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# EFFECT OF TEMPERATURE ON CONDUCTOR CONCENTRICITY IN A BENT RG-18/U CO-AXIAL CABLE UNDER UNIFORM VIBRATION

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

A series of ten tests was performed on short lengths of RG-18/U cable, bent through 90 degrees, with radius of approximately 6 in. The cable was fixed at one end and vibrated laterally through ± 0.2 in. at the free end in the plane of the bend, at temperatures ranging from 200 to 300°F. Adopting 20% or more shift from concentricity of the inner conductor in less than 1000 hours as the failure criterion, the critical temperature was found to be 220°F.

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(1 table, 8 illus.)

## INTRODUCTION

In a letter, file No. NSC 7401-500-7 (EEC), dated 25 October 1956, from the Naval Secretary, Department of National Defence, Ottawa, Ontario, the Physical Metallurgy Division of the Mines Branch was requested to carry out a series of tests on RG-18/U co-axial cable to determine the effect of temperature on conductor concentricity. Failure of cables in service, due to extreme eccentricity of the conductors, occurring at a bend in the cable where it was clamped to a mast near the funnel, prompted the request for the tests.

During subsequent discussion it was suggested that the tests be made on cable with a 90° bend, while it was subjected to vibration of constant amplitude and frequency in the plane of bending. This test procedure was decided upon as a reasonable approximation of service conditions. It was agreed that a 20% radial shift in the position of the inner conductor would constitute failure.

## METHOD OF TEST

The only furnace available for the investigation would accommodate a cable length of not more than about 20 in. Since it was deemed desirable to simulate the constraining effect of a long cable (50 or more feet) on the axial movement of the inner conductor at the bend, it was necessary to fix the inner conductor securely to both the dielectric and outer conductor at each end of the short length. This was first attempted by drilling diametrically through the armour, jacket, outer conductor, dielectric, and inner conductor, and fixing the ends with taper pins. Since it was planned to measure, if possible, changes in capacity during progress of the tests, it was necessary to insulate the pins from the outer conductor and armour with an epoxy resin. The method proved to be unsatisfactory, however, because of excessive softening of the dielectric at the higher temperatures, and consequent axial movement of the inner conductor. The ends were finally fixed satisfactorily by exposing an inch or two of the inner conductor at either end, and capping the entire ends in epoxy resin as shown in the photograph, Figure 1. (The end caps can also be seen in Figure 4.) The ends were fixed with the cable length straight, in order to simulate the stresses imposed at a bend in a long cable. The cable was then clamped, near one end, to a brass framework built to fit inside the furnace, and bent through $90^{o}$, with an inside radius of approximately 6 in. A pivoted connecting rod, driven by an eccentric, was clamped near the free end. The eccentric was adjusted to vibrate the "free" end of the cable in the vertical direction through $\pm$ 0.20 in. at a frequency of 300 $\pm$ 50 cpm. The furnace temperature was maintained within about $\pm$ 4 $F^{o}$. The general arrangement of the apparatus is shown in Figure 1, a photograph taken at the end of a test.

