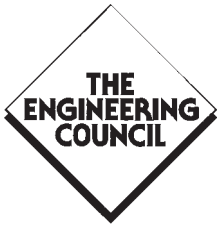
TEP
TECHNOLOGY
ENHANCEMENT
PROGRAMME

MINI DC GENERATOR

Version 1



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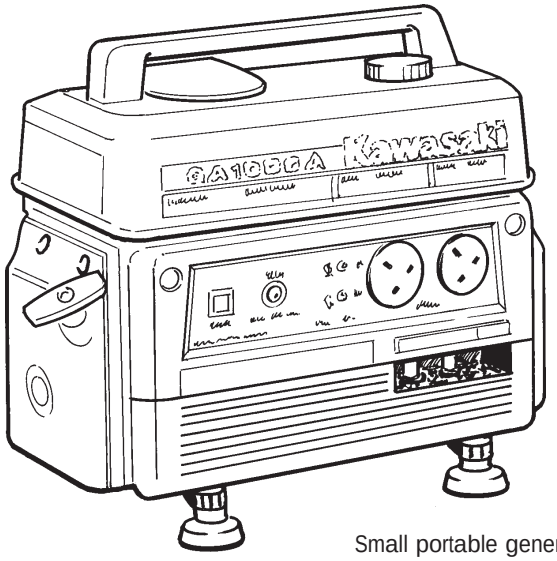
A MINI DC GENERATOR

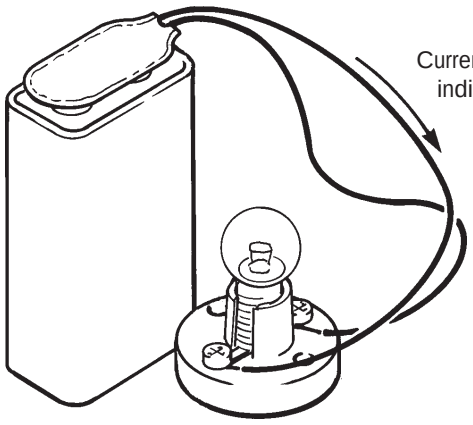
A generator converts mechanical energy into electrical energy. To understand how this happens, you need to know something about *electric current*; *magnetic fields* and what happens when a conductor such as copper wire *is moved within* a magnetic field.



Small portable generator - petrol driven

ELECTRIC CURRENT

Electric current is a movement of electrons through a conductor. The ampere (A) or “amp” for short is the unit of current and is the *rate* at which electrons move through a point in a conductor. A current of one amp is equivalent to approximately six million, million, million electrons flowing per second! (A strict definition of one amp is as follows: 'one Ampere is the current flowing in a resistance of one Ohm across which there is a potential difference of one Volt'.) When a source of current such as a battery is connected into a circuit we say that current *flows* . We use this word because in the early days of electrical science it was mistakenly thought that electricity was a type of fluid.

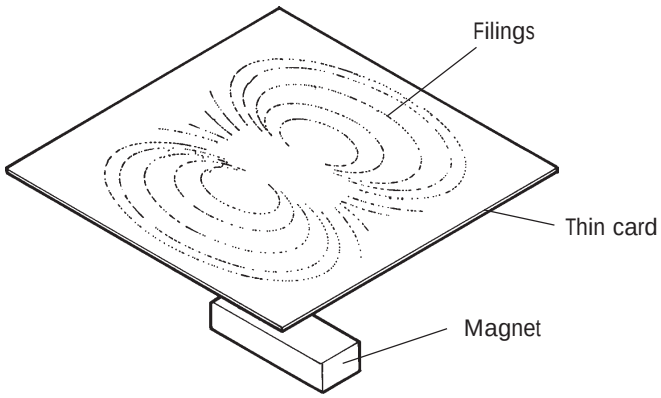


Current flow is often indicated by an arrow

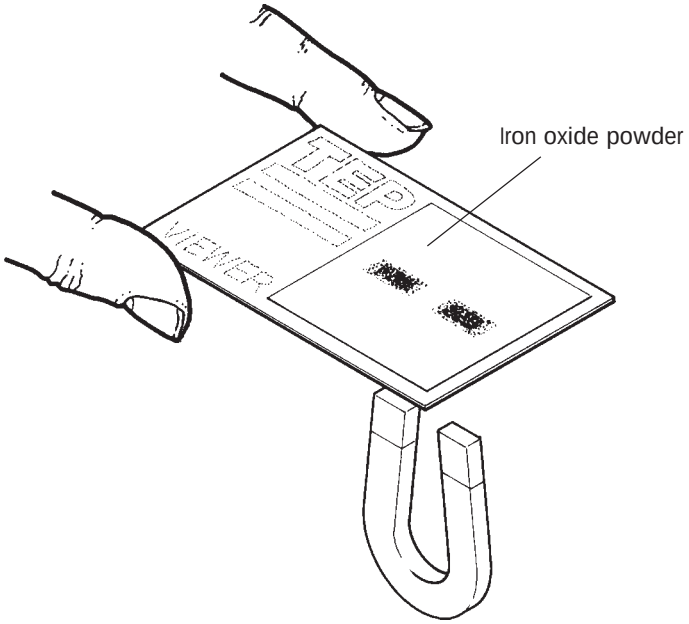
Electrons actually 'move' from the (-) to (+) terminals on a battery or power supply when a circuit is connected. However, because of earlier beliefs, it is still more common to talk about current flowing from (+) to (-). This is called *conventional current* flow.

MAGNETIC FIELDS

A magnetic field is the region of influence around a magnet that will attract materials such as iron. The field is invisible but shows up, for example, when a magnet is placed under a sheet of thin card covered with fine iron filings. The iron fillings are pulled by the magnet into the shape of the magnetic field which appears as a series of lines called *lines of flux* or *lines of force*.

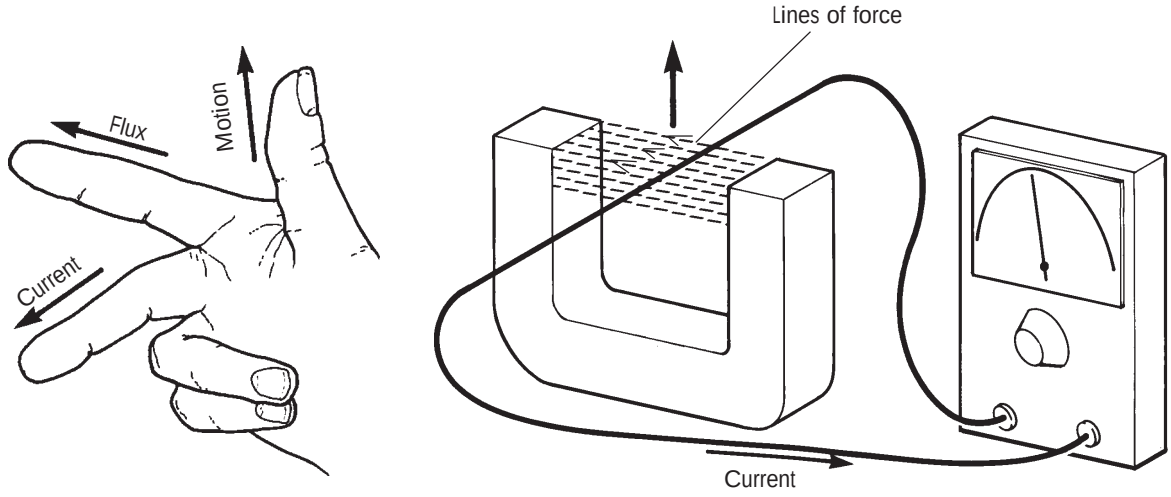


A modern version of the paper and iron filings is the TEP magnetic viewer. This is a small see-through plastic envelope with a thin gap between the clear front and back layers containing iron oxide powder. When you hold the card over a magnet, the powder is pulled into the shape of the field like the iron filings.

