

ELECTRIC PHENOMENA IN RELATION TO LUBRICATION OF MACHINES

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General.

The effect of shaft currents passing through an oil film in a bearing is to accelerate polymerization and oxidation and cause thermal decomposition. The oil darkens in colour, sometimes increases in acidity, and generally deposits a chocolate-colour precipitate in the oil system. Arcing will also cause small particles of metal to flake off and contaminate the oil.

If a shaft current is produced in any one of the ways described below, it may, if of sufficient strength, arc through the oil film and cause pitting of the shaft and bearing. Electrolysis or galvanic action might cause currents to flow through the oil film without the presence of actual sparking or arcing.

Current flow in bearings can be caused by electrolysis, arcing, galvanic action or static charges.

Electrolysis.

Electrolysis can be defined as the resolution of compounds into their elements under the action of a current of electricity. The ionic theory of electrolysis assumes the establishment of positively and negatively charged ions, known as cations and anions, in the electrolyte. Experimental evidence indicates that, with saturated oils, conduction of an electrical current is of an ionic nature. The source of the ions is not definitely known, but experiments show that impurities are the main cause of conductivity rather than the molecules in the oil itself. This suggests that oil is not an electrolyte, but impurities dissolved in the oil materially affect its electrical characteristics.

In Michie's experiments on insulating oils he was unable to cause the oil to deposit any precipitate merely by an electrical stress, but he found that the deposits in oil-cooled transformers are products of oxidation of petroleum.

Electrolytic action is found to be present in most bearings where it is possible for the bearing and journal to act as electrodes, and where, due to some electrical phenomena, a difference of potential exists between them. It will be noted from what has been said above that uncontaminated oil cannot act as an electrolyte: the presence of water or other foreign matter is essential before action can commence.

Frequently it is found that where a leakage current has passed through a bearing, polymerization without an increase in neutralization value has taken place. This may be due to an effect similar to that found in the Voltol process of producing heavy, high-

viscosity-index oils. In this process the oil trickles over rotating electrodes, and is subjected at temperatures of 60°C. to 80°C. to the action of discharges of a frequency of about 1,000 cycles per second and a tension of 4,300 to 4,600 volts in an atmosphere of hydrogen at 60 to 65 m.m. of mercury to avoid oxidation. This treatment results in a very great increase in viscosity.

A hypothesis by Nernst assumes that the shock action of the ions produced by the silent discharge produces the principal effect. These ions impinge upon the oil molecules with great violence and detach from them a portion of their hydrogen atoms, leaving unsaturated residues which polymerize.

Arcing.

Arcing can occur between a bearing and the shaft, or between the ring of a ring-oiled bearing and its housing whenever a potential difference exists between these components. The production of the arc is caused by the dissipation of this difference of potential, thus breaking down the resistance of the oil film.

Arcing is generally due to leakage of dynamic electric currents, which can occur, for instance, in electric traction systems where the return current flows through the axles and wheels to the rails. A failure of the collector ring or brush gear may divert current through the bearings, with possible disastrous results. An earth fault on any electric machine may in certain circumstances cause current to flow through bearings.

Galvanic Action.

On *rare* occasions it is possible for local galvanic currents to cause corrosion of a shaft or bearing, oil cooler tubes or hydraulic relay pistons. In the latter case reference is made in literature to the fact that galvanic currents may eat away the sharp edges of hydraulic pilot valves.

The experiments of Hovorka and Antony have shown that in bearings or other machine parts in which two dissimilar metals are separated by oil, the whole set-up can act as a galvanic cell. One of the metals may, because of its electrolytic solution pressure, dissolve in the oil and form a conducting solution. The metals may then act as electrodes and oxidation of the oil may take place at their surfaces, resulting in chemical reaction between the metals and the oxidation products. Thus it may be possible

that the electrode potential so produced is responsible, directly or indirectly, for corrosion which takes place in some bearing combinations. The above experimenters found that with a cadmium-silver-oil-steel combination, a potential of up to 0.6 volts could be produced. However, the voltage did not appear until the oil temperature reached 200°F.

The galvanic currents just mentioned have not presented any lubricating problems in the majority of bearings, and we have found little evidence in practice to support this theory as a general cause of bearing failure.

Static Charges.

Static electricity is the electrical potential difference set up between one section of a machine and another by the action of ions being violently separated, and in so doing, building opposite charges. This can occur, for example, due to the friction of a tyre tread on the surface of a road; high velocity steam impinging on the machine components, or static might be collected from dust in the atmosphere. Static charges due to friction drives or belts can cause bearing currents.