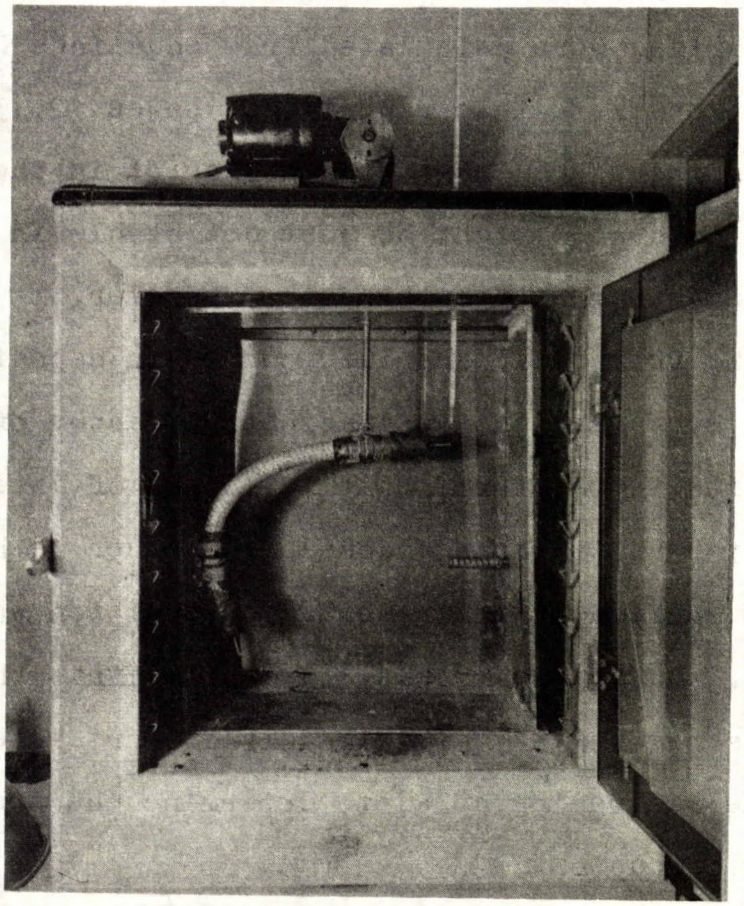

**Fig. 1** - Photo of furnace and test cable after a test.

An attempt was made to monitor any shift in the inner core during the tests, by means of a continuous measurement of capacity between the inner and outer conductors. The capacities of the test cable and leads to a capacitance bridge were calculated from equations (b) and (d) of the appendix to this report (see pages 12,13) and it appeared from these results that a 20% shift in the position of the inner conductor might be just detectable in the capacitance measurement. In practice, however, it was found that the very small absolute change in capacitance was obscured by variations in dissipation factor of the dielectric with temperature, so this method of determining inner conductor shift was abandoned. No other methods of continuously monitoring inner conductor position were investigated. During each test, the entire frame holding the cable was removed at approximately 100 hr intervals, and the cable was radiographed to determine the position of the inner conductor.

The films were examined, and any shift of more than 20%, in the position of the inner conductor at the bend, was considered as failure. Tests were discontinued if no failure was observed after approximately 1000 hours.

RESULTS OF TESTS

Assuming the dielectric constant ($K_e = \frac{\varepsilon}{\varepsilon_o}$) of polyethylene to be 2.25 and the permittivity of free space $\varepsilon_o$ to be $8.85 \times 10^{-12}$ farads/m, then $\varepsilon = 19.93 \times 10^{-12}$ farads/m. Substituting this value, and using a cable length of 0.42 m in the capacity formula (Equation (b), Appendix), the capacity of the No. 2 specimen is 42 μμf before test.

The capacity after test was determined to be 48.5 μμf, from Fig. 8, which is a plot of capacity per metre against distance along the cable. The capacity per metre was determined from measurements of inner conductor shift (D) on the radiograph (Fig. 3). The capacity of the test leads, computed from equation (d) was 27.4 μμf; hence the total capacity changed from 69.4 to 75.9 μμf. The measured change, using a Heathkit Capacity Meter, which had been checked against a G. R. Impedance Bridge, was from 66 to 69 μμfd. The dissipation factor, measured on the G.R. bridge, varied between 0.0014 and 0.0052, depending on temperature, with no inner conductor shift. Although an inner conductor shift of the magnitude, shown in Fig. 3, was readily detected by capacity measurement, it may be computed that for a small shift, for example 20% shift over a length of 5 cm, the increase in capacity is only 0.66 μμf, which could not be detected with certainty, considering the change in dissipation factor.