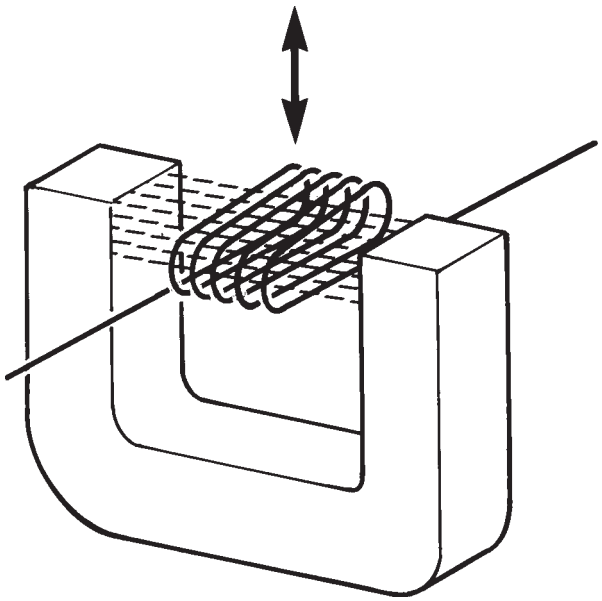


ELECTROMAGNETIC INDUCTION

When a conductor such as copper wire is moved within a magnetic field and cuts across the lines of force, an electric current flows. The direction of current flow can be determined using called *Fleming's right hand rule.*



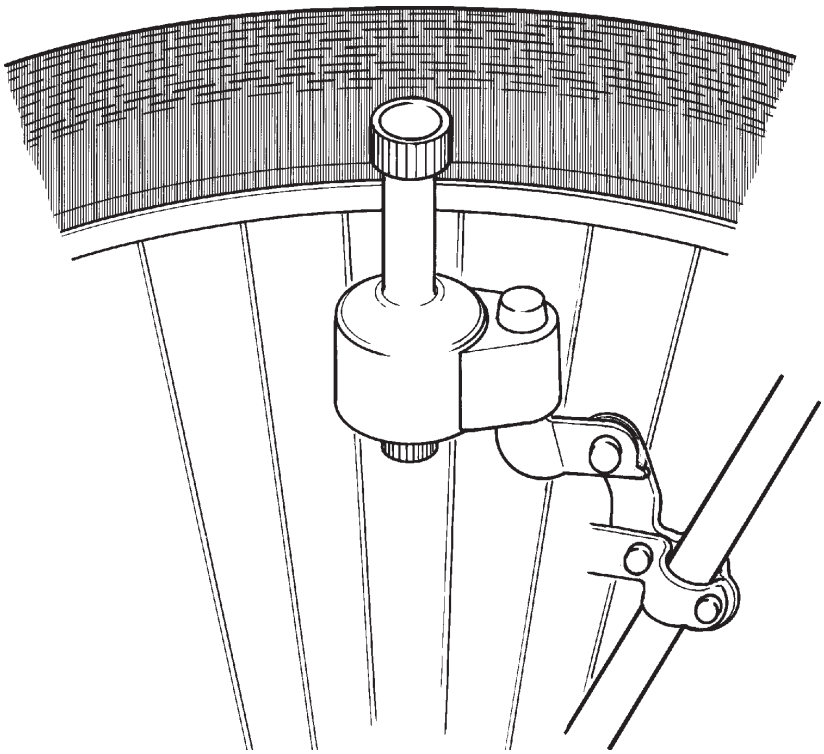
If the wire is made into a coil and moved in the field, a larger current flows. A current can also be made to flow by moving the magnet rather than the coil.

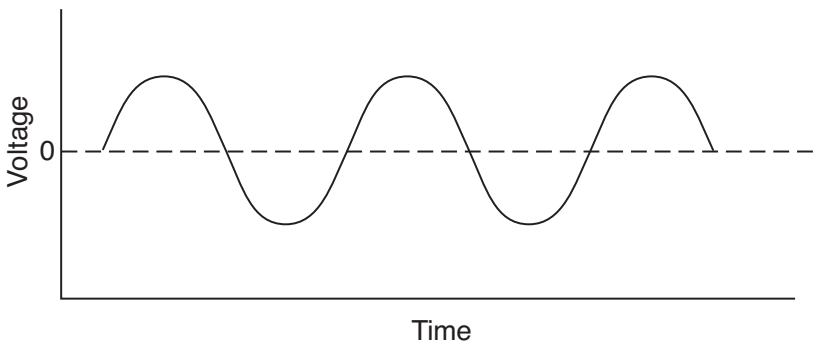


GENERATING ELECTRIC CURRENT

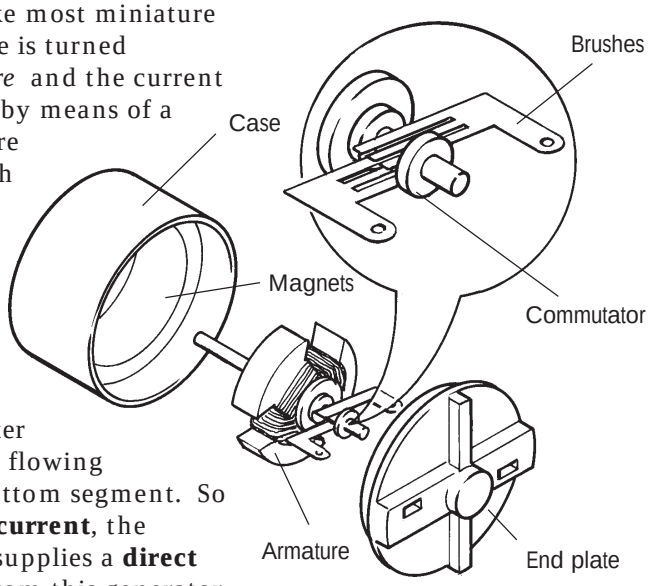
To generate a continuous supply of current, machines are designed that use the principle of electromagnetic induction. There are several types. Some, for example, use rotating coils within a magnetic field and some use magnets rotating between fixed coils.

Many bicycle generators have at their centre a rotating magnet . The magnet is rapidly turned within a pair of coils by means of a friction wheel rubbing on the edge of a tyre. This type of generator produces a supply of current known as *alternating current* (AC) because as the magnet rotates through each turn it causes current to flow first one way and then the opposite way. This is like having a battery whose terminals are rapidly changing their polarity from (+) to (-) and vice versa. We can draw a time graph to show AC.