If an insulating medium exists between the parts of a machine, then these charges will build up sometimes to a very high potential. For example, under running conditions the shaft of a machine can be insulated from the bearing by the presence of an oil film. If conditions conducive to the generation of a static charge exist, then the shaft might accumulate a positive static charge. Whatever the degree of this positive charge, the opposite components of the machine—in this instance, the bearing and pedestal—will carry an equal negative charge, or *vice versa*.

There is a constant tendency for these charges to equalize by discharging across the insulation boundary—in our case, the oil film. When this occurs, a spark of high potential jumps across the insulating medium or the oil film. The potential of

the static charges may be in the region of thousands of volts, but the arc resulting from an equalization of these charges is not as destructive as an arc from dynamic electricity, in that the former is accompanied by a very small current during the flash-over.

In order to distinguish this behaviour it should be remembered that with dynamic electricity an arc is the effect of the interruption of a current of electricity, whereas with static charges, sparking is the equalizing of high potentials.

One turbine manufacturer has confirmed that static charges built up on the rotor and frame of turbines are caused by high velocity steam impinging on the turbine blades.

Static charges can be detected by the gold-leaf electroscope, but they can only be successfully analyzed by the use of an oscilloscope.

Electrical Phenomena in Turbo Generators.

Possible causes of currents which might lead to bearing trouble are tabulated below:—

(a) *Stray magnetic fields.* The arrangement of the D.C. connections to the exciter and alternator rotor is important. If the positive lead is led out on one side of the bearing pedestal and the negative lead on the other, it constitutes a complete turn around the pedestal. When the current flows, a magnetic current will be set up in the bearing pedestal and shaft.

This condition will cause the shaft to be pulled on to the bearing, thus unduly loading it, but a high excitation current is necessary before this condition becomes serious.

(b) With a magnetic field passing from the bearing pedestal to the shaft, as mentioned above and shown in Fig. 1, the shaft becomes a single conductor armature cutting the flux and generating a voltage in the shaft section of the bearing. If

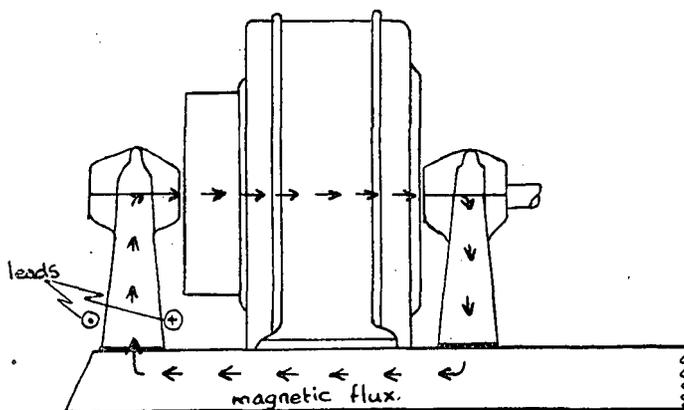


Fig. 1.

the flux is sufficiently dense and the speed high, the voltage may be of sufficient magnitude to break down through the oil film and cause a current to circulate between the shaft and the bearings, as indicated by the dotted lines in Fig. 2.

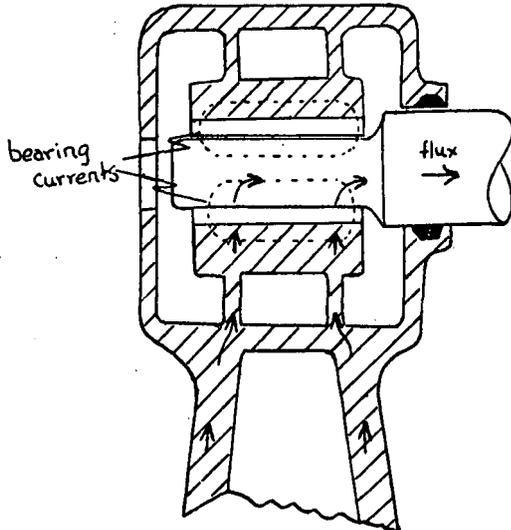


Fig. 2.

In such cases, the potential may not be high enough to cause direct arcing; nevertheless, the difference in potential may cause the shaft and bearing surfaces to act as electrodes, leading to breakdown by electrolysis.

