COMMUTATION

OF

D.C. MACHINES

BY

THOMAS HARMON

GRANITE CITY STEEL COMPANY
GRANITE CITY, ILLINOIS

HELWIG CARBON PRODUCTS, INC.
8900 W. TOWER AVE. P.O. BOX 24400
MILWAUKEE, WI 53224-0400
TEL. 414-354-2411 FAX 414-354-2421
FAX 1-800-365-3113

COMMUTATION OF D. C. MACHINES

By

Thomas Harmon

With all of the excellent articles and books that are available on commutation, the big mystery to me is how I may be able to supplement this fine material.

The first thing to decide is the course to follow on my dissertation, on this broad subject. There were two courses open for me to follow, one being a general discussion and the other trying to enlarge on one of the many important phases. Thinking we would all get more out of it, the general discussion scheme was chosen. This left the way open to talk about design or maintenance and here there wasn't any choice. I am familiar with maintenance and don't even have a speaking acquaintance with design, so there isn't any doubt as to the contents of this paper. There is still a lot of room left for more information on commutation.

One reason for some lack of information may be caused by a seemingly lack of interest in Direct Current machinery by new graduate engineers. Recently, I escorted a group of students thru our facilities, all of whom were amazed by the large size and quantity of our Direct Current machinery. They were under the impression it passed out of the picture with Mr. Edison. This outlook should be corrected in our colleges and universities, as most process industries use D. C. equipment.

In this paper, I will attempt to condense and summarize some of the fine material that is available in printed form on commutation. To this, I will add some of my colleagues' and my own personal experiences and pass it on to you for evaluation.

Commutators with their resulting problems in commutation is the big economic item when you start comparing cost of maintenance between D.C. and A.C. motors. It is the one item in a D.C. motor that requires more attention than you might have to give an A.C. motor. Being an employee of the Electric Department of the Granite City Steel Company, brings me in daily contact with large rotating D.C. Machines. Most of you are familiar with installations such as ours and can understand how commutation troubles could quickly develop into costly repairs and shutdown of expensive mass production equipment.

We in the maintenance field owe a vote of thanks to our competent designers, because if it were not for them, we would have much more trouble than we do. From time to time, however, troubles do develop and we must solve them, and the purpose of this paper is to try and help you gentlemen so that you might help me. By exchanging troubles and information thru meetings such as these, our knowledge on all subjects discussed is increased many times.

FUNDAMENTALS

Quite often in trying to reach the solution to a problem, we lose sight of the fundamentals involved and try to find the answer by complicated means. I recall some years ago when I was an apprentice electrician in the shop, a motor design was changed by the manufacturer for our company. The same frame was used, but horsepower and speed were to be increased, by changing the fields and the installation of a new armature. Changes were made and the motor installed, but when tried out, the motor sparked very badly at the commutator. An electrician with whom I was working said, "The commutating poles were hooked up wrong", but he was ignored. After many engineering consultations and recheck on the paper work, no one had any answers, so it was decided to try reversing the polarity of the commutating poles. Need I say the electrician was correct. You might say that would never happen to me, but similar incidents are taking place every day. Naturally they are not too widely publicized because who goes around telling about his mistakes. The moral to this tale, of course, is do not overlook the simple things, as the answer may be right in front of you.

With that thought in mind, I would like to take a chance on boring you by reviewing a few of the fundamentals about commutation along with its whys and wherefores.

The coils that are considered to be undergoing commutation are those moving parallel to the main field flux, because at this position they are not generating effective voltage or carrying load current. Before and after being short circuited by the brush, the armature coils connected to the commutator bars are carrying the full load current. The voltage passes thru zero and as a result the current must be suppressed because the current is flowing in one direction in the coil, then the current is short circuited and re-restablished in the opposite direction. Remember, the commutator is a rectifier device, in that it allows the current to flow in only one direction. If the short circuiting does not take place at the proper instant, the short circuit current of the coil undergoing commutation will cause injurious sparking to occur between the commutator bars and the brush. Sparking is injurious to commutators only when it causes a destructive action to take place at the leaving edge of the commutator bar. When small pits or streaks start appearing on the leaving edge of the bars, it is time to correct the conditions that are causing the abnormal sparking.