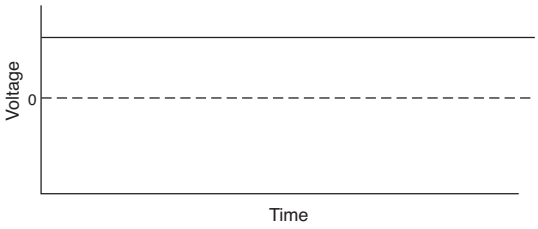


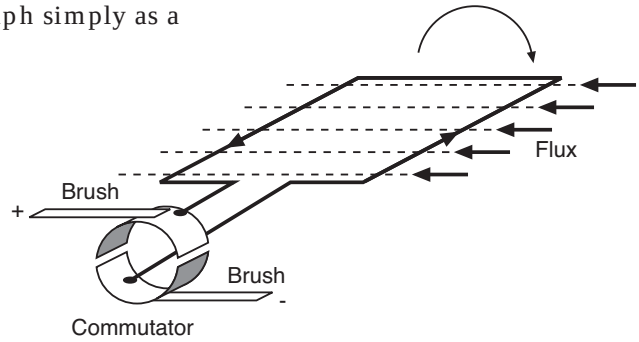


The TEP generator has coils rotating between fixed magnets. It was in fact designed as an electric motor but like most miniature motors it works as a generator when the spindle is turned rapidly. The coils are wound around an *armature* and the current generated in them passes to a pair of terminals by means of a *commutator* and *brushes*. The ends of the coils are connected to commutator segments from which a direct current (DC) is drawn by means of brushes in contact with the segments. The simplified diagram of a single coil rotating in a magnetic fiels shows how the commutator works. The segments are mounted on the shaft and rotate with the coil. The current in the coil flows towards the top segment and away from the bottom segment. Half a turn later the current in the coil has reversed but it is still flowing towards the top segment and away from the bottom segment. So although the coil is generating an **alternating current**, the commutator acts as a mechanical rectifier and supplies a **direct current** from the brushes. The direct current from this generator always flows the same way, unless you reverse the direction of rotation of the shaft.

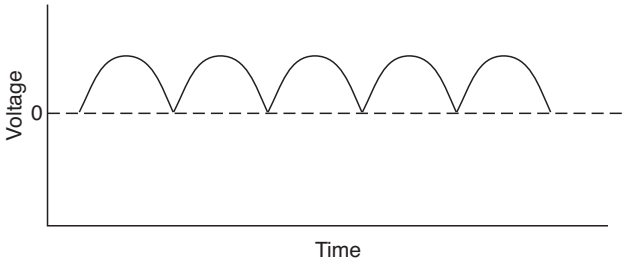


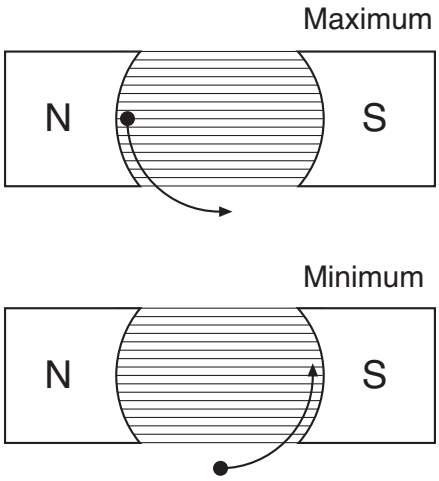
Ideally, the output of a DC generator should be *smooth* like that supplied by a battery. This appears on a time graph simply as a straight line.





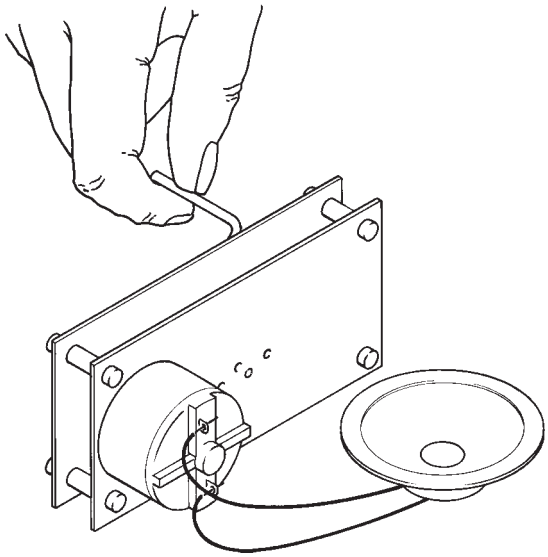
The TEP generator, however, provides *pulsating* DC. This is because the current flow rises to a maximum when the coils cut directly across the lines of force and then falls to a minimum when they move along the lines of force.



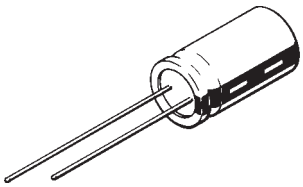


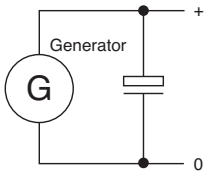
IMPROVING THE DC OUTPUT

If the TEP generator is connected to a loudspeaker, the pulsations are heard as a loud sound. The pitch of this sound rises as the generator's speed is increased. If the generator is used to power a radio, these pulsations may seriously interfere with the music or speech from the radio itself. For this type of application, a way has to be found to make the output as smooth as possible.

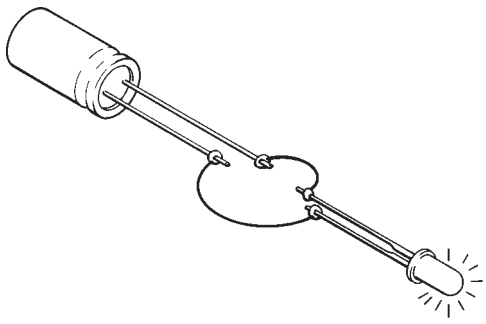


The most common method of smoothing a pulsating supply, is to connect a capacitor in parallel with it. A capacitor is a device that stores electrical charge and is sometimes thought of as a rechargeable battery with a very rapid charge time and short life.

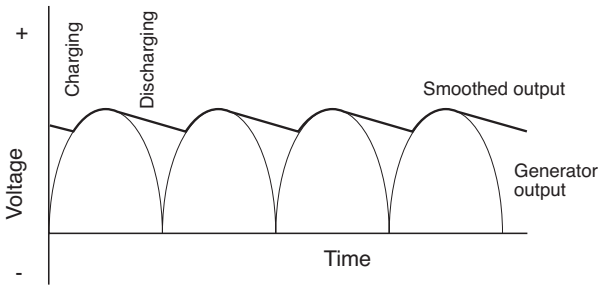




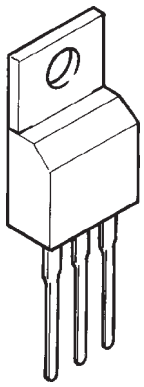
The unit of capacitance is the Farad which is a very large value. A microfarad (µF) is one millionth of a Farad. If you place a 1000 µF capacitor across a 4.5 V battery, it charges up almost instantly. If it is then connected - say - to an LED, this will light up, but only for a short period.



When a capacitor is connected in parallel with the generator, it charges up during each pulsation and discharges to 'fill in' the gaps between pulsations as the diagram shows. A capacitor by itself does not give perfect DC but can turn a pulsating supply into one with only a small “ripple”.

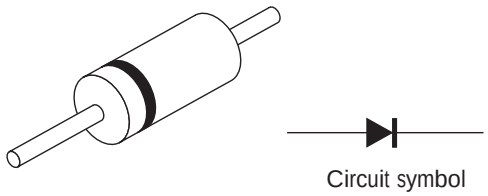


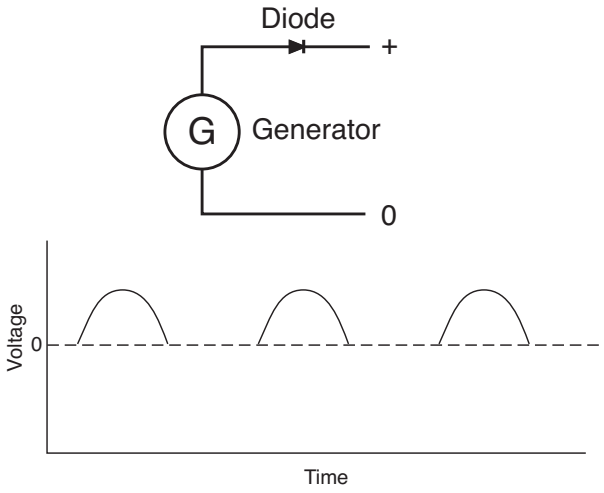
(In order to produce a perfect DC supply, we need also to add a device called a *voltage regulator* which senses the ripples and corrects them to give almost perfect DC. Voltage regulators are available in a small compact package and are now quite low in cost.)



