Electromagnetic Engine

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Electromagnetic Engine

Chapter 1: Introduction

1.1 Abstract

Our engine is totally different from ordinary IC Engine, because of the inventory advancement in operating principles. We have changed the operating principle of IC Engine by using electromagnetic effect instead of combustion of fossil fuels. This engine works on the principle of magnetic repulsion between two magnets. This electromagnetic engine consists of two magnets, one of them is an Electromagnet and other one is a Permanent Magnet. Permanent Magnet acts as piston and Electromagnet is located at the top of the cylinder instead of spark plug and valve arrangement in IC Engines. In this way this engine does not contain any spark plug and fuel injection system. The Electromagnet is energized by a battery source of suitable voltage and the polarities of electromagnet are set in such a way that it will repel the permanent magnet i.e. piston from TDC to BDC, which will result in the rotary motion of crank shaft. When the piston is at BDC the supply of Electromagnet is discontinued, the permanent magnet which was repelled to BDC will come back to its initial position i.e. TDC. This procedure completes one revolution of crank shaft i.e. our output work. A copper winding is also wound to the cylinder block to get additional power to the piston to reciprocate. This winding is connected to a battery to create a magnetic field inside the cylinder and reciprocate permanent magnet piston on basis of repulsion forces created by winding. The total power supplied by battery will be just to fulfil the copper losses of winding and power required to magnetize the windings. The present project relates to an electromagnetic piston engine adapted to produce driving power by the electromagnetic force created by a reciprocal movement of a piston in a cylinder. In the recent years, the development of electric vehicles is exploding. Such electric vehicles use an electric drive motor as a power source.

Conventional electric drive motors are designed to pick up rotational energy of a rotor as a power by directly rotating the rotor by electromagnetic force. The electric drive motors of such a type, however, lead naturally to an increase in the weight of a rotor in order to pick up greater outputs and, as a consequence, suffer from the disadvantages that the weight of the portion corresponding to a rotary assembly section becomes heavy. Then such electric drive motors require a power transmission mechanism for transmitting the driving power from a power source to the wheels to be designed to be adapted to the features of the electric drive motors. Power transmission mechanisms for internal combustion piston engines, which have been generally used for conventional vehicles, cannot always be applied to electric vehicles as they are. These problems impose greater burdens upon the designing of electric vehicles.

For internal combustion piston engines, there are a variety of resistance that result from their structures. They may include, for example,

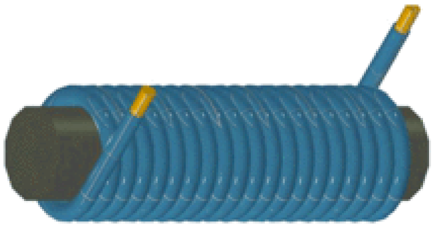
1. Air intake resistance of an air cleaner
2. Resistance of a cam shaft
3. Compression resistance in a cylinder
4. Resistance of a piston to an inner wall of a cylinder
5. Resistance of a cooling fan
6. Resistance of a water pump
7. Resistance of an oil pump.

The loss of energy due to these resistances is the causes of reducing the energy efficiency of the internal combustion piston engines. An overall system assembly of the internal combustion piston engine further has the additional problem with an increase in the entire weight due to the necessity of instalment of a mechanism for cooling the internal combustion piston engine because the internal combustion piston engine cannot avoid the generation of a considerably large amount of heat by the principles of the engine themselves. Given the foregoing problems inherent in conventional internal combustion piston engines, the present invention has the object to provide an electromagnetic piston engine which can offer the effects of eliminating the various resistances inherent in the conventional internal combustion piston engines, reducing the weight corresponding to a rotary assembly section even if greater outputs can be taken, further making ready applications to power transmission mechanisms for use with conventional internal combustion piston engines, and achieving improved efficiency in utilizing energy.

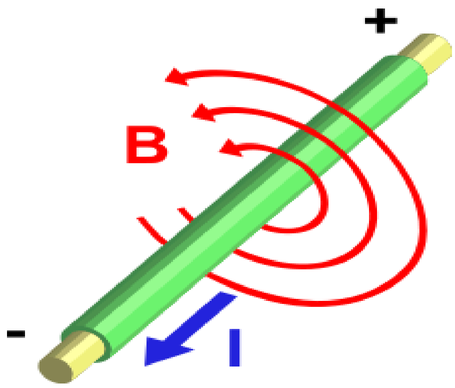
Chapter 2: Literature Review

2.1 Electromagnets

An **electromagnet** is a type of magnet in which the magnetic field is produced by the flow of electric current. The magnetic field disappears when the current is turned off. Electromagnets are widely used as components of other electrical devices, such as motors, generators, relays, loudspeakers, hard disks, MRI machines, scientific instruments, and magnetic separation equipment, as well as being employed as industrial lifting electromagnets for picking up and moving heavy iron objects like scrap iron.

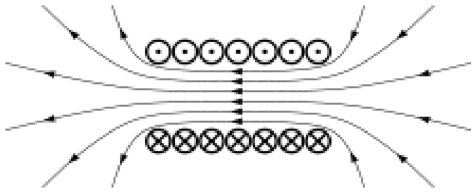


A simple electromagnet consisting of a coil of insulated wire wrapped around an iron core. The strength of magnetic field generated is proportional to the amount of current.



Current (I) through a wire produces a magnetic field (B). The field is oriented according to the right-hand rule. An electric current flowing in a wire creates a magnetic field around the wire (see drawing below). To concentrate the magnetic field, in an electromagnet the wire is wound into a coil with many turns of wire lying side by side. The magnetic field of all the turns of wire passes through the centre of the coil, creating a strong magnetic field there.

A coil forming the shape of a straight tube (a helix) is called a solenoid; a solenoid that is bent into a donut shape so that the ends meet is called a toroid. Much stronger magnetic fields can be produced if a "core" of ferromagnetic material, such as soft iron, is placed inside the coil. The ferromagnetic core increases the magnetic field to thousands of times the strength of the field of the coil alone, due to the high magnetic permeability μ of the ferromagnetic material. This is called a ferromagnetic-core or iron-core electromagnet.



Magnetic field produced by a solenoid (coil of wire). This drawing shows a cross section through the centre of the coil. The crosses are wires in which current is moving into the page; the dots are wires in which current is moving up out of the page.

The direction of the magnetic field through a coil of wire can be found from a form of the right-hand rule. If the fingers of the right hand are curled around the coil in the direction of current flow (conventional current, flow of positive charge) through the windings, the thumb points in the direction of the field inside the coil. The side of the magnet that the field lines emerge from is defined to be the *North Pole*. The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be rapidly manipulated over a wide range by controlling the amount of electric current. However, a continuous supply of electrical energy is required to maintain the field.

2.2 Working of Iron Core

The material of the core of the magnet (usually iron) is composed of small regions called magnetic domains that act like tiny magnets (see ferromagnetism). Before the current in the electromagnet is turned on, the domains in the iron core point in random directions, so their tiny magnetic fields cancel each other out, and the iron has no large scale magnetic field. When a current is passed through the wire wrapped around the iron, its magnetic field penetrates the iron, and causes the domains to turn, aligning parallel to the magnetic field, so their tiny magnetic fields add to the wire's field, creating a large magnetic field that extends into the space around the magnet. The larger the current passed through the wire coil, the more the domains align, and the stronger the magnetic field is. Finally, all the domains are lined up, and further increases in current only cause's slight increases in the magnetic field: this phenomenon is called saturation.

When the current in the coil is turned off, most of the domains lose alignment and return to a random state and the field disappears. However, some of the alignment persists, because the domains have difficulty turning their direction of magnetization, leaving the core a weak permanent magnet. This phenomenon is called hysteresis and the remaining magnetic field is called remnant magnetism. The residual magnetization of the core can be removed by degaussing.

Fig: Electromagnet used in the Tevatron particle accelerator, Fermilab, USA

2.3 History

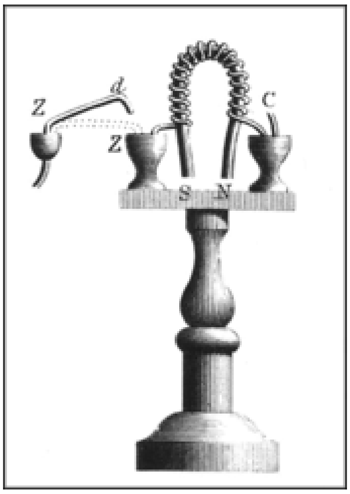


Fig: Sturgeon’s electromagnet, 1824

Danish scientist Hans Christianorsted discovered in 1820 that electric currents create magnetic fields. British scientist William Sturgeon invented the electromagnet in 1824.His first electromagnet was a horseshoe-shaped piece of iron that was wrapped with about 18 turns of bare copper wire (insulated wire didn't exist yet). The iron was varnished to insulate it from the windings. When a current was passed through the coil, the iron became magnetized and attracted other pieces of iron; when the current was stopped, it lost magnetization. Sturgeon displayed its power by showing that although it only weighed seven ounces (roughly 200 grams), it could lift nine pounds (roughly 4 kilos) when the current of a single-cell battery was applied. However, Sturgeon's magnets were weak because the uninsulated wire he used could only be wrapped in a single spaced out layer around the core, limiting the number of turns. Beginning in 1827, US scientist Joseph Henry systematically improved and popularized the electromagnet. By using wire insulated by silk thread he was able to wind multiple layers of wire on cores, creating powerful magnets with thousands of turns of wire, including one that could support 2,063 lb (936 kg). The first major use for electromagnets was in telegraph sounders.

The magnetic domain theory of how ferromagnetic cores work was first proposed in 1906 by French physicist Pierre-Ernest Weiss, and the detailed modern quantum mechanical theory of ferromagnetism was worked out in the 1920s by Werner Heisenberg, Lev Landau, Felix Bloch and others.