(c) A fault in the rotor windings might cause unequal ampere-turns within the rotor which will produce a leakage of flux through the shaft and alternator frame (excessive vibration will often give warning of an earth fault). An electrical fault may not necessarily cause the passage of a current through the bearings, but will produce stray magnetic fields which, in turn, might be responsible for the magnetization of the shaft, as mentioned above. Possible paths of this leakage flux are shown in Fig. 3.

(d) The possibility of a static charge being generated on turbine rotors has already been referred to. If the potential built up by these static charges is sufficient, arcing across the oil

film can of course occur, although in our experience bearing failures have not been traced to this. It is probable that the small clearance between the stationary and moving rotor blades, the labyrinth gland or carbon packings, dissipate this charge.

Leakage Currents in Electric Motors and Generators.

In every multi-pole electric machine the flux of each pole, after crossing the air gap, splits up into two sections, with one taking a clockwise path through the yoke, and the other a counter-clockwise path. If, for any reason, the clockwise flux is not equal to the counter-clockwise flux, the difference will circulate around the yoke. This stray flux will link the shaft, and its alternations will induce a voltage in the circuit path of shaft, bearing pedestal, and bed plate. In this manner, a shaft current of constant value, not affected by load on the machine, will flow through the bearing.

To illustrate the above, consider the four-pole rotating field in Fig. 4. The paths of the magnetic flux are as indicated by the solid lines and arrow-heads. If the magnetic circuits are uniform, the flux will be equal in each path; consequently, they will be equally distributed about the shaft. If joints are put in the core, as in Fig. 4, the reluctance of the flux paths through the joints may be considerably higher than through other paths. This unequal distribution of the flux in the different circuits may cause part of the magnetic field to link the shaft. At points E and F in the hub the magnetic field is less dense than at G and H. The result is a tendency for some of the flux passing through G and H to take the easier paths through E and F, and thus work all paths in the hub at the same density.

What happens is indicated by the dotted lines: part of the flux links from pole D to A, then to B and C, and back to A. This flux surrounds the shaft, and if it varies in density a voltage will be induced therein.

Where conditions are favourable to the generation of the shaft voltages they increase rapidly with the size of machine, and shaft currents may increase at

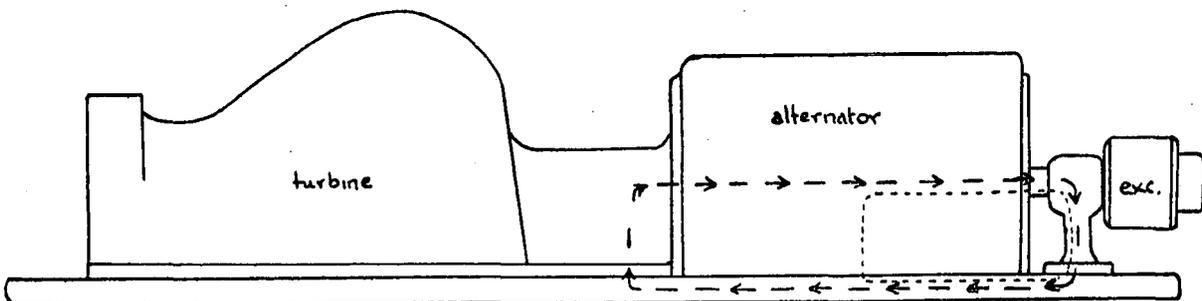


Fig. 3.

an even greater rate because of the larger bearing area.

Length of air gap is also a factor. With short air gaps, as in induction motors, the possibilities of shaft currents giving trouble are greater than in machines with long air gaps.

As in the turbo alternator, a fault in the windings of a machine may cause a current to flow through the bearings. For example, a ground in the armature of a direct-current generator may cause a heavy current to flow through the bearings before the circuit breaker opens if the frame of the machine is effectively grounded and one side of the power circuit is earthed. Under severe conditions of this nature bearings have been injured.

Where the frame of a machine is earthed but the resistance of the connections is comparatively high, a current may flow to earth continuously through the bearings without opening the protective device. Such a condition may not injure plain bearings but might be detrimental to anti-friction bearings with their small contact area with the shaft.

that the oil rings may make contact between the shaft and the bearings due to the free movement of the ring in its housing. The first signs of trouble from shaft currents often appear under the oil rings in the form of scratches on the shaft, and sometimes small pit marks on the insides and faces of the oil ring. This is caused by the oil rings making good metallic contact between the bearing and shaft, and when a heavy current has started to flow, movement of the ring breaks the circuit and causes a spark that results in pitting.

