# THE DIELECTRIC STRENGTH OF TRANSFORMER OIL IN A POSITIVE SPHERE-PLANE GAP UNDER IMPULSE VOLTAGES OF VARIOUS DURATIONS

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by
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# ABSTRACT

High voltage impulses of various wavefront and wavetail durations were applied across a sphere-plane electrode gap immersed in technically pure transformer oil. The effect of the wavefront duration on the dielectric strength of the oil was investigated as well as the effect of gap length and impulse application procedure. Pre-breakdown current was measured and the appearance and effects of corona pulses examined. The breakdown results were analyzed statistically and an explanation was given for the effect of the impulse test procedure and the change in scatter of breakdown results with changing wavefront. A trigatron surge diverter was used to reduce the deteriorating effects of the spark discharges in the oil. The operation and effectiveness of the diverter was described.

# TABLE OF CONTENTS

APPENDICES

# LIST OF TABLES, PLATES, AND FIGURES

FIGURE PAGE

# CHAPTER ONE

# INTRODUCTION

The study of liquid dielectrics under high electrical stress has generally branched off into two areas; the study of liquids of technical importance such as transformer oil and the askarels under technically significant test conditions, and the study of highly purified liquids of doubtful commercial importance such as n-hexane and liquid paraffins, in test situations which often have no technical counterpart.

Much of the work of later years has fallen into the second area because of frustration engendered in the past from trying to develop theories explaining the breakdown behavior of technically pure mineral insulating oil. The basic difficulty faced in studying a technically pure liquid is that the dielectric strength is not a basic material property but is determined by the amount of gas, moisture, and other soluble or insoluble materials in the oil, the electrode material and configuration, and other factors which would apply in a technical situation. The study of highly purified liquids represents an attempt to rule out all the accidental factors which lower the dielectric strength of the material, and be left with the investigation of a dielectric strength solely determined by the basic material property; the intrinsic strength.

The important role played by dielectric liquids including transformer oil, in power systems, merits the further investigation of the dielectric properties of these liquids, especially under test conditions which approximate the conditions they may face in a commercial function. Such work is further warranted in view of progress made toward the development of power systems operating at higher voltage levels.

## 1.1 TRANSFORMER OIL:

Transformer oil is a mineral insulating oil specially refined for use in transformers, switches, and circuit breakers. In EHV power system apparatus oil finds its greatest use in the transformers, where it serves as both an insulator and thermal conductor. As an insulator it is expected to withstand high voltages under a variety of stress distributions, most of which could be classified as nonlinear.

## 1.2 SWITCHING SURGES:

Switching surges are transient overvoltages generated by switching operations in power systems. Surges of the greatest magnitude are produced by restrikes in current interrupting devices. The magnitude and waveshape of the surge is determined by the nature of the switching operation as well as the electrical characteristics of the circuit parameters. The magnitude of the surge may exceed the peak line to ground operating voltage of the system by as much as 500%. The waveshape may appear as a damped oscillation, particularly in a circuit having significant inductance, or take on the appearance usually associated with lightning surges, although with a much longer wavefront and wavetail duration. Usually it will have a waveform which lies somewhere between the two extremes.

## 1.3 INSULATION AND EHV SYSTEMS

In the past, protection systems and insulation levels of high voltage power systems were determined by expected lightning surge voltages. If the system was adequately protected against lightning surges it was capable of withstanding any transient overvoltages which might arise from the system itself. With the development of EHV systems, however ($345^{KV}$ plus) it was found that the switching surge voltages could become the dominant overvoltage. For this reason EHV insulation and protection equipment are designed and coordinated to protect the power system against switching surge overvoltages.

In order to insulate an EHV system properly and yet avoid the extra costs incurred in overinsulating it, it is necessary to have a thorough understanding of the behavior of the insulating materials and equipment which make up the system.

As transformer oil plays an integral part in the insulating of a power system, it is essential that its dielectric behavior be thoroughly understood. Since any type of EHV system overvoltage may be of significant magnitude to seriously test the dielectric strength of the transformer oil, this understanding should include a knowledge of its breakdown behavior when subjected to voltages of various waveshapes under a variety of field conditions.