2.4 Uses of Electromagnets

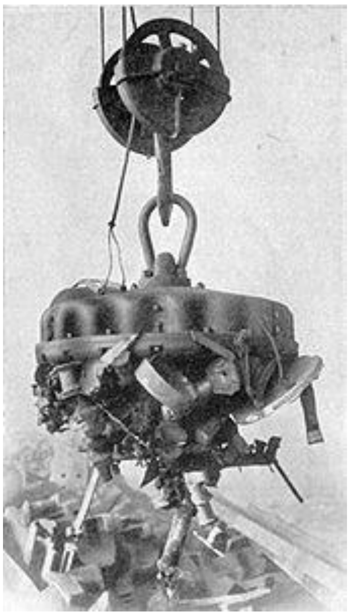


Fig: Industrial electromagnet lifting scrap iron, 1914

Electromagnets are very widely used in electric and electromechanical devices, including:

1. Motors and generators
2. Transformers
3. Relays, including reed relays originally used in telephone exchanges
4. Electric bells
5. Loudspeakers
6. Magnetic recording and data storage equipment: tape recorders, VCRs, hard disks
7. Scientific instruments such as MRI machines and mass spectrometers
8. Particle accelerators
9. Magnetic locks
10. Magnetic separation of material
11. Industrial lifting magnets
12. Electromagnetic suspension used for MAGLEV trains

2.5 Analysis of ferromagnetic electromagnets

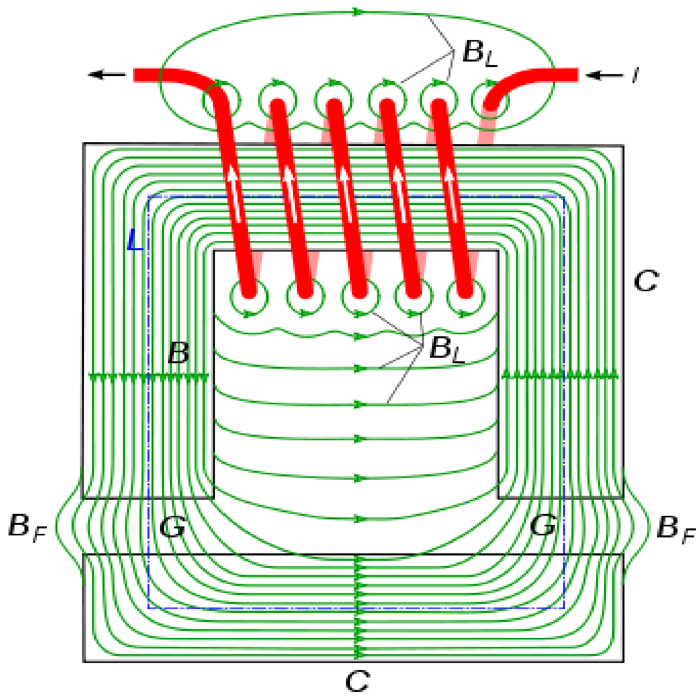
For definitions of the variables below, see box at end of article.

The magnetic field of electromagnets in the general case is given by Ampere's Law:

$$\int \mathbf{J} \cdot d\mathbf{A} = \oint \mathbf{H} \cdot d\mathbf{l}$$

Which says that the integral of the magnetizing field H around any closed loop of the field is equal to the sum of the current flowing through the loop? Another equation used, that gives the magnetic field due to each small segment of current, is the Biot-Savart law. Computing the magnetic field and force exerted by ferromagnetic materials is difficult for two reasons. First, because the strength of the field varies from point to point in a complicated way, particularly outside the core and in air gaps, where *fringing fields* and *leakage flux* must be considered. Second, because the magnetic field B and force are nonlinear functions of the current, depending on the nonlinear relation between B and H for the particular core material used. For precise calculations, computer programs that can produce a model of the magnetic field using the finite element method are employed.

Magnetic circuit – The constant *B* field approximation



Magnetic field *(green)* of a typical electromagnet, with the iron core *C* forming a closed loop with two air gaps *G* in it. Most of the magnetic field *B* is concentrated in the core. However, some of the field lines B_L, called the "leakage flux", do not follow the full core circuit and so do not contribute to the force exerted by the electromagnet. In the gaps *G* the field lines spread out beyond the boundaries of the core in "fringing fields" B_F. This increases the "resistance" (reluctance) of the magnetic circuit, decreasing the total magnetic flux in the core. Both the leakage flux and the fringing fields get larger as the gaps are increased, reducing the force exerted by the magnet. Line *L* shows the average length of the magnetic circuit, used in equation (1) below. It is the sum of the length in the iron core and the length L_{gap} in the air gaps

In many practical applications of electromagnets, such as motors, generators, transformers, lifting magnets, and loudspeakers, the iron core is in the form of a loop or magnetic circuit, possibly broken by a few narrow air gaps. This is because iron presents much less "resistance" (reluctance) to the magnetic field than air, so a stronger field can be obtained if most of the magnetic field's path is within the core. Since most of the magnetic field is confined within the outlines of the core loop, this allows a simplification of the mathematical analysis. See the drawing at right. A common simplifying assumption satisfied by many electromagnets, which will be used in this section, is that the magnetic field strength *B* is constant around the magnetic circuit and zero outside it. Most of the magnetic field will be concentrated in the core material *(C)*. Within the core the magnetic field *(B)* will be approximately uniform across any cross section, so if in addition the core has roughly constant area throughout its length, the field in the core will be constant. This just leaves the air gaps *(G)*, if any, between core sections. In the gaps the magnetic field lines are no longer confined by the core, so they 'bulge' out beyond the outlines of the core before curving back to enter the next piece of core material, reducing the field strength in the gap.

The bulges *(B_F)* are called *fringing fields*. However, as long as the length of the gap is smaller than the cross section dimensions of the core, the field in the gap will be approximately the same as in the core. In addition, some of the magnetic field lines *(B_L)* will take 'short cuts' and not pass through the entire core circuit, and thus will not contribute to the force exerted by the magnet. This also includes field lines that encircle the wire windings but do not enter the core. This is called *leakage flux*. Therefore, the equations in this section are valid for electromagnets for which:

1. The magnetic circuit is a single loop of core material, possibly broken by a few air gaps
2. The core has roughly the same cross sectional area throughout its length.
3. Any air gaps between sections of core material are not large compared with the cross sectional dimensions of the core.
4. There is negligible leakage flux

The main nonlinear feature of ferromagnetic materials is that the B field saturates at a certain value, which is around 1.6 Teslas (T) for highest permeability core steels. The B field increases quickly with increasing current up to that value, but above that value the field levels off and becomes almost constant, regardless of how much current is sent through the windings.

Magnetic field created by a current

The magnetic field created by an electromagnet is proportional to both the number of turns in the winding, *N*, and the current in the wire, *I*, hence this product, *NI*, in ampere-turns, is given the name magneto motive force. For an electromagnet with a single magnetic circuit, of which lengthL_{core} is in the core material and length L_{gap} is in air gaps, Ampere's Law reduces to:

$$NI = H_{\text{core}} L_{\text{core}} + H_{\text{gap}} L_{\text{gap}}$$

$$NI = B\left(\frac{L_{\text{core}}}{\mu} + \frac{L_{\text{gap}}}{\mu_0}\right) \qquad (1)$$

Where $\mu = B/H$

$$\mu_0 = 4\pi(10^{-7})\ \mathrm{N \cdot A^{-2}}$$

Is the permeability of free space (or air) . A is amperes.

This is a nonlinear equation, because the permeability of the core, μ, varies with the magnetic field *B*. For an exact solution, the value of μ at the *B* value used must be obtained from the core material hysteresis curve. If *B* is unknown, the equation must be solved by numerical methods. However, if the magneto motive force is well above saturation, so the core material is in saturation, the magnetic field will be approximately the saturation value B_{sat} for the material, and won't vary much with changes in *NI*. For a closed magnetic circuit (no air gap) most core materials saturate at a magneto motive force of roughly 800 ampere-turns per meter of flux path.

For most core materials,

$$\mu_r = \mu/\mu_0 \approx 2000 - 6000.$$

So in equation (1) above, the second term dominates. Therefore, in magnetic circuits with an air gap, the strength of the magnetic field *B* depends strongly on the length of the air gap, and the length of the flux path in the core doesn't matter much.

Force exerted by magnetic field

The force exerted by an electromagnet on a section of core material is:

$$F = \frac{B^2 A}{2\mu_0} \qquad (2)$$

The 1.6 T limit on the field mentioned above sets a limit on the maximum force per unit core area, or pressure, an iron-core electromagnet can exert; roughly:

$$\frac{F}{A} = \frac{B_{sat}^2}{2\mu_0} \approx 1000 \text{ kPa} = 10^6 \text{N/m}^2 = 145 \text{ lbf} \cdot \text{in}^{-2}$$

In more intuitive units it's useful to remember that at 1T the magnetic pressure is approximately 4 atmospheres, or kg/cm^2.

Given core geometry, the B field needed for a given force can be calculated from (2); if it comes out to much more than 1.6 T, a larger core must be used.

Closed magnetic circuit

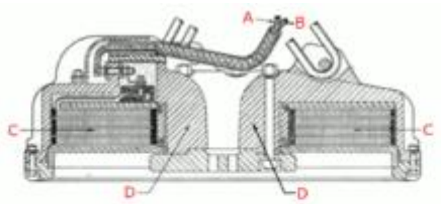


Fig: Cross section of lifting electromagnet

Fig. showing cylindrical construction. The windings *(C)* are flat copper strips to withstand the Lorentz force of the magnetic field. The core is formed by the thick iron *D)* that wraps around the windings.

For a closed magnetic circuit (no air gap), such as would be found in an electromagnet lifting a piece of iron bridged across its poles, equation (1) becomes:

$$B = \frac{NI\mu}{L} \tag{3}$$

Substituting into (2), the force is:

$$F = \frac{\mu^2 N^2 I^2 A}{2\mu_0 L^2} \tag{4}$$

It can be seen that to maximize the force, a core with a short flux path *L* and a wide cross sectional area *A* is preferred. To achieve this, in applications like lifting magnets (see photo above) and loudspeakers a flat cylindrical design is often used. The winding is wrapped around a short wide cylindrical core that forms one pole, and a thick metal housing that wraps around the outside of the windings forms the other part of the magnetic circuit, bringing the magnetic field to the front to form the other pole.

2.6 Force between electromagnets

The above methods are inapplicable when most of the magnetic field path is outside the core. For electromagnets (or permanent magnets) with well defined 'poles' where the field lines emerge from the core, the force between two electromagnets can be found using the 'Gilbert model' which assumes the magnetic field is produced by fictitious 'magnetic charges' on the surface of the poles, with pole strength *m* and units of Ampere-turn meter. Magnetic pole strength of electromagnets can be found from:

$$m = \frac{NIA}{L}$$

The force between two poles is:

$$F = \frac{\mu_0 m_1 m_2}{4\pi r^2}$$

This model doesn't give the correct magnetic field inside the core, and thus gives incorrect results if the pole of one magnet gets too close to another magnet.

Side effects in large electromagnets:

There are several side effects which become important in large electromagnets and must be provided for in their design:

Ohmic heating

Fig: Large aluminium bus bars carrying current into the electromagnets at the LNCMI (Laboratories National des Champs Magnétiques Intenses) high field laboratory.

The only power consumed in a DC electromagnet is due to the resistance of the windings, and is dissipated as heat. Some large electromagnets require cooling water circulating through pipes in the windings to carry off the waste heat. Since the magnetic field is proportional to the product *NI*, the number of turns in the windings *N* and the current *I* can be chosen to minimize heat losses, as long as their product is constant. Since the power dissipation, $P = I^2R$, increases with the square of the current but only increases approximately linearly with the number of windings, the power lost in the windings can be minimized by reducing *I* and increasing the number of turns '*N'* proportionally. For example, halving 'I' and doubling 'N' halves the power loss. This is one reason most electromagnets have windings with many turns of wire.

However, the limit to increasing '*N'* is that the larger number of windings takes up more room between the magnet's core pieces. If the area available for the windings is filled up, more turns require going to a smaller diameter of wire, which has higher resistance, which cancels the advantage of using more turns. So in large magnets there is a minimum amount of heat loss that can't be reduced. This increases with the square of the magnetic flux B^2.

