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Paper 33A

Developments in Overhead Equipment

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1 Introduction

The first railway electrification project in this country using alternating current at the standard frequency of 50 cycles/sec. was carried out between Lancaster, Morecambe and Heysham in the years 1952/53. This experimental installation energised at 6,600V, enabled an early comparison to be made between different forms of masts, cantilevers, insulators and other features of the overhead catenary system.

Following the inception of British Railways' Modernisation Programme in 1955, a range of equipment was designed following on the award of a contract for Designs which were developed in association with and to the requirements of the Chief Electrical Engineer, British Transport Commission. These designs were based on previous experience and had as the main objects the use of standardised components, a high standard of operating performance and the minimum of maintenance in the arduous service conditions known to exist. The present schemes on the London Midland, Scottish and Eastern Regions of British Railways are being carried out using this equipment.

Throughout these years, an intensive research and development programme has been vigorously pursued in parallel with current manufacture and installation. In this Paper the authors outline some of the developments with which they are concerned and indicate new materials and improved manufacturing techniques which are at present being applied, or which offer promising lines for further exploration and study. Resulting from this work technically advanced designs of line fittings and assemblies are now planned or in production.

2 The Catenary System

2.1 *New Materials*

Although of relatively recent application to the catenary system it seems probable that few materials offer such scope for development as the resin based materials of the phenolic, epoxide or polyester types. Included in this general category is a wide range of casting resins, adhesives and moulding compounds which can give good resistance to thermal shock, chemical stability, high mechanical strength and satisfactory electrical performance. They may be modified by the inclusion of inorganic fillers, the addition of internal reinforcement or the application of protective surface finishes to improve their electrical and mechanical characteristics.

Chief among the reinforcing materials now in use is glass fibre. Used in the manufacture of moulded components and in the production of laminates, tubes and rods, glass fibre can give reinforced products with extremely good mechanical properties. This may be seen by reference to Table 1 which sets out minimum values which can now be obtained with resin bonded glass fibre rods.

Table 1

Mechanical Properties of Resin Bonded Glass Fibre Rod

	p.s.i	*kg/cm²*
Modulus of elasticity in bending	$5{\cdot}5 \times 10^6$	$0{\cdot}39 \times 10^6$
Modulus of elasticity in tension	$4{\cdot}5 \times 10^6$	$0{\cdot}32 \times 10^6$
Modulus of rigidity	$0{\cdot}45 \times 10^6$	$0{\cdot}32 \times 10^5$
Compressive stress	70,000	4,920
Tensile stress	120,000	8,420

Laboratory examination of these rods has also shown the fatigue strength and creep resistance to be very high although for certain applications problems arise due to the unacceptable degree of deflection.

The electrical performance of resin based materials is limited by their susceptibility to surface tracking under high electrical stress, and this is particularly apparent in the presence of dust or salt deposits when areas of high electrical stress may develop even with low or medium voltage applications. Prolonged outdoor testing at stresses up to 5,000 volts/inch, has shown that the incorporation of hydrated alumina, silica, mica and other inorganic fillers yields a marked improvement in anti-tracking properties. Such additions however require careful control of the particle size of the filler employed and where they are included at the expense of the glass content in glass reinforced resins, a lower mechanical strength will result. For these reasons surface protection by other means is preferred. Sleeves of silicone rubber, P.T.F.E. (polytetrafluoroethylene) and ceramics have been successfully used with glass fibre rod insulators and further studies made of protective varnishes and surface depositions of P.T.F.E. in suspension. Despite the high initial cost, P.T.F.E. offers many advantages being chemically stable and possessing natural moisture and dirt repellency; in the form of sleeves, P.T.F.E. is flame and arc resistant and serves to protect the underlying glass fibre insulation from tracking and the effects of weathering and local heating, as shown by fig.1.