Results of measurements of inner conductor shift, made on radiographs, are given in Table 1. Figures 2, 3, 4 and 5 are prints from typical radiographs, arranged in order of increasing temperatures, each having been taken at the end of a test. The first radiograph taken after commencement of a test showed that the curvature at the bend, which was initially uniform, increased noticeably near the fixed clamps and decreased farther out. Further, the fixed clamps deformed the outer conductor. This was probably due to softening of the dielectric with increased temperature, since the effect was not observed on radiographs taken after the cable had been clamped for 65 hours at room temperature. No action was taken to alleviate these conditions, since it was felt that similar conditions would occur in service.

TABLE 1

Results of Tests

| Temp. (°F) | Inner Conductor Shift | Running Time (hr ) | Test No. | Cable |
|---|---|---|---|---|
| 200 | 0 | 623 | 1 | A |
| 210 | 0 | 1004 | 3 | C |
| 215 | 0 | 998 | 4 | C |
| 220 | 80% | 173 | 2 | B |
| 220 | 0 | 1004 | 5 | C |
| 220 | 0 | 1030 | 8 | E |
| 225 | 20% | 248 | 7 | D |
| 225 | 30% | 120 | 9 | E |
| 230 | 70% | 99 | 6 | C |
| 300 | 90% | 29 | 10 | A |

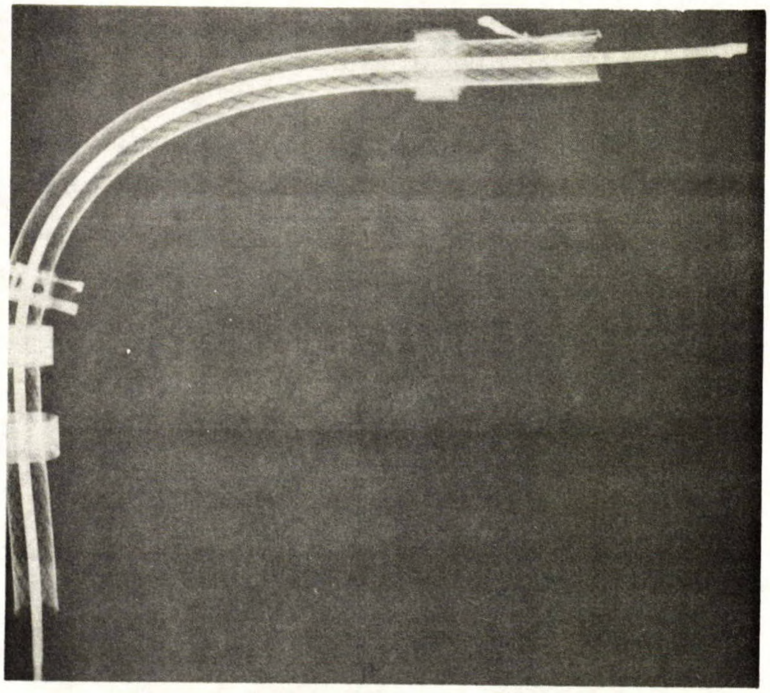

Fig. 2 - Radiograph, Test 3; 1004 hr at 210°F.

