DECCA AUSTIN INSULATORS

A PRELIMINARY INVESTIGATION

INTO SOME FAILURE MODES

OF EGG TYPE INSULATORS

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TITLE

A PRELIMINARY INVESTIGATION INTO SOME FAILURE MODES OF EGG TYPE INSULATORS

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INTRODUCTION

"With the installation of 200 kilowatt Alexanderson alternators in the New Brunswick, New Jersey and Marion, Massachusetts, radio stations, it was found that the insulators previously used in the antennas at these stations were unsuited to the new conditions. There were a number of different types of insulators available at that time, but very little information was available on their characteristics for radio frequency, high voltage, continuous wave use."

The quotation is from a technical paper published in 1923. (Reference 1). The statement made concerning the lack of availability of information on insulators for radio frequency use is as true today as it was then.

As the title of this paper suggests, we have made a preliminary investigation into some failure modes of egg type guy insulators. This is not a "be unkind to egg insulator week", but we have explored the electrical behaviour of the insulators we manufacture and we thought it wise to look at the behaviour of egg insulators, which we buy from other manufacturers and offer for sale. Others working in the insulator field have carried out similar investigations and, where we have knowledge of their results, these are mentioned later in the paper. Our work is by no means complete but it seemed worth while to let you know what we have determined so far.

60 Hz CHARACTERISTICS

The egg insulator is unique in the sense that it is the only “do it yourself” type you can buy. The behaviour of the insulator is influenced by the attachments made to it. The manufacturer of the egg, beyond controlling the quality of the piece of ceramic he supplies, has no — control over the behaviour of the insulation system. Egg insulators differ in minor respects depending on the manufacturer, but they are all basically similar.

Figures 1 and 2 show differing styles of insulators in common use. Figure 1 is typical of British manufacture and Figure 2, U.S.A. and Canada. Figure 3 shows the electrical characteristics of several types of eggs. The first three on the list are the most interesting because they are virtually identical and commonly used in Canada. Decades ago, this type was made to a U.S. Navy Specification and we believe several companies still produce them. It is significant to note that Locke, one of the original manufacturers of this style insulator, specifically did not recommend its use as primary insulation at radio frequencies. The last two insulators mentioned in the Table are somewhat larger units than the three referred to above.

Tests were made several years ago in the U.S.A. on somewhat larger eggs than those mentioned above. (Reference 2). The tests were made at 60 Hz though the investigation was concerned with the application of these insulators at radio frequency. Figure 4 summarizes the results of these dry and wet tests. You will notice that the wet flashover is about half the dry flashover for one or two units in a string, but there is an improvement in the wet flash—over with four units. A general conclusion would be that the wet flashover of a string of insulators is about fifty to seventy per cent of the dry flashover, and the effect of wet conditions is to even out the voltage gradient along the string. The report states that little improvement in flashover capability is achieved by putting more than four insulators in a string.

It will be noted in Figure 4 that one wet test was carried out with the insulator inclined to the vertical. The flashover voltage was higher and attributed to the fact that when the string was vertical, drip water fell from the bottom of the upper cable loop down onto the lower cable.

The tests made with the contaminated insulators show a lowered flashover voltage. This gives some indication of the performance if the system is located in a polluted area or near a salt water coast. The corona inception voltage of 14 KV on one dry insulator is low compared with the flashover voltage. The onset of corona is the beginning of an electrical discharge which will become visible and may turn into an arc. The low corona onset is a warning that operating voltages on egg insulators must be kept low in relation to flashover rating.

FAILURE MODES

Before discussing Radio Frequency tests it would be appropriate to examine some general characteristics of insulator materials when subjected to high voltage stress.

An egg insulator behaves as the dielectric of a capacitor, the metallic guy loops being the plates. The principles of dielectric engineering apply. (Reference 3)

There is no clear line of demarcation between an insulator and a conductor, and there is a third classification, the semi—conductor. One broad distinction between these classifications is the volume resistivity and surface resistivity. The point when you cease to call a material an insulator and classify it as a semi—conductor or a conductor is arguable. A further important distinction concerning the behaviour of an insulator and of a conductor is that, generally speaking, the resistance of a conductor increases with temperature whereas the resistance of an insulator decreases with the temperature. This is an important characteristic because the lowering of resistance with increasing temperature of an insulator tends to enhance electrical breakdown phenomena.

