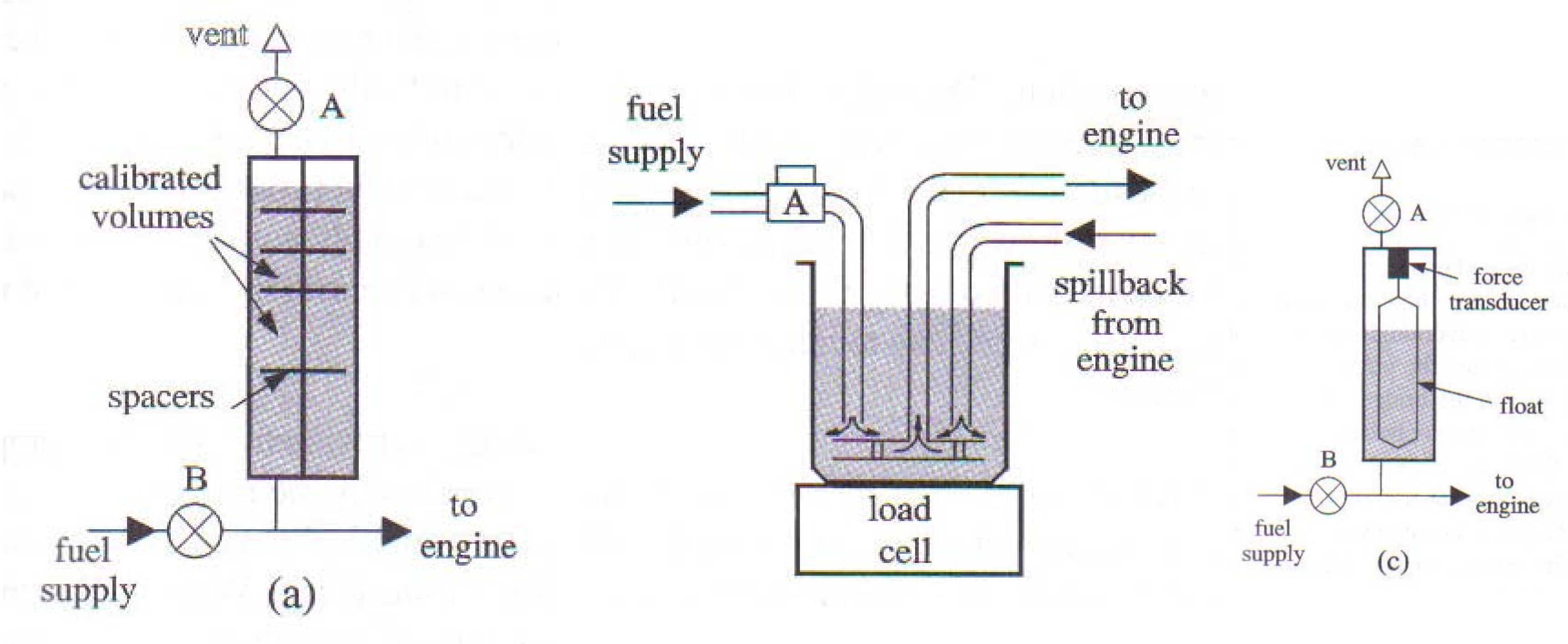
## MAF Estimate by Exhaust Gas Analysis

Be capable of measuring the instantaneous air mass flow

# Fuel Flow Rate Measurement

- On board fuel injection amount correcting: estimate via MAF sensor and lambda sensor for SI engines; for diesel engine – knock sensor

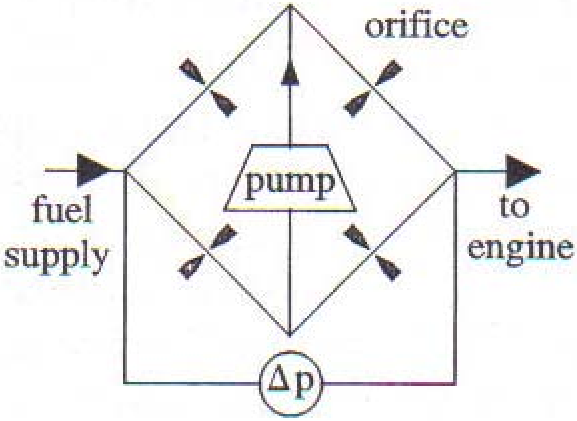
# Average Fuel Consumption Rate

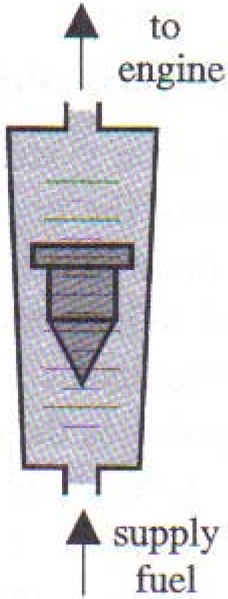



Recording time taken for the engine to consume a certain volume of fuel

Weighing method (fuel mass)

# Instantaneous Fuel Consumption Rate



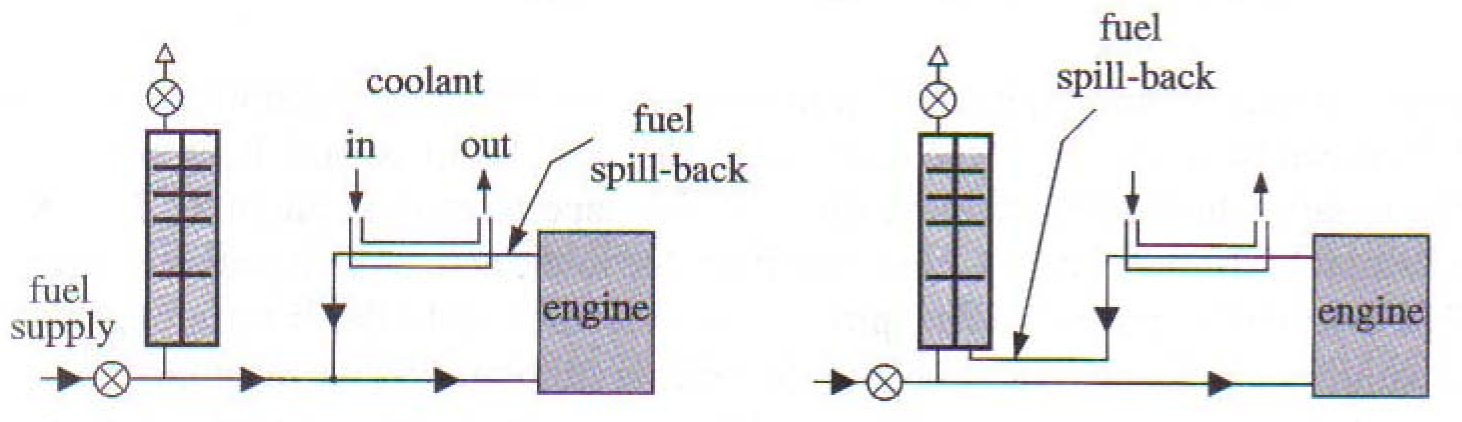

Flo-Tron system

- Accuracy better than 0.5%
- Response time < 0.5s
- Not affected by liquid viscosity and density

Rotameter

- Variable-area flow meter
- Must be calibrated for different viscosity/density liquid

# Fuel Spill-Back

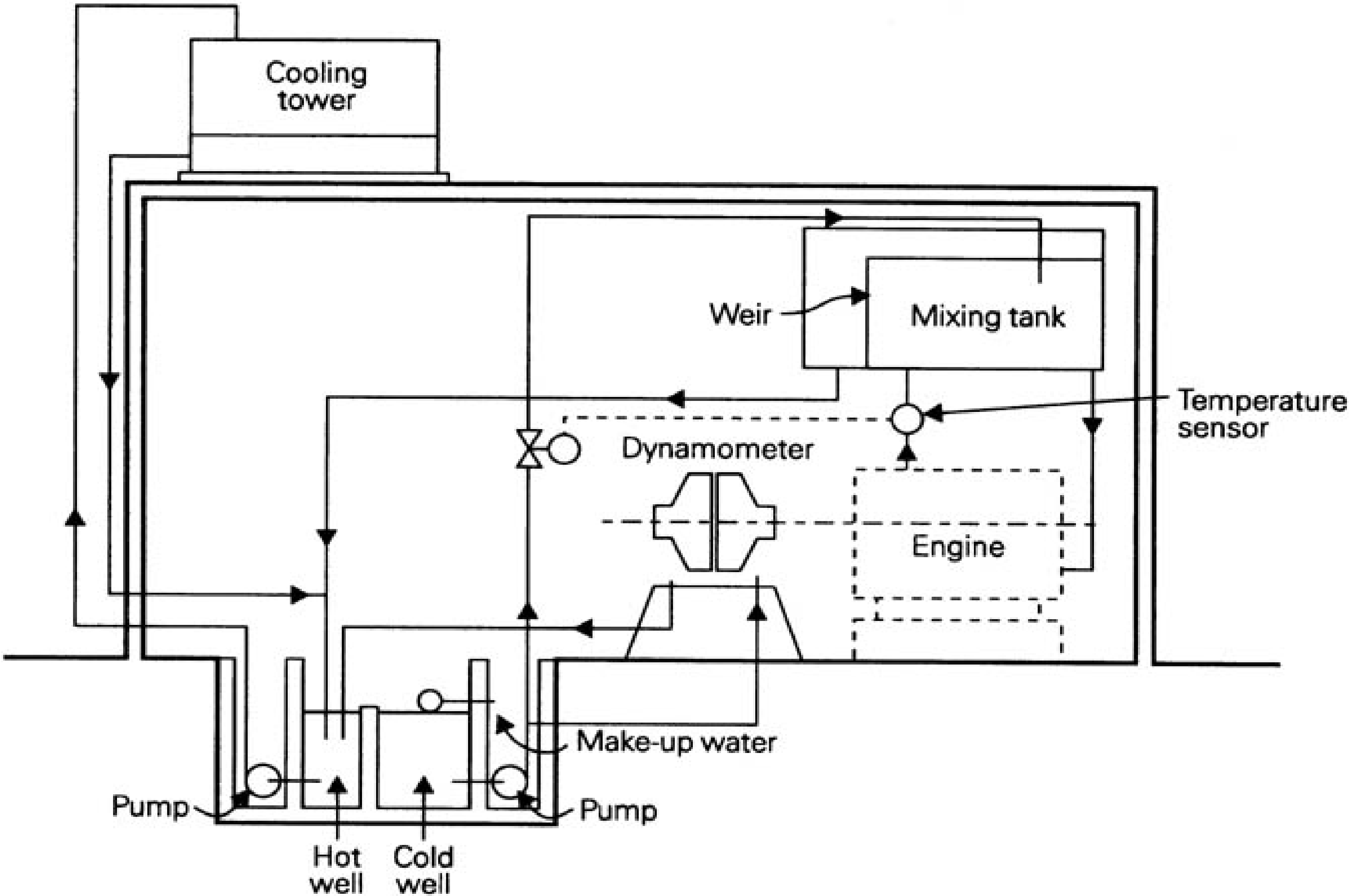



- Necessary for diesel engines and fuel injected gasoline engines
- Intercooler is needed for returned fuel
- Note air and fuel vapour in the fuel return line

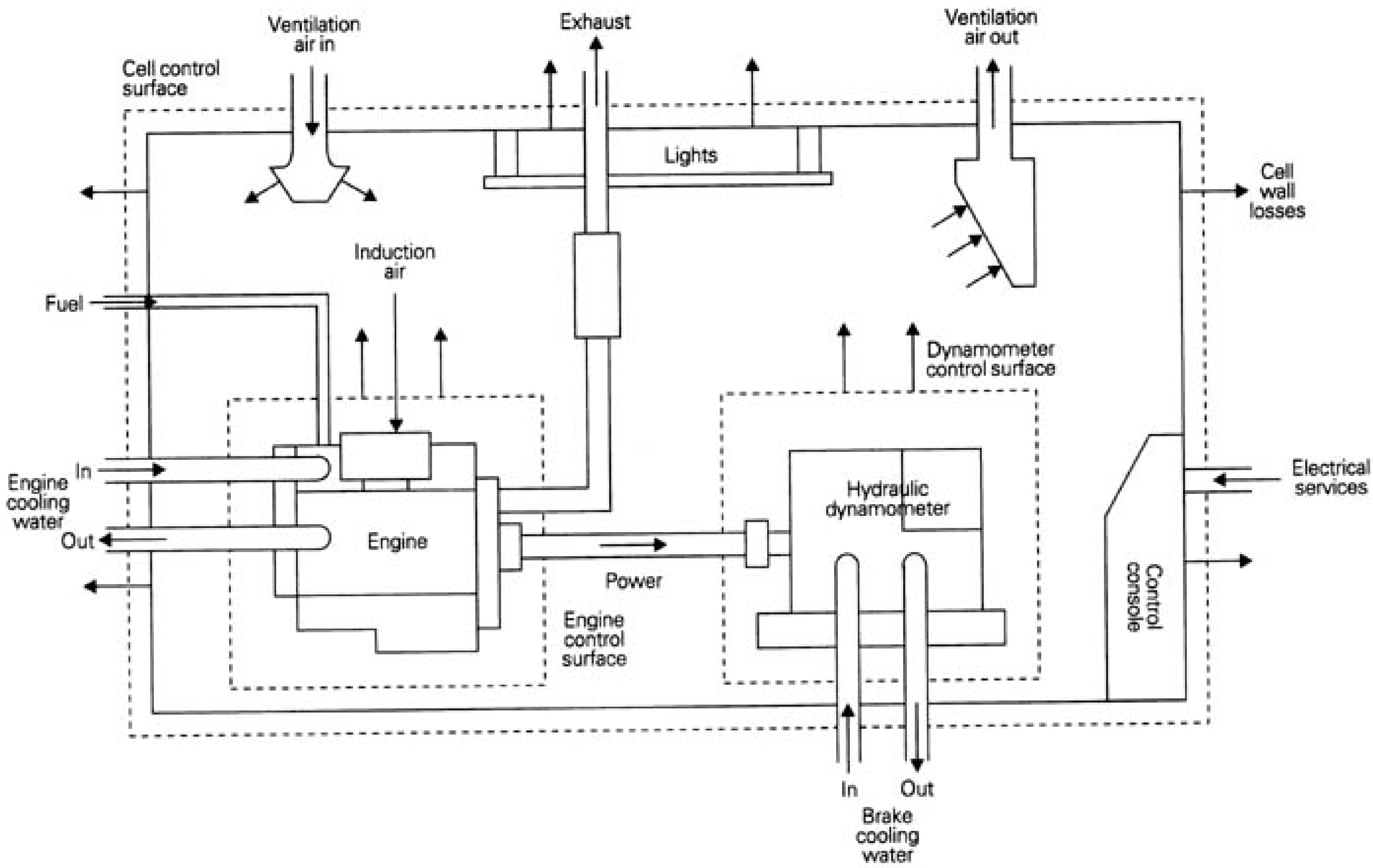
# Engine Speed

- Simply the rotational speed of the engine
- Usually expressed in rev/min; rpm or rev/second (s)
- Measured using an encoder
- Turbocharger shaft speed may be measured
- Relative camshaft position is used to determine where in the cycle the engine is