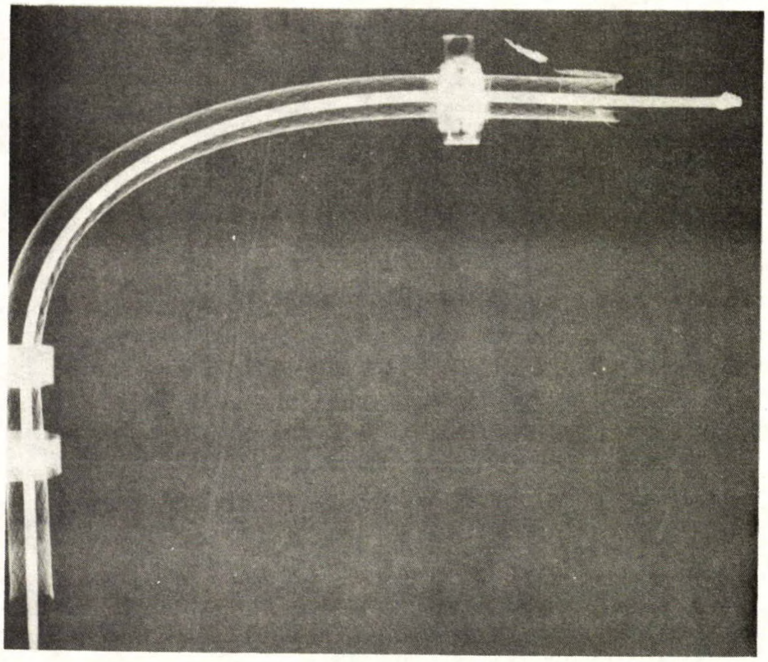

Fig. 3 - Radiograph, Test 2; 173 hr at 220°F.

