CHAPTER III

DESIGN OF THE 32 KV IMPULSE VOLTAGE GENERATOR

Consideration

In the design of the impulse voltage generator, the important considerations are dealt with :-

1. The required impulse out put voltage.
2. The charging equipment which provides the DC for charging the generator capacitance.

Therefore, a single stage or multi-stage impulse generator is contemplated depends upon the above considerations.

Single - stage Impulse Generator

The single stage impulse generator consists of a basic impulse circuit, the charging equipment and a trigger sphere gap.

It is mainly employed in low voltage applications. But in some cases, it can be made up to a voltage out put above 100 KV which is used in some large industrial laboratories. However the out put voltages of 200 V to 10 KV are obtained very inexpensively. Figure 3-1 shows a circuit diagram of the single stage impulse generator.

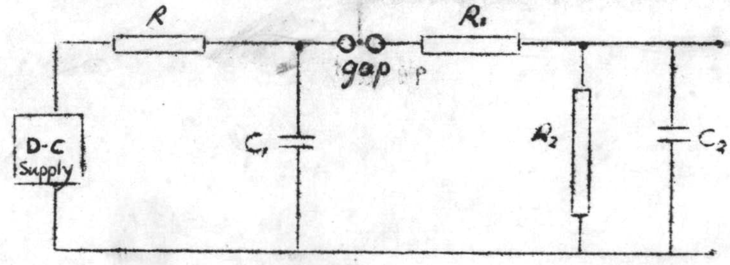


Fig. 3-1. A single-stage impulse generator circuit with charging equipment.

The charging equipment is of a conventional type, incorporating either valve or metal rectifiers with DC voltage of 10 KV to 200 KV. In figure 3-2 shows a half wave and a full wave rectifier which may be used. If higher charging voltages are required, the voltage doubling rectifiers (also shown) are used instead. One of the popular used in high voltage is the Cockcroft multiplying circuit.

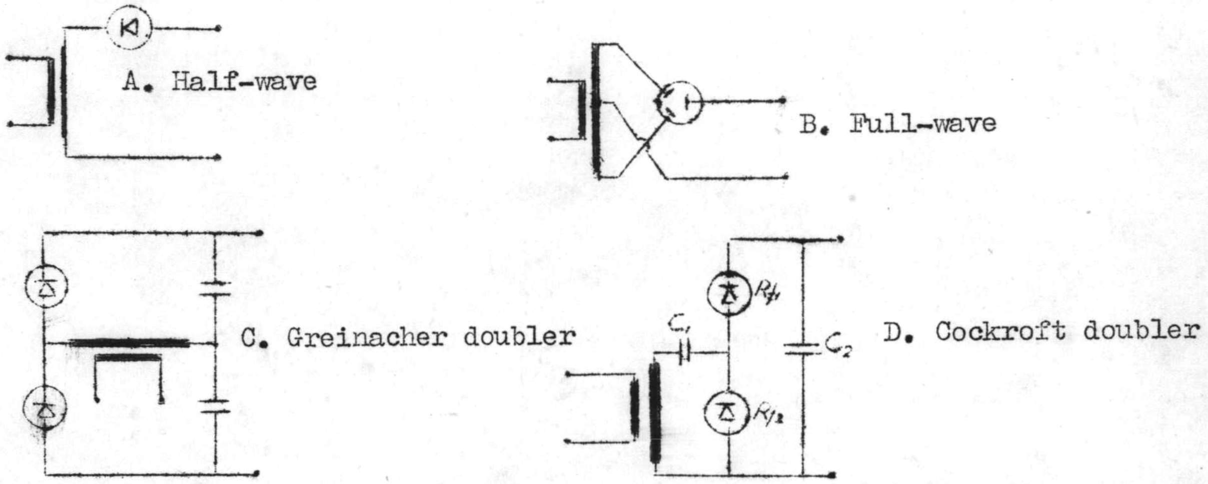


Fig. 3-2 Conventional rectifier circuits

The trigger sphere gap can be

1. A simple trigger sphere gap.
2. A simple thyratron.
3. A special 3-ball gap which can be tripped by applying a momentary potential to the middle ball.

Note Relating to Alternative Trigger Gaps

When an oscillograph is used in conjunction with an impulse generator. In practice it is either.

1. to trip the oscillograph by sending a tripping pulse along the trip lead,

2. or to trip the impulse generator from the oscillograph.

The second is an alternative method, and is known as controlled tripping.

An excellent 3-ball gap is the air trigatron, given in figure 3-3. This Trigatron is adjustable for setting purpose. In operation, the electrode shell of cast aluminum alloy is the earthed member of the bottom stage gap of the impulse generator. When a tripping pulse is applied to the probe, a discharge appears between the prove tip and the shell. The ionization thus produced is fed into the main gap, which, being under electrical stress, is caused to break down.

