THE ELECTRIC VEHICLE GUIDE
A Beginner’s Guide to EV Technology
The Electric Vehicle Guide Book
A Guide to Electric-Vehicle Technology

The guidebook documents the experience and knowledge gained from DIYguru’s consultants. Using IEEE, SAE, ARAI and ASME as the accountability tool, the resource has been designed to foster improvement in overall technical and nontechnical knowledge of electric vehicle. The guidebook will be continuously updated and expanded to encompass the new technology in this domain. It is our hope that by creating and sharing this resource, we can support others in their learning as we all strive to meet the profound challenge of becoming an environmentally sustainable society.
Project Team

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Foreword

This Beginners Guide on Electric Vehicle Technology is a crucial guide for anyone who wants to have a clear picture of what an Electric Vehicle Fundamentally constitutes and how the different part works altogether to make the car run on the road. After reading this book, the reader will be in a position to deep dive into the detailed Technical aspects of Electric Vehicle Engineering. The book is written in a very simple and lucid manner explaining each and every component that constitutes the whole body. There has been a brief discussion on the history and advancement of electric vehicles since 90’s.

I congratulate Mr. Nikhil, Mr. Anubhav and other DIYguru members and Board of Advisors on putting forward this book with accuracy and precision. Mr. Nikhil has been instrumental in making the Formula Electric Community stronger in India, he has been the champion of Formula Student Event in 2016 and has been the mentor for teams from IIT’s & NIT’s in India. Mr. Anubhav has worked as a design engineer with Volvo and has five years of experience in formulating contents and delivering it to engineers in house.

And, finally, I thank each and every entrepreneur associated with DIYguru for opening their knowledgebase and sharing their valuable insights in E-Mobility. Strive For Excellence!

Mr. Avinash Kumar Singh
Director, DIYguru Education and Research Pvt. Ltd.
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1. Electric and Hybrid Vehicle

Introduction

There are two basic types of EVs:

a) Electric vehicles (EVs)
b) Plug-in hybrid electric vehicles (PHEVs)

All-electric vehicles (AEVs) run only on electricity. Most have all-electric ranges of 80 to 100 miles, while a few luxury models have ranges up to 250 miles. When the battery is depleted, it can take from 30 minutes (with fast charging) up to nearly a full day (with Level 1 charging) to recharge it, depending on the type of charger and battery.

If this range is not sufficient, a plug-in electric vehicle (PHEV) may be a better choice. PHEVs run on electricity for shorter ranges (6 to 40 miles), then switch over to an internal combustion engine running on gasoline when the battery is depleted. The flexibility of PHEVs allows drivers to use electricity as often as possible while also being able to fuel up with gasoline if needed. Powering the vehicle with electricity from the grid reduces fuel costs, cuts petroleum consumption, and reduces tailpipe emissions compared with conventional vehicles. When driving distances are longer than the all-electric range, PHEVs act like hybrid electric vehicles, consuming less fuel and producing fewer emissions than similar conventional vehicles.

a) Electric Vehicle

All-electric vehicles (AEVs) run only on electricity. Most have all-electric ranges of 80 to 100 miles, while a few luxury models have ranges up to 250 miles. When the battery is depleted, it can take from 30 minutes (with fast charging) up to nearly a
full day (with Level 1 charging) to recharge it, depending on the type of charger and battery.

b) Hybrid electric Vehicle

Hybrid electric vehicles are powered by an internal combustion engine and an electric motor, which uses energy stored in batteries. A hybrid electric vehicle cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and by the internal combustion engine. The extra power provided by the electric motor can potentially allow for a smaller engine. The battery can also power auxiliary loads like sound systems and headlights, and reduce engine idling when stopped. Together, these features result in better fuel economy without sacrificing performance.

Modern HEVs make use of efficiency-improving technologies such as regenerative brakes which convert the vehicle's kinetic energy to electric energy, which is stored in a battery or supercapacitor. Some varieties of HEV use an internal combustion engine to turn an electrical generator, which either recharges the vehicle's batteries or directly powers its electric drive motors; this combination is known as a motor-generator.

History

The invention of the first model electric vehicle is attributed to various people. In 1828, Ányos Jedlik invented an early type of electric motor, and created a small model car powered by his new motor. In 1834, Vermont blacksmith Thomas
Davenport built a similar contraption which operated on a short, circular, electrified track. In 1834, Professor Sibrandus Stratingh of Groningen, the Netherlands and his assistant Christopher Becker created a small-scale electric car, powered by non-rechargeable primary cells.

An electric vehicle held the vehicular land speed record until around 1900. The high cost, low top speed, and short range of battery electric vehicles, compared to later internal combustion engine vehicles, led to a worldwide decline in their use; although electric vehicles have continued to be used in the form of electric trains and other niche uses.