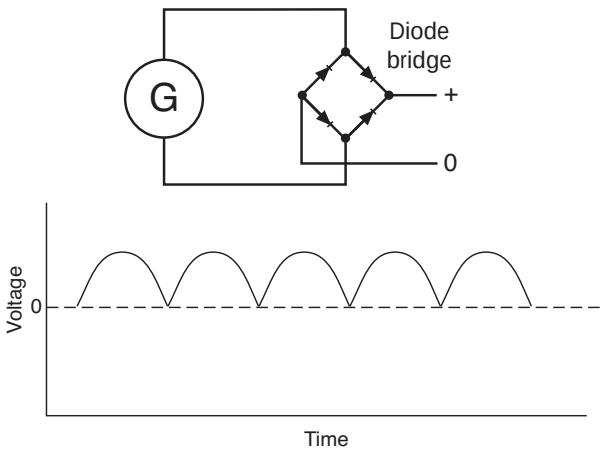
Voltage regulator

If we need to convert the output from an AC generator to DC, it can be done with *diodes* which allow current to flow in one direction only. This process is called *rectification*. The simplest circuit uses just one diode and gives *half wave rectification*. As the time graph shows, the diode stops current flowing one way and produces pulsations with a gap between each. This output can be smoothed with a capacitor to fill in the gaps.



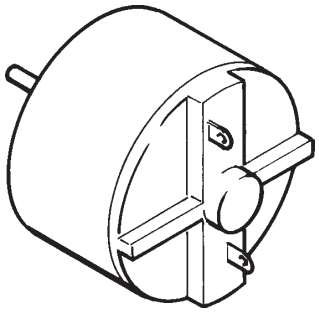


A better form of rectification uses four diodes often supplied as single component. This is called *full wave rectification*.

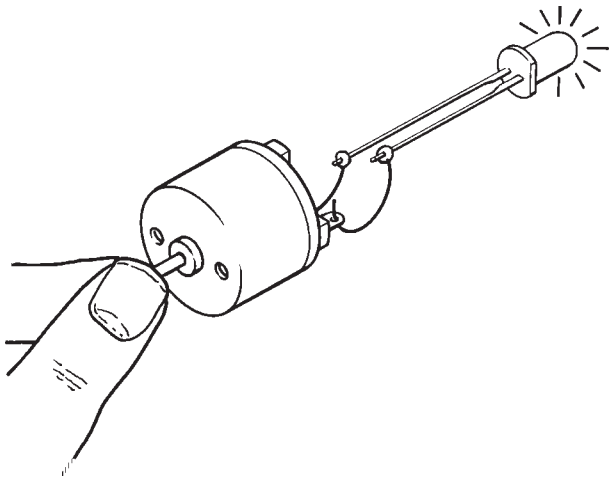


THE TEP MINI-GENERATOR

The TEP generator was actually designed as a special motor to operate from very small sources of current such as solar cells. It is larger in diameter than other miniature motors because it has a bigger armature and slightly larger permanent magnets. It also has better spindle bearings and brushes that contact the commutator with very little friction.

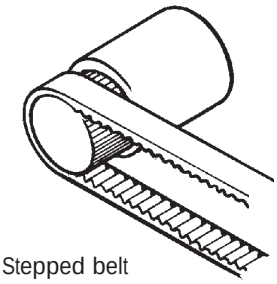


To generate useful current, the armature has to be turned rapidly. For example, to generate the output needed to energise a standard LED, the spindle has to be turned at a minimum speed of 300 revolutions per minute (r.p.m.). You can do this for just a moment by spinning it between finger and thumb. To generate a continuous useful current, the generator's spindle has to be rotated at a speed of at least 1500 r.p.m.



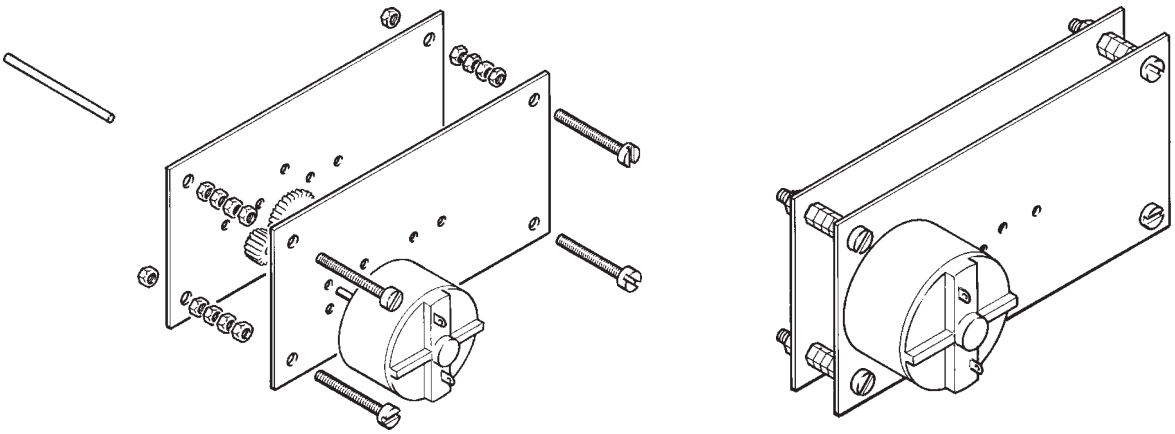
A PRACTICAL MINI-GENERATOR WITH GEARBOX

The TEP generator cannot be driven *directly* by hand (or from several other power sources) because the speed of rotation provided is too low. A way has to be found to increase this speed to at least 1500 r.p.m. Connecting a power source to a generator to get the best performance is called *matching*. A pulley system can be used but unless stepped belts and pulleys are used, the belts are likely to slip. A step-up gearbox is the most common method employed.



Stepped belt

A gearbox for a the TEP generator is assembled very quickly using the two-plate method. The generator is supplied with two pre-drilled side plates and a selection of gears giving three different ratios.



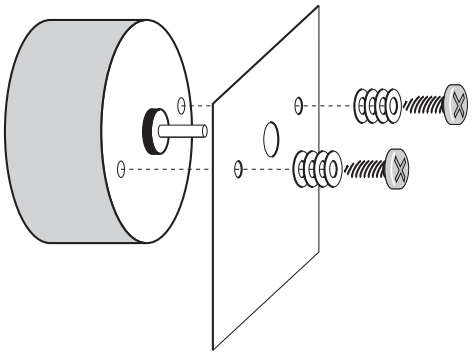
This gearbox is assembled by the following steps:

- choose the gears to be used and position each of these onto a length of 2 mm shafting

  (If you know the input speed and the required output speed of a gearbox, a suitable combination of gears can be worked out. The easiest method is to multiply input speed by the *gear ratio*. For example, if a 60 tooth driver gear meshes with a 10 tooth pinion, the gear ratio is 6:1. The driven gear will rotate 6 times for each revolution of the driver. In other words, it will rotate six times faster. If the driven gear is turned by hand at 50 r.p.m, the driven gear will rotate at 6 x 50 r.p.m. = 300 r.p.m.