Inductive voltage spikes

An electromagnet is a large inductor, and resists changes in the current through its windings. Any sudden changes in the winding current cause large voltage spikes across the windings. This is because when the current through the magnet is increased, such as when it is turned on, energy from the circuit must be stored in the magnetic field. When it is turned off the energy in the field is returned to the circuit.

If an ordinary switch is used to control the winding current, this can cause sparks at the terminals of the switch. This doesn't occur when the magnet is switched on, because the voltage is limited to the power supply voltage. But when it is switched off, the energy in the magnetic field is suddenly returned to the circuit, causing a large voltage spike and an arc across the switch contacts, which can damage them. With small electromagnets a capacitor is often used across the contacts, which reduces arcing by temporarily storing the current. More often a diode is used to prevent voltage spikes by providing a path for the current to recirculate through the winding until the energy is dissipated as heat. The diode is connected across the winding, oriented so it is reverse-biased during steady state operation and doesn't conduct. When the supply voltage is removed, the voltage spike forward-biases the diode and the reactive current continue to flow through the winding, through the diode and back into the winding. A diode used in this way is often called a fly back diode.

Large electromagnets are usually powered by variable current electronic power supplies, controlled by a microprocessor, which prevent voltage spikes by accomplishing current changes slowly, in gentle ramps. It may take several minutes to energize or de-energize a large magnet.

Lorentz forces

In powerful electromagnets, the magnetic field exerts a force on each turn of the windings, due to the Lorentz force $q\mathbf{v} \times \mathbf{B}$ acting on the moving charges within the wire. The Lorentz force is perpendicular to both the axis of the wire and the magnetic field. It can be visualized as a pressure between the magnetic field lines, pushing them apart. It has two effects on an electromagnet's windings:

1. The field lines within the axis of the coil exert a radial force on each turn of the windings, tending to push them outward in all directions. This causes a tensile stress in the wire.
2. The leakage field lines between each turn of the coil exert a repulsive force between adjacent turns, tending to push them apart.

The Lorentz forces increase with B^2. In large electromagnets the windings must be firmly clamped in place, to prevent motion on power-up and power-down from causing metal fatigue in the windings. In the Bitter design, below, used in very high field research magnets, the windings are constructed as flat disks to resist the radial forces, and clamped in an axial direction to resist the axial ones.

Core losses

In alternating current (AC) electromagnets, used in transformers, inductors, and AC motors and generators, the magnetic field is constantly changing. This causes energy losses in their magnetic cores that are dissipated as heat in the core. The losses stem from two processes:

1. **Eddy currents**: From Faraday's law of induction, the changing magnetic field induces circulating electric currents inside nearby conductors, called eddy currents. The energy in these currents is dissipated as heat in the electrical resistance of the conductor, so they are a cause of energy loss. Since the magnet's iron core is conductive, and most of the magnetic field is concentrated there, eddy currents in the core are the major problem. Eddy currents are closed loops of current that flow in planes perpendicular to the magnetic field. The energy dissipated is proportional to the area enclosed by the loop. To prevent them, the cores of AC electromagnets are made of stacks of thin steel sheets, or laminations, oriented parallel to the magnetic field, with an insulating coating on the surface. The insulation layers prevent eddy current from flowing between the sheets. Any remaining eddy currents must flow within the cross section of each individual lamination, which reduces losses greatly. Another alternative is to use a ferrite core, which is a non-conductor.
2. **Hysteresis losses**: Reversing the direction of magnetization of the magnetic domains in the core material each cycle causes energy loss, because of the coercivity of the material. These losses are called hysteresis. The energy lost per cycle is proportional to the area of the hysteresis loop in the *BH* graph. To minimize this loss, magnetic cores used in transformers and other AC electromagnets are made of "soft" low coercivity of the materials, such as silicon steel or soft ferrite. The energy loss per cycle of the AC current is constant for each of these processes, so the power loss increases linearly with frequency.

Superconducting electromagnets

When a magnetic field higher than the ferromagnetic limit of 1.6 T is needed, superconducting electromagnets can be used. Instead of using ferromagnetic materials, these use superconducting windings cooled with liquid helium, which conduct current without electrical resistance. These allow enormous currents to flow, which generate intense magnetic fields. Superconducting magnets are limited by the field strength at which the winding material ceases to be superconducting. Current designs are limited to 10–20 T, with the current (2009) record of 33.8 T. The necessary refrigeration equipment and cryostat make them much more expensive than ordinary electromagnets. However, in high power applications this can be offset by lower operating costs, since after start-up no power is required for the windings, since no energy is lost to ohmic heating. They are used in particle accelerators, MRI machines, and research.

Bitter electromagnets

Both iron-core and superconducting electromagnets have limits to the field they can produce. Therefore, the most powerful man-made magnetic fields have been generated by *air-core* non superconducting electromagnets of a design invented by Francis Bitter in 1933, called Bitter electromagnets. Instead of wire windings, a Bitter magnet consists of a solenoid made of a stack of conducting disks, arranged so that the current moves in a helical path through them. This design has the mechanical strength to withstand the extreme Lorentz forces of the field, which increase with B^2. The disks are pierced with holes through which cooling water passes to carry away the heat caused by the high current. The strongest continuous field achieved with a resistive magnet is currently (2008) 35 T, produced by a Bitter electromagnet. The strongest continuous magnetic field, 45 T, was achieved with a hybrid device consisting of a Bitter magnet inside a superconducting magnet.

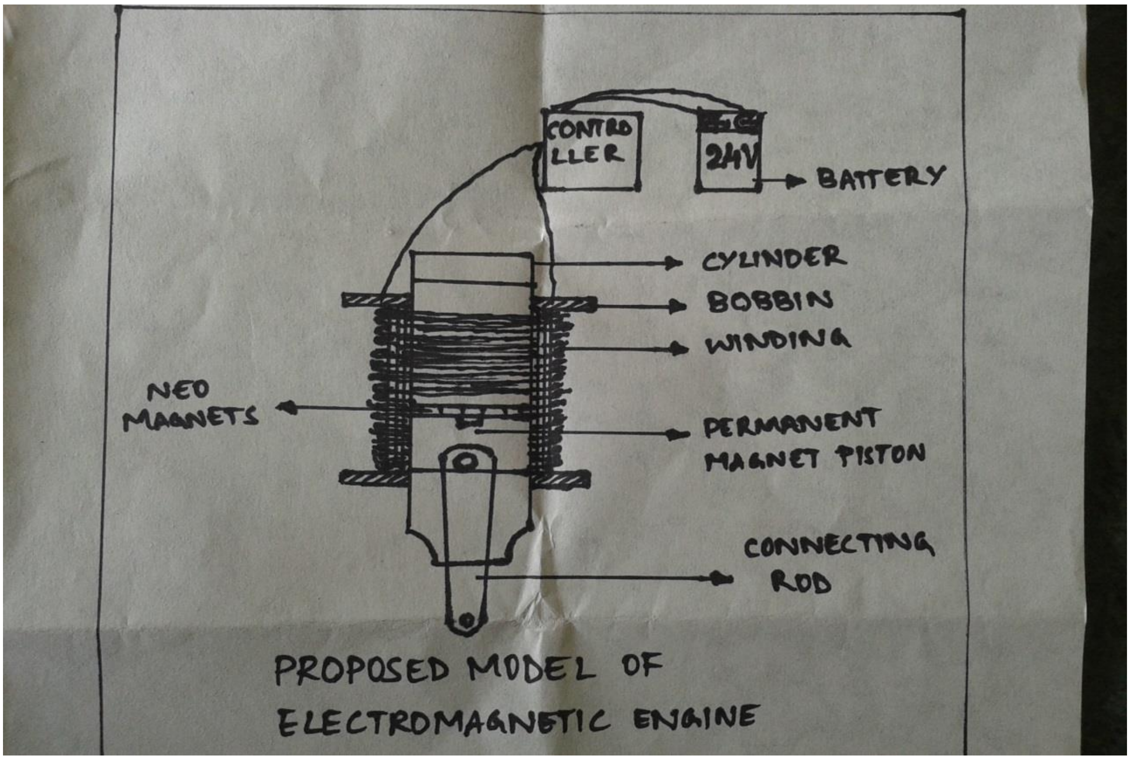
Chapter 3: Electromagnetic Engine

3.1 Working Principle

The electromagnetic engine according to the present invention in one aspect comprises a cylinder and a piston, each made of a non-magnetic material, cylinder is surrounded by a copper winding which is wound in a several layers at a length with which the piston reciprocates. Piston which reciprocates inside the cylinder must be made of nonmagnetic material and fixed with a strong permanent magnet at its top. When D.C current is supplied to the coil, it gets magnetized and two poles are created at the two ends of the coil. The magnetic field is strong enough to attract and repel the permanent magnet fixed at the piston top. So, magnetized coil attracts piston up, when it reaches the TDC, we change the direction of the current through the controller circuit, with this poles are exchanged, repulsion occurs and piston moves downwards to BDC. In this way we get reciprocating motion for the Piston. Piston is connected to flywheel with the help of a connecting rod.

The electromagnetic engine according to the present invention in a still further aspect is constructed by arranging a combination of the cylinder with the piston in -the aspects described above as a one assembly, arranging the one assembly in plural numbers and operating the plural assemblies in a parallel way, and converting a reciprocal movement of the piston in each of the plural assemblies into a rotary movement of a single crank shaft by a crank mechanism so that more can be produce for propelling any heavy vehicle.

3.2 Proposed Model of Electromagnetic Engine



3.3 Construction

As discussed in the principle, this model of engine is constructed mainly on the cylinder, a cylindrical pipe of a certain thickness which is made of a non-magnetic material is used, in this case Aluminium has been used to reduce net weight. This cylinder is machined to the required diameter so that piston reciprocates freely inside it. Piston which is shown in the figure is used to connect the magnetic top and the connecting rod. Grooves are visible which fix the connecting rod.

Fig: Cylinder and piston base

Now, Cylinder is to be surrounded by the magnetic coil. For that, A plastic bobbin has been used to support the winding and also to insert it around the cylinder as shown in the figure. Here insulating coil has been used for the purpose of creating flux free magnetic field.

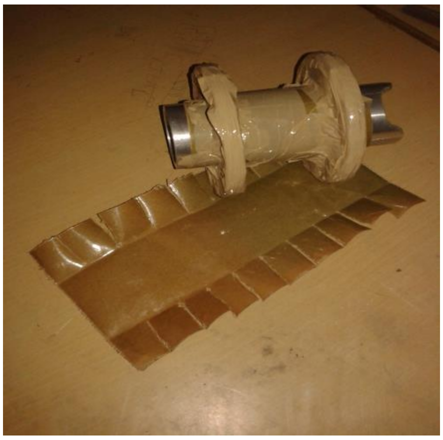


Fig: Cylinder surrrounded by the bobbin; Fig: Bobbin and the copper winding

When the bobbin is installed on the cylinder, insulating coil is tobe wound around the surface of the bobbin, copper coil is to be wound tightly on the bobbin so that no air gaps are present. Two ends of the coils must be left for electrical connections.