**Economic and Environmental Impact**

Electric cars (EVs) (also known as battery electric cars) have several environmental benefits compared to conventional internal combustion engine cars. They have lower operating and maintenance costs, produce little or no local air pollution, reduce dependence on petroleum and also have the potential to reduce greenhouse gas emissions. Electric motors are significantly more efficient than internal combustion engines and thus, even accounting for distribution losses, less energy is required to operate an EV. Producing batteries for electric cars requires additional resources and energy, so they may have a larger environmental footprint when new.

Reduced noise emissions resulting from substantial use of the electric motor at idling and low speeds, leading to roadway noise reduction, in comparison to conventional gasoline or diesel powered engine vehicles, resulting in beneficial noise health effects (although road noise from tires and wind, the loudest noises at highway speeds from the interior of most vehicles, are not affected by the hybrid design alone). Reduced noise may not be beneficial for all road users, as blind people or the visually impaired consider the noise of combustion engines a helpful aid while crossing streets and feel quiet hybrids could pose an unexpected hazard.

**Basic Design**

a) **Configuration of Electric Vehicle**
b) Various Architecture of Hybrid Electric Vehicle

(a) Series hybrid
(b) Parallel hybrid
(c) Series-parallel hybrid
(d) Complex hybrid

Operating modes

a) Electric Vehicle
Motor and battery only
To see the full content of this book, enroll in DIYguru Electric Vehicle Course.
3. Fuel Cells

Hydrogen + Oxygen = Electricity + Water Vapor

Cathode: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$
Anode: $2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$
Overall: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

A fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy. A PEM (Proton Exchange Membrane) cell uses hydrogen gas (H2) and oxygen gas (O2) as fuel. The products of the reaction in the cell are water, electricity, and heat. This is a big improvement over internal combustion engines, coal burning power plants, and nuclear power plants, all of which produce harmful by-products.

Since O2 is readily available in the atmosphere, we only need to supply the fuel cell with H2 which can come from an electrolysis process (see Alkaline electrolysis or PEM electrolysis).
Fuel Cell Technologies

a) Hydrogen Fuel cell

![Alkaline Fuel Cell Diagram]

b) Proton exchange Membrane

![Proton Exchange Membrane Diagram]

c) Direct methanol Fuel cell
d) Molten Carbonate Fuel Cell
4. Short Term Storage Systems

Ultra flywheel

Flying wheel energy storage systems (FESS) use electric energy input which is stored in the form of kinetic energy. Kinetic energy can be described as “energy of motion,” in this case the motion of a spinning mass, called a rotor. The rotor spins in a nearly frictionless enclosure. When short-term backup power is required because utility power fluctuates or is lost, the inertia allows the rotor to continue spinning and the resulting kinetic energy is converted to electricity.

Most modern high-speed flywheel energy storage systems consist of a massive rotating cylinder (a rim attached to a shaft) that is supported on a stator – the stationary part of an electric generator – by magnetically levitated bearings. To maintain efficiency, the flywheel system is operated in a vacuum to reduce drag. The flywheel is connected to a motor-generator that interacts with the utility grid through advanced power electronics.

Supercapacitors
In the best factories cell assembly is usually carried out on highly automated equipment, however there are still many smaller manufacturers who use manual assembly methods.

Prismatic Cells

Prismatic cells are often used for high capacity battery applications to optimize the use of space. These designs use a stacked electrode structure in which the anode
and cathode foils are cut into individual electrode plates which are stacked alternately and kept apart by the separator. The separator may be cut to the same size as the electrodes but more likely it is applied in a long strip wound in a zig zag fashion between alternate electrodes in the stack.

**Cylindrical Cells**

For cylindrical cells the anode and cathode foils are cut into two long strips which are wound on a cylindrical mandrel, together with the separator which keeps them apart, to form a jelly roll (Swiss roll in the UK). Cylindrical cells thus have only two electrode strips which simplifies the construction considerably.

**Formation**

Once the cell assembly is complete the cell must be put through at least one precisely controlled charge / discharge cycle to activate the working materials, transforming them into their usable form. Instead of the normal constant current - constant voltage charging curve, the charging process begins with a low voltage which builds up gradually. This is called the Formation Process. For most Lithium chemistries this involves creating the SEI (solid electrolyte interface) on the anode. This is a passivating layer which is essential for moderating the charging process under normal use.