The first associated commercial application of glass fibre insulation took place in 1956 when 650 insulating steady arms were installed in tunnels during the execution of a 1,500V D.C. electrification project for the New South Wales Railways. To gain further experience with this type of insulation a small number of insulating steady arms and cantilever top tie insulators were experimentally installed near Liverpool Street Station on the 1,500V D.C. equipment and at 6,600V A.C. on the coastal line between Lancaster and Morecambe. Although no special measures were taken with these insulators to inhibit surface tracking, examination on removal after periods up to 2½ years has shown them to be in a satisfactory condition.

At the standard single phase system voltage of 25 kV electrical design stresses of between 600 and 800 volts/inch have been adopted and allowance made for the effects of corona, ionisation and surface erosion. Limited field trials with P.T.F.E. protected glass fibre insulators at 25 kV were put in hand in March 1959 on the line between Crewe and Manchester and at the present time there are representative insulators in service at conductor terminations, section insulators and in cantilever assemblies. These insulators have not been cleaned and are all in excellent condition.

For other applications consideration is being given to the use of the high strength alumina ceramics and devitrified glass. Although of high density and lower tensile strength than resin bonded glass fibre, these materials possess extreme hardness and chemical stability with resistance to arcing, heat, impact and weathering. The properties of the ceramics are capable of considerable modification during manufacture to meet specific requirements and seem well suited to their projected development as insulating and mechanical members of the catenary system. Tests on in-running ceramic units are shortly to be made with the principal object of simplifying high speed neutral sections and other electrical sectioning arrangements thus permitting more freedom in siting and substantial economy in installation.

2.2 *New Processes*

In the aircraft and other industries resin adhesives are widely used in place of welded, riveted and bolted connections. For galvanised steel work, where fitted bolts cannot be used, it has already been shown that resin filling of the clearance in the hole reduces the deflection of a structure.

For railway catenary systems the application of resin adhesives to porcelain/metal connections and to the termination of glass fibre insulators has been studied. The adaptation of these materials to structural steel work also offers promising lines for exploration.

For the connection of smaller components and wires the technique of compression jointing is now highly developed and affords a reliable and simple method of attachment. Using hydraulic pressure, ferrules of steel, aluminium, copper, malleable cast iron and other metals may be compressed on to structural sections which include rods, tubes, flat strip or stranded conductors. Similarly the ends of tubular members may be compressed on to inserts of smaller section. This method is now used extensively to dispense with bolted connections and to simplify assembly. Compression joints are used to terminate glass fibre rod insulators, the length and size of the ferrule determining the strength of the joints which may be consistently reproduced.

2.3 *New Components*

Many thousands of insulators are used each year in the execution of the electrification contracts. Hitherto these have been usually of porcelain and have given satisfactory performance under widely different climatic and loading conditions. There remains, however, the obvious susceptibility of porcelain to damage from impact whether during or after erection; flashover may also cause mechanical damage. At overlap spans, neutral sections and section insulators the bulk and weight of porcelain insulators and end fittings impose limitations on the design of these arrangements for high speed running.

It is thus opportune that following an extended period of development, resin bonded glass fibre should be adopted by British Railways as one of the standard forms of insulation for future work. Possessing high impact and tensile strength, lightness and flexibility, glass fibre insulators will initially be used at those locations where these properties may be used to maximum advantage. The insulators will take the form of resin bonded glass fibre rods of various diameters, fully protected by P.T.F.E. sleeves and terminated by compression ferrules.

A new form of section insulator has been designed weighing much less than the porcelain designs and completely symmetrical to preserve stability and give equal performance in either running direction. The design incorporates two P.T.F.E. covered glass fibre insulating tension members and runners of toughened glass which are provided to protect the P.T.F.E. from abrasion or cutting by the pantograph. At a test site specially prepared by the London Midland Region, fig.2, section insulators in a 25 kV circuit are being arc tested. It has been found that arcs of 200 amperes for periods of from 1 to 45 seconds and occasional short time arcs up to several times this current have not caused significant damage to any part of the section insulator.