Permanent magnet which is to be fitted to the piston base is made of magnetic material, here we used Mild steel. Neo magnets are fixed at its top using LN Key, as shown in the figure. This acts as the permanent magnet, used to run the engine.

Permanent Magnet fitted to mild steel using LN key Connecting Rod assembly

Now, D.C current of around 24 Volts is supplied to the coils, it gets magnetized. Strong magnetic field is created inside the cylinder. Two poles are formed at the either ends of cylinder. When permanent magnet is placed pointing its north pole upwards, to get attracted to the top of the cylinger which is set as the opposite pole using the controller. Now, piston moves to TDC and when direction of the current is changed, north pole is formed at the top of the cylinder and north pole of the piston gets repelled downwards. Piston now moves to the BDC. This is the resultant Reciprocationg motion which converted to the rotary motion of the flywheel, using Connecting rod assembly as shown in the figure.

Chapter 4: Power Supply

4.1 Need of power supply

In alternating current, the electron flow is alternate, i.e. the electron flow increases to maximum in one direction, decreases back to zero. It then increases in the other direction and then decreases to zero again. Direct current flows in one direction only. Rectifier converts alternating current to flow in one direction only. When the anode of the diode is positive with respect to its cathode, it is forward biased, allowing current to flow. But when its anode is negative with respect to the cathode, it is reverse biased and does not allow current to flow. This unidirectional property of the diode is useful for rectification. A single diode arranged back-to-back might allow the electrons to flow during positive half cycles only and suppress the negative half cycles. Double diodes arranged back-to-back might act as full wave rectifiers as they may allow the electron flow during both positive and negative half cycles. Four diodes can be arranged to make a full wave bridge rectifier. Different types of filter circuits are used to smooth out the pulsations in amplitude of the output voltage from a rectifier. The property of capacitor to oppose any change in the voltage applied across them by storing energy in the electric field of the capacitor and of inductors to oppose any change in the current flowing through them by storing energy in the magnetic field of coil may be utilized. To remove pulsation of the direct current obtained from the rectifier, different types of combination of capacitor, inductors and resistors may be also being used to increase to action of filtering. Perhaps all of you are aware that a 'power supply' is a primary requirement for the 'Test Bench' of a home experimenter's mini lab. A battery eliminator can eliminate or replace the batteries of solid-state electronic equipment and the equipment thus can be operated by 230v A.C. mains instead of the batteries or dry cells. Nowadays, the use of commercial battery eliminator or power supply unit has become increasingly popular as power source for household appliances like trans-receivers, record player, cassette players, digital clock etc.

4.2 Use of Diodes in Rectifiers:

Electric energy is available in homes and industries in India, in the form of alternating voltage. The supply has a voltage of 220V (r.m.s) at a frequency of 50 Hz. In the USA, it is 110V at 60 Hz. For the operation of most of the devices in electronic equipment, a dc voltage is needed. For instance, a transistor radio requires a dc supply for its operation. Usually, this supply is provided by dry cells. But sometime we use a battery eliminator in place of dry cells. The battery eliminator converts the ac voltage into dc voltage and thus eliminates the need for dry cells. Nowadays, almost all-electronic equipment includes a circuit that converts ac voltage of mains supply into dc voltage. This part of the equipment is called Power Supply. In general, at the input of the power supply, there is a power transformer. It is followed by a diode circuit called Rectifier. The output of the rectifier goes to a smoothing filter, and then to a voltage regulator circuit. The rectifier circuit is the heart of a power supply.

Rectification:

Rectification is a process of rendering an alternating current or voltage into a unidirectional one. The component used for rectification is called ‘Rectifier’. A rectifier permits current to flow only during the positive half cycles of the applied AC voltage by eliminating the negative half cycles or alternations of the applied AC voltage. Thus pulsating DC is obtained. To obtain smooth DC power, additional filter circuits are required. A diode can be used as rectifier. There are various types of diodes. But, semiconductor diodes are very popularly used as rectifiers. A semiconductor diode is a solid-state device consisting of two elements is being an electron emitter or cathode, the other an electron collector or anode. Since electrons in a semiconductor diode can flow in one direction only-from emitter to collector- the diode provides the unilateral conduction necessary for rectification. Out of the semiconductor diodes, copper oxide and selenium rectifier are also commonly used.

4.2.1 Full Wave Rectifier

It is possible to rectify both alternations of the input voltage by using two diodes in the circuit arrangement. Assume 6.3 V r.m.s (18 V p-p) is applied to the circuit. Assume further that two equal-valued series-connected resistors R are placed in parallel with the ac source. The 18 V p-p appears across the two resistors connected between points AC and CB, and point C is the electrical midpoint between A and B. Hence 9 V p-p appears across each resistor. At any moment during a cycle of v_{in}, if point A is positive relative to C, point B is negative relative to C. When A is negative to C, point B is positive relative to C. The effective voltage in proper time phase which each diode "sees" is in Fig. The voltage applied to the anode of each diode is equal but opposite in polarity at any given instant.

When A is positive relative to C, the anode of D_1 is positive with respect to its cathode. Hence D_1 will conduct but D_2 will not. During the second alternation, B is positive relative to C. The anode of D_2 is therefore positive with respect to its cathode and D_2 conducts while D_1 is cut off.

There is conduction then by either D_1 or D_2 during the entire input-voltage cycle. Since the two diodes have a common-cathode load resistor R_L, the output voltage across R_L will result from the alternate conduction of D_1 and D_2. The output waveform v_{out} across R_L, therefore has no gaps as in the case of the half-wave rectifier.

The output of a full-wave rectifier is also pulsating direct current. In the diagram, the two equal resistors R across the input voltage are necessary to provide a voltage midpoint C for circuit connection and zero reference. Note that the load resistor R_L is connected from the cathodes to this center reference point C.

An interesting fact about the output waveform v_{out} is that its peak amplitude is not 9 V as in the case of the half-wave rectifier using the same power source, but is less than 4½ V. The reason, of course, is that the peak positive voltage of A relative to C is 4½ V, not 9 V, and part of the 4½ V is lost across R.

Though the full wave rectifier fills in the conduction gaps, it delivers less than half the peak output voltage that results from half-wave rectification.

4.2.2 Bridge Rectifier

A more widely used full-wave rectifier circuit is the bridge rectifier. It requires four diodes instead of two, but avoids the need for a centre-tapped transformer. During the positive half-cycle of the secondary voltage, diodes D2 and D4 are conducting and diodes D1 and D3 are non-conducting. Therefore, current flows through the secondary winding, diode D2, load resistor RL and diode D4. During negative half-cycles of the secondary voltage, diodes D1 and D3 conduct, and the diodes D2 and D4 do not conduct. The current therefore flows through the secondary winding, diode D1, load resistor RL and diode D3. In both cases, the current passes through the load resistor in the same direction. Therefore, a fluctuating, unidirectional voltage is developed across the load.

Filtration:

The rectifier circuits we have discussed above deliver an output voltage that always has the same polarity: but however, this output is not suitable as DC power supply for solid-state circuits. This is due to the pulsation or ripples of the output voltage. This should be removed out before the output voltage can be supplied to any circuit. This smoothing is done by incorporating filter networks. The filter network consists of inductors and capacitors. The inductors or choke coils are generally connected in series with the rectifier output and the load. The inductors oppose any change in the magnitude of a current flowing through them by storing up energy in a magnetic field.

An inductor offers very low resistance for DC whereas; it offers very high resistance to AC. Thus, a series connected choke coil in a rectifier circuit helps to reduce the pulsations or ripples to a great extent in the output voltage. The fitter capacitors are usually connected in parallel with the rectifier output and the load. As, AC can pass through a capacitor but DC cannot, the ripples are thus limited and the output becomes smoothed. When the voltage across its plates tends to rise, it stores up energy back into voltage and current. Thus, the fluctuations in the output voltage are reduced considerable. Filter network circuits may be of two types in general:

Choke input filter:

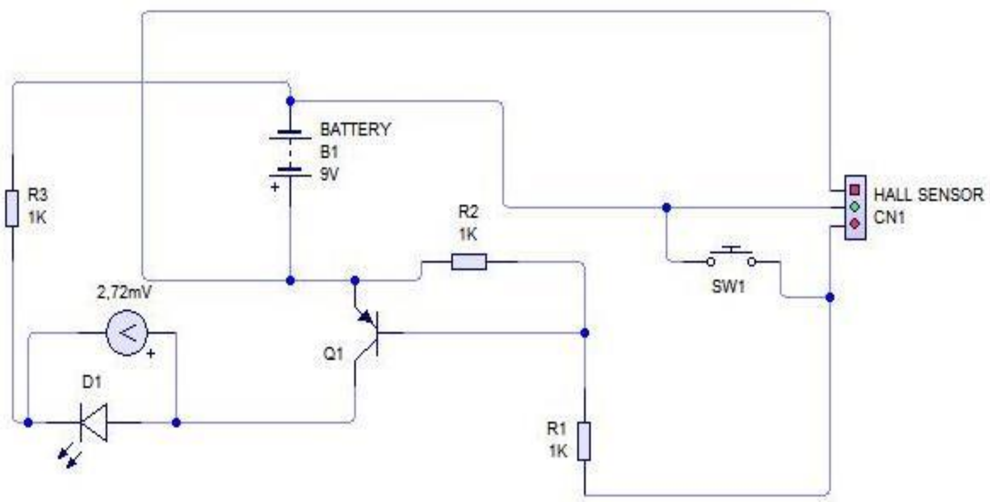
If a choke coil or an inductor is used as the 'first- components' in the filter network, the filter is called 'choke input filter'. The D.C. along with AC pulsation from the rectifier circuit at first passes through the choke (L). It opposes the AC pulsations but allows the DC to pass through it freely. Thus AC pulsations are largely reduced. The further ripples are by passed through the parallel capacitor C. But, however, a little nipple remains unaffected, which are considered negligible. This little ripple may be reduced by incorporating a series a choke input filters.

Capacitor input filter:

If a capacitor is placed before the inductors of a choke-input filter network, the filter is called capacitor input filter. The D.C. along with AC ripples from the rectifier circuit starts charging the capacitor C. to about peak value. The AC ripples are then diminished slightly. Now the capacitor C, discharges through the inductor or choke coil, which opposes the AC ripples, except the DC. The second capacitor C by passes the further AC ripples. A small ripple is still present in the output of DC, which may be reduced by adding additional filter network in series.