**C-rate (hours)**

Sometimes the battery specification may refer to the C-Rate or charge time (hours). The Nominal Capacity of the battery is given at this C Rate. The discharge current can then be worked out from the C Rate and the Nominal Capacity.
Recycling Batteries

Widespread battery recycling would keep hazardous materials from entering the waste stream, both at the end of a battery's useful life, as well as during its production. Work is now under way to develop battery-recycling processes that minimize the life-cycle impacts of using lithium-ion and other kinds of batteries in vehicles. But not all recycling processes are the same:

a) Smelting

Smelting processes recover basic elements or salts. These processes are operational now on a large scale and can accept multiple kinds of batteries, including lithium-ion and nickel-metal hydride batteries. Smelting takes place at high temperatures, and organic materials, including the electrolyte and carbon anodes, are burned as fuel or reductant. The valuable metals are recovered and sent to refining so that the product is suitable for any use. The other materials, including lithium, are contained in the slag, which is now used as an additive in concrete.

b) Direct recovery

At the other extreme, some recycling processes directly recover battery-grade materials. Components are separated by a variety of physical and chemical processes, and all active materials and metals can be recovered. Direct recovery is a low-temperature process with minimal energy requirements.

c) Intermediate processes

The third type of process is between the two extremes. Such processes may accept multiple kinds of batteries, unlike direct recovery, but recover materials further along the production chain than smelting does.
Battery Management System

The BMS is the brains behind plug-in hybrid (PHEV) and electric vehicles (EV), managing battery and other vital vehicle functions, so certainly this debate is essential in determining the proper technology and placement thereof to ensure years of increased PHEV and EV production without rapidly aging the charging infrastructure.

Battery management systems work in real time to control many functions including battery monitoring, maintenance, regeneration, battery optimizing, failure prediction and/or prevention, battery data collection/analysis and planning. BMSs are an integral component of PHEVs and EVs to ensure proper battery operation and to protect the highly expensive automotive component.

Apart from the battery module, the key components in the BMS include the following:

Battery Monitoring Unit (BMU): It uses a microprocessor-based unit to monitor the various parameters such as state of charge, cell balancing and cell temperature and compares them with the specifications and communicate to the BCU. It also communicates with other devices through the CAN bus.

Battery Control Unit (BCU): It receives inputs from the BMU and incorporates any remedial measures needed to protect the battery or balance the cell or maintain the SOC. BCU is designed with power electronics components.
Control Wiring

Two aviation-style screw-lock plugs for all control/low power connections—one with 4 pins for the throttle and one with 5 pins for power input and CAN bus connections. The diagram below shows pin identifications as viewed on the controller case.

Plug 1: Throttle

- a) 5V: Output power supply for throttle. Max 50mA output (internal self-resetting fuse).
- b) Gnd: Ground connection for throttle.
- c) Throttle A: First throttle input, usually the analog level, 0-5V input.
- d) Throttle B: Second throttle input, either enable switch or 2nd analog, 0-5V input.
- e) Plug 2: Power and CAN
  - f) 12V In: Connect to a key-switched 12V supply so the controller comes on when the key is turned on. Often wired in parallel with your main contactor. Maximum voltage range 8-18V input, approx. 200mA draw.
  - g) Gnd: Connect to ground / vehicle chassis.
  - h) CAN L and CAN H: Two wires for CAN bus communications.
  - i) Shield: Not required (usually for pass through of shielding on CAN-bus cables).

CAN Bus Communications

The industry-standard CAN bus interface, allowing the user to monitor and/or log information in real-time from the controllers such as voltages, currents, throttle levels, controller temperature, and a variety of possible error conditions. It also supports throttle control over CAN bus, and the reprogramming of controller settings.

The easy way to interface over CAN bus is to use our EVMS Monitor. The Monitor will automatically detect the motor controller on the bus and display operating information on its colour touchscreen. (An EVMS Core or Lite can share the same CAN bus and EVMS Monitor if present, but is not required.)
The following settings are available:

a) **Minimum battery voltage:**

This setting can be useful to avoid overworking or over-discharging your battery, by setting it to whatever voltage represents a low state of charge (flat battery). Note that this cannot replace a proper battery management system for protecting your cells!

b) **Maximum motor voltage:**

If using a motor rated to a lower voltage than your battery pack, you can use this setting to ensure that the motor controller will not over-speed the motor.

c) **Maximum motor current:**

In vehicles with smaller motors, you may wish to reduce the maximum motor current in order to avoid damaging your motor from overcurrent. Most larger Series DC motors will be fine with the maximum 600A setting.

d) **Maximum battery current:**

If using small or weak batteries, you can adjust this setting to avoid overworking your batteries. (This typically does not affect acceleration when setting off, but may reduce high speed performance.)
To see the full content of this book, enroll in DIYguru Electric Vehicle Course.
9. Regenerative Braking

Energy Recovery System

The energy stored under braking is made available to the pilot, who can decide to reuse it in specific situations - straight stretches, while overtaking other cars or at strategic points of the track - providing a power boost during each lap through a pushbutton or throttle.

The device is connected directly to the drive shaft through a motor-generator that, under braking, driven by the same shaft, converts kinetic energy into electrical energy. Through the control unit and through shielded wiring, this current recharge lithium ion batteries. Under acceleration, on the other hand, kinetic energy is taken from the batteries when the pilot operates the power boost and, again through the electronic control unit, it is sent to the motor-generator, which rotates in the opposite direction and applies an accelerating force on the drive shaft. The motor-generator can reach up to 40,000 revolutions per minute.
The Advanced Hybrid Electrical Systems ingeniously recycle energy produced by the brakes and exhaust gases. Optimizing power through these advanced efficiencies

**Turbocharger**
Mechanics of Force Generation

The forces on a tire are not applied at a point, but are the resultant from normal and shear stresses distributed in the contact patch. The pressure distribution under a tire is not uniform but will vary in the X and Y directions. When rolling, it is generally not symmetrical about the Y-axis but tends to be higher in the forward region of the contact patch.

