The BMC Engineering Companion

By

Tony Cripps

Contents

Preface

In modern times, BMC/Leyland cars are classic vehicles of a bygone era, and as such, require specialist knowledge for their upkeep. Most practitioners rely on the official workshop manuals and parts lists for repair and service information. I am of the view that although very useful, it is often very advantageous to know more about how various systems work in order to get the most from them.

This book presents what looks at first sight like the usual array of topics which make up a workshop manual, but each chapter is something a bit unusual. In each section, an engineering discussion is presented followed by some practical examples that relate to BMC/ Leyland Australia vehicles. I hope the engineering content adds another dimension to your ownership and appreciation of BMC/Leyland vehicles.

I wish you happy reading.

Tony Cripps

About the Author

Tony Cripps has a Certificate in Automotive Engineering from Sydney Technical College, a Bachelor of Applied Science from the University of Technology, Sydney, (UTS), and a PhD from the University of Sydney. He has worked as a technical officer at the ex-Leyland Australia vehicle emissions laboratory at Victoria Park; a technical officer and lecturer at UTS, and a visiting scientist at the National Bureau of Standards in Washington DC. He achieved the rank of Senior Principal Research Scientist at the CSIRO Division of Applied Physics followed by 12 years conducting his own scientific instrumentation business. Tony is the author of several books in the fields of materials science, physics, and engineering.

Acknowledgements

The kind contributions made by my friends and colleagues, particularly Peter Davis (dec), Ron Moss (dec), Bruce Elson are greatly appreciated. Much of the information presented here was taught as part of the Sydney Technical College Automotive Engineering Certificate course whose champion was Mr Brian Le Grice. He and his colleagues, by virtue of their expert tuition, provided a unique and lifelong asset for their grateful students.

Actual manufacture proceeded via the use of planning documents prepared by Planning Engineering whose responsibilities were:

- Factory Layout
- Tooling Required
- Build Sequence
- Source of Components
- Routing of Components

Then, there is a multitude of other documents prepared later that allow the vehicles to be serviced, such as Workshop Manuals, Service Parts Lists with associated Parts Amendment Advice, Technical Bulletins, Product Problem Advice, Service Liaison Summaries, Product Fault Summaries etc.

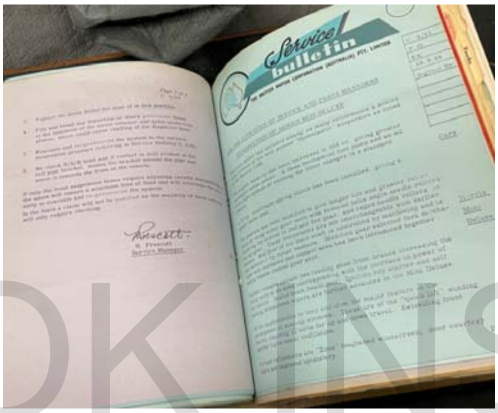

Fig. 1.1.7 *Technical Bulletins*.

The Service Parts Lists/Parts Catalogues are not catalogues for what was fitted in production (although they are often used by us now for reference purposes). Service Parts Lists were published by the Parts and Accessories Division (P&A). P&A did, however, have a copy of a subset of the Product Engineering drawings and the P&A drawings set are still in existence. In many cases, P&A arranged manufacture of the part with an outside supplier different to that which supplied production line items. The Service Parts Lists show “replacement parts”.

1.2 Vehicle Identification

1.2.1 Introduction

With the increasing values of classic cars, the issue of vehicle identification has now become more important than ever. The value of a particular vehicle can be influenced by thousands of dollars depending on its degree of originality. A knowledge of what was actually fitted to a vehicle at the factory is an essential ingredient in establishing market value. In this Section, the Mini and Moke range of vehicles is used as an example of the way in which Product Engineering identified production vehicles.

For some years now, there have been published listings of identification details for the Mini and Moke range of vehicles based upon observations made of Identification Plates, Compliance Plates, A similar mistake occurs with YDO22. These vehicles should be stamped 022X2S1M10. Why “1” you say? Because originally (before the Leyland Mini SS, Sunshine and LS models) there was only one level of trim for YDO22 and even though it was more luxurious than that fitted to YDO21, for the YDO22 model, it was the lowest (and only) level of trim available. But, someone got things mixed up and stamped these cars 022X2S2M10 which often goes un-noticed because one thinks that the “2” signifies the more luxurious Leyland Mini S compared to the basic standard Leyland Mini. This is incorrect. YDO21 and YDO22, despite their obvious similarities, are different models. The trim level applies *to that model only*, and so a Leyland Mini S, should be stamped 022X2S1M10.

In later years, a Leyland Mini Sunshine would be stamped 2S2, a Leyland Mini SS would be stamped 2S3, and a Leyland Mini LS, 2S4 which follows the correct procedure. Confusingly, at Enfield, someone caught on to these mistakes and Leyland Mini S started being stamped 2S1 which by coincidence, happened about the same time as the introduction of the UK CBU 998 power units, which by a further coincidence corresponded soon after the move of manufacturing to Enfield and a change of Quality Control manager.

1.2.10 The Leyland UK 8 Digit Code

From March 1978, Leyland Australia used the UK-assigned 8 Digit Prefix Code. It should be noted at the outset that Australia was not part of the European Economic Community and therefore was not required to have vehicles stamped with a VIN number. A VIN number is a 17 digit code in total. The code used by Leyland Australia does not include all the VIN fields and it is not precisely a VIN number - although it is referred to as such in company literature. The 8 Digit Code – for the fields in encompasses – is, however, similar to the VIN standard as used in UK.

Identifier	Symbol	Interpretation
Model Code (Marque)	XN AK	Leyland Mini Leyland Moke
Model Class	F H P	High Line Mid Line Low Line
Body Style	A F P	Saloon 2 Door Van 2 Door Buckboard (Moke)
Engine Capacity	B D	A Series 998cc A Series 1275cc
Transmission/Drive	1 2	Manual, 4 Speed, RHD Manual, 4 Speed, LHD
Year of Model Introduction	8 9	1978 1979
Country of Origin	Y	Australia
Car Serial No.	Numeric	Commencing at 100001

Table 11.2.5 *Leyland UK 8 Digit code.*

1.3 Power Unit Identification

1.3.1 Introduction

A variety of power units with differing engine capacities, transmission specifications, final drive and other mechanical items are fitted to the BMC range. The coding used for power unit identification changed over the years as it became necessary to distinguish the ever-increasing complexity of vehicle specifications.

In general, for the Mini and Moke range, there are four basic types of Engine Prefix Codes:

1.4 Vehicle Identification Standards

1.4.1 Introduction

The Product Engineering Department in Australia was responsible for vehicle identification and the specifications for the procedures are documented in Standards published internally for company use.

Naturally, these Standards are modelled closely on those issued by UK Engineering Departments but there were some departures for local conditions. For example, individual YDO vehicle identification numbers were issued by the Australian department, as well as the 10 digit Leyland Australia Type Code.

Many of these Standards still exist and are an excellent resource for historians interested in vehicle identification at BMC and Leyland Australia.

1.4.2 Engineering Standards (Australia)

Part 1 of this Standard deals with Product Engineering standard procedures and includes Vehicle Identification as well as Parts Lists; Part Numbering System; internal Production documents such as Engineering Release Notes, Stop Orders, and Process Specifications.

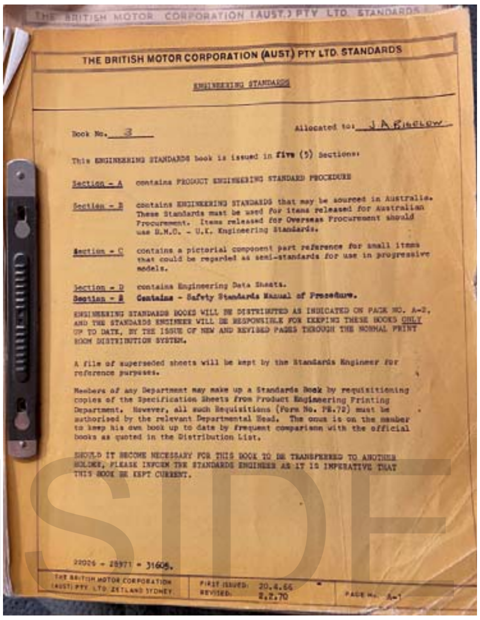

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Fig. 1.4.1 *Front page of BMC (Australia) Engineering Standards issued 1966.*

1.4.3 Engineering Technical Data

Engineering Technical Data sheets are a detailed listing of specifications, both body and mechanical, for each model produced. They represent a complete description of basic specifications, additional items, special production orders, for individual models.

1.4.4 Standard Procedure Instructions

Standard Procedure Instructions give many details about Company operations from an upper management perspective and include details of major changes to Vehicle Identification schemes, such as the introduction of the 10 digit code.

1.4.5 Service Documentation

Service Liaison Summaries, Drawing Office Instructions, Service Bulletins, Technical Bulletins, Product Problem Advice, Product Fault Summaries, Service Parts Lists, and Workshop Manuals also give details of Vehicle Identification from different perspectives which help detail changes to vehicle specification as production proceeded.

1.4.6 UK Standards

In early years, Product Engineering in Australia relied heavily on established UK practice. During the 1960s and 1970s, the Australian Product Engineering department was somewhat autonomous. Somewhat ironically, towards the end of Australian production, the reliance on UK standards returned with the introduction of world-wide model type codes and engine numbering systems. UK Standards were issued by British Leyland Standards Department, Longbridge, in Birmingham UK.


POWER UNIT SERIAL NUMBERS.

SECOND PREFIX GROUP

THIRD GROUP

Fig. 1.4.2 *British Leyland Standards (Longbridge) 1968*.

1.5 Production Numbers

1.5.1 Introduction

Of particular interest to Mini and Moke enthusiasts is the question of how many of each model were built. This is a difficult question to answer, and one which engenders considerable acrimonious debate amongst enthusiasts.

1.5.2 Mini

In this section, a different approach to that taken by others is presented where actual factory figures are referred to as they have been discovered. Not all models can be treated in this way because some data has been aggregated before being tabulated in factory documents, but an overall picture can be gained.

For the Morris Mini range, there is excellent data available from the personal records made by Major John Frew. Frew was known to G.A. Lloyd and after his rather extensive and traumatic war experience, Lloyd told Service Manager Tom Poole to find Frew a job at the factory. Included in a wealth of technical documentation he amassed, Frew personally recorded the Type Code, Car No, and Engine No. for all production cars at the beginning of each year starting in 1955. He retired from BMC in the early 1970s.

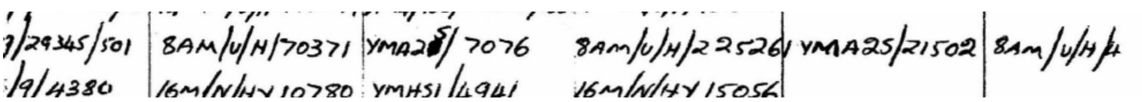


Fig. 1.5.1 *Sample of John Frew's hand-written record showing first production ADO15*.

CHAPTER 2.
POWER UNIT

2.1 Introduction

2.1.1 The Mechanics of Machines

2.1.1.1 The Four-Bar Mechanism

A machine is a combination of solid bodies with constrained relative motions which is used for transmitting or transforming available energy for the purpose of doing work. The components of a machine, the mechanism, are in their simplest form, a series of bars linked together.

A bar is constrained by being paired with another bar. The pairing might take the form of a pin joint, or a sliding joint, or a line contact. Some examples of the derivatives of a four-bar kinematic chain are shown in Fig. 2.1.1.

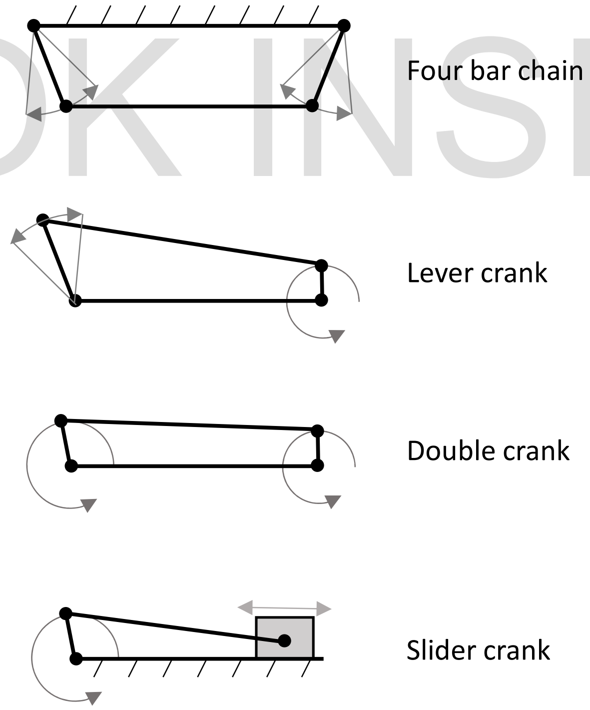


Fig. 2.1.1 *Examples of the derivatives of a four-bar chain*.