Chapter 5: CIRCUIT DIAGRAM

5.1 Hall Circuit

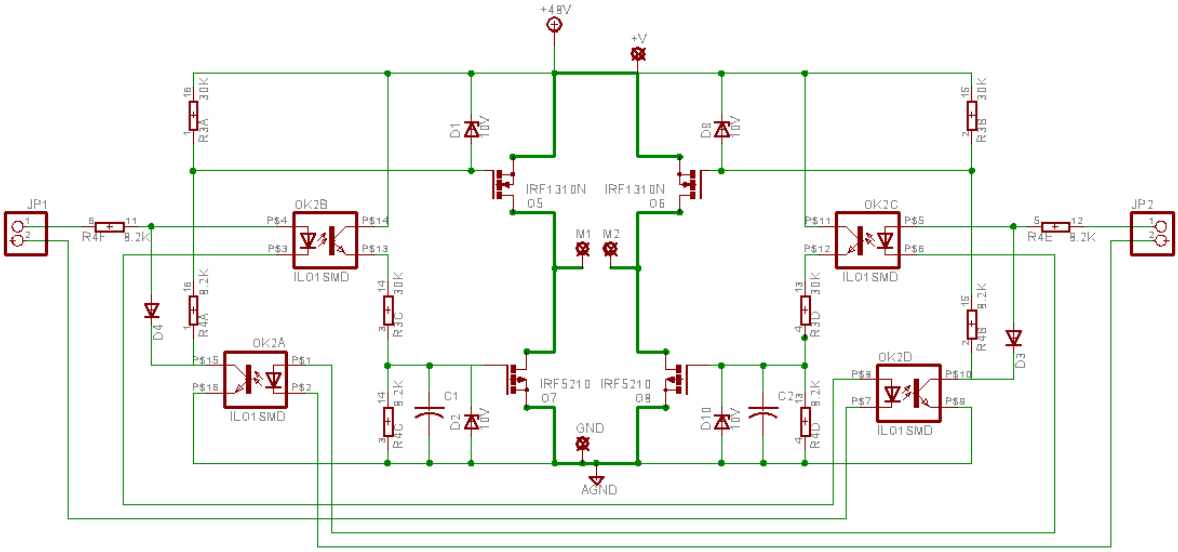


A Hall Effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall Effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

In its simplest form, the sensor operates as an Analogue transducer, directly returning a voltage. With a known magnetic field, its distance from the Hall plate can be determined. Using groups of sensors, the relative position of the magnet can be deduced. Electricity carried through a conductor will produce a magnetic field that varies with current, and a Hall sensor can be used to measure the current without interrupting the circuit. Typically, the sensor is integrated with a wound core or permanent magnet that surrounds the conductor to be measured.

Frequently, a Hall sensor is combined with circuitry that allows the device to act in a digital (on/off) mode, and may be called a switch in this configuration. Commonly seen in industrial applications such as the pictured pneumatic cylinder, they are also used in consumer equipment; for example, some computer printers use them to detect missing paper and open covers. When high reliability is required, they are used in keyboards.

5.2 H-Bridge



The H-bridge arrangement is generally used to reverse the polarity of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit. The following table summarises operation, with S1-S4 corresponding to the diagram above.

A solid-state H bridge is typically constructed using opposite polarity devices, such as PNP BJTs or P-channel MOSFETs connected to the high voltage bus and NPN BJTs or N-channel MOSFETs connected to the low voltage bus. The most efficient MOSFET designs use N-channel MOSFETs on both the high side and low side because they typically have a third of the ON resistance of P-channel MOSFETs. This requires a more complex design since the gates of the high side MOSFETs must be driven positive with respect to the DC supply rail.

However, many integrated circuit MOSFET drivers include a charge pump within the device to achieve this. Alternatively, a switched-mode DC–DC converter can be used to provide isolated ('floating') supplies to the gate drive circuitry. A multiple-output fly back converter is well-suited to this application.

Another method for driving MOSFET-bridges is the use of a specialised transformer known as a GDT (Gate Drive Transformer), which gives the isolated outputs for driving the upper FETs gates. The transformer core is usually a ferrite toroid, with 1:1 or 4:9 winding ratio. However, this method can only be used with high frequency signals. The design of the transformer is also very important, as the leakage inductance should be minimized, or cross conduction may occur. The outputs of the transformer also need to be usually clamped by Zener diodes, because high voltage spikes could destroy the MOSFET gates.

A common variation of this circuit uses just the two transistors on one side of the load, similar to a class AB amplifier. Such a configuration is called a "half bridge". [2] The half bridge is used in some switched-mode power supplies that use synchronous rectifiers and in switching amplifiers. The half-H bridge type is commonly abbreviated to "Half-H" to distinguish it from full ("Full-H") H bridges. Another common variation, adding a third 'leg' to the bridge, creates a three-phase inverter. The three-phase inverter is the core of any AC motor drive. A further variation is the half-controlled bridge, where the low-side switching device on one side of the bridge, and the high-side switching device on the opposite side of the bridge, are each replaced with diodes. This eliminates the shoot-through failure mode, and is commonly used to drive variable/switched reluctance machines and actuators where bi-directional current flow is not required. A "double pole double throw" relay can generally achieve the same electrical functionality as an H bridge (considering the usual function of the device). An H bridge would be preferable to the relay where a smaller physical size, high speed switching, or low driving voltage is needed, or where the wearing out of mechanical parts is undesirable.

Chapter 6: Windings

6.1 Typical Winding Arrangements

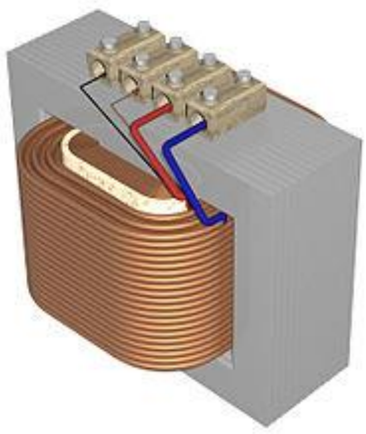
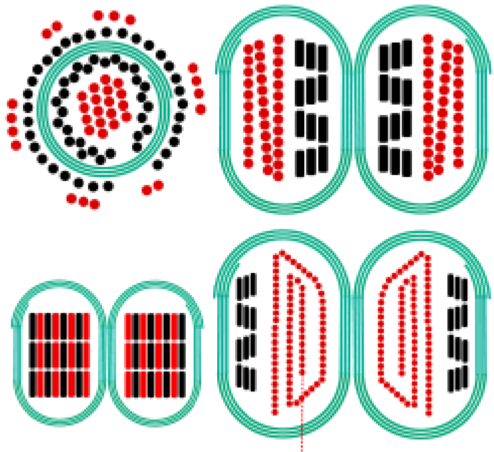


Fig: Typical windings arrangement

Windings are usually arranged concentrically to minimize flux leakage. The conducting material used for the windings depends upon the application, but in all cases the individual turns must be electrically insulated from each other to ensure that the current travels throughout every turn. For small power and signal transformers, in which currents are low and the potential difference between adjacent turns is small, the coils are often wound from enamelled magnet wire, such as Formvar wire. Larger power transformers operating at high voltages may be wound with copper rectangular strip conductors insulated by oil-impregnated paper and blocks of pressboard.



Cut view through transformer windings. White: insulator. Green spiral: Grain oriented silicon steel. Black: Primary winding made of oxygen-free copper. Red: Secondary winding. Top left: Toroidal transformer. Right: C-core, but E-core would be similar. The black windings are made of film. Top: Equally low capacitance between all ends of both windings. Since most cores are at least moderately conductive they also need insulation. Bottom: Lowest capacitance for one end of the secondary winding needed for low-power high-voltage transformers. Bottom left: Reduction of leakage inductance would lead to increase of capacitance.

High-frequency transformers operating in the tens to hundreds of kilohertz often have windings made of braided Litz wire to minimize the skin-effect and proximity effect losses. Large power transformers use multiple-stranded conductors as well, since even at low power frequencies non-uniform distribution of current would otherwise exist in high-current windings. Each strand is individually insulated, and the strands are arranged so that at certain points in the winding, or throughout the whole winding, each portion occupies different relative positions in the complete conductor. The transposition equalizes the current flowing in each strand of the conductor, and reduces eddy current losses in the winding itself. The stranded conductor is also more flexible than a solid conductor of similar size, aiding manufacture.

For signal transformers, the windings may be arranged in a way to minimize leakage inductance and stray capacitance to improve high-frequency response. This can be done by splitting up each coil into sections, and those sections placed in layers between the sections of the other winding. This is known as a stacked type or interleaved winding.

Power transformers often have internal connections or taps at intermediate points on the winding, usually on the higher voltage winding side, for voltage regulation control purposes.

Such taps are normally manually operated, automatic on-load tap changers being reserved, for cost and reliability considerations, to higher power rated or specialized transformers supplying transmission or distribution circuits or certain utilization loads such as furnace transformers. Audio-frequency transformers, used for the distribution of audio to public address loudspeakers, have taps to allow adjustment of impedance to each speaker. A centre-tapped transformer is often used in the output stage of an audio power amplifier in a push-pull circuit. Modulation transformers in AM transmitters are very similar.

Certain transformers have the windings protected by epoxy resin. By impregnating the transformer with epoxy under a vacuum, one can replace air spaces within the windings with epoxy, thus sealing the windings and helping to prevent the possible formation of corona and absorption of dirt or water. This produces transformers more suited to damp or dirty environments, but at increased manufacturing cost.

Chapter 7: Cooling

7.1 Transformer Cooling

Fig: Cutaway view of oil-filled power transformer

The conservator (reservoir) at top provides oil-to-atmosphere isolation. Tank walls' cooling fins provide required heat dissipation balance. Though it is not uncommon for oil-filled transformers to have today been in operation for over fifty years high temperature damages winding insulation, the accepted rule of thumb being that transformer life expectancy is halved for every 8-degree C increase in operating temperature. At the lower end of the power rating range, dry and liquid-immersed transformers are often self-cooled by natural convection and radiation heat dissipation. As power ratings increase, transformers are often cooled by such other means as forced-air cooling, force-oil cooling, water-cooling, or a combination of these. The dielectric coolant used in many outdoor utility and industrial service transformers is transformer oil that both cools and insulates the windings.

Transformer oil is a highly refined mineral oil that inherently helps thermally stabilize winding conductor insulation, typically paper, within acceptable insulation temperature rating limitations. However, the heat removal problem is central to all electrical apparatus such that in the case of high value transformer assets, this often translates in a need to monitor, model, forecast and manage oil and winding conductor insulation temperature conditions under varying, possibly difficult, power loading conditions. Indoor liquid-filled transformers are required by building regulations in many jurisdictions to either use a non-flammable liquid or to be located in fire-resistant rooms. Air-cooled dry transformers are preferred for indoor applications even at capacity ratings where oil-cooled construction would be more economical, because their cost is offset by the reduced building construction cost.

The oil-filled tank often has radiators through which the oil circulates by natural convection. Some large transformers employ electric-operated fans or pumps for forced-air or forced-oil cooling or heat exchanger-based water-cooling. Oil-filled transformers undergo prolonged drying processes to ensure that the transformer is completely free of water vapour before the cooling oil is introduced. This helps prevent electrical breakdown under load. Oil-filled transformers may be equipped with Buchholz relays, which detect gas evolved during internal arcing and rapidly de-energize the transformer to avert catastrophic failure. Oil-filled transformers may fail, rupture, and burn, causing power outages and losses. Installations of oil-filled transformers usually include fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems.

