ATMOSPHERIC CONTAMINATION ON HIGH VOLTAGE INSULATORS AND A STUDY TO IMPROVE CONDITIONS

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SUMMARY

Comparative studies of leakage currents, dry and wet flashover of contaminated insulators with similar readings taken on new insulators are made. The possibilities of removing the encrustation on insulators are studied. The presence of the electrical field on the insulator has an effect on the deposition of impurities and some means are suggested to avoid or reduce the amount of deposits.

Whenever a transmission line or a switching station is constructed careful attention is paid to the co-ordination of the insulation of the line with that of the other equipment both for power frequency and impulse surges. The number of insulators is fixed so as to have a wet flashover voltage between 3 to 3·5 times line to neutral voltage and to have an impulse flashover equal to at least the basic impulse insulation level of the apparatus. This is necessary to avoid as far as possible an interruption to service due to a breakdown of this insulation except under severe abnormal conditions. The flashover characteristics of insulators in air will vary with atmospheric conditions around the insulators and with the surface conditions on the insulator. Detailed studies have been made with regard to the variation in the flashover characteristics with variation of barometric pressure and humidity of the atmosphere and the performance of the insulator under variation of these conditions could be fairly accurately predicted. But one of the major unsolved problems of the electric supply industry is the behaviour of insulators under conditions of industrial contamination. It is often necessary that electrical lines should be situated in close proximity to industrial installations which throw out various solid impurities into the atmosphere and with changing winds and probably due also to the presence of the electrical field around the insulator these solid particles settle on the insulator surface changing their electrical properties completely. This problem assumes greater importance with the increasing industrialization of the country and has been engaging the attention of the insulator manufacturers and also of the supply industry from a number of years. The manufacturers have put forward special types of insulators to suit conditions of severe atmospheric contamination. In the simplest type of such insulators the leakage path is made considerably longer by the provision of additional petticoats. More complicated designs using an oil seal in the leakage path have also been recommended. Attempts have also been made to get more uniform voltage distribution along the stack by the use of special resistances built into them. Resistance glazes have also been tried for the same purpose. Over-insulation of the portion of the line lying in the industrial zone is one of the methods usually adopted. British standard specification No. 137–1941 recommends that for selecting insulators for use in polluted atmospheres, insulators suitable for the next higher rating should be selected and that for use under highly polluted atmospheric condition the length of leakage path must be increased to at least double that of the leakage path of the normal type of insulators—this increase in leakage path to be obtained partly by using insulators for the next higher rating and partly by using special insulators with long leakage path known as anti-dust or anti-fog insulators.

In order to study this problem of the behaviour of insulators under conditions of atmospheric contamination in greater detail a number of insulators which had been in actual service for varying lengths of time were obtained from the supply industry. These insulators had been exposed over a period of years to different kinds of atmospheric contamination. Tests indicated that the deposits on the insulators varied depending on the location from which the insulators had been removed. Various types of deposits like ordinary dust and dirt, a mixture of dust soot and oil, deposit of calcium and magnesium carbonates, ordinary salt, deposit of cement dust, and other foreign materials were met with. In one case of insulators removed from a chemical factory even the glaze on the porcelain had been attacked. The foreign material was not uniformly deposited on the surface but possibly due to wind, the electrical field, and the humidity of the air showed various thicknesses at different spots. Some of the deposits could be easily removed by washing with ordinary water but in some cases specially in the case of insulators removed from the proximity of a cement factory chemical means had to be adopted to remove the impurities.

These surface layers which are nearly non-conducting while dry become conducting or semi-conducting under wet conditions. The main effects of these conducting films on the surface of outdoor insulators when subjected to high voltage are the leakage current, flashover, local sparking, and corrosion. The effect and relative importance on the operating conditions of the insulators of each one of these depend on the type and nature of the contamination on the insulator surface. The leakage current flowing between the line and the ground would be inversely proportional to the total resistance of the contaminating film and since for a given line all these leakage currents are in parallel their sum may sometimes assume a high enough proportion to trip out the line. Also the presence of these semi-conducting films on the surface of the insulator results in a distortion of the voltage gradient over the insulators and these voltage stresses may assume values high enough to cause flashover over the insulator surface specially under rain. Sometimes even if complete flashover does not take place local sparking can occur over the surface of dirty insulators which may result in temperature rise or even puncture of the insulators if the combination of the local voltage gradient and local temperature rise is high enough. Further the leakage current flowing over the surface of the insulator appears to have directional property and an electrolytic action on the metal of the insulators. The ozone and nitric oxide formed as a result of corona on the insulator surface further accelerates this corrosion.

Therefore the investigation work in the laboratory was directed to answer the following questions:

1. How are the electrical properties changed by encrustation?

2. Can the encrustation be removed completely without damage to the insulators?

3. Is it possible to improve the electrical design or electrical working condition of a station to prevent further encrustation?

TEST PIECES

Out of a number of samples received 3 specimens were particularly selected for detailed tests. Specimen 1 is a pedestal insulator illustrated in Fig. 1, and has a total height of 26″ and a leakage distance of 44″. Specimen 2 also a pedestal insulator is illustrated in Fig. 2, and has a height of $9\frac{3}{4}''$ and a leakage distance of 18″. Specimen 3 is a string of 8 standard suspension insulators 10″ diameter $5\frac{3}{4}''$ spacing.

