The Carbon Commutator
The Future of Electric Motors

by Allan Warner

Abstract

Relatively low cost carbon commutators are or will be available that allow DC and Universal motors to be substituted for induction motors as well as brushless DC motors. Because of the carbon commutator, the life and efficiency of the DC or Universal motor has been extended to a point where it can functionally compete with induction motors and brushless DC motors, but at a much lower cost.

In the beginning, when mechanical energy was converted to electrical energy, engineers had to deal with the metallic commutator and carbon brush, and all its weaknesses. Edison used what is similar to today's copper commutator and carbon (graphite) brushes to generate electric power. He also reversed the process and used the same type of device, which had a commutator and carbon brushes, to do the opposite and consume electric power which then generated rotary energy - thus, the motor. Not much has changed in over a hundred years - Until now!

Background

An electric motor's (We shall be discussing motors, not generators, for the balance of this paper.) commutator is a device that is either tube (also known as a barrel type commutator) or disk shaped (also known as a face type commutator) consisting of individually insulated conducting members,[1] that are supported in a structure that is insulated from the conducting members. The conducting members of the commutator have an exposed surface to which brushes, that are usually made of graphite, a form of the element carbon, are in mechanical contact. Electrical energy is passed between the commutator's conducting member's surface or brush track and the brushes. The carbon brushes run perpendicular to the cylindrical ring or disk, and pressure is applied so that an intimate sliding contact is made between the brushes and commutator bar.

Commutators and brushes that are used in electric motors basically function as a mechanical switch, which allows electric energy to pass through the rotating coils of the electric motor's armature that are in a stationary external magnetic field.[2] The armature's rotating coils are wound around iron poles which the coils magnetize. Basically, the commutator switches power on and off, as it moves from one commutator bar to another. The armature's coils are physically and electrically attached to the commutator's bars. As the armature turns, the commutator is applying electric energy from one coil to another coil, and creating a magnetic field in the proper order and time, so that the motor's armature turns continuously.

A motor that uses a commutator is called a DC or Universal[3] motor. This type of motor is just about the least expensive to build, as well as being able to easily control rotational speed. The DC or Universal motor outputs more energy, speed and torque per weight and size of the motor, than any other type of motor. There are other types of electric motors that do not require a commutator but are usually more expensive to build, are much larger and have costly rotational speed control systems. The weakness of a DC or Universal motor is that it uses brushes that rub against a commutator, which causes both of these devices to wear relatively fast.

Metal Commutators

Until recently, the commutator's conducting members were normally made of metal, usually copper or a copper alloy, but occasionally gold or silver, as well as other metals.

There are a number of different manufacturing processes that occur either during commutator manufacture or armature manufacture. Some of these processes are described below.

The electric motor's armature coil lead wires must be attached to the commutator bar. There are two different common physical forms of attachment, a tang connection and a slotted connection. On very large armatures, there is a third attachment form, where the leads from the coils can also be attached directly to the surface of the commutator's bar. All attachment methods use some form of heat. They can be soft or hard soldered,[4] as well as being joined by a process called Commutator Fusing.[5] All of these joining processes use heat, which means that the commutator becomes hot.

Another manufacturing process is Commutator Turning. This is accomplished with a special lathe that turns the commutator's brush track, so that it is concentric to the armature's shaft. Turning is done with diamond or tungsten carbide cutters, so that a specific finish is obtained on the surface of the commutator's metal brush track.

The heat that is introduced during the joining process can shorten the life of the motor, because the commutator bars can anneal either totally, or more seriously, selectively. This annealing or softening of the metal can also cause manufacturing problems during armature turning, due to inconsistent surface hardness.

When working with metal commutator bars, a specific surface condition must be maintained at a consistent hardness. This is because during the first few minutes of the motor's operation, the carbon brushes must create a uniform and adherent film on the surface of the metal commutator's brush track. This is accomplished during the first few rotations [6] of the armature. This rotation time period is called brush run-in or seating. During run-in, the carbon brush's material is transferred to the commutator by direct physical wiping of the carbon brush against the commutator's bars, and also by some limited electrolytic action. Run-in also physically forms the carbon brushes to the surface of the commutator.

