CLM - R 155

CLM - R 155

UKAEA RESEARCH GROUP

Report

RADIO FREQUENCY SPECTRUM ANALYSIS AS A METHOD FOR INVESTIGATING ELECTROSTATIC SPARKS IN HOSTILE ENVIRONMENTS

G J BUTTERWORTH

CULHAM LABORATORY
Abingdon Oxfordshire

1976

Available from H. M. Stationery Office

50p.

UDC:
537.2:614.83

CLM-R 155

RADIO FREQUENCY SPECTRUM ANALYSIS AS A METHOD FOR INVESTIGATING ELECTROSTATIC SPARKS IN HOSTILE ENVIRONMENTS

G J Butterworth

UKAEA Research Group
Culham Laboratory
Abingdon, Oxon, OX14 3DB, UK

December 1975

SBN: 85311 042 5

1. INTRODUCTION

It is already well established that the occurrence of electrostatic sparks, even of very low energy, can be detected through the radio frequency emission they produce[1,2]. This fact has formed the basis of practical radio monitoring of sparks in a number of previous shipboard investigations[3]. It might be expected, however, that the RF radiation would carry some information about the spark event itself. For instance, the time development of the discharge current depends on such factors as the nature of the electrode surfaces, the breakdown potential and the geometry of the bodies involved. The time scale of the discharge is important because it determines, through the Fourier components of the current pulse, the frequency spectrum of the radiation from the spark. Experiments with a current probe show that with metal electrodes and low breakdown voltages, of order 1 kV, the rise time of the current pulse is below 2 nanoseconds, which would imply the presence of frequencies well above 1 GHz. At higher breakdown voltages the timescale of the pulse increases and so more energy will appear at lower frequencies. Observations on the way in which the radiated energy diminishes at the high frequency end of the RF spectrum might thus offer the possibility of inferring the breakdown potential of the discharge. Since electromagnetic coupling exists between the discharge channel and the bodies associated with a spark it might also be anticipated that the geometry of these bodies, acting as radiating antennae, will modify the spectrum of the radio waves generated so that in this way it might be possible to gain information about the bodies involved.

With these considerations in mind we have conducted some basic studies to test the potential value of frequency spectrum analysis as a diagnostic tool for the investigation of discharges in inaccessible situations. In the case of oil tankers the chief ignition hazards are believed to arise when bodies such as slugs of brine produced by the tank washing operation acquire an electric charge by induction in the strong ambient field and discharge either at a projection into the tank space or at the tank wall(3,4). In these studies we have tried to simulate some of the circumstances that seemed relevant to the tanker situation, but with the following differences. Firstly, the present tests were conducted with sparks between clean metallic surfaces, rather than brine-metal or brine-brine surfaces, for two main reasons: (a) it is difficult experimentally to obtain discharges from liquid surfaces with the necessary degree of repeatability; and (b) there is evidence to support the view, and we hope to confirm this later, that if a charged brine body approaches the surface to which it discharges with even a modest speed there is insufficient time for the liquid surface to distort, and a discharge of metal-metal character results. Secondly, the radio experiments described here were carried out in a reflection-free environment rather than in a conducting enclosure that would more closely resemble a ship's cargo tank. Some experiments have also been performed in an old aircraft hangar, which has a volume comparable to a cargo tank, but these are not yet complete. The presence of a conducting enclosure will undoubtedly modify some of the results obtained outdoors, though present indications are that the effect is not great. Outdoor experiments are in any case an indispensible aid in elucidating the mechanism of radio wave generation by sparks.