RESULTS

The results given in Tables I, II, III and V are the average of a number of readings taken on different dates on the same set of insulators and have been corrected to standard temperature and pressure. Comparative measurements of the leakage current through the insulators (both capacity and surface leakage) when excited to 110 kV r.m.s. and the wet and dry flashover of the insulators were taken and compared with values obtained on similar new insulators.

The *leakage currents* obtained are given in Table I. It will be noticed that the value of these currents depends on the nature of the impurity and that it assumes a fairly high value when the insulator is moistened. These high values of leakage currents may give rise to local heating of the porcelain with deleterious results.

TABLE I

Specimen	Insulator	Leakage current mA Dry	Wet
I	Pedestal insulators (cement and iron ore dust contaminated) (2 units) ..	0·65	1·5
	New insulators of same type as above (2 units)	0·1	0·5
II	Pedestal insulators exposed to acid fumes and chemical dust (4 units) ..	0·55	over 6 rapidly varying
	New insulators of the same type as II above (4 units)	less than 0·1	0·3

Comparative results of the *dry flashover* values are given in Table II. Specimens 2 and 3 which show a reduction of about 8 and 15% in the dry flashover values were very badly contaminated with acid fumes which had damaged the glaze on the porcelain in places. Specimen 1 exhibits an increase of about 5·5% in the dry flashover values. This specimen was coated with a thick layer of cement and iron ore dust. This rise may probably be explained by the fact that the insulator stack behaves as a resistance voltage divider and not as a capacitance divider.

When an encrusted unit is however subjected to moisture some of the dust, cement and salts might go into solution producing a conducting film. In the presence of large quantities of water some conducting elements may be leached out and hence the most dangerous condition for a contaminated insulator will not be during periods of heavy rain storm but when a drizzling rain or fog starts after a relatively long spell of dry weather when large quantities of dust have had an opportunity to accumulate on the surface. Under these circumstances the contaminated insulators give out heavy streamers, and corona over the entire contaminated surface and in some

TABLE II

Specimen	Insulator	Dry Flashover Voltage kV r.m.s. New	Dry Flashover Voltage kV r.m.s. Contaminated	Δ	Nature of Contamination
I	Pedestal Insulator (1 unit) ..	276	295	+5·45%	Cement and iron ore dust
	Do. (2 units)	409	410	..	Do.
II	Pedestal Insulators (4 units) ..	371	342	−7·8%	Acid fumes and chemical dust
III	Suspension Insulators (string of 8) ..	464	394	−15%	Do.

cases flashovers occur or the leakage currents assume such high proportions as to shatter the porcelain due to excessive heat. Further the insulation co-ordination of the whole system will be completely lost giving rise to unexpected and prolonged interruption.

A number of these encrusted units were subjected to *wet flashover* tests as per B.S.S. 137/1941 and the flashover was found to be 15 to 20% less than that of similar insulators not so contaminated. The values of the measurements are given in Table III.

TABLE III

Specimen	Insulator	Wet Flashover Voltage kV r.m.s. New	Wet Flashover Voltage kV r.m.s. Contaminated	Δ	Nature of Contamination
I	Pedestal Insulator (1 unit)	174	140	−19·5%	Cement and iron ore dust
	Do. (2 units)	299	220	−16·4%	Do.
II	Pedestal Insulator (4 units)	231	184	−20·4%	Acid fumes and chemical dust
III	Suspension Insulators (string of 8) ..	335	286	−14·6%	Do.

Effect of the electrical field on contamination.—To investigate if the presence of the electrical field on the insulator has a bearing on the dust precipitation, experiments were conducted in the laboratory with various types of smoke generators. After various trials the most successful type of smoke generator was found to be a paraffin oil smoke generator rigged up in the laboratory in which hot paraffin oil was blown over a coil of wire electrically heated. The jet of smoke so obtained was directed against the insulators and a noticeable alteration was found with and without the electrical field. While the smoke was curling round the insulator without the field it was noticed to be getting drawn into the electrical field and rise up in a column round the insulator when the same was charged (Figs. 3 and 4). The electrical field was then changed by interposing a circular plate 2½′ in diameter between the insulator and the conductor at the top and the disposition of the smoke was found to have altered, now being drawn to the edge of the plate and rising up in the form of an inverted cone (Figs. 5 and 6). Further work on this aspect is proceeding, and it may be possible to minimize the accumulation of dust by suitably designed guardrings.

Cleaning of insulators.—The regular cleaning of the insulators whilst energised, by pressure water, has been adopted by the supply industry since 1930. Under normal conditions this pressure water will effectively leach out most of the impurities. Ordinary dust and dirt can be completely removed but some thick encrustation like cement dust, calcium and magnesium salts, soot and oil combination can only be removed with varying degrees of success by this method. But even the thick and hard deposit of cement dust on the investigated insulators which are not removed by ordinary washing could be removed effectively by cleaning the insulators with dilute hydrochloric acid and rinsing them. The tests performed after this cleaning confirmed that the insulators had regained their original, dry and wet electrical properties. Considerable work has been done in the last few years to improve the electrical behaviour of porcelain insulators exposed to humid atmospheres. Conducting glaze has been applied to avoid any electrical charges remaining on the surfaces after transients or flashover and thus lowering the flashover voltage for the next transients. Further glass and ceramic surfaces previously conditioned to equilibrium with an atmosphere at 50–90% relative humidity adsorb methyl or ethyl chlorosilanes, hydrochloric acid being formed during the reaction. The product on the porcelain surface is a long chain silicon polymer adsorbed on the surface in such a manner that all the methyl groups form an outer layer giving a strongly water repellent surface which maintains a high electrical insulation even under very moist conditions (see Fig. 7).