The four-bar chain is a fundamental mechanism from which all others can be derived. If any link has rotary motion, it is called a "crank". If any link has oscillatory motion, it is called a "lever". Thus, a simple four-bar chain can be one that is found on the steering mechanism of a motor vehicle. Lever-crank mechanisms can be found in the wiper motor mechanism. A double-crank

The area enclosed by the main working cycle is the net mechanical work output, while that enclosed by the pumping cycle represents a mechanical loss. Similar in concept to the mean effective pressure, the brake mean effective pressure is that constant pressure that would be applied to the piston on the power stroke that gives the same energy output, that is, the area enclosed by the p-V diagram. The values for b.m.e.p. are often to be found on an engine performance graph such as that shown in Fig. 2.8.1.

2.1.4 Brake Power

When the output of an engine is to be measured, it is operated under load in a dynamometer. The dynamometer applies a measurable load to the output of the engine. The load can be in the form of a friction brake, a water brake, or even an eddy current electrical brake. The important point is that the engine is braked in some manner.

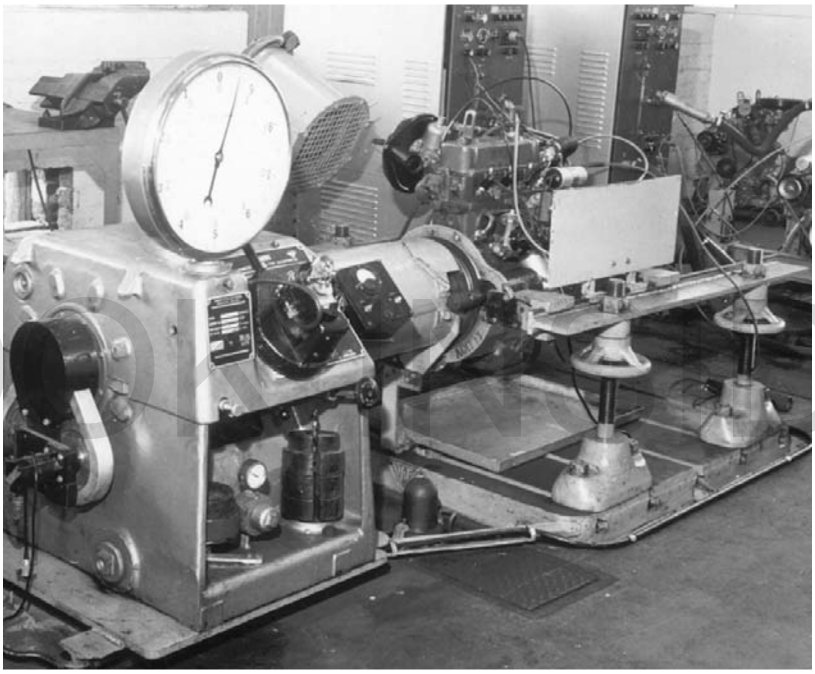


Fig. 2.1.7 *B series engine on engine dynamometer*.

The measured output power from the dynamometer is thus termed the brake power. Most often, the values are given in horsepower, hence the term “bhp”. 1hp = 0.746 kW.

2.2 Efficiency

2.2.1 Thermal Efficiency

Thermal efficiency is the percentage of mechanical work produced as an output relative to the energy input (in this case, the energy released by combustion of the fuel, which is specified by the fuel’s calorific value). The calorific value of petrol is about 45 MJ/kg.

$$Q = V_m \frac{\pi B^2}{4}$$

The same volume flow rate is to be passed through the valve of diameter *d*. Thus,

$$43\left(\pi \frac{d^2}{4}\right) = V_m \frac{\pi B^2}{4} = \frac{(2S \times 10^{-3})N}{60}\left(\frac{\pi B^2}{4}\right)$$

Adjusting for changes from m to mm, the optimum valve throat diameter is shown to be:

$$d = \sqrt{\frac{SND^2}{1290000}}$$

where *N* is the rpm, and all distances *S*, *N* and *D* are in mm.

Usually, the valve opening and closing positions for the inlet and exhaust valves must overlap. This allows some time for the full flow area around each valve to be established, and it is the design of the camshaft that reflects this requirement.

Volumetric efficiency is usually of the order of 80% at full throttle. In practice, motor vehicles are seldom driven at full throttle, and so at part throttle, the volumetric efficiency during normal motoring is quite low.

2.2.4 Mechanical Efficiency

Mechanical efficiency is the ratio of the power actually delivered by the engine to the power developed inside the cylinders as a result of actual combustion.

More formally, it is the ratio of the brake power (as measured by a brake on an engine dynamometer) to the indicated power (as indicated by the enclosed area on a pressure/volume graph).

Mechanical efficiency is usually of the order of 80% and losses arise mainly due to friction (piston rings, bearings, etc), the viscosity of the engine oil, gearbox friction, fan, water pump and charging systems, power steering, etc. Pumping losses associated with intake and exhaust are also causes of loss of mechanical efficiency.

2.3 Combustion Chamber

The influence on efficiency on the compression ratio, and its connection with the octane rating of the fuel, brings into focus the importance of the combustion chamber volume.

In practice, the combustion chamber volume can be measured with a pipette. But the combustion chamber volume is not the compressed volume – that is, the volume of the space above the piston at TDC.

The compression ratio is found from the total volume above the piston at bottom dead centre divided by the total volume above the piston at top dead centre. If we take the swept volume (SV) to be that swept out by the piston from BDC to TDC, and if CV is the compressed volume, then:

Australian engineers found that the UK style of rear mount for this vehicle failed due to the heat from the engine block affecting the rubber to metal bond. Initially, an insulating asbestos spacer was made available, and then a short time later, the "outrigger" style mountings were devised.

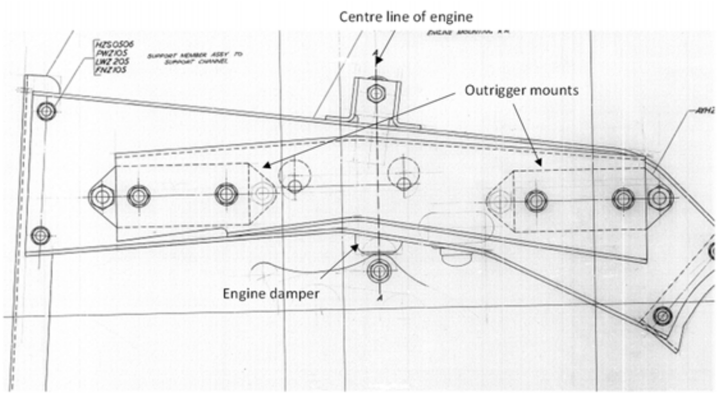


Fig. 2.4.2 *Outrigger engine mounts, Austin 1800, ADO17*.

Although the outrigger style mountings removed the rubber parts out away from the block, they also moved the mountings out from the centre line to almost the same distance as the front mountings and so any vibrations are magnified by the resulting leverage as a result. However, placing engine mountings at the centreline also means that the capacity for taking care of reverse torque reaction from the engine is also very much diminished and this is why we have widely space engine mounts at the front of the block as well as a tie rod at the rear – which on Australian Austin 1800 cars had to be moved to the underneath of the gearbox because the original position (up near the rear engine mount was no longer available due to the outrigger mounting).

Another notable feature of the Austin 1800 engine mountings is the inclusion of a damper, or shock absorber, connected between the engine centre line at the bell housing and the engine mounting cross member. Evidently balance of this power unit was difficult to achieve and the damper a costly addition.

2.5 Camshaft

2.5.1 Introduction

One of the most important design features of an automotive engine is that of the camshaft. Apart from the necessity of opening and closing the inlet and exhaust valves in the proper sequence, comes all the second order issues such as mechanical reliability, the effect on volumetric efficiency, valve head cooling, tractability, and the engine rpm at which maximum torque and maximum power become available.

Associated with the camshaft are the followers or tappets, the pushrods, and the rocker arms. The cam profile must be developed to impart a suitable motion to all these parts for a wide range of engine rpm reliably since any failure will most likely result in extensive damage to the rest of the engine.

The camshaft turns at half engine speed.

Apart from the base circle which is easily defined, the shape of the opening and closing ramps, and the nose are usually tabulated in terms of the cam interval in degrees, the tangent lift off the base circle and the tangent height above the cam centreline in 1° steps.

2.6 Clutch

2.6.1 Clutch Performance

The clutch allows disconnection of drive from the engine to the transmission for the purpose of changing gears. The synchromesh cones within the transmission speed up, or slow down the input drive train (including the clutch driven plate), to match the rotation of the output gear train which is determined by the speed of the vehicle. When disengaged, the clutch must transmit full engine torque to the input gear train of the transmission.

For smooth gear changes, the clutch driven plate should have as low as a moment of inertia as possible so as to reduce the load and wear on the synchromesh. Since moment of inertia depends upon the total mass, and how that mass is distributed, it is found that the clutch driven plate is usually a thin metal disc with friction lining around the edges so that the total mass may be reduced, but an adequate level of torque may be applied and transmitted under a reasonable spring pressure with while providing an acceptable pedal effort for the driver.

For a Morris 850, ADO15, the dimensions of the driven plate are shown in Fig. 2.6.1 and the arrangement of the driven and driving plates and springs in Fig. 2.6.2. The clutch for other models in the Mini range is similar with the exception of the spring unit, which in later models is of a diaphragm type in the manner of a Belville washer with a 12° included angle.

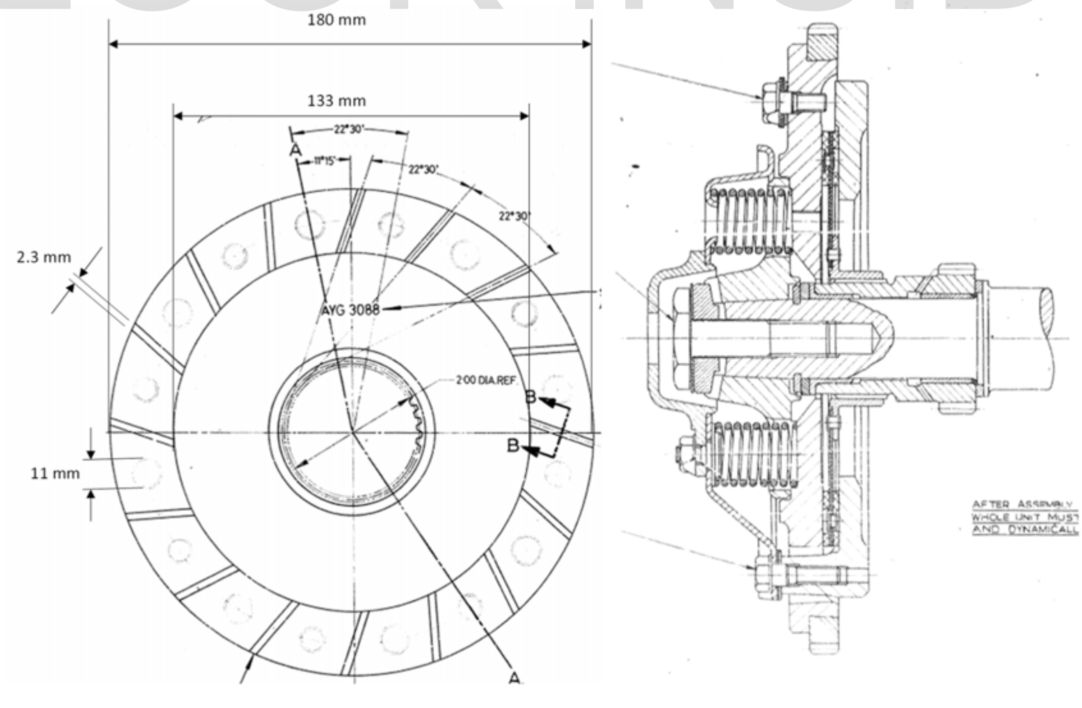


Fig. 2.6.1 *Clutch driven plate Mini range (B354) and arrangement*.