Because of the tire’s visco-elasticity, deformation in the leading portion of the contact patch causes the vertical pressure to be shifted forward. The centroid of the vertical force does not pass through the spin axis and therefore generates rolling resistance. With a tire rolling on a road, both tractive and lateral forces are developed by a shear mechanism. Each element of the tire tread passing through the tire contact patch exerts a shear stress which, if integrated over the contact area, is equal to the tractive and/or lateral forces developed by the tire.

There are two primary mechanisms responsible for the friction coupling between the tire and the road. Surface adhesion arises from the intermolecular bonds between the rubber and the aggregate in the road surface. The adhesion component is the larger of the two mechanisms on dry roads, but is reduced substantially when the road surface is contaminated with water; hence, the loss of friction on wet roads. The hysteresis mechanism represents energy loss in the rubber as it deforms when sliding over the aggregate in the road. Hysteresis friction is not so affected by water on the road surface, thus better wet traction is achieved with tires that have high-hysteresis rubber in the tread. Both adhesion and hysteresis friction depend on some small amount of slip occurring at the tire-road interface.
Slip Angle
In vehicle dynamics, slip angle of sideslip angle is the angle between the direction in which a wheel is pointing and the direction in which it is actually traveling (i.e., the angle between the forward velocity vector \(v_x\) and the vector sum of wheel forward velocity \(v_x\) and lateral velocity \(v_y\), as defined in the image to the right). This slip angle results in a force, the cornering force, which is in the plane of the contact patch and perpendicular to the intersection of the contact patch and the midplane of the wheel. This cornering force increases approximately linearly for the first few degrees of slip angle, and then increases non-linearly to a maximum before beginning to decrease.

![Image showing slip angle and its effects](image)

Causes
A non-zero slip angle arises because of deformation in the tire carcass and tread. As the tire rotates, the friction between the contact patch and the road results in individual tread 'elements' (finite sections of tread) remaining stationary with respect to the road. If a side-slip velocity \(u\) is introduced, the contact patch will be deformed. When a tread element enters the contact patch, the friction between the road and the tire causes the tread element to remain stationary, yet the tire continues to move laterally. Thus, the tread element will be ‘deflected’ sideways. While it is equally valid to frame this as the tire/wheel being deflected away from the stationary tread element, convention is for the coordinate system to be fixed around the wheel mid-plane. While the tread element moves through the contact patch it is deflected further from the wheel mid-plane. This deflection gives rise to the slip angle, and the cornering force. The rate at which the cornering force builds up is described by the relaxation length.

Effects
The ratios between the slip angles of the front and rear axles (a function of the slip angles of the front and rear tires respectively) will determine the vehicle's behavior
in a given turn. If the ratio of front to rear slip angles is greater than 1:1, the vehicle will tend to understeer, while a ratio of less than 1:1 will produce oversteer. Actual instantaneous slip angles depend on many factors, including the condition of the road surface, but a vehicle’s suspension can be designed to promote specific dynamic characteristics. A principal means of adjusting developed slip angles is to alter the relative roll couple (the rate at which weight transfers from the inside to the outside wheel in a turn) front to rear by varying the relative amount of front and rear lateral load transfer. This can be achieved by modifying the height of the roll centers, or by adjusting roll stiffness, either through suspension changes or the addition of an anti-roll bar.

Because of asymmetries in the side-slip along the length of the contact patch, the resultant force of this side-slip occurs away from the geometric center of the contact patch, a distance described as the pneumatic trail, and so creates a torque on the tire, the so-called self-aligning torque.

**Treactive Properties**

Under acceleration and braking, additional slip is observed as a result of the deformation of the rubber elements in the tire tread as they deflect to develop and sustain the friction force.

![Diagram of tire with contact length and travel direction](image)

**Braking deformation in the contact patch**

**Slip**

On a dry road, when the slip approaches approximately 15-20 percent, the friction force will reach a maximum (typically in the range of 70 to 90 percent of the load) as the majority of tread elements are worked most effectively without significant slip. Beyond this point friction force begins to drop off as the slip region in the rear
of the contact patch extends further forward. The force continues to diminish as the tire goes to lockup (100% slip).

Brake forces v/s slip

**Vertical Load**

Increasing vertical load is known categorically to reduce friction coefficients under both wet and dry conditions. That is, as load increases, the peak and slide friction forces do not increase proportionately. Typically, in the vicinity of a tire’s rated load, both coefficients will decrease on the order of 0.01 for a 10% increase in load.

