# CHAPTER IV

# MEASUREMENT OF IMPULSE VOLTAGE

## Measurement of Voltage with Sphere gaps[24]

A sphere gap is a simple instrument used for the determination of the peak value of a voltage wave. It may also be used for the checking and calibrating of the voltage-measuring devices for high-voltage tests.

The chief point is that, the impulse voltage wave must be free from oscillations as possible, since the sphere gaps generally measure the peak value of the voltage.

By means of the sphere gaps, the peak voltages may be measured from about 2 KV to about 2,500 KV; Appendix III. These tables may used for the measurement of impulse voltages of negative and positive polarity, and of wave shapes having fronts of at least 1 μS and times to half value of at least 5 μS.

## The Sparking Distance

The sparking distance between spheres should preferably not exceed 0.5 D, that is (figure 4-1).

$$S \leqslant 0.5\ D \qquad \ldots\ 4\text{-}1$$

where D is the spheres diameter.

The accuracy of the results will be ± 3 percent if this condition is fulfilled.

The impulse breakdown voltage of a given gap is taken as the voltage which causes breakdown in 50 percent of the applications.

## Sizes of Spheres

The standard spheres are of the following diameters: - 2.0, 5.0, 6.25, 10.0, 12.5, 15.0, 25.0, 50.0, 75.0, 100.0, 150.0 and 200.0 centimeters respectively.

The measurements of the correct curvature are made with a spherometer at various positions over an area enclosed by a circle of radius 0.3 D about the sparking point. The errors in reading of ± 0.001 D of the correct diameter are allowable.

### Position of Spheres

The sphere gap should be situated in a space comparatively free from external electric fields and from bodies and suffaces which might distort the field between the spheres.

The vertical mounting of the one earthed sphere gaps is given in figure 4-1. The distance from the sparking point of the high voltage sphere to the equivalent earth plane to which the earthed sphere is connected is given by the expression,*

$$\left( 0.25 + \frac{u_{peak}}{300} \right) \text{ meters} \qquad \ldots \quad 4\text{-}2$$

note that, when the large spheres are used for the measurement of low voltages, this expression may have a very small value. Thus the limiting distance shall not be reduced to less than a sphere diameter in any circumstances.

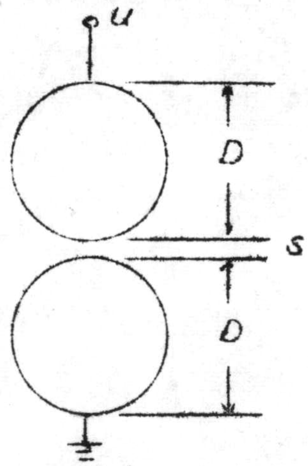


Fig. 4-1 Sphere-gaps used in measurement

The above express valids only, when no conductor or body having a conducting surface shall be nearer the spark point of the high voltage sphere than the distance given by the expression.

* W.G.Hawley, Impulse Voltage Testing, Chapman & Hall, Ltd., London, 1959, P.67.

## Surface of Spheres

The spheres of brass, broze, steel, copper, aluminium alloys are recommended to be used. The surface of the spheres should be cleaned immediately before use with a dry chamois leather to remove grease films, dust or deposited moisture. Afterwards the spheres shall not be handled.

## Using of Spheres

It is advisable to repeat the preliminary discharges until the breakdown voltage for a given sparking distance becomes constant before test readings are taken.

The sufficient duration of discharges to prevent any appreciable heating of the spheres must be at the rate of one every 5 seconds.

## Correction for Air Density

With decreasing pressure and increasing temperature, the breakdown of the sphere gap will decrease, and it is nearly proportional to the relative air density, given by

$$K_\delta = \frac{p}{760} \frac{(273 + 20)}{(273 + t)} = \frac{0.386p}{273 + t} \quad \ldots \quad 4\text{-}3$$

where p is the barometric pressure in mm. Hg.

t is the temperature in $^{o}C$

and $K_\delta$ is the relative air density or correction factor. For the rapid determination of $K_\delta$ is given in figure 4-2.