Effect of inductance of the coil when the current is reversed adds to the problem, along with distortion of the field flux. All of the causes of sparking can be condensed into three main groups. These are: brushes not on neutral, interruption of load current and interruption of short circuit current. There are many reasons why each of the above conditions may exist.

You might ask how would brushes get off neutral once they are set unless someone changed the brush-holder yoke. There are many things that can happen to effectively shift the neutral without moving the yoke. A few months back a couple of us had to get out of bed and go out to the plant because one of the mills would not stop under normal conditions. The only way it would stop was by tripping the breakers. Completely explaining the control scheme is beyond the scope of this paper, so if some of the following explanation seems a bit vague, please excuse me.

The trouble was traced to a rotating regulator on which the voltage remained up. Checking thru all six field circuits of the machine we could find nothing wrong. Further check revealed the machine would not build up voltage with all of the fields disconnected, but once the voltage was up, we could remove all field connections and the voltage would remain up. After tearing our hair out, and one look at my bald head proves we did tear it out, we decided to head to the patent office and take out patents on a generator without fields. Before doing this, however, we decided to do some more checking.

Close examination of the commutator revealed the edges of the bars were burned and questioning revealed the machine had been sparking rather heavily for a few days. This resulted in the brushes being shifted off neutral due to burned bars, and as the armature circuit was directly connected to its load without any contactors, it caused the machine to compound on its own interpoles. As a result, when the voltage built up under normal field control, it would remain up after the control opened the field circuits. This caused a six-hour delay on this unit which is a good illustration, I think, of the importance of good commutation.

Continuing with the fundamentals, the ampere turns in the armature establish a flux at right angles to that of the main field. This causes the flux density to be increased under the trailing pole tips and to be decreased under the leading pole tips in a generator with the reverse being true in a motor.

Were it not for these conditions, the neutral position of the brushes would fall in the center of the pole pieces on non-commutating pole machines where the connected coil is midway between poles. Due to the field distortion caused by the armature flux, however, the brushes of a generator have to be shifted forward in the direction of rotation and for a motor, they may be shifted backward against the direction of rotation. The proper neutral point, therefore, does not fall on the center line of the pole piece. The neutral position is important so that commutation will take place at the proper instant. Shifting the brushes of a generator against rotation will raise the voltage, while shifting the brushes of a motor against rotation will increase its speed. The setting should always be at the position which gives the best results as the neutral may shift with the load. Glowing and pitting is usually a sign of improper neutral. The lead is given the brushes so that the fringe flux from the pole tip can cause the proper reversal of current in the coil undergoing commutation.

Many methods have been devised to reduce field distortion. Some of these are, a long air gap and strong field, special shapes of pole pieces, cast iron pole shoes and commutating or interpoles. The terms commutating and interpole get bandied around a lot as to which is the correct term, so the English call them compoles. I usually use both terms having no preference, though commutating pole should be the preferred name.

Correction of field distortion is most commonly done with the interpoles. They correct the distortion in the commutation zone and allow the machine to be operated without sparking at the brushes over the entire load range. Sparking may occur if the interpoles should become saturated under heavy load. Polarity of the commutating poles are a matter of utmost importance. In a generator the polarity should be the same as the next main pole in the direction of rotation. The commutating poles should be adjusted so that their strength is correct at full load or slightly above. Sometimes a shunt winding of small magnitude added to the interpole connected in opposition to the series winding provides a reversing flux more nearly proportional to the load. This is used to offset some of the series ampere turns to prevent saturation of the interpoles. Thusly, if the shunt ampere turns equaled 2% of the series turns at full load on the machine, then the shunt winding would neutralize 2% of the series winding at full load. At 50% load on the machine, 4% of the series winding would be neutralized, while at 200% load, only 1% of the series winding would be neutralized. A diverter can be used by connecting a resistor across the interpole and adjusting it for the proper current in the interpole for best commutation. The adjustment is best made by test and not calculation. When reversing the direction of a motor, be sure the interpole polarity is reversed along with that of the armature.

The best running position for loads from zero to 200% will probably fall two to four segments in front of the neutral position for a generator in the direction of rotation and behind the neutral position for a motor. As a rule the greater the load, the greater the lead for best commutation.