The film that is deposited on the metal surface of the commutator's brush track is called the Graphite Film. Without this film, the brushes will wear too fast as cuprous oxide forms and must be mechanically removed during commutation. The film provides a lubricant and surface protectant which slows brush wear and allows for efficient transfer of electric power as well as low wear commutation.

Lack of humidity, retards or completely eliminates the forming of the graphite film. Special brushes are available that contain a binder which assists the brushes in maintaining moisture, but some atmospheric moisture must be present.

Another result of using a metal commutator is noise. The rubbing of the brushes against the commutator's metal brush track can cause mechanical sound, as the brushes wear because of friction. Electrical noise is also generated because of electric current arcing between the commutator's brush track and the brushes.

Carbon Commutators

Now that you have spent some time reading about the metal commutator, why would you even consider a carbon commutator. The main reason is extremely long brush life compared to metal commutators. Let's take a look at the history of this type of commutator.

Prior to 1928,[7] it had been known that carbon could be used as the conducting surface of a commutator. However, the cost for this type of commutator was so great that it was not realistically considered for production motors. In 1928, a man named Clyde W. Landers applied for a United States patent,[8] which described a commutator that used carbon material as the brush-track for a face type commutator. The design shown in the patent assumed that metal stationary brushes would rub against the moving carbon commutator segments. From reading the patent, someone skilled in motor manufacture would realize that carbon brushes could also be used.

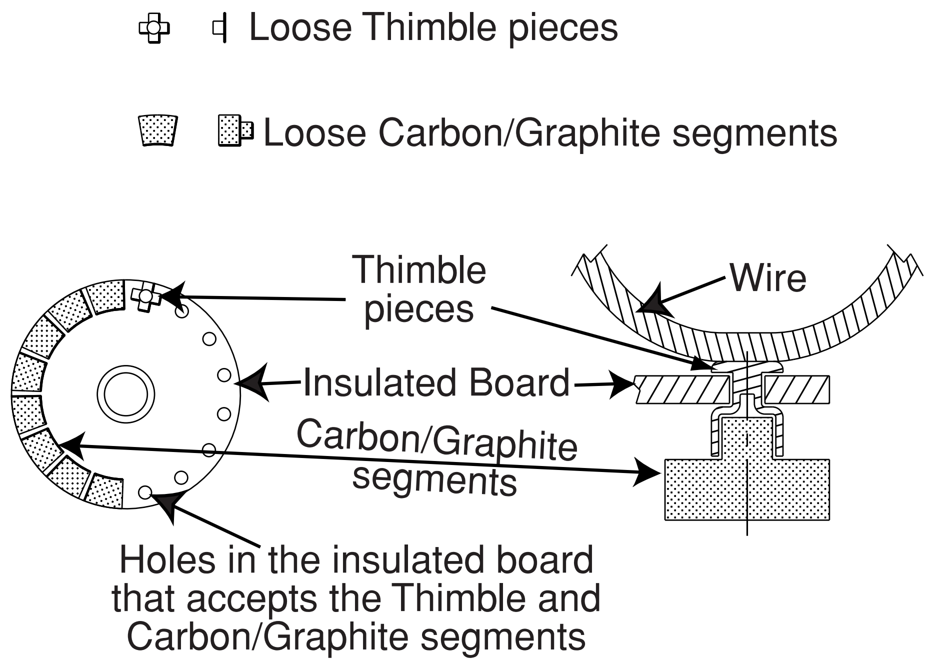
Mr. Landers' invention solved the two basic problems that must be solved when attempting to build a carbon commutator:

- Attaching the carbon to insulated material which would be mounted on the armature's shaft;
- Attaching a metallic device to which the armature's windings could be terminated to the commutator's carbon segments.

All carbon commutators are made of three parts: An insulated support that mounts on the armature's shaft, carbon that is used as the commutator's brush track and a metallic material that makes electrical contact with the commutator's carbon and allows lead wires from the armature's windings to be terminated to the commutator.

Up to the present, the metal device (usually made of copper) that makes contact with the carbon and allows armature lead wire termination seems to be an essential part of the design of a carbon commutator. No practical method has been found for attaching the armature lead wires directly to the carbon.