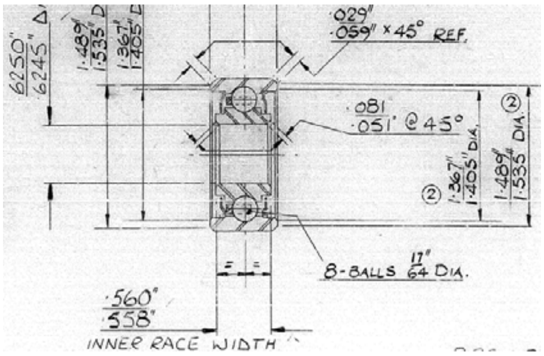


Fig. 2.6.2 *Clutch release bearing DAM1654*.

DAM1654 appears adequate considering the 2.9 kN clamping force required for the 1287cc engine. The bearing is called upon to provide more than the clamping force since the spring has to be compressed further to provide running clearance for the driven plate when the clutch is engaged.

For the coil spring clutch, Table 2.6.4 shows the load at maximum compression for each spring calculated on the basis of the specified free length, fitted length and fitted load, and maximum compression, according to Hooke's Law.

Bearing load - coil spring	**850cc**	**Unit**
Free Length	68.12	mm
Fitted length	35.61	mm
Fitted load	289.12	N
Spring constant	8.89	N/mm
Maximm deflection	30.73	
Load at max deflection	332.29	N
Throwout bearing load	1994	N

Table 2.6.4 *Coil spring clutch calculated maximum load for one spring*.

With 6 springs, the maximum loading on the throwout bearing is approximately 2kN. This load is of course then supported by the crankshaft thrust washers. This is well within the capability of the throwout bearing fitted.

When first introduced in Australia in 1961, the clutch release bearing for the Mini range was Part No. 7MJT5/8 which is a Ransom and Marles thrust bearing 5/8" ID (BMC Part No 2A3653). Over the years, this would change to Part Nos are 3/W5/8, CR5/8B, GRB201, GRB238 and DAM1654.

2.7 Transmission

2.7.1 Introduction

Why do we have a gearbox in our cars? These days, and especially with the popularity of automatic transmissions, we tend not to give the question a thought.

2.8 Vehicle Performance

2.8.1 Introduction

The overall performance of the vehicle on the road under different driving conditions can be shown on a vehicle performance graph. Such a graph shows road speed on the *x* axis, and both engine rpm and tractive effort on the *y* axis. We shall look at such a curve with respect to a 1098cc power unit as fitted to a Morris Mini 1100 vehicle 2/YDO5.

2.8.2 Engine Power Curve

The net power curve for a 1098cc engine is given by BMC as:

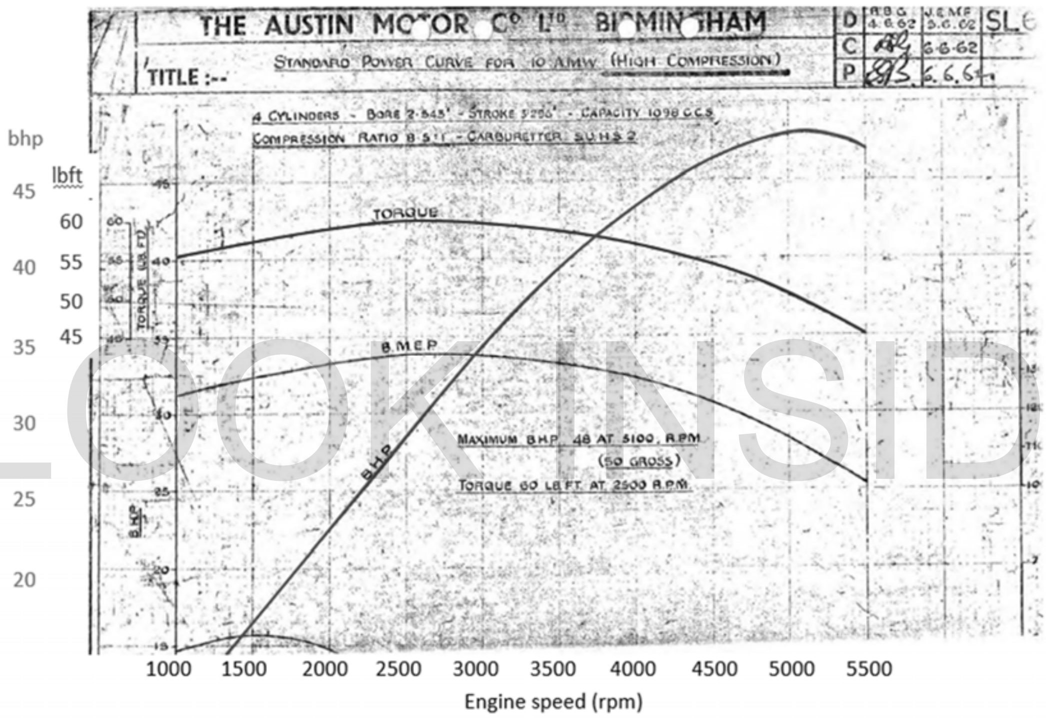


Fig. 2.8.1 *Power and torque (gross) curves for 1098cc A series engine*.

Maximum torque is shown as 60 lbft (corresponding to 81.3 Nm) at 2500 rpm and maximum power as 50 bhp (37 kW) at 5100 rpm. These are net figures. When gross figures are used, allowance must be made for various losses as shown in Table 2.8.1.

Item	Power Loss
Air cleaner	2%
Alternator	1%
Fan	2%
Distributor	3%
Exhaust	5%
Total	13%

Table 2.8.1 *Losses due to ancillaries (generalised average figures).*

CHAPTER 3.
EMISSION CONTROL

3.1 Emission Control

3.1.1 Introduction

One of the most pressing problems of our time is the issue of exhaust emissions from motor vehicles. Since the 1960s, the number of motor vehicles has increased to the extent that they are a major source of air pollution.

Before the introduction of emission control systems, a typical motor vehicle would emit unburnt hydrocarbons (HC) of which about 50% would be found in the exhaust gases, 20% from crankcase vent, 10% from the carburetter float bowl vent, and 20% form the fuel tank vent. The presence of these hydrocarbons in the atmosphere, together with the oxides of nitrogen (NO_x) emitted from the exhaust system, are the ingredients for photochemical smog.

Although the combustion process ideally produces just carbon dioxide and water, in practice, exhaust gases contain carbon dioxide, carbon monoxide (CO), oxides of nitrogen, carbon particles, unburnt hydrocarbons, lead (when it used to be added to petrol), and of course, water.

To reduce the formation of harmful acids and dilution of engine oil, crankcases have been traditionally vented via a flow-through air system – the simplest of which was a tube pointing downwards into the air stream from the crankcase, and a vented oil filler cap. Air flow from vehicle motion passing the end of the tube creates a suction which draws a flow of fresh air through the crankcase via the filler cap. In time, this system underwent a significant improvement with the introduction of positive crankcase ventilation where instead of venting crankcase gases out to the atmosphere, they were fed back into the air cleaner and burnt in the combustion chamber. A PCV valve regulated the flow of air through the system.

While a worthy undertaking, much more sophisticated methods are required to reduce exhaust and evaporative emissions. In Australia, various state and federal bodies legislated the requirements for both type of emissions, chiefly through the NSW Clean Air Act, and the Commonwealth Australian Design Rule (ADR) system.

Initially, from 1974, the concentration of CO at idle was limited to 4.5%. In 1976, the levels of CO, HC and NO_x were constrained to limits when vehicles were tested in a prescribed manner on a dynamometer in a testing laboratory. From 1975 onwards, the lead content in petrol was required to be reduced, and in 1985, unleaded petrol was prescribed for all new vehicles. The introduction of unleaded fuel allowed vehicles to be fitted with catalytic converters in the exhaust system which would reduce the levels of CO and HC appreciably. A summary of the legislated levels of

$$a = \frac{TE_{eff}}{m_{eff}}$$

The time taken is:

$$t = \frac{v_2 - v_1}{a}$$

And the distance travelled:

$$d = v_1 t + 0.5at^2$$

Knowing the accumulated time to reach, say, 118.6 km/h, then the kinetic energy expended over that time indicates the power available used in accelerating the vehicle.[14]

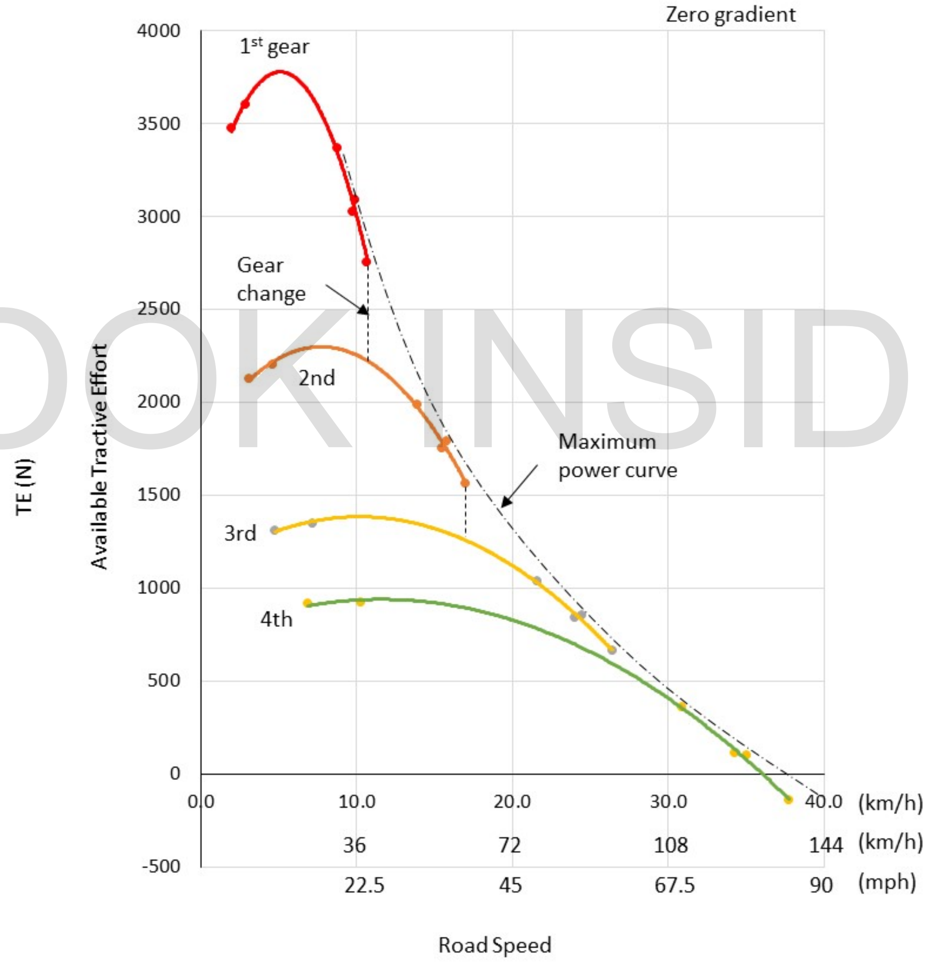


Fig. 2.8.5 *Net tractive effort for data plotted in Fig. 2.8.3 for zero gradient.*

[14] The figures indicated in Table 2.8.10 for power have been calculated without the gear change time included. This is the "excess" power required to accelerate the vehicle mass calculated from the kinetic energy of the vehicle over the accumulated time.