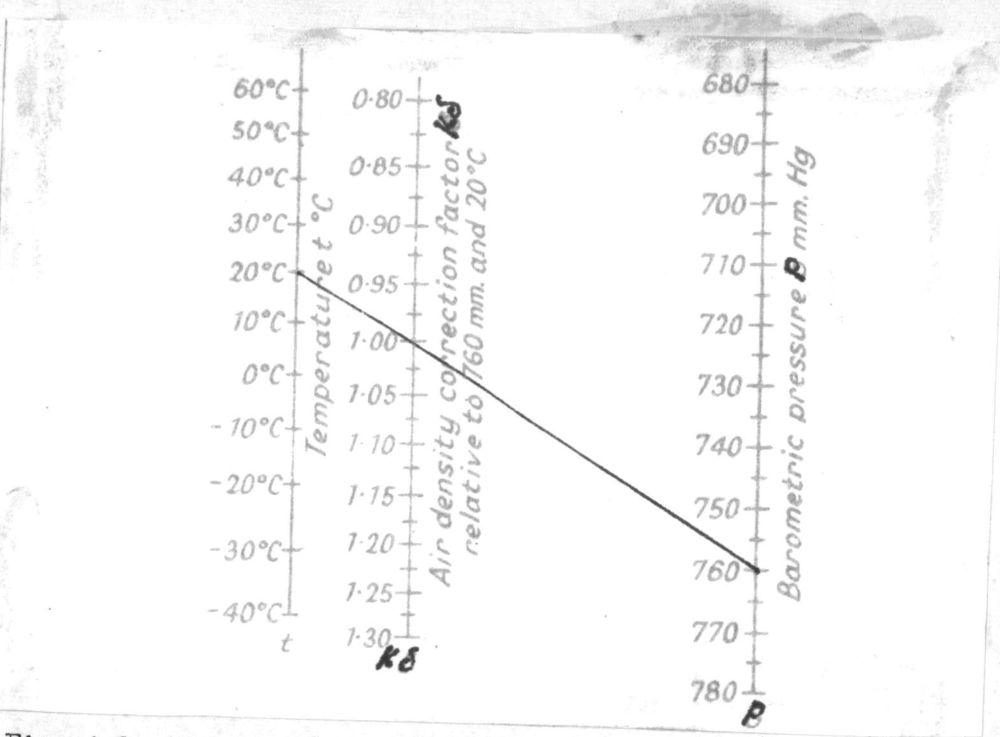


Fig. 4-2 Air density correction factor

If $u_n$ is the breakdown voltage for the standard atmospheric conditions;

$$t = 20^{\circ}C$$

$$p = 760 \text{ mm. Hg.} \qquad \ldots \quad 4\text{-}4$$

then the correct voltage for other atmospheric conditions is given by

$$u_n = K_\delta u \qquad \ldots \quad 4\text{-}5$$

The sparking distance corresponding to a certain breakdown voltage under standard atmospheric condition is given in Calibration Tables in Appendix III.

## Effect of Atmospheric Humidity

The other atmospheric condition effects the sparking distances covered by the calibration tables in Appendix III is the humidity of the air. The breakdown voltage of the sphere gap is independent of it, such as the deposited dew on the surface of spheres lowers the breakdown voltage and invalidates the calibrations.

## Measurement of Voltage by CRO and by Calibrated Potentiometer

This is the only method applicable to the measurement of impulses voltages. It is also clear necessary for determining the impulse voltages chopped and the time to puncture of the test samples.

For the measurement of high impulse voltages, a potential divider is necessary for the purpose of tapping off a sample of high impulse voltages sufficient for producing a suitable deflection on the recording device. But attention must be given to the accuracy of the potential divider under consideration.

## Capacitance Potential Divider

The capacitor divider is shown in figure 4-3. It is simply represented as two impedances $Z_1$ and $Z_2$ in series, and the sample voltage required for measurement being taken from across $Z_2$ by

$$u_2 = \frac{Z_2}{Z_1 + Z_2} u \qquad \ldots \; 4\text{-}6$$

$$= \frac{\frac{1}{wC_2}}{\frac{1}{wC_1} + \frac{1}{wC_2}} u$$

$$= \frac{C_1}{C_1 + C_2} u_1 \qquad \ldots \; 4\text{-}7$$

The voltage $u_2$ is normally a few hundred volts at most, $Z_2$ is adjusted to a value sufficient to produce full scale deflection on a CRO.

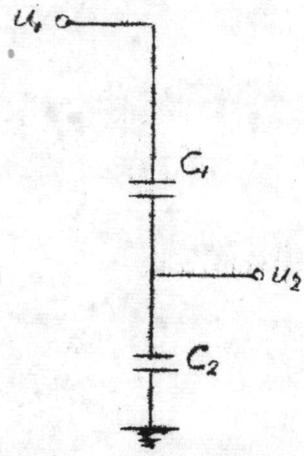


Fig. 4-3 Capacitor divider

It is sometimes convenient to write down the dividing ratio

$$\eta_c = \frac{C_1}{C_1+C_2} \qquad \ldots 4\text{-}8$$

Resistance Potential Divider

The resistor divider is widely used, its resistance value has to be taken into account in relation to the equivalent resistance of the generator itself, in order to ensure the correct value of the wave-tail required.

The length of the divider depends upon the surface flashover gradient (in the order of 8-10 KV/in.) and the resistance value. Therefore it is indxtricably bound up with the self-capacitance of the resistance column given by

$$C = \frac{1.11\ L}{2\left[\ln \frac{2L}{r} - 1\right] - 1.09}\ \text{pF} \qquad \ldots 4\text{-}9$$

where L is the length of the column in cm.

r is the radius of the column in cm.