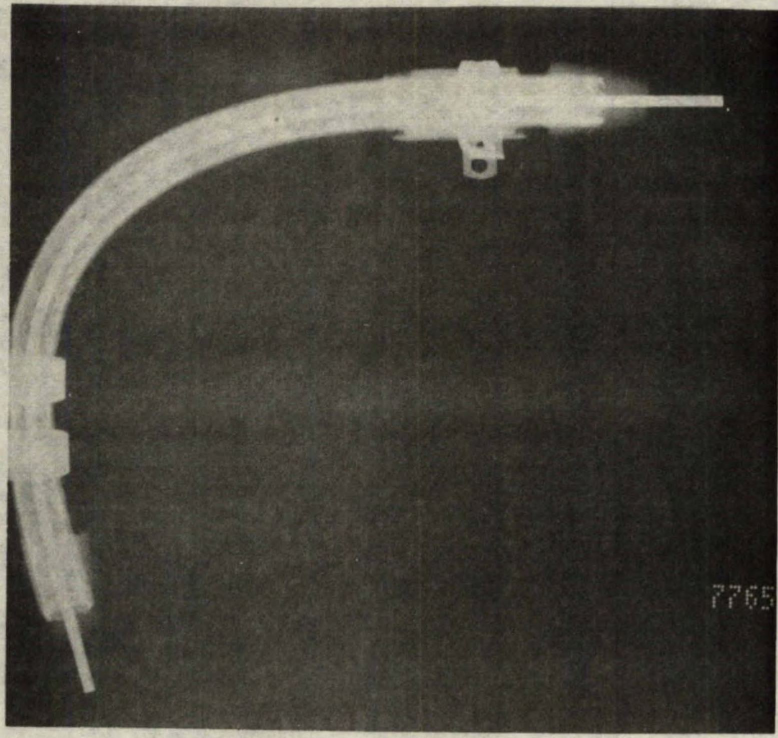


**Fig. 4** - Radiograph, Test 8; 1030 hr at 220°F.

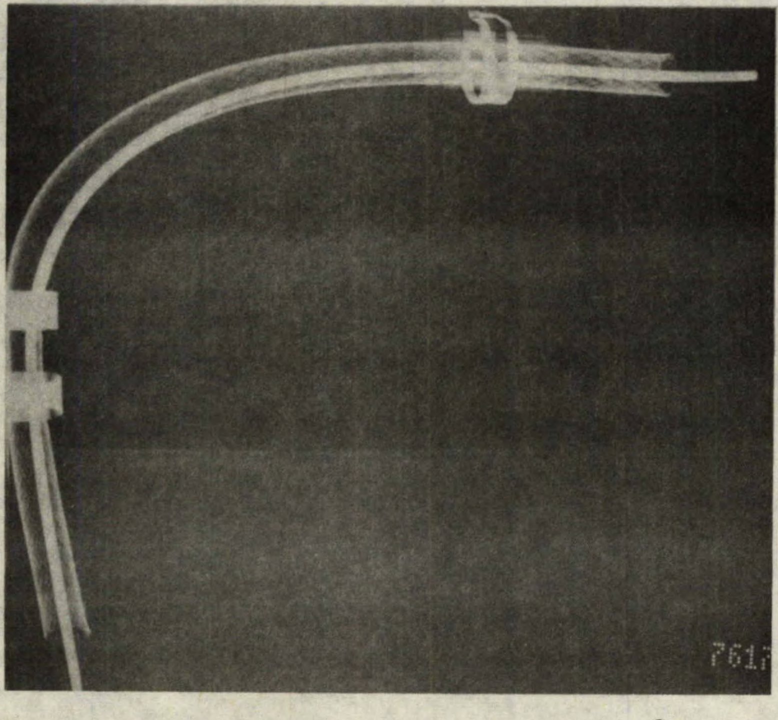

**Fig. 5** - Radiograph, Test 7; 505 hr at 225°F.

## DISCUSSION OF RESULTS

It appears, from Table 1, that a sudden drop occurs in mechanical properties of the dielectric at approximately 220$^{\circ}$F. At this temperature, three tests were made: tests 2 and 8 with new cables, and test 5 with a cable that had previously run 2000 hours at lower temperatures. Tests 7 and 9, at 225$^{\circ}$F, were also made with new and previously tested cables, respectively. Test 7 was continued after failure, and showed 100% inner conductor shift after 505 hours (Fig 5). Test 2 appears to have given anomalous results, but this is probably due to statistical variation in the critical temperature, which is taken to be nominally 220$^{\circ}$F. During all tests, temperatures were observed at 24 hr intervals, with more frequent observations during the initial 6 hrs. On a few occasions, temperatures were observed to vary by $\pm$ 4 F$^{\circ}$ from nominal, but in general they were maintained within $\pm$ 2 F$^{\circ}$. Thus, although facilities were not available for continuously recording temperatures, it is considered unlikely that the short life of test 2 would be due to loss of temperature control.

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(An appendix follows,
(on pages 10 to 15.)

# A P P E N D I X

## Capacitance Calculations for Co-axial Cable

Although this appendix, and the discussion above on capacity measurement, are not pertinent to the test results, they have been included in this report at the request of the office of the Electrical Engineer-in-Chief, Naval Technical Services, D.N.D., Ottawa.

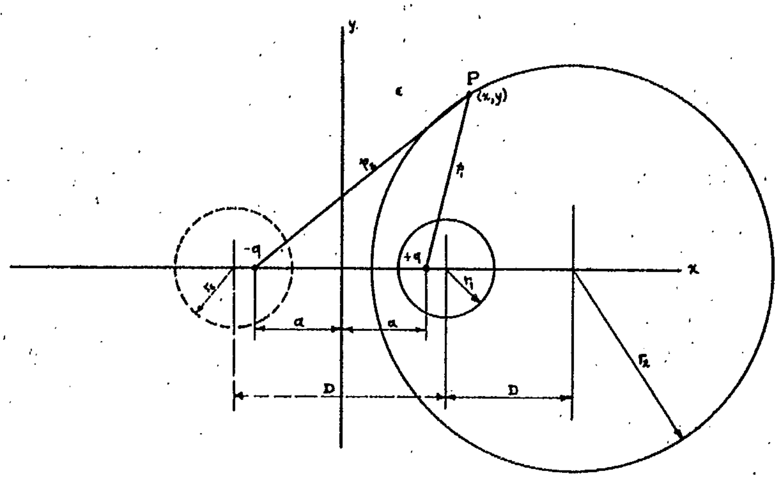



Fig. 6

Referring to Figure 6, assume two line charges of +q and -q coulombs/m at $x = \pm a$, $y = 0$. Then the potential at any point P(x,y) is

$$V_p = -\frac{1}{2\pi\varepsilon} \sum_{1}^{n} q_i \ln p_i = \frac{q}{2\pi\varepsilon} \ln \frac{p_2}{p_1}$$