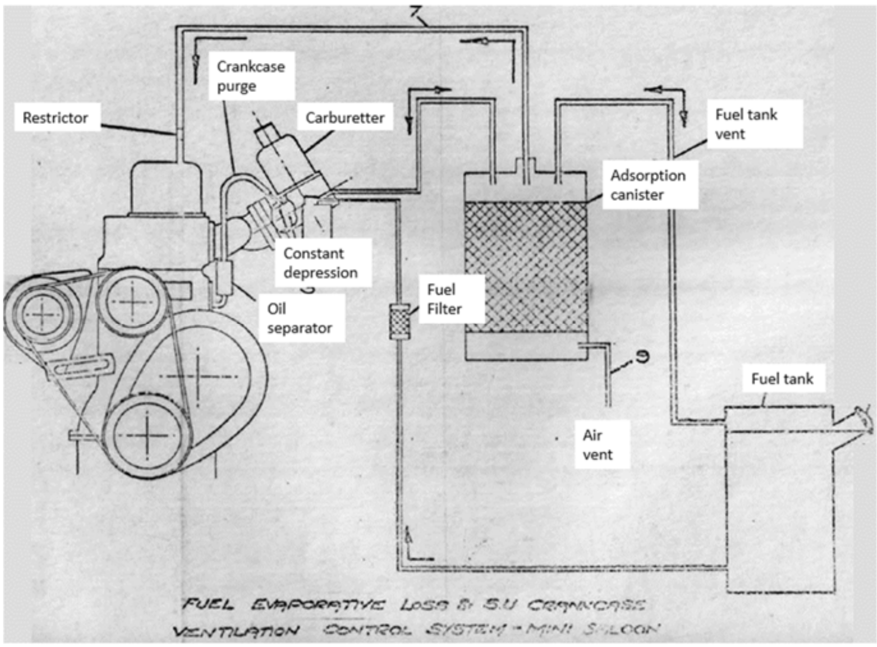


Fig. 3.1.7 *Evaporative emissions charcoal canister*.

The fuel cap is fitted with a vacuum relief and pressure relief valves.

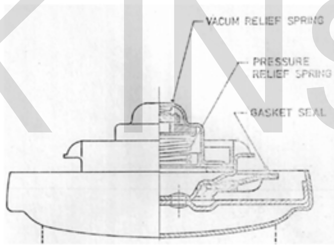


Fig. 3.1.8 *Fuel tank for evaporative emission control*.

3.2 Emission Control Testing

ADR27A testing was performed at two sites at Leyland Australia. An emission control testing laboratory was established near the Product Engineering building at Zetland in 1972. This facility kept operating until the factory closed in 1974 but was retained and operated by the Commonwealth Department of Transport until 1985 for research into the introduction of unleaded fuel in Australia.

A second laboratory was built at Moorebank, next door to the Parts and Accessories division. This was a large purpose built Environmental Centre, but with the wind-down of operations after 1974, it became a reduced facility for emissions testing and was used for product engineering development and then later, manufacture, of the Army Land Rover models.

An emissions test is performed on a vehicle which has been parked beforehand for a prescribed period (usually overnight) at a constant temperature. The vehicle is then positioned on a chassis dynamometer, but one that is fitted with inertia flywheels whose moment of inertia can be

CHAPTER 4. IGNITION SYSTEM

4.1 Introduction

The process of igniting the fuel air mixture in the combustion chamber at the right time, and in the right cylinder, is the province of the ignition system. The ignition system must first generate a high enough voltage to cause a spark at the spark plug, and the distributor must distribute this high voltage so that the correct spark plug fires.

The voltage at which a spark appears at the spark plug depends upon several factors. The most important is the shape of the electrodes. The sharper the edges of the electrodes, the lower the sparking voltage needs to be. This is because an electric field is more dense around the space at a sharp corner compared to a rounded corner, and it is the strength of the electric field that causes ionization of the gases in this vicinity, and hence the establishment of a spark. The ideal shape of the spark plug electrode would be a sharp pin, but such a geometry would be subject to erosion by heat.

The larger the gap, the higher the voltage required to initiate a spark. The presence of fuel in the mixture slightly lowers the sparking voltage. The higher the pressure, the higher the sparking voltage. The lower the temperature, the lower the sparking voltage. The rate of application of the high voltage also affects the sparking voltage, a higher rate resulting in the sparking voltage increasing.

The spark itself is thought to consist of two components. The first is called the capacitive component and coincides with the opening of the points in the distributor. This is a bright, short flash at the spark plug. This is immediately followed by what is called the inductive component which has the appearance of a short series of fainter sparks over a relatively longer period. It is the capacitive component of the spark that initiates ignition of the mixture. It is the energy of the capacitive component, which depends greatly on the rate of application of voltage, that is the most important factor in producing ignition. What happens thereafter at the spark plug is of little consequence.

4.2 The Ignition Coil

The standard ignition system used on nearly all BMC/Leyland cars consists of points, condenser, coil, distributor, and spark plugs. This highly evolved system was preceded by trembler coil and hot wire methods. As is now well known, it is the switching action of the mechanical points that induces a high voltage in the ignition coil which is sufficient to create a spark at the spark plug inside the cylinder. The distributor itself distributes this high voltage to the correct spark plug at the correct time in the compression stroke.

current is very high (because the points open suddenly, and there is no “resistor” in the circuit as there was when the points closed). This rate of change of current is opposite in sign compared to the rate of change of current when the coil was being charged. That is to say, a falling current rather than a rising current.

When the points close, the back emf opposes the 12 V at the SW terminal in a gradually decreasing manner. When the points open, the rate of change of current in the primary coil is very high. The “forward” emf is of the order of 200 to 300V and appears at the CB terminal of the coil – which is now no longer connected to earth. The forward emf, sometimes called the “kick” voltage, or the “primary kick”, is responsible for a far higher voltage generated in the secondary compared to the case when the points were closing.

We would expect such a large kick voltage to result in arcing of the points. This arcing would act as a kind of resistor (current flows through the arc) and would thus decrease the rate of change of current and limit the magnitude of the secondary voltage. The capacitor is charged by the kick voltage, and this takes time. Time enough for the points to separate so that arcing across the points is much reduced. Because of the capacitor stores the energy which would otherwise be wasted at an arc at the points, the primary current is more abruptly terminated resulting in a larger kick and higher secondary voltage.

Initially, the capacitor is charged with the kick voltage, but when the voltage at the CB terminal reduces (as the magnetic field in the primary becomes weaker as it discharged), the capacitor then discharges current back into the primary (reverse direction to that which occurs when the coil is being “charged” by the voltage at the SW terminal), and as a result, there is a back emf opposing this current and the voltage at the CB terminal rises. This back emf dissipates as the capacitor is discharged, and then the coil now with a new magnetic field (of reduced intensity) discharges again. The result is a series of oscillations at the CB terminal of a diminishing nature and the spark (now established) continues until the oscillations are reduced along the “spark line”, or “burn line”.

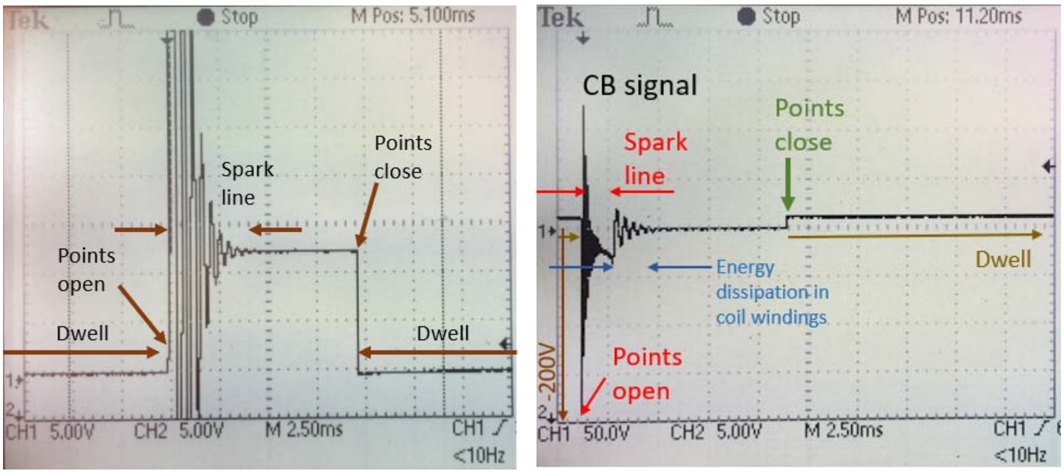


Fig. 4.2.3 *Voltage waveform at the CB terminal while engine is running. (a) Negative earth configuration (b) Positive earth.*

4.3 Spark Plug

4.3.1 Spark Plug Details

It is the opening of the points that interrupts the current in the ignition coil, and the resulting collapse of the magnetic field in the primary winding of the coil induces a high voltage in the secondary winding of the coil. This high voltage is applied to the electrodes of the spark plug whereupon the mixture in the cylinder is ignited. The high voltage is *distributed* to the correct plug via the rotation of the rotor button inside the distributor cap.

Now, firstly it is important to know that the spark at the plug is more efficient if the centre electrode is made negative with respect to the ground or cylinder head casting. This causes the spark to jump from the centre electrode to the outer edge of the plug. Even on a negative earth car, the polarity of the spark is more negative (by hundreds of volts) than the -12V at the outer ground terminal. This is why the terminals of the coil are marked + and -. Sometimes, the points side of the coil is marked CB for "contact breaker" and the other side SW for ignition switch. However, what is not generally appreciated is that there is a difference in internal connection for coils made for a positive earth car and a negative earth car. It has to do with the connection of the secondary winding inside the coil. When converting from positive earth to negative earth, one should not just swap the wires on the coil around, but one should obtain a coil wired for negative earth. The part numbers for coils for the two types of earthing systems are different.

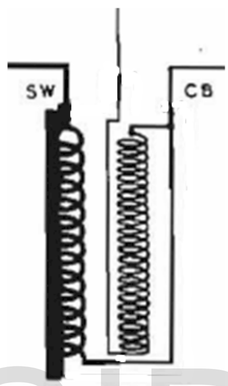


Fig. 4.3.1 Coil windings for negative earth car with SW being -VE and CB being +VE.

A further interesting point is that when the high voltage is distributed inside the cap, there is of course no direct connection between the rotor button and the cap terminals, so the high voltage has to arc across a small gap. Experiments show that this arcing causes metal to vapourise from the side from which the spark originates – that is, from the cap terminal (which is positive with respect to the rotor button) *to* the rotor button. Thus, when the coil polarity is correct, "wear" of the cap terminals will occur rather than wear of the rotor button – thus more evenly spreading out the wear of metal material rather than concentrating it at the rotor button.

A notable feature of the rotor button is the extension to the terminal in the direction of rotation. The width of the terminal has to be made long enough to allow the spark to proceed across the gap between it and the cap terminal while the rotor button is turning. If the rotor button terminal is too short, then it may pass by the cap terminal before all the energy is transferred – especially at high engine revs. Further, the extension in length of the rotor button is made in the direction of rotation. Lucas claim that this tends to minimise the chance of back-running of the engine (the spark is abruptly cut off) should the engine be turning in the opposite direction (which can sometimes happen during "running on" after the ignition is turned off.

CHAPTER 5.
COOLING SYSTEM

5.1 Introduction

The internal combustion engine, despite its great utility, has a thermal efficiency of only about 25% when one considers the energy available from combustion of the fuel and the mechanical work produced. This is far greater than previous attempts at mechanization and it can be appreciated arises from the high temperatures attained during combustion within the combustion chamber.

After combustion, the temperature in the cylinder is of the order of 1500°C which is sufficient to melt cast iron and aluminium. In practice, an engine may withstand such temperatures in the combustion chamber because they exist for a very short period, and heat is carried away by the cooling system.

As a further consideration, the viscosity of lubricating oil decreases with increasing temperature and so if the cylinder walls become too hot, the lubrication offered by the oil will diminish and friction thus increase, leading to seizure.

BMC factory documents describe the cooling system as pressurised thermos-syphon with pump and fan assistance. The thermo-syphon function relies upon a difference in pressure arising from the difference in density of the hot water in the water jackets and that of the cooler water in the radiator. The cooler water “sinks” and thus displaces hot water in the water jacket upwards into the top of the radiator, whereupon it is cooled and then recirculates.

In a pump circulation system, water enters the pump from the bottom radiator hose near the centre of the impeller and is then thrown outwards by centrifugal action imparted by rotating vanes. The cooled water, now under pressure, is directed into the water jacket of the cylinder block and then up to the cylinder head where it extracts heat and is then forced upwards under pump pressure through the thermostat into the top radiator hose.

A cooling fan is typically attached to the water pump, or electrically driven, to force air through the radiator.

5.2 Radiator

5.2.1 Radiator Function

The radiator serves to remove heat energy from the cooling water and so lower its temperature so that it may be recirculated for continuous cooling of the cylinder walls and cylinder head. The name is a misnomer in the sense that most of the heat transfer occurs via convection rather than radiation.

an initial tension of 290 N, and with a coefficient of friction of 0.3, and an angle of contact of 113.5°, the crankshaft pulley is capable of supplying about 15 kW before belt slippage, whereas if the initial tension were halved, the power available would also be halved. Given that the power to be transferred to the water pump and alternator is specified at 2.42 and 1.61 kW respectively, there appears to be plenty of crankshaft capacity in reserve to account for in-service wear and maladjustment.