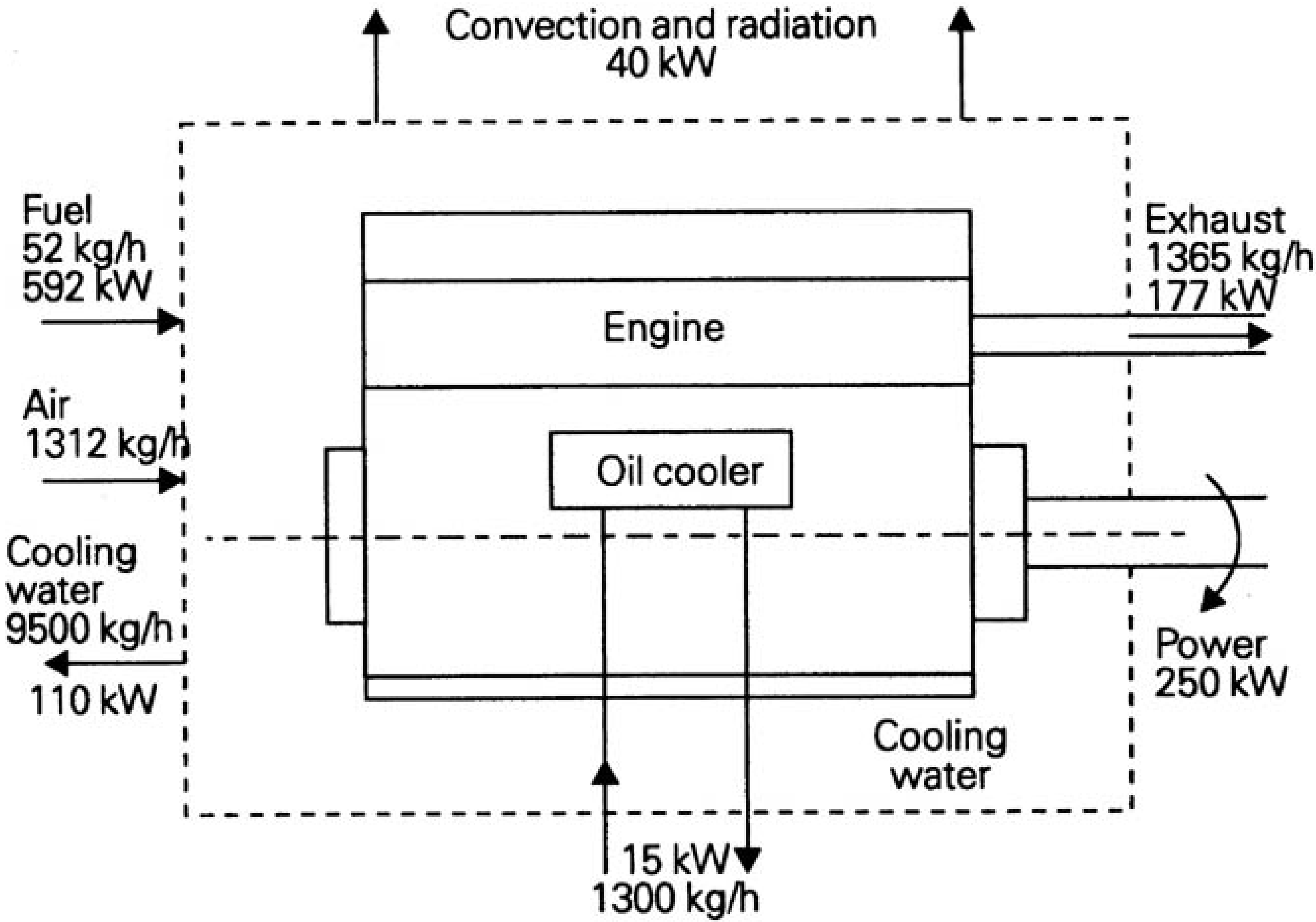
# Basic cell coolant circuit



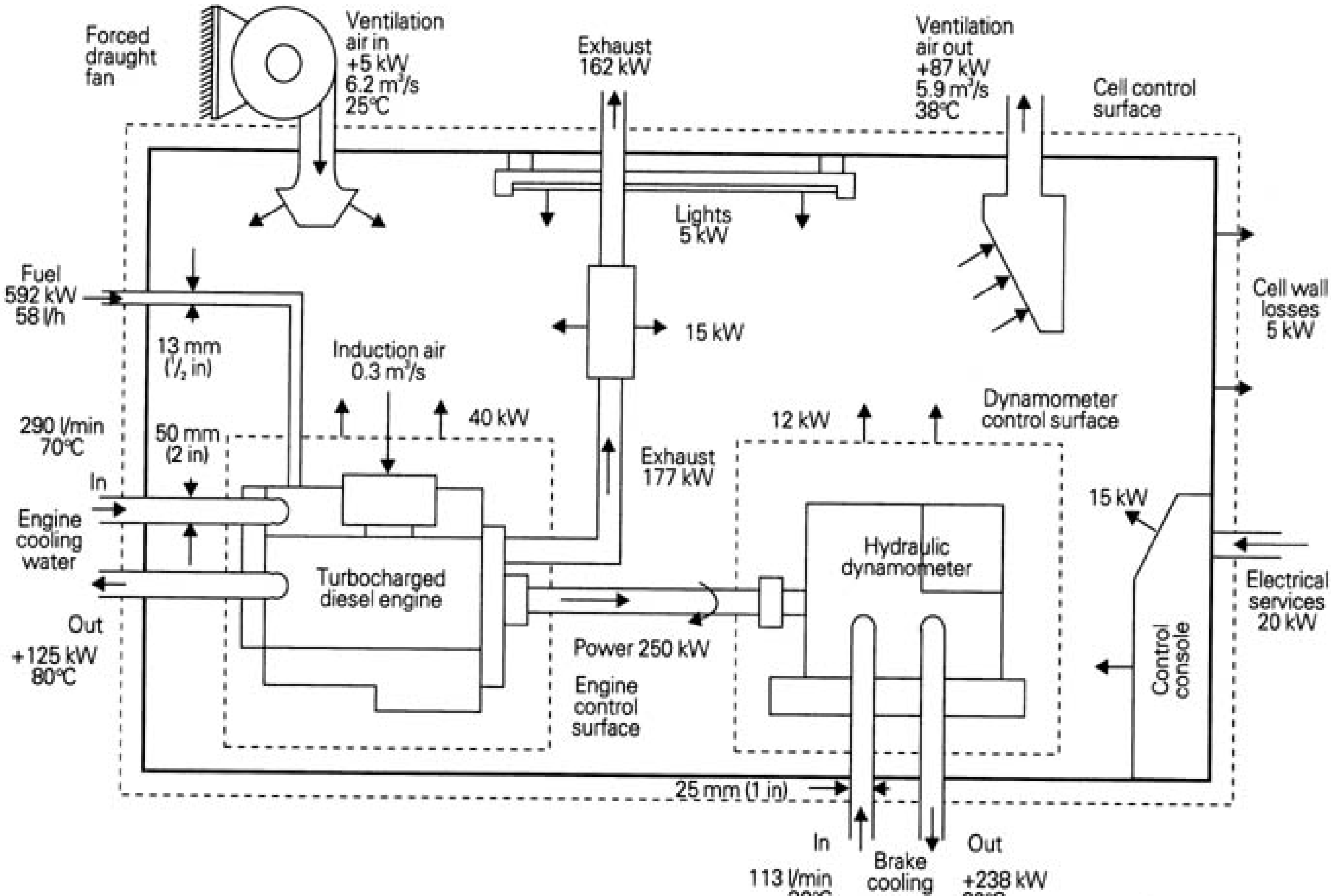
# Services in and out of the test cell



# Energy balance of engine



# Energy balance in a test cell



# A worked example

2.4 Litre Euro 3 engine. 75 kW at the flywheel at a rated speed of 4,100rev/min. Specific fuel consumption at net peak torque is 255g/kWh.

Therefore,

Fuel = 0.255x75=19.125 kg/h.

SG of this fuel lay between 0.815 and 0.855 kg/litre thus approximate fuel:

19.125 kg = 15.58 Litre

Given 3.8 litre of typical diesel fuel = 155 x $10^6$ joules (147,000 Btu)

15.58 litre diesel fuel = 635.5 x $10^6$ joules

1 kW.h = 3.6 x $10^6$ joules

Hence 19.125 kg fuel: 635.5 x $10^6$ /3.8 x $10^6$ =176.53 kW

Energy in = 176.53 kW

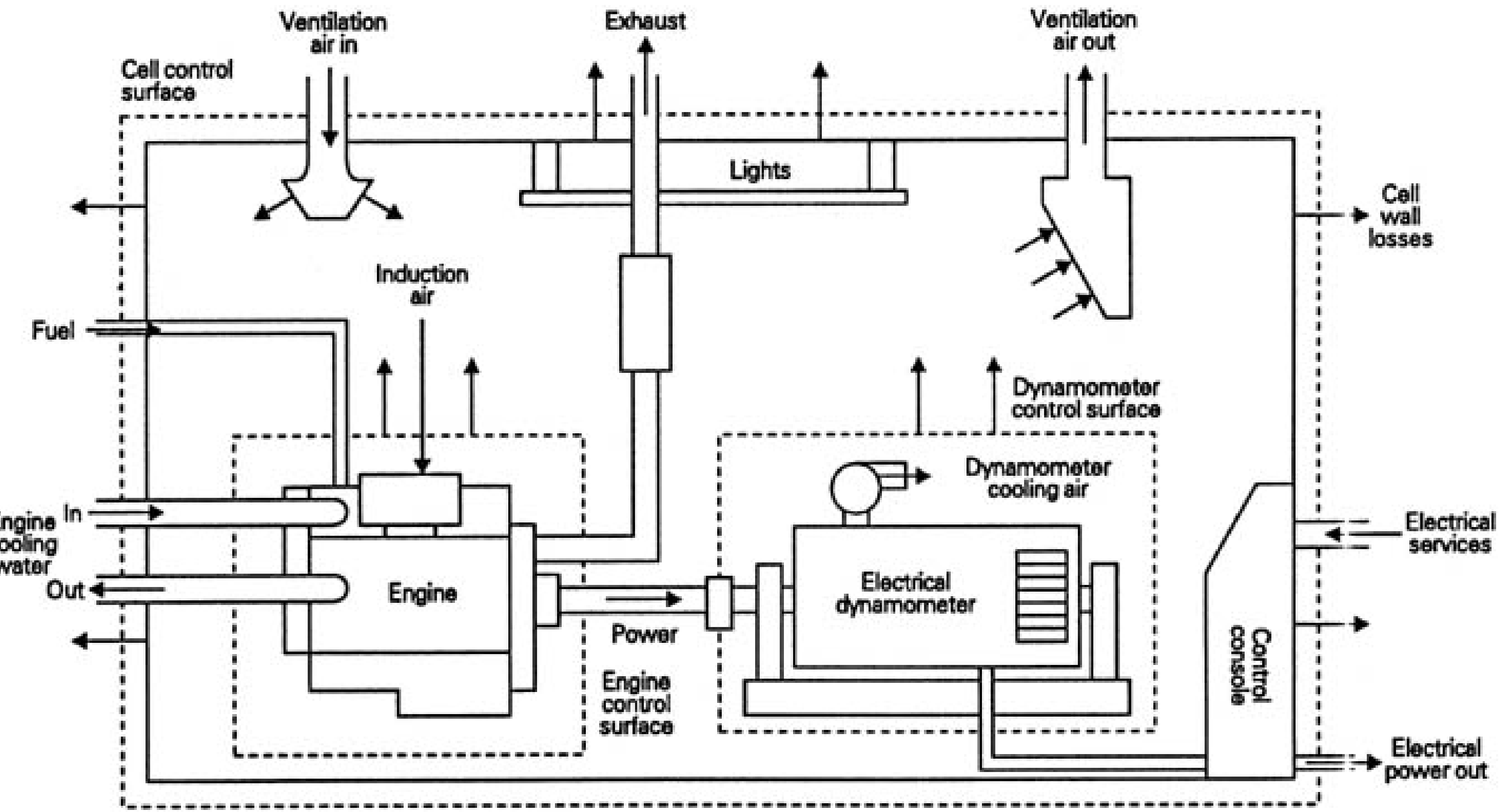
Energy to flywheel = 75 kW

This equates to 42.58% efficiency but true figure would be 35%

# Energy balance for engine

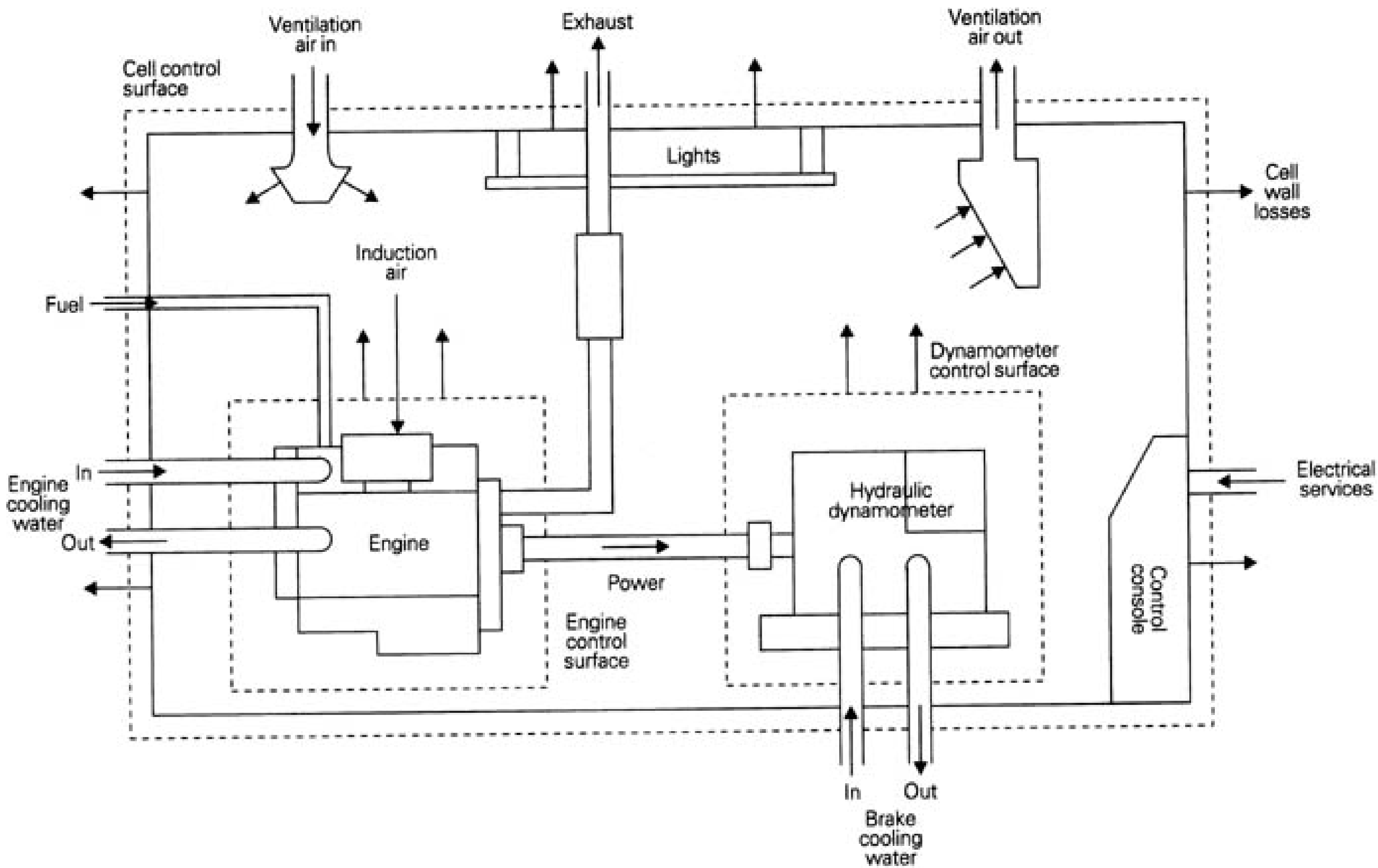
| In to system | | Energy share | |
|---|---|---|---|
| Fuel energy | 176.53 kW | Power | 75kW (42.2%) |
| | | Heat to coolant | 33kW (18.6%) |
| | | Heat to oil | 4.5kW (2.5%) |
| | | Heat to Exhaust | 53.1 kW (29.9%) |
| | | Convection & Radiation | 11kW ( 6.8%) |
| Total in to system | 176.53 kW | Total out | 176.53kW |

# Electrical dyno services

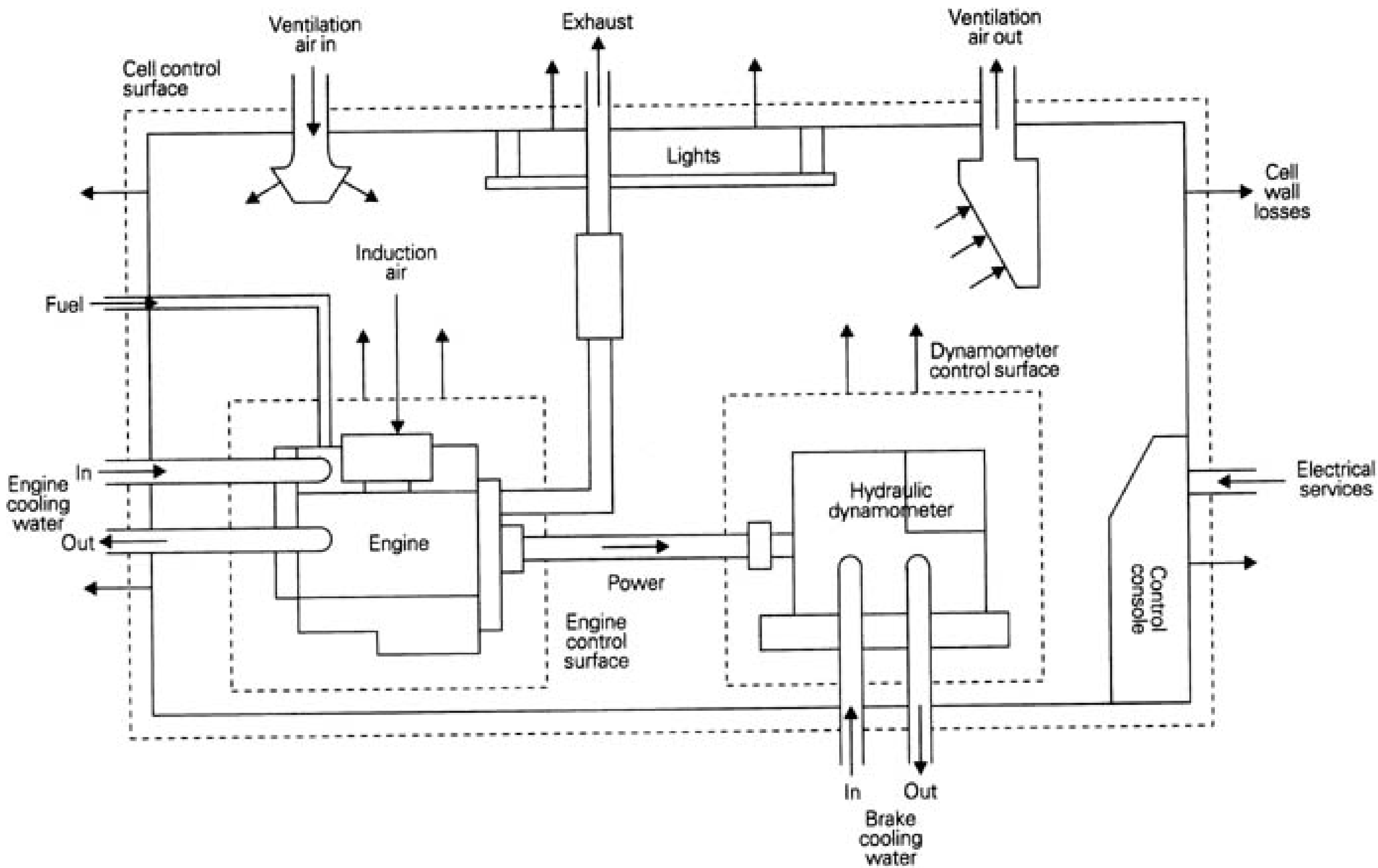


# Assume a turbo diesel producing 112 kW
# Calculate the fuel, coolant airflow etc.

**(approx 1/3 power, 1/3 coolant, 1/3 exhaust)**



# Assume a gasoline fuelled engine of 205 kW calculate all the requirements



# Typical Steady State Test Room

**Eddy Current Absorption Dynamometer**

**150 kW @ 8000rpm**

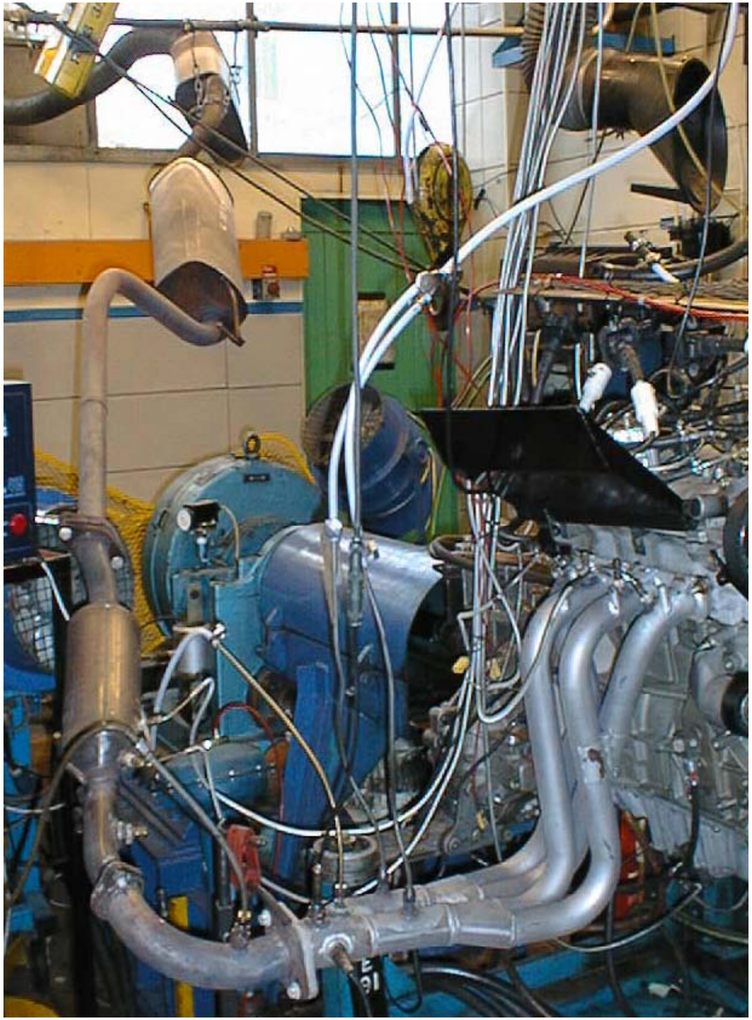
**Primary Data Channels (72)**

**Calculated Data Channels (72)**

**Fuel Flow Measurement – Pierburg**

**0.15 – 60 kgh +/-1.0%**

- **Pre Catalyst  Feed Gas Emission**
- **Measurement THC, NOx, CO, $CO_2$, $O_2$**