Polychlorinated biphenyls have properties that once favoured their use as a dielectric coolant, though concerns over their environmental persistence led to a widespread ban on their use. Today, non-toxic, stable silicone-based oils, or fluorinated hydrocarbons may be used where the expense of a fire-resistant liquid offsets additional building cost for a transformer vault. Before 1977, even transformers that were nominally filled only with mineral oils may also have been contaminated with polychlorinated biphenyls at 10-20 ppm. Since mineral oil and PCB fluid mix, maintenance equipment used for both PCB and oil-filled transformers could carry over small amounts of PCB, contaminating oil-filled transformers. Some "dry" transformers (containing no liquid) are enclosed in sealed, pressurized tanks and cooled by nitrogen or sulphur hexafluoride gas. Experimental power transformers in the 2 MVA range have been built with superconducting windings which eliminates the copper losses, but not the core steel loss.

Insulation drying: Construction of oil-filled transformers requires that the insulation covering the windings be thoroughly dried before the oil is introduced. There are several different methods of drying. Common for all is that they are carried out in vacuum environment. The vacuum makes it difficult to transfer energy (heat) to the insulation. For this there are several different methods. The traditional drying is done by circulating hot air over the active part and cycles this with periods of hot-air vacuum (HAV) drying. More common for larger transformers is to use evaporated solvent which condenses on the colder active part. This process is commonly called vapour-phase drying (VPD). For distribution transformers, which are smaller and have a smaller insulation weight, resistance heating can be used. This is a method where current is injected in the windings to heat the insulation. The method is called low-frequency heating (LFH) since the current is injected at a much lower frequency than the nominal of the grid, which is normally 50 or 60 Hz. A lower frequency reduces the effect of the inductance in the transformer, so the voltage needed to induce the current can be reduced.

Chapter 8: Rectifiers

8.1 Rectifier Devices

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves, solid-state diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulphide) to serve as a point-contact rectifier or "crystal detector".

Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of flame.

The simple process of rectification produces a type of DC characterized by pulsating voltages and currents (although still unidirectional). Depending upon the type of end-use, this type of DC current may then be further modified into the type of relatively constant voltage DC characteristically produced by such sources as batteries and solar cells.

A device which performs the opposite function (converting DC to AC) is known as an inverter.

Rectifier devices:

Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used. With the introduction of semiconductor electronics, vacuum tube rectifiers became obsolete, except for some enthusiasts of vacuum tube audio equipment. For power rectification from very low to very high current, semiconductor diodes of various types (junction diodes, Schottky diodes, etc.) are widely used. Other devices which have control electrodes as well as acting as unidirectional current valves are used where more than simple rectification is required, e.g., where variable output voltage is needed. High power rectifiers, such as are used in high-voltage direct current power transmission, employ silicon semiconductor devices of various types. These are thyristors or other controlled switching solid-state switches which effectively function as diodes to pass current in only one direction.

8.2 Half-Wave Rectifier

In half wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much more filtering is needed to eliminate harmonics of the AC frequency from the output.

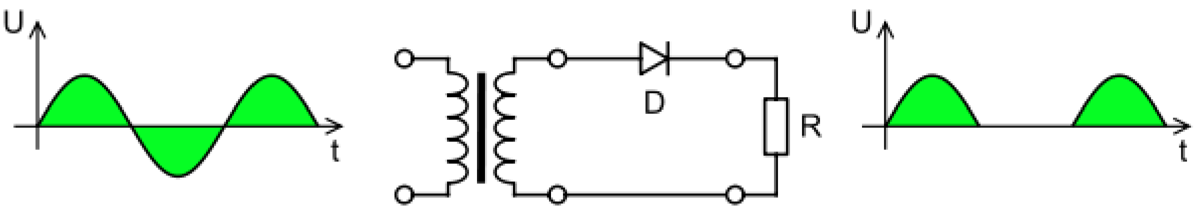


Fig: half wave rectifier

The output DC voltage of an ideal half wave rectifier is:

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{2}$$

$$V_{\mathrm{dc}} = \frac{V_{\mathrm{peak}}}{\pi}$$

A real rectifier will have a characteristic which drops part of the input voltage (a voltage drop, for silicon devices, of typically 0.7 volts plus an equivalent resistance, in general non-linear), and at high frequencies will distort waveforms in other ways; unlike an ideal rectifier, it will dissipate power.

8.3 Full-Wave Rectifier

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to DC (direct current), and yields a higher mean output voltage. Two diodes and a centre tapped transformer, or four diodes in a bridge configuration and any AC source (including a transformer without centre tap), are needed. Single semiconductor diodes, double diodes with common cathode or common anode, and four-diode bridges, are manufactured as single components.

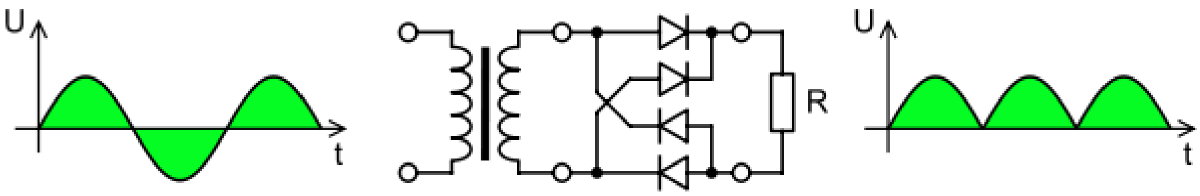


Fig: A full-wave rectifier using 4 diodes.

For single-phase AC, if the transformer is centre-tapped, then two diodes back-to-back (cathode-to-cathode or anode-to-anode, depending upon output polarity required) can form a full-wave rectifier. Twice as many turns are required on the transformer secondary to obtain the same output voltage than for a bridge rectifier, but the power rating is unchanged.

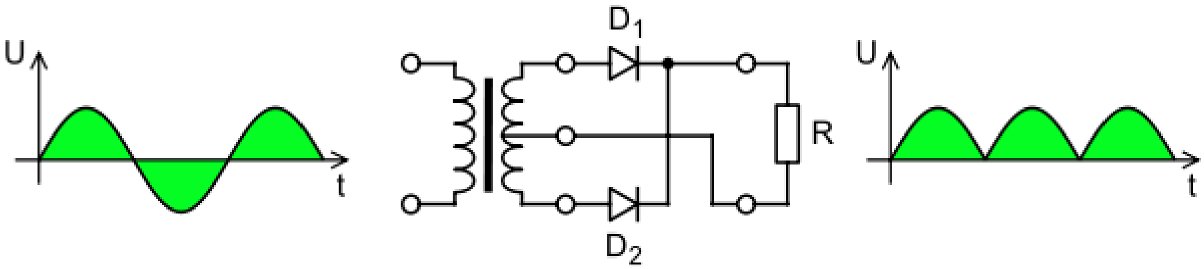


Fig: A Full wave rectifier with two diodes

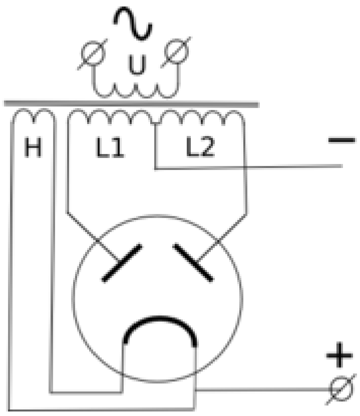


Fig: Full wave rectifier, with vacuum tube having two anodes.

A very common double-diode rectifier tube contained a single common cathode and two anodes inside a single envelope, achieving full-wave rectification with positive output. The 5U4 and 5Y3 were popular examples of this configuration.

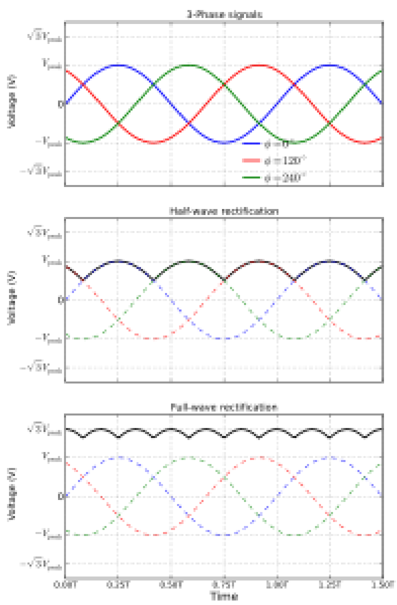


Fig:3-phase AC input, half & full-wave rectified DC output waveforms

For three-phase AC, six diodes are used. Double diodes in series, with the anode of the first diode connected to the cathode of the second, are manufactured as a single component for this purpose. Some commercially available double diodes have all four terminals available so the user can configure them for single-phase split supply use, half a bridge, or three-phase rectifier.

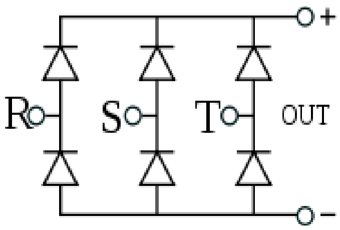


Fig: Three-phase bridge rectifier

Fig: Disassembled automobile alternator, showing the six diodes that comprise a full-wave three-phase bridge rectifier.

Many devices that generate alternating current (some such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.

The average and root-mean-square output voltages of an ideal single-phase full-wave rectifier are:

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{2V_{\mathrm{peak}}}{\pi}$$

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}}$$

For a three-phase full-wave rectifier with ideal thyristors, the average output voltage is

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3\sqrt{3}V_{\mathrm{peak}}}{\pi}\cos\alpha$$

Where:

V_{dc}, V_{av} - the DC or average output voltage,

V_{peak} - the peak value of half wave,

V_{rms} - the root-mean-square value of output voltage.

π = ~ 3.14159

α = firing angle of the thyristor (0 if diodes are used to perform rectification)

Peak loss:

An aspect of most rectification is a loss from the peak input voltage to the peak output voltage, caused by the built-in voltage drop across the diodes (around 0.7 V for ordinary silicon p–n junction diodes and 0.3 V for Schottky diodes). Half-wave rectification and full-wave rectification using a centre-tapped secondary will have a peak voltage loss of one diode drop. Bridge rectification will have a loss of two diode drops. This reduces output voltage, and limits the available output voltage if a very low alternating voltage must be rectified. As the diodes do not conduct below this voltage, the circuit only passes current through for a portion of each half-cycle, causing short segments of zero voltage (where instantaneous input voltage is below one or two diode drops) to appear between each "hump".

Rectifier output smoothing:

While half-wave and full-wave rectification can deliver unidirectional current, neither produces a constant voltage. In order to produce steady DC from a rectified AC supply, a smoothing circuit or filter is required. In its simplest form this can be just a reservoir capacitor or smoothing capacitor, placed at the DC output of the rectifier. There will still be an AC ripple voltage component at the power supply frequency for a half-wave rectifier, twice that for full-wave, where the voltage is not completely smoothed.