2. EXPERIMENTAL ARRANGEMENT

The tests were performed over a metal ground plane made up of well-bonded aluminium alloy sheets and measuring about 11 x 4 m. As indicated in Fig.1 a short monopole antenna (125 mm long, 12.5 mm diameter) was set up near one end of the plane,

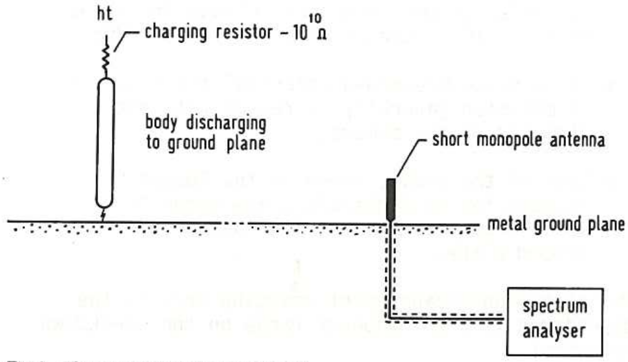

Fig.1 The experimental arrangement.

while the spark source was placed near the other end, the range being either 6 or 8 m. Provided such a monopole is electrically short (<< λ/4 at the highest frequency) its response is relatively insensitive to frequency. If it is too short the received signal becomes swamped in noise, therefore a compromise is necessary. As it seemed probable that attempts at frequency analysis in practical situations would be limited to frequencies below 500 MHz, the antenna length was chosen so that the quarter wave resonance occurred at 600 MHz. The signal from the antenna is taken via a short length of high quality coaxial cable to a spectrum analyser (Tektronix 7L12, range 1.8 GHz) placed, with its operator, in a hole below ground level.

Likely circumstances leading to sparks in the tanker situation are of two kinds: charged bodies of brine discharge in one case at large plane surfaces and in the other case they discharge to projections such as girders, washing machine supports, walkways, etc. To simulate these situations we have investigated the radio spectra originating in discharges from metal spheres and cylinders (simulating slugs of brine) to the ground plane and in discharges from a metal sphere to vertical grounded conductors of representative geometries. These experiments were as follows:

A. Radiation from bodies discharging to ground plane

   (a) metal spheres of various sizes;

   (b) cylindrical bodies normal to ground plane; bodies of various conductivities.

B. Radiation from grounded projections excited by spark discharge

(a) vertical pole of variable length spark-excited at a variable point along its length;

(b) sheet like structure with I section, excited at top.

3. EXPERIMENTAL RESULTS

A(a) Spheres discharging to ground plane

Measurements were made with spheres of diameter 25, 50, 125 mm at range 6 m and breakdown voltages 2.5-15 kV. The general features of spectra from discharging spheres, a few of which are shown in Fig.2, may be summarised as follows:

- The structure is quite complex with no obvious relationship between spectral peaks and the size of the sphere.
- The frequency range is very wide, with components up to at least 2 GHz at low breakdown voltages.
- The high frequency end is progressively curtailed as the breakdown voltage increases (e.g. at 15 kV the range is only to 500 MHz).
- For a given breakdown potential the intensity of emission generally increases with the diameter of the sphere.
- Some of the peaks, those at the lowest frequencies in particular, are known to arise from resonant oscillations in the ground plane.

The most significant point emerging here is the dependence of the frequency range on the breakdown potential.

A(b) Long bodies discharging to ground plane

(i) Copper rod of variable length

A copper rod of diameter 13 mm and variable length was supported vertically above the ground plane. Its lower end, where the sparks occurred, was of hemispherical shape. Runs were made at breakdown potentials of 3.7, 5.6, 7.0, 8.9 kV and a range of 6 m. A series of spectra with 3.7 kV and different lengths of rod is shown in Fig.3 and illustrates the effect of the cylinder length. The salient features of these spectra are as follows:

- The spectra are fairly complex but less so than those for radiating spheres (peaks from spurious resonances, such as those of the ground plane, will still be present).
- Prominent peaks are identifiable, and these are related to the length ℓ of the body by $\ell = \frac{n\lambda}{4}$, n being an odd integer. This offers a prospect of deducing the length of the discharging body from spectral observations.
- As with spheres, the extent of the spectrum at high frequencies depends on the breakdown potential.

The evidence so far confirms the view that the form of a radiation spectrum is determined essentially by the response of the body to the transient discharge current, frequencies present in the Fourier components of I(t) being radiated with an efficiency depending on how closely they match the antenna conditions for the body in question.