For the locus of P to be an equipotential, i.e. $V_p$ = const.,

$$\ln \frac{p_2}{p_1} = \frac{2\pi\varepsilon}{q} V_p = C, \text{ where } C \text{ is a constant}$$

$$\therefore \frac{(p_2)^2}{(p_1)} = \frac{(x + a)^2 + y^2}{(x - a)^2 + y^2} = e^{2C}$$

$$\therefore (x + ak)^2 + y^2 = a^2(k^2 - 1)$$

$$\text{where } k = \frac{1 + e^{2C}}{1 - e^{2C}} = -\coth C.$$

Hence the locus of P is a cylinder of radius

$$r = \pm a\sqrt{k^2 - 1} = \pm a \operatorname{csch} C$$

with centre at $x = -ak = a \coth C$

$y = 0$

On any equipotential cylinder, $\nabla^2 V = 0$, and hence the cylinder can be made conducting without affecting the field. The cylinder then carries $\pm q$ coulombs/m and can therefore be connected to the nearest line charge. In the case of two cylinders on the same side of the y axis, the cylinders could be the conductors of a co-axial cable, truly co-axial when $D = 0$. For one cylinder on either side of the y axis, they form a parallel line.

I. <u>Co-axial Cable</u>

$$\text{(a)} \quad \begin{cases} D = x_2 - x_1 = \pm(a \coth C_2 - a \coth C_1) \\ r_1 = \pm\, a \operatorname{csch} C_1 \\ r_2 = \pm\, a \operatorname{csch} C_2 \end{cases}$$

Note that the + signs must be used when both cylinders are on the +x side of the y axis, and vice versa. Hence, if $r_2 > r_1$, $|V_{p_2}| < |V_{p_1}|$, $\therefore |C_2| < |C_1|$, and $\therefore |\coth C_2| > |\coth C_1|$, so that D, $r_1$, $r_2$ will always be positive.

From equations (a), $\pm(r_2 \cosh C_2 - r_1 \cosh C_1) = D$

$$\pm(r_1 \sinh C_1 - r_2 \sinh C_2) = 0$$

Squaring and subtracting:

$$r_1^2 + r_2^2 - 2r_1 r_2 \cosh(C_2 - C_1) = D^2$$

$$\therefore \quad C_2 - C_1 = \cosh^{-1} \frac{D^2 - r_1^2 - r_2^2}{-2r_1 r_2}$$

The capacity per unit length between cylinders is $\dfrac{q}{V_{p_2} - V_{p_1}}$, but $V_p = \dfrac{q}{2\pi\varepsilon}\, C$, $\therefore$ the capacity per unit length is

$$\frac{2\pi\varepsilon}{C_2 - C_1} = \frac{2\pi\varepsilon}{\cosh^{-1} \dfrac{D^2 - r_1^2 - r_2^2}{-2r_1 r_2}} \quad ..(b)$$

in the units of $\varepsilon$, which is expressed as farads/m in the rationalized MKS system, used here.

Equation (b) is plotted in Fig. 7, where $r_1$, $r_2$ are nominal values for RG-18/U, and D is in inches.

For truly co-axial conductors, D = 0, and

$$\cosh^{-1} \frac{r_1^2 + r_2^2}{2r_1r_2} = \ln \frac{r_2}{r_1} .$$

II. Parallel Lines

$$(c)\begin{cases} D = x_1 - x_2 = a \coth C_1 - a \coth C_2 \\ r_1 = + a \operatorname{csch} C_1 \\ r_2 = - a \operatorname{csch} C_2 \end{cases}$$

assuming $x_2$ is negative. Hence $C_2$ is negative, and again D, $r_1$, $r_2$ are always positive.

