training chart manual

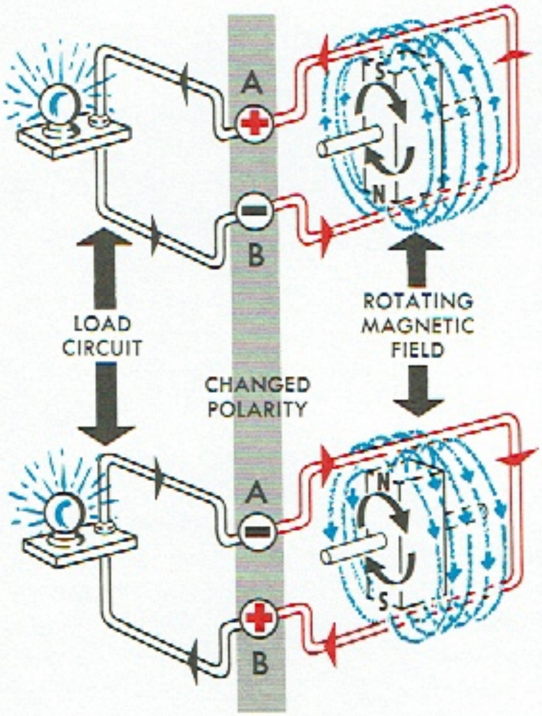
SECTION K

FUNDAMENTALS OF DELCOTRON® GENERATORS

Delco Remy

operating principles of Delcotron generators

In the review of electrical fundamentals, it was observed that a voltage will be induced in a conductor when a magnetic field is moved across the conductor. For example, consider a bar magnet with its magnetic field rotating inside a loop of wire.

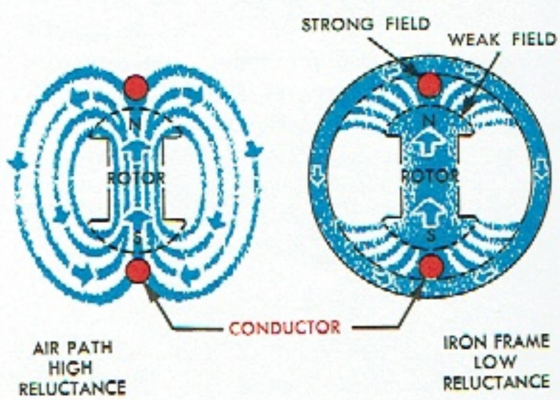


With the magnet rotating as indicated, and with the S pole of the magnet directly under the top portion of the loop and the N pole directly over the bottom portion, the induced voltage, as determined by the Right Hand Rule, will cause current to flow in the circuit in the direction shown. Since current flows from positive to negative through the external or load circuit, the end of the loop of wire marked "A" will be positive (+) polarity and the end marked "B" will be negative (−).

After the bar magnet has moved through one-half revolution, the N pole will have moved directly under the top conductor and the S pole directly over the bottom conductor. The induced voltage as determined by the Right Hand Rule will now cause current to flow in the opposite direction. The end of the loop of wire marked "A" will become negative (−) polarity, and the end marked "B" will become positive (+). Therefore, the polarity of the ends of the wire has changed. After a second one-half revolution, the bar magnet will be back at the starting point where "A" is positive (+) and "B" negative (−).

Consequently, current will flow through the load or external circuit first in one direction and then in the other. This is an alternating current which is developed internally by a Delcotron generator.