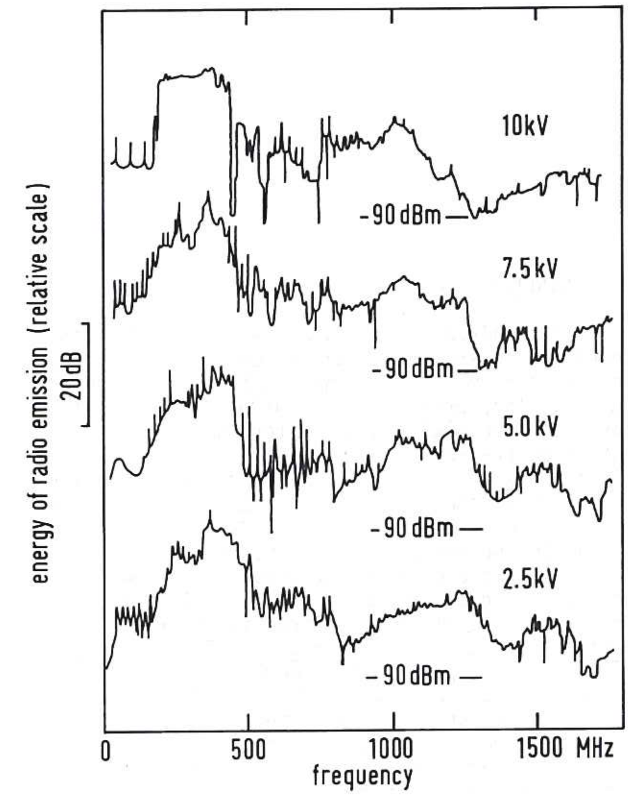

Fig.2 Spectra of radio emission from metal sphere of diameter 125 mm discharging to ground plane with various breakdown potentials.

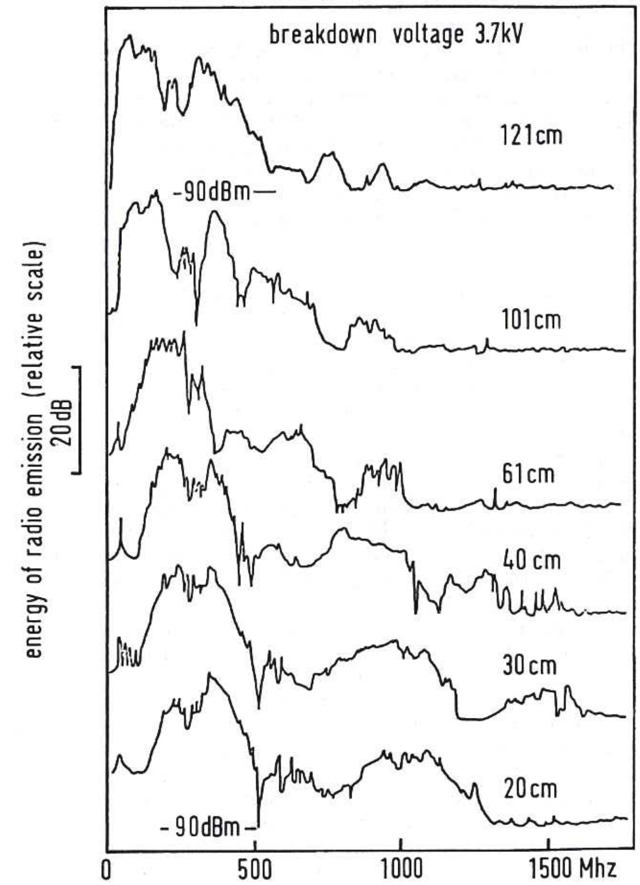

Fig.3 Radio spectra from a copper rod of diameter 13 mm and variable length discharging to ground plane at breakdown voltage 3.7 kV.