Concerning the two above basic problems, the following should be understood. There is no natural adhesion between copper and most insulating resins that are used for commutator construction. Therefore, there must be some type of mechanical connection to hold these materials together. The same



Face Type Commutator using the Landers Method

statement applies to adhesion between carbon and copper. Also, there is no natural adhesion between carbon and most of the insulated resins that are used for commutator construction. It has, however, been shown that a mixed mechanical interface between carbon and specific insulating resins can result under certain circumstances.

Mr. Landers' patent describes an invention where an individual metal "thimble"[9] that is mechanically attached to an insulated board or substrate is mounted on the armature's shaft. Individual carbon commutator segments have an appendage on their bottom surface that is designed to fit into the thimbles. The metal thimbles are compressed to engulf the carbon commutator appendages, to both physically hold them and make electrical contact. The lead wires from the armature's windings are then attached to the rear portion of the thimble that is mounted on the insulated material.

Mr. Landers' carbon commutator will work, but would not be very easy to build in large quantities. This commutator is made of individual carbon segments. No modern carbon commutator is built this way. Presently, the carbon starts as one solid piece across the entire commutator that must be cut so that the commutator bars are electrically separated.

In the late 1980s, governmental bodies decided to add various amounts of alcohol to gasoline, to lower the amount of carbon monoxide that is discharged by a motor vehicle, and also raise the octane of the gasoline, without any harmful environmental side effects.[10]

One of the problems when adding alcohol to gasoline is that any copper in contact with the solution and carbon brushes would erode, as a result of electrolytic action that occurs during commutation because of the higher conductivity of gasoline that contains alcohol. Therefore, the alcohol - gasoline mixture causes accelerated wear of the commutator's copper brush track which in turn, shortens the life of the motor.

The entire automotive fuel pump is submerged in gasoline in the gas tank, including the electric motor's armature that incorporates a copper metal commutator. Therefore, other commutator materials were examined, and it was found that carbon worked perfectly, was relatively inexpensive and was chemically inert in a gasoline - alcohol solution. Now, a commutator with a carbon brush track had to be developed, that could be produced efficiently in large quantities.

During carbon commutator development for the fuel pump application, it was found that if the graphite that was used for both the commutator's brush track and carbon brushes were matched mechanically to each other, the result would be an armature with extremely long brush life. This is because there was less friction between the carbon brush track and the carbon brushes, versus the carbon brushes and a metal commutator's brush track. During testing, there were times where the motor's bearings failed prior to the commutator/brush assembly wearing out.

The carbon on the commutator's brush track, as well as the brushes, were designed so that the carbon on both components had the same or just about the same hardness. Because of this, there would be very little wear on either part. This resulted in extremely long life for both carbon surfaces, as mechanical wear was just about non-existent.

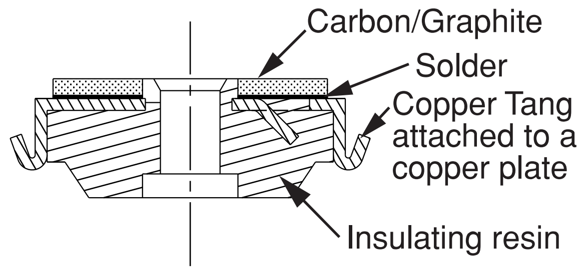
Operating life for DC or Universal motors is normally determined by brush life, as well as occasionally commutator life. With brushes and commutator brush track surface that barely wear, the operating life problem is practically eliminated. It is possible for some other mechanical part on the motor, such as the bearings, to wear out prior to the brushes or the commutator's brush track.

A type of Graphite Film is created on carbon commutators when matched to appropriate carbon brushes that increases surface contact by up to 15%. This means that electrical energy can be transferred between the brushes and carbon commutator much more efficiently. There is less electrical resistance between the carbon brushes and the commutator's carbon brush track when using a carbon commutator in comparison to the contact resistance between the carbon brush and the metal brush track on metal commutators.

Because of the lower contact resistance between the carbon brushes and the commutator's carbon brush track, less arcing occurs between the brush track and the brushes. This results in lower RFI (Radio Frequency Interference), and the need for extra cost devices to suppress the RFI.

The Present

Motors with carbon commutators are now being used around the world for automobile fuel pumps. Other than being compatible with alcohol in gasoline, these carbon commutators offer the motors that they are being used on, a life that is usually greater than the automobile into which they are installed.