The work of this thesis involves the investigation of the dielectric strength and corona characteristics of transformer oil of technical purity in a sphere-plane electrode configuration subjected to nonoscillatory impulses of various wavefront and wavetail durations. The waveforms vary from a fast wave similar to a lightning surge through progressively slower waves to one which approaches switching surge durations.

As most transformer impulse testing is confined to the application of 1.2/50 usec waves it is useful to compare breakdown strength tests of transformer oil under slow waves with breakdown results under standard impulses in an otherwise identical test situation.

# CHAPTER TWO

# TEST APPARATUS

## 2.1 THE TEST CELL

The purpose of a test cell is to simulate an electrode-dielectric configuration as accurately as possible. In this case the cell was designed to simulate a sphere-plane gap in technically pure transformer oil.

### 2.1.1 Design

The complete test cell is shown in Figure 2.1 with the majority of the constructional details illustrated in Figures 2.2 and 2.3. The following criteria were considered in the design:

(1) The electrode simulation had to be accurate for a sphere of 7mm and gap lengths from 2mm to 6mm. The plate electrode was to be the high voltage electrode.

(2) The cell was to contain a large volumn of oil in order that by-products of a breakdown, diffusing into the volume of the liquid, would have little effect on further breakdowns.

(3) The contact of oil and free air was to be minimized. This would prevent dust and lint in the air from settling in the liquid and also limit the exposure of the oil to oxygen and water vapour in the atmosphere.

(4) A means of adjusting the gap length between the sphere and plane, without disturbing the oil sample, was to be incorporated.