Field distortion that is beyond the control of the interpoles can be reduced by the use of a compensating winding set in the faces of the pole pieces. The interpoles offset the shifting effect of armature current ampere turns while the pole face winding offsets the weakening effect of armature current ampere turns. Ring fire and a reduction in the possibilities of flashover are greatly reduced by use of the compensating winding. The pole face winding as it is often called is used where a wide range of speed and load is encountered. The current flow must be in the opposite direction to that in the armature coil in this winding. The compensating winding is used to neutralize the distortion due to the armature current ampere turns. They improve commutation especially during heavy overloads such as found on rolling mill equipment.

As perfect commutation can only be reached on paper and not on the machines as manufactured, many problems arise for the men who must maintain the equipment in the field. Up to this point I have spoken of things over which we in industry haven't any control. The designers give us the machine and we must carry on from there. Now I will attempt to give some information on what we can do in the plants to correct undesirable commutating conditions.

There are many good lists available on sparking or poor commutation and how to cure it. These can be consulted for details and what follows is a comprehensive summary.

BRUSH CURVE

When sparking occurs and the reason is not easily located, a brush curve is probably the most useful device to use in diagnosing the trouble. What we strive for, but are unable to reach in practice, is a linear drop from toe to heel of the brush; an excessive drop plus a current reversal indicates overcompensation of the field flux. This overcompensation should be corrected by weakening the interpoles, or by shifting the brushes against rotation. It is evident then that under compensation can be corrected by strengthening the interpole, or shifting the brushes in the direction of rotation.

When the commutating field is too strong, the brush curve will fall off sharply across the face of the brush and when it is too weak, it will rise rapidly in the direction of rotation. A brush potential curve with a slightly falling nature is preferable to one with a rising characteristic. As a general rule the critical voltage at the trailing edge of the brush will be lower than that of the leading edge. The above statements apply to both motors and generators; however, there is a slight difference between the curves of a generator and a motor.

BRUSHES

The brushes must carry the load current and maintain a good commutator. The proper grade to be used will vary from motor to motor and will even vary in the same motor on a different application. For the best grade you can try those you might have available or better yet consult the motor manufacturer or one of the brush manufacturers for a recommendation. It is best not to mix brush grades of different makes even though they are similar. We have attributed trouble several times to different makes of brush being in the same machine. Brush manufacturing and application is still pretty much of an art and not a science.

Brush make-up can be divided into four classes. These are: carbon brushes used for low current density and low speeds; electrographite brushes for higher currents and speeds where cleaning action is not too important; graphite brushes with any amount of abrasive as needed incorporated in the brush make-up; the use of this brush is restricted to a small field; copper graphite brushes used on slip rings and commutators where high currents are to be carried.

In the past I believe we have damaged our commutators by trying for long brush life, thus sacrificing the commutator for economical brush wear with resulting expensive losses. Brush life should be secondary to good commutation.

Temperature at the brush face also effects its commutating qualities. Tests have shown that operation at about 100° centigrade gives the best performance. As a rule the brushes will run hotter than the commutator, and selective action of the brushes is usually indicated by heating of the brushes involved. Steps should be taken to remedy the situation as soon as possible. Brush pressure is a very important factor and one that is often overlooked. We used to hear of 2½ pounds to the square inch being the optimum, but today you will find pressures below and above this value, which will give the best results. When in trouble it is best to try increasing or decreasing the pressure until best results are obtained. Light pressure will cause rapid wear due to electrical action and heavy pressure will cause rapid wear due to mechanical action. Sometimes dust and dirt cause mechanical wear on brushes, but to the eye, the wear will seem to be due to electrical action. This is especially true on traction motors.

Remember that brush wear should be secondary to commutator wear. The ideal pressure is that which will maintain contact between the brush and the commutator or slip ring and give a minimum amount of wear and temperature rise. This will probably vary from about 1 pound per square inch in some motors to 6 pounds per square inch in locomotive traction motors where severe vibrations are set up from road bed shock. On rolling mill motors 2 to 3 pounds per square inch is probably a good average. These same pressures also hold true for slip rings. On fractional horsepower motors due to the large amount of friction present between brush and commutator, pressures usually run high. It is a good idea to check and readjust brush pressure about every 1/4" of brush wear. Quite often unequal load distribution can be traced to varying brush pressure. Springs that have lost their tension are often overlooked, along with poor contact between brush shunt and brush holder. Low spring pressure will cause selective action, copper picking, streaking and grooving of the collector ring or commutator. Copper picking is usually the result of selective action.