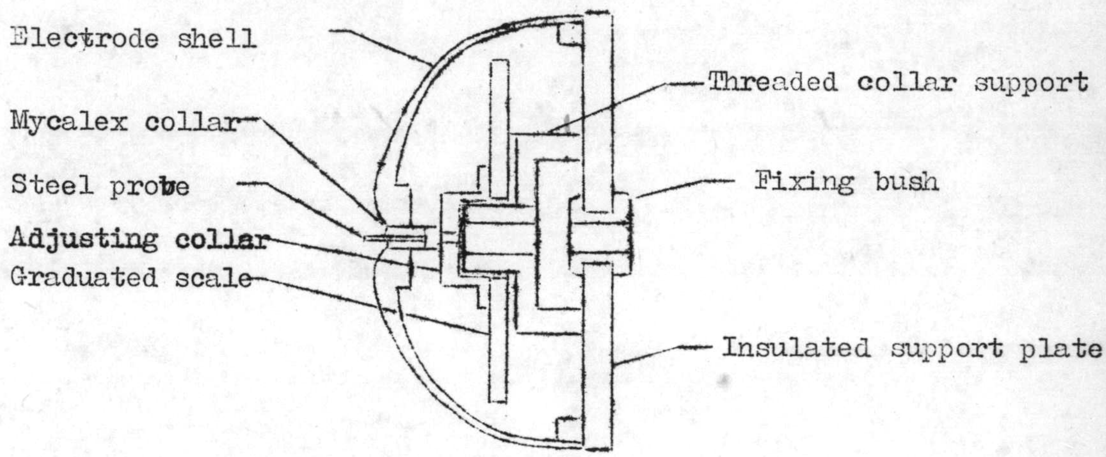


Fig. 3-3 Air Trigatron

The delay to the voltage plates of the oscillograph is brought about by the time constant of the tripping circuit, by varying resistance or capacitance, or both.

Advantages of the Single-stage Impulse Generator

Though the out put voltage may sound low, but there are important applications at this level of voltage.

The great advantages are

1. Since the out put voltage is not so high that recording on oscillographs can be done directly, without the intervention of potential dividers which contribute a small amount of error.
2. A large value of capacitance dan be incorporated in the generator, thus enabling high capacitance loads to be impulse tested.

Multi-stage Impulse Generator

General

The multi-stage impulse generator is a sound preposition of the single-stage, whenever a higher out put voltage is required. And still small charging equipment can be used and obtained inexpensively.

In figure 3-4, the generator of several stage capacitors are charged in parallel and then antomatically discharged in series.

Modification of Marx Circuit

The multi-stage impulse generator circuit is built up on the Marx principle. The circuit operates as follow.

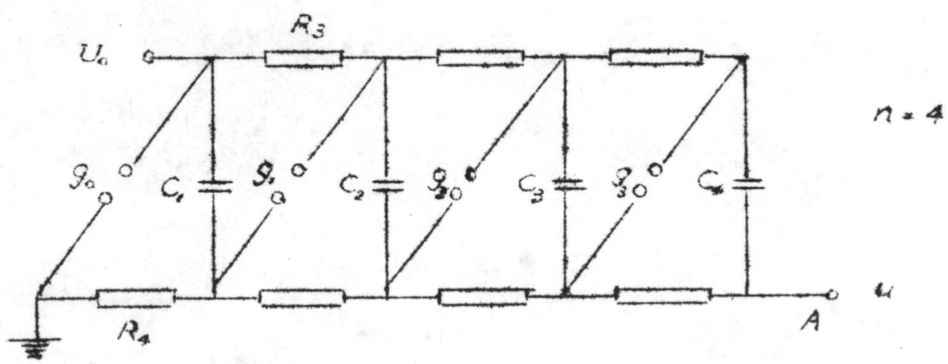


Fig. 3-4 Multi-stage impulse generator circuit

All the stage capacitors are charged in parallel through the front resistances R_3 until they reach the value + U_o, with their lower plates being at earth potential because of their connection to ground through the tail resistances R_4.

If the gap g_o breaks down,(g_o, g_1, g_2 ... are set to spark one after the other); there will be a momentary redistribution of charge potential on capacitor C_1, its top plate falling to zero potential, its lower plate, suddenly rising to − U_o. Across gap g_1, therefore, suddenly appears a potential $2U_o$, and this gap then instantly breaks down. This process is repeated in every stage of the generator, and the out put impulse voltage at terminal A is theoretically $-nU_o$, if there are n stages.

The full impulse is developed across the total tail resistance. And it has the advantage that the test object is maintained at earth potential until the impulse appears across the tail resistance.

Analysis of the Multi-stage Circuit

As an exercise in the design of a multi-stage impulse generator, consider again the 4-stage circuit of figure 3-4.

When the gaps have all broken down, the spark resistance in each gap may be regarded as negligible compared to the R_3 and R_4 resistances. The circuit can then be redawn as in figure 3-5 a.

But all the resistances are all of the same value, then by reason of symmetry (equal potentials), so that the links may all be omitted. The circuit now resolves itself into figure 3-5 b.