BMC fan belts are designed to provide 25,000 miles service under normal running conditions with proper tension and alignment over a temperature range of -35°C to 71°C. Table 5.6.2 shows the design belt grades.

Grade	Description
FBY-1A	Premium quality for use with small pulley (under 2.8”) diameters.
FBY-1B	Premium quality for use with pulleys 2.8” diameter and larger and for vehicles having power steering.
FBY-1C	Regular quality for use with pulleys 2.8” diameter and larger.

Table 5.4.2 *Grades of BMC V belts*.

5.5 Thermostat

5.5.1 Need for a Thermostat

It is well known that cars used for taxi work can accumulate high mileages without any engine work other than scheduled maintenance. The reason is that taxis and most commercial vehicles are in continuous use and thus avoid the deleterious conditions associated with a cold start of the engine.

Manufacturers set tolerances and clearances for pistons, rings and bearings, based on a certain normal operating temperature. This temperature is a compromise between being too hot (and therefore not enough cooling reserve from the radiator for hot days) and too cold (causing incomplete combustion and increased friction from the lubricating oil).

The most desirable scenario (apart from keeping engines heated electrically overnight) is to raise the temperature of the engine as quickly as possible and to keep it at its designed operating temperature. This is the function of the thermostat. By blocking or reducing the flow of cooling water during initial running, the temperature of the engine rises rapidly, and then, when the thermostat opens, it remains at the correct temperature. Excess fuel consumption from choke operation is reduced, and blow-by of harmful compounds to the crankcase is decreased, and what does blow by, is more readily boiled off in the sump and purged by the PCV system.

In the fully open condition, the size of the opening of the thermostat is taken into account by the manufacturer so that the correct flow rate of cooling water is achieved during normal operation.

5.5.2 Thermostat Design

Thermostats of older design are often unreliable. The mode of operation is based on the expansion of a bellows or concertina which is filled with acetone. Evaporation of the acetone (at about 60 to 80°C) expands the bellows and opens up the thermostat flap valve. When this type of thermostat fails, it remains open. Note also that this type of thermostat relies on a difference in

CHAPTER 6.
FUEL SYSTEM

6.1 Fluid Dynamics

Much of the operation of any carburetter is governed by the principles of fluid flow, both of gases and liquids.

When particles in a fluid follow smooth, well-defined paths, the flow is said to be laminar. Streamlines indicate the path of the particles. A vector drawn tangent to the streamline may be used to indicate velocity at any particular point.

At low particle velocities, in the absence of any disturbances, the flow of fluid in a pipe is usually laminar. However, as the velocity increases, irregularities in the walls of the pipe cause vortices to form and at higher velocities, the flow becomes turbulent.

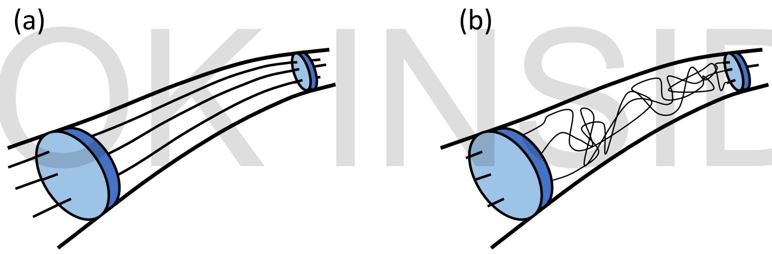


Fig. 6.1.1 *(a) Laminar flow (b) Turbulent flow*.

Experiments show that a measure of turbulence can be given by the Reynolds Number Re. The Reynolds Number is dimensionless and arises from a consistent grouping of quantities that have been shown, by experiment, to influence the type of observed flow. At low values of Re, viscosity forces dominate and the flow is laminar. At high Re, inertia forces dominate and the flow is influenced by vortices and other instabilities.

$$\mathrm{Re} = \frac{\rho v l}{\eta}$$

In this equation, ρ is the density of the fluid, v is the velocity of the fluid particles, η is the viscosity, and l is the characteristic length. The characteristic length depends on the physical situation. For a tube, it is most likely the diameter. For flow over a flat plate, it is the dimensions of the plate in the direction of flow.

For a tube of diameter equal to the length, $l = D$, Re < 2000 and the flow is probably laminar, When Re > 3000 the flow is probably turbulent.

Carburetion, manifolding, and exhaust is all about gas flow. The dependence of flow on the diameter of the passage means that only slight changes are needed to make a substantial difference in the flow rates. The objective throughout is to design these components for maximum volumetric efficiency.

6.2 Combustion

In an internal combustion engine, hydrocarbon fuel and oxygen are ignited by the spark plug to provide pressure in the combustion chamber. The ratio of the mass of air to the mass of fuel is very important and is called the air-fuel ratio or "mixture". Theoretically, a little over 14.5 times the amount of air (by mass) than fuel (the actual ratio depends on the blend of the fuel) is needed for complete combustion. At this mixture ratio, all the hydrocarbons in the fuel combine with all the oxygen in the air during combustion and there is no free oxygen or hydrocarbons left over. The products of combustion under these conditions are carbon dioxide and water. In practice, this never happens, and the products of combustion are carbon dioxide (CO_2), water, carbon monoxide (CO), unburnt hydrocarbons (HC), and oxides of nitrogen (NO_x). The combination of unburnt hydrocarbons and oxides of nitrogen, with sunlight, produce photochemical smog. If the mixture is too weak, or too rich, the fuel will not burn at all and flat spots and rough running are the result.

At idle, (especially when the engine is cold), the mass of air and fuel (i.e. the "charge") coming into the combustion chamber is a minimum. Near the cylinder head walls, some of the liquid fuel doesn't completely get surrounded by oxygen. When the charge of the air-fuel mixture is greater (such as in wide open throttle) there is still some fuel near the walls of the combustion chamber, but this is a smaller proportion in comparison to the idle condition. Fuel at this location may not get completely burnt and instead of forming CO_2, will form CO instead, which can be measured in the tailpipe emissions by a CO meter. Some fuel may not burn at all in which case it passes out the exhaust system as free hydrocarbons (HC). The level of CO in the exhaust emissions is usually about 4% at idle for a pre-emission control car, dropping to about 1% at part throttle.

A major disadvantage of liquid hydrocarbon fuel is the requirement that liquid fuel be vapourised before it enters the combustion chamber. If liquid appears in the combustion chamber, not only will the hydrocarbon molecules inside the drop not be next to an oxygen molecule, ready for combustion at the command of the spark plug, but the spark plug will become wet and cease to function.

It takes heat to convert a liquid into a vapour, as one can readily experience by the cooling effect of perspiration. Thus, carburettors tend to run cold as heat is used to vaporise the fuel entering the inlet manifold. The original Mini engine was turned around 180 ° because when the carburettor was at the front, it got so cold that it iced up.

Often, car manufacturers connect the inlet and exhaust manifolds together so as to form a hot spot directly under the carburettor to help with vaporising the fuel. Others employ water heating of the manifold, particular in cross-flow head designs where the inlet manifold is on the other side of the cylinder head than the exhaust. The unfortunate side effect of this is that the density of charge of air/fuel entering the combustion chamber is reduced, thus reducing the available maximum power output.

The *mass* of air entering the carburettor, and hence into the combustion chamber, is dictated by the throttle plate angle. The mass of fuel being delivered by the carburettor depends on the diameter of a tube (the jet) through which the fuel passes from the float chamber into the air stream, and the pressure difference between one side of the jet and the other. The pressure on one side of the jet is atmospheric (the side that is connected to the float chamber) and the other side, is at the pressure at the venturi in the carburettor. The air passage of air past the venturi increases in velocity and decreases in pressure. It is the decrease in pressure (compared to the float chamber side of the jet) that causes liquid fuel to rise up through the jet into the air stream – although it is more accurate to say that the increased pressure on the float chamber side pushes the fuel through the jet. It is important to know that the pressure, or depression, at the throat of a venturi depends on the flow rate (in litres per minute) and the size of the venturi. The greater the flow rate, the lower the pressure compared to that on the upstream and downstream sides of the venturi. The narrower the size of the venturi, the lower the pressure.

At idle, a relatively small amount of fuel flow is required. At part throttle, or full throttle, a greater amount of fuel flow is required. Either the pressure difference, or the jet diameter can be increased to accomplish this. At acceleration, the throttle is opened quite rapidly. Air, having a lower density than liquid fuel, rushes through the carburettor and into the combustion chamber. The fuel, being a liquid, is at the same time being sucked through the jet in the carburettor but is slower to move than the air. The mixture in the combustion chamber is therefore weak (air-fuel ratio too high). To maintain a combustible mixture, the amount of fuel entering the air stream has to be temporarily increased.

6.3 The SU Carburetter

6.3.1 Introduction

The SU (Skinners Union) carburettor is a common fixture on BMC vehicles and indeed, Nuffield purchased the company in the mid 1920s. It is a simple device, but as with all simple devices, it is the second order terms that make it work in practice.

In an SU carburettor, the diameter of the jet and the size of the venturi are altered to let more or less fuel through it in response to air flow. The diameter of the jet is altered by putting a tapered needle down through the middle of it. The more the needle is inserted, the narrower the effective diameter of the jet. The needle position is determined by the height of a piston to which the needle is connected. The operation of this piston is important. The significance is that this piston can be held at nearly any position from fully down, or closed, to the fully up position with much the same amount of force. The force has to overcome the mass of the piston, and the relatively soft damper spring. The piston itself acts as a restriction to the air flow. That is, it is itself acting as a variable venturi, or narrowing, of the passage of air through the carburettor. This venturi is in fact a rectangle of constant width and variable height. The upper side of the piston is ported to the pressure at the venturi narrowing.

At a particular throttle opening, a certain amount of air in litres per minute is drawn through the carburettor. At idle, the piston is initially down. If the throttle is opened slightly, engine manifold vacuum tends to pull more air through the rectangular venturi formed by the piston and the throttle body. The greater flow rate of air through this venturi results in a *decrease* in pressure,

CHAPTER 7. SUSPENSION

7.1 Suspension Geometry

7.1.1 The Reason for a Suspension System

We all tend to take it for granted that motor vehicles have a suspension system but tend to forget why this might be so. The simple answer is that a suspension system provides a comfortable ride. While this might seem trite, the concept is of extreme importance and, together with handling and steering characteristics, makes up a considerable portion of motor vehicle design.

Research shows that in relation to vibrations transmitted to the passengers, the higher the frequency, the smaller the amplitude of the vibrations are tolerable to maintain comfort. On the other hand, for low frequency vibrations, passengers can cope with larger amplitudes. There is an empirically derived "comfort curve" that provides limits for designers to work with when designing spring rates and damping characteristics.

The suspension system essentially deals with the movement of the body in three directions as a result of forces acting on the centre of mass through cornering, braking, and variations in the road surface. Another important factor is the effect of the variation in static weight of the vehicle as passengers and goods are added or removed.

In this Section we will not discuss commonly studied topics such as castor, camber and king pin inclination, but examine some less-known concepts, in particular, roll centres and mass.

7.1.2 Roll Centres

One of the most significant design parameters of a motor vehicle suspension system is the disposition of the front and rear roll centres. A line which joins these two points is called the roll axis and is the axis about which the vehicle body rolls when cornering. Such is the influence this axis has on handling that it behoves us to learn more about it.

Consider the simplified geometry shown in Fig. 7.1.1. At rest, the weight W of the car acts through the centre of mass and is supported by springs, and then the tyre, with the reaction forces $W/2$ shown on each side of the vehicle (ignoring the weight of the wheels and axle and the other wheels). Suppose now a sideways force F is applied at the centre of mass. Fig. 7.1.1 (b) shows the reaction forces at the point of attachment of the springs. Since these reaction forces act at a distance h from the centre of mass, there is a turning moment of magnitude Fh created.

To maintain equilibrium, it is not sufficient to just balance the sideways forces, but the turning moment must also be balanced. This is done by an increase in the right hand vertical force (arising from compression of the spring on that side) and a decrease in the left hand vertical force (arising from a relaxation of the spring on that side), both of these acting through a distance *t*. That is, the body tilts around a point RC, which is the roll centre.

Thus, the spring forces change by an amount *q*, which is added to (right hand side) and subtracted from (left hand side) of the upwards spring forces. The magnitude of *q* depends on the magnitude of the sideways for *F* and the moment arm *t*. A moment's thought will show it doesn't matter where the moments are referred to, the resulting magnitude of *q* will be *Fh*/*t*. Since the upward deflection of the spring at a will be matched by the downward deflection of the spring, then the centre of rotation must be midway between.