On some machines where brush grade seems to be the culprit and proper grade cannot be found, putting one grade of brush in the positive brush holder and a different grade in the negative holder may solve your problem. This trick may be used, especially on low voltage machines or on those where commutation is extremely difficult. When using an abrasive brush as a cleaner, be sure to replace all of the brushes in one holder with the cleaner brush. Preferably the cleaner brushes should be placed in a negative holder on a generator and in a positive holder on a motor.

Brushes should be replaced before wearing too short as short brushes will increase the tendency to flashover. They should always be staggered for best results, being sure to keep a positive and a negative brush in the same plane. This will result in a more uniform looking commutator surface as well as reduce commutator wear. It is best not to replace a complete set of brushes at one time if it can be avoided.

It is a good practice to replace all of the brushes on one arm when brushes need replacing, saving the long one for individual replacement in the other arms.

It is very important that the brushes be properly fitted to the commutator. Sanding them in usually leaves much to be desired, as it is a tedious job, and there is a tendency on the part of the workman to do a sloppy job. Brush seating stones do a very good job and they are easy to use.

Split brushes offer better commutation as they present many more contact points than a solid brush does. Also they present a higher resistance from toe to heel, thus helping to decrease the current that must be short circuited with an improvement in commutation. Their cost is slightly higher, but where they can be used to an advantage, the higher cost will be repaid many times in improved performance. Some years ago, we had four generators of 2500 KW, 600 Volts D.C. operating in parallel. One of these machines continually gave commutation troubles, though all of the machines were alike. We changed to a split brush on this one generator and had no further trouble. Recently, we added two more generators, raised the operating voltage and changed the control. This brought to our attention a case of uneven load division between machines. The two latter generators had split brushes which, along with the one original machine, gave us three generators with split brushes, plus the original three with solid brushes. The load division could be seen on the meters showing up between the split and solid brush machines with the split brush machines taking the load. We have now changed to all split brushes with improved commutation and performance.

After carrying heavy currents, some brushes have a tendency to swell, causing the brushes to stick in the holders. As a result, after heavy overloads it is a good idea to check for stuck brushes. Oil and dirt also cause this trouble. You might reclaim oil soaked brushes by soaking them in a non-leaded gasoline.

On the other hand, you might improve brush performance under adverse conditions by allowing the brushes to be dipped in an oil bath.

BRUSH ANGLE AND SPACING

Brush angle can play a very important part in good commutation. I know of cases where commutation was very much improved by changing the angle of contact between brush and commutator. Current practice calls for a trailing angle of 15° to 20°, but if the motor is to reverse, you will find a 10° angle to be about the limit. On modern mill type motors with heavy duty reversing service the brushes are radial, and very good results are obtained. Chattering may be reduced by increasing spring pressure or changing the brush angle.

Brush spacing is very important and it should be uniform around the commutator, not being more than about 1/32" difference between holders. A roll of adding machine paper is very handy for checking the spacing. Place the paper around the commutator and mark the same edge of every brush, using the toe of the brush as a guide.

Care should also be taken to make sure that the brushes are parallel with the commutator bars. Misalignment causes the brushes to carry a high current from the coils undergoing commutation. This misalignment should be corrected at once.

BRUSH HOLDERS

Brush holders are probably one of the most overlooked items when it comes to correcting the troubles of poor commutation. They must be kept in good condition and properly adjusted. On motors where spare armatures are on hand, it is a safe bet to say that when the armature is changed, the brush holder will not be properly readjusted to fit the new commutator.