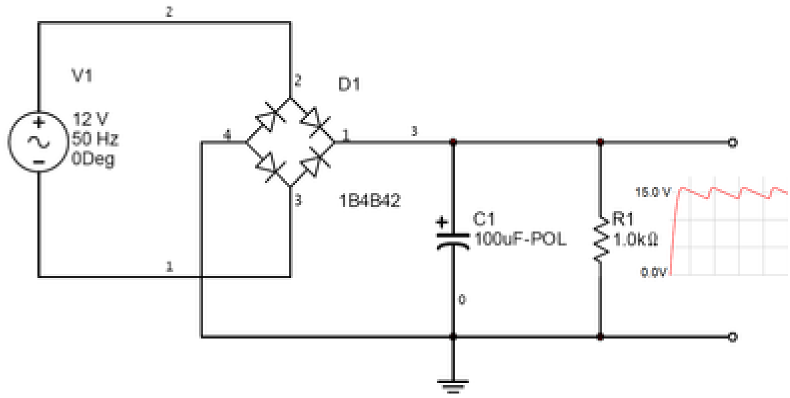


Fig: RC-Filter Rectifier

This circuit was designed and simulated using Multi sim 8 software. Sizing of the capacitor represents a trade-off. For a given load, a larger capacitor will reduce ripple but will cost more and will create higher peak currents in the transformer secondary and in the supply feeding it. The peak current is set in principle by the rate of rise of the supply voltage on the rising edge of the incoming sine-wave, but in practice it is reduced by the resistance of the transformer windings. In extreme cases where many rectifiers are loaded onto a power distribution circuit, peak currents may cause difficulty in maintaining a correctly shaped sinusoidal voltage on the ac supply.

To limit ripple to a specified value the required capacitor size is proportional to the load current and inversely proportional to the supply frequency and the number of output peaks of the rectifier per input cycle. The load current and the supply frequency are generally outside the control of the designer of the rectifier system but the number of peaks per input cycle can be affected by the choice of rectifier design.

A half-wave rectifier will only give one peak per cycle and for this and other reasons is only used in very small power supplies. A full wave rectifier achieves two peaks per cycle, the best possible with a single-phase input. For three-phase inputs a three-phase bridge will give six peaks per cycle; higher numbers of peaks can be achieved by using transformer networks placed before the rectifier to convert to a higher phase order.

To further reduce ripple, a capacitor-input filter can be used. This complements the reservoir capacitor with a choke (inductor) and a second filter capacitor, so that a steadier DC output can be obtained across the terminals of the filter capacitor. The choke presents high impedance to the ripple current. For use at power-line frequencies inductors require cores of iron or other magnetic materials, and add weight and size. Their use in power supplies for electronic equipment has therefore dwindled in favour of semiconductor circuits such as voltage regulators.

A more usual alternative to a filter, and essential if the DC load requires very low ripple voltage, is to follow the reservoir capacitor with an active voltage regulator circuit. The reservoir capacitor needs to be large enough to prevent the troughs of the ripple dropping below the minimum voltage required by the regulator to produce the required output voltage. The regulator serves both to significantly reduce the ripple and to deal with variations in supply and load characteristics. It would be possible to use a smaller reservoir capacitor (these can be large on high-current power supplies) and then apply some filtering as well as the regulator, but this is not a common strategy. The extreme of this approach is to dispense with the reservoir capacitor altogether and put the rectified waveform straight into a choke-input filter. The advantage of this circuit is that the current waveform is smoother and consequently the rectifier no longer has to deal with the current as a large current pulse, but instead the current delivery is spread over the entire cycle. The disadvantage, apart from extra size and weight, is that the voltage output is much lower – approximately the average of an AC half-cycle rather than the peak.

Voltage-Multiplying Rectifiers:

The simple half wave rectifier can be built in two electrical configurations with the diode pointing in opposite directions, one version connects the negative terminal of the output direct to the AC supply and the other connects the positive terminal of the output direct to the AC supply. By combining both of these with separate output smoothing it is possible to get an output voltage of nearly double the peak AC input voltage. This also provides a tap in the middle, which allows use of such a circuit as a split rail supply.

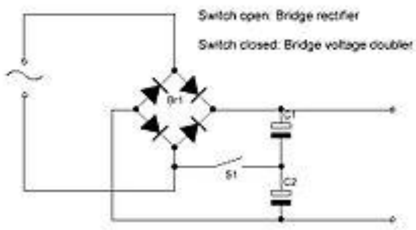


Fig: Switchable full bridge / Voltage doubler.

A variant of this is to use two capacitors in series for the output smoothing on a bridge rectifier then place a switch between the midpoint of those capacitors and one of the AC input terminals. With the switch open this circuit will act like a normal bridge rectifier: with it closed it will act like a voltage doubling rectifier. In other words, this makes it easy to derive a voltage of roughly 320V (+/- around 15%) DC from any mains supply in the world, this can then be fed into a relatively simple switched-mode power supply.

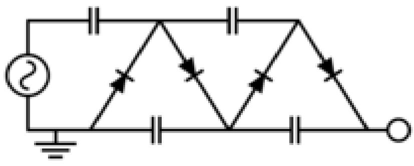


Fig: Voltage multiplier

Cascaded diode and capacitor stages can be added to make a voltage multiplier (Cockroft-Walton circuit). These circuits are capable of producing a DC output voltage potential tens of times that of the peak AC input voltage, but are limited in current capacity and regulation. Diode voltage multipliers, frequently used as a trailing boost stage or primary high voltage (HV) source, are used in HV laser power supplies, powering devices such as cathode ray tubes (CRT) (like those used in CRT based television, radar and sonar displays), photon amplifying devices found in image intensifying and photo multiplier tubes (PMT), and magnetron based radio frequency (RF) devices used in radar transmitters and microwave ovens. Before the introduction of semiconductor electronics, transformer less vacuum tube equipment powered directly from AC power sometimes used voltage doublers to generate about 170VDC from a 100-120V power line.

Applications:

The primary application of rectifiers is to derive DC power from an AC supply. Virtually all electronic devices require DC, so rectifiers are used inside the power supplies of virtually all electronic equipment.

Converting DC power from one voltage to another is much more complicated. One method of DC-to-DC conversion first converts power to AC (using a device called an inverter), then use a transformer to change the voltage, and finally rectifies power back to DC. A frequency of typically several tens of kilohertz is used, as this requires much smaller inductance than at lower frequencies and obviates the use of heavy, bulky, and expensive iron-cored units.

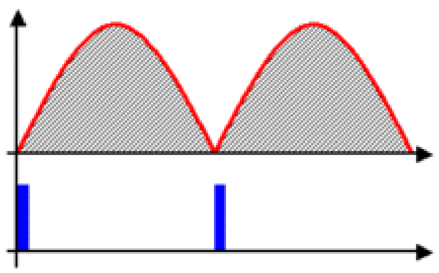


Fig: Output voltage of a full-wave rectifier with controlled thyristors

Rectifiers are also used for detection of amplitude modulated radio signals. The signal may be amplified before detection. If not, a very low voltage drop diode or a diode biased with a fixed voltage must be used. When using a rectifier for demodulation the capacitor and load resistance must be carefully matched: too low a capacitance will result in the high frequency carrier passing to the output, and too high will result in the capacitor just charging and staying charged.

Rectifiers are used to supply polarised voltage for welding. In such circuits control of the output current is required; this is sometimes achieved by replacing some of the diodes in a bridge rectifier with thyristors, effectively diodes whose voltage output can be regulated by switching on and off with phase fired controllers.

Thyristors are used in various classes of railway rolling stock systems so that fine control of the traction motors can be achieved. Gate turn-off thyristors are used to produce alternating current from a DC supply, for example on the Euro star Trains to power the three-phase traction motors.

8.4 Rectification Technologies

Electromechanical:

Early power conversion systems were purely electro-mechanical in design, since electronic devices were not available to handle significant power. Mechanical rectification systems usually use some form of rotation or resonant vibration (e.g. vibrators) in order to move quickly enough to follow the frequency of the input power source, and cannot operate beyond several thousand cycles per second.

Due to reliance on fast-moving parts of mechanical systems, they needed a high level of maintenance to keep operating correctly. Moving parts will have friction, which requires lubrication and replacement due to wear. Opening mechanical contacts under load results in electrical arcs and sparks that heat and erode the contacts.

Synchronous Rectifier:

To convert alternating into direct current in electric locomotives, a **synchronous rectifier** may be uses it consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load at an instant when the sinusoidal current goes through a zero-crossing. The contacts do not have to *switch* a large current, but they need to be able to *carry* a large current to supply the locomotive's DC traction motors.

Vibrator:

Vibrators used to generate AC from DC in pre-semiconductor battery-to-high-voltage-DC power supplies often contained a second set of contacts that performed synchronous mechanical rectification of the stepped-up voltage.

Motor-generator set:

A motor-generator set, or the similar rotary converter, is not strictly a rectifier as it does not actually rectify current, but rather generates DC from an AC source. In an "M-G set", the shaft of an AC motor is mechanically coupled to that of a DC generator. The DC generator produces multiphase alternating currents in its armature windings, which a commutator on the armature shaft converts into a direct current output; or a monopolar generator produces a direct current without the need for a commutator. M-G sets are useful for producing DC for railway traction motors, industrial motors and other high-current applications, and were common in many high power D.C. uses (for example, carbon-arc lamp projectors for outdoor theatre’s) before high-power semiconductors became widely available.

Electrolytic:

The electrolytic rectifier was a device from the early twentieth century that is no longer used. A home-made version is illustrated in the 1913 book *The Boy Mechanic* [5] but it would only be suitable for use at very low voltages because of the low breakdown voltage and the risk of electric shock. A more complex device of this kind was patented by G. W. Carpenter in 1928 (US Patent 1671970).

When two different metals are suspended in an electrolyte solution, direct current flowing one way through the solution sees less resistance than in the other direction. Electrolytic rectifiers most commonly used an aluminium anode and a lead or steel cathode, suspended in a solution of tri-ammonium ortho-phosphate.

The rectification action is due to a thin coating of aluminium hydroxide on the aluminium electrode, formed by first applying a strong current to the cell to build up the coating. The rectification process is temperature-sensitive, and for best efficiency should not operate above 86 °F (30 °C). There is also a breakdown voltage where the coating is penetrated and the cell is short-circuited. Electrochemical methods are often more fragile than mechanical methods, and can be sensitive to usage variations which can drastically change or completely disrupt the rectification processes.

Similar electrolytic devices were used as lightning arresters around the same era by suspending many aluminium cones in a tank of tri-ammonium ortho-phosphate solution. Unlike the rectifier above, only aluminium electrodes were used, and used on A.C., there was no polarization and thus no rectifier action, but the chemistry was similar.

The modern electrolytic capacitor, an essential component of most rectifier circuit configurations was also developed from the electrolytic rectifier.

Plasma type:

Mercury arc

A rectifier used in high-voltage direct current (HVDC) power transmission systems and industrial processing between about 1909 to 1975 is a *mercury arc rectifier* or *mercury arc valve*. The device is enclosed in a bulbous glass vessel or large metal tub. One electrode, the cathode, is submerged in a pool of liquid mercury at the bottom of the vessel and one or more high purity graphite electrodes, called anodes, are suspended above the pool. There may be several auxiliary electrodes to aid in starting and maintaining the arc. When an electric arc is established between the cathode pool and suspended anodes, a stream of electrons flows from the cathode to the anodes through the ionized mercury, but not the other way (in principle, this is a higher-power counterpart to flame rectification, which uses the same one-way current transmission properties of the plasma naturally present in a flame).