The application of glass fibre insulation to neutral sections is likely to have equally far reaching effects. Here it is intended to use short lengths of insulation cut into the contact and catenary wires to replace the complicated and costly provision of four air gap clearances at the standard carrier wire high speed neutral sections. The current use of four section insulators for this purpose is not suited for running at the higher speeds where the additional weight and loss of flexibility become important. Ideally the insulation inserted in the contact wire should not introduce any irregularity likely to impair the quality of current collection. The use of glass fibre insulation, with a ceramic or other covering to resist abrasion, should enable an advance to be made towards this objective.

Other components designed to preserve constant elasticity of the contact line include 'roller' and 'plunger' contact wire registration devices. These have been developed to meet the need in large stations of methods of registration which will accept the heavy radial loads at crossovers without imposing a corresponding downward vertical force at the registration position. All moving parts are sealed against the ingress of dust and moisture, a principle which is applied to the turnbuckles used at wire terminations. In this design the screw threads are totally enclosed in the tubular galvanised steel body which is sealed at each end by means of neoprene caps. Internally, the threads are well greased and remain completely free moving after years of service in exposed areas.

Because of the importance of the correct greasing of such items, swivel fittings, etc., where continued lubrication in service is essential, laboratory evaluation was undertaken to examine the performance of a range of greases at low and high temperatures and after subjection to the leaching action of rainfall and chemical salts in solution. Further greases were considered for those applications where capacity effects or sparking might be expected to give rise to television interference. The influence of different greases on the performance of insulators under polluted conditions has been the subject of a most exhaustive study including trials at the fully instrumented insulator test gantry at Bishopsgate, London (see Papers 6 and 34). Following the correlation of the results of these tests with observed behaviour in normal operation, the adoption of a silicone grease has been recommended, conveniently applied as a thin film using pressure packs.

Where steam traffic will continue to operate over electrified lines, in industrial areas, and near the coast, difficulties may be encountered due to the corrosion of line fittings and structural steelwork. Certain components will call for occasional adjustment and it is thus desirable under these circumstances to avoid the use of screwed or bolted connections. For this reason and to simplify erection methods all catenary and contact wire clips, jumper support clips and certain other fittings are secured by cam operation, of which fig.3 is an example.

On the present schemes steel cantilever strut and steady arm tubes have been protected by the specially devised technique of copper cladding, each tube being hermetically sealed by soldered copper or neoprene caps. A new protection has now been demonstrated employing a resin based bituminous paint which is primarily intended for use with later designs of galvanised components. Different forms of paint treatment were initially applied to structures on the Lancaster – Morecambe – Heysham electrification where tubular steel, braced lattice and broad flanged beam masts were installed in addition to masts of aluminium alloy, timber and concrete. Subsequent trials with test panels installed in corrosive atmospheres have served to confirm the extensive data acquired.

2.3 *The New B.T.C. Design Range*

Electrification work in this country has been concentrated, in the main, in areas where heavy pollution could be expected and as a result the specifications for materials and insulation have probably been more severe than encountered anywhere else in the world. Coupled with this was the desire to reduce the necessity and cost of maintenance to a minimum on lines with high traffic densities.

Amongst the details specified to meet these conditions were limiting dimensions for the thickness of galvanised steel members, a normal creepage length for 25 kV insulators of 42 ins. and non-ferrous metal work on the live side of the insulators.

With the spread of electrification into rural areas some relaxation of these specifications is permissible and more attention can be concentrated on designs which allow for very rapid erection, adjustment and maintenance. Substantial economies accrue from these considerations and the simultaneous adoption of maximum standardisation.

To meet these changed requirements a new range of components and assemblies is in course of development. Some fittings are already in production. The main features of these are set out below:—

(*a*) One tool alone will be required for the assembly of all components.

(*b*) No nuts need be taken off bolt threads at any time after manufacture.