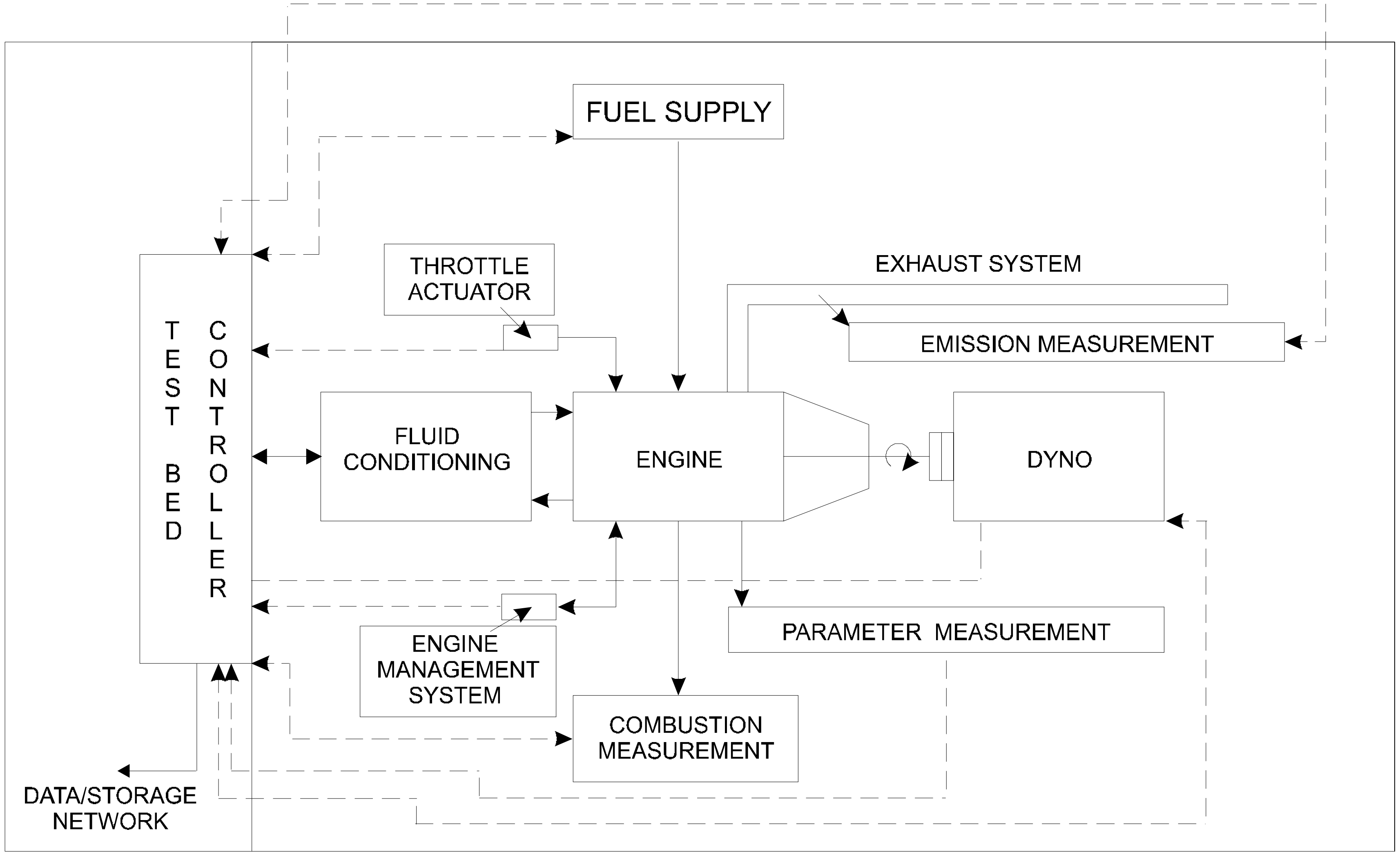


**Combustion Data Measurement System**

**Vehicle Induction & Exhaust System**

**Vehicle Mount / PTO, Simulated FEAD**

# Test Room Overview



# Transient Dyno Control Room

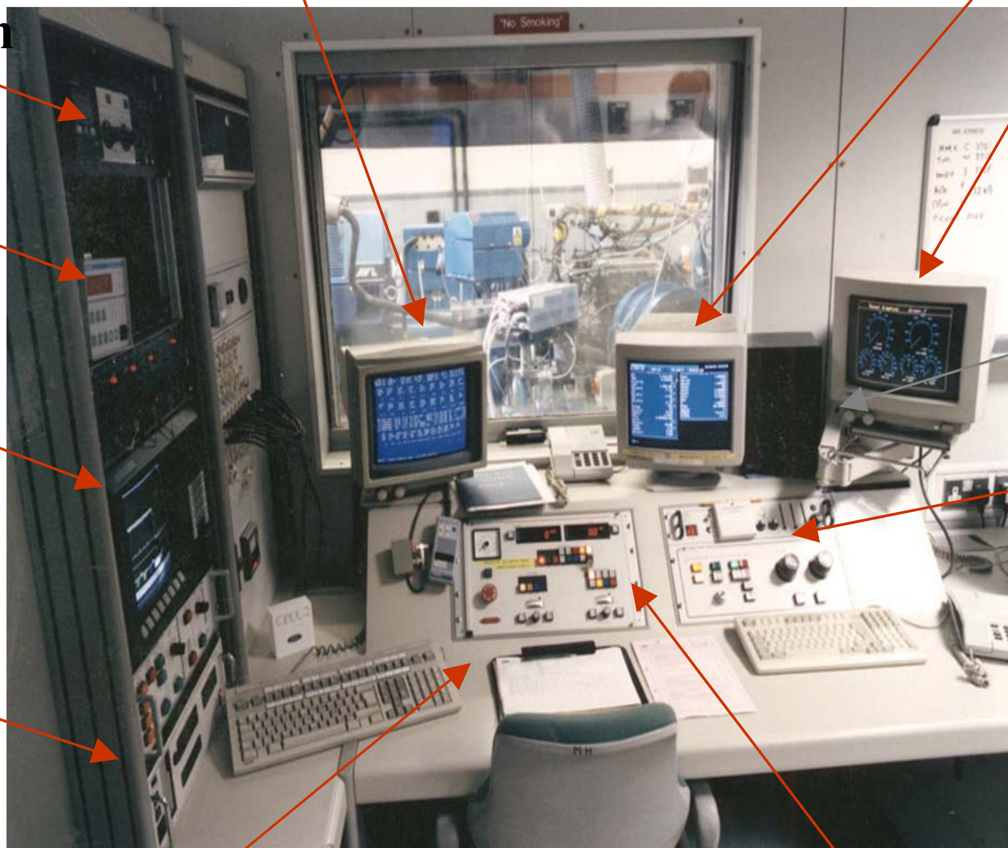
**Cell Computer Test Log Display.**
**All parameters available Multi Page Display**

**PCM Controller Display**

**nstrumentation**
**Alarms**

**Transient Test Tim**
**Aligned Parameter**
**Display**

**UEGO AFR**
**Meter**




**Comb Data Acquisition System**

**Throttle, Dyno Load, Coolant Oil Temp, Air Temp Control**

**gnition Angle Meter**

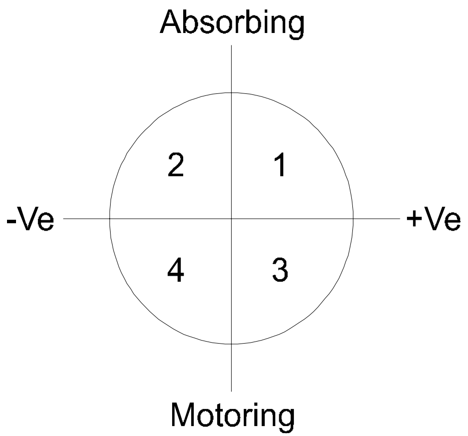
**Test Room Operator's**
**Cell Log (electronic pilot)**

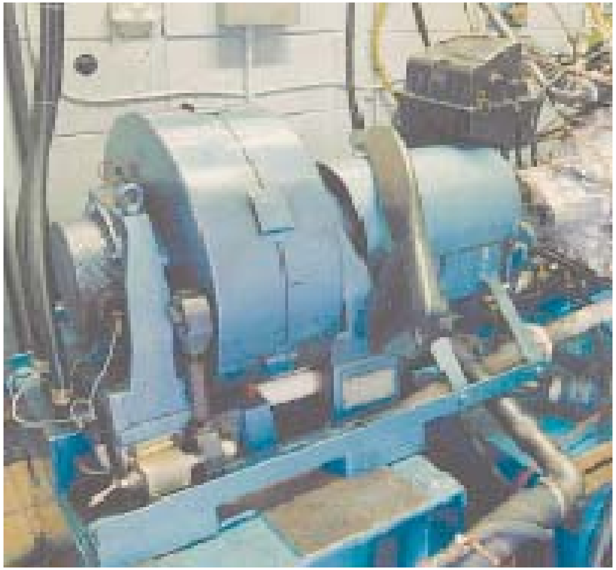
**Torque & Speed Display**

# Dynamometers

- **Dynamometer Types – Absorption & Motoring**

  - Absorption Eddy Current (2 pole) Absorbs Engine Torque Only
  - Motoring D.C. Machine (4 pole) Absorbs and Motors Engine.
  - A.C. Machine (4 pole) Fast Response Engine Speed or Load based control strategy
  - Move from Water to Air Cooling (AVL).
  - Future Move to low Inertia Synchronous for better transient control



# Torque Signal Measurement

Load Cell Measures Torque Reaction.

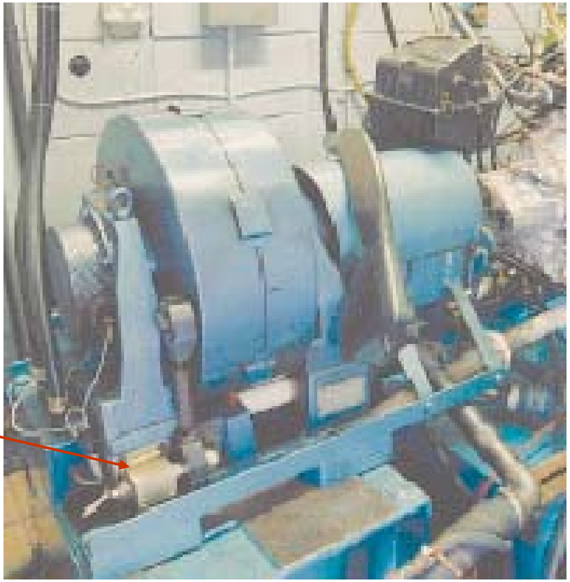
Need to avoid Sticktion.

Future system Torque model Load Cell & Electrical.

In-line Torque measurement using Torque Disks & Transponder now available.

Fast response
Used in Full Powertrain Dynos.

Load Cell



# Emission Analyser

Cost £100K+

Regular calibration verification checks using alpha std gas

Specific analysis for each gas

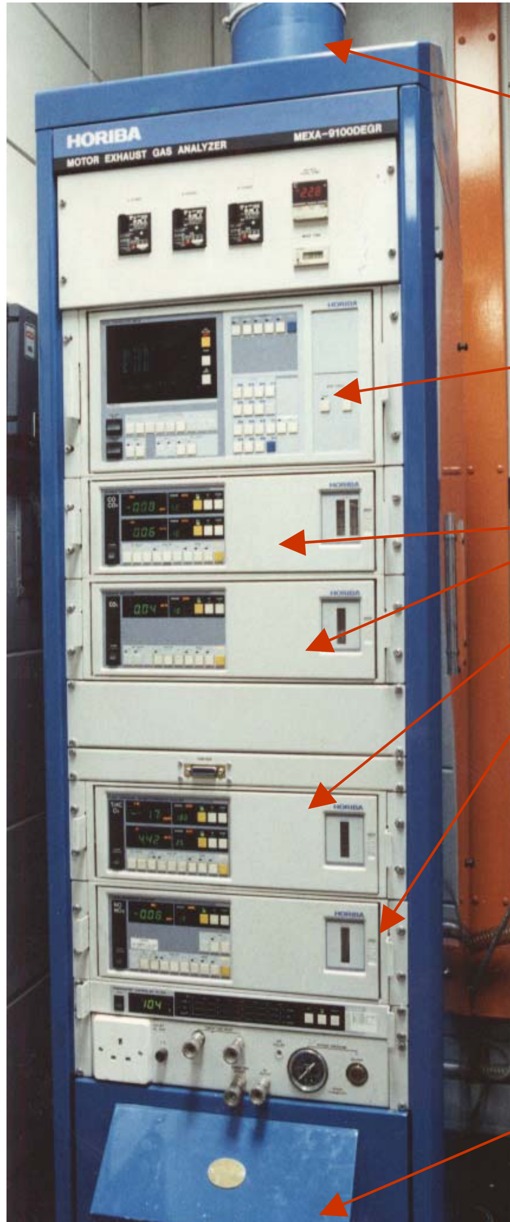
THC – FID / Hot

NOx – CLA / Hot

O2 – MPA

Chilled

CO / CO2 – NDIR




Exhaust 11–30 ltr/min

Control System

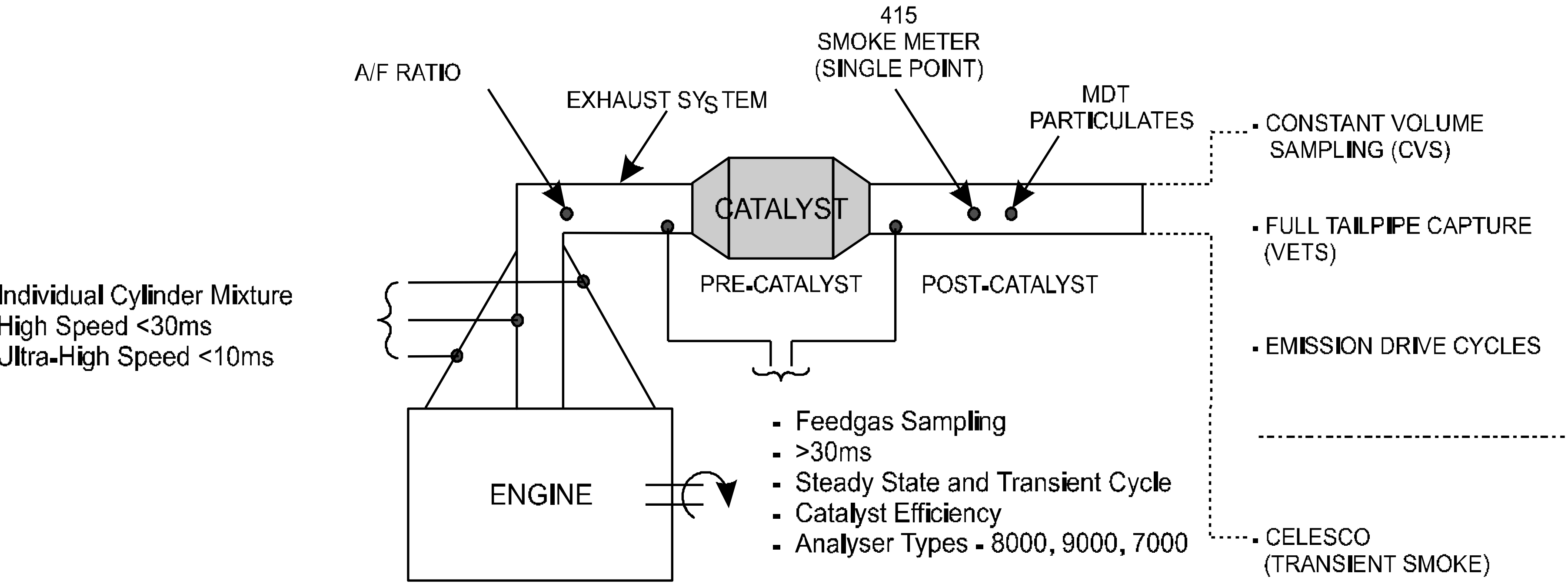
Analyser Banks

Solenoid Bank & Sample Entry

# Emission Measurement Schematic

## Response & Transport Delay Important

- **Pre & Post Catalyst Emission Measurement – Steady State & Transient**



# Combustion Data Acquisition

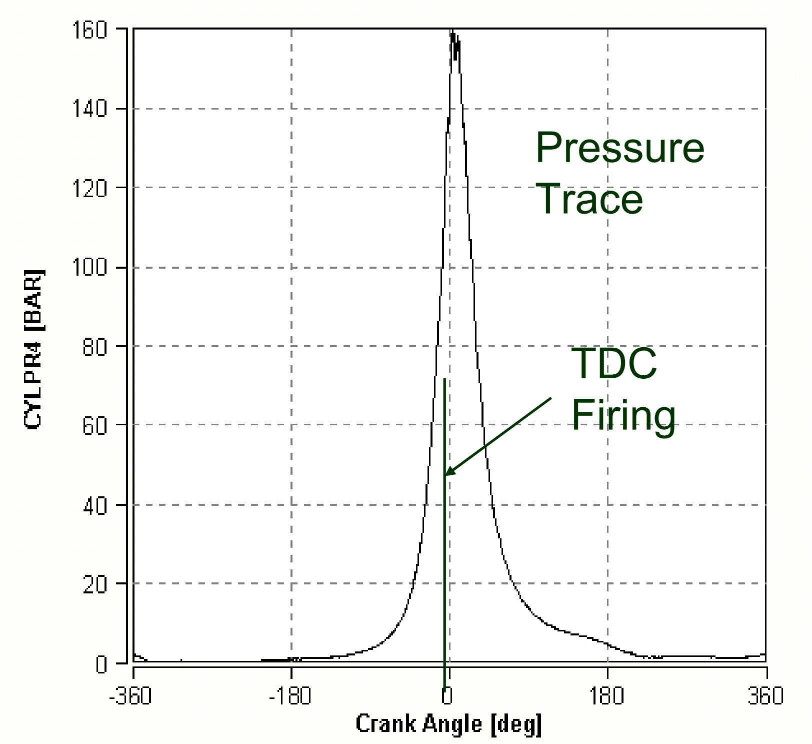
High Speed Data Acquisition System Capture cylinder pressure data one channel per cylinder at up to 2MHz per Channel