By a similar argument to the above, where the tyres take the place of the springs, the reaction forces at the road change by an amount *p* = *FH*/*T* where *T* is the track, and *H* is the height of the centre of mass above the ground and the centre of mass rotates around the centreline at ground level. Evidently, the reaction forces at the road depend not only on the sideways cornering forces, but also the distance between the centre of mass and the roll centre.

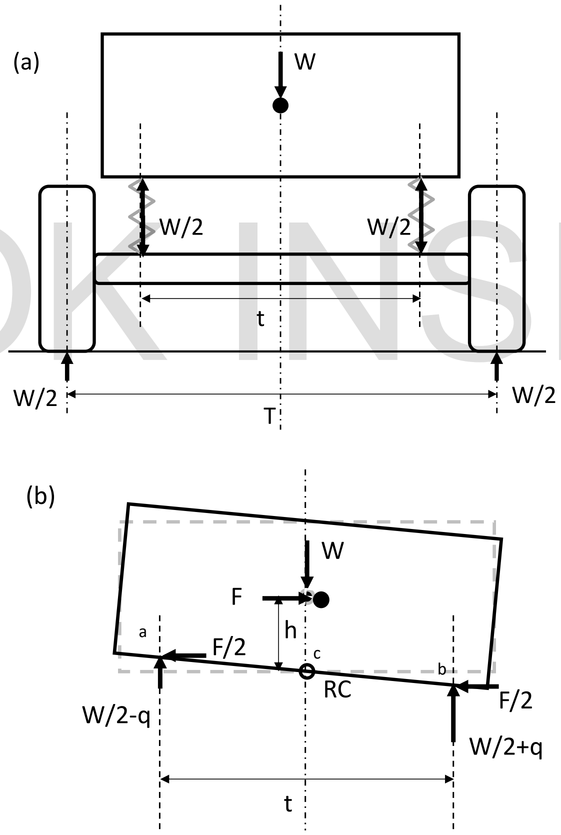


Fig. 7.1.1 *Location of front roll centre for a simple suspension system*.

Most vehicles do not have a suspension geometry of this type but employ more complicated arrangements of links as shown in Fig. 7.1.2. The upper and lower links may be parallel, or they might converge at a point inside or outside the wheel. Fig. 7.1.2 shows the position of the roll centre for a variety of suspension geometries. Note that for parallel links that are parallel to the ground, the roll centre is at ground level even if the links themselves are above.

7.2 Hydrolastic Displacers

7.2.1 Introduction

One of the more unique features of BMC vehicles of the mid-sixties is the hydrolastic suspension system developed by Alex Moulton.

This type of suspension was introduced in Australia in 1964 for YDO16 Morris 1100 and was carried over to the Mini range in 1965, and also the Austin 1800/Tasman/Kimberley. It was phased out in 1973 with the introduction of the Leyland Mini. In Australia, the hydrolastic units were manufactured by Dunlop.

It should be realised that although the movement of the suspension causes fluid to be displaced within the unit from the lower chamber to the upper chamber, and vice versa, the actual springing medium is the rubber cone insert just as in the case of the dry suspension fitted to ADO15.

The damping and rubber characteristics are tuned for each application. Identification of particular specification is usually made by painted bands on the outside of the unit which are easily seen (when new), but somewhat difficult to find in more modern times. Part numbers stamped into the casing can also be used in some cases to identify specifications. The coloured bands may be either near the top outside edge, or near the circumferential swage towards the middle.

In this Section, the distance *b* is that measured from the edge of the mould line of the rubber at the top inside of the unit to the centre point of the blend radius *d* with the rubber spring (in the unpressurised condition) as shown in Fig. 7.2.1. Although internally there are different specifications for the flap valve bleed diameters, the units cannot be dismantled for inspection and the distance *d* and the coloured bands are probably the only external means of identification available.

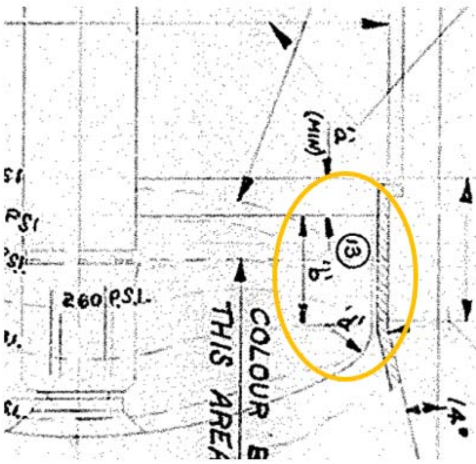


Fig. 7.2.1 *Hydrolastic unit detail showing distance b, 21A1477.*

7.4 Secret Life of a Tyre

The mechanism by which a tyre supports the weight of a motor vehicle is a somewhat complicated one. When the tyre air pressure is low, the tyre appears flat, and the weight of the car makes the whole affair sag so the air pressure does have something to do with it. But how is the weight of the car supported by this air pressure if the pressure is the same all the way around the rim? Surely the air pressure pushing down on the top half of the rim surface will be balanced out by the pressure pushing upwards from the bottom half? So exactly how is the weight supported?

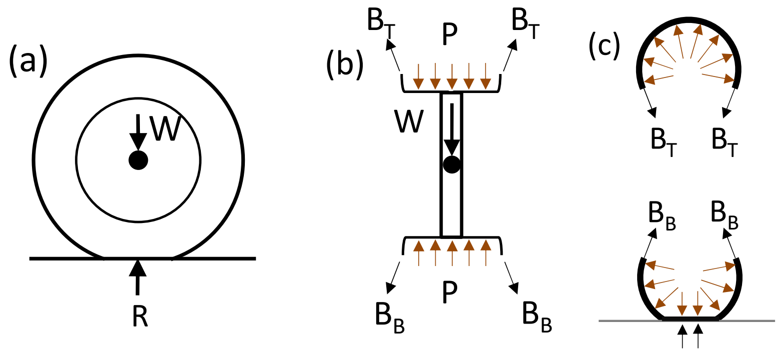


Fig. 7.4.1 *(a) Weight W of car is balanced by reaction R from road. (b) Free body diagram of wheel (c) Free body diagram of tyre.*

Consider Fig 7.4.1 (a). Here is shown the weight of the car *W* and the reaction force *R* from the road. The two forces are in balance (otherwise the wheel and tyre would move in the vertical direction). The question is, how is the force *W* at the wheel hub transmitted down to the surface of the road so that the road can support it?

Pressure in a gas is distributed evenly throughout the volume. That is, in a balloon full of compressed air, it is not found that the pressure in the balloon is greater at one place compared to another. Rather, the pressure is uniform throughout. Now, when pressure acts over a surface, the force applied is found by multiplying the pressure times the area over which the pressure acts.

What this means for a tyre and wheel is that the pressure inside the tyre is distributed uniformly throughout the volume of the tyre. So, for every square centimetre of wheel rim surface, we have the same force acting. Further, this force acts perpendicular to the surface upon which it acts. But, if the pressure is the same at the top and the bottom of, and all the way around, the rim, then all these forces will balance out. So, the question is, if the forces due to the air pressure balance out, just what is supporting the weight *W* of the car?

To appreciate what is happening, a free-body diagram of the cross-section of the wheel is required. This is shown in Fig. 7.4.1 (b). The wheel is drawn in complete isolation except that each and every force acting on the object is shown. In this case, the forces acting directly on the wheel are:

(1) The weight *W* of the car.
(2) The distributed forces *P* due to the pressure of the compressed air.
(3) The forces *B* acting on the rim where the tyre bead is in contact with the rim.

CHAPTER 8. STEERING

8.1 The Ackerman Principle

8.1.1 Rolling Motion

It is instructive to examine the design of the steering mechanism of a motor vehicle so that an appreciation of the underlying issues can be gained. Rather than discuss the well-known parameters of castor, camber and so on, in this section, we look at some more fundamental issues.

When a vehicle is moving in a straight line, the wheels have a purely rolling motion in the direction of motion. When it is desired to have the vehicle turn, then in order to preserve a purely rolling motion and thus avoid any slip at the contact patch between the tyre and the road, it is necessary that the wheels take a circular path whose centres all meet at one point. In a simple beam axle type of steering, such as may be found on a billy cart, the situation is as shown in Fig. 8.1.1:

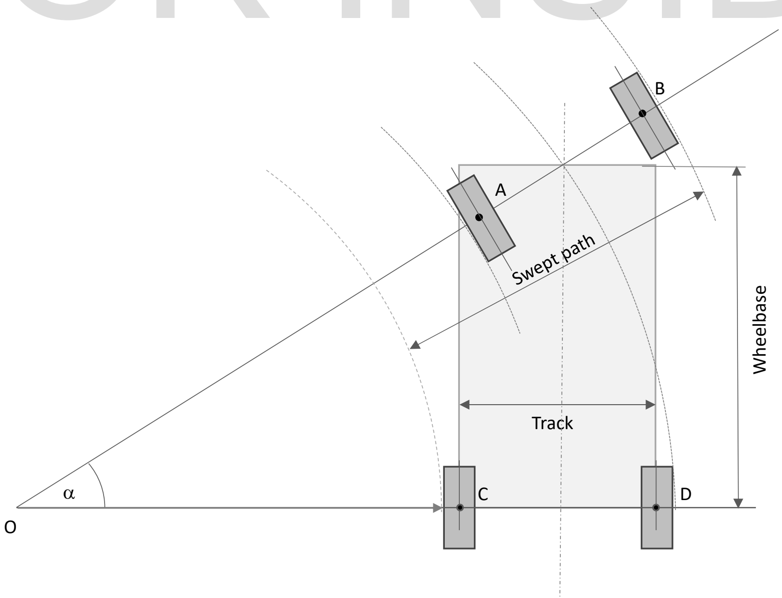


Fig. 8.1.1 *Billy cart steering mechanism. All wheels turn about a fixed point O.*

This type of steering is unsuitable for motor vehicles on account of the excessive lateral movements of the wheel and bub, and so an alternative approach is usually taken.

8.1.2 Perfect Turning

Rather than pivot the whole front axle, each wheel pivots on a stub axle such as shown in Fig. 8.1.2. For the wheels to all turn about a single point O, the outer front wheel must be at a different angle to the inner wheel.

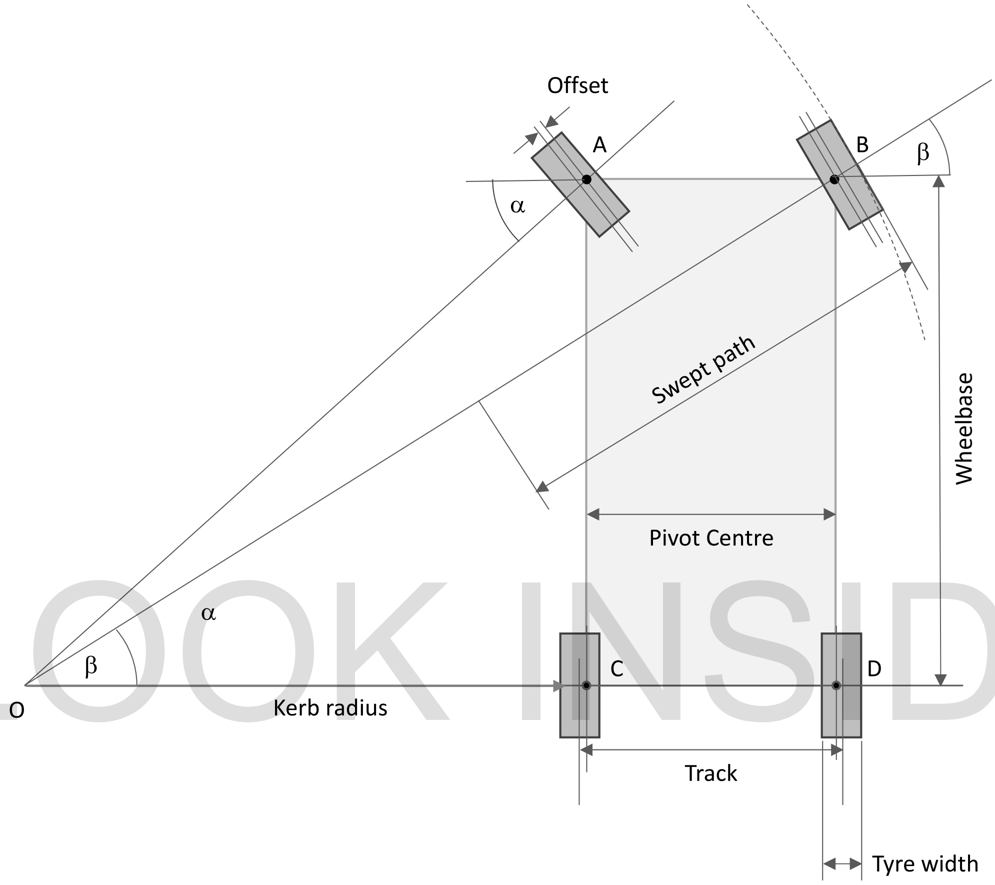


Fig. 8.1.2 *Stub axle steering. All wheels turn about a fixed point O. Dimensions shown for Morris Mini.*

For a given vehicle dimension, AC is the wheelbase. OC is the kerb radius plus half the tyre width and the offset. We may wish to know, for example, what the angle β should be for a particular turning α of the inner wheel given the track and wheelbase.