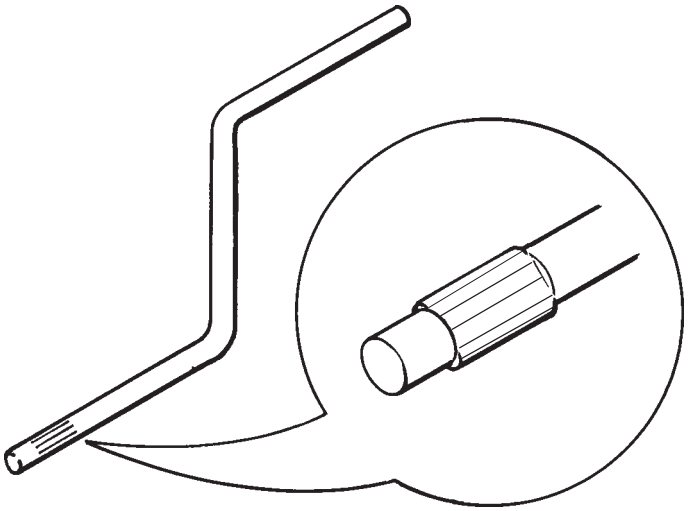
If the outside of the second gear has 50 teeth and meshes with a pinion of 10 teeth, this ratio is 5:1 and the speed of 300 r.p.m. now becomes 5 x 300 r.p.m = 1,500 r.p.m.)

- fasten the generator to one side plate using self-tapping screws and the packing washers (the washers are important to prevent the screws touching the generator's armature).



- attach spacing bolts on the same plate and add enough nuts to provide spacing between the two plates.
- place the shafts through the bearing holes and fix the second plate.

To test the gearbox and generator, a length of 2 mm shaft can be bent as a crank. Where it passes through the driving gear, it should be flattened slightly or upset to give a form of "spline" to prevent the gear slipping round.

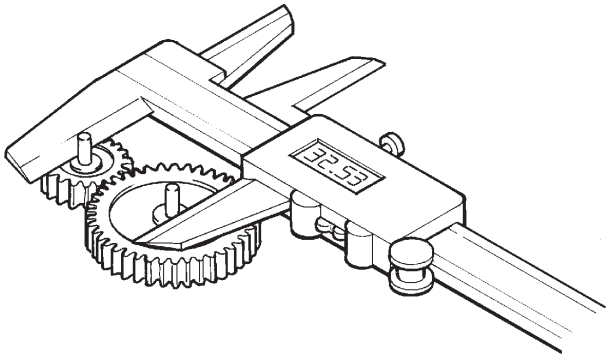


The TEP generator gearbox side plates are pre-drilled to allow several different combinations of gears. If you want to drill holes for a different gear train, use the following method:

Getting gears to mesh properly
The most important aspect of making a gear box is making the gears mesh together properly. If they press together too tightly, there is a lot of friction and they may not turn at all. If they are too far apart, the teeth may jump over one another. You need to mark the bearing holes in the side plates that support the shafts very accurately to make sure the teeth mesh with just enough clearance to turn freely. Calculate it using the simple method below:

1. Place the two gears on a flat surface with a short length of metal shaft forced into the centre.

2. Push the two gears together between finger and thumb and then measure the distance between the two shafts.



3. Subtract the diameter of one shaft to give the distance between centres.

4. Add a small allowance to the distance to enable the gears to run freely. As a rule of thumb (a rough rule) add 1.0 mm to the distance for large gears and 0.5 mm for small gears.

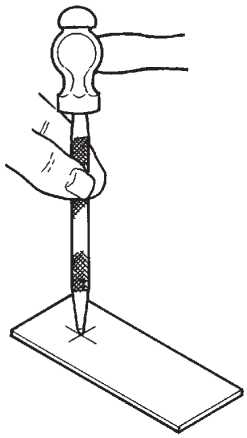
Example: The measured distance is 32 mm and the shaft diameter 3 mm.

32 mm - 3 mm = 29 mm between centres.

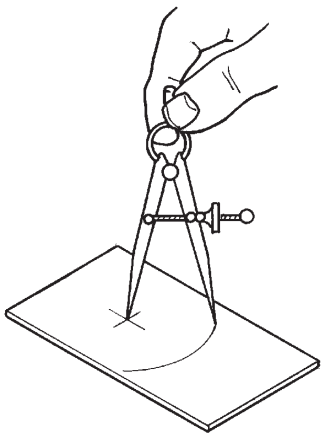
Adding allowance of 1 mm for free running gives 29 mm + 1 mm = 30 mm.

The positions of the bearing holes for the shaft are marked out on just one plate since the two plates are clamped together for drilling at the same time.

Mark out the position for the first shaft and make a small centre punch dot. (The position of this first shaft is important because the gear mounted on it has to mesh with one on the motor.)

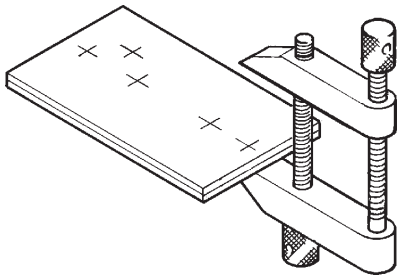


Open a pair of metalworking compasses to the correct distance between centres that you have worked out for the meshing gear and scribe an arc.



You can make a centre punch dot anywhere along this arc for the second gear shaft. Its position depends on how you have decided to set out the gear train. If a bearing hole for a third shaft is needed, the same procedure is repeated with the compass opened to the correct distance. The centre punch dots can now be made larger before drilling.

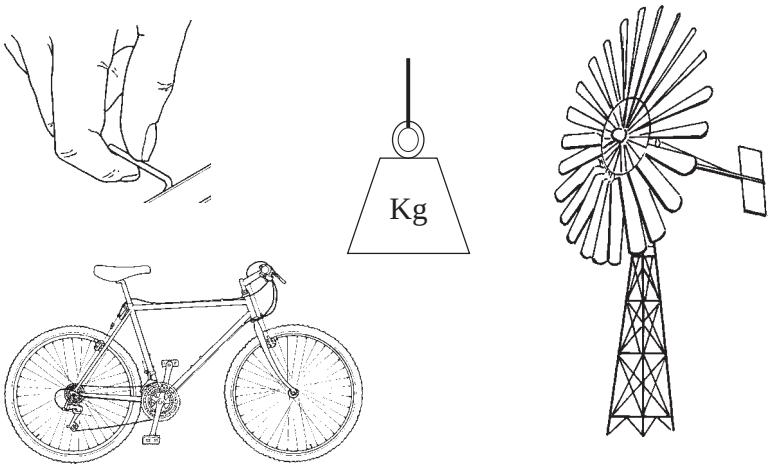
The two side plates are finally clamped together with toolmaker's clamps and carefully drilled. It is also a good idea at this stage to drill holes for the spacers.