Crank Angle resolved data capture varied rate across cycle e.g. 0.2 (-50/+50) 2 deg resolution

Multi Channel processing of IMEP, Heat Release and other combustion parameters Extensive data post processing internally & via LUCID

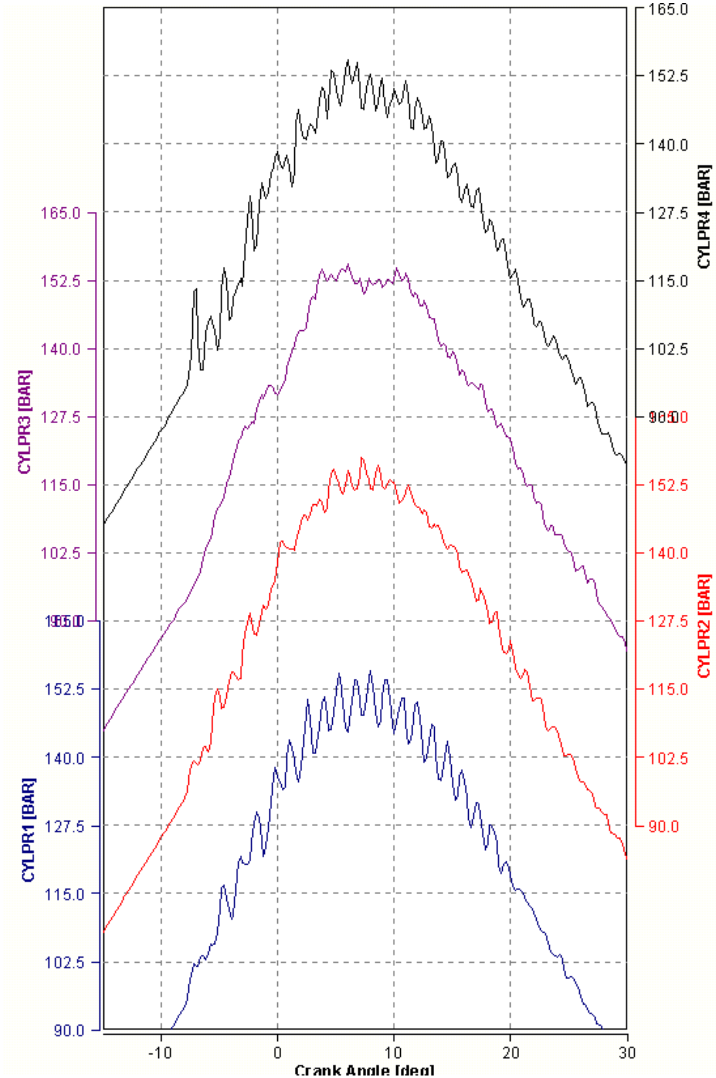
Typically, Ethernet link to central site Host

# Cylinder Pressure Analysis



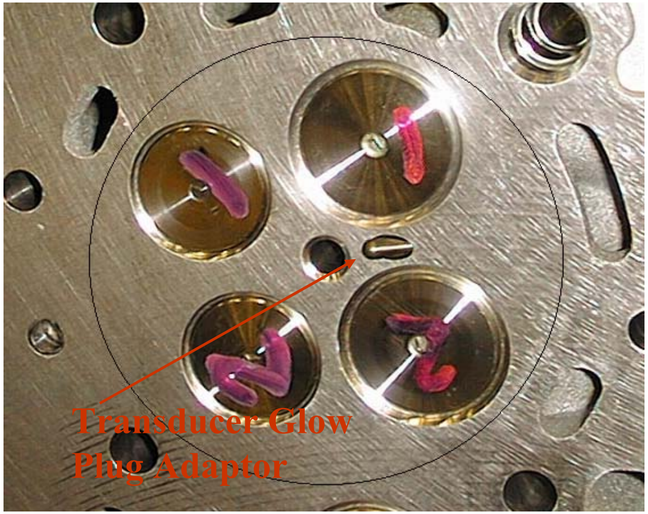

## Graph & Tabulated Data - Statistical Analysis

| Crank Angle | CYLPR1 | CYLPR2 | CYLPR3 | CYLPR4 |
|---|---|---|---|---|
| deg | BAR | BAR | BAR | BAR |
| Min | 152.14 | 151.64 | 152.48 | 152.13 |
| Max | 161.35 | 159.21 | 158.74 | 162.36 |
| Count | 300.00 | 300.00 | 300.00 | 300.00 |
| Mean | 155.66 | 155.70 | 155.39 | 157.61 |
| Median | 155.68 | 155.58 | 155.32 | 157.61 |
| Std.Dev. | 1.54 | 1.30 | 1.08 | 1.73 |
| Skewness | 0.32 | 0.08 | 0.27 | -0.08 |
| Kurtosis | 0.13 | 0.18 | -0.04 | -0.05 |
| CoV | 0.99 | 0.84 | 0.70 | 1.10 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |




## 1 Cycle from 50 Cycles 4 Cylinder

# Cylinder Pressure Transducer Signal



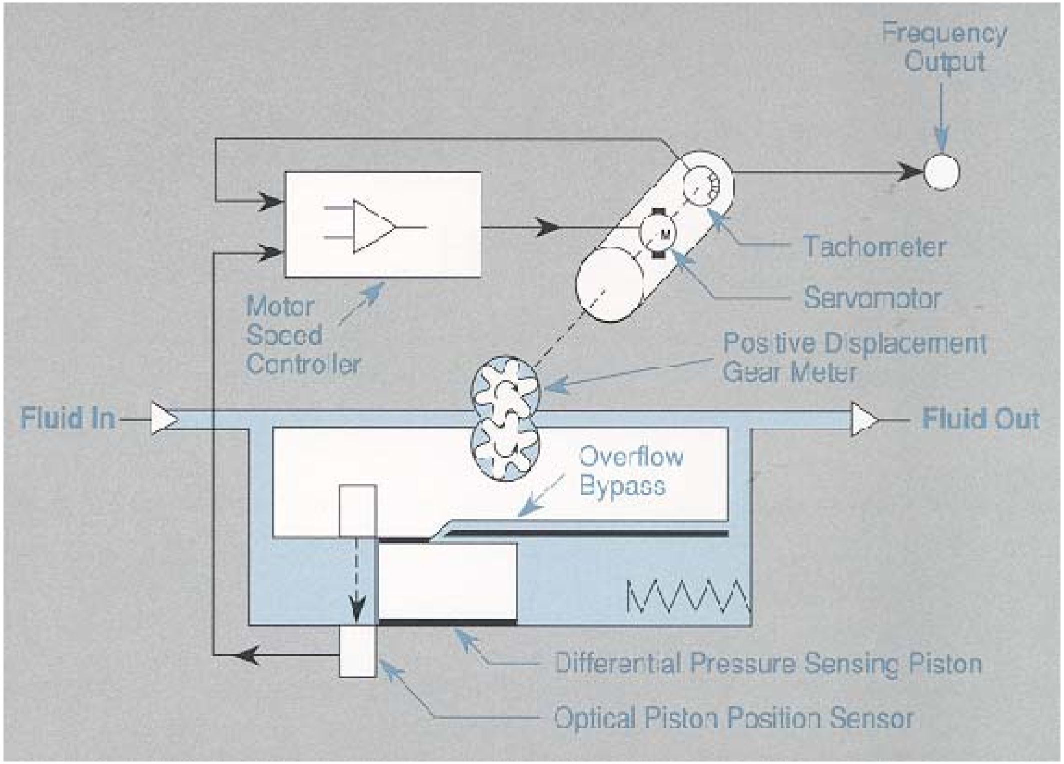

- Piezoelectric effect - Quartz crystal becomes electrically charged when body force changes.
- Charge Amplifier converts charge to Voltage (Analogue).
- 14bit Analogue to Digital converter.

**Diesel Glowplug Adaptor & Cylinder Pressure Transducer**

**Kistler 6125A Transducer Ground Isolated Piezo Resistive Type**

# Fuel Mass Flow Measurement

- **Pierburg Fuel Measurement System**




Measurement Requirements 0.5 kg/hr minimum to-date 0.15 kg/hr new requirement

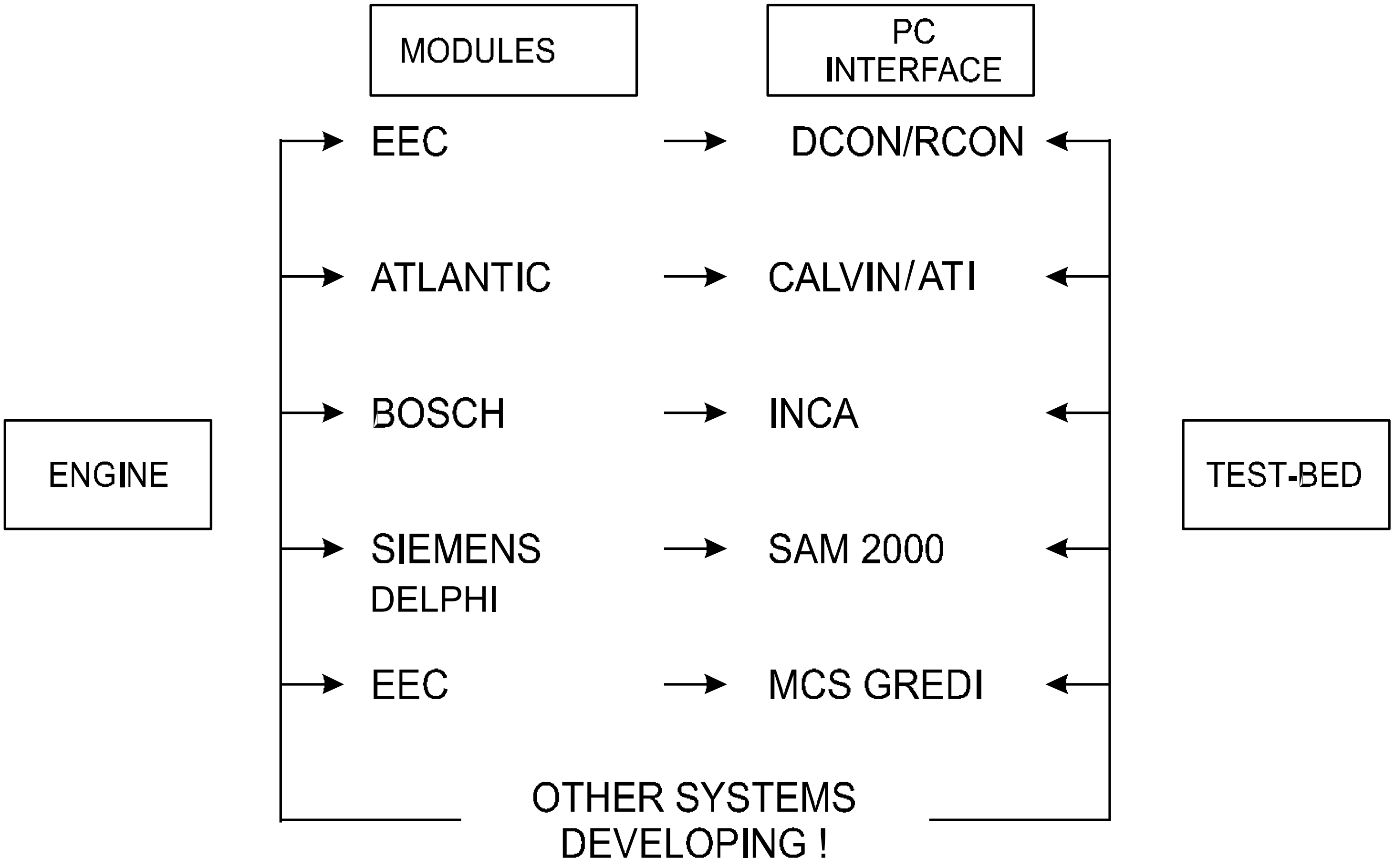
Measurement Capability Transient Measurement 1.0% Accuracy

Measurement affected by Temperature Changes, Pipe Configurations

Volumetric Servo Assisted Measurement. In-line Density meter delivers Mass Flow

# Base Dynamometer Elements

## Engine Management Control Systems



# Base Dynamometer Elements

Test-Bed equipment selected to suit specific Test Needs

- \- Dynamometer
- \- Torque Measurement
- \- Installation
- \- Emissions Measurement
- \- Combustion Data Acquisition
- \- Control Room Features
- \- Test Data Handling

# Challenge (Changing Development Process)

- Base Dynamometer Elements
- Facility & Powertrain Development
- Data Analysis
- New Technology & Automation
- New Technology Demands

- Transient Race Engine
- Summary

# Range of Testing Modes

- Steady State Fired & Motoring

  Mapping of air calibration, fuel calibration, base borderline and MBT spark calibration. Data is recorded using a bucketed moving average, typically 40 sec

- Transient Test

  Throttle steps to support transient fuel calibration

- Powertrain by Simulation

  NEDC drive cycles

- Full Powertrain testing

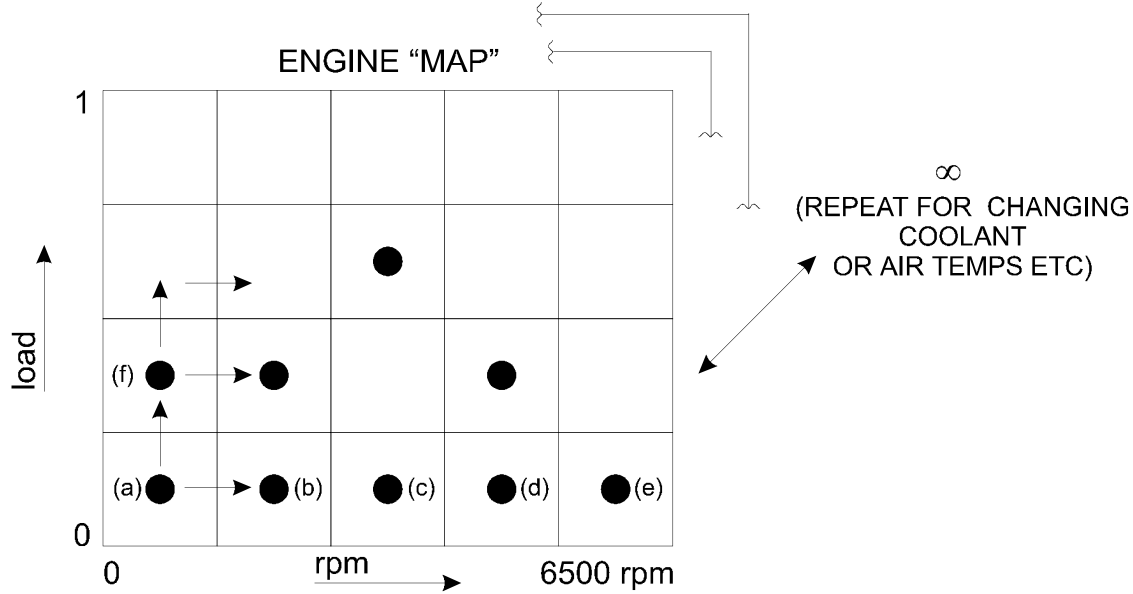
  Drive Cycles, Powertrain Durability, Real world Fuel Economy

# Steady State Test Facility

- **Main Features**
  - Manual or Limited Test-Bed control
  - Low Tech Equipment Specification
  - Absorbing Dyno, Basic Throttle Actuator, AFR and Feedgas Measurement

- **Usage / Capability**
  - Base Calibration, H/W Development
  - Long Set-Up process
  - Limited Data Output
  - Calibrate total 'Engine Map' under controlled conditions
  - Identify Optimised Single Point Calibration
  - Limited Vehicle Equivalent Calibration

# Steady State Test Facility




- **Limited Calibration**
  - **Only calibrate at individual `map’ points (‘a to ‘b’ to ‘c’ etc)**
  - **Repeat for Condition / Parameter Change (3D map)**
  - **Calibration Interpolates Between Points**
  - **Vehicle Driving, requires Optimum Calibration moving Transiently between points**

# Steady State Testing

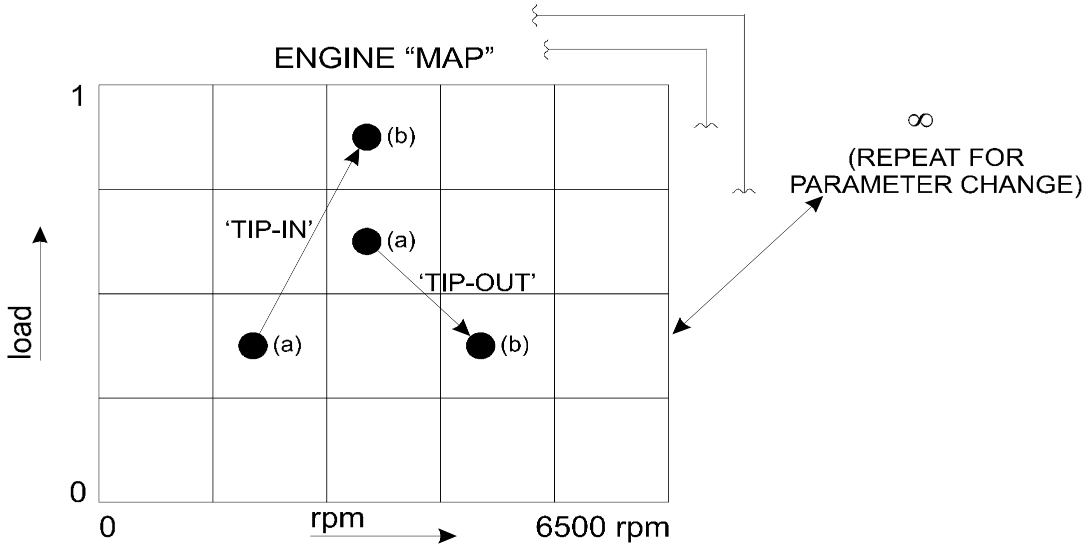
- **Typical types of parameters calibrated**
  - **Air Calibration**
    - **load maps, MAF transfer function, Speed/density map, max load line**
  - **Fuel**
    - **open loop, closed loop, WOT fuelling, AFR distribution**
  - **Spark**
    - **MBT, borderline, min RON spark, offsets for temp, fuel, air & EGR**
  - **EGR mapping, EGR distribution**
  - **Hardware development**
    - **HEGO position, injector characterisation, manifold dynamics, thrott**
    - **progression, data for CVSP**

# Transient Test Facility

- **Main features**
- **-Auto Test-Bed Control**
- **-Motoring Dyno, High Speed Throttle and Emissions Capture**
- **Vehicle Equivalent `In-gear' Inertia Present**

- **Usage / Capacity**
- **-Improved Calibration Development**
- **Closer Comparison to 'Vehicle'**
- **Control of Transient Fuelling / Spark**
- **-Map Whole Engine under Controlled Conditions**