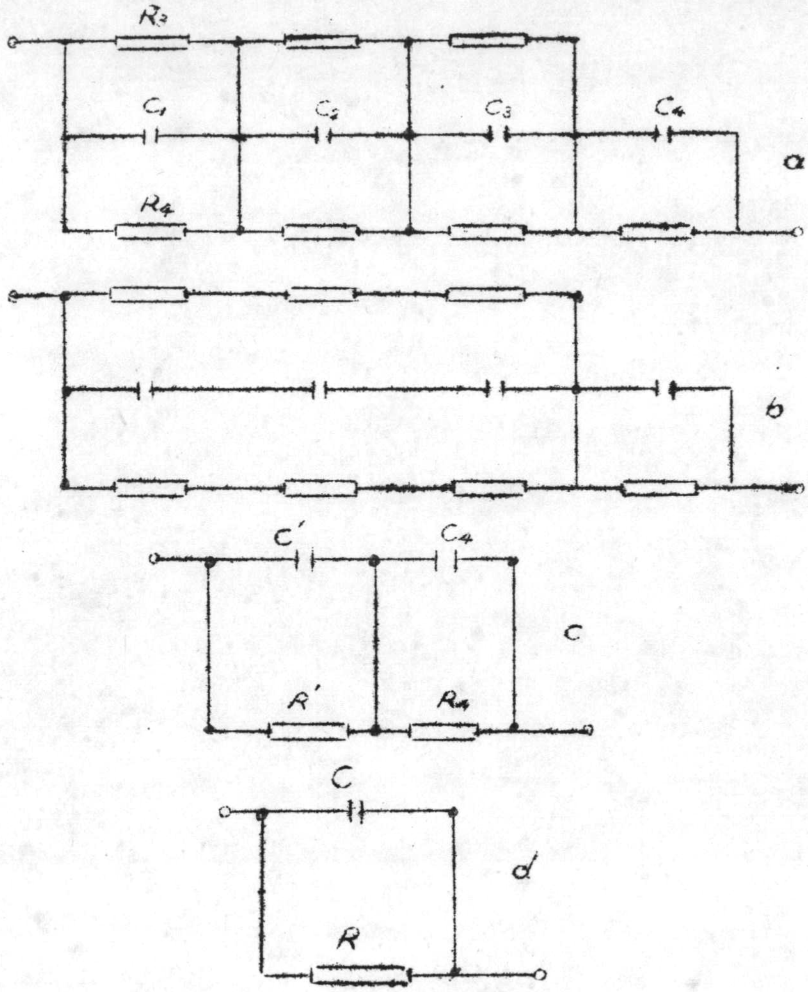


Fig. 3-5 Analysis of a 4 stage impulse generator circuit of figure 3-4.

If let C' is the sum of C_1, C_2, and C_3 in series, and R' is the equivalent resistance of series-parallel circuit comprising R_3 and R_4. This reduces to figure 3-5 c.

The final equivalent circuit is simply a capacitor C and a resistor R in parallel shown in figure 3-5 d.

Alternative Circuit of Multi-stage Impulse

Generator

The alternative circuit of figure 3-6 is in popular use. It has also the advantage of the test piece being at earthe potential until the impulse voltage is applied.

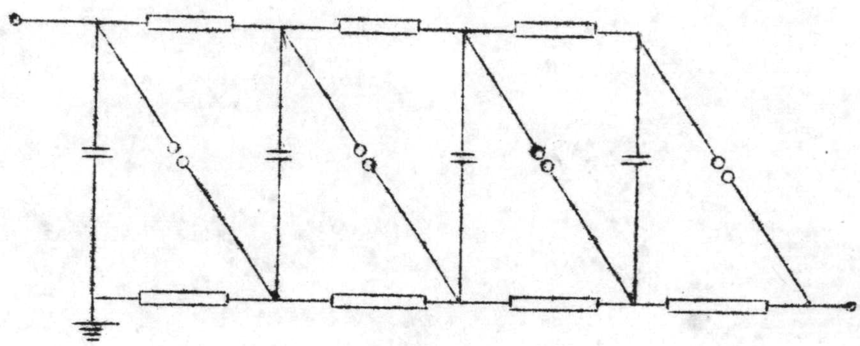


Fig. 3-6 An alternative schematic diagram of a multi-stage impulse generator circuit.

The alternative circuit is different from that of the usual circuit that, the bottom of the first capacitor stage is directly earthed. The gap is now issolated from ground by a discharging or tail resistance.

However, the height of the generator is saved by one unit, because the generator can be errected immediately upon the capacitor stage.

The equivalent circuit of this alternative multi-stage impulse generator with its inherent inductance is given in figure 3-7.

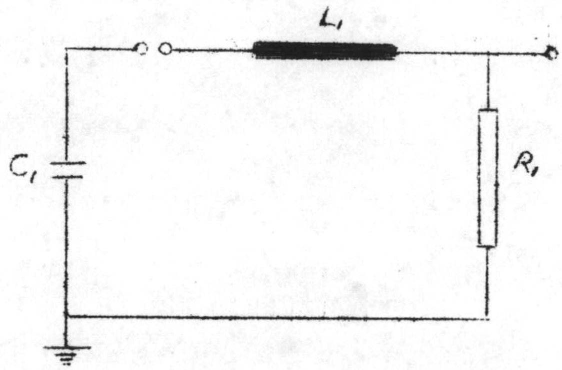
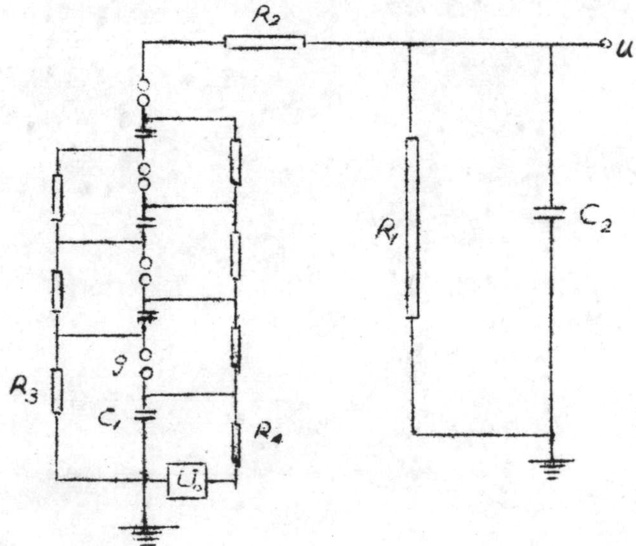


Fig. 3-7 The equivalent alternative circuit

The Additional of Test Circuits

Usually, the impulse generator is operated in conjunction with test circuit, which results in a modification of the impulse wave shape. Figure 3-8.



19,20
Fig. 3-8 A 4-stage impulse generator circuit inconjunction with the test circuit

Such as the aggregate load capacitance C_2 effects the wave shape by lengthening the front of the impulse wave. While a series resistance R_2 is introduced into the circuit between the actual out put terminal of the generator and the test object, for the purpose of improving unwanted oscillations from the peak of the impulse wave caused by the self inductance L_1.

The potential divider of the resistance variety type R_1 is connected into the circuit across the test object C_2, then the generator resistances will have lower values, and the wave tail of the impulse will be shorted.

Since the inductance causes oscillations of the impulse wave and it also lengthens the wave front. Then the inductance must be kept as low as possible.

Moreover, it is practicable to keep the ratios of C_1/C_2 for at least 5 : 1* in order to obtain the maximum efficiency.