This expression is valid for a vertical column with one end just not in contact with the ground plane, and the time constant RC must not exceed the duration of the wave-front $t_1$. Otherwise, the divider was not behaving correctly.

The resistor divider is shown in figure 4-4, and the dividing ratio is

$$n_R = \frac{R_2}{R_1+R_2} \qquad \ldots \; 4\text{-}10$$

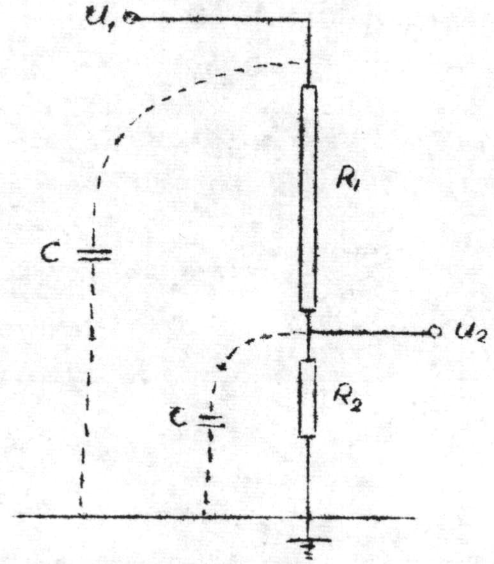


Fig. 4-4 Resistor divider

CRO and Resistor Divider Circuit

Usually, it is not possible to record the voltage directly on the voltage arm of the divider, because of the necessary clearance between high voltage leads and the recording instrument. Then the divider and recorder are connected by a coaxial [30] measuring cable; figure 4-5

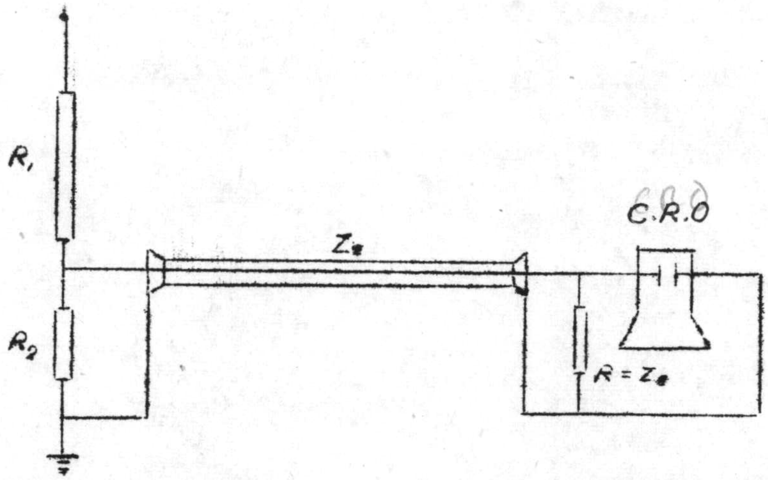


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Fig. 4-5 Resistance potential divider recording circuit

This delay cable represents an additional lead for the divider and a possible source of additional errors.

The resistor R is added at the CRO end of the delay cable for matching purposes, that is,

$$R = Z_c \qquad \ldots \quad 4\text{-}11$$

The dividing ratio of the circuit is then,

$$n_R = \frac{R_1 + Z_2}{Z_2} \qquad \ldots \quad 4\text{-}12$$

Here the equivalent impedance $Z_2$ of R in parallel with $R_2$ is given by

$$Z_2 = \frac{R_2 R}{R_2 + R} \qquad \ldots \quad 4\text{-}13$$

Therefore, the voltage wave transmitted along this delay cable is neither doubled nor reflected at the plates of the C.R.O.

## The Delay Cable

The delay cable is a screened lead used to convey the sample of the impulse voltage wave tapped across the low voltage arm $R_2$ of the potential divider to the voltage plates of CRO.

In practice, the length of the delay cable is of a few meters and its surge impedance $Z_c$ is 76 ohms. Thus the time taken by the travelling wave is ample for the CRO to get set in. The wave shape at CRO is no substantial difference from that produced by the generator.

Attennation[27] in a delay cable cannot be avoided, and in any case, can be determined and allowed for in oscillogram analysis.

## The CRO Trip Lead

The CRO has a sweep circuit associated with a pair of X-plates for producing a single time-sweep. These X plates, between the electron beam passes, form part of a balanced R-C circuit is discharged by means of a 3 electrode device.

But the method adopted in this thesis is to have an aerial wire suspended at a safe distance from the generator when the generator operates a potential is picked up electro-statically by the aerial and conveyed to the CRO tripping device. The aerial wire should be terminated in a resistance at the CRO and to suppress reflections along its length.