When considering electrical grade porcelain, we are firmly in the realm of insulators. In the practical case of an egg insulator subjected to voltages normally encountered in a broadcast antenna system, the resistivity of porcelain is extremely high and the conduction current can be ignored. Surface leakage may become a problem if the surface becomes contaminated, but this is not due to any electrical property of the porcelain.

Porcelain has a very high dielectric strength averaging 200 to 300 volts per mil for thin sections. The dielectric strength decreases somewhat as sections become thicker, but in any practical egg insulator there is sufficient thickness to guarantee that the insulator will not fail by puncturing simply due to inadequate dielectric strength.

At the power frequency of 60 Hz (50 Hz), and considering the insulator as a capacitor, the charging current is small, due to the small capacity and high capacitive reactance. The amount of power lost in the dielectric is relatively small and heating effects are not usually a problem. As the frequency is raised, the current increases in proportion to the change in frequency. The amount of heat generated in the dielectric also increases. As we move into the lower radio frequencies, heating becomes a more serious consideration since we are now dealing with several hundred KHz. In the MF broadcast band, at 600 KHz, we have increased the frequency, and hence the current, ten thousand times.

It is important to have a clear understanding of this particular cause of heating. We are not considering an I^2R loss due to current flow through a resistance. The resistance of the porcelain is extremely high and the true conduction current extremely low.

Dielectric heating, i.e. the rather complicated interaction of the molecules of the material with the electrical field is the main consideration. Not all the energy stored in the capacitor during each half cycle is recovered. The energy lost heats the dielectric. Usually when quoting the loss factor of an insulator, it is this loss that is being referred to. A more complete explanation is beyond the scope of this paper but there are many practical references on dielectric engineering.

Dielectric heating, in raising the temperature of the ceramic, increases the insulator’s vulnerability to thermal shock and resultant mechanical failure, and it also reduces the dielectric strength by increasing the mobility of the charge carriers. We seldom experience failure due solely to the heating effect in the dielectric unless it results in an excessive mechanical stress. What then is the principal cause of trouble? There is one failure mode which is likely to be predominant in any instance of egg insulator failure in a broadcast antenna system.

The interface between a conductor and a dielectric material, in this case the wire loop around the insulator, is a critical area. With the egg insulator under a compressive load between the loops, the wire is making intimate contact with some portion of the porcelain, but there is an adjoining area near the point of contact where there is a highly stressed region or air. Figure 5 illustrates this. As soon as this air is over–stressed, ionization occurs, a small arc develops, and highly destructive ozone and heat are produced. The insulator surface, at the point where the arc occurs, becomes very hot, and if the arc is allowed to continue, the glaze may melt and the insulator surface erode. A more likely occurrence is for the ceramic to crack quickly due to mechanical stress resulting from the heat of the arc. The arc will then work its way through the crack since air will enter and readily break down. The process continues until the insulator falls apart.

It must be emphasized that one can only speak in general terms unless one is discussing a specific instance of failure. The variations in the possible sequence of events is almost limitless, but some photographs (Slides 1–8) will help to visualize the usual failure mechanism.

We have heard that failures are less likely to occur if ‘Preformed’ loops are used rather than wrapping the guy cable around the egg. We have also been told that it is good practice to put a lead sheath between the cable and the insulator. A number of our informants imply that these techniques reduce the possibility of failure due to mechanical loading. We think, rather, that the effect is to reduce the likelihood of arcs forming and that any failures which may otherwise have occurred would have resulted from thermal stress as a result of arcing.

RADIO FREQUENCY TESTS

We selected an Austin AOA 20 for testing. This insulator is stated by the manufacturer to have a 16 KV dry 60 Hz flashover and a wet flashover of 8 KV. In our literature we quote the 8 KV wet flashover rating and recommend a maximum radio frequency working voltage of 1.5 KV RMS.

Slide 1.