With reference to Fig. 8.1.2, the following geometrical analysis applies:

$$tan(\alpha) = \frac{AC}{OC}$$
$$OC = \frac{AC}{tan(\alpha)}$$

Now, with respect to the angle β,

$$tan(\beta) = \frac{BD}{OD}$$

CHAPTER 9. BRAKES

9.1 The Theory of Braking

9.1.1 Introduction

It is a surprise for most to learn that despite all the paraphernalia attached to the power unit – carburetters, exhaust, ignition, cooling system etc, and the attention given to torque and power output specifications, the brakes are more powerful than the engine. Occupying a relatively small amount of space, they are called upon to dissipate the kinetic energy of the vehicle without fuss, and in repeated applications. Their capability is familiar to anyone who compares the feeling of being thrown forward during heavy braking to that pushing rearwards under acceleration.

As shown in Chapter 2, the engine provides torque to the driving wheels, and a tractive effort is generated at the tyre contact path which propels the car forward. Braking is the reverse, in the sense that a braking tractive effort is generated at the contact patch opposite in direction to the tractive effort at the driving wheels during constant velocity or acceleration.

It is the function of the brakes to transfer the kinetic energy of motion of the vehicle to heat. The handbrake, which is often termed an emergency brake, is usually used to stop the vehicle rolling away when parked. It is the footbrake that is the focus of our attention here.

9.1.2 Load Distribution

Under braking, there is significant shift in weight to the front wheels as can be imagined, but precisely why this is so is deserving of some careful scrutiny.

The redistribution of load under braking has particular importance, not only in terms of its effect on handling, but also on the loads applied to suspension ball joints and other structural members.

At the static condition, the reaction force R_f front and rear (i.e. total reaction force for two wheels) is shown in Fig. 9.1.1. The new reaction forces under a deceleration *a'* are required, where *a'* is given by:

$$a' = \frac{a}{g}$$

That is, *a'* is the linear acceleration *a* in m/s^2 divided by *g* = 9.81 m/s^2. The new reaction forces are found by taking moments about a convenient centre. In fig. 9.1.1, the weight transfer *q* to the front wheels during forward braking is the desired quantity LD is the static load distribution over the wheels expressed as a ratio front to rear (e.g. 60/40).

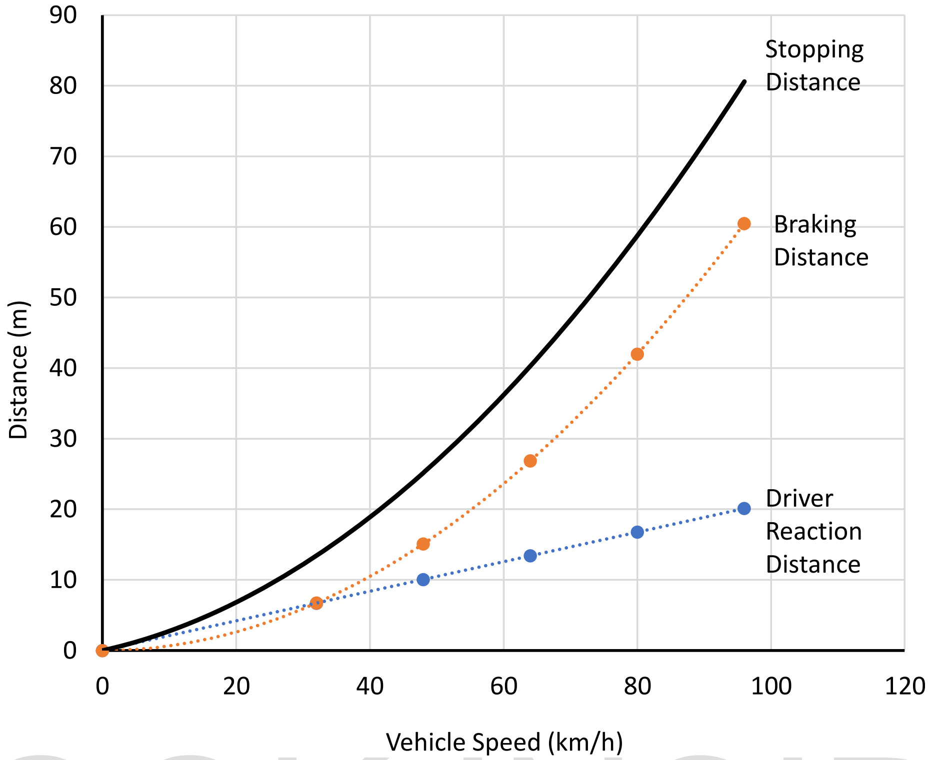


Fig. 9.1.7 *Driver reaction, braking and stopping distances vs vehicle speed for a deceleration of 0.6g.*

As an example, a road test[26] on a Morris 850 reports a stopping distance of 8.5 m from 48 km/h, which according to the above formula, represents a deceleration of 1g.

A comparison of the equations above for stopping time and stopping distance reveals that the time taken to come to a stop from some initial speed depends linearly on that speed, whereas the distance covered to come to a stop depends on the square of the initial speed. Whether or not a particular vehicle can stop within the distances shown depends on the capability of the brakes to provide the requisite deceleration, which in turn depends upon the brake system design and the mass of the vehicle.

9.2 Morris 850 ADO15

9.2.1 Foot brake

Fig. 9.2.1 shows the brake pedal and details of the master and slave cylinders for a Morris 850 ADO15 (approx. mid 1963 specification) with leading and trailing show brakes at the front and rear with a 0.7" diameter master cylinder, 15/16" diameter wheel cylinders at the front, and 5/8" diameter wheel cylinders at the rear.

The 7" (178 mm) diameter brake drums are operated on by shoes of size 6.75" length by 1.24" wide, and have an area per wheel of 16.88 sq ins. The rolling radius for each wheel is 252 mm.

[26] Modern Motor magazine May 1961

CHAPTER 10. ELECTRICAL

10.1 Voltage and Current

Experiments show that, for a particular piece of material, when the applied voltage *V* is increased, the current *I* increases in the same proportion. In other words,

$$V = IR$$

The constant of proportionality is called resistance, *R*. This is Ohm's law.

When a voltage is applied to a conductor such as a copper wire, the mobile electrons within the wire are accelerated by the electric field, then collide with other electrons and atoms losing kinetic energy as electromagnetic radiation (i.e. heat). Eventually the net average velocity of the electrons reaches a steady value called the drift current, and the rate of flow of charge through the wire is constant. This is direct current, DC.

If the applied electric field, i.e. the voltage, is periodically reversed in polarity, the current changes direction periodically as well. This is alternating current, AC.

The rate of conversion of electric energy into heat is the power *P* dissipated by the circuit and is calculated from both the voltage *V* and the current *I*, of the current I and the resistance *R*.

$$\begin{aligned} P &= VI \\ &= I^2R \end{aligned}$$

Significant complications arise when components like capacitors and inductors are present in a circuit since the resistance to the flow of current in these devices depends on the rate of application of voltage and current to them (Chapter 4).

What is not often appreciated are the difficulties arising from inductances. An inductor is a coil of wire which, when current passes through it, forms an electromagnet. However, when the current is increasing, there is a backwards acting voltage applied to resist the incoming current. When the current is turned off, the magnetic field in the inductor reduces and the changing field induces a voltage in the coil that attempts to keep the current running. Both these effects play a significant role in the operation of the ignition coil.

10.2 Battery

A battery is a collection of electrochemical cells arranged in series. In a motor vehicle lead acid battery, there are six cells, each producing about 2V, arranged in series to provide 12V for the vehicle. The oxidation-reduction chemical species involved are:

In (a), with no load connected across the output, the output voltage $V_{out} = V_T$. This is the open-circuit voltage $V_{oc} = V_T$. In effect, the "load resistance" is infinite. In (b), if we reduce the load resistance R_L from an infinitely high value, the current drawn from the power supply increases and the output voltage V_{out} decreases. Why? Because of the voltage drop across R_{int}. As $R_L \rightarrow 0$, the current reaches a maximum called the short-circuit current and all of V_T is dropped across R_{int}. With $R_L = 0$, it is evident that all of V_T must be dropped across R_{int}.

That is, in practice, V_T and I_{sc} can be measured by measuring the open-circuit voltage and short circuit current. It is strongly advised that the short circuit current of a motor vehicle battery not be measured directly since the current is extremely large, and the resulting heat dissipated in the "internal resistance" would most likely cause an explosion. However, the internal resistance can be estimated from the voltage drop at the battery terminals when the starter motor is operated and the current through the starter motor is measured. Some early design battery testing machines impose a heavy current drain on the battery and monitor the terminal voltage as a measure of battery health. For a 12V motor vehicle battery, the internal resistance is a few mΩ.

V_T and R_{int} are useful tools for reducing a complicated power supply circuit to a simpler circuit. This is Thevenin's theorem. That is, any two-terminal voltage source, no matter how complicated, can be represented by V_T and R_{int}.

If a battery is through of as containing a cell and an internal resistance, then a much better understanding of what happens in a vehicle electrical system can be had. For example, when a high current device is activated, such as the starter motor, it is observed that the headlamps dim. This is because even though the interior cell voltage may remain the same at 12.15V, the voltage drop across the internal resistance increases as more current is drawn from the battery, and consequently, the terminal voltage decreases and the headlamps dim.

The internal resistance increases as the cell deteriorates with age and use to the point where it cannot be reversed by charging and so little if no current can be drawn before all the available cell voltage is dropped across it. The battery is flat.

10.3 Starter Motor and Generator

10.3.1 Electromagnetic Induction

The operation of the starter motor and the generator relies on the remarkable circumstance that if a charged particle, whether positive or negative, with a charge q moves with a velocity v in a magnetic field of strength B, a force F is exerted on that particle. In circuit analysis, the charged particle that moves is taken to be positively charged for historical reasons.

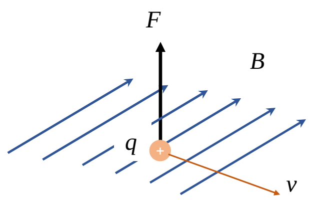


Fig. 10.3.1 *Force experienced by a charged particle in a magnetic field*.

With a spark, not only is light emitted, but a whole spectrum of electromagnetic waves and since these waves fall into the radio spectrum, are received by the radio aerial and amplified along with the desired station.

It is therefore common practice to eliminate this source of radio interference by the use of a suppressor in the ignition leads.

It is the rapid fluctuations in current across the plug gap result in emission of radio frequency electromagnetic radiation (i.e., static). The "time constant" of such a circuit depends on the product of the resistance R and the capacitance C. Increasing the resistance of the circuit increases the time constant, and so the fluctuations are at a lower frequency – leading to reduced radiation emission in the radio spectrum, thus reducing the static that we hear.

In the case of the ignition leads, the circuit consists of a resistor (the wire) and a capacitor (the plug gap and the distributor cap gap).

10.8 Wiring and Fuses

10.8.1 Wiring Harness

Wiring harnesses for vehicles using Lucas electrical equipment follows a standardised design. Most wires for low current systems are specified as either 9/0.012 (5A capacity) or 14/0.012 (7A capacity) with rubber and fabric insulation. Heavy duty cables such as those for headlamps are 28/0.012 (14A capacity) while the main battery feed from the starter switch and generator output is 44/0.012 (22A). The first number in these specifications being the number of strands and the second, the strand diameter in inches. 0.012" diameter cable is equivalent to 30 SWG. Heavy copper stranded cable 37/20 SWG is used for the battery connection and starter motor. In general, but dependent on conditions, the current carrying capacity of the wires in the harness are:

Wire size	Current Carrying Capacity
9/0.012	5
14/0.012	7
28/0.012	14
44/0.012	22
37/20 SWG	Starter Cable 400A

Table 10.8.1 *Current carrying capacity of wire*.