From equations (c),

$$r_1 \cosh C_1 + r_2 \cosh C_2 = D$$

$$r_1 \sinh C_1 + r_2 \sinh C_2 = 0$$

Squaring and subtracting:

$$r_1^2 + r_2^2 + 2r_1r_2 \cosh (C_2 - C_1) = D^2$$

$$\therefore C_2 - C_1 = \cosh^{-1} \frac{D^2 - r_1^2 - r_2^2}{2r_1r_2}$$

$\therefore$ the capacity per unit length is:

$$\frac{2\pi\varepsilon}{\cosh^{-1} \dfrac{D^2 - r_1^2 - r_2^2}{2r_1r_2}}$$

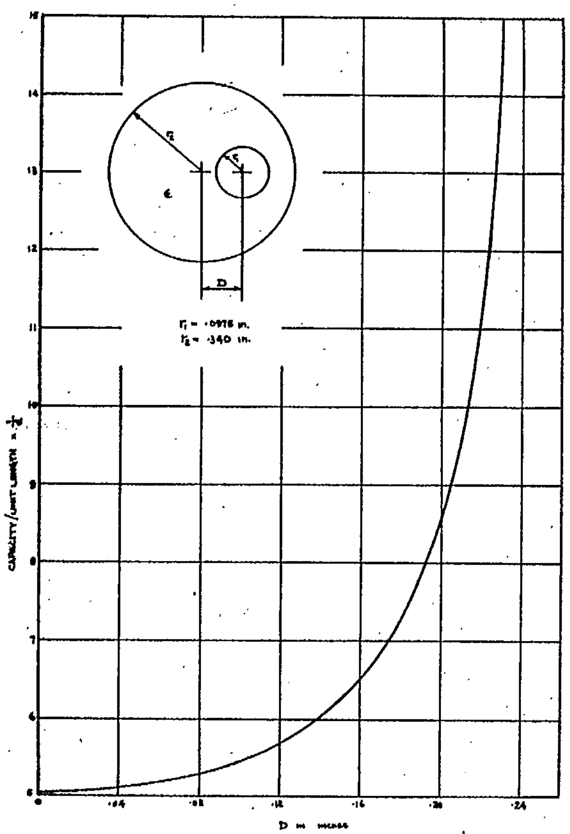
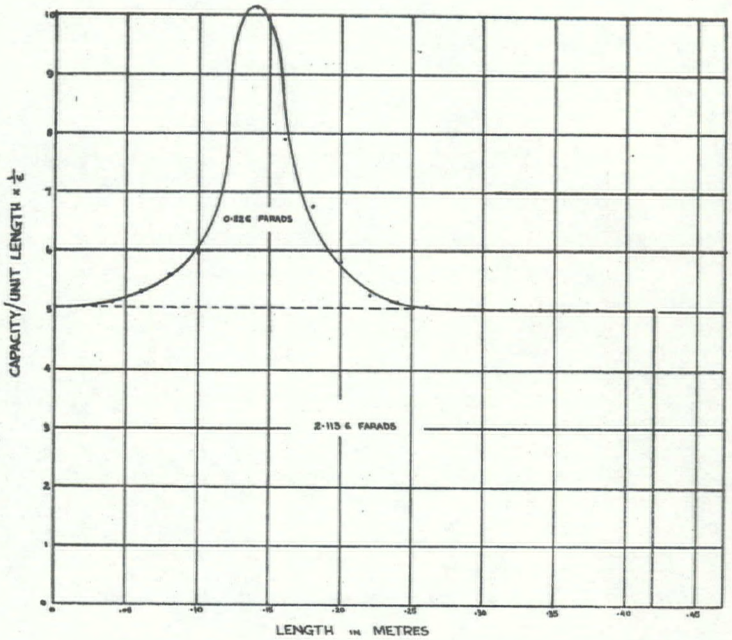



**Fig. 7** - Capacity per unit length $x\frac{1}{\varepsilon}$ plotted against D in inches for RG-18/U co-axial cable




<u>Fig. 8</u> - Capacity per unit length $x\frac{1}{\varepsilon}$ plotted against distance along test cable, in metres, from test No. 2 (Fig. 3). The capacity values shown for concentric and eccentric parts are respective areas under the curves, and are for ε in farads per metre.

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