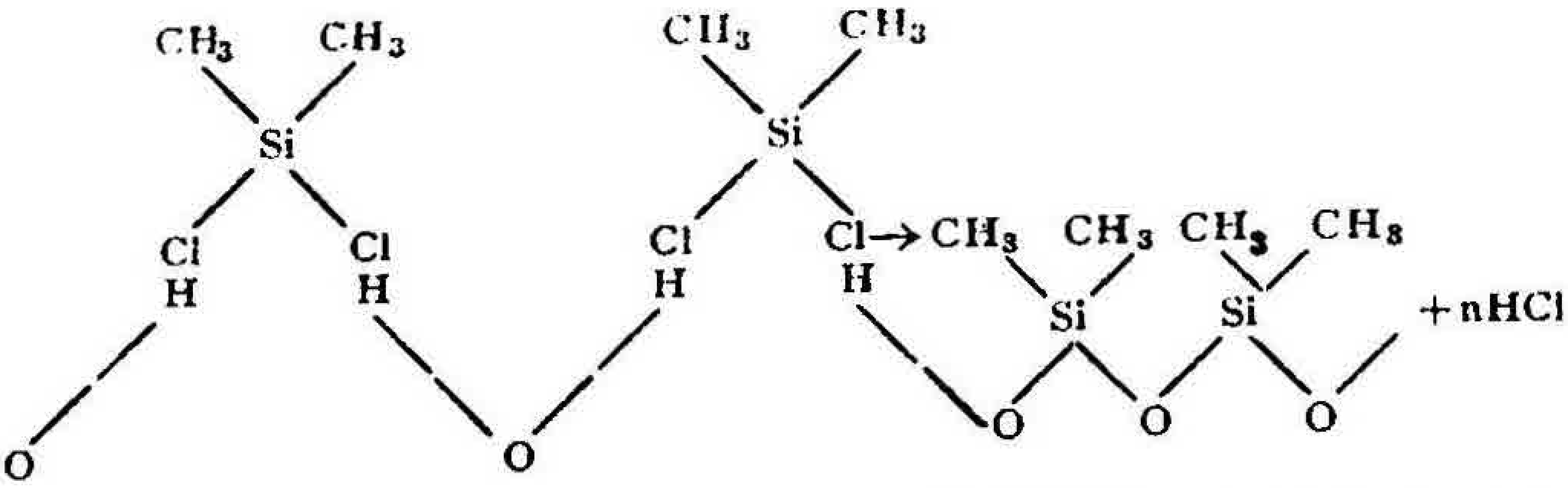

FIG. 7. Porcelain Surface—Reaction of dimethyl dichloro-silane on a porcelain surface

Some values of resistances reached by such treatment according to R. J. Meakins and others are given in Table IV.

TABLE IV

Treatment	Insulation Resistance (Megohms) at 98–100% Relative Humidity Nature of Surfaces		
	Glass Microscope Slides	Metallized Pyrex Tubes	Steatite Terminal Strips
1. Controls—			
(*a*) As received from the manufacturer	6×10^2	..	..
(*b*) Cleaned with chromic acid ..	5×10^2	5×10^2	1×10^2
2. Treated with methylchlorosilane vapour	10^6	10^6	2×10^5

Even a treatment with oil or grease of organosilicon compound will increase the surface resistance considerably. Such porcelain surfaces will stand the exposure to sun radiation and atmospheric conditions for a long time without change. There was only a decrease of the surface resistance from 10^6 Megohm to 4×10^5 Megohm after 57 days exposure at 98–100% relative humidity after samples were heated for 1 hour at 200–250° C.

It is doubtful if the increase of resistance of the insulator surface will make the insulator more suitable and more resistant against contamination. The application of a semiconducting coating like silicon grease might even give better results. Application of silicon grease* is very simple. Experiments were conducted in this laboratory on insulator specimens 1 and 2 by

* The materials are available from Dow Cornig Corporation,

coating them with Dow Cornig No. 41 silicon grease. The dry and wet flashover voltages obtained after this treatment are given in Table V along with the corresponding values for clean insulators not so coated. It will be noticed that while the dry flashover voltage of the insulator remains practically the same after it is coated with this grease, the wet flashover voltage of such insulators increases by as much as 23 to 30% above the wet flashover voltage of the new insulator.