Face Type Commutator using the Gerlach Method

Until recently, the carbon commutator was very difficult to work with during production. Also, these commutators were quite expensive. However, new developments in carbon commutator manufacturing technology has resulted in much more robust carbon commutators, that are operationally superior to metal commutators, and at relatively reasonable costs.

Carbon Commutator Construction

A number of different types of carbon commutator construction have been developed that seem to work efficiently, and can be built in large quantities at moderately reasonable costs. However, the carbon commutator today still costs more than a commutator with a metal brush track.

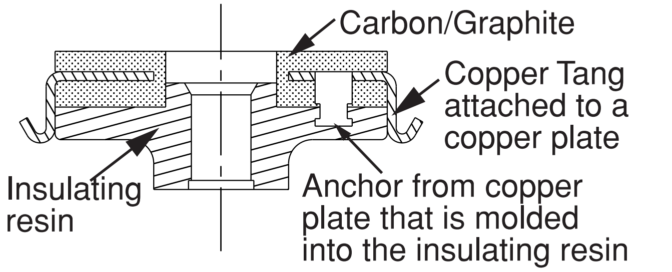
As previously discussed, the construction of the modern carbon commutator must still solve two basic problems:

- Attaching the carbon to insulated material which would be mounted on the armature's shaft;
- Attaching a metallic device to which the armature's windings could be terminated to the commutator's carbon segments.

One of the first practical modern methods of carbon commutator construction, which we will call the Gerlach method,[11] has a copper plate with hooks bent outward from it. This copper plate is placed in a mold so that thermoset plastic resin [12] can flow around one side, the side that has the hooks bent outward. These hooks are engulfed by the thermoset plastic to give a strong intimate contact between the copper disk and the thermoset plastic. A metallic plated carbon disk is then soldered to the copper plate.[13] After soldering, the commutator is cut so that the commutator bars are separated.

Another method, which we will call the Kobman method,[14] purportedly eliminates the solder, and has hooks on one side of the copper plate, the same as the previous method. The carbon, however, is completely molded around the copper plate, which results in the encapsulation of the plate inside the carbon. Hooks are bent upward from the copper plate and extend through the carbon, with a portion of the hook exiting the carbon. Thermoset insulated resin is molded around the portion of the carbon with the extended hooks. The extended hooks are intended to mechanically anchor the carbon to the thermoset material. After molding, the commutator is cut so that the commutator bars are separated.

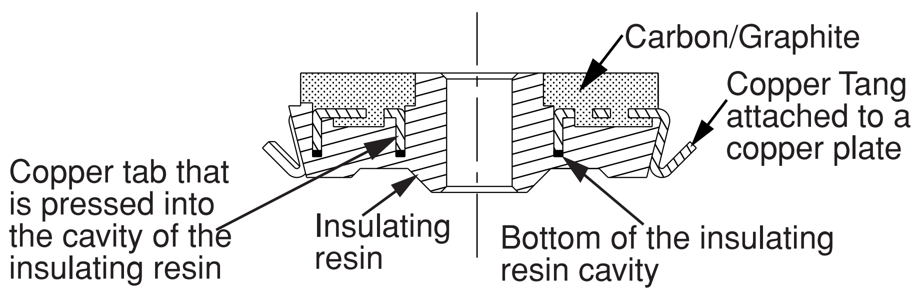
A method, which we will call the Stobl method,[15] is very similar to the Kobman method, except that thermoset plastic is not molded around hooks that are extended from the carbon. There are hooks that are extended from the carbon, but they are forced into cavities that are



Face Type Commutator using the Kobman Method

molded into the thermoset plastic resin. With this method, the two separately molded parts, carbon and thermoset plastic, form a plug and socket arrangement where the extended hook acts as the plug and the cavity that is molded into the thermoset plastic acts as the socket. Friction holds the commutator together.

An interesting method, which we will call the Ziegler method,[16] shows a barrel type commutator where carbon is molded inside a pre-molded insulated resin cavity. A copper ring that is anchored to the insulated resin molding makes electrical contact with the carbon.