The equivalent circuits are of the forms given in the previous chapter.

Design of the 32 KV Multi-stage Impulse Generator

Purpose of Miniature Equipments

For the production of impulse voltage of 32 KV peak used for apparatus testing and for laboratory studying. A small multi-stage generator charged up to a maximum of 8 KV can be used. This can be obtained inexpensively.

Miniature equipments are therefore excellent for this purpose, as the technique is identical with that adopted in the large laboratories.

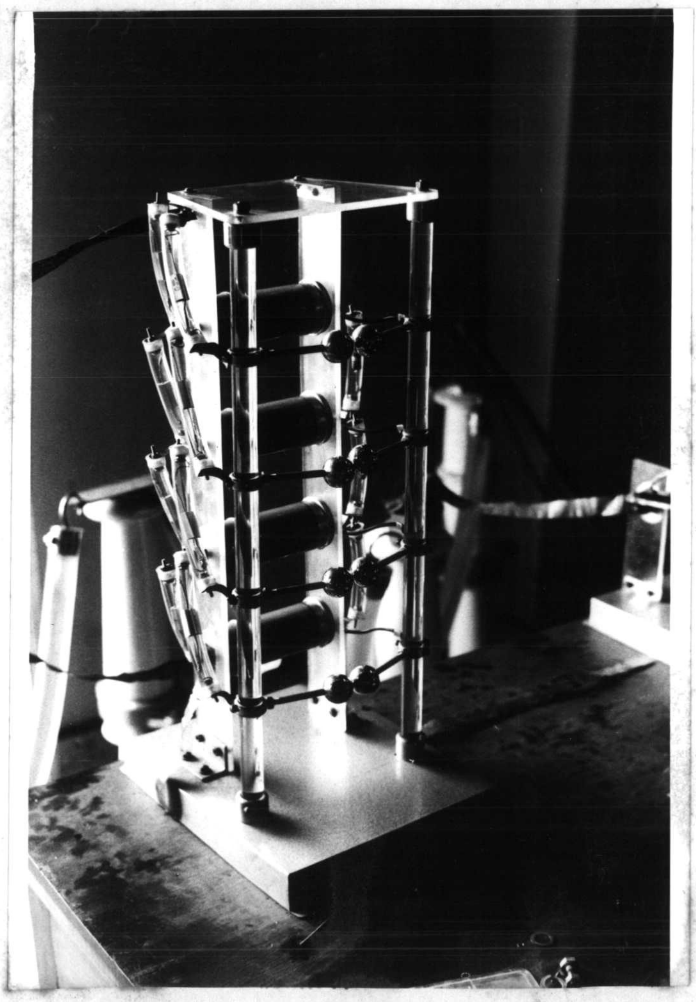
Capacitors

This small multi-stage impulse generator requires a number of individual stage capacitors suitable for 8 KV charging (via suitable resistances) in order to restrict

* I.E.C. 60: 1962.

the number of stages to 4. Each will be at least 0.1 μF in capacitance, so as to produce a discharge capacitance comparable with standard equipments. Such as, in the 4-stage generator four 0.1 μF would give a discharge capacitance of 0.025 μF, a value in common use. With a DC charging voltage of 8 KV such a generator should, neglecting losses, theoretically be able to produce an out put voltage of 32 KV.

The capacitors of cylindical plastic type are best assembled between two insulating side pannels, allowing sufficient spacing between them to give clearance for the charging voltage, and to accommodate the charging resistors on one side and the discharging or tail resistors on the other. Figure 3-9, these capacitors areall short circuit proof, so that they can be discharged without any damping resistance, even when fully charged.



Figu 3-9 The 32 KV multi-stage impulse generator

Resistors

For the charging voltage envisaged, ordinary 1-watt carbon resistors of commercial quality are satisfied. The values of each resistor can conveniently be all the same throughout for any equivalent discharging circuit.

However, it is preferable to use non-inductive wound wire resistors in the actual generator circuit, whenever the voltage exceeds 8-10 KV per resistor.

The ohmic value of the wound wire resistor is depended on the length and the diameter of the wire.[21] The data sheet Silko resistance ribbon is given in Appendix.[24] These resistors are of such ample dimensions that even with the greatest impulse energies and short intervals, there is no excessive heating. The resistors used exclusively for charging, are wound in the normal way, but the discharging and damping resistors are made in a special way to obtain a very low self-inductance. Usually, the damping resistors are provided in the right proportion to the total self inductance and the capacity of the circuit, so that the right wave shape is produced and oscillations on the voltage wave are prevented. The resistances of these resistors are given that.

Charging resistance 10 KΩ / 10 KV each, 3 pieces

Discharging resistance 887.5 KΩ/10 KV each, 4 pieces

Damping resistance 54 KΩ/ 10 KV each, 4 pieces

30 KΩ/10 KV each, 1 pieces.

Spark - Gaps

The spark gaps are mounted on two cylindical rods made of insulating substance, called plexiglass. These gaps are actuated by hands, so that the spark gaps of all stages require careful initial adjustment. But once set subsequent handling is rarely necessary.

The sparking distance of gaps is set at any desired spark voltage, with the lowest gap leading and other gaps follow one after the other. Resulting an impulse voltage of the desired peak value at the out put terminal of the generator.

The used spark gaps are of the steel balls about 2.5 cm. in diameter. Their surfaces are coated with chromium in ordor to have good sparking property.

Circuit Connecting Leads

The connecting leads between the various components of the impulse circuit should be kept as short as possible in order to minimize the self inductance of the generator.