TABLE V

Speci-men	Insulator	Dry Flashover Voltage kV r.m.s.		Wet Flashover Voltage kV r.m.s.		% Increase in wet flashover
		New	Coated with silicon grease	New	Coated with silicon grease	
I	Pedestal Insulator (2 units) ..	409	400	299	368	23%
II	Do. (4 units) ..	371	362	231	300	30%

CONCLUSION

The atmospheric contamination of high voltage insulators is a serious problem in some parts of the country. Cleaning of encrusted insulators is possible but in some cases very costly and toilsome. Two methods described are suggested to reduce the contamination of endangered insulators: field changes round the porcelain insulator and the application of a semi-conducting silicon grease.

REFERENCES

1. Frey, H. A. .. "Insulator surface contamination," *Trans. Amer. Inst. Elect. Engrs.*, 1948, 67, 1420-1425.
2. Taylor, J. J. .. "Insulators to withstand air borne deposits", *Ibid.*, 1948, 67, 1436-1441.
3. Bradley Cozzens and Blakeslee, T. M. "Performance of dust contaminated insulators in fog", *Ibid.*, 1948, 67, 1686-1692.
4. Leslie Hill, G. .. "Tests and developments in connection with hot-line insulator washing," *Ibid.*, 1947, 66, 1203-1216.
5. John, W. J. and Sayers, F. M. .. "Transmission line insulators under deposit conditions," *Journ. Inst. Elect. Engrs.*, 1935, 77, 629-662.

6. Forrest, J. J. .. "The characteristics and performance in service of High Voltage porcelain insulators," *Ibid.*, 1942, 89, 60–92.

7. John, W. J. and Clark, C. H. W. "Testing of transmission line insulators under deposit conditions," *Ibid.*, 1939, 85, 590–609.

8. Johanson, O. K. and Torak, J. J. "The use of dimethyl silicone to produce water repellent surfaces on glass insulator bodies," *Proc. Int. Radio Engrs. N. Y., wav Electrons*, May 1946, 34, 296–302.

9. Dreyden, J. S. and Meakins, R. J. "Treatment of glass and steatite ceramic with quaternary ammonium compounds for the improvement of electrical insulation resistance", *Nature*, (Lond.), Jan. 3, 1948, 161, 23–24.

10. ———— "Major fault at Portobello", *Elect. Times*, 19th Feb. 1953.