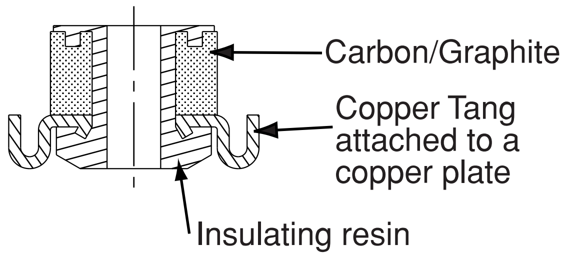


Face Type Commutator using the Stobl Method

The final method that I would like to discuss is called the Hockaday method.[17] With this method, the carbon and thermoset plastic are molded simultaneously, with flexed metal copper fingers between them that make physical and electrical contact with the carbon. During molding, the carbon and thermoplastic are forced together under pressure and heat, which results in either fully or partially curing the materials, so that they attain their maximum strength. While performing this molding and curing, there is an intermingling of the materials at their interface, which joins them together in one solid mass.

The carbon and copper metal side walls of the Hockaday carbon commutator are held together because a dovetail type groove has been cut into the inside wall of the copper. The carbon is compressed into the dovetail groove. This arrangement gives a second physical and electrical contact between the copper and the carbon.

The five methods of producing carbon commutators that are discussed above are only some of the methods used today. There are many other methods that have been developed and are or can be used. Take a look at the attached drawings which show the various carbon commutator construction methods. They will give you a better idea as to how these



Barrel Type Commutator using the Ziegler Method

with every known type of carbon commutator construction, and definitely the five construction methods described above.

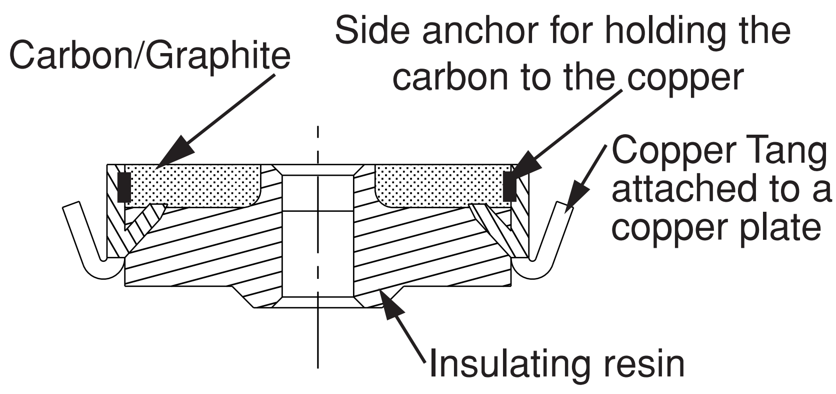
The Gerlach method, and possibly the Ziegler method, produces a commutator that is most susceptible to excess heat. Fusing and brazing solutions have been developed to work very easily with these types of commutators. The Gerlach type of commutator is, most likely, the most popular style of carbon commutator that is used today, without any real armature production problems.

commutators are constructed. As this paper is an introduction to DC or Universal electric motors that do or could use a carbon commutator, a discussion of the pros and cons of the various methods will not take place.

Metal contact parts have been mentioned, to which the armature's coil leads are attached to the commutator. A portion of the metal parts must make intimate contact with the carbon material. Another portion of these metal parts must be extended to the outside of the commutator, where some type of electric contact with the armature's windings can be made. Types of contact that can be used are soldering, brazing, and Commutator Fusing.

Commutator Fusing and Brazing equipment have been developed to work

Another major problem when producing a carbon commutator is the separating of the carbon into individual commutator bars or segments. All of the types of carbon commutators described above, other than the Landers type, must have their carbon brush tracks separated by some cutting method. Carbon is much more brittle than copper, and care must be given when separating the bars. If too much of the carbon is physically broken or chipped during cutting, the surface area of the individual commutator bars



Face Type Commutator using the Hockaday Method

might become too small to efficiently conduct the electrical current that is required. Cutter speed and cutter design for carbon commutators are different than what is used for separating metal commutators. With good manufacturing management, a very high acceptable yield of usable carbon commutators can be obtained.

A production problem that can be easily overcome through design and correct armature winding machine tooling setup, is the movement of the tang or the contact area where the armature's coil windings are terminated to the commutator. Too much wire tension on the tang could move it enough where it will place uneven pressure on the brittle carbon, which might then chip or crack. Even though this is not a major problem, it must be considered when designing the commutator and building the armature.