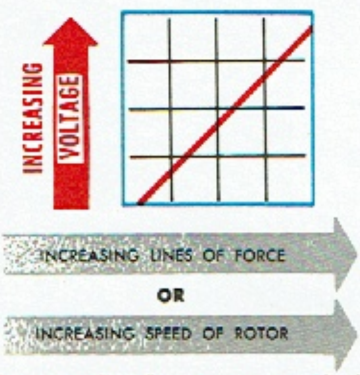
A Delcotron generator made with a bar magnet rotating inside a single loop of wire is not practical, since very little voltage and current are produced. The performance is improved when both the loop of wire and the magnet are placed inside an iron frame. The iron frame not only provides a place onto which the loop of wire can be assembled, but also acts as a conducting path for the magnetic lines of force. Without the iron frame, magnetism, after leaving the N pole of the rotating bar magnet, must travel through air to get to the S pole. Because air has a high reluctance to magnetism, only a few lines of force will come out of the N pole and enter the S pole. Since iron conducts magnetism very easily, adding the iron frame greatly increases the number of lines of force between the N pole and the S pole. This means that more lines of force will be cutting across



the conductor which lies between the bar magnet and the frame.

It is important to note that a very large number of magnetic lines of force are at the center of the tip of the magnet, whereas there are only a few lines of force at the leading and trailing edges of the tips. Thus, there is a strong magnetic field at the center and a weak magnetic field at the leading and trailing edges. This condition results when the distance, called the air gap, between the magnet and field frame is greater at the leading and trailing edges than at the center of the magnet.

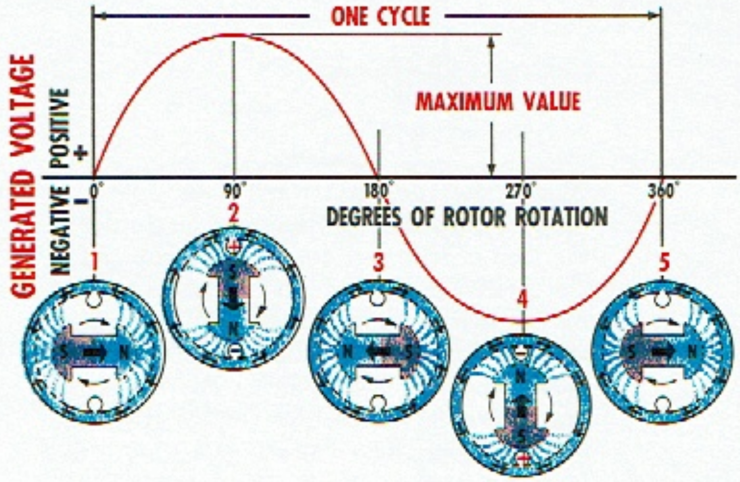
The amount of the voltage induced in a conductor is proportional to the number of lines of force which cut across the conductor in a given length of time. Therefore, if the number of lines of force is doubled, the induced voltage will be doubled.



The voltage will also increase if the bar magnet is made to turn faster because the lines of force will be cutting across the wire in a shorter period of time.

It is important to remember that either increasing the speed of rotation of the bar magnet, or increasing the number of lines of force cutting across the conductor, will result in increasing the voltage. Similarly, decreasing the speed of rotation or decreasing the number of lines of force will cause the voltage to decrease.

The rotating magnet in a Delcotron generator is called the rotor, and the loop of wire and outside frame assembly is called the stator.

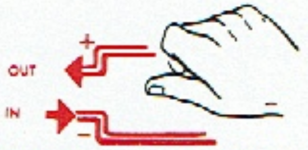


Pictured in the illustration are different positions of the rotor as it rotates at constant speed. In the top portion of the illustration is a curve showing the magnitude of the voltage which is generated in the loop of wire as the rotor revolves.

The voltage curve shows the generated voltage or electrical pressure which can be measured across the ends of the wire, just as voltage can be measured across the terminal posts of a battery.

With the rotor in the first position (1), there is no voltage being generated in the loop of wire because there are no magnetic lines of force cutting across the conductor. As the rotor turns and approaches position (2), the rather weak magnetic field at the leading edge of the rotor starts to cut across the conductor, and the voltage increases. When the rotor reaches position (2), the generated voltage has reached its maximum value, as shown above the horizontal line in the illustration. The maximum voltage occurs when the rotor poles are directly under the conductor. It is in this position that the conductor is being cut by the heaviest concentration of magnetic lines of force.