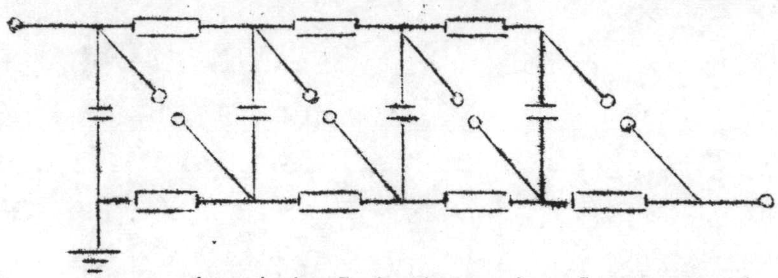
It sometimes uses the thin strap of copper for this purpose.

Earthing of Impulse Generator

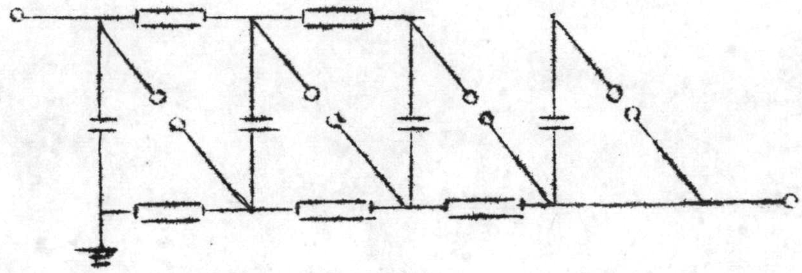
The generator earth should have as low an inpedance as possible. The earthing plates can be buried in the ground directly below the base of the generator position, or otherwise the generator should be placed to the rearest point from the ground position and used a copper strap as its lead.

Adaptability of Miniature Impulse Generator

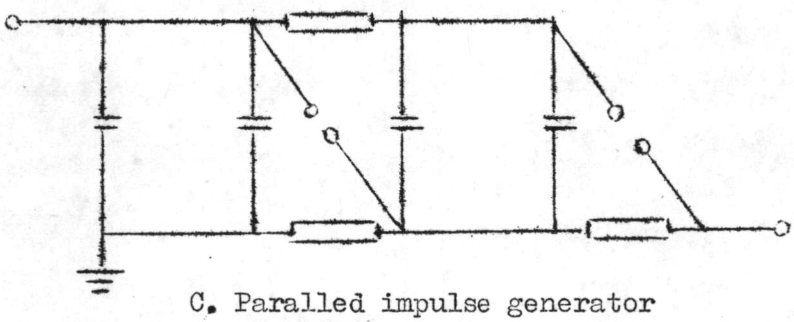
The miniature generator is permissible to reduce the number of stages by the simple expedient of removing two resistances. See figure 3-10. The following stages can there be receivedno charge, so that the stage gaps beyond the last left in circuit need not be opened out.



A. Actual 4-stages impulse generator



B. Reduced 3-stages impulse generator



C. Paralled impulse generator

Fig. 3-10 Adaptability of miniature impulse generator

There will be a slight change in wave tail length, but it is still possible remain within the tolerance allowed.* In any case, it is a simple matter to check the wave tail, either by calculation or by oscillograph, and to make whatever adjustment is necessary.

Advantages of Reducing of Generator Stages

The advantages of reducing the number of stages where possible are that

1. circuit loops, and therefore inductances, are made smaller
2. the discharge capacitance of the generator circuit is there by increased.

Both of these having a beneficial effect on the wave front which can be of value when testing large capacitance load.

Another method to increase the generator capacitance is obtained by paralleling generator stages.

Location of Impulse Generator

If the impulse generator is place near one wall of the H.V. room, Clearance from the highest potential point facing the wall to the wall surface is based on a figure of 11 KV per inch. For instance, this 4-stage generator with a nominal output voltage of 32 KV. Then it can safely be situated 4 inch from the wall.

Charging Equipments

The stage capacitors of the impulse generator are charged by the charging voltage, generated in a voltage doubler circuit; the same given in figure 3-2, provided with silicon or selenium rectifiers. Each rectifier is suitable for 4 KV charging voltage, with its DC out put of 8 KV. This DC voltage (8 KV) then charges the stage capacitors of the generator through a suitable limiting resistor of the liquid type.

* See Chapter I,P.IO.

Its resistive value would be high enough so that it will protect the rectifiers against damage when flash over in the spark gaps is occurred during discharging process.

The polarities of the charging voltage may be positive or negative.

Voltage Doubler Circuit

The voltage doubler circuit in which the selenium rectifiers are connected in cascade is given in figure 3-11. By means of the two selenium rectifiers and two capacitors of equal capacitance, it is possible to obtain a steady DC voltage (8 KV) with equals the peak to peak voltage of the rectified AC voltage (4 KV).