Feed wires are brown for current supply or feed to all services, white for ignition-switch controlled circuits, yellow for generator and field circuits.

Colour	Application
Red	Side and tail lamp circuits starting from light switch.
Blue	Headlamp lighting circuit starting from light switch.
Purple	Auxiliary circuits protected by a fuse A2.
Green	Auxiliary circuits fed through the ignition switch and protected by fuse A4.
Black	Earth circuit.

Table 10.8.2 *Lucas circuit colour coding*.

CHAPTER 11.
BODY

11.1 Body Engineering

11.1.1 Introduction

The design of a motor vehicle body as distinct from the mechanicals is of course of utmost importance in determining the success of the vehicle in the market. There are two aspects to body design which should, in ideal circumstances, work hand in hand: body engineering and styling.

The most critical aspect of body engineering is mass, or weight. Overall weight is a determining factor for the cost, and hence selling price of the model. For vehicles manufactured and sold by BMC in Australia, body design was largely outside the control of local engineers – it being done in UK. However, during the years 1968 to 1973, the local company had the opportunity to design and build a vehicle model range entirely from scratch – Model A, and Model B. Model B was to become the Leyland P76. Model A was eventually named P82, but never made it beyond a prototype stage. As such, local engineers took on a significantly greater responsibility than previously. The only design target at this point was that the factory should produce a large vehicle to compete with other local manufacturers who were enjoying considerable sales successes with their models. As well, to cater for the market for smaller vehicles, that within which BMC were more familiar, a new small to medium sized model would be designed with many common design features as the larger car.

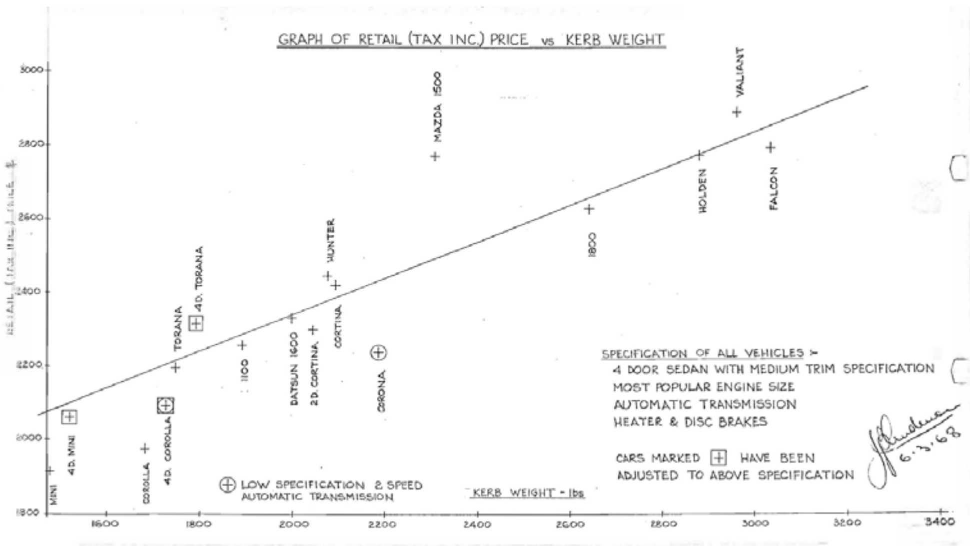


Fig. 11.1.1 *Retail price vs kerb weight for various vehicles in the Australian market both large and small, 1968*.

particular motor vehicle is a public statement of support for the vehicle's style, and to a lesser extent, its engineering. Should the customer not wish to be personally associated with a vehicle, it can always be said that "it's a company car", but for the most part, the car is an extension of the customer's personality. a statement of his or her astuteness, and an indication of aesthetic taste.

Styling at BMC/Leyland both in UK and Australia always appeared to have an uneasy relationship with engineering. When leaving the UK company, Roy Haynes wrote to Australian Managing Director David Beech saying

> *"It all gets back to how much importance you attach to the value of styling and what sort of car is eventually reflected to the buyer."*

11.3 Rust

11.3.1 Chemical Reaction

In simple terms, the complex redox reaction for the rusting of iron and steel is written as:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

In practice, the rusting of iron requires both air (O_2) and water, and the reaction proceeds as a series of steps. The oxidation half-reaction is:

$$Fe(s) \rightarrow Fe_2^{2+} + 2e^-$$

And the reduction half-reaction is:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The OH^- ions react with the Fe^{2+} ions:

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$
$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow Fe(OH)_3(s)$$
$$Fe(OH)_3(s) \rightarrow Fe_2O_3, H_2O + 2H_2O$$

The brown coloured metal we usually associate with rust is the compound

$$Fe_2O_3, H_2O$$

an Fe(III) hydrated oxide.

Iron and steel often rust badly because the rust has a lower density than the parent metal and tends to flake off, thus exposing more of the material to water and oxygen and promoting further rusting.

Water and oxygen are typically excluded by painting the article. However, a very effective way to reduce rusting of iron is to attach a more reactive metal (i.e. one with a lower E^o so that the iron undergoes reduction and the sacrificial anode (usually zinc) undergoes oxidation. This process is often called cathodic protection. The chemical species involved are:

CHAPTER 12.
LIGHTING & MIRRORS

12.1 Introduction

Most repair and parts books put lighting in with the electrical system, but there is more to motor vehicle lighting than just the way in which they are powered. In the early days of the motor vehicle, lights were power by burning gases. Once a source of light is established, whether it be by heat, or some other means, then the process of light transmission to outside the vehicle is important.

As well, mirrors both internal and external, are important safety features of any motor vehicle and the passage of light incident and reflected from them deserves some attention and analysis.

These topics are therefore the subject of this chapter.

12.2. Reflection and Refraction

12.2.1 Reflection

Consider a light source in the form of a point. The directions in which light waves radiate from the source are indicated by straight lines called rays. Rays are drawn perpendicular to the wave front of the light waves.

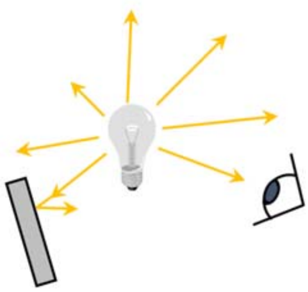


Fig. 12.2.1 *Light rays emanating from a light source*.

Rays of light emanate from the source and radiate outwards in all directions. Some rays enter an observer's eye and are focussed by the lens in the eye to form an image of the source on the retina. Other rays are reflected and/or absorbed by the surroundings.

When light rays strike a surface, the angle of reflection = the angle of incidence.

$$\theta_i = \theta_r$$

$$\frac{1}{f} = \left[\frac{n_2}{n_1} - 1\right]\left[\frac{1}{r'} - \frac{1}{r}\right]$$

The linear magnification *m* is the ratio of the image size to the object size:

$$m = \frac{h'}{h} = -\frac{s'}{s}$$

where n_1 is the refractive index of the medium (e.g. air), and n_2 is the refractive index of the lens material.

The power of a thin lens in air is given by the reciprocal of the focal length and has units dioptres.

$$P = \frac{1}{f}$$

12.3. Headlamps

Headlamps are used primarily to light the road ahead so that the driver may see where he or she is going at night. There are two problems to be overcome. First, the source of the light must provide as white a light as possible, consume as little current as possible, and withstand the mechanical and electrical shock of going from room temperature to full heat in less than a millisecond. Secondly, once the light is produced, it must be directed to illuminate the road ahead without dazzling oncoming drivers.

As far as the headlamps go, the light source for BMC cars of the 1960s is a filament globe located at the focus of a parabolic mirror. Rays which reflect off the mirror are parallel. They then pass through the front lens of the headlamp and are refracted. A shield is placed over the filament to block direct transmission from the filament to the glass lens. Sometimes the shield takes the form of what is called a "getter", a silvery film inside the bulb which is used to adsorb the final traces of gas during manufacture of the globe.

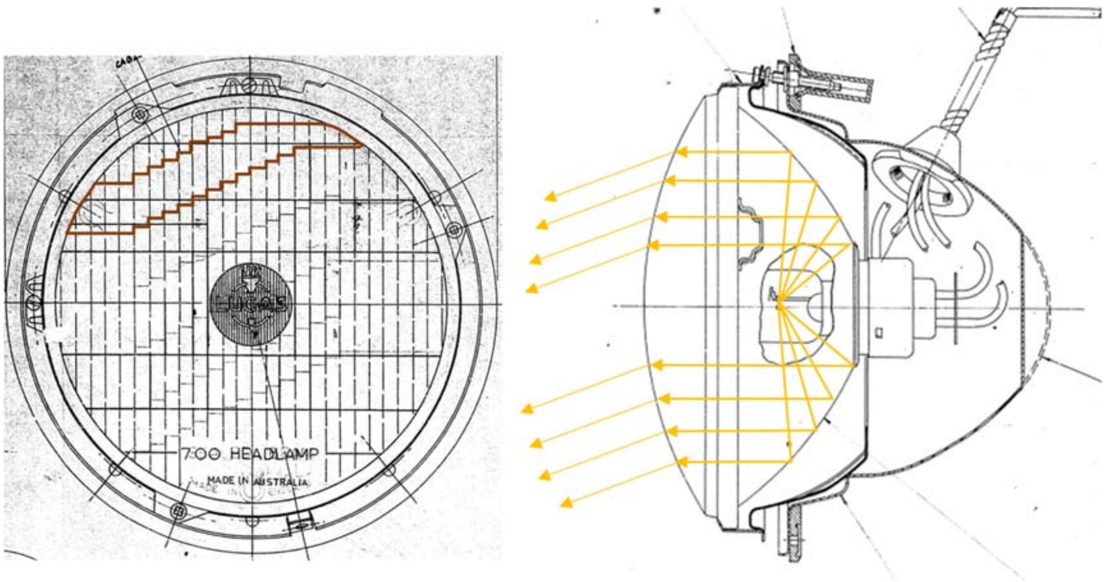


Fig. 12.3.1 *Rays emanating from a headlamp*.

In practice, there are usually two filaments side by side in the globe. The main or high beam filament is located at the focus, while the dipped beam is mounted a little off focus so as to cause the emanating rays to be directed downwards a little rather than straight ahead as shown in Fig. 12.3.1. However, rays arising from the off-focus position are divergent from the outer edges of the parabolic reflector and so must the steered downwards by the glass lens.

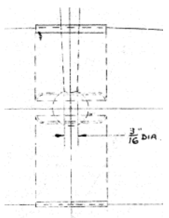
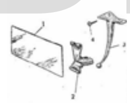
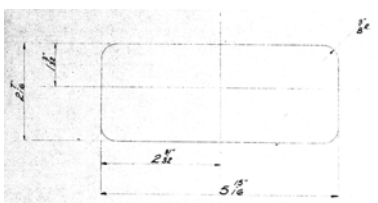
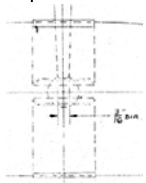
The glass lens comprises several different areas which are designed to direct light rays in the desired direction. Fig. 12.3.1 shows one area at the top left where the thickness of glass is greater compared to the region below it. The thickness is calculated so that the rays are projected downwards. These portions of the lens also act on the main beam bringing the light rays downward where they are of more use.

Horizontal spread of the beam is controlled by the vertical flutes in the glass. These act as concave lens which cause the rays to diverge as shown in Fig. 12.2.7. In addition, the divergence is biased towards the left for RHD vehicles and to the right for LHD vehicles.

12.4 Interior Mirrors

There are 32 different interior mirrors used throughout the BMC/Leyland range counting both UK and Australian manufacture. For the Australian Morris Mini range, later models use interior mirrors are common to the Leyland P76 and Marina models.

A review of the Service Parts Lists and drawings for Mini and Moke show the following details:

Parts Book	Model	Mirror	Bracket	Parts Book Picture or Photo
HYL 2980 PUB 1012	ADO15	14A5762 (ND) Clips 14A5763 (14A5578)  • See discussion at end of Table for more information about clips.	14A7036 (ND) 	
HYL 2980 PUB 1012	ADO15	14G3747 (alternative to 14A5762) 	14A7036 (ND) Clips 14A5763  Black crackle finish.