Methods of Preventing Shaft Currents.

Proper machine design is the most desirable method of avoiding shaft currents. However, if trouble develops in service, remedies must be applied on site, although to-day all well-known manufacturers incorporate the necessary devices in the machine, if not to avoid, at least to minimize the danger of shaft currents.

A common method of preventing shaft currents is to insulate the bearing pedestal from the frame. In the case of electrical machines where the bearings

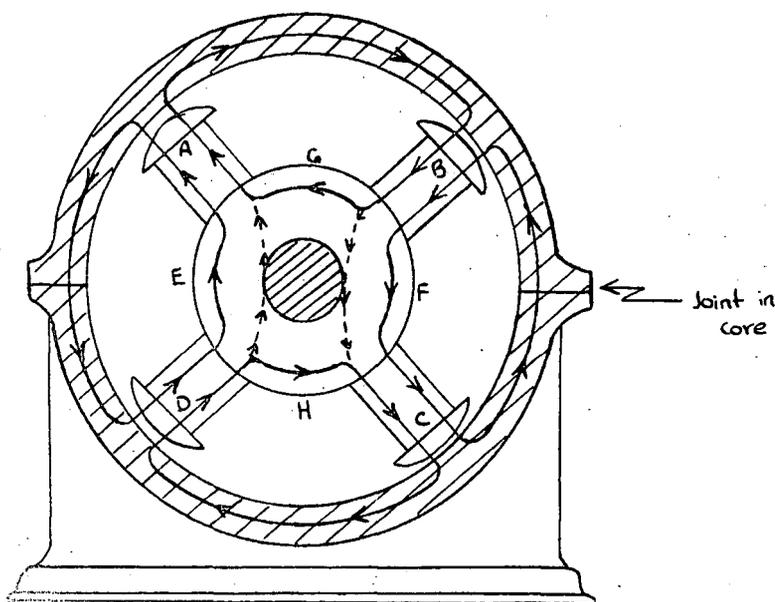


Fig. 4

End play of the shaft is also a factor in shaft currents. If the collars of the shaft run free of the bearings at both ends, the oil films in the two bearings are in series and may effectively insulate the shaft. If the collar on one end rubs hard on its bearing, the shaft current will be earthed. In one instance of electrolysis in bearings, the greatest deposit was found in the discharge oil pipe from the horse-shoe collar thrust bearing.

As ring-oiled bearings are commonly fitted to electrical machines, it is as well to point out here

are supported in end brackets attached to the stator frame, bearings must be insulated in the housing. However, neither one of these methods is effective in preventing bearing currents produced by a magnetic flux in the bed plate and shaft, as illustrated in Figs. 1 and 2. To break the flux path, non-magnetic material may be introduced by making one of the pedestals of non-magnetic material.

Where a machine has bearing pedestals, as shown in Figs. 3 and 5, an insulating pad placed under the pedestal will prevent shaft currents. Substances such

as fibre should not be used as an insulation medium at the pedestal base because of its absorption properties: non-absorbent insulation only should be employed, such as bakelite. The bolts and dowels holding the pedestal to the bed plate must also be insulated from the pedestal as well as the oil pipes and handrails. It is common practice to insulate only one pedestal, as the rotor then remains grounded to the bed plate through the other pedestal. This is desirable as electrical protective devices are incorporated in the earth circuit. On vertical shaft water-wheel generators, the upper bearing bracket is insulated from the stator frame. In some installations it will be found that the thrust bearing is also insulated from its support.

Another method of eliminating the effects of shaft currents is to fit earth brushes to connect the shaft with the bearing pedestal, thus shunting the oil film. Regular attention must be paid to rings and brushes in service, as their effectiveness is likely to be reduced by dirt, oil, etc.

Static charges caused by friction drives or belts can be reduced by placing a discharge comb in close proximity to the rubbing surfaces.

Methods of Testing for Leakage Currents and Static Charges.

(a) *Testing of Pedestal Insulation.* The most common practice is to mega-test the insulation—Fig. 5. A reading of 100,000 ohms is considered a minimum, and a higher resistance is generally aimed at.

(b) Shaft voltages can be taken using a voltmeter or milli-volt meter; the most suitable points for reading being shown in Fig. 5. On 40,000 Kw. turbines at full load (full excitation) a reading of 10 volts is common.

Checks should be made for both D.C. and A.C. potentials. The frequency of the A.C. currents likely to occur due to leakage fluxes is at present unknown. However, as polymerization always accompanies a leakage current, it is possible that high-frequency A.C. currents are involved, (vide remarks under "Electrolysis" regarding the Voltol process).