It should be noted in particular that the magnitude of the voltage varies because the concentration of magnetic lines of force cutting across the loop of wire varies. The voltage curve shown is not a result of a change in rotor speed, because in the illustration the rotor is considered to be turning at a constant speed.



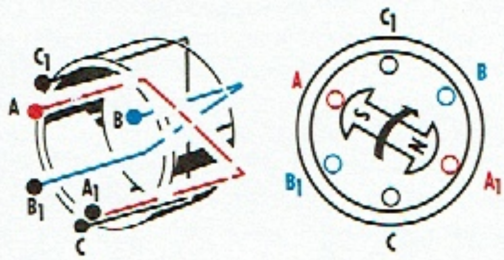
By applying the Right Hand Rule to position (2), it is seen that the direction of current in the loop of wire will be out of the top end of the conductor, and into the bottom end. Thus, the top end of the conductor will be positive, and the bottom end negative. The voltage curve which is shown above the horizontal line represents the positive voltage at the top end of the wire loop which is generated as the rotor turns from position (1) to position (3).

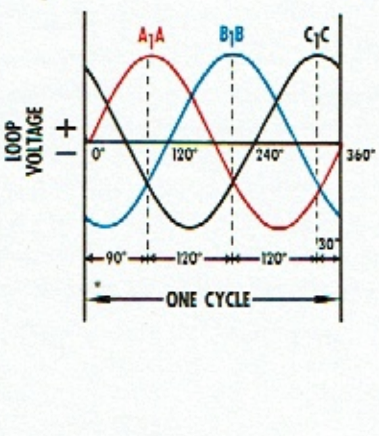
As the rotor turns from position (2) to position (3), the voltage decreases until at position (3) it again becomes zero.

As the rotor turns from position (3) to position (4), note that the N pole of the rotor is now passing under the top part of the wire loop, and the S pole under the bottom part. From the Right Hand Rule, the top end of the loop of wire is now negative, and the bottom end positive. The negative voltage at the top end of the loop is pictured in the illustration by the curve which is below the horizontal line.

The voltage again returns to zero when the rotor turns from position (4) to position (5).

The voltage curve in the illustration represents one complete turn or cycle of the rotor.

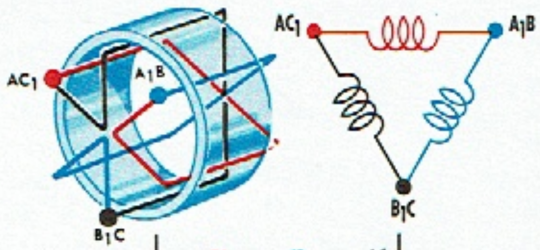


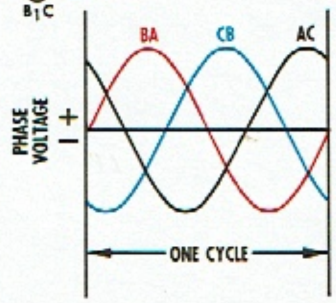


With the rotor making 60 complete turns in one second, there will be 60 such curves, one coming right after the other, resulting in 60 cycles per second. The number of cycles per second is called the frequency. Since the generator speed varies in automotive type applications, the frequency also varies.

The single loop of wire acting as a stator winding, and the bar magnet acting as the rotor, serve to illustrate how an A. C. voltage is produced in a basic generator. When two more separate loops of wire, spaced 120 degrees apart, are added to our basic generator, two more separate voltages will be produced.