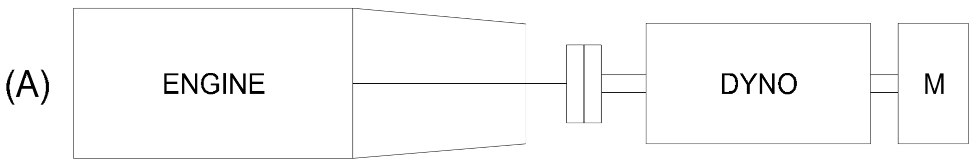
# Transient Test Facility




- **Improved Calibration**
- - **Calibration Robust for Transient Point-to-Point movement within Map**
- - **Repeat for Condition/Parameter Change**
- - **'In-gear' base Inertia (Vehicle Loading) Capability**
- - **Vehicle Equivalent Calibration requires 'Dynamic' movement within map (Load, Speed and Time Variation)**

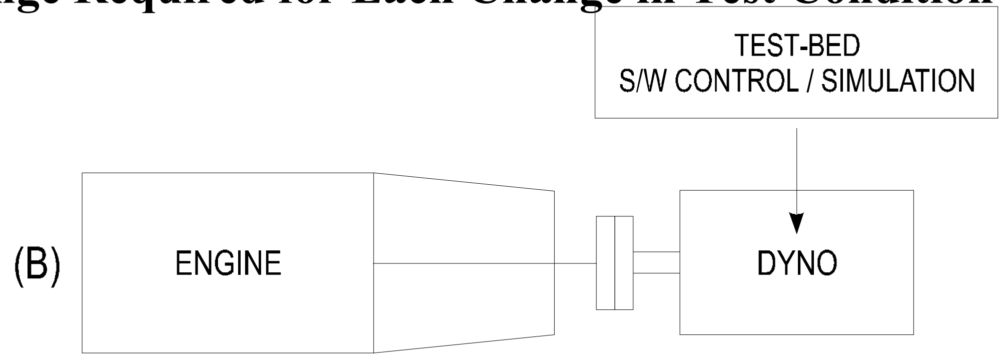
# Transient Test Facility

VEHICLE EQUIVALENT BASE INERTIA




## Mechanical Loading / Inertia

- Select Flywheel Mass Equivalent to Given Vehicle in Given Gear
- Mass Change Required for Each Change in Test Condition - Time Consuming

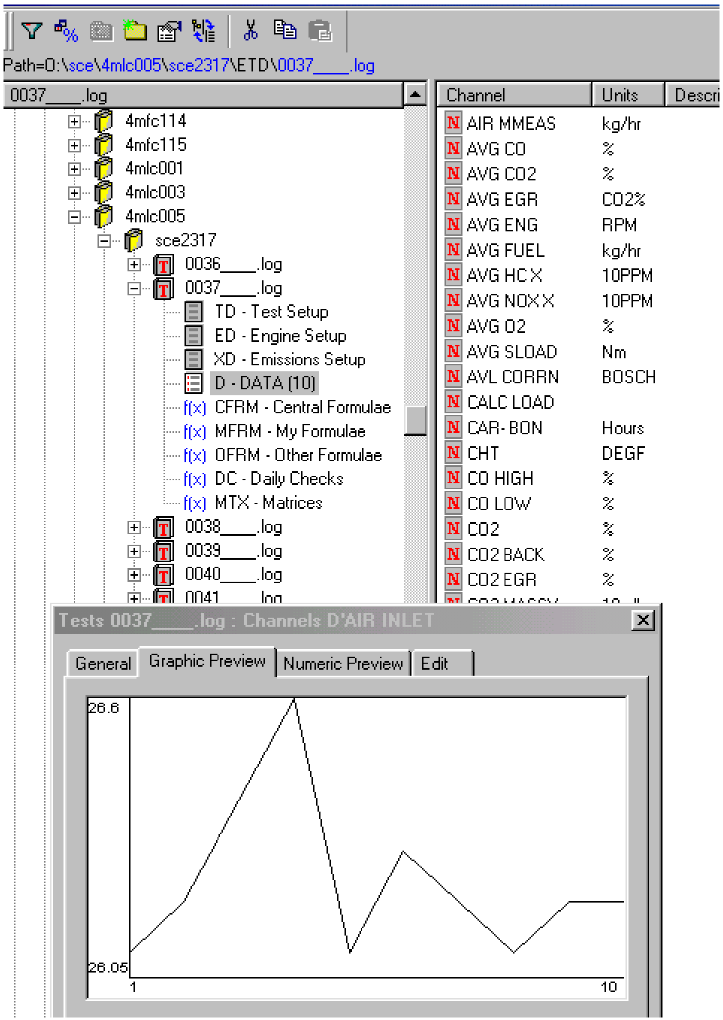



- **Simulated Loading / Inertia**
- - Loading Calculated by S/W given Road Load Curve Parameters (RLC)
- - Optimum Test Efficiency
- - High Specification Motoring Dyno and Control System Required

# Transient/Motoring Testing

- **Typical types of parameters calibrated**
  - Air
    - Load prediction, throttle mapping, manifold dynamics, inferred load, min load line, idle speed control, coast down
  - Fuel
    - Transient fuel, tip-in, back-out, idle fuel, EVAP
  - Spark
    - Tip in detonation, transient spark, feedback spark (idle)

# Test Data Analysis



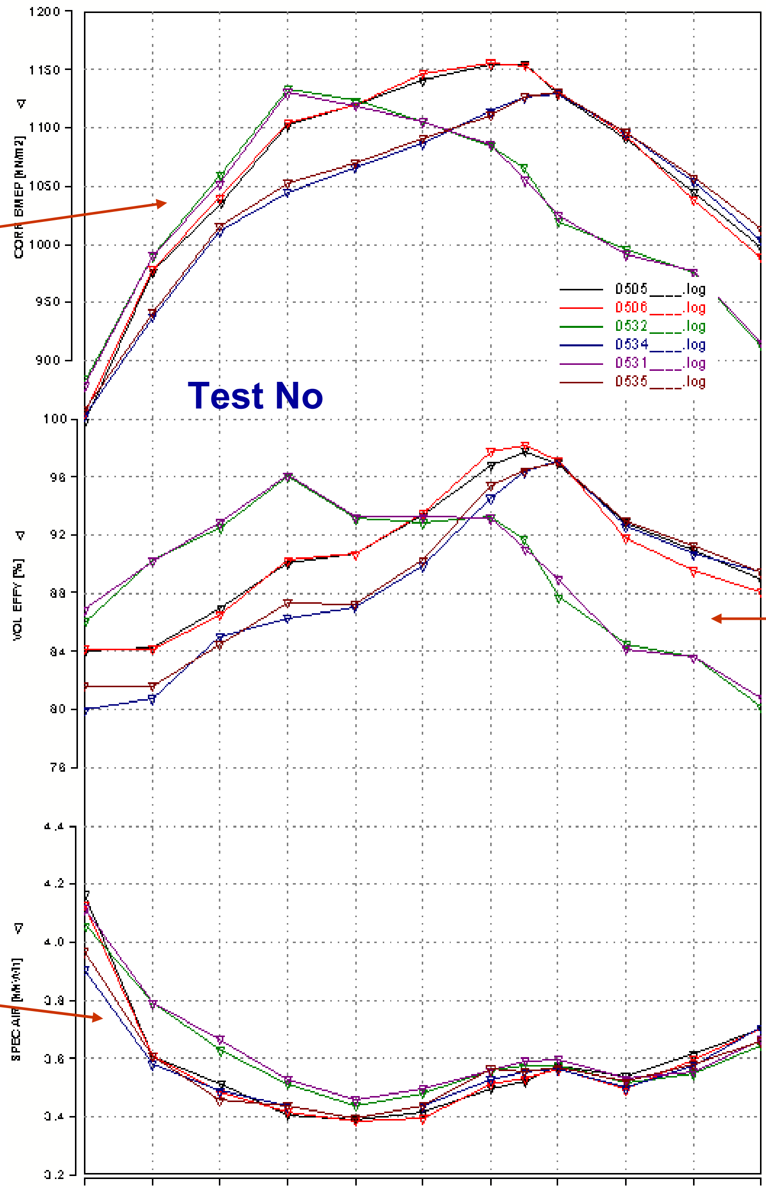

- Test Data stored on central host server by Engine/ETR/Test_ No/Parameter
- All Data Types stored:Test, Engine, Emission, Combustion, Set-Up
- Automatic data processing via Script files & Macros
- One stop shop data analysis providing end report.

  Minimised data transport and analysis errors

# Test Data Analysis

Intake Cam PL Timing Swing Example

**Corrected Torque**




**Volumetric Efficiency**

**Brake Specific Fuel Consumption**

# Test Data Analysis - Validation

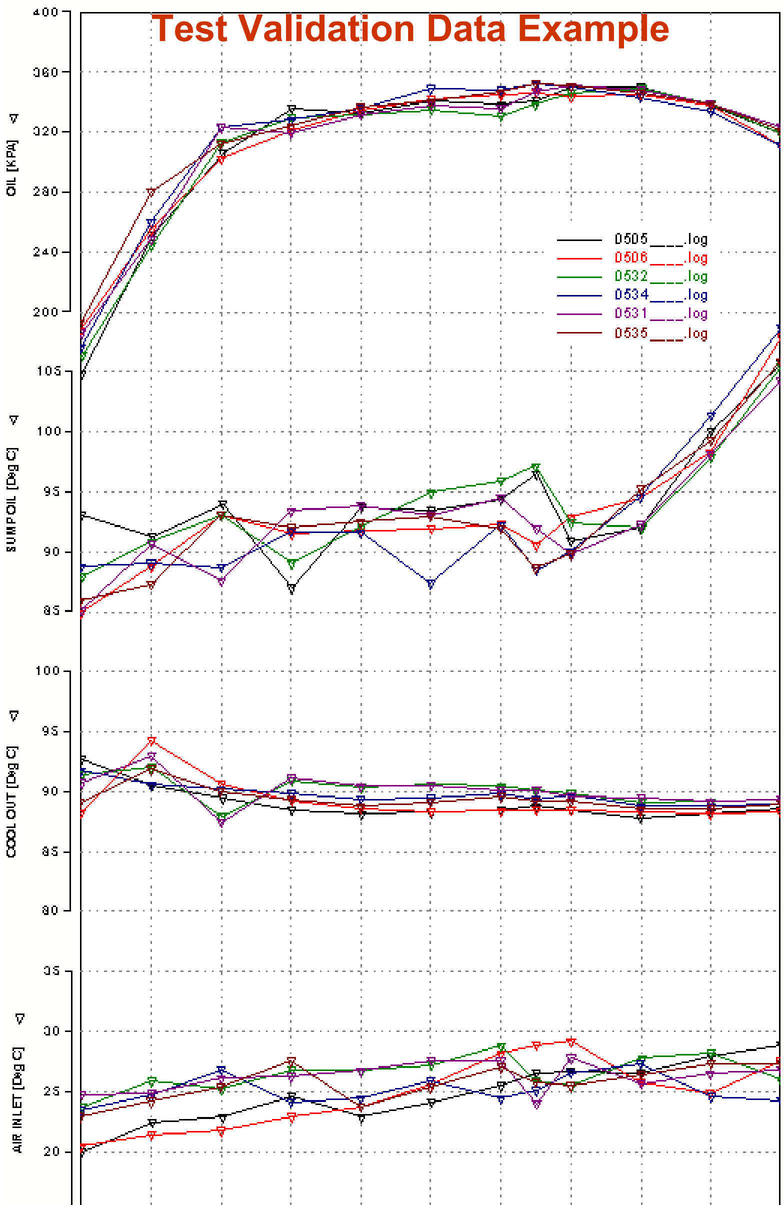
Oil Pressure

Sump Oil Temperature

Other Data Metrics also available e.g EPB Air Intake Temp from around 400 Channels

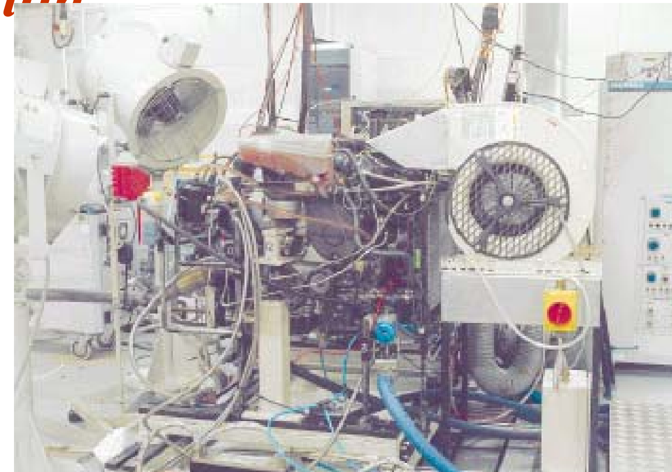
Coolant Out Temperature

Air Fuel Ratio



# Changing development processes

- Base Dynamometer Elements
- Dynamometer Facility & Powertrain Development
- Data Analysis
- ***New Technology & Automation***
- New Technology Demands
- Transient Race Engine
- Summary

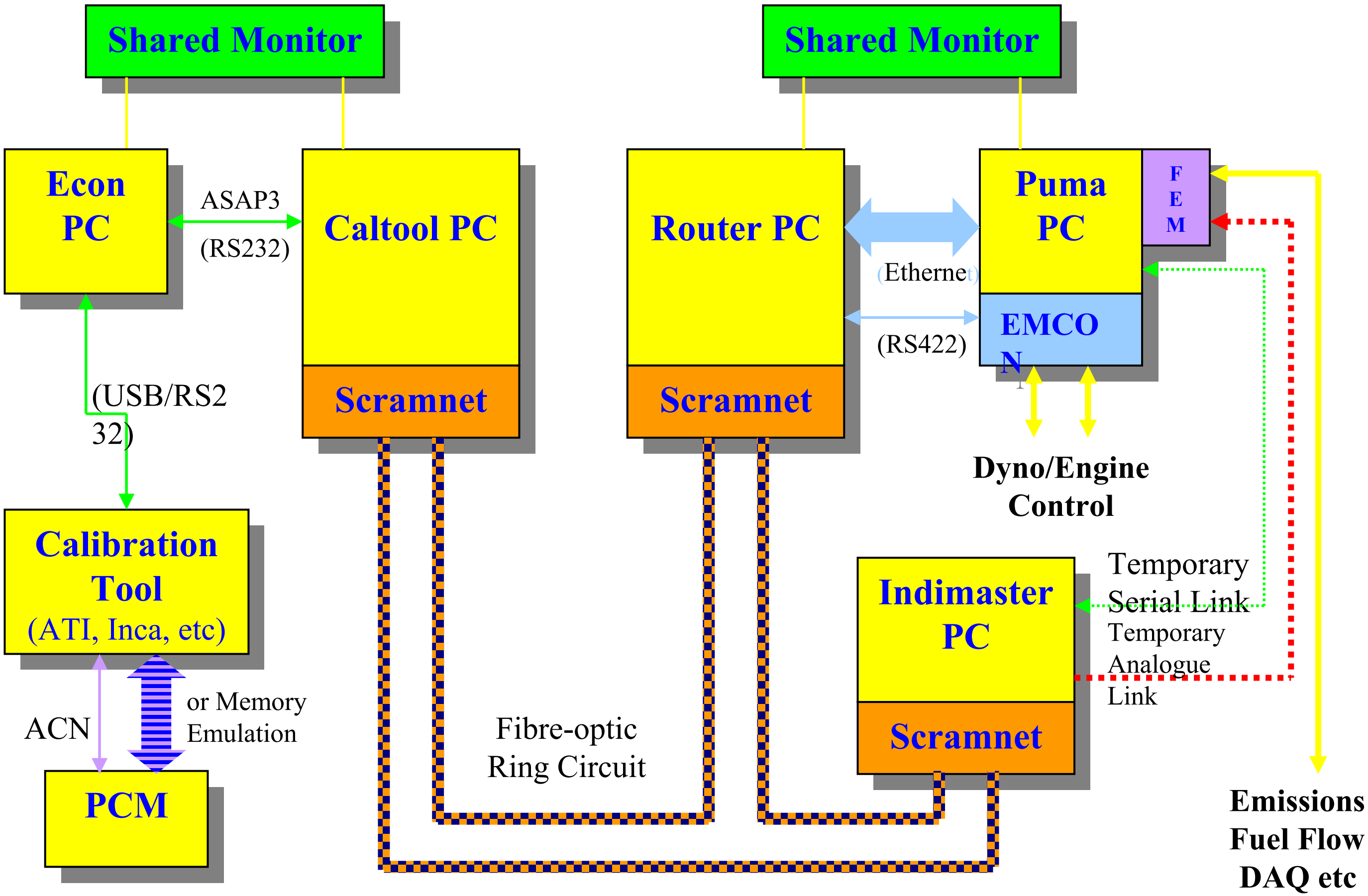


# Creation of a Generic Powertrain Testing Platform

- **Objective**
  - Test Environment/Software Independent of Test-Bed Type
  - Utilizes Common / Global Test Procedures
  - Full Automation of Test-Bed Operation, Test Set-Up and Control
  - Reduces Test Time & Development Costs
  - One Digital Data Format Generated
  - No Different Formats: No Time Alignment Concerns
- Global Initiative
  - Aids / Reduces Test Analysis Time
  - Global Comparison of Data
  - Networked Interface To Analytical Modeling Tools
  - Auto Generation of Procedures and Data Comparison

# Test Control & Data Handling

## Typical – System Architecture



## Procedure Advantages

- Average number of spark sweeps increased from 5 to 30 per shift.

- BLD mapping time reduced by two thirds compared to manual process.

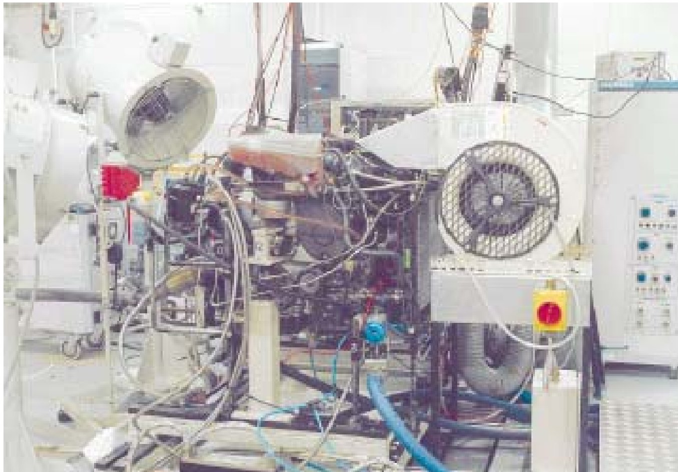
- DISI mapping time reduced from 5 to 2 Weeks.

- Average rate of gasoline steady state data production increased by 20%.

- Basic diesel calibration available in 2 days compared to 2 weeks using manual process.