During the present development of the carbon commutator, since about 1988, the commutator and its brushes were designed to function in a liquid. The liquid, gasoline and alcohol, acts as a lubricant. The motor into which the carbon commutator is built has an open enclosure, and is submersed in the gasoline - alcohol mixture, while it is operating.

The next challenge was to develop a carbon commutator and its compatible carbon brushes that can efficiently operate in air. The speed of this development has been slower than one would imagine. The strange part of this is that originally, prior to the Landers development and then after,[18] the carbon commutator was designed to operate in air.

During the Second World War, the Germans used electric motors with carbon commutators for various weapon systems.[19] Aircraft and rockets used electric motors for a number of purposes that incorporated carbon commutators. One purpose was to overcome the problem of creating a reliable graphite film on metal commutators, because of the extremely low operating temperatures and low humidity (the absence of moisture) at high altitudes. Another reason was the need for long brush life.

The Germans were also successful in using graphite and copper powder mixtures to create both carbon commutators and their brushes. Graphite and copper powder mixtures are common today for motor brushes, but not for the brush track surface of a commutator.

After the war, German rocket scientists who came to the United States to man the U. S. missile program initially used motors with carbon commutators. However, in the late 1940s, the development of the transistor and later the silicon controlled rectifier (thyrister) moved the technology away from DC motors, and motors with carbon commutators seemed to have been forgotten.

We know that it is possible for motors with carbon commutators and the appropriate brushes to operate in air. It has been successfully done before, and will again be done.

The Future

As the production of carbon commutators increases, their costs will decrease to a point where they will cost just about the same as metal commutators. As costs become no longer significant, there will be a stampede towards the use of carbon commutators in applications where metal

Chart Showing the Relative Cost - Efficiency - Life[20] of Various Motor Types

Motor Type	Cost Index	Efficiency	Life
DC	100	90%	Short
Brushless DC	488	88%	Long
Universal	98	90%	Short
AC Single Phase	276	60%	Medium
AC Three Phase	220	70%	Very Long
DC or Universal With Carbon Commutator	308	90%	Very Long

The reason the Cost Index for motors with carbon commutators is so high, is that today the cost of the carbon commutator is five to ten times the cost of an equivalent metal commutator. As production increases, manufacturing efficiencies will force the cost down.

commutators are now used. The main reason will be the increased life expectancy of the motor, without an appreciable increase in cost. However, using carbon commutators instead of metal commutators is not the whole story.

Using carbon commutator DC or Universal motors instead of Induction or other types of motors is the real future.

Let’s look at an example. Motors used in hermetic compressors for window air conditioners and household refrigerators are made in huge quantities. They use induction motors that are sealed in a relatively large container with a compressor and Freon gas. The motor drives the compressor which compresses the Freon gas. The motor itself is relatively large. It has a large stator with both start and run stator coils, as well as an iron rotor where aluminum or sometimes other metals are die cast with it. Also, a centrifugal switch or some other device must be used to switch from the start coil to the run coil, at the appropriate time. All of this is relatively expensive.

If we could replace the induction motor that is inside the hermetic compressor with a DC or Universal motor outputting the same power, we could achieve tremendous savings. We would save the cost of a very large stator, as well as the dual coils in the stator that use a large amount of wire. Also, the cost of energy to die cast the rotor would be eliminated as would the centrifugal switch. Another savings would occur because the hermetic compressor’s container would be smaller and less Freon would be needed.

Another advantage is that controlling the speed of the rotation of a DC or Universal motor is more easily done and less expensive, versus an induction motor. This means that new functions and outputs can be added to the appliance in which the hermetic compressor is installed, at a relatively low additional cost.

However, in the past, the use of a DC or Universal motor was just about impossible in a hermetic compressor, because of the poor brush life of the motor. With the new carbon commutator, a DC or Universal motor can be substituted for the presently used induction motor with savings as high as 75%.[21] DC and Universal carbon commutator motors can also be used in various appliance applications, such as washing machines, dryers, dishwashers, etc. An added benefit is that a DC or Universal motor is usually more energy efficient than an induction motor of similar output, with or without the efficiency added by the carbon commutator.

Since the late 1980s, the brushless DC motor has become popular as it functions similarly to a DC motor with a commutator, but without the brush wear problem. However, the brushless DC motor and it's control system is much more expensive to build. Now, with the carbon commutator, we can achieve all of the benefits of the brushless DC motor, but without the large increase in cost.