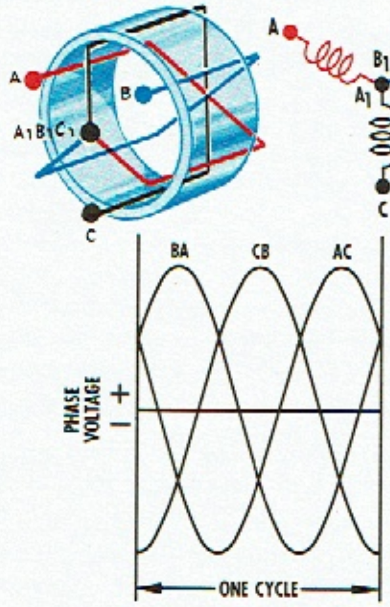
With the S pole of the rotor directly under the A conductor the voltage at A will be maximum in magnitude and positive in polarity. After the rotor has turned through 120 degrees, the S pole will be directly under the B conductor and the voltage at B will be maximum positive. Similarly, 120 degrees later, the voltage at C will be maximum positive. This means that the peak positive voltages at A, B and C in each loop of wire occur 120 degrees apart. These loop voltage curves are shown in the illustration.





When the ends of the loops of wire marked A_1, B_1 and C_1 are connected to the ends marked B, C and A respectively, as illustrated, a basic three phase "delta"-connected stator is formed. The three A. C. voltages available from the delta-connected stator are identical to the three voltages previously discussed, and may now be denoted as the voltages from B to A, C to B, and A to C, or more simply BA, CB and AC. An inspection of the illustration will show the logic of this notation. Example: The voltage formerly called A_1A may now be called BA.

When the ends of the loops of wire marked A_1, B_1 and C_1 are connected together, a basic three-phase "Y"-connected stator is formed. The three voltages available from the "Y"-connected stator may be labeled BA, CB and



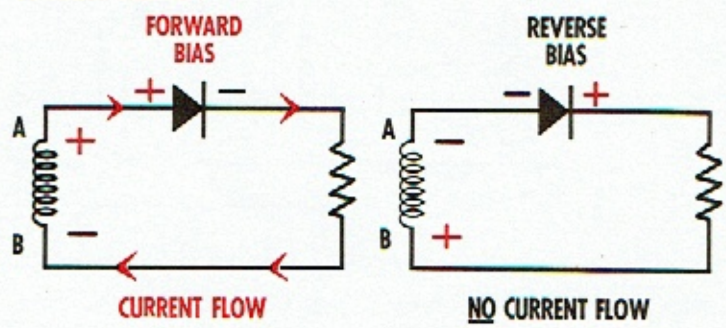
AC. From the illustration it may be seen that each of these voltages consists of the voltages in two loops of wire added together. For example, the voltage measured from B to A consists of the voltages in loops B_1B and A_1A added together. This addition yields a voltage curve BA similar in shape and form to the individual loop voltages, except that the voltage curve BA will be approximately 1.7 times as large in magnitude as an individual loop voltage. The addition of the loop voltages involves a mathematical process which will not be presented here, since it is only necessary to remember that three A. C. voltages spaced 120 degrees apart are available from the "Y"-connected stator, as illustrated. These voltage curves will be considered in more detail in the following sections.

At this point in our discussion we have developed the two basic types of stator windings, and have shown how three separate complete cycles of A. C. voltage spaced 120 degrees apart are developed for each complete revolution of the rotor. We now turn our attention to the diode, and will see how six diodes connected to the stator winding change the three A. C. voltages to a single D. C. voltage needed for the D. C. electrical system.

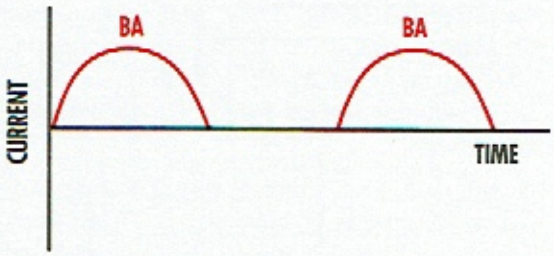
A complete description of the operating principles of diodes is covered in Delco-Remy Training Chart Manual DR-5133J, entitled, "Fundamentals of Semiconductors." For the purposes of this section, we need know only that a diode is an electrical device that will allow current to flow through itself in one direction only. The diode is often pictured by this symbol, and current can flow through the diode only in the direction indicated by the arrow.