These devices can be used at power levels of hundreds of kilowatts, and may be built to handle one to six phases of AC current. Mercury arc rectifiers have been replaced by silicon semiconductor rectifiers and high power thyristor circuits in the mid-1970s. The most powerful mercury arc rectifiers ever built were installed in the Manitoba Hydro Nelson River Bipole HVDC project, with a combined rating of more than 1 GW and 450 kV

Argon gas electron tube

The General Electric Tungar rectifier was an argon gas-filled electron tube device with a tungsten filament cathode and a carbon button anode. It was used for battery chargers and similar applications from the 1920s until lower-cost metal rectifiers, and later semiconductor diodes, supplanted it. These were made up to a few hundred volts and a few amperes rating, and in some sizes strongly resembled an incandescent lamp with an additional electrode.

The 0Z4 was a gas-filled rectifier tube commonly used in vacuum tube car radios in the 1940s and 1950s. It was a conventional full-wave rectifier tube with two anodes and one cathode, but was unique in that it had no filament (thus the "0" in its type number). The electrodes were shaped such that the reverse breakdown voltage was much higher than the forward breakdown voltage. Once the breakdown voltage was exceeded, the 0Z4 switched to a low-resistance state with a forward voltage drop of about 24 V.

Vacuum tube (valve)

Since the discovery of the Edison effect or thermionic emission, various vacuum tube devices were developed to rectify alternating currents. The simplest is the simple vacuum diode (the term "valve" came into use for vacuum tubes in general due to this unidirectional property, by analogy with a unidirectional fluid flow valve). Low-current devices were used as signal detectors, first used in radio by Fleming in 1904. Many vacuum-tube devices also used vacuum diode rectifiers in their power supplies, for example the All American Five radio receiver. Vacuum rectifiers were made for very high voltages, such as the high voltage power supply for the cathode ray tube of television receivers, and the kenotron used for power supply in X-ray equipment. However, vacuum rectifiers generally had current capacity rarely exceeding 250 mA owing to the maximum current density that could be obtained by electrodes heated to temperatures compatible with long life.

Another limitation of the vacuum tube rectifier was that the heater power supply often required special arrangements to insulate it from the high voltages of the rectifier circuit.

Solid State:

Crystal detector

The cat's-whisker detector, typically using a crystal of galena, was the earliest type of semiconductor diode, though not recognised as such at the time.

Selenium and copper oxide rectifiers

Once common until replaced by more compact and less costly silicon solid-state rectifiers, these units used stacks of metal plates and took advantage of the semiconductor properties of selenium or copper oxide. While selenium rectifiers were lighter in weight and used less power than comparable vacuum tube rectifiers, they had the disadvantage of finite life expectancy, increasing resistance with age, and were only suitable to use at low frequencies. Both selenium and copper oxide rectifiers have somewhat better tolerance of momentary voltage transients than silicon rectifiers.

Typically, these rectifiers were made up of stacks of metal plates or washers, held together by a central bolt, with the number of stacks determined by voltage; each cell was rated for about 20 V. An automotive battery charger rectifier might have only one cell: the high-voltage power supply for a vacuum tube might have dozens of stacked plates. Current density in an air-cooled selenium stack was about 600 mA per square inch of active area (about 90 mA per square centimetre).

Silicon and Germanium Diodes

In the modern world, silicon diodes are the most widely used rectifiers for lower voltages and powers, and have largely replaced earlier germanium diodes. For very high voltages and powers, the added need for controllability has in practice caused simple silicon diodes to be replaced by high-power thyristors (see below) and their newer actively-gate-controlled cousins.

High Power: Thyristors (SCRs) and newer Silicon-based voltage sourced converters

In high power applications, from 1975–2000, most mercury valve arc-rectifiers were replaced by stacks of very high power thyristors, silicon devices with two extra layers of semiconductor, in comparison to a simple diode.

In medium power-transmission applications, even more complex and sophisticated voltage sourced converter (VSC) silicon semiconductor rectifier systems, such as insulated gate bipolar transistors (IGBT) and gate turn-off thyristors (GTO), have made smaller high voltage DC power transmission systems economical. All of these devices function as rectifiers.

As of 2009 it was expected that these high-power silicon "self-commutating switches," in particular IGBTs and a variant thyristor (related to the GTO) called the integrated gate-commutated thyristor (IGCT), would be scaled-up in power rating to the point that they would eventually replace simple thyristor-based AC rectification systems for the highest power-transmission DC applications.

Early 21st century developments:

High-speed rectifiers

Researchers at Idaho National Laboratory (INL) have proposed high-speed rectifiers that would sit at the centre of spiral nano antennas and convert infrared frequency electricity from AC to DC Infrared frequencies range from 0.3 to 400 terahertz.

Unimolecular rectifiers Unimolecular rectifier is a single organic molecule which functions as a rectifier, in the experimental stage as of 2012.

Chapter 9: Industrial Utilizability

9.1 Applications

The electromagnetic engine according to the present invention is operated by the electromagnetic action and can generate greater magnetic force by a smaller exciting current because the number of windings of exciting coils can be increased to a large extent by its structure. Further, the magnetic force so produced can be utilized as a driving force so that this engine is extremely superior from the energy-saving point of view to usual electric drive motors and that it is suitable as a driving source particularly for electric vehicles and so on.

Where the magnetic force so produced is utilized as a driving force for electric vehicles in the manner as described hereinabove, a variety of technology developed for internal combustion piston engines for vehicles, such as power transmission mechanisms and so on, may also be used for electric vehicles with ease. Therefore, the current plants and equipment for manufacturing vehicles can also be applied to manufacturing electric vehicles and the technology involved in the present invention can also greatly contribute to facilitating the development of electric vehicles.

Further, the electromagnetic engine according to the present invention is not of the type rotating the rotor directly by the electromagnetic action as with conventional electric drive motors so that the problems with the heavy weight of a portion corresponding to the rotary assembly portion and so on, which are involved in conventional electric drive motors for vehicles, may be solved at once.

Moreover, the electromagnetic engine according to the present invention does not generate such a large amount of heat from its principles as with conventional internal combustion piston engines so that no cooling mechanism for cooling engines for vehicles is required, thereby contributing to making electric vehicles lightweight and compact in size.

Also, as the electromagnetic piston engine according to the present invention can eliminate various mechanical resistances which are otherwise caused naturally from the structure itself of internal combustion piston engines, efficiency of energy consumption can be increased.

In addition, the electromagnetic engine according to the present invention is higher in efficiency of energy consumption as compared with gasoline engines, so that it is extremely advantageous over gasoline engines in terms of saving energy. Furthermore, as the electromagnetic engine uses electricity that is clean energy, it is extremely useful in terms of preservation of the environment of the earth

Chapter 10: Advantages and Disadvantages

10.1 Advantages

The Electromagnetic Engine can be used as a viable, clean alternative, which will all but eliminate the production of CO_2 resulting from the burning of fossil fuels (i.e., oil and coal). The Electromagnetic Engine will not require any fuel, thereby creating no need for oil, Coal or any other burning of Fossil fuels, hence, no CO_2 production. Several market applications have been identified for the new technology, including vehicle propulsion, renewable electricity, and air travel. The primary market is renewable electricity that will clean water anywhere.

The world is facing two large problems, Global Warming and Oil supply ending. We will affect both problems by replacing the one common source, the Combustion Engine. The combustion engine requires fossil fuel, oil, to operate. The Combustion Engine burns fuel producing greenhouse gases.

Electromagnetic Engine:

1. Does not require fossil fuel or produce any CO_2 gas.
2. Produce 88% more Horse power than the Combustion Engine and 87% less energy.
3. Produces the electricity for electromagnets and others systems- Renewable power.

10.2 Engine Efficiency

The Electromagnetic Engine is efficient in converting energy from Electromagnetic Energy to Mechanical Energy by using Crank shaft. The Combustion Engine uses crankshaft, but very inefficiently. The Electromagnetic Engine turns the crankshaft more efficiently than the Combustion Engine, requires less strokes and energy to produce more horse power than the Combustion Engine.

10.3 Less power consumption

The Electromagnetic engine turns the crankshaft half a stroke or turn before power is provided. This small Distance decreases the amount of Force that is required to turn the crank. This decrease will increase that the engine will produce.

10.4 Disadvantages

1. It provides less uniform torque than the Internal Combustion Engine
2. Still research has to done for the system to be applicable for a Multi-Cylinder system
3. Permanent Magnets loose efficiency with time and hence electro-magnets have to be incorporated
4. Neo Magnets are costly to manufacture and thus the price of the system is more than a general internal combustion Engine
5. Flux losses occur inside the cylinder and eventually they become very difficult to control
6. Life span of the engine tested in lower than the Internal Combustion Engine and a better choice of the engine material has to be made to increase the life span
7. Though we have a working prototype of the model suggested but many design changes still have to be incorporated to increase the efficiency of the system as a whole

Chapter 11: Conclusions

The Electromagnetic engine developed is an attempt to curb the pollution generated by present Internal Combustion Engines. We have successfully demonstrated the concept of using electromagnetics to produce crank shaft rotation in an Internal Combustion Engine model. The research conducted is an example that the present internal combustion engines can be modified and made eco-friendly by using the suggested concept. Though the research conducted in this report in not adequate to be commercially applied but we believe that with adequate funding and further research we would be able to develop the first ever commercially usable electromagnetic engine. The electromagnetic engine designed is totally different from motor, because the working principle of both are different as well as the power consumption is also very less in electromagnetic engine. The only power consumed is the power consumed by electromagnet. Electromagnet used here is to repel the permanent magnet. There are no other power consuming components. Movement of magnet doesn't induce back electromotive force in windings of electromagnet and hence nothing happens similar to electric motor here. Power to be produced at shaft of the engine is much more than the power to be consumed by electromagnet to repel permanent magnet.

10.1 Recommendations

1. To generate more power, the number of windings must be increased and effective cooling technique should be adopted.
2. All the parts of the IC Engine must be casted with non-magnetic material.
3. Neo-magnets on the piston cylinder should be designed for heavy flux density and their strength should be shielded by avoiding its contact with magnetic materials.
4. Controller circuit should be cooled effectively by using alloy heat sinks as large currents are drawn during excitation of the cylinder coil.

Appendix:

A	square meter	cross sectional area of core
B	Tesla	Magnetic field (Magnetic flux density)
F	Newton	Force exerted by magnetic field
H	ampere per meter	Magnetizing field
I	Ampere	Current in the winding wire
L	Meter	Total length of the magnetic field path $L_{\mathrm{core}} + L_{\mathrm{gap}}$
L_{core}	Meter	Length of the magnetic field path in the core material
L_{gap}	Meter	Length of the magnetic field path in air gaps
m_1, m_2	ampere meter	Pole strength of the electromagnet
μ	Newton per square ampere	Permeability of the electromagnet core material
μ_0	Newton per square ampere	Permeability of free space (or air) = 4π(10^{-7})
μ_r	-	Relative permeability of the electromagnet core material
N	-	Number of turns of wire on the electromagnet
r	Meter	Distance between the poles

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