DRIVING THE MINI-DC GENERATOR

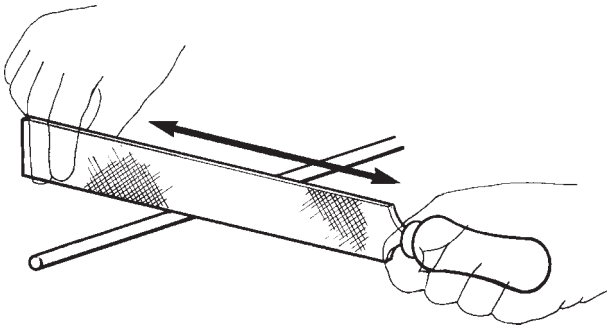
The generator can be driven directly only if the means of rotation is very fast (e.g. a small CO_2 motor used to power model aircraft). If the step-up gearbox is used to increase speed - i.e., matching power source to generator - a variety of power sources are available. These include:

- coiled spring or elastic
- falling mass
- hand turning
- air propeller or rotor
- water wheel
- connection to moving object (e.g. bicycle)



The first two of these power sources use stored energy and may need some form of speed regulation before attachment to the gearbox input. A spring or elastic band will tend to have high torque ('turning power') when fully wound up and less when it is run down. A falling mass will accelerate as it falls, but connection to the generator and gearbox causes drag and the mass - providing it is not too large - will fall at a more uniform rate.

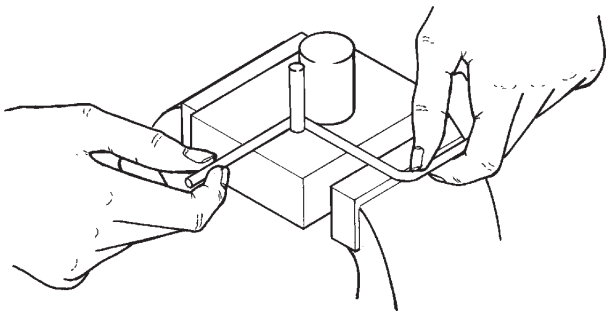
Although the gearbox can be powered through a 2 mm diameter input shaft, it is preferable to use one of larger diameter if possible. This provides more strength and makes it less likely that the first gear will slip on the shaft as it is turned. If a 3 mm diameter shaft is used, for example, the two side plate bearing holes also need to be drilled out to 3 mm. If the gear centre is drilled out to 2.9 mm, this will provide a tight *interference* fit. Nevertheless, it is an advantage to create *splines* on the shaft so that it locks more tightly onto the gear. One way of doing this is to press the edge of a file against the shaft and slowly roll it back and forth over a smooth surface.



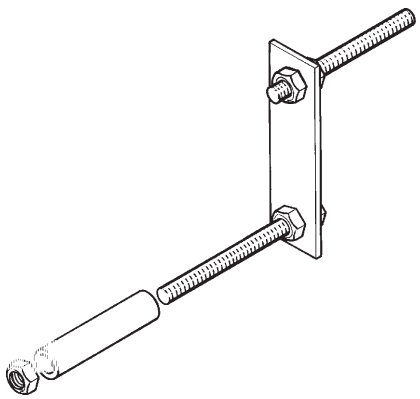
MAKING AN INPUT CRANK

There are a number of methods for making cranks. These include:

- Bending a long shaft.

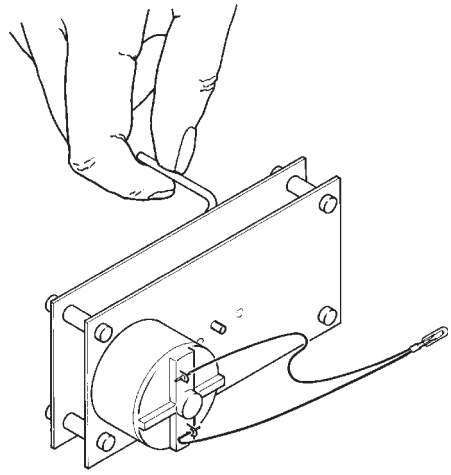


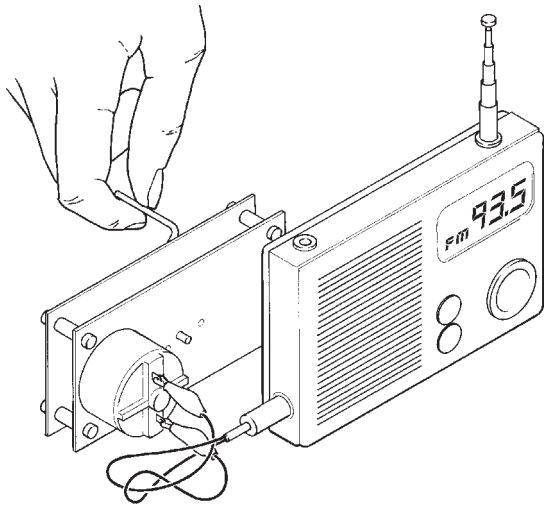
- Fitting the end of the shaft and a crank handle to a third piece of material as shown. The joints must be carefully considered. There are many options. A very easy one is to use metal studding for both the shaft and the handle.



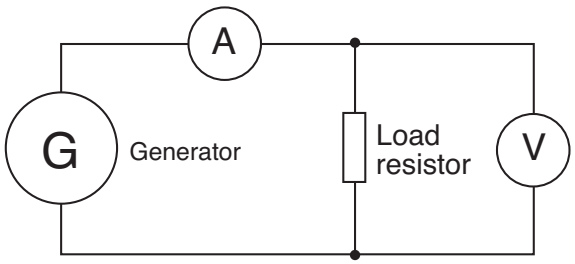
PERFORMANCE OF THE TEP MINI-DC GENERATOR

The technical term for something connected to and driven by a generator is called the *load*. This could be a light bulb for example, or a radio. The *size of the load is measured by the amount of current consumed or drawn* and not the physical size. A small torch bulb drawing a current of 0.5 A represents a larger load than a radio drawing 0.3 A even though the radio itself is much bigger.



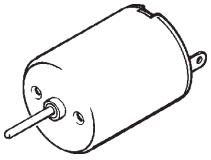


To examine the performance of the TEP generator, a load has to be connected. The current flowing through the circuit and the voltage across it are both measured. For accurate measurements, *load resistors* are used rather than bulbs etc. A low value resistor represents a greater load than a high value one because more current passes. If the load is increased by reducing the value of the load resistor, the voltage will drop, because of the increased voltage drop in the internal resistance of the generator.

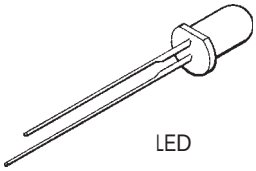


The load connected to a generator has to be correctly matched to the generator's output. A large or heavy load reduces the output voltage and will also make the generator very difficult to turn. Remember that the generator is converting mechanical energy into electrical energy. If you power the generator without a load connected, it will turn easily. If you then connect a load such as a bulb, the generator becomes noticeably harder to turn. *This resistance to turning is the work you have to do to produce electrical energy.*

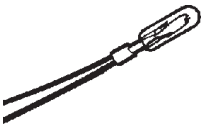
To give a 'feel' for the effect of different loads, try connecting the TEP generator to the following:



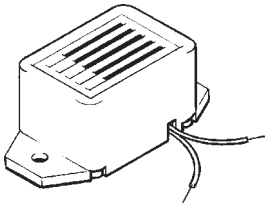
Small motor



LED

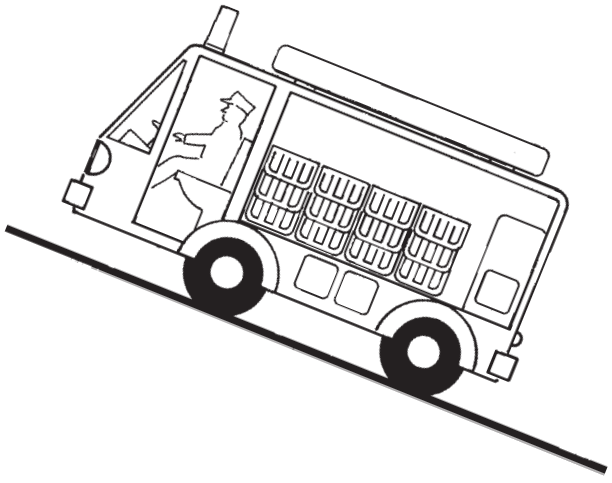


Grain of wheat bulb



Small buzzer

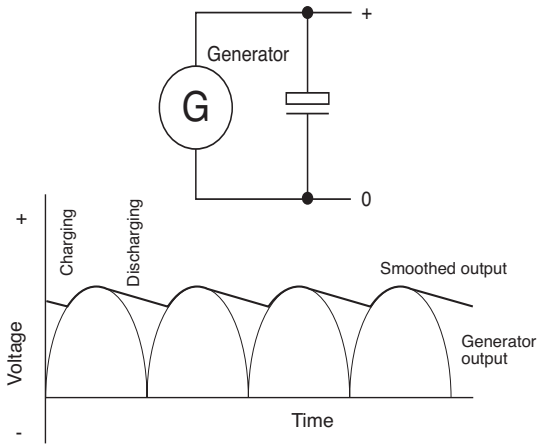
Connecting a load acts as a *brake* on the generator. This effect is used by electric vehicles to save wear on normal brakes and to conserve batteries. An electric vehicle going up hill is driven by a motor supplied from batteries. When it is going down hill, the motor is switched over so that it acts as a generator to re-charge the batteries. In so doing, the motor offers resistance to turning and has a braking effect on the vehicle.



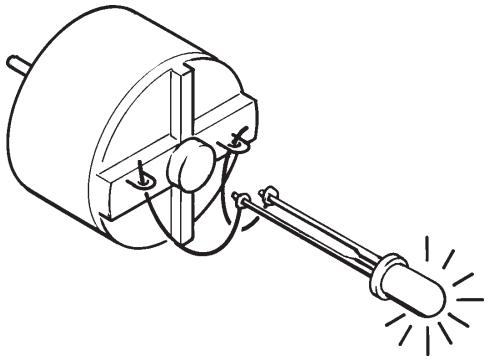
The TEP generator can be used in the same way because it is also an electric motor. It can also be used simply as a brake for other devices. The generator offers little resistance to turning with no load. However, as soon as you close a switch to connect - say -a load resistor, it offers considerable resistance to turning. When the generator is acting as a brake, the work it does is eventually converted into heat in the load (and in the coils of the generator).

IMPROVING THE MINI-GENERATOR'S OUTPUT

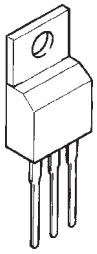
The pulsating DC output from the TEP generator can be improved by connecting a capacitor in parallel across the output terminals. This should be as large as possible but for most purposes a 2000 µF capacitor will suffice. Remember, though, to connect the capacitor to the generator the correct way round in relation to the polarity of the generator.



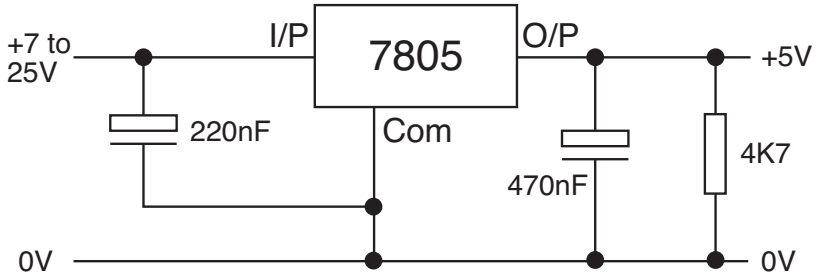
You can test for positive and negative by offering an LED to the generator terminals; it will light up only when the cathode leg is connected to the negative terminal.



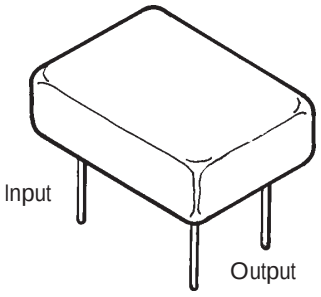
For an even smoother DC output from the generator, you should select a suitable voltage regulator from a supply catalogue and make up the recommended circuit. This usually involves adding just one or two external components; an example is shown. It is important to note that the regulator always needs an input voltage higher than the regulated output voltage.



Voltage regulator

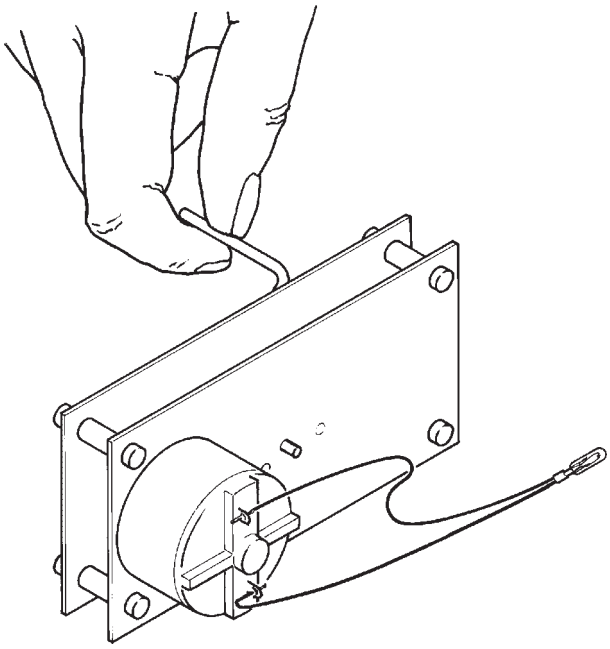


With an AC supply, a transformer can be used to *step* output voltages either up or down. This is not possible with a DC supply. However, there is now a range of electronic circuits called DC to DC converters that will either increase or decrease the voltage from a DC supply. You should consult a supply catalogue under the heading of “DC to DC converter” to select a suitable device.



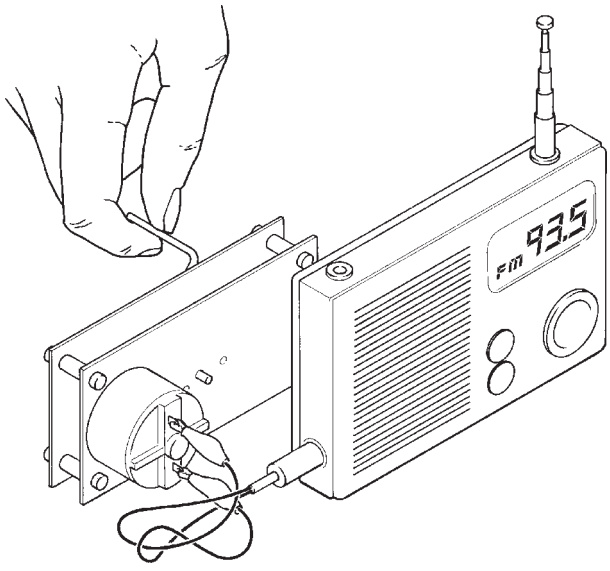
DC to DC converter

POSSIBLE USES FOR THE MINI-DC GENERATOR



• Emergency generator for lighting

Many people keep a torch in the home or other places where an emergency light might be needed in the event of a power failure. Sometimes, though, the torch is used rarely and when it is needed, the batteries are found to have gone past their shelf life. Inexpensive batteries will probably last for only two to three years if unused because of the internal chemical changes that take place.