11. British standard specifications, 1941, 137.

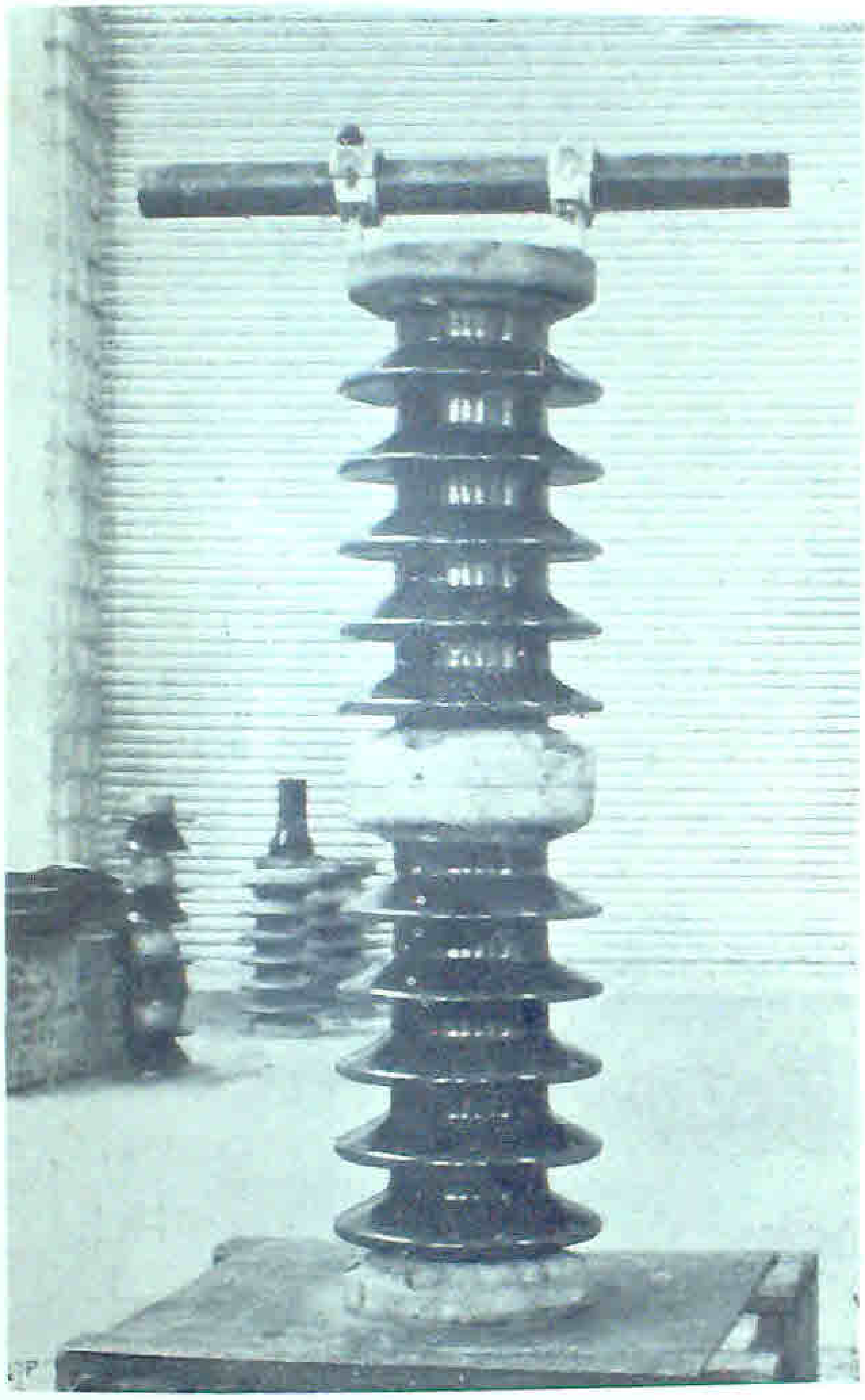

FIG. 1. Pedestal Insulator, Height 26", Leakage distance 44"

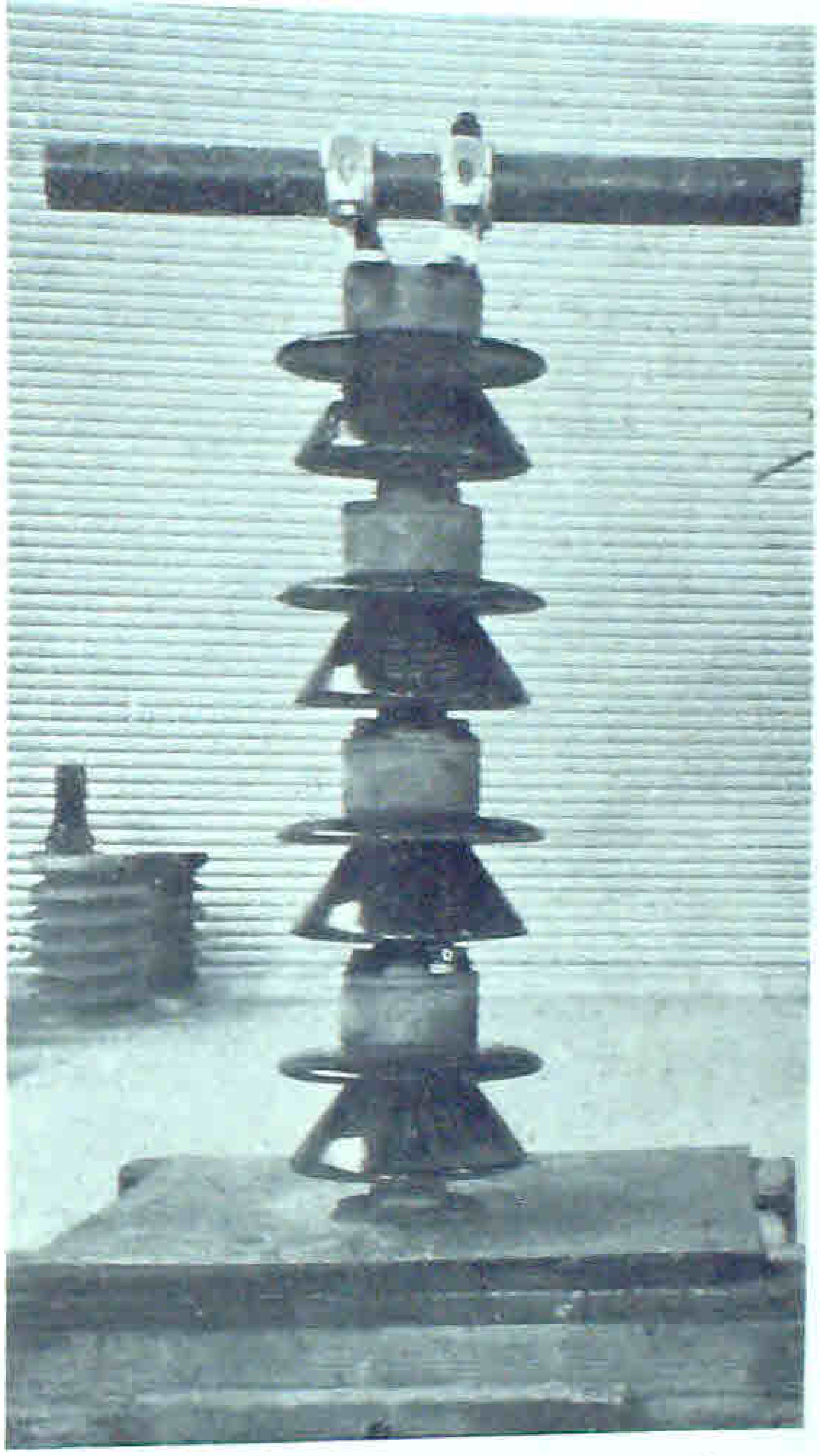

FIG. 2. Pedestal Insulator. Height $9\frac{3}{4}$" Leakage distance 18"