**Inflation Pressure**

On dry roads, peak and slide coefficients are only mildly affected by inflation pressure. On wet surfaces, inflation pressure increases are known to significantly improve both coefficients.
Speed
On dry roads, both peak and slide coefficients decrease with velocity as illustrated in Figure 10.9. Under wet conditions, even greater speed sensitivity prevails because of the difficulty of displacing water in the contact patch at high speeds. When the speed and water film thickness are sufficient, the tire tread will lift from the road creating a condition known as hydroplaning.

![Sliding coefficient as a function of speed on various surfaces](image)
11. Automotive Chassis

Materials

Before deciding which material is most suitable for any particular component, we clearly need to know something about material properties, and the main properties of concern to us are:

- Strength
- Stiffness
- Density (or specific gravity)
- Ductility
- Fatigue resistance
- Available joining methods
- Cost of material
- Cost of machining and working

Top left shows the meaning of the term stress. The significance of strain is shown below that. A typical stress strain curve for steel is on the right. The initial slope of the line is the Young’s Modulus.

The stress strain curve shows the typical performance of a non-brittle material such as the grades of steel used in frame construction. If we subject a piece of the material to a stress below the yield limit then a certain degree of strain occurs, as explained above, but this is elastic strain and when we remove that stress then the material returns to its original unstrained shape and size. This is called elastic deformation because it behaves like a spring. However, if we attempt to apply a higher stress than the yield point, then the material gives and deforms permanently. When the stress is removed the object does not return to its original condition. This is known as plastic deformation. When we continue to apply sufficient load beyond the yield point, we reach the point of ultimate failure and the material actually breaks. The amount of strain that occurs between the yield point and the failure point is a measure of the materials ductility.
Density is a measure of mass per unit volume; hence, size for size, it compares the masses of different materials. We get the same comparison from specific gravity, since that is just the density of any material compared with that of water under standard conditions. The above properties are a rough guide only, as the tensile strength may vary considerably, depending on the metal composition or alloy and its state of heat treatment and working. In particular the tubing used for frame construction will lose some strength after welding, and composites vary considerably.

The specific gravity and Young’s Modulus do not vary in this way. In the above table, the term “relative stiffness” means the ratio of Young’s Modulus to specific gravity referenced to that of steel, which is a measure of stiffness per unit weight. Thus, the most efficient way to use light-weight materials is to make the sections as large as possible consistent with maintaining a practical wall thickness. But, in maintaining similar structural characteristics to those of steel, our light alloy tube will weigh more than a simple comparison of density indicates. The density of aluminum is 33 per cent that of steel but the structural weights of our bar and tube in the foregoing examples are 58 and 70 per cent respectively.

The terms chrome-moly, T45, 4130 and 531 are frequently bandied about as though they have some magical significance, implying extra stiffness and lightness, to such steels. In fact, these terms are simply standards or commercial references and refer to steels with alloying elements calculated to enhance strength, particularly strength after welding. Their Young’s modulus, hence stiffness, is no different from that of other steel alloys, nor is their density.

A Reynolds trade name, 531 is often referred to as chrome-moly, whereas it is actually a manganese molybdenum steel, which Reynolds claim has superior properties to those of a chrome-molybdenum steel. For many years this tube type

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<td>7.3</td>
<td>1.27</td>
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<td>7.8</td>
<td>2.1</td>
<td>1.00</td>
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<td>78</td>
<td>7.8</td>
<td>2.1</td>
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<td>2.7</td>
<td>0.7</td>
<td>0.95</td>
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<td>2.7</td>
<td>0.44</td>
<td>0.96</td>
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<tr>
<td>Titanium alloys</td>
<td>47 - 126</td>
<td>4.4</td>
<td>1.2</td>
<td>1.01</td>
</tr>
<tr>
<td>Nylon</td>
<td>8</td>
<td>1.1</td>
<td>0.14 – 0.26</td>
<td>0.47 – 0.95</td>
</tr>
<tr>
<td>PVC</td>
<td>6</td>
<td>1.4</td>
<td>0.026 – 0.042</td>
<td>0.07 – 0.11</td>
</tr>
<tr>
<td>PTFE (Teflon)</td>
<td>13</td>
<td>2.2</td>
<td>0.036 – 0.042</td>
<td>0.06 – 0.07</td>
</tr>
<tr>
<td>GRP (Glass Reinforced Plastic)</td>
<td>16 – 35</td>
<td>1.7</td>
<td>0.07 – 0.2</td>
<td>0.15 – 0.44</td>
</tr>
<tr>
<td>Carbon fibre (In direction of fibres, Fibres only, properties reduced in resin matrix)</td>
<td>140</td>
<td>1.6</td>
<td>2.2</td>
<td>5.11</td>
</tr>
</tbody>
</table>
was a favorite amongst British specialist frame builders. The main alloying elements in Reynolds 531 are as follows:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.23 to 0.29 per cent</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.15 to 0.35 per cent</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.25 to 1.45 per cent</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.15 to 0.25 per cent</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.45 per cent maximum</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.45 per cent maximum</td>
</tr>
</tbody>
</table>