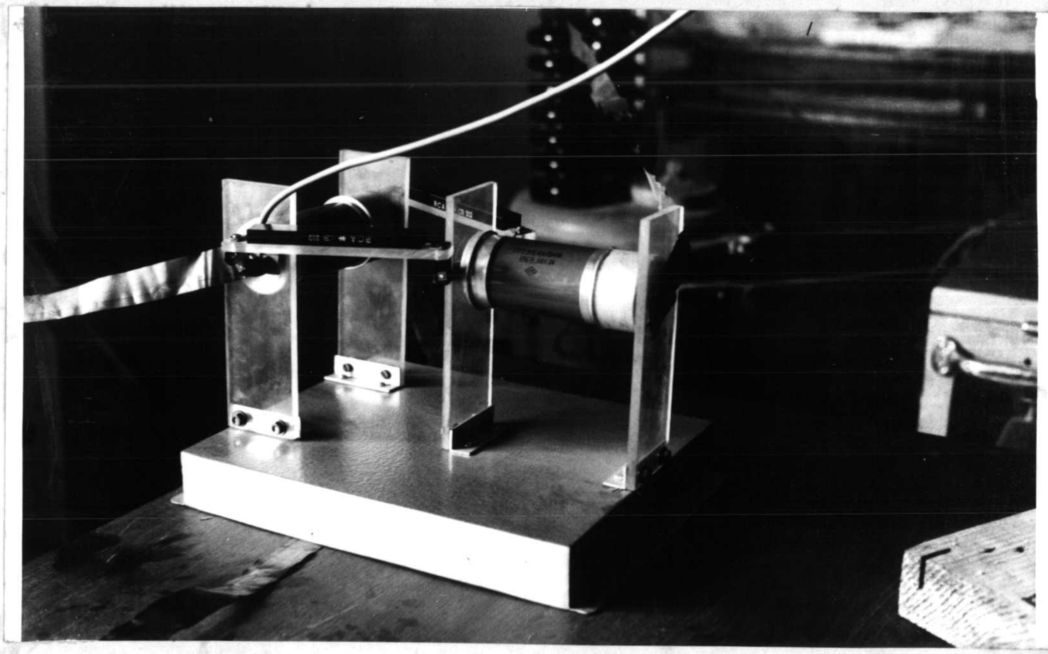


Fig. 3-11 Voltage Doubler Circuit

The operation of this circuit can be explained as follow: if the rectifier Rf_1 is disconnected, then the condencer C_1 will charge to the peak supply voltage , and the potential at point A will fluctuate between zero and twice the supply voltage. If now rectifier Rf_1 is connected, the voltage between A and ground will tend to charge C_2 to the peak voltage excisting at A, thereby giving the possibility of twice the peak supply voltage being obtained at the out put.

The exact out put voltage of this doubler circuit depends upon the voltage drop in the rectifier units, that is produced by the DC current that is drawn by the load connected to the out put. As the load current is increased to the moderate value, the out put voltage will drop off rapidly; i.e. the voltage regulation is poor in this system.

Data :

Rf_1, Rf_2 Two selenium rectifiers. R.C.A. maximum inverse peak voltage 10 KV. maximum current 1 A continuously in ambient temperature not exceeding $30^{\circ}C$.

C_1, C_2 Two condencers 0.1 μF / 10 KV.

Limiting Resistance

The limiting resistors are of the liquid type shown in figure 3-12. The liquid used is the pured water and is contained in plastic tube of suitable length with its ends are of the hook type, make it possible to connect each other on the insulators.

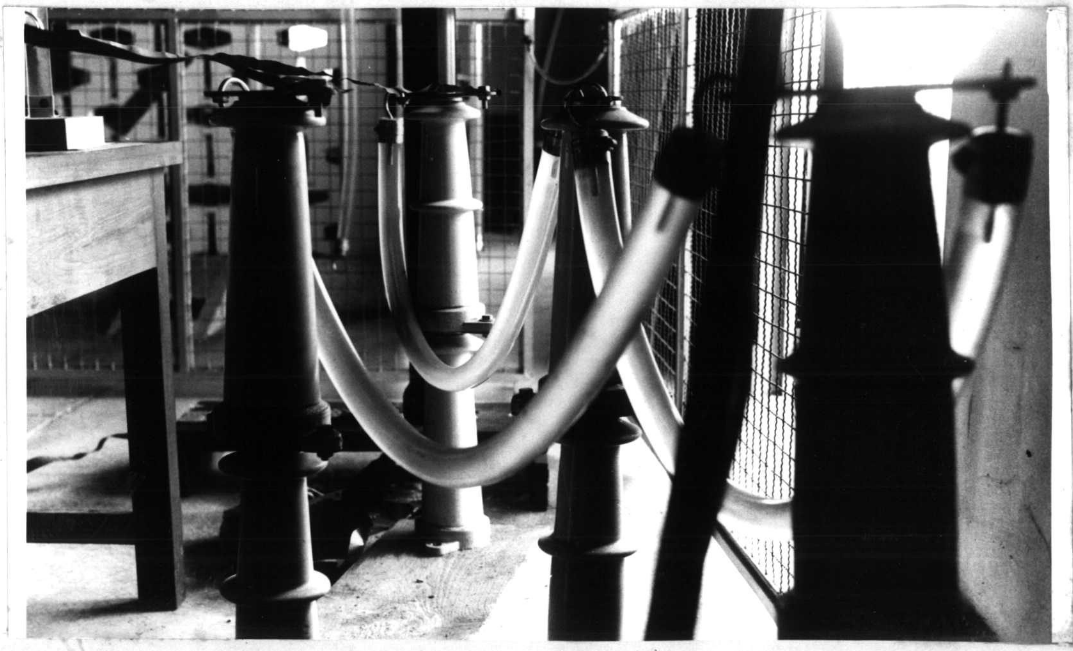


Fig. 3-12 Liquid Resistors used as the limiting resistances of the voltage doubler circuit

The resistive value depends upon the length of the tube as well as the diameter; i.e. the cross-section area of the tube. And the resistances are measured by the meg-ohm meter.

Rectified High-voltage Transformer [23]

A high voltage transformer of the oil immersed type is used. Here the low 1 voltage coils is connected to the AC low voltage main of 240 / 480 V 50 Hz, so that, the high voltage coil will give an out put AC voltage of 6/12 KV. This high voltage coil is connected directly to the rectifier doubler circuit with one bushing connectin to ground.

The necessary power out put of the transformer is given by

$$p = 2 \pi f V^2 C \times 10^{-9} \text{ KVA}$$

where f = frequency of supply voltage (50 Hz)

V = AC out put voltage at the terminals in KV rms.

C = loading capacitance in PF

Here, the used transformer has a power of 5 KVA at the maximum out put of 12 KV. Figure 3-13.