The brush holder should be kept adjusted to about 1/8" off the commutator; a piece of 1/8" fiber makes a very good gage for this adjustment. This helps to insure proper location of the brush on the neutral point. Worn boxes are often a source of trouble. Clearance between the brush holders and the brushes would fall between .003 to .010 on width and between .002 and .007 on thickness. This will allow the brush to move freely, yet keep it in the proper position. Brushes often stick in their holders, and this should be checked regularly. Severe vibrations that have developed in machines have been traced to stuck brushes. Bent brush holder studs are often a cause of poor commutation, as they cause the brush to be off the neutral point. Brushes chipping and breaking also cause a shift of the neutral to take place. Slight differences in neutral can be noticed in armatures also. We have one motor that whenever we swap armatures we have to readjust the brush holders for neutral. This is a reversing motor, so we put a tachometer on the shaft and run it in both directions, moving the brush holder until the speed is the same in both directions.

COMMUTATOR

Trueness of the commutator must be kept fairly accurate, the peripheral speed being the determining factor in how much tolerance in out of round can be allowed. As little as .0001 of an inch can cause considerable trouble, though for slow speed machines .003" is acceptable. For commutators whose peripheral speeds do not exceed 6000 FPM the out of roundness should not be more than .001", and when the speed goes up to 10,000 FPM, they should be held to within .0005". This can easily be checked with a dial indicator and necessary steps taken to correct the condition.

Grinding is preferable to turning and by far the most economical. Whenever possible, armatures should be in their own bearings and the grinding should be done at normal running speed. For safety, breakers should be at their minimum setting with grinding. A compound fitted to a brush holder is the best method if it can be used. Handgrinding should only be done for slight imperfections as it is physically impossible to maintain a constant pressure.

Flats are often due to faulty connections between the winding and commutator bar. On machines with long risers the trouble can be at either the winding or commutator end. The grinding should be done with the commutator rotating toward the operator and the stone moved back and forth with light pressure. If the commutator is out of round, only the high spots should be hit first. Some means should be provided to keep the copper dust out of the machine and it should be stopped at intervals and the brushes freed in their holders. The commutator should be cleaned of all grease and oil before grinding is started for best results.

Stones are graded coarse, medium and fine according to the grit or mesh that the original composition can be passed through. Coarse stones are usually 80 mesh, medium stones 120 mesh, and fine stones 200 mesh. After grinding, the commutator should be polished with a hard maple block, finishing off with a piece of canvas or felt. There are now many fine flexible abrasives on the market for polishing commutators.

UNDERCUTTING

If necessary, and it usually is, the commutator should be undercut. A "U" shaped cutter is probably best to use, but a "V" shaped one is much easier to use. Whenever possible the "U" shaped cutter should be used, but a "V" shaped cutter should be used where there is considerable dust and dirt present to clog up the slots. The "V" shaped slot makes a much quieter running machine where noise is a factor. After using either one it is very important to remove the feather edge that may be left right at the edge of the bar.

As a rule, the depth of the undercut should not exceed the thickness of the mica. In most cases it can be about 1/16" deep plus or minus 1/64". The saw should be about .003" wider than the mica. After undercutting, the edge of the bars should be chamfered about 1/32" at 45° for medium bars. This will vary with the width of the bar.

A commutator in a dirty location should be undercut, then the slots filled with cement. This will allow the wear to be even as the cement will wear away with the copper where the mica would not.

SURFACE FILM

The film that is formed on the commutator during operation probably has more to do with good commutation than anything else. It can be used to diagnose troubles with the machine, but unfortunately there aren't any rules to apply. Experience is about the only teacher available at the present time.

The color is usually a good indicator as to when we are getting good commutation and when we aren't. Do not confuse a good color formed from a film with one that is caused by burning.

Total thickness of the film would be mighty hard to determine being probably not more than .00001" thick at the very most. This film formation is the result of brush deposit on the commutator with one brush putting it on and the one of opposite polarity taking it off. When starting from scratch, a film deposit may take from 1½ hours to 2 weeks to reach a stable condition, varying with conditions.

Usually for most conditions a thick dark film is best, but you will find many cases where a thin light film works better. The film can be controlled in most cases by varying brush pressure and/or the brush grades. Do not allow the commutator to become highly glazed as it will cause brush chatter and the brushes will chip.

Threading of the film can easily be caused by too low a current density in the brushes. We know of several cases where we started to get poor commutation when loads were lightened. Taking some of the brushes out so as to load the remaining brushes up solved the problem.