This shows a portion of our radio frequency test assembly. It is simply an oscillator (partly hidden to the left of the slide) with a power output capability up to 5 KW and a peak radio frequency voltage output up to 120 KV. Testing can be carried out in the MF range with this equipment. To the right can be seen an insulated frame in which we have suspended under tension a string of 3 egg insulators. It is important when carrying out tests of this nature that the insulators are under at least a few hundred pounds compressive load in the guy loops to ensure good contact between the conductors and the ceramic.

Slide 2.

We first investigated the behaviour of one insulator under dry conditions. A few patches of blue discharge appeared at 8.5 KV as the voltage was being raised. This visible discharge was similar to that which will be seen on Slide 5.

As the voltage was raised further, the blue discharge became intense at 10 KV and after a few seconds an arc occurred which was initially over the surface of the porcelain at the top and between the wire loops. This is shown in Slide 2.

Slide 3.

After a minute or so a crack developed in the porcelain and the appearance of the arc changed from that shown in Slide 2. It will be noted in Slide 3 that the arc is not continuous over the top of the porcelain but is, in fact, passing through a crack.

Though voltages of 8 - 10 KV were involved in the initiation of the arc, once the arc was formed the voltage across the insulator dropped to about 3 KV and required a further reduction to extinguish it.

After a few minutes of operation with the arc present, the glaze melted under the arc and when the power was shut off the ceramic was white hot in the area where the arc occurred.

Slide 4.

This shows the insulator and the broken chip.

We then carried out wet tests. The water used was of much greater conductivity than used in standard wet tests and we did not attempt to simulate standard 60 Hz wet test conditions but merely used a hose to spray the insulator.

Slides 5 and 6.

With the insulator wet a visible discharge started at 7 KV. The discharge was at the bottom of the insulator, probably due to the concentration of water at that point. (Slide 5 has been inadvertently printed upside down).

Slide 7.

This slide shows the effect of further wetting and an increase in voltage to 8 KV. There is more evidence of visible discharge and an arc has formed.

Slide 8.

This test is of 3 eggs of the same type in a string with 18 KV across the string. The top insulator has arced over. The second insulator has arced over and there is also some partial discharge. The bottom insulator has not arced but there is some discharge, only visible as a small blue dot on the slide. The uneven voltage distribution across the string is apparent. In this case the uneven distribution results from having the lower end of the string only a short distance above a large diameter metal ground plane.

An investigation somewhat similar to ours was undertaken a few years ago by the Engineering Staff of the Canadian Broadcasting Corporation. (Reference 4). A frequency of 900 KHz was used and the behaviour of the egg insulator was reported as follows:

> "As the voltage is increased a point is reached where a corona discharge occurs from the cable wrapped around the insulator, generally near the centre of the loop. This corona arc wanders around over a small area of the loop for a short period, about 10 — 15 seconds, until it becomes concentrated in one spot and an arc to the porcelain is sustained. This arc is of very small diameter and shortly a spot will develop where the porcelain becomes white hot. After about two minutes of this the porcelain fractures."

The insulators tested were similar to the unit we selected for our test. Four sizes were tested and the RMS voltage under dry conditions required to establish an arc averaged 8 KV. Once the arc was established, it required a reduction in voltage to about 3 KV before the arc extinguished. One of the conclusions stated in the C.B.C. report is that insulators of the type tested have a maximum safe operating voltage of 3 KV regardless of the size, this being based on the voltage at which an arc, once established, will extinguish.

Though it is true that under dry conditions the tests we carried out and those carried out by the C.B.C. appear to establish 3 KV as being the arc extinction voltage for the insulators tested, there are many other factors to take into account. If an arc forms on the underside of some surface, it may be sustained at a lower voltage than if it is on an upper surface. An arc generates a lot of heat. If this heat is trapped and cannot rise, it will be more difficult to gut the arc extinguished. If the hot gases are free to rise, this tends to lengthen the arc and increase the extinction voltage. An arc is more readily extinguished under windy conditions than in still air because the arc can be literally blown away. Any mechanism which tends to increase an arc path length also increases the extinction voltage. Though voltages of 8 to 12 KV were required on indoor dry tests to establish an arc across on insulator a higher or lower voltage may start an arc on an aerial system outdoors. The presence of dirt, sharp projections on the cable, rain, et cetera, may initiate an arc at a relatively low voltage.