Its minimum strength properties are:

<table>
<thead>
<tr>
<th></th>
<th>Yield stress</th>
<th>Ultimate stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>As drawn</td>
<td>71 kgf/mm²</td>
<td>79 kgf/mm²</td>
</tr>
<tr>
<td>After brazing</td>
<td>63 kgf/mm²</td>
<td>71 kgf/mm²</td>
</tr>
</tbody>
</table>

These figures indicate the excellent retention of strength after brazing, which is a great boon. The use of this and other high-strength tubing is normally confined to competition machines, for roadsters the extra cost is not usually warranted. Now that we have dealt with the principles underlying the selection of materials, let us consider the choices open for various components.

Frame

Steel is easily the most common material here, either as tube or sheet, depending on design. There are several reasons for its choice, viz:

- Raw material cost is relatively low.
- Well-developed manipulating and joining techniques are available.
- Young’s Modulus is high, so the required stiffness can be obtained with small tube sizes.
- Aluminum has often been used for specials and racing machines in the form of monocoques and large section backbones such as the fabricated Ossa and Kawasaki mentioned earlier. Cast-aluminum backbones have been tried by Eric Offenstadt in France and Terry Shepherd in England. However, components such as complete frames are rarely cast because the minimum material thickness needed for the casting process usually results in excessively heavy components.
Then tubular aluminum frames started to appear on works racers, with Yamaha taking the initiative. This trend started cautiously, when just the pivoted rear fork was made in light alloy, before spreading to the complete chassis. In the development of aluminum frames, however, it is interesting to note that tube sizes increased rapidly to compensate for the low Young’s Modulus, as explained earlier. A great help in this context would be the spread of proper triangulation. In GP racing now, the use of aluminum alloy fabricated twin-spar frames is almost universal, and is also widely featured on expensive sports models for the street. It must be remembered that the fatigue characteristics of aluminum are such that failure is inevitable eventually in components subjected to alternating stress, hence limited life must be accepted. In the case of works racers, their natural rapid obsolescence makes this less of a serious problem.

Wheels

For most of motorcycle history, the traditional wheel was a composite of hub, spokes and rim. Hubs have been made in steel, cast iron, aluminum and magnesium. In the days of drum brakes, the light alloy hubs usually had a cast-iron brake drum. Although some people experimented with various forms of plating or other hard surfacing direct on the drum surface to improve heat dissipation and save weight. Spokes were of steel, sometimes titanium, usually with brass nipples, though these were sometimes in aluminum for racing. Rims have mostly been of steel, except that aluminum took over for sports and competition machines and some roadsters. Since the late 1960s, however, cast wheels have become increasingly popular, first for racing (where magnesium predominates) then on roadsters, where cost and corrosion problems favor aluminum. Even cheap mopeds now use die-cast aluminum wheels.

In magnesium, a properly designed cast wheel may well be lighter than a steel-spoked wheel with an aluminum rim and magnesium hub; but cast-aluminum wheels usually have a weight penalty though in some cases they may be stiffer laterally and run more accurately.
An ingenious sheet-aluminum design by Tony Dawson consists of left and right pressings riveted together at the rim and bolted to a cast hub. The higher strength of the wrought material used enabled these wheels to compete with cast magnesium for weight, while the greater ductility of the sheet material gives a high safety factor. It would be interesting to see this technique tried with magnesium sheet.

Honda developed a multi-part wheel called the Comstar. As with conventional wire spoked wheels this comprised separate rim, hub and spokes, but where it was different was in the spokes. In place of the normal wire spokes they used aluminum stampings and these were bolted to the hub and riveted to the rim. The rims for these wheels had a rib running around the inner circumference on which to fix the spokes.

A similar rim can also be used in another type of composite wheel. The hub and spokes are cast, like a complete cast wheel without the rim, and the end of the spokes are machined to fit the aforementioned rib inside the rim. This form of construction is useful for low volume production “specials” because it is considerably cheaper to make patterns and castings made and machined than for full cast wheels. It also has the advantage that various width rims can be tried without the expense of new castings. Compared to full cast wheels it has the disadvantage that the rim would not run so true, although it will likely spin truer than a conventional spoked wheel. Standard aluminum rims are available with this inner rib and the central spider could be cast in either aluminum or magnesium.

Where expense was of little concern, complete wheels have been machined from an Aluminum billet and this has become a more practical proposition for one-offs and show machines, with the spread of CNC machine tools.
Fuel Tank

Steel is the traditional material here for roadsters, aluminum for racers. To prevent cracking, care must be taken to isolate aluminum tanks from vibration. Plastic tanks - both glass fibre-reinforced and moulded thermoplastics (ABS or similar) - have been successfully used for competition duty (particularly on off-road machines) but the Construction and Use regulations forbid the use of non-metallic tanks on public roads in Britain. As with many other components Carbon Fibre reinforced material is now making an appearance in fuel tanks also.