# New Technology & Automation

- Significantly increase test data quality
- Significantly reduce test cycle time
- Standardised test methods
- Repeatable & Reproducible
- Reduced risk of test failure



# Changing Development Process

- **Challenge (Base Dynamometer Elements**
- **Dynamometer Facility & Powertrain Development**
- **Data Analysis**
- **New Technology & Automation**
- ***New Technology Demands***
- **Example: Transient Race Engine**
- **Summary**

# Implementation

## ncreased System Support

- **Robust Data Network**
  - Automated Data Storage and Analysis
  - Different Test-Beds
  - In-House / EP
  - Combustion Systems
  - Calibration Tools
- **Numerous Data Types**
- **Increased Data Parameters**
  - Greater Data Storage Needs
- **Solution**
  - Identify Customer Test Needs
  - Data Generation Quantities
  - Robust Data Transfer and Back-up Process

# Implementation

- **Increased Data Generation Affects Customer Operation**

| | | |
|---|---|---|
| • More Data Generation | - | More Data Analysis Time |
| • Facility Utilization Affected | - | Operation Time Reduced |
| • Greater Test Planning Required | - | Maximise Test Efficiency |
| | - | Achieve Challenging FPDS Timings |

## Increased Technology Offers Increased Challenges

- Support Areas / Customers must have capable personnel
- Greater Integration / Appreciation of Test Objectives
- Greater Understanding of Facility Capabilities / Limitations
- Inefficient Utilization - Lost Test Time
  - Wasted Investment in Expensive Facilities

# Implementation

- **New Facility / Test Needs Require Communicating**

- **Up-Front Communications**
  - **Generate Technical Solutions**
  - **Develop Investment Plan**
  - **Meet Timings / Support Programs**

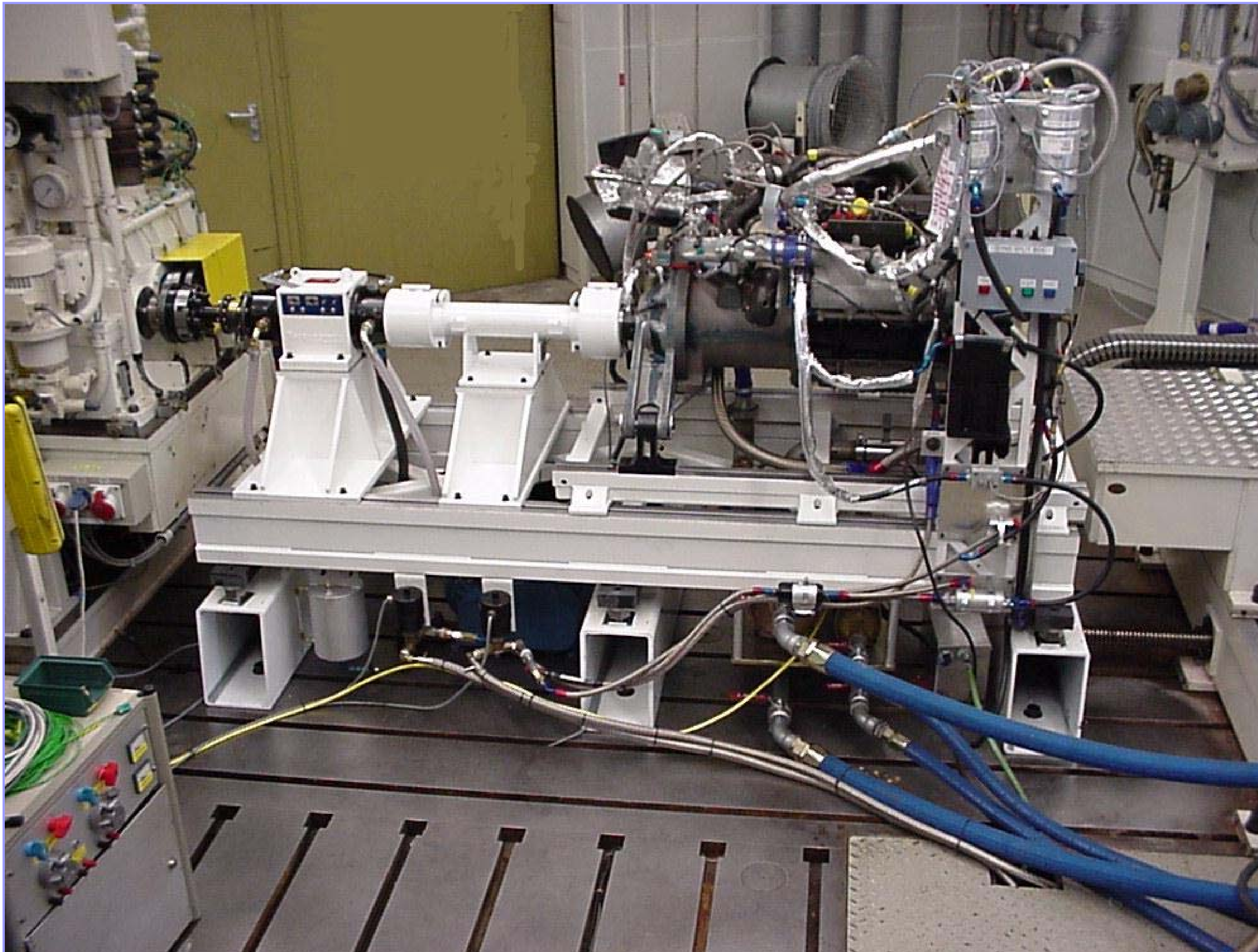
## New Test Methodologies

- **Move to Statistical Testing**
  - **Use of Designed Experiments DOE to minimise data collection sweeps and surfaces (applied successfully to DISI)**
  - **Sample Size selection & Confidence Interval usage**
  - **MapView as standard modelling tool. CAGE to fit model to different strategies**

# New Technology Demands

- Increased Systems Support
- Increased Data Generation impact on Customer
- Improved knowledge of systems and measurement
- Improved communication
- New test methodology

# Transient Race Engine



# Focus WRC Engine - 2002

**Ford 2.0-ltr Cosworth Duratec R engine. Four cylinders, 16 valves. Ford electronic engine management system. Garrett TR30R water cooled turbocharger. FIA required 34 mm inlet restrictor Air/air intercooler + external water spray. Catalytic converter.**

**Expected Performance**

| | |
|---|---|
| **Power** | **300 bhp at 6500 rpm** |
| **Torque** | **550 Nm at 4000 rpm** |

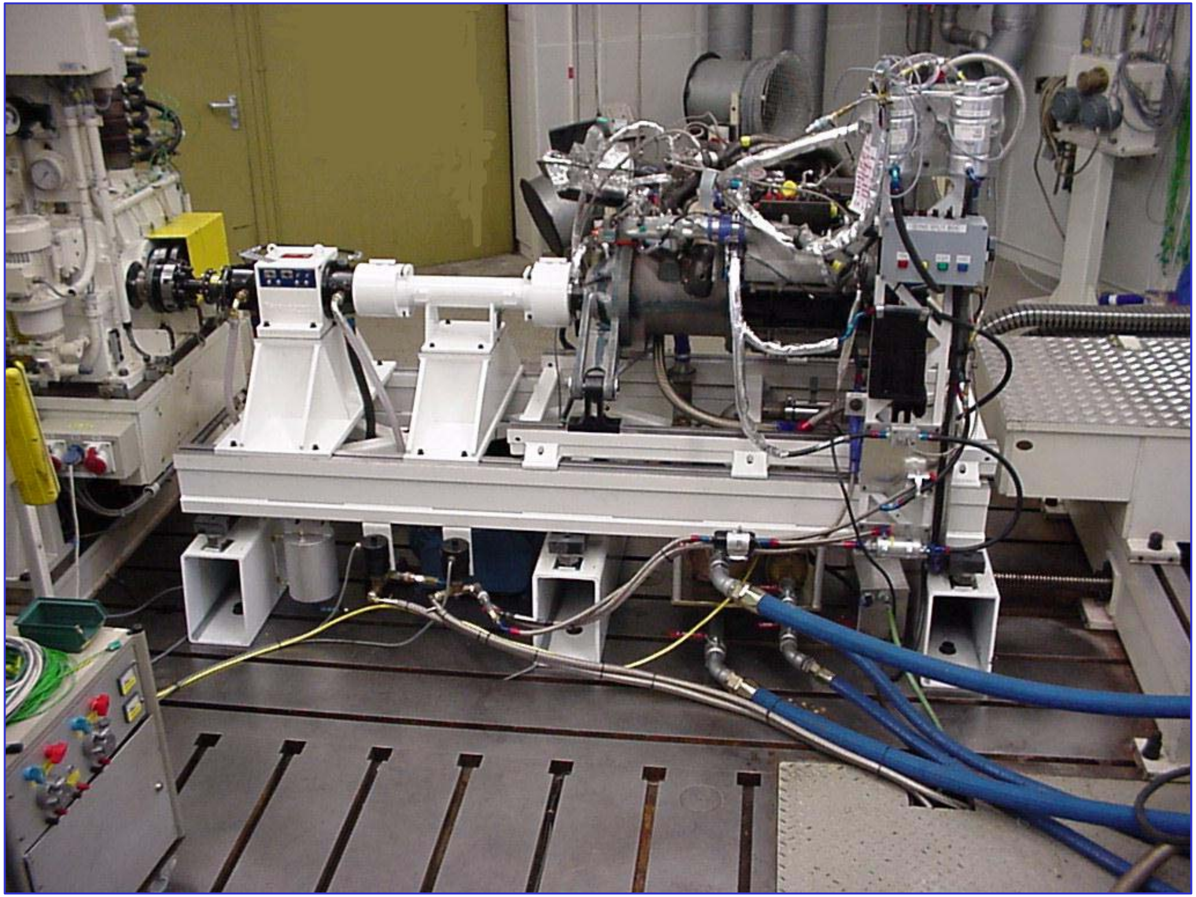
**Focus 2.0-ltr Zetec-E N/A comparison**

| | |
|---|---|
| **Power** | **130 ps at 5750 rpm** |
| **Torque** | **178 Nm at 4500 rpm** |

- **Cosworth Duratec R engine is an evolutionary development of last year's power unit. In 2001 the Evo 2 version of the Duratec R introduced at San Remo, with revised cylinder head and camshafts. That engine showed a marked performance upgrade, with good useable power from 3,500 revs, combined with excellent reliability. From Finland onwards to season end, Ford had a good clear run without a single engine-related problem. The goal for 2002 was a tough one, to make an even better performing, but lighter engine with no loss of reliability.**

- **References:** www.fordracing.net, www.fordrallysport.com, www.fordracing.com

# Dynamometer Significant Features



Max. Speed 10.000 rpm

Max. Torque 1.000 Nm

Speed Gradient 10.000 rpm/sec

Fuel 180Ltr/h

Cooling 600 kW

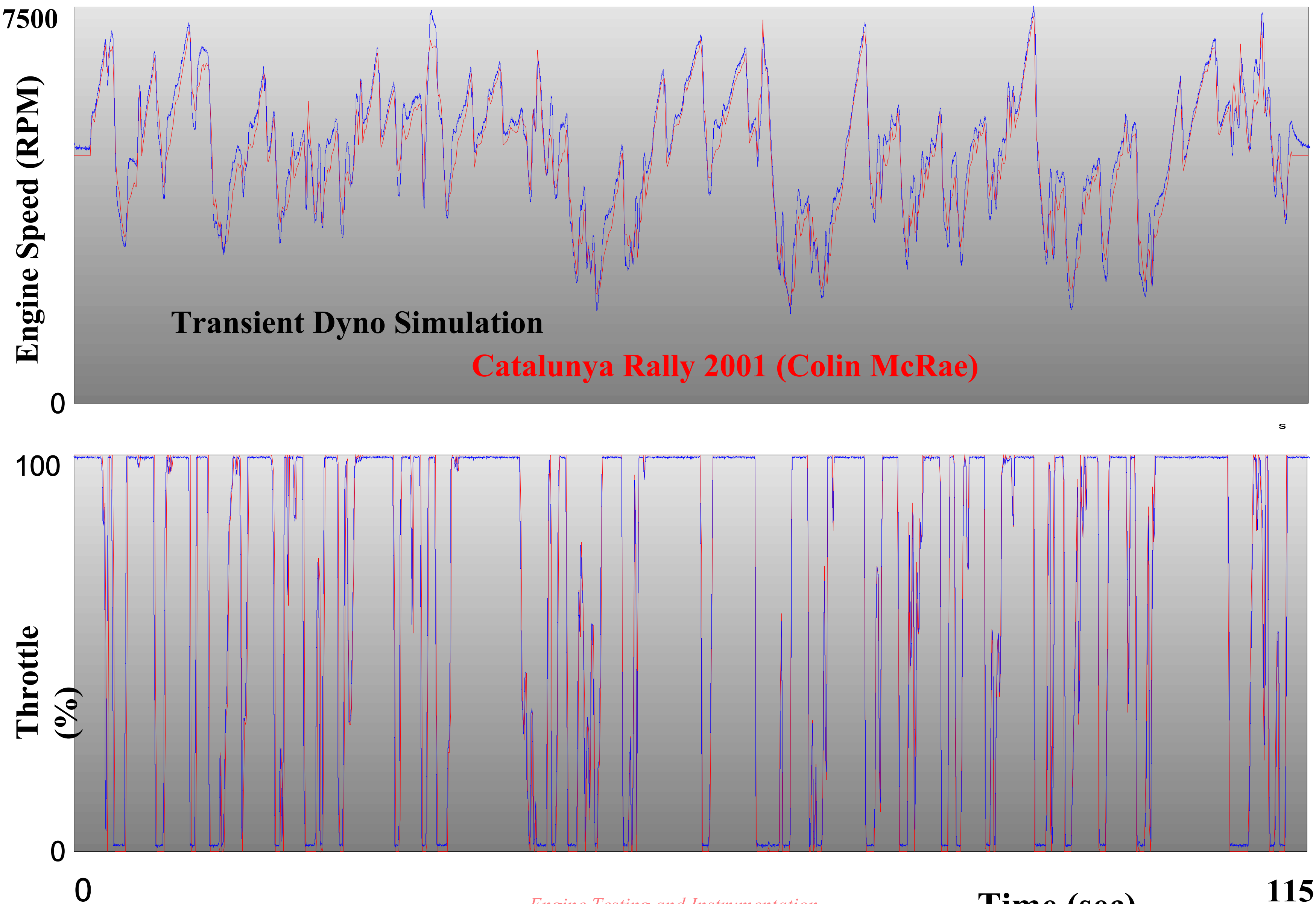
Cycle Simulation 10 Hz

Std. Data Acquisition [96 Channels, 50 Hz]

High Speed Data Acquisition [16 Channels 50 kHz, 6 Speed Channels 10 GHz]

Cylinder Pressure Indication [4 Channels 0.05 Deg. Crank angle]