During our tests, we found that when we were getting a visible discharge which is the initial stage leading to an arc, it was only distinguishable at close range in a darkened room. This suggests that the chance of being able to observe this potentially dangerous situation on an antenna system by an observation made from the ground is practically zero. Even the small initial arcs which are incandescent gases and quite bright may still not be visible. It is only when the arc develops to a dangerous stage that it is likely to be visible from the ground.

It is interesting to conjecture on the power loss when an insulator is arcing. We do have some initial data and we hope to make some measurements under sufficiently controlled conditions to be able to quote loss figures with authority at a later date.

In the C.B.C. tests a 1 KW transmitter was used. Our test oscillator is a simple Hartley circuit and during the arc tests the power input to the transmitter was about 900 watts. We can assume we had about 500 to 600 watts available for an external load. The nature of our high voltage test circuit is such that it is inherently quite lossy and we estimate that only 300 to 400 watts of power was actually expended in the test piece. The concentration of heat in the arc is terrific when one thinks of the power involved and the fact that we know the temperature reached something above 1000 °C because it melted the glaze on the insulator. Porcelain does not conduct heat very well and it does not take kindly to mechanical stresses imposed by steep temperature gradients. It only takes a few minutes for the arc to crack the porcelain. Even if the insulator does not fall apart, the crack will be there. It will absorb moisture and from then on there will probably be electrical breakdowns.

CONCLUSIONS

This paper does not fully cover the subject of insulator failure. Any conclusions drawn should be more in the nature of guide lines than dogmatic statements. The following are a few of our thoughts:

1. Due to the geometry of an egg insulator and the common method of making attachments to it, the only way to reduce the hazard of an electrical failure is to keep the operating voltage at a low level,

   less than 5 KV per egg. Since in a long string it is likely that about forty per cent of the total voltage will appear across one insulator, this would limit the maximum operating voltage of any string of eggs to 12 KV. A safer figure for a string would be 7 KV based on a likely 3 KV maximum across the insulator carrying the highest stress.

2. The only advantage in increasing the number of eggs in a string beyond four is likely to result from an increase in surface leakage path which could be advantageous in wet weather or in a contaminated environment.

3. If an egg insulator appears to have broken in service, it is not safe to assume that it was faulty or over–stressed mechanically. The failure may have occurred as a result of electrical stress.

4. If an egg is being replaced in the guy loops, examine the cable carefully for signs of pitting or other roughness. If this is not remedied the replacement insulator may also fail in a short time.

5. Electrical failure of an egg insulator is not necessarily associated with high power. A few hundred watts is all that is needed.

REFERENCES

(1) W. W. Brown - Radio Frequency Tests on Antenna Insulators — Proceedings of the Institute of Radio Engineers, Volume II, 1923.

(2) General Electric Company - Unpublished report, High Voltage Laboratory 1969.

(3) Dr. Andrew Blanck — Principles of Dielectric Engineering, Electro—Technology, June 1967.

(4) J. K. MacDonald - Report No. 7:24:92, September 1967 — C.B.C. Engineering Headquarters, Montreal.