Bodywork

The use of steel or aluminum for seats, mudguards, fairings and suchlike has been largely superseded in racing by reinforced plastics. Initially this was GRP or Glass Reinforced Plastic, polyester being the plastic or resin most used. This has been overtaken by the use of Carbon Fibre Reinforced Plastic, polyester has given way to the stronger and more stable epoxy resin. Carbon fibre has the advantage of having a very high Young’s modulus, that is, it is very stiff. Some of this stiffness is given up when imbedded in the epoxy but the overall resulting composite material is still stiffer than most other forms of construction. This enables thin and hence light weight panels and shapes to be moulded, without undue flexibility in the finished component.

Like GRP, carbon fibre parts can be made at home or in a small workshop, but for the best results the work needs to be done with specialist facilities. The final setting or hardening of the material is done in autoclaves (ovens) and some form of pressure moulding (such as vacuum bagging) is best to ensure an even thickness and uniform matrix. It is important to expel any air trapped in the liquid resin. Working with the
the lower wishbone longer while keeping the upper wishbone pick up points at their desired position relative to chassis design.

**Roll centre static height**

As the front view IC is determined by the inboard pickup points, by changing the position of the inboard pick up points along the Z axis, the static roll centre height can be fixed. The static roll centre height at the front is generally kept greater than the rear to allow the rear of the car to catch up during cornering with the front. However too high a roll centre will cause jacking which is unwanted.

**d) Anti-Roll Bar**

The anti-roll bar itself is a simple piece of engineering. It’s essentially a U-shaped cylindrical piece of metal that connects both the left and right ends of an axle. When you round a corner, the mass of your car shifts to the outside of the turn due to centrifugal force, causing the car to “roll”. By connecting both ends, the anti-roll bar forces both ends of the axle - the wheels in this case - to raise or lower to a similar
height, preventing roll. The bar resists twisting, or torsion, through its torsional rigidity. The stiffer the bar, the less the car leans in turns. One benefit of such bars is that the vehicle can be made to lean less without increasing the stiffness of the suspension, which compromises ride quality. Some bars are even adjustable via the positions of the mounting position of the bar to the end links, or through a computer-controlled setup.

15. Steering System
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Hydraulic fluid

Power steering fluid is a sub type of hydraulic fluid. Most are mineral oil or silicone-based fluids, while some use automatic transmission fluid, made from synthetic base oil. Automatic transmissions use fluids for their lubrication, cooling and hydraulic properties for viscous couplings. Use of the wrong type of fluid can lead to failure of the power steering pump.

Steering fluid reservoir

Just like how we have a petrol tank for petrol, we have a steering fluid tank for steering fluid. Whenever we are using fluid, we always have a container that holds them when we are not using them. There is nothing too fancy about this part here, and its purpose is quite self-explanatory too. But, the journey of a hydraulic power steering begins here. When we fill the steering fluid, we put it into this reservoir. It holds the fluid, and supplies them to the steering pump through rubber hoses.

Steering pump

You can find the steering pump attached to the car engine, usually right next to the car alternator and A/C compressor. We connect the steering pump to the engine through a belt-pulley mechanism using an engine belt. When your car’s engine is running, the engine belt turns in a loop and that also turns the steering pump. With that, the pump pulls the steering fluid from the steering fluid reservoir and pressurizes them.
room want more space as well! Very quickly, this becomes a tug of war where the stronger team pushes the wall to the other side.
Anyway, this “pushing of the wall” is what gives us the extra power. Since both ends of the steering rack is connected to the car wheels, when the steering rack move to the right, so will the car wheels. And... *Voilà!* The car changes direction and steering fluid flows back to the steering fluid reservoir to repeat the entire process again.

b) Electronic Power Steering

An Electronic Power Steering (EPS) system’s advantage over a hydraulic system is if the engine stalls, you will still have steering assist. This advantage can also be a disadvantage if the system should shut down while the engine is running you lose steering assist.
A driver unaware of this condition would become concerned if an electrical or electronic failure occurred while the engine was running, as the loss of assist would not be expected.
Electronic power steering systems eliminate the need for a pump, hoses and a drive belt connected to the engine using variable amounts of power. The configuration of an EPS system can allow the entire power assist system to be packaged on the rack and pinion steering gear or in the steering column.
The system does not drag on the engine from either a power steering pump or alternator because it will not provide assist until required by driver input. Also, there is no hydraulic fluid.
An EPS steering application uses a bidirectional brushless motor, sensors and electronic controller to provide steering assist. The motor will drive a gear that can
be connected to the steering column shaft or the steering rack. Sensors located in the steering column measure two primary driver inputs — torque (steering effort) and steering wheel speed and position.