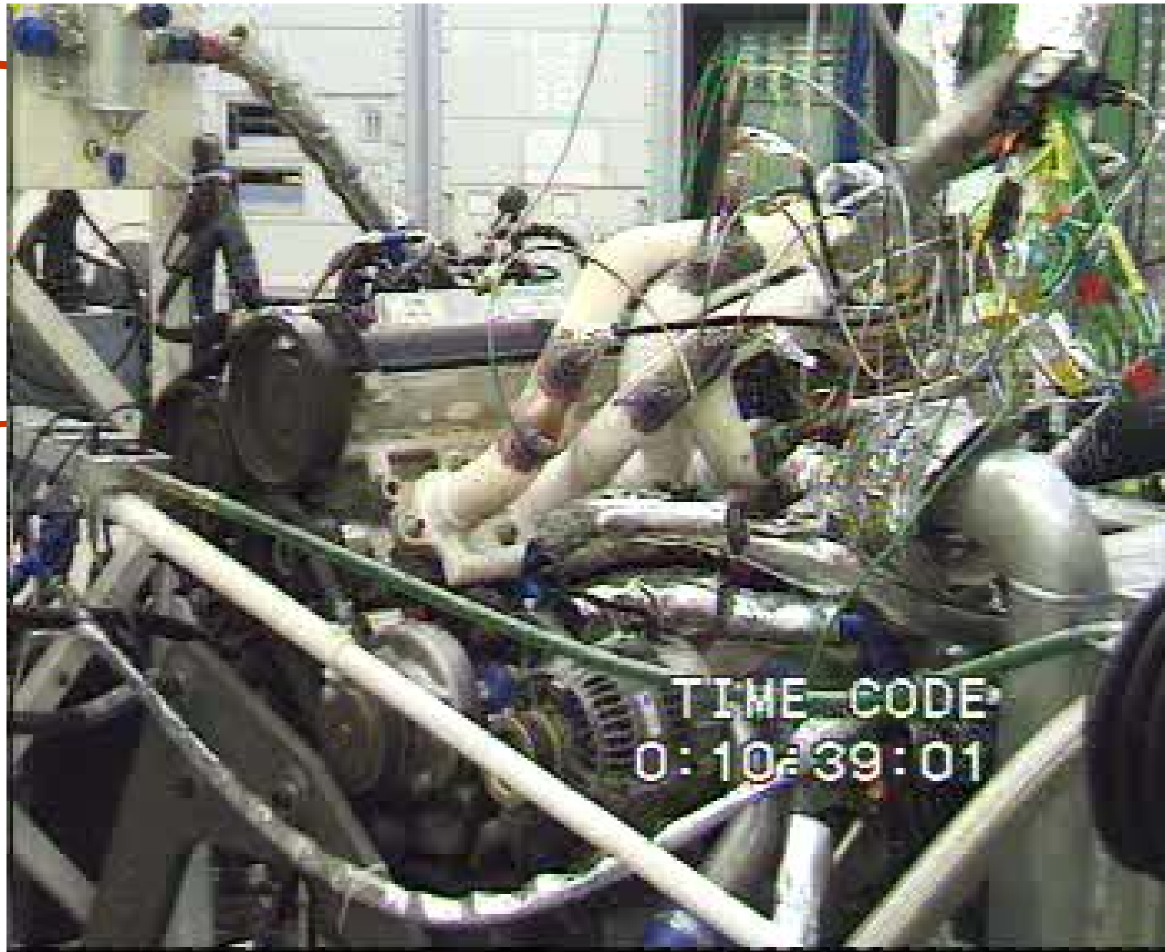
# Transient Test Cycle



# Dynamometer Engine Test

Emission Analyser

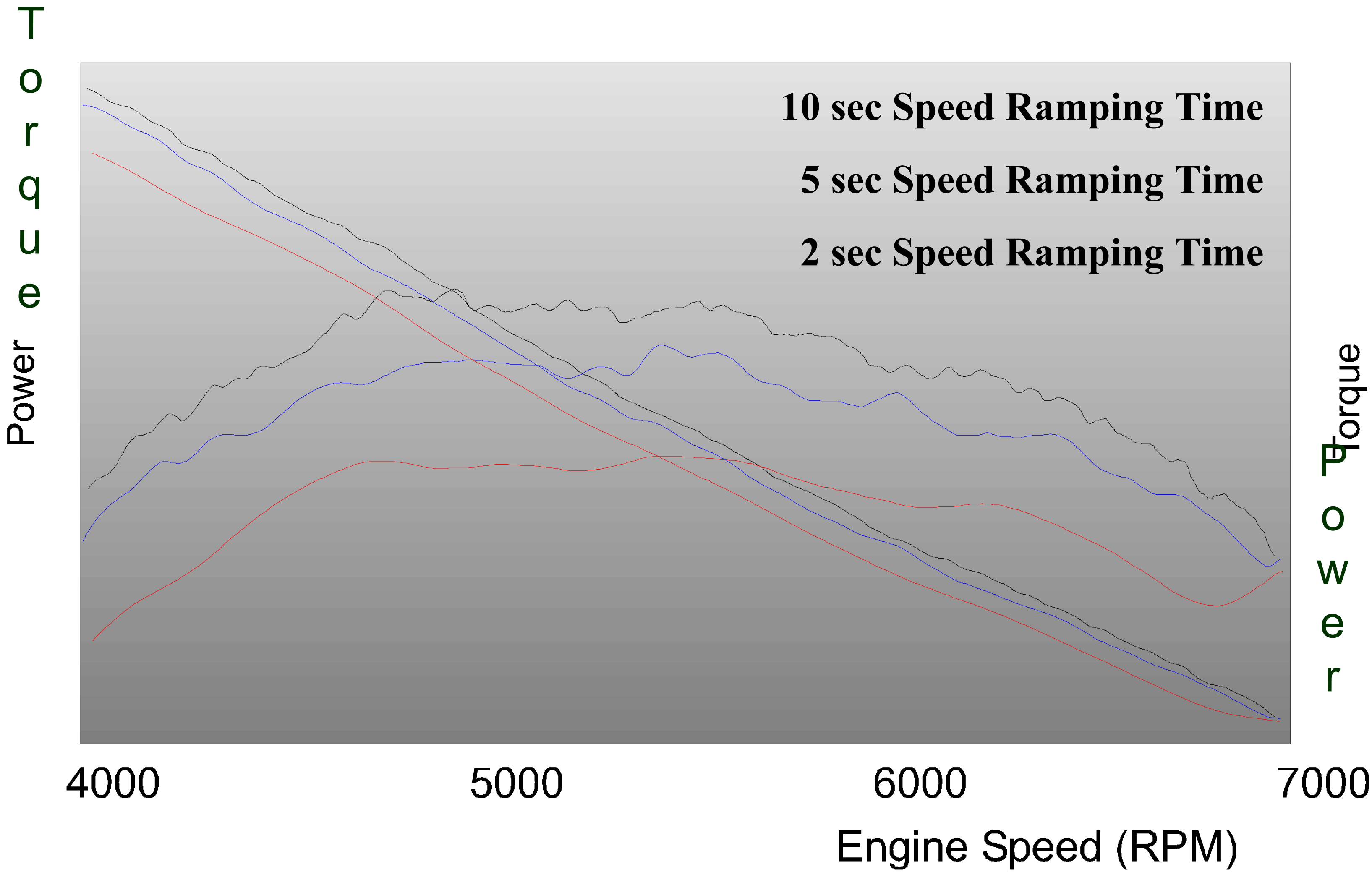
Throttle Control



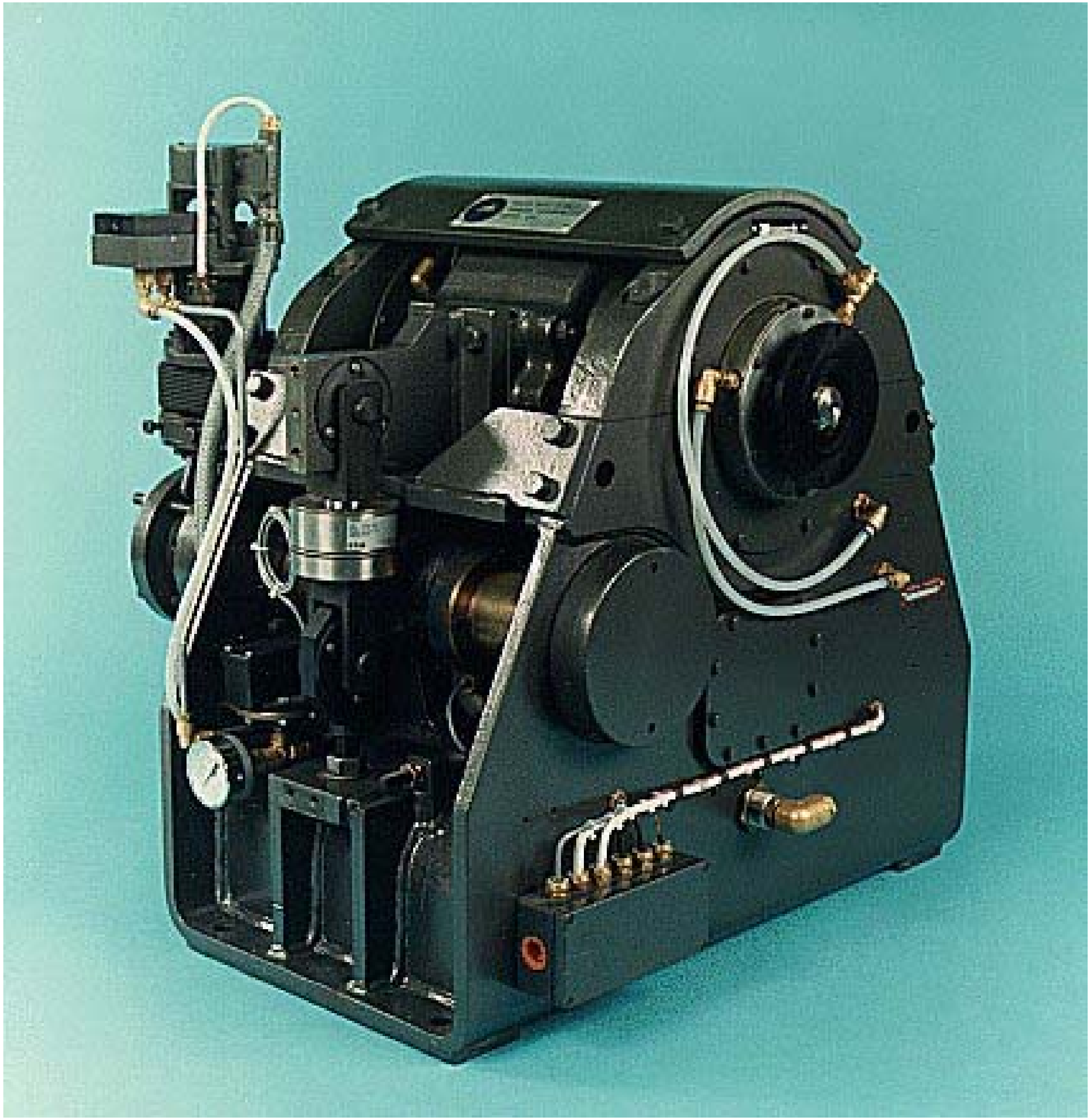

Turbo Charge

Exhaust

# Transient Performance Testing



# Schenk W series eddy current



**Froude Consine**

High performance dynamometer

18,000 rev/min

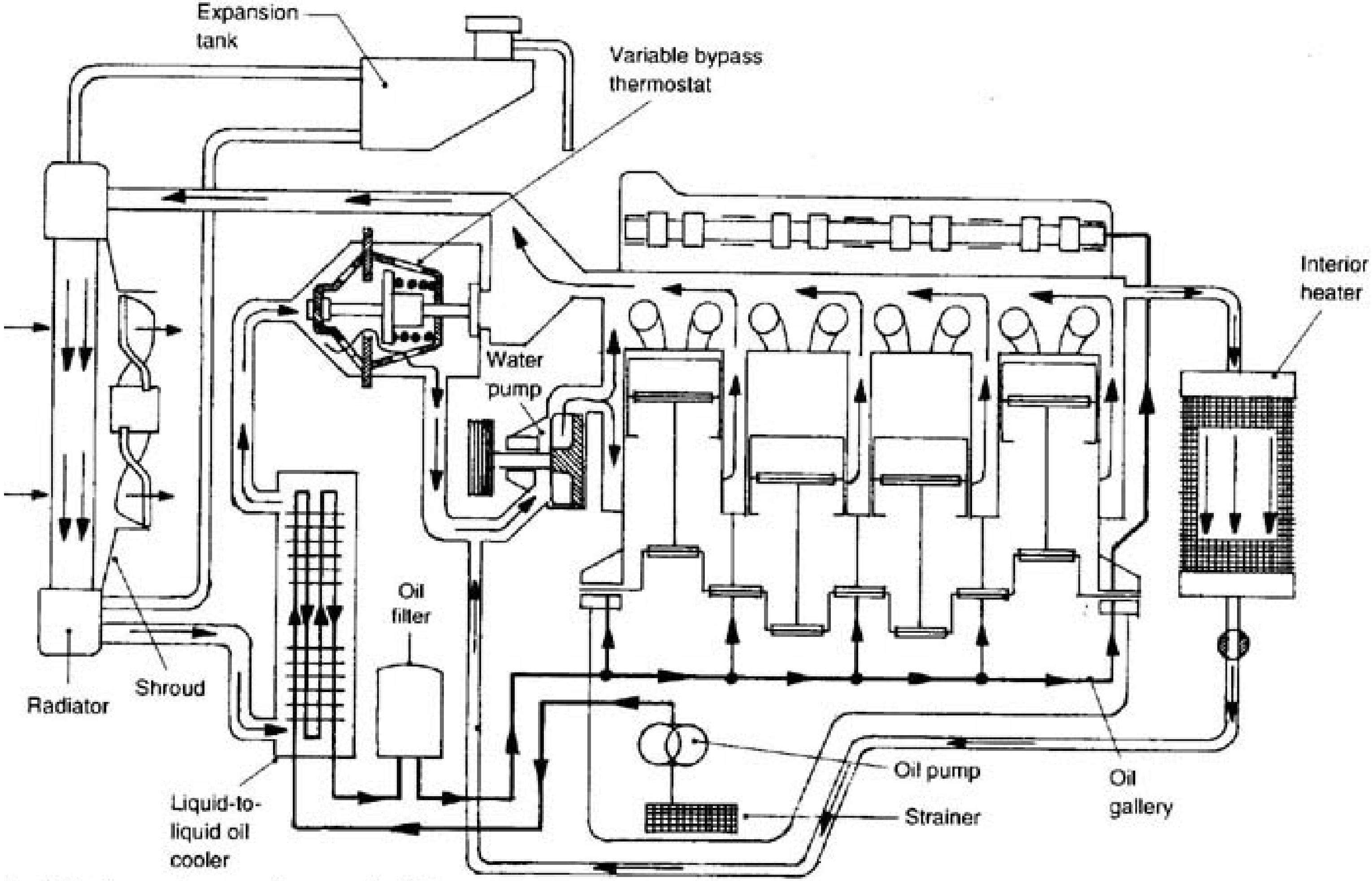
1,000 BHP

Continuously rated

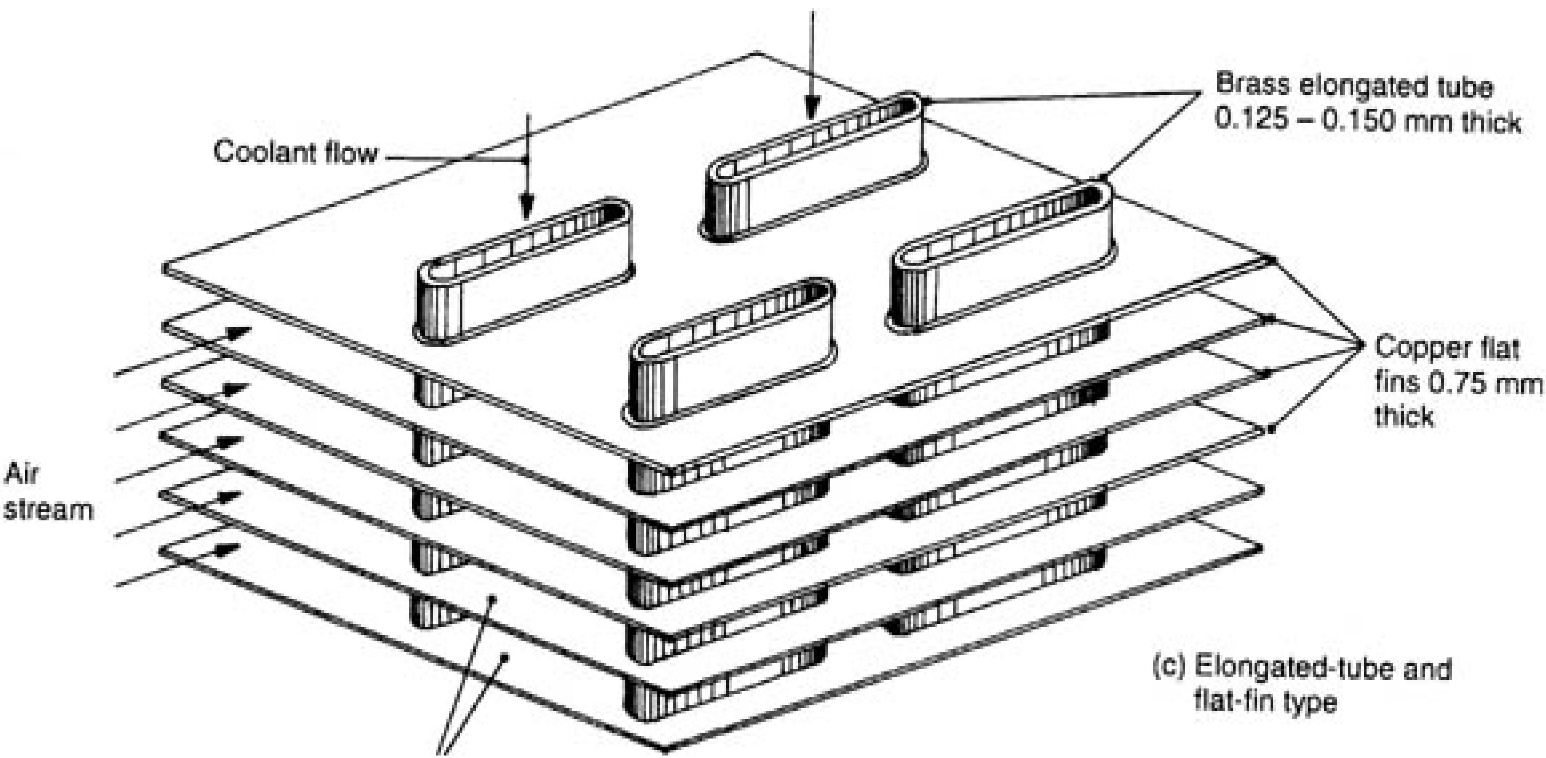
Oil mist lubrication

Shaft Inertia, bursting speed ?

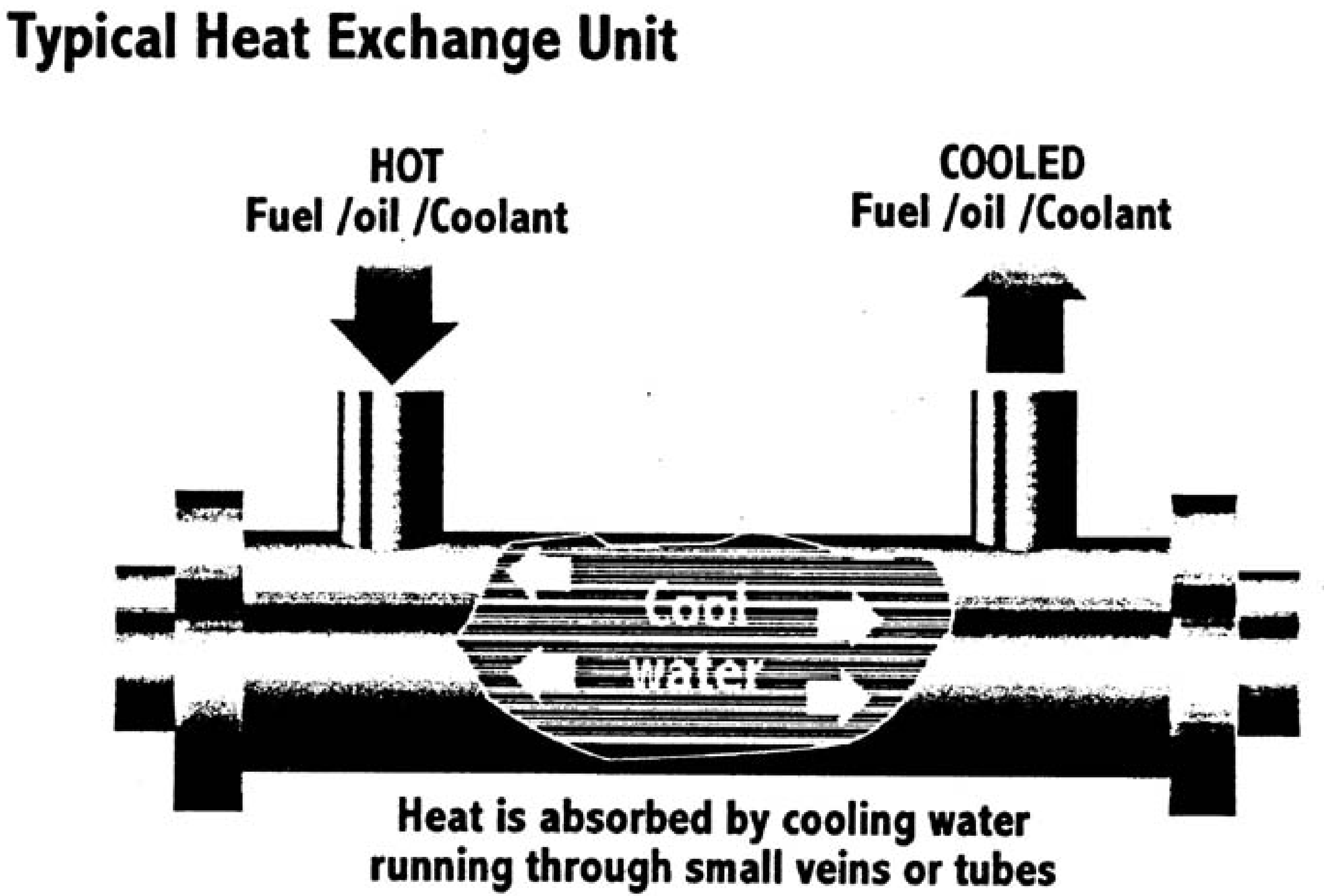
# Coolant and Lubrication engine systems