(5) With the exceptions of breakdowns in the test

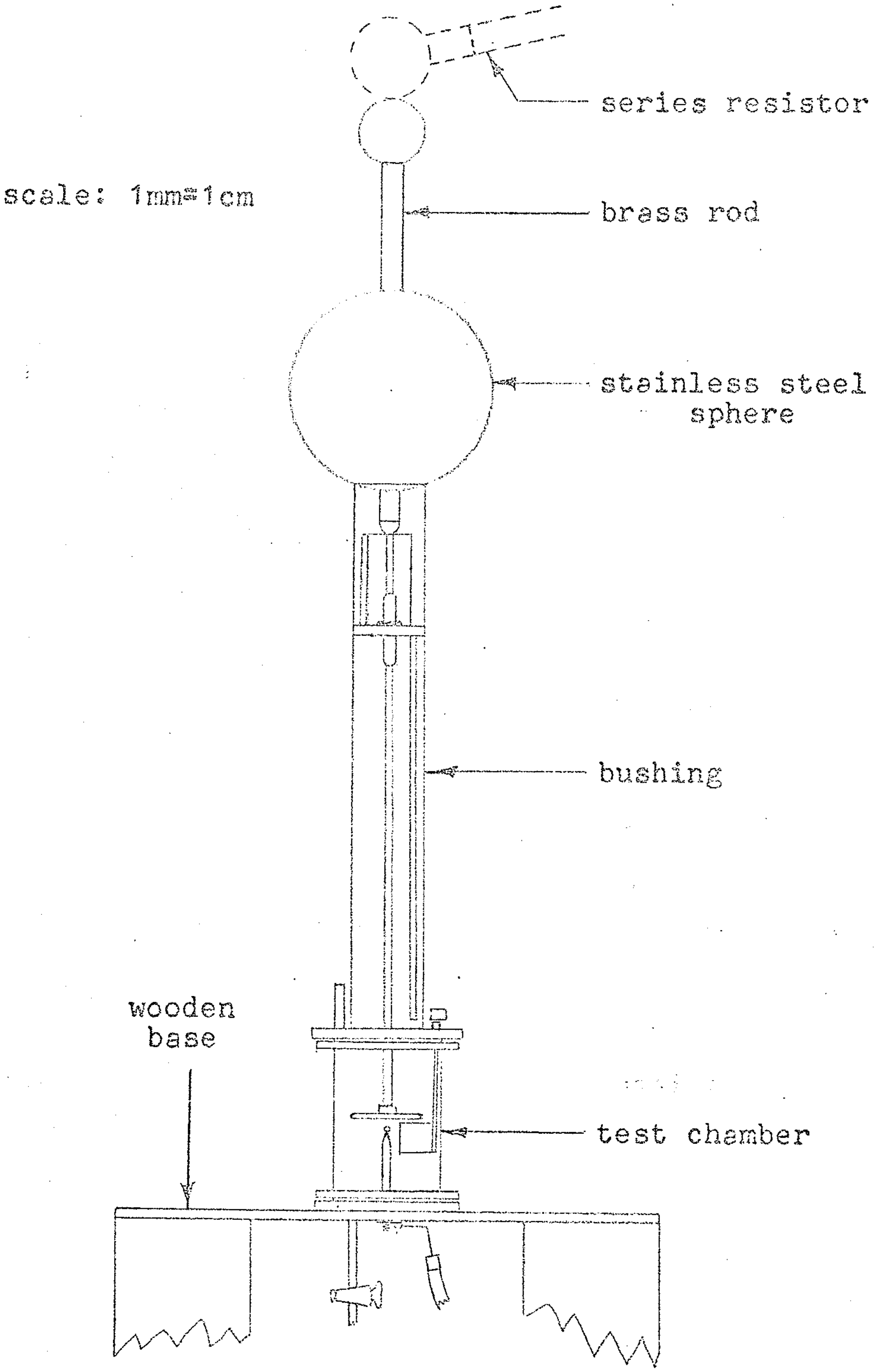
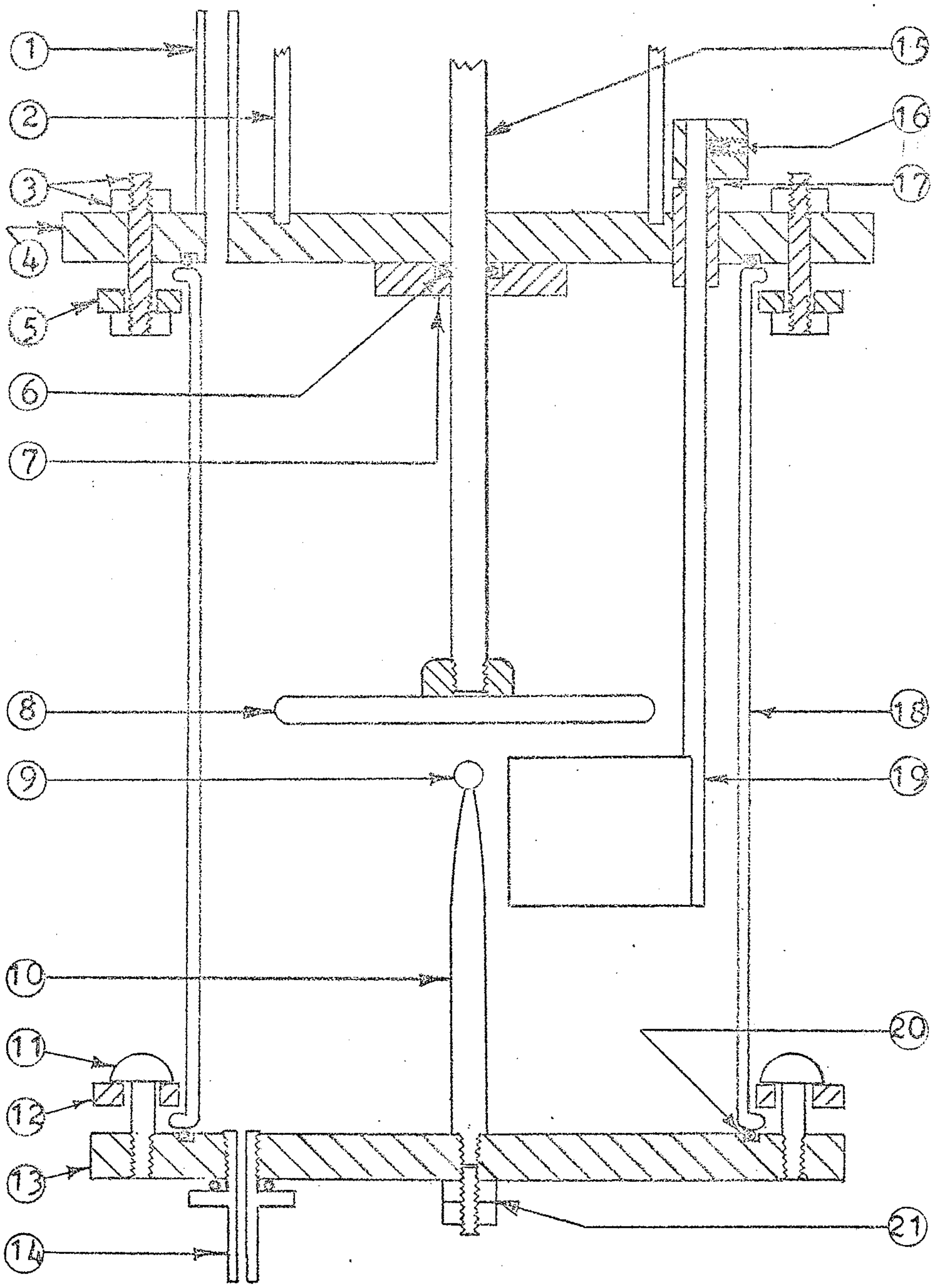