## The Oscillogram[28,31]

In dealing with an oscillograph, it is necessary intimately to know one's instrument, as well as to have a good working knowledge of transient theory. It is also necessary to acquire a good eye so as to see the front of an impulse wave on the screen; for an oscillogram which does not show the start of a wave is as good as useless.

If, in taking an oscillogram, there is any doubt or any occurance indeed which might mar the oscillogram, it is wise precaution to take, if possible, a repeat shot.

An oscillogram should show not only the impulse wave, but also a zero line, a timing oscillation , and a calibrating line. Although the actual oscillogram is not absolutely essential, it must go into the preparation of a hand drawn reproduction.

Each negative of an oscillographic film should be replaced by a figure number stuck on the corner of the film with indelible ink before reproduction.

Sometimes, a steep wave-front can be seen on a negative but gets lost in reprodution of a print. In this case, it is probably better to rely on a hand-drawn reproduction.

The oscillograph is shown in figure 4-6.

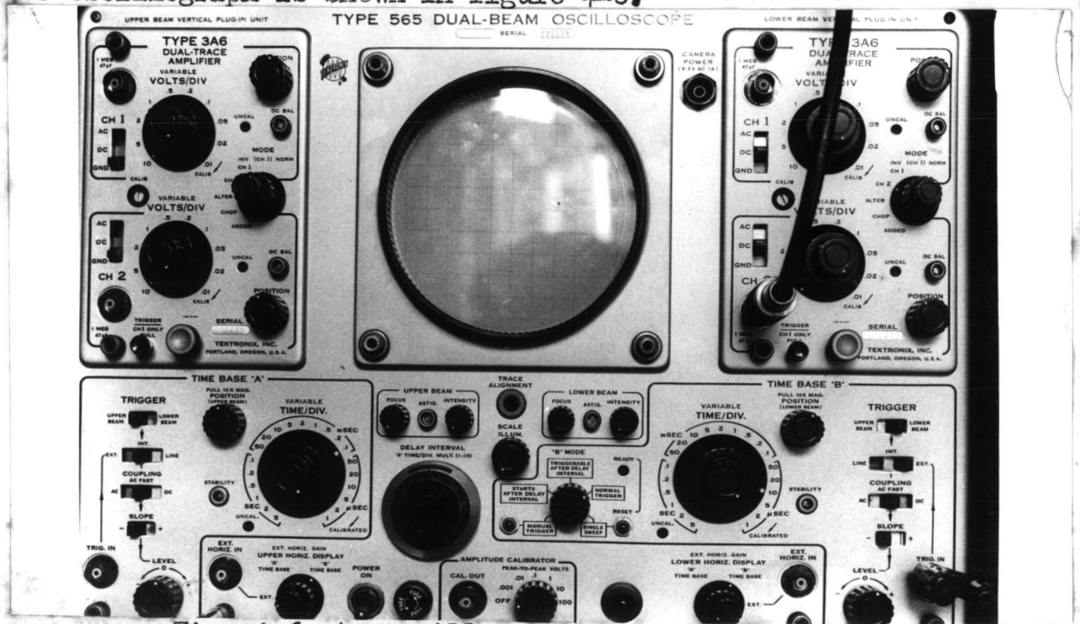


Fig. 4-6 An oscillograph

# Impulse Voltmeter

The impulse voltmeter; figure 4-7, is a measuring instrument to indicate directly the sample of impulse voltage taken from the potential divider. For accuracy in measurement, the meter must be warmed up for at least half an hour, and the reading must be calibrated between 0 - 200 volts both for positive and negative measurements.


Fig. 4-7 Impulse voltmeter

This impulse voltmeter has a selective multiplier scale, in order to measure any value of impulse voltages for the accurate readings.

Accuracy

For every new measuring set up, the delay cable must be shorted at the potential divider terminals, so that no signal may be shown on the CRO if a signal is applied to the high voltage terminal of the divider.

But if there may be a signal caused by any sheath current on the cable, then the sheath of cable must be grounded. This grounding of sheath of cable also prevents the interferance of the travelling wave[29] in the cable.

More-over, any magnetic or electric fields must be prevented from the CRO, thus a Faraday cage or net is used to avoid these errors.

In measurement, the impulse measuring devices shall be approved for tests, such that, the response time of the whole circuits should not be more than the values given below.

*

| Impulse shape to be recorded | Response time not more than | Error |
|---|---|---|
| Full standard impulse and standard impulse chopped on the wave tail. | 0.2 $\mu$S | 3% |
| Impulse voltage chopped on the wave front. | 0.05 $t_3$ $\mu$S | 5% |
| Impulse voltage 1.2/5 wave | 0.2 $\mu$S | 3% |

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* B.W. Stanb, Introduction to High Voltage Technique, Chulalongkorn University, Sept., 1968, p. 15.