The steering wheel is referred to as a hand wheel in the service information. The torque, speed and position inputs, vehicle speed signal, and other inputs are interpreted in the electronic control module.

The controller processes the steering effort and hand wheel position through a series of algorithms for assist and return to produce the proper amount of polarity and current to the motor. Other inputs that will affect assist and return are vehicle speed, engine speed and chassis control systems such as ABS and electronic stability control (ESC).

The brushless motor uses a permanent magnet rotor and three electromagnetic coils to propel the rotor. Most applications use a motor worm gear to drive the gear on the steering shaft or rack.
c) Rear-Wheel Steering

At the rear axle is a steering system containing an electrical spindle drive and two track rods. They activate to turn the wheels a few degrees in the same or opposite direction relative to the front wheels, depending on the car’s speed. At low speeds, the rear wheels turn in the opposite direction to the front wheels. That reduces the car’s turning circle by about one meter, making the car more agile. The rear-wheel steering is most significantly felt when maneuvering the car through tight spaces like car parks or parking gantries. At higher speeds around 60km/h, the rear wheels follow the direction of the front wheels. Turning all the wheels in the same direction improves on the steering response and further increases stability in evasive maneuvers.

Steering Gearbox

a) Rack and Pinion
b) Worm and roller
c) Worm and sector
d) Cam and Roller
e) Reciprocating Ball
f) Worm and Ball Bearing
Explanation

Rack and Pinion

A rack and pinion are commonly found in the steering mechanism of cars or other wheeled, steered vehicles. Rack and pinion provide less mechanical advantage than other mechanisms such as recirculating ball, but less backlash and greater feedback, or steering “feel”. The mechanism may be power-assisted, usually by hydraulic or electrical means. The use of a variable rack (still using a normal pinion) was invented by Arthur Ernest Bishop in the 1970s, so as to improve vehicle response and steering “feel,” especially at high speeds. He also created a low-cost press forging process to manufacture the racks, eliminating the need to machine the gear teeth.

Reciprocating Ball

The recirculating ball steering mechanism contains a worm gear inside a block with a threaded hole in it; this block has gear teeth cut into the outside to engage the
sector shaft (also called a sector gear) which moves the Pitman arm. The steering wheel connects to a shaft, which rotates the worm gear inside of the block. Instead of twisting further into the block, the worm gear is fixed so that when it rotates, it moves the block, which transmits the motion through the gear to the Pitman arm, causing the road wheels to turn.

**Bearing balls**

The worm gear is similar in design to a ball screw; the threads are filled with steel balls that recirculate through the gear and rack as it turns. The balls serve to reduce friction and wear in the gear, and reduce slop. Slop, when the gears come out of contact with each other, would be felt when changing the direction of the steering wheel, causing the wheel to feel loose.

### 16. Ergonomics

![Ergonomics Diagram](image)

Ergonomics is the process of designing or arranging workplaces, products and systems so that they fit the people who use them. When it comes to car, it involves almost everything that is related to the passengers sitting inside the car. First thing that comes to our mind is seats. seating position, sitting posture, seat bolstering, under thigh support, lumbar support etc. are the few things which comes first to my mind when we talk about automobile ergonomics.
Next comes the position and reach of the Pedals, Dials and Stalks. Pedals are very important part, for example, there are many people who enjoy laid back sitting position while driving. So, even when they push back the seat to enjoy their comfortable sitting position, ABC pedals should be within their reach. If they are not, driving experience will become cumbersome and tiring. This is where ergonomics comes into play.

Similarly, for stalks and dials, it’s not just that they should be positioned where one expects them to be, they should be well within the reach of your hand. For example, I expect the volume control dial should be positioned just below the stereo system and its present there as well. But what if the dashboard is placed too far and it’s not in my reach or even if it’s in my reach, dashboard is tilted towards the passenger rather than the driver. In both the cases, it’ll be extremely uncomfortable for me to use the dials.

So, it’s the Ergonomics which deals with all these designs and makes our journey not only more comfortable and plusher but enhances security as well.

Prolonged periods of sitting can place heavy demands on our posture, particularly when sitting in a vehicle due to added effects of movement and vibration on the body. Being comfortable and well positioned in a vehicle aims to reduce driver fatigue and the development of musculoskeletal disorders.

It is imperative that everyone using a vehicle for work observes adequate ergonomic requirements to minimize the risk of injury.

a) Seat Height
   • Raise the seat to ensure the driver has maximum vision of the road.
   • Ensure there is adequate clearance
   • From the roof.

b) Lower Limb Position
   • Knees should be bent, in order to comfortably operate
   • The accelerator/Clutch and break.
   • The steering wheel should not come into contact with the top of the legs.

c) Seat Pan
   • Thighs supported along the length of the cushion.
   • Avoid pressure behind the knees.

d) Back Rest
   • Adjust the backrest so it provides continued support along the length.
   • Shoulders slightly behind the hips.
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