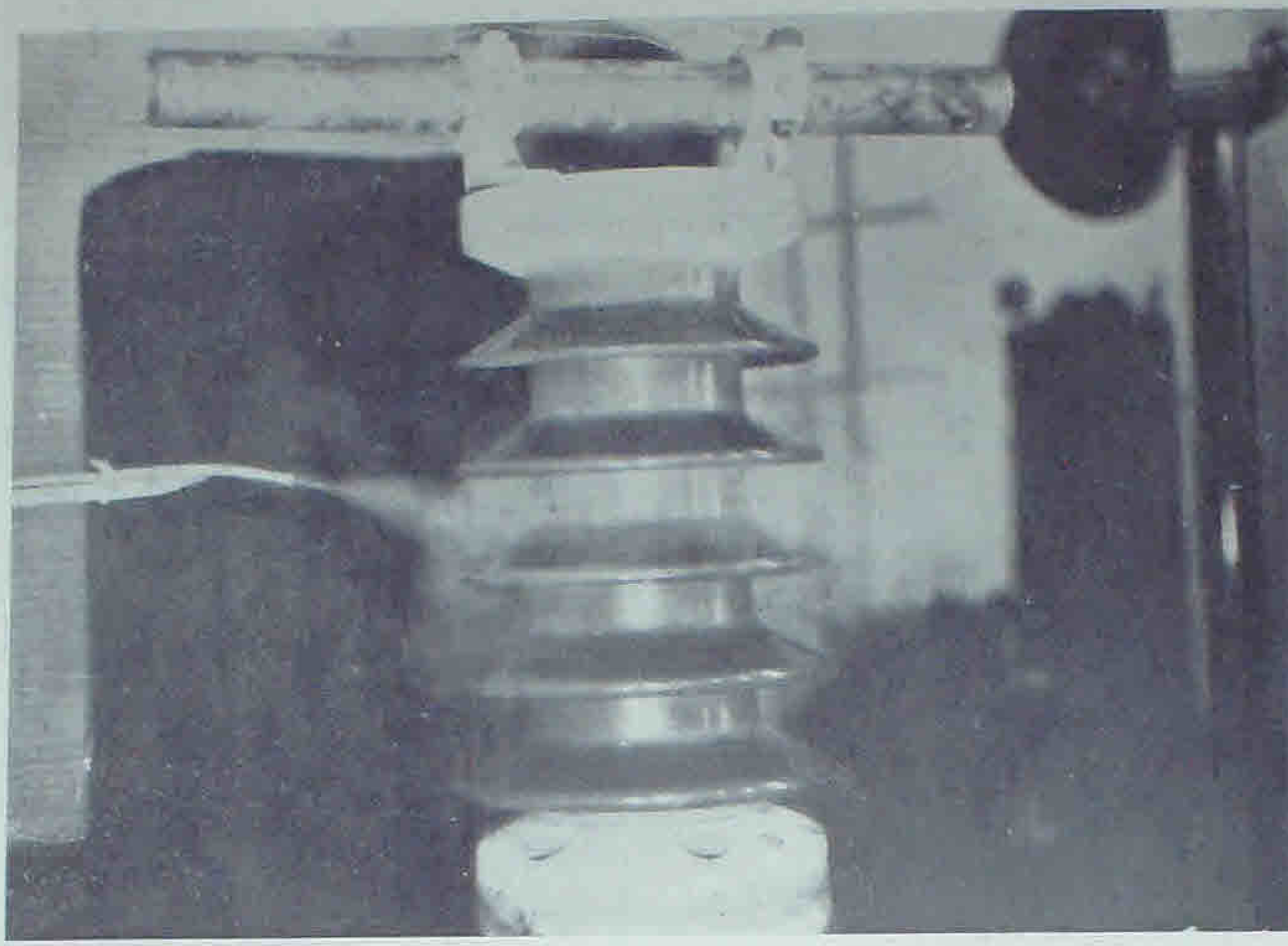

FIG. 3. Pedestal Insulator with smoke—No electrical field

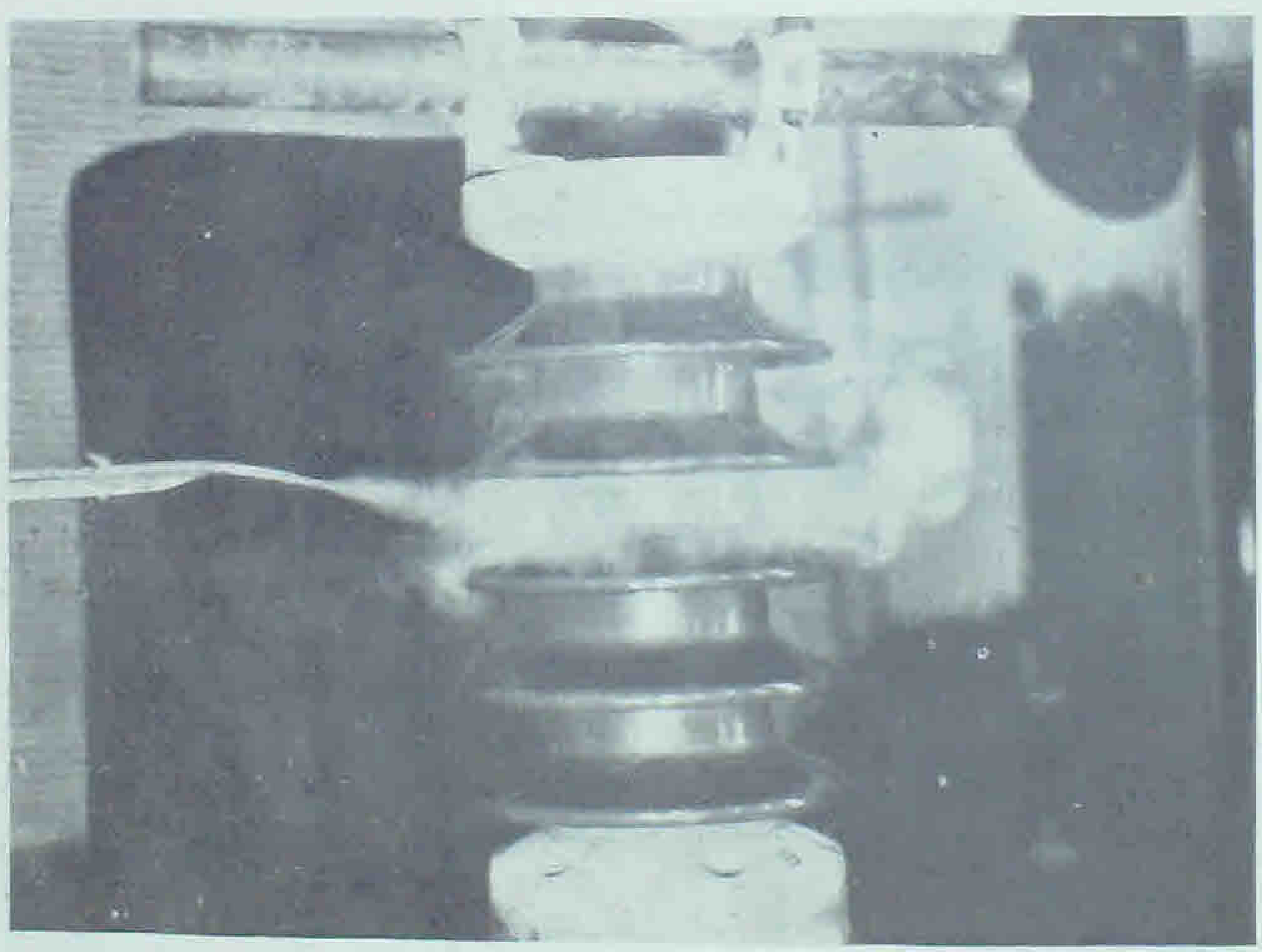