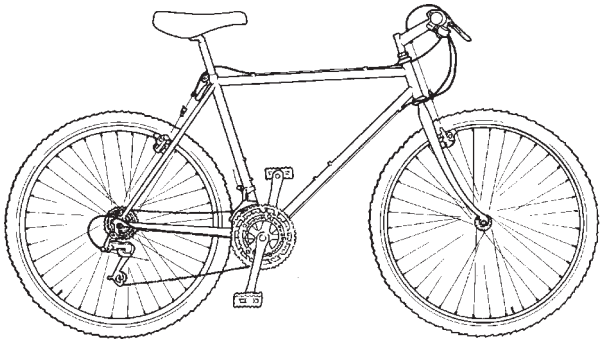


• Battery alternative

In many developing countries, it is possible to obtain small radios but not a reliable supply of batteries - which can be both expensive and environmentally damaging. The mini-DC generator could be used as an alternative by continuous turning of a handle or preferably by storing and slowly releasing energy. Probably the easiest way of doing this is to “wind up” or raise a mass and then let it fall so that it rotates a shaft. A relatively small mass suitably raised and matched to the generator with a gearbox can give several minutes operating time for a transistor radio.

• Cell charger

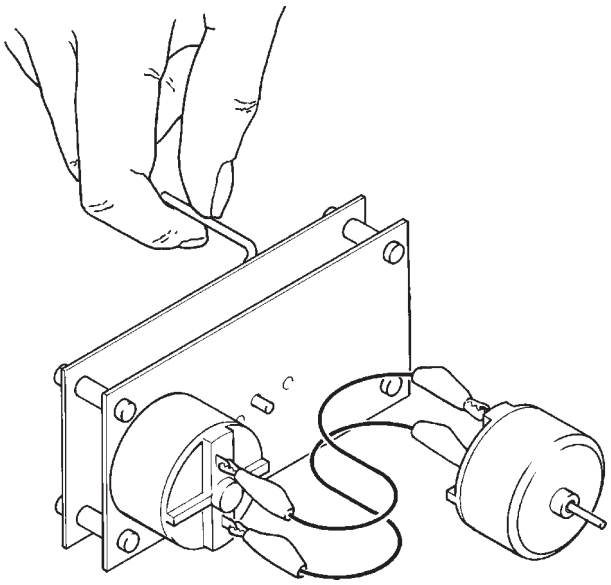
The generator can be used for charging rechargeable batteries - for example those used in a cycle lamp. A generator driven by the chain or tyre of the cycle will produce current whenever the cycle is used. However, depending upon what batteries are used, the generator's output will almost certainly require a circuit to (a) ensure a smooth charging output at the correct voltage and (b) a means to ensure that the batteries do not discharge into the generator.



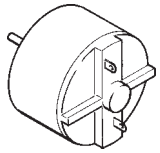
You should take advice from your teacher before embarking on a project involving rechargeable batteries.

• Power transmission

The TEP generator is a *reversible* device. This means that one generator can be used to drive another and vice versa. There is some loss of energy in such a system, but two generators connected together can be used to replace mechanical linkages and drives in some applications. The illustration shows a simple toy. *Experimenting with pairs of generator/motor units connected together convinced pioneer electrical engineers that power could be transmitted over distances by means of electrical current.*



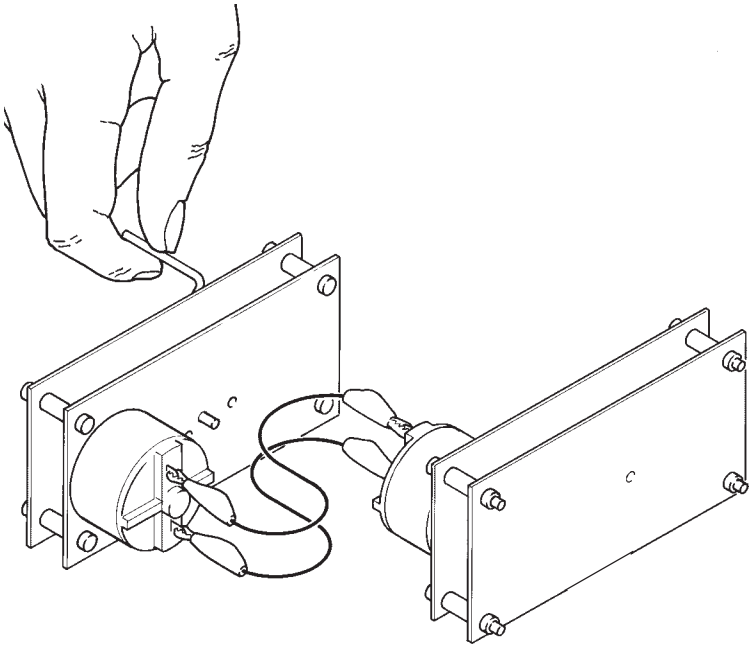
USING THE TEP GENERATOR AS A MOTOR



The TEP generator can be used with or without its gearbox as an electric motor. It has the following specification:

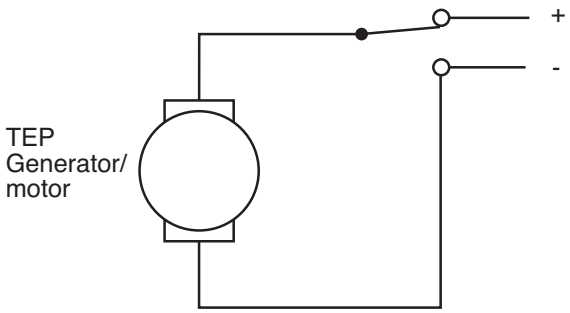
NOMINAL	NO LOAD		AT MAXIMUM EFFICIENCY					
Constant Volts	Speed rpm	Current A	Speed rpm	Current A	Torque g-cm	Output W	Efficiency %	Stall Torque g-cm
3.0	1800	0.022	1430	0.085	8.4	0.123	48.3	41
6.0	3700	0.028	3060	0.134	14.5	0.455	56.4	84

The motor can be driven by a battery, power supply unit (PSU), or by a second TEP generator. Its current consumption increases in proportion to the amount of work it does. If you try to make a motor do too much work, it slows down and eventually *stalls* or stops. Because current continues to flow, the armature windings heat up and may eventually burn out. The small motor in a cordless drill is only about two to three times larger than the TEP generator/motor and will burn out very quickly if the drill is stalled. A fuse, which melts when a certain current is exceeded, offers some protection.



The property of the TEP generator to act as a motor and vice versa enables a free-running motor to be stopped by *shunt braking*. Normally when the supply to a motor is switched off, the motor runs on for a little time because its armature acts like a flywheel. However, if the generator terminals are connected together (short circuited) at the moment current is switched off, the motor instantly becomes a generator and is slowed down by the short-circuit “load”.

This principle can be shown in an experiment using a single pole, double throw (SPDT) switch connected between the battery and motor/generator. If you just disconnect the battery, the motor slows down to stop; if you operate the SPDT switch, it stops almost instantly and gives a sharp “kick”.



NOTE ON RESOURCES

Parts for the TEP mini DC generator referred to in this book can be obtained from:

Middlesex University Teaching Resources
Bramley Road
Oakwood
London N14 4XS

Tel: 0181 447 0342

Please quote:	PAC 902	for a sample pack of two generators £6.00
	PAC 910	for a class pack of 10 generators £25.00

A full Teaching Resources catalogue can be supplied on request.