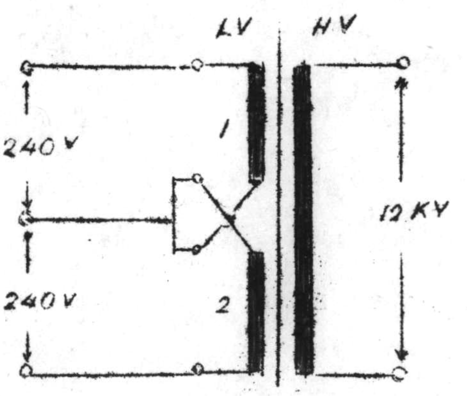


Fig. 3-13 Power transformer

Potentiometer

For voltage variation of the low AC voltage supply, in order to charge the rectified voltage at any desired voltage, a potentiometer is connected to a 220 V mains via automatic circuit divice for safety protection. The tapping control is taken to the low voltage coils of the power transformer across which the AC voltage is indicated by a volt-meter. Fig. 3-14

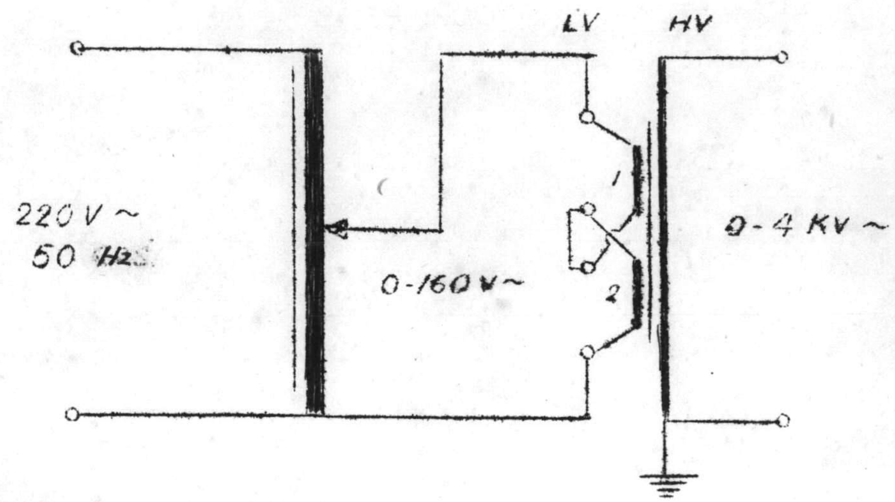


Fig. 3-14 [24] Potentiometer

With this potentiometer, the AC main voltage is varied from 0 - 160 V corresponds to high voltage out put to the rectifiers varied from 0 - 4 KV, for the two low voltage coils of the transformer are connected in series.

DC Charging Voltage

The DC charging voltage of the rectifier doubler circuit is measured by means of a series high resistance to which a microammeter is connected.

With the resistance of 277.7 MΩ, the current recorded by the microammeter about 28 μA corresponds of 4 KV of the charging voltage value.

The calibretion of the charging voltage to micro-ampere is given in figure 3-15.