DIODE SYMBOL

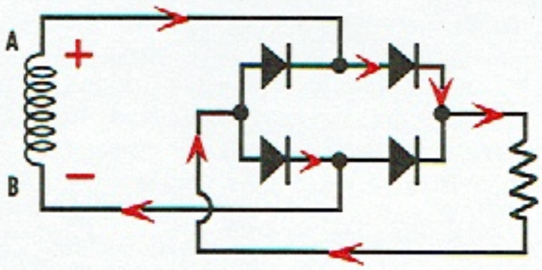
When a diode is connected to an A. C. voltage source having ends marked A and B, current will flow through the diode when A is positive (+) and B is negative (−). The diode is said to be "forward-biased," and with the voltage polarity across the diode as shown, it will conduct current. When the voltage at A is negative and at B is positive, the diode is said to be "reverse-biased" and it will not conduct current.

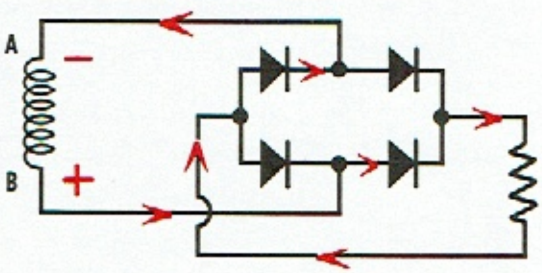


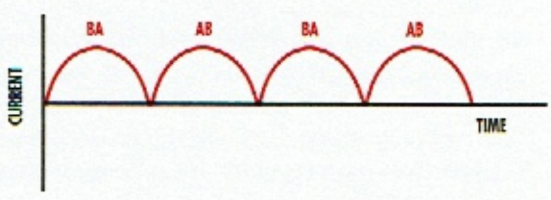
The current flow that would be obtained from this arrangement is illustrated. Since the current flows only half the time, the diode provides what is called "half-wave rectification." A generator having only one diode would provide very limited output.



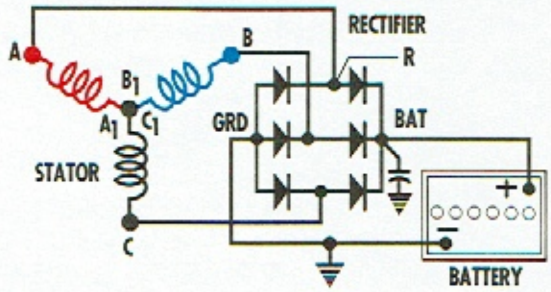
The output is increased when four diodes are used to provide "full wave rectification." Note that the current is more continuous than with one diode, but that the current varies from a maximum value to a zero value. It is particularly important to observe that the current flow through the external load resistor is in one direction only. The A. C. voltage and





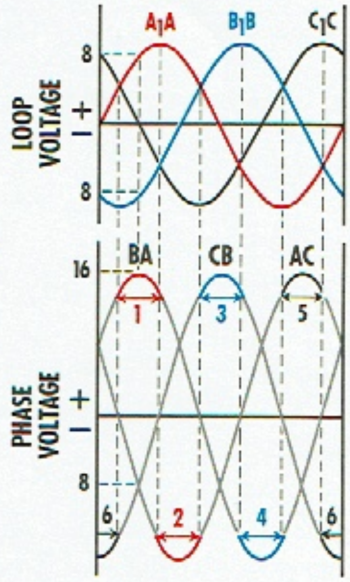


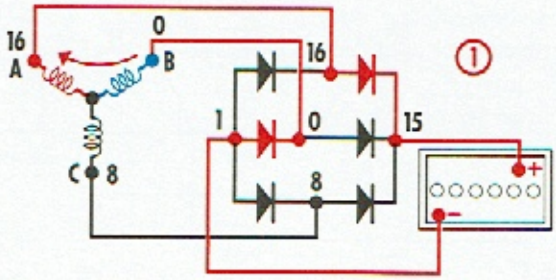
current have, therefore, been rectified to a unidirectional or D. C. voltage and current. This circuit arrangement could be used to charge a D. C. battery, but it does not produce the most output that can be obtained in a generator.