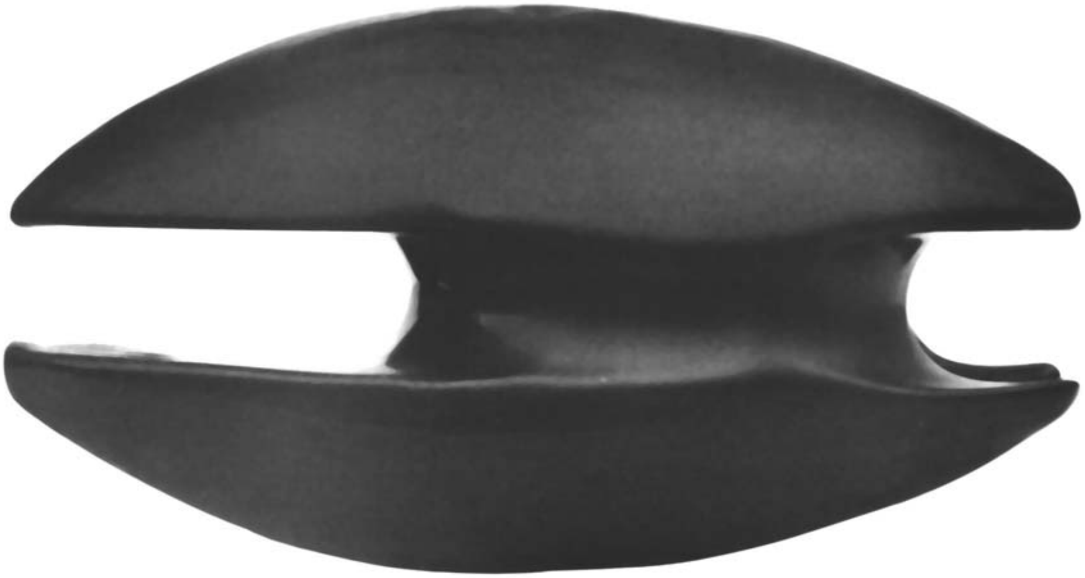


Figure 1

Figure 2

COMPARISON OF SIMILAR "EGG" OPEN END GUY INSULATORS

Supplier or Manufacturer	TYPE NUMBER	50/60 Hz Dry Flashover K.V.	50/60 Hz Wet Flashover K.V.	Recommended Maximum RF Working Voltage K.V. RMS	Manufacturer's Comments
Canadian Porcelain	23004	21	10.5	-	Nominal voltage rating given as 0.6 K.V. Said suitable for radio tower guys. See Note 1.
Locke (year 1955)	24369	21	10.5	-	Not recommended for use as primary insulation at Radio Frequency
Austin	AOA42	-	10.5	2.5	Not recommended for primary insulation next to the radiator
Bullers	12446	35	-	-	Listed under Radio Aerial Insulators
Rosenthal (Stemag)	60051	-	18 Note 2	-	R.F. flashover quoted as 13 K.V.

Note 1. The o.6 K.V. refers to the voltage of the 60 Hz power transmission system on which its use is recommended.

Note 2. The European and North American Standard Wet Tests differ in conductivity and rate of flow of water used.

FIGURE 3

SUMMARY OF 60 Hz TESTS ON EGG TYPE INSULATORS

CONDITIONS OF TEST	NUMBER OF UNITS IN THE STRING	MEAN FLASHOVER VOLTAGE K.V.	CORONA INCEPTION
Dry (Vertical String)	1	59	14
	2	109	-
	4	151	-
Wet (Vertical String)	1	28	-
	2	59	-
	4	116	-
Wet (60^{o} to the Vertical)	1	34	-
Contaminated (Heavy salt solution)	1	14	-
	2	22	-
	4	44	-

FIGURE 4.

CORONA DISCHARGE PRODUCES HIGH FIELD STRESS IN SOLID DIELECTRIC AND EVENTUALLY CAUSES FAILURE.