(ii) Brine column contained in glass tube

In order to see what difference in radiation properties there might be between a metallic body and a brine body of like geometry some experiments were made using a brine-filled glass tube having a hemispherical copper end cap. With 0.1 molar NaCl solution the radiation was found to emanate almost entirely from the copper cap alone, showing that brine of this concentration does not form an effective conductor at high frequencies. When 2M solution is used, however, spectra more nearly characteristic of the long metal body are observed. These differences are believed to be due to variations of the conductivity with concentration and frequency caused by relaxation effects in the ionic medium. Since sea water has a molarity around 0.6 it seems clear that such effects would strongly influence the properties of sea water bodies as sources of radio emission. Further experiments to clarify this question are planned.

B(a) Radiation from pole excited by spark

The spectra given as examples here (Figs 4,5) were taken using aluminium poles of diam. 50 mm and lengths 3.5 and 6.2 m, placed vertically on the ground plane at range 8 m. The spark occurred between the pole and a 50 mm copper sphere placed at various positions and charged through a decoupling lead having resistance $\sim 10^{10}\ \Omega$.

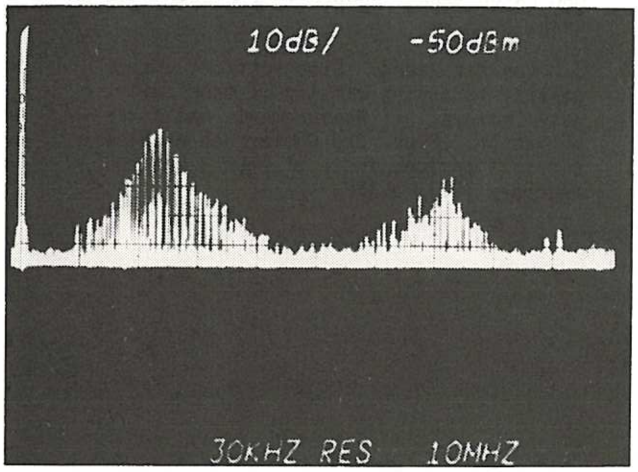

Fig.4 Spectrum of radio emission from a vertical grounded pole of length 3.5m excited at the top by 15kV sparks from a 50mm metal sphere.

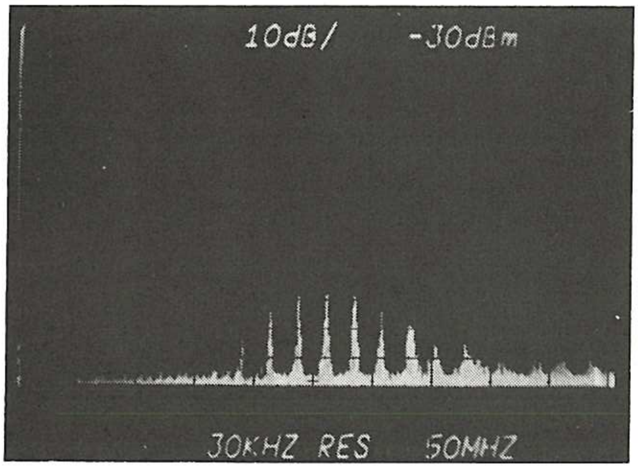

Fig.5 Spectrum of radio emission from a vertical grounded pole of length 6.2m excited 20cm above the base by 7.5kV sparks from a 50mm metal sphere.

(i) Pole excited near the top

The spectra (Fig.4) show the following features:

- The spectra consist of discrete lines having a constant separation determined by the length of the conductor.

- The principal mode of oscillation is one in which odd multiples of quarter wavelengths coincide with the electrical length of the pole;

$$\ell = \frac{n\lambda}{4} \qquad n = 1, 3, 5, \ldots$$

though a weaker oscillation in the half wave mode such that

$$\ell = \frac{m\lambda}{2} \qquad m = 1, 2, 3, \ldots$$

occurs simultaneously under suitable conditions.

- The extent of the spectrum depends on the breakdown voltage, the greatest number of lines appearing at low voltage.