It may come as a surprise to some of you, but the old electrical cleaner, carbontetrachloride, will ruin a good commutator film as quickly as any other means known and cause an increase in brush wear. There are many commutator salves now on the market that have very good film forming properties. Probably one of the easiest and best things to use to keep a commutator film in good condition is the old standby canvas wiper. A service engineer for one of our large manufacturers told me of being sent on a job where poor commutation was the culprit. This plant had two motor rooms operating under almost identical conditions, yet one room had commutation troubles and the other did not. One day while observing the machines which were not causing trouble, the shifts changed and the operator came along with a canvas pad and ran it over the commutators. This was a daily habit of his and he had been doing it for years. The practice was introduced into the room where the troubles were occurring and the commutation troubles disappeared in a short time. There are also many fine cleaning stones now on the market.

Streaking and threading may be corrected by shifting the brushes, but it is preferable to adjust the strength of the interpole. A loose or high resistance coil to bar connection is indicated by burning of the next bar ahead while burning of every second or third bar symmetrically around the commutator can be corrected by proper brush position, increasing the interpole air gap, or by shunting the interpoles. Equi-distant marks on the commutator spaced two pole pitches apart is usually due to poor contact between equalizers and risers.

Many times when burnt bars occur a brush spacing apart, a mechanical vibration is present. This impact or vibration causes all the brushes to raise off the commutator at the same time with resulting arcing and burning. Examination will disclose a carbon deposit under the positive brush and deposition of copper under the negative brush. If the impact is from the machine being driven, you might find it difficult to convince your mechanical people that something is wrong. The vibration may not be excessive from their point of view, but it will cause you to have commutator troubles.

We had some generators that flashed over oftener than we figured they should. One day my colleague Mr. Schletche reached the conclusion that vibration was causing the ends of the brush holders next to the risers to come closer together than normal and with other conditions being right, we had a flashover. The out-board edge of these arms were tied together rigidly originally so we tied the ends of the arms next to the risers together in a similar manner, and I do not believe we have had a flash-over since.

You will find a strobotac handy in observing the commutator and brushes under operating conditions, especially since these units are now available with a bright light.

Many times bar burning will occur symmetrically around the commutator. Investigation will reveal more than one coil per slot, which means that a compromise on the neutral setting of the brush must be reached. This results in the bars burning on both sides of the bars that are on neutral. I don't have any answer on how to correct this condition, but am open to suggestion.

You will find that the greatest arcing usually takes place where the current leaves the machine. Thus in a generator most of the arcing will take place at the positive brush, while in a motor it will take place at the negative brush. This is one reason why changing the polarity of the slip rings keeps them in much better shape than allowing them to remain at one polarity.

A commutator is probably in best condition when it has medium chocolate color, medium polish and is perfectly smooth. Too high a current density in the brushes will cause copper picking by electrolytic action and circulating currents can cause both the positive and negative brushes to copper plate.

Copper dragover at the edge of the commutator bars can be caused by chattering brushes or by the electrolytic action of an arc at the leaving edge of the brush. This arc will cause deterioration of the bar, allowing it to be dragged over by mechanical means.

HUMIDITY

Until the last war when much research had to be done for aircraft, it was known that humidity effected commutation, but it was not known to what degree it effected it. Low humidity can cause brush breakage and result in poor commutator film, while high humidity can result in threading and breaking up of the surface film.

During periods of low humidity, you can notice a decrease in brush life as the wear is much more rapid. This is especially true at high peripheral speeds. The critical wear point is a combination of temperature and the absolute humidity. When the absolute humidity falls below about 1.5 grains per cubic foot, increased wear can be expected.

Translating this to our everyday terms, it means you can run from about 23° F, 100% relative humidity to 104° F, 6% relative humidity and maintain this minimum water content. At about 70° F you should have about 50% relative humidity. Charts are available to give the above information at any temperature.

Sometime ago we had a motor in an extremely hot and dry location that we were unable to keep brushes in. They were always chipping and breaking up and we were unable to find the trouble. Everything was checked and repaired that could be found wrong or even suspected as a source of trouble, but without result. We lived with the condition until the process was replaced. I wished that this machine was still operating so we could introduce some moisture into the air and prove the theory we now have, that trouble was due to low humidity.