In the future, the carbon commutator will gradually replace metal commutators, as they eliminate the previous weak points of DC and Universal motors, without added costs.

Notes

The easiest and most organized method of identifying the various patents that are mentioned in this paper, is by using the last name of the first inventor that is listed on the patent. This is the method that is used by the United States Patent Office and the courts to identify patents.

1 Called the commutator bar - All of the commutator bar's conducting surfaces are called the brush track, the area where the carbon brush rubs the commutator.

2 The non-rotating stator or permanent magnet assembly creates the magnetic field.

3 A Universal Motor can consume either AC or DC electric current.

4 Soft solder has a working temperature below 1,000° F or 538° C, while hard solder has a working temperature above 1,000° F.

5 Fusing is a system of joining low resistance metals with a type of resistance welding machine, but without appreciable distortion of the parts being joined. What actually happens is that the parts are heated and pushed together until all the air between them is eliminated and the high points of one part are pushed into the low points of the other, and vice versa. A surface adhesion contact then will hold the parts together.

Commutator Fusing is a specific method that uses the general fusing process. This method is used for joining the lead wires (which are usually film insulated magnet wires) of a Universal or D.C. electric motor's armature to its commutator. The commutator fusing process removes the the magnet wire's film insulation as it joins the wire.

6 The number of rotations depends upon the design of the armature, the brush track surface desired.

7 The first instance that I can find where a carbon commutator is mentioned in U.S. Patent Office records was May 22, 1894, patent number 520,264 issued to a Carl Hoffmann, and filed on September 28, 1893. The inclusion of carbon, it seems, is only mentioned for broadening of the patent's claims.

8 United States Patent 1,811,180, applied for on October 26, 1928, and granted on June 23, 1931 to Clyde W. Landers of New York City. This patent was not assigned to a firm. We cannot find any further information concerning Mr. Landers.

9 "Thimble" is the word that is used in the Landers patent to describe the device that holds the carbon segment to the insulating matter support, and which the armature's lead wires are attached.

10 At about the same time, it was found that the widely used octane raising, and oxygenating chemical compound, Methyl Tertiary-Butyl Ether (MTBE) was causing severe ground water pollution and had to be eliminated.

11 United States Patent 5,157,299

12 Such as phenolic or melamine resin.

[13] United States Patent 5,157,299 discloses that silver hard solder with a melting temperature range between 630° C and 650° C (1,166° F and 1,202° F) is used. In production, soft solder is also used to solder the carbon to the copper plate.

[14] United States Patent 5,962,946

[15] United States Patent 5,677,588

[16] United States Patent 5,962,946. This patent also contains claims where carbon is plated with a metallic layer which is then soldered to the copper plate, similar to the Gerlach method. A face type commutator using the Ziegler method is described by United States Patent 5,912,523.

[17] United States Patent 6,236,136

[18] Around 1907, the Hall Signal Company used electric motors with barrel type carbon commutators to change filters that were placed in front of a light source on railroad signal lamps. The reason they did this was to use a single light source to display three different colors on demand, with only one pair of wires to conduct the power (and signal) to the electric motor. The Hall company applied for U.S. Patent number 866,262 on January 24, 1907. The inventor, was a Mr. Clarence W. Coleman, and the patent was issued on September 17, 1907. What is interesting about this method of producing a carbon commutator is that the entire graphite structure was plated with a metallic surface. The armature's lead wires were attached to the plated metal. The metal coating was turned off of the brush track on a lathe, so that the graphite brush track could make contact with the graphite brushes. The reason that a carbon commutator was used in this application was to avoid short brush life that occurred when using metal commutators.

[19] A number of carbon commutator patents were filed by German companies prior to the Second World War. One patent, which was subsequently found to cover a method of producing carbon commutators that were used to control rocket trajectories, number 2,297,464 was filed on May 5, 1941, before the United States entered the war. This patent was issued on September 29, 1942, after the start of the war. It showed a Mr. Kurt Fleischmann of Mannheim, Germany as the inventor, and was seized by the Alien Property Custodian, Office for Emergency Management of the U.S. Department of Justice.

[20] Source: industry catalogs and price lists.

[21] The savings include the use of less Freon and smaller compressor containment enclosures.