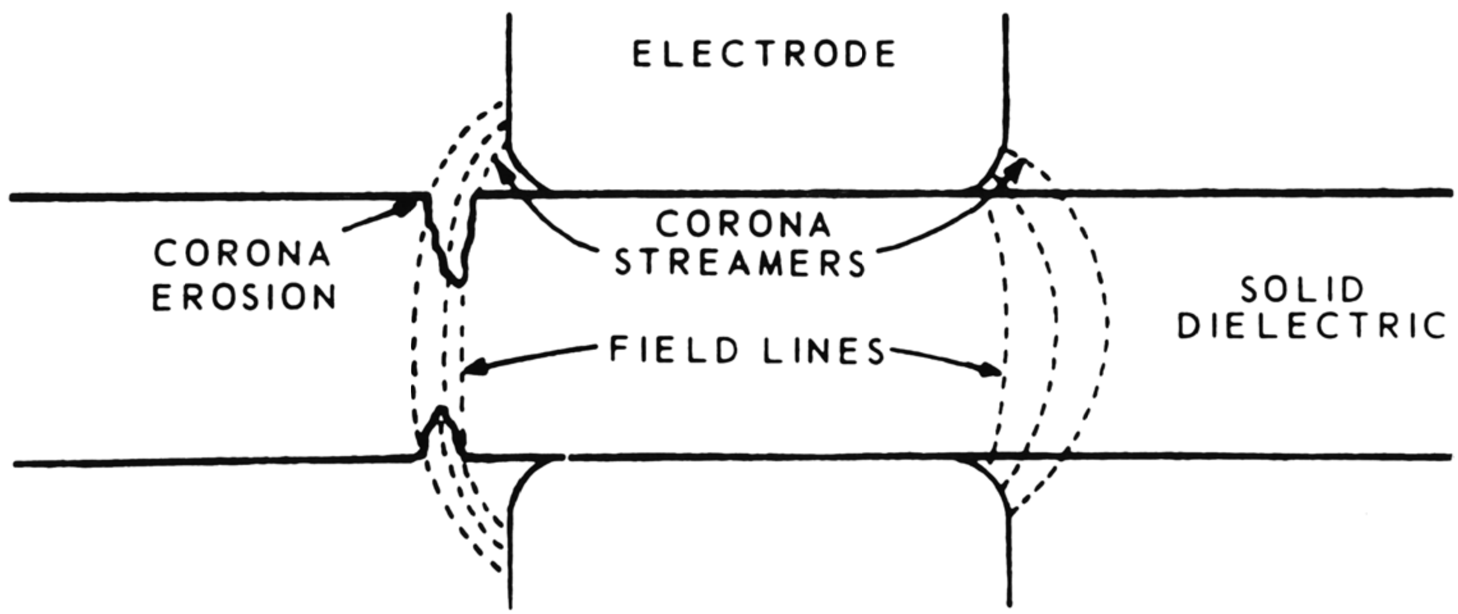
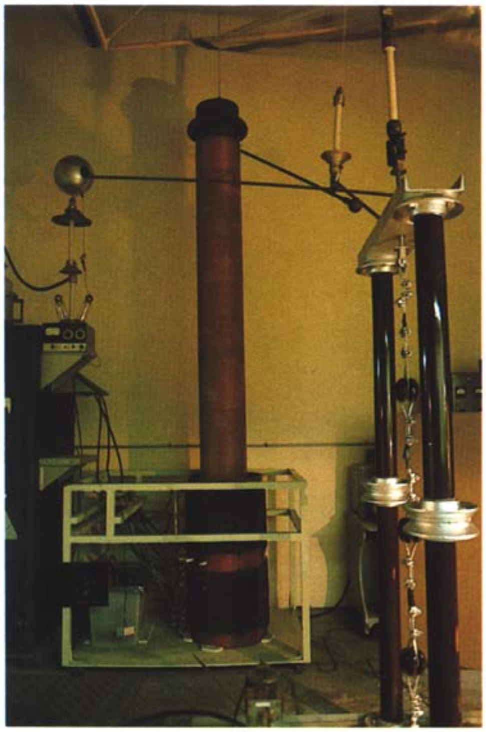


Figure 5



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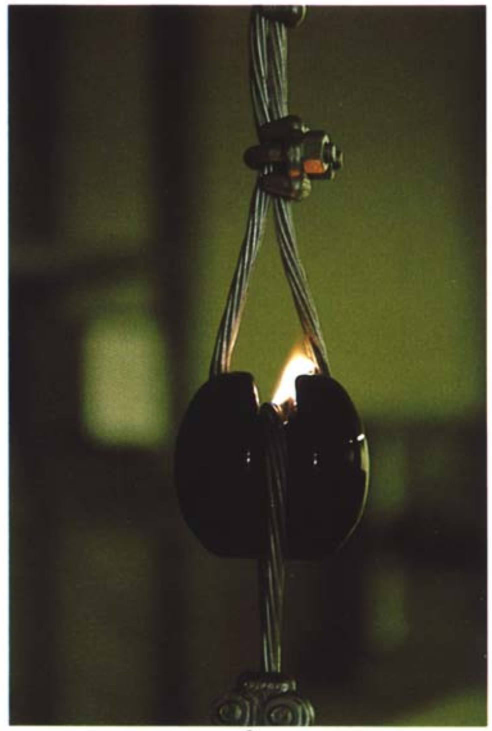

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3

4

SLIDES A

5

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SLIDES B