FIGURE 2.1

THE TEST CELL



scale: 1cm=2cm

see page 7a for list of components

FIGURE 2.2

TEST CHAMBER

1-vent

2-10.4cm diameter perspex cylnder

3-threaded permalley rod and nylon nut

4-perspex plate

5-plywood annulus

6-neoprene O-ring

7-perspex plate

8-chrome plated brass disk

9-stainless steel, 7mm diameter ball

10-9.5mm diameter brass rod

11-brass screw

12-plywood annulus

13-brass plate

14-brass connector

15-9.5mm diameter brass rod

16-set screw

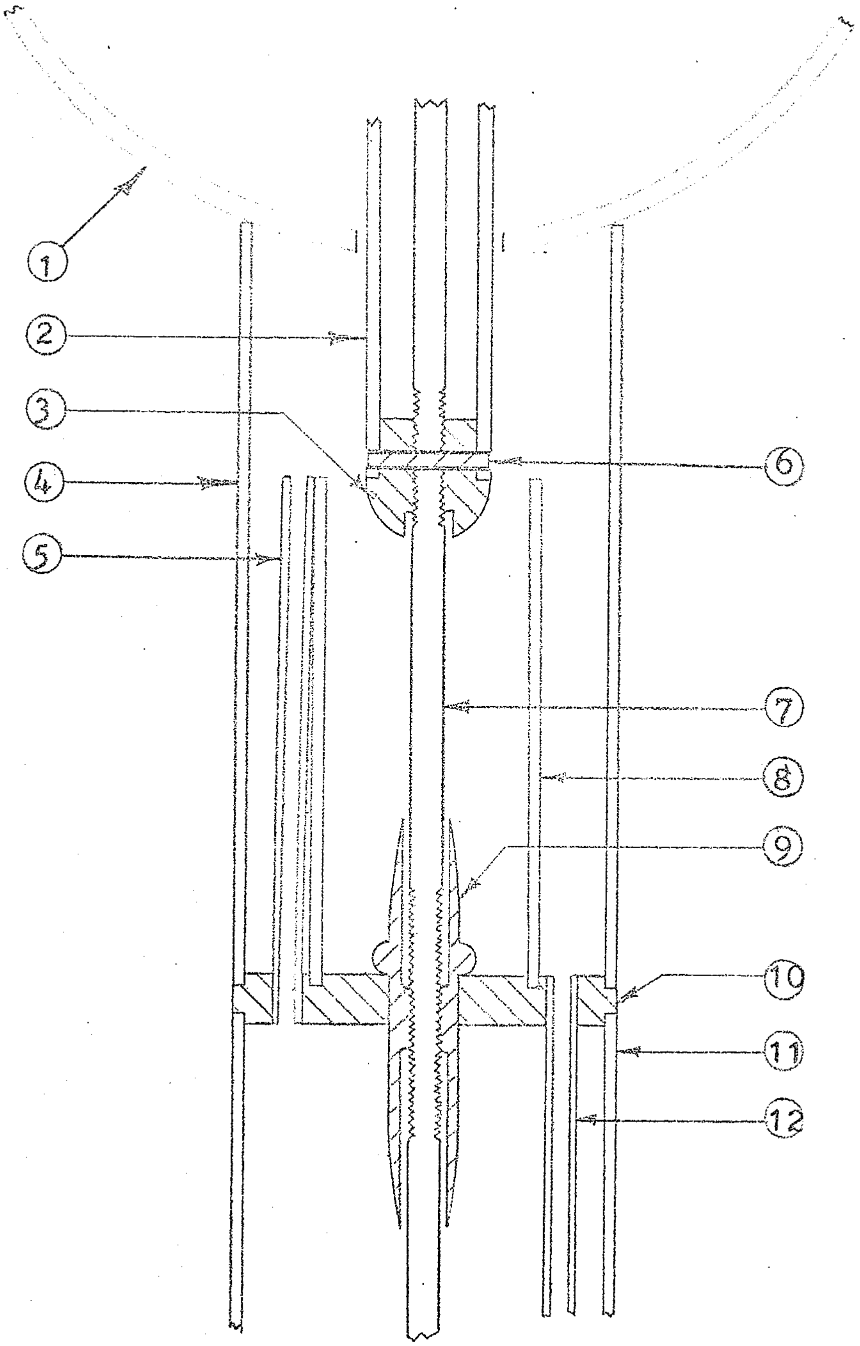
17-neoprene O-ring

18-pyrex cylinder

19-perspex stirrer

20-neoprene O-ring

21-electrical attachment



scale: 1cm≃2cm

see page 8a for list of components

FIGURE 2.3

TOP END OF BUSHING

1-28cm diameter stainless steel sphere
2-3.4cm diameter brass pipe
3-brass plug
4-10.4cm diameter perspex cylinder
5-glass vent
6-brass pin
7-9.5mm diameter rod
8-6cm diameter perspex cylinder
9-brass collar
10-perspex plate
11-10.4cm diameter perspex cylinder
12-glass filling tube

gap, the cell was to be capable of withstanding voltages up to $300^{KV}$.

(6) A means of removing bubbles, which would accumulate under the plate electrode after breakdown, was to be included.

The cell consisted of a 23.6cm long, 15.2cm diameter pyrex cylinder, clamped between a brass plate at the bottom and a perspex plate at the top, and held approximately 3.95 litres of oil. A vent on the perspex plate allowed air to escape during the filling of the test cell and vented off gasses produced by breakdowns in the test gap. A paddle, passing through the perspex plate, was operated manually. Its function was to drive bubbles from the underside of the plate electrode and aid in circulating the oil in the cell.

The brass rod supporting the plate electrode was centered in a perspex tube filled with transformer oil, forming a simple bushing. The top portion of the brass rod was threaded and passed through a brass collar which was threaded internally. The brass collar was firmly glued to a perspex disk mounted on the bushing cylinder. An additional cylinder was attached to the top of the perspex disk extending the length of the bushing. A neoprene o-ring prevented the oil of the bushing from leaking into the test cell. All metal edges within the test cell and bushing were rounded and all threads shielded to prevent corona which would interfere with current measurements and contaminate the oil in the test cell and bushing.

### 2.1.2 Gap Adjustment

The plate electrode was raised or lowered by turning the brass rod. The collar was rigidly fixed to the bushing so that the rod was forced to move when turned; being threaded in the collar.

A small inner perspex cylinder was attached to the top portion of the bushing. This cylinder was marked with 30 equally spaced graduations around its circumference. The brass rod and collar had 24 threads per inch.

The gap length was set as follows. An ohmmeter was attached to the top of the brass rod and to the brass plate (the base of the test cell). The rod was turned, moving the plate electrode toward the sphere electrode until the ohmmeter indicated contact of the two. The rod was then rotated in the opposite direction through the required number of graduations to give the gap length desired. As an example, a 2mm gap required the turning of the rod through 56.6 graduations.

### 2.1.3 Electrical Attachment of Cell with Circuit

Figure 2.1 illustrates the brass rod which supports the plate electrode, attached to the series resistor in the generator circuit. The 28cm diameter sphere was mounted at the top end of the bushing to reduce electrical stress. The spheres at the end of the 3.5cm diameter brass pipe and resistor ensured a corona free electrical contact between the two.

Contact with the sphere electrode was accomplished