FIG. 4. Pedestal Insulator with smoke—electrical field, 150 kV. applied

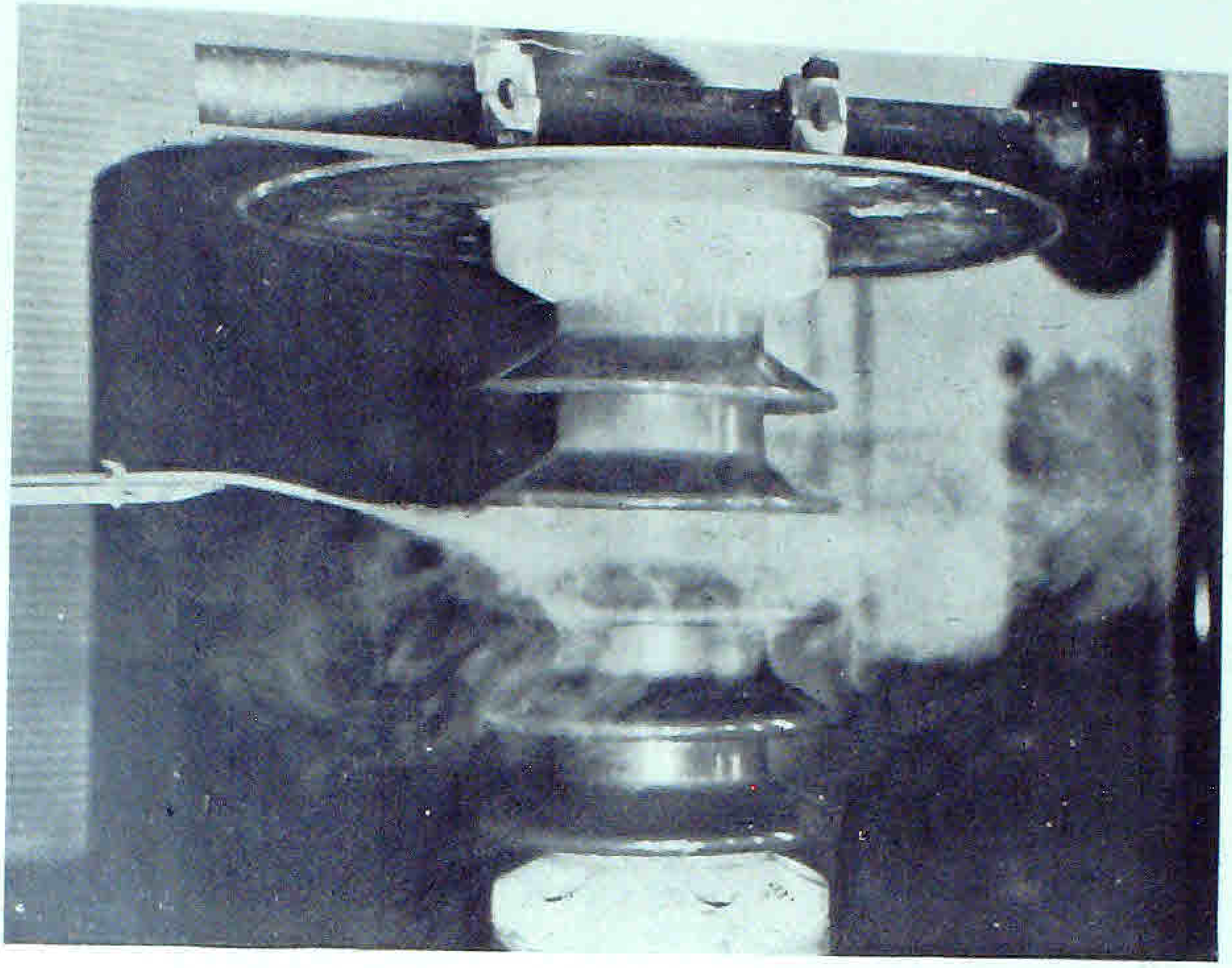

FIG. 5.—Pedestal Insulator with plate and