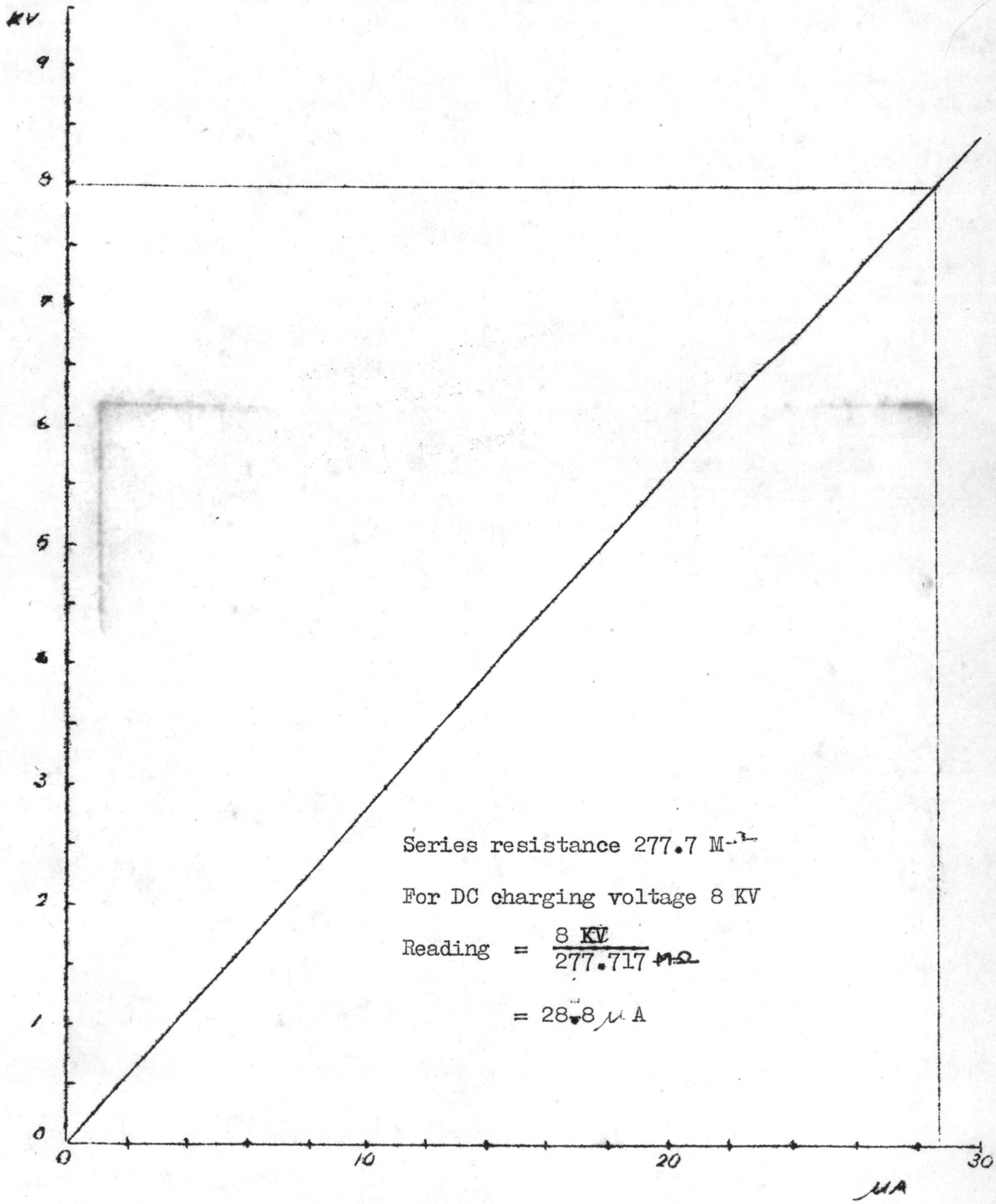


Fig. 3-15 Calibrating Curve

Operational Technique

The miniature impulse generator can be operated in relatively confined space, or it should be worked in screened enclosures having openings interlocked with the supply to the charging equipments.

The generator is set up at one end of a table where grounding is available. The controls of its charging unit should be on the right, close at hand, leaving enoug floor in front left hand corner of the table for oscillograph, impulse voltage meter and test data sheets Fig. 3-16.

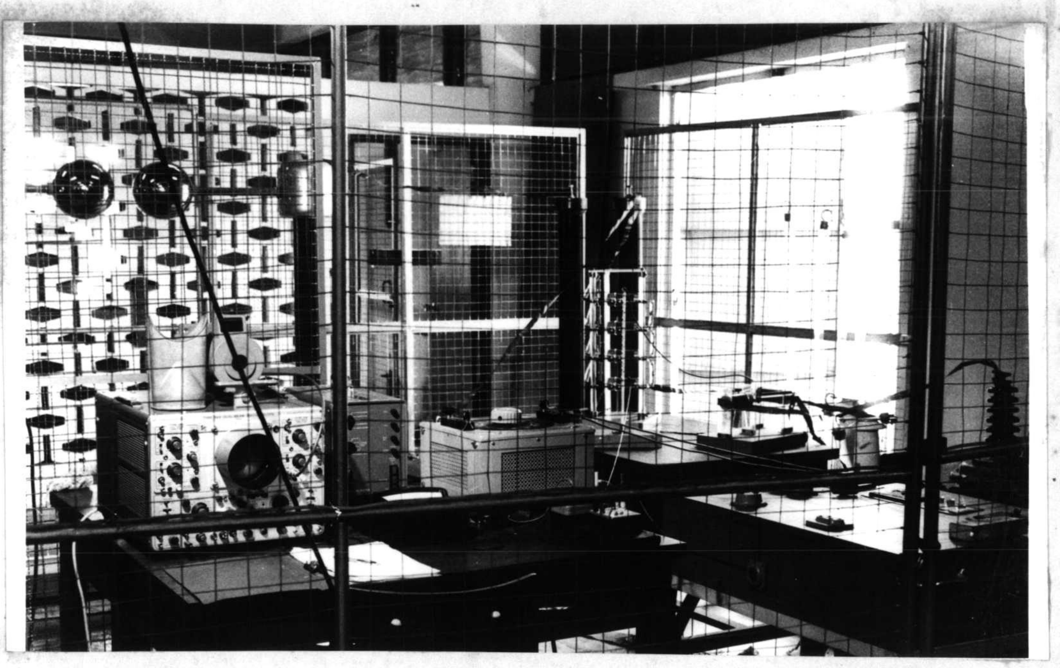


Fig. 3-16 Layout of the generator for testing

Electrical Data

Impulse Generator

Nominal output impulse voltage 32 KV.

Number of stage capacitors in series 4 units.

Total capacitances C_s (each 0.1 μF) 0.025 μF

Spark gaps (4 pairs of steel balls) 2.5 cm. in diameter

Damping resistances (4 ea.) 216 Ω / 32 KV.

192 Ω / 32 KV.

Charging resistances (5 ea.) 30 KΩ / 32 KV.

Discharging resistances (4 ea.) 3550 Ω / 32 KV.

D-C Charging Equipments

Selenium rectifiers (Rf_1, Rf_2) each 10 KV Inverse peak voltage

1 A Imax. at 30°C.

Condencers (C_1, C_2) each 0.1 μF / 10 KV.

AC Supplied Mains

Potentiometer for AC low voltage 0 - 240 V 50 Hz.

Power transformer for AC rectified voltage

Low voltage coils 240 - 480 V. 50 Hz.

High voltage coil 12 KV. 50 Hz.

Rated power 5 KVA at 12 KV 50 Hz.

Type oil immersed

Control Desk

It contains all the controls and safety devices required for the installation. There are controls for high voltage transformer, limiting the primary current of the transformer, meters indicating primary voltage and current and the out put voltage of the charging equipments, the C.R.O. and impulse voltmeter. It also carries various equipments and the data sheets.

Accessories

Series measuring resistor 277.7 MΩ / 10 KV.

Sphere gaps for measurement of impulse voltage 25 cm. in diameter, copper balls : with one of it is earthed.

Load capacitances 2000 pF / 700 KV. 200 pF / 350 KV

4000 pF / 700 KV. 3000 pF / 750 KV

Series inductances 5.12 μH / 32 KV.

8.70 μH / 32 KV.

9.72 μH / 32 KV.

External discharging resistances 181 Ω / 32 KV.

2800 Ω / 32 KV.

Potential divider 7440.62 Ω

dividing ratio 95.5 for positive and negative polarities.

CRO. for recording the impulse voltages with cathode-ray tubes and camera bracket.

Camera . Kodax, Retina IV. 35 mm. lens. 2.8 f.

Impulse voltmeter.

Tripping device.