# Elongated tube- flat fin heat exchanger



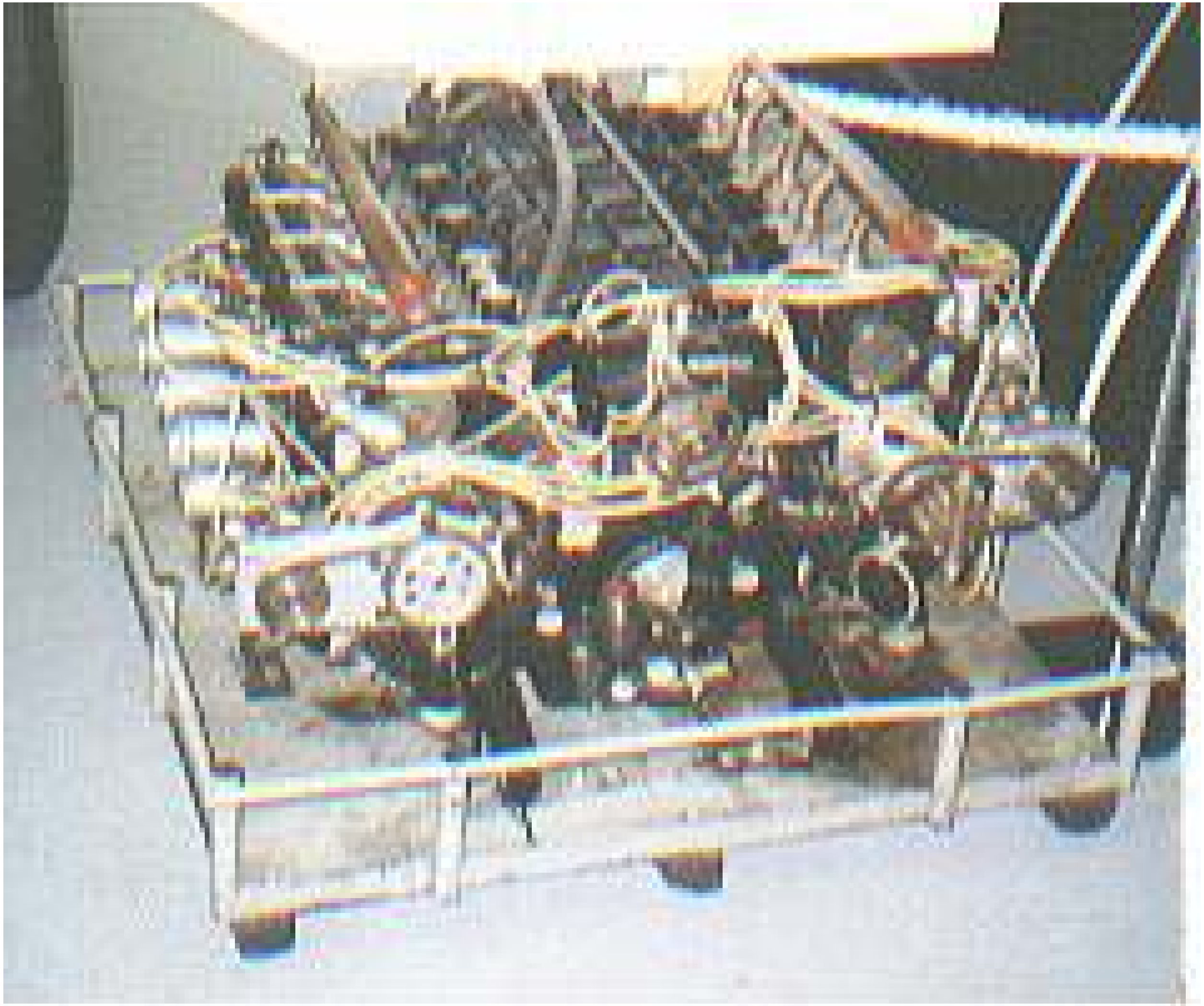
# Core tube heat exchanger Bowman type



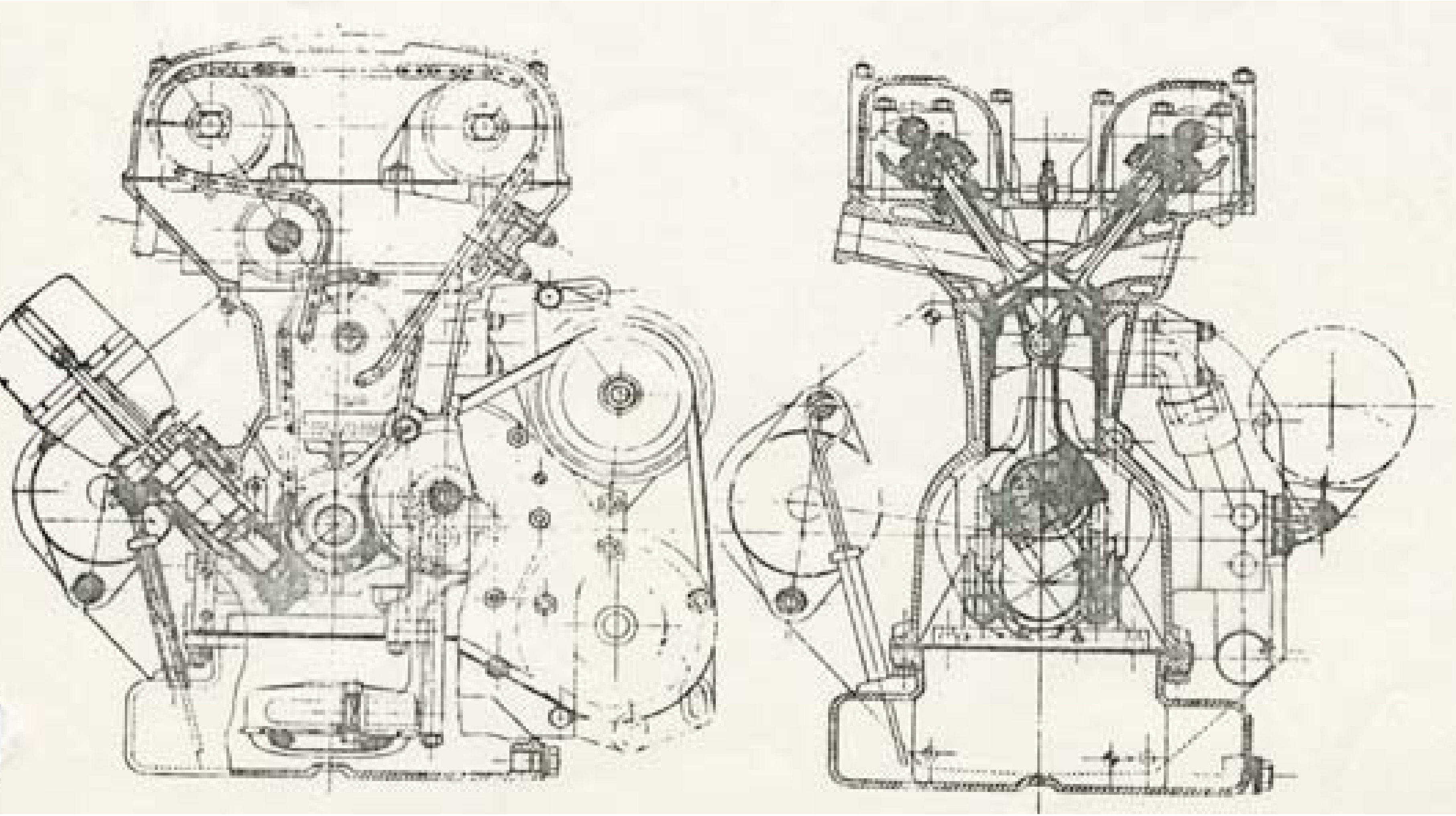
# The Technology of testing

- From their concept Formula 1 engines have idiosyncrasy which present unique challenges and  problems when they are tested on a dynamometer.
- Traditional testing methods are no longer sufficient
- The development of the dynamometer has an important part to play

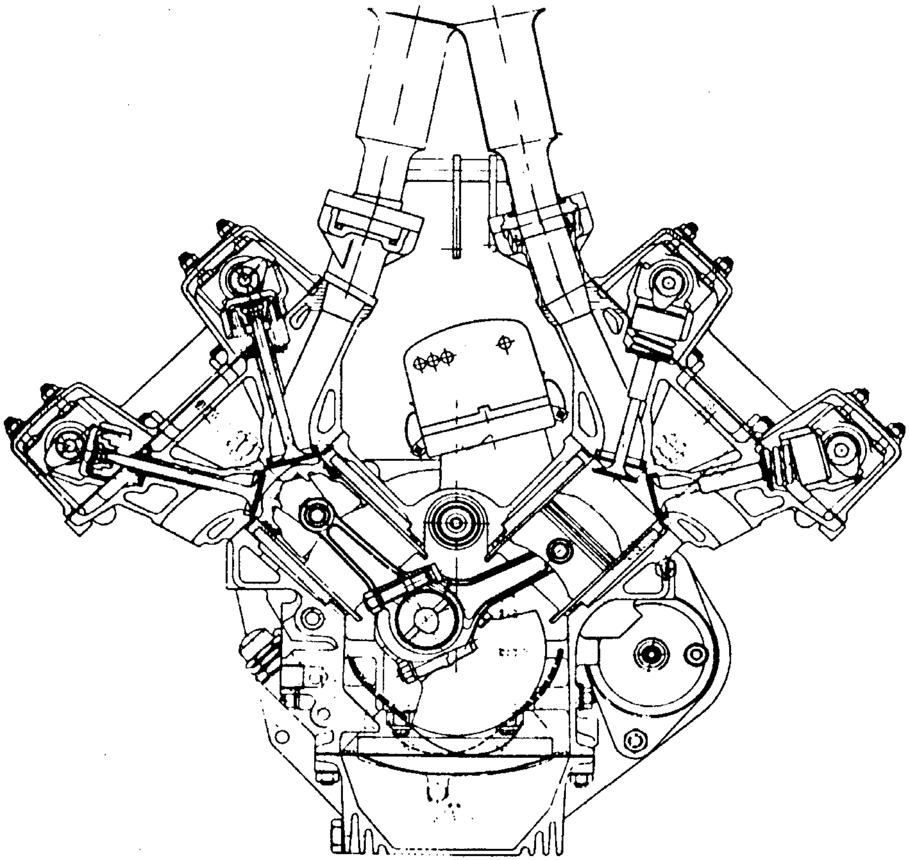
# Engines more complex higher output BRM H16



# Coventry Climax FWMC 742 cc
# 82.5 BHPc @ 8500 rev/min



# Formula 1 engine 1963/65
# Coventry Climax  1,497 cc



217 BHPc @ 10,750 rev/min

204 BMEP psi @ 7,750

190 + BMEP from 7,000 to 10,500 rev/min

# The challenges today

- The engines of today are a very different animal
- Very high specific output > 300 bhp/litre
- Very high rotation speed ~ 17,000 rev/min
- Very Light weight < 145 kgs
- Very high cost
- Very short life ~ race distance between re-builds about 500 kms.

# Use new technology

- Extra running time spent on a test bed  will shorten the engines useful life at the track.
- Test rapidity is required
- Instrumentation is critical and must be accurate, a 1% change in out put of a formula 1 engine is significant, and a 2% improvement is a major breakthrough !

## Powertrain By Simulation

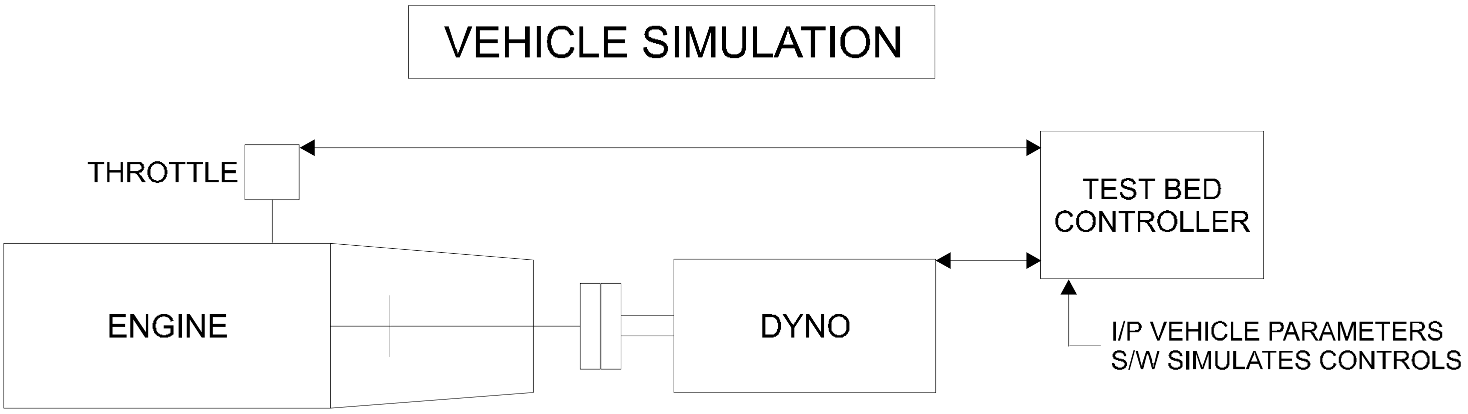
### Facility requirements

- **Main Features**
- - Fully Automated Test-Bed Controller
- - Rapid Response Motoring Dyno
- - High Speed Throttle
- - Full Emission Measurement
- - Extensive Equipment Interfaces, Measurement, Control Capability

**Usage / Capability**

- Full Vehicle Equivalent Drive Capability (Full Simulation)
- Generate Full Engine-Map Calibration under Controlled Conditions
- Dyno and Control System become the Simulated Vehicle

# Powertrain By Simulation Facility




- **Vehicle Parameters**
- **- Vehicle, Flywheel, Clutch Masses**
- **- Road Load Conditions for given Vehicle**
- **- Gear Ratios / Efficiencies (Manual and Auto)**
  - **Driver Characteristics**
  - **Simulated Throttle and Clutch Gear Change Operation**

# Powertrain By Simulation Facility

- **Dynamic Operation**

- Test-Bed S/W calculates "Vehicle" Loadings Real Time

- Operates Throttle Actuator with Loading Changes to Simulate Clutch Operation / Gear Changes

- Drive-Away, 1st to 2nd, 2nd to 3rd, 3rd to 4th, etc

- Enables Drive Cycle Capability FTP, MVEURO, Customer Specific

- - Develop Calibration as In-Vehicle

- Measure Vehicle Equivalent O/P's (Drive Cycle Emissions, Fuel Economy Performance)

- - Reduced Vehicle Dependency to Achieve Full Calibration

# Full Powertrain Test Facility

- **Dynamic Operation**

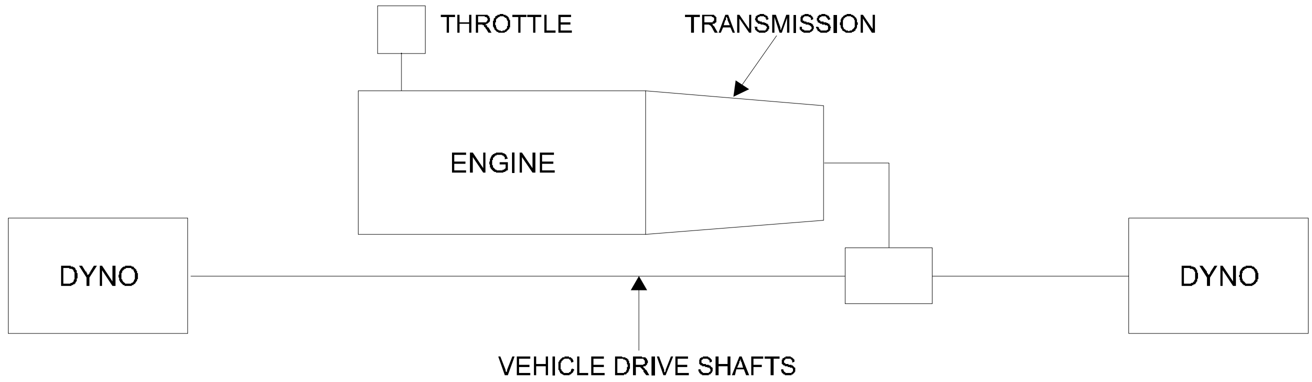
- **Simulates Total Vehicle except Engine and Flywheel**
- **Hardware not required**

- **Powertrain Operation**

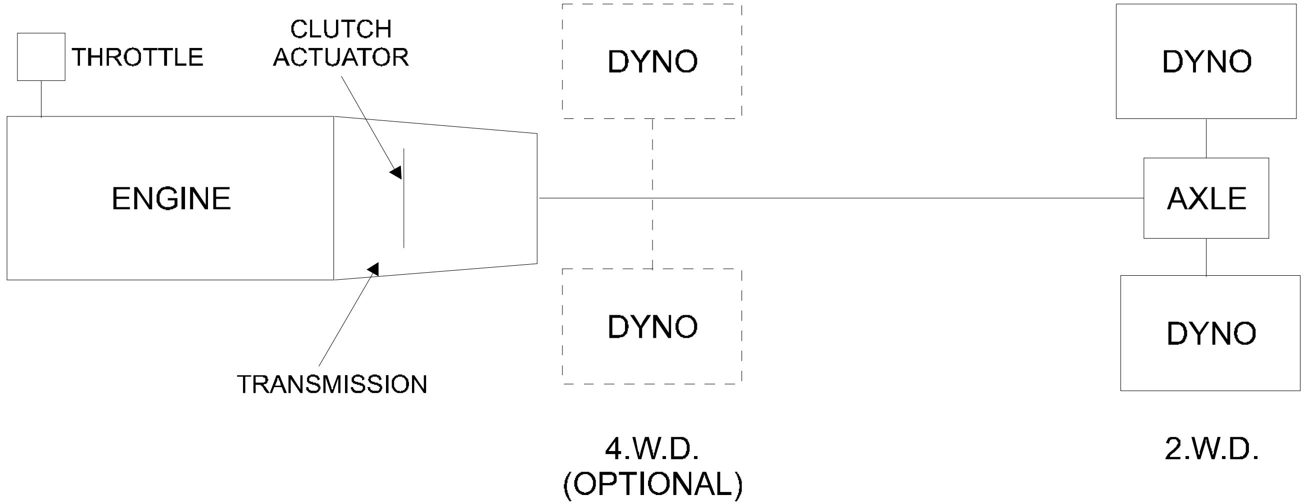
  - **Gearbox and Driveline Hardware required**
  - **Simulation S/W not as "Powerful" as Full Dynamic Control**
  - **RLC and Driver Characteristics still required**

# Full Powertrain Test Facility

FWD




RWD



# Facility & Powertrain Development Requirements

- **Test-Bed Types**
  - Steady State
  - Transient
  - Powertrain By Simulation / Dynamic
  - Full Powertrain

**Adaptable to Support Differing Phases of Development Process**

- Facility Type provides Desired Capability
- Upgradeable at Minimum Cost, Equipment
- Flexibility to support increased Customer Test Requirements