smoke—No electrical field

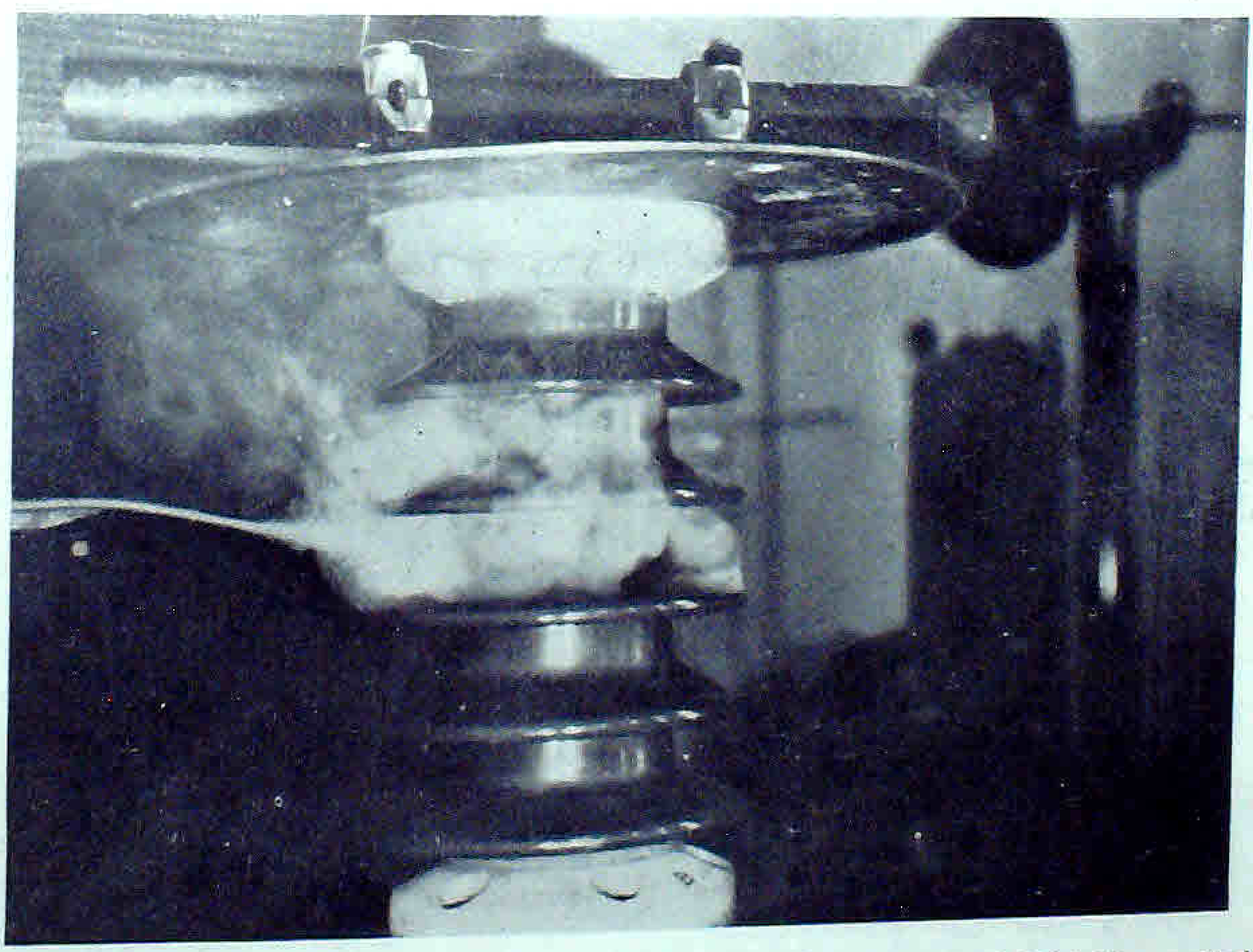

FIG. 6.—Pedestal Insulator with plate and smoke—electrical field 200 kV. applied