As the average milli-volt meter will not necessarily show high-frequency A.C. currents, tests for the presence of these would have to be made by an expert using an oscilloscope.

(c) Where static charges are known to be present and no current readings can be taken, a gold-leaf electroscope might detect their presence. A more satisfactory method of testing, however, is by means of an oscilloscope.

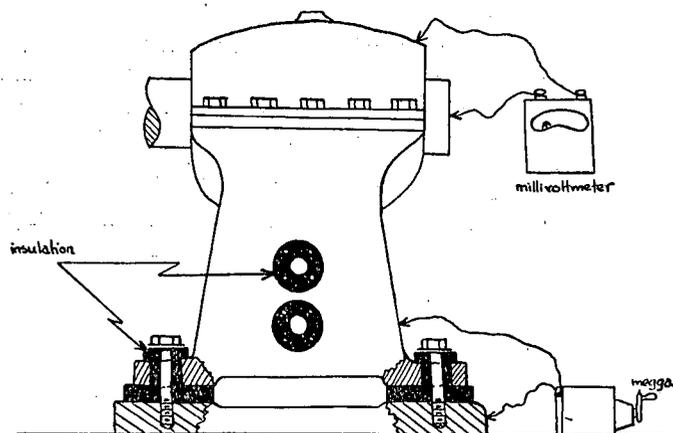


Fig. 5

Mr. McCulloch asked whether Mr. Hilliard had found that the worst faults occurred with motors which were started up frequently. He also asked for his experiences with roller bearings compared with ball bearings and whether trouble had been experienced with white-metal bearings and bearings which were not lubricated.

Mr. Hilliard replied that trouble had been experienced with motors which were started up frequently and also with white metal bearings. In the cases of roller and ball bearings his experience was that leakages were not so severe with roller bearings.

Mr. Rault asked for information on the precautions taken in tankers to prevent such things as high-static charges which might lead to explosions. He had in mind the recent accident in Durban. He also referred to a strange case where carbon dioxide was being handled. This took place on starting the fan sucking the gas from the lime kiln to be delivered to the carbonatation tanks. He thought the cause might have been the large amount of coke and lime dust particles in the area above the stove in the kiln, carrying a static charge. It was also known that grain mills, and even bagging rooms full of sugar dust particles, might be the site of explosions for the same reason.

Mr. Hilliard said he could not speak with certainty on the tanker explosion but the importance of observing all normal precautions could not be over-emphasised. Hundreds of tankers were handled daily in this country and overseas, and cases such as occurred in Durban were rare.

Mr. Barnes asked for permission to go somewhat beyond the scope of the paper. He said that some years previously, after a new factory was put into operation in Jamaica, it was found impossible to maintain the five boilers at the same pH or at a satisfactory pH for operation. The assertion that the trouble was due to electrical phenomena was never satisfactorily settled. In the same building and directly connected with the same steam lines

were two 1,000 kVa A.C. generators. Another thing which occurred at the same factory was severe pitting of the mill roller journals, which was attributed to incorrect lubrication. It seemed possible, after hearing Mr. Hilliard's paper, that arcing had occurred.

Mr. Hilliard said that on the second point the explanation was a good one but he could say nothing about the first. It was unusual to find it in a mill because there was usually no time for static charges to be built up or for galvanic charges to take place. Usually in a mill there were many places where currents would go to earth before reaching the mill bearing; this was a case where one would have to be on the spot to obtain an explanation.

Mr. Farquharson said most of the phenomena mentioned were known to electrical manufacturers and precautions were taken to prevent these troubles occurring. Not all electrical rotary machinery was fitted with self-oiled bearings. It occurred to him, from his own experience, that where a brass cage separated the balls or rollers and that cage gradually disintegrated, the cause might be electrical in nature. He asked whether it might not be caused by the brass and the lubricant forming a compound which became electrolytic.

Mr. Hilliard replied that it was possibly due to the result of galvanic action if the bearing were grease-packed. The whole setup would form a galvanic cell and the brass would probably be the first material affected, although he had no records of such an occurrence. He asked what type of machinery was involved.

Mr. Farquharson said one was a vertical motor and the other horizontal, both with greased bearings; a third case had mechanical oil lubrication. He had not experienced trouble with steel-caged bearings but only with brass.

Mr. Hilliard expressed the view that it was possible that the leakage flux might have passed along to the affected bearing.