- Practically all the radiation emanates from the excited conductor, rather than from the discharging body.

(ii) Pole excited near the bottom

With the spark excitation further down the pole the relative strengths of the quarter wave and half wave oscillation modes vary and an increasing proportion of energy is radiated at higher frequencies. Figure 5 shows the result of excitation 20 cm above the base of the pole. For this case the spectra have the following properties:

- The spectra consist of a fairly small number of sharp lines having uniform spacing.

- Few lines appear below 150 MHz and the amplitudes follow a smooth Gaussian-like envelope peaking near 250 MHz and extending in the case of low breakdown potentials to about 500 MHz.

- When the pole is long only relatively low frequencies are excited and the form of the spectrum is insensitive to breakdown voltage.

- The maximum of the envelope corresponds to the frequency at which the distance from base to excitation point is $\lambda/4$ approximately.

- The well defined peaks occur within the envelope as different numbers of half wavelengths fit into the upper part of the pole.

In the case of sparks to long projections (e.g. the washing machine support in an oil tanker) the direct relationship between the frequencies appearing and the dimension of the projection might in prospect provide a means of locating individual sparks.

B(b) Sheet structure

In order to simulate a two dimensional structure such as might approximate to a tank stiffening girder having an I section, a sheet of aluminium 1 m x 2 m with angle pieces at top and bottom edges was placed vertically on the ground plane. Sparks were produced from a 50 mm sphere at the middle of the upper edge and measurements at 6 m range were made in both end-on and normal orientations to the receiving aerial.

The spectra exhibit the following features:

- The spectra are continuous and show a limited number of broad peaks consonant with a principal excitation of the quarter wave modes of a vertical conductor.

- At low breakdown voltages the greatest energy appears in the third peak (for this structure) but as the voltage is increased a larger proportion goes to the lower frequencies.

- When the sheet is oriented in the plane of the receiving aerial the spectra are rather less distinct, though it is still possible to recognise the quarter wave resonance frequencies.

The observed features agree with expectation. Since the sheet can be considered as an array of parallel vertical wires the resonant frequencies for excitation at the top edge should be close to those for a thin conductor having the same height. The impedance bandwidth of a sheet radiator, however, should be considerably wider than that of a linear radiator and the spectral peaks of the sheet radiator should therefore be much broader than those of a cylindrical projection of equal height.

4. CONCLUSION

The present studies suggest that radio frequency spectrum analysis could in principle provide a valuable technique for investigating electrostatic discharges in hostile environments. Using characteristic features of the radio spectra, such as the location and sometimes the amplitude of resonance peaks as well as the way in which the radiated energy diminishes at high frequencies it should be possible to obtain information about the dimensions of bodies involved in the discharge and their sparking potential. Such information would assist in locating the sources of potentially incendive sparks in a tank and thus indicate any particular features of either the washing operation or the tank structure that may be conducive to the production of these sparks.

The experiments described here were performed under idealised conditions, and it is clearly necessary to test the frequency analysis technique under practical conditions. Some equipment for frequency analysis in oil tankers has already been developed and observations on board ship will be made shortly.

References

1. J N Chubb, S K Erents, I E Pollard. Radio detection of low energy electrostatic sparks. Nature 245 (No.5422), September 1973, p.206.

2. J N Chubb. Radio signals from low energy electrostatic sparks. Paper presented at IEE Conference on Gas Discharges, London 9-12 September 1974. IEE Conference Publication 118.

3. J N Chubb. Practical and computer assessments of ignition hazards during tank washing and during wave action in part ballasted OBO cargo tanks. Journal of Electrostatics 1, 1975, p.61.

4. J M van der Weerd. Electrostatic charge generation during washing of tanks with water sprays. II Measurements and interpretation. Proc. 3rd Conference on Static Electrification, Inst. of Phys., London, February 1971, p.158.

HER MAJESTY'S STATIONERY OFFICE

Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government publications are also available through booksellers