In order to obtain a higher output and a smoother voltage and current, a three-phase stator is connected to six diodes which together form a "three-phase full-wave bridge rectifier." The operation of the "Y"-connected stator will be illustrated first, then that of the delta-connected stator. A battery connected to the D. C. output terminal will have its energy restored as the generator provides charging current. Note that the blocking action of the diodes prevents the battery from discharging directly through the rectifier.

In order to explain the direction of current flow in the stator-rectifier combination, we will review briefly our previous discussion concerning the three A. C. voltage curves produced in the "Y"-connected stator winding. Our first reference was to the voltages developed in each loop. These loop voltage curves A_1A, B_1B and C_1C are reproduced here for reference. However, these individual loop voltages do not appear across the rectifier diodes, because the rectifier is connected only to the A, B and C terminals of the stator. Therefore, the voltages which appear across the rectifier diodes are the phase voltages BA, CB and AC.





The phase voltage curves BA, CB and AC are also reproduced here, and are obtained as previously explained by adding together each pair of loop voltages. As an example, phase voltage BA is obtained by adding together the voltages in loops A_1A and B_1B. In order to obtain the phase curve BA, we add together the voltage from B to B_1, and the voltage from A_1 to A. Consider the instant when the voltage in curve BA is maximum in magnitude and positive in polarity. At this same instant the voltage B_1B is minus 8, or the voltage from B to B_1 is plus 8. This value added to the A_1A loop voltage of plus 8 volts yields a maximum positive voltage of 16 volts for curve BA. By taking different instants of time, the entire curve BA and curves CB and AC, can be obtained in this same manner.

For convenience, the three A. C. voltage curves provided by the "Y"-connected stator for each revolution of the rotor have been divided into six periods, 1 through 6. Each period represents one-sixth of a rotor revolution, or 60 degrees.

An inspection of the voltage curves during period 1 reveals that the maximum voltage being produced appears across stator terminals BA. This means that the current flow will be from B to A in the stator winding during this period, and through the diodes as illustrated.

In order to see more clearly why the current flows during period 1 as illustrated, assume that the peak phase voltage developed from B to A is 16 volts. This means that the potential at B is zero volts, and the potential at A is 16 volts. Similarly, from the curves the phase voltage from C to B at this instant is minus 8 volts. This means that the potential at C is 8 volts, since C to B, or 8 to zero, represents a minus 8 volts. At this same instant the phase voltage from A to C is also minus 8 volts. This checks, since A to C, or 16 to 8, represents minus 8 volts.

Neglecting voltage drops in the wiring, and assuming a one volt drop in the conducting diodes, the voltage potentials are noted on the rectifier. Only two of the diodes will conduct current, since these diodes are the only ones in which current can flow in the forward direction. The other diodes will not conduct current *because they are reverse biased.* For example, the lower right-hand diode is reverse biased by 7 volts ($15 - 8 = 7$), and the right-hand middle diode is reverse biased by 15 volts ($15 - 0 = 15$). *It is the biasing of the individual diodes, provided by the stator, that determines how current flows in the stator-rectifier combination.* Throughout period 1 the current flows as indicated, because the bias direction across the diodes does not change from that shown. Although the voltage potentials across the diodes will vary numerically, this variation is not sufficient during period 1 to change a diode from reverse bias to forward bias and from forward bias to reverse bias.