(*c*) Compression jointing of parts will be used wherever possible.
(*d*) All main components on the cantilevers will employ a single standardised connector.
(*e*) Main components will be suitable for a range of mast and cantilever tube size.
(*f*) The friction of all moving parts will be reduced to a minimum.
(*g*) Insulators may be rapidly changed.
(*h*) The maximum adjustment will be available to erection and maintenance personnel.

Fig.4 illustrates the features of the new cantilever design which embodies glass fibre insulation and galvanised ferrous components.

Equal attention has been paid to designs for use with multi-track structures where the standard form of suspension carries the catenaries on rollers over the structure bridge. To ensure satisfactory fatigue life of the catenary wires, accelerated tests have been conducted continuously over the past three years, establishing firstly the correct size, material and make-up of the catenary strand, and secondly, the material, groove profile and limiting diameter of the roller. A series of test curves in fig.5 enables a comparison to be made of roller characteristics. The present rollers incorporate an efficient self-lubricating roller bearing but recent tests with P.T.F.E./metal bearings have yielded very satisfactory results and will be adopted for future work.

The application of new techniques and materials to other items of overhead equipment is being pursued and it may well prove that some of the conventional design features for high voltage A.C. overhead equipment will emerge in modified form.

2.4 *New Assemblies*

It is generally accepted that to obtain a high quality of current collection at speed over the ambient temperature range it is essential to prevent tension variations in the contact and catenary wires and to compensate for the thermal contraction or expansion. The most usual method of securing this objective is by terminating the wires using a system of pulleys and balance weights and this arrangement is necessary at each anchor position. Apart from the expense of this system, difficulties arise under broken wire conditions and several types of balance weight arrestor have been tried in different countries with varying degrees of success. In co-operation with other manufacturers, designs have been produced of a hydraulically tensioned conductor termination and a prototype is now under study. This design suffers from none of the defects of the earlier balance weight arrangement. In principle, the conductors are tensioned by fluid pressure acting on a piston which moves in a cylinder of length equivalent to the maximum extension of the conductors due to temperature variation. It is simpler, very much cheaper, employs standard components, requires no arrestor device and tends to compensate for the friction drag at cantilever or roller supports.

The second stage in this development envisages a single hydraulic unit, replacing two balance weight terminations and associated anchor structures, at overlap spans where electrical sectioning is not required.

Other temperature sensitive devices are being investigated for related applications and early indications appear very promising.

Another most costly feature associated with present electrification schemes in this country is the civil engineering work necessary to provide the minimum electrical clearances particularly at overbridges and tunnels. For example, of the 92 bridges on the 40 route miles between Manchester and Crewe, 82 of these had to be lifted or modified in some form to provide clearance to the catenary at 25 kV. In Paper 14, reference is made to a scheme for secondary insulation at overbridges. As finally designed this takes the form of a butyl rubber mat installed between the catenary and the bridge lining to increase the electrical strength of the reduced clearance to a level commensurate with that of a minimum acceptable air clearance for a nominal 25 kV single phase system.

Where the width of the bridge becomes large or it lies on a skew alignment relative to the centre line of the track it becomes necessary to arrange for one or more intermediate supports for the catenary under the bridge. This too must not degrade the insulation level of the whole assembly. The requirement could be met within the space limitations only by an insulating arm designed to allow for the worst conditions of loading, pantograph sway and wear on both contact wire and pan collector strip.

The first arm designed and recently installed at Bridge 1041 on the Colchester – Clacton – Walton electrification is fabricated from glass reinforced polyester resin of suitably moulded profile, but the time interval is as yet too short to allow any assessment of final performance. A second design and one more readily adapted to variations in bridge or tunnel profile is based on quite different principles and makes use of a tubular steel member sheathed overall with P.T.F.E. or other insulant and electrically sectioned with glass fibre.

Subject to the satisfactory performance and acceptance of bridge secondary insulation it will be possible to equip at 25 kV, sections of line which would otherwise only be practicable at some lower voltage or following extensive remodelling of bridges en route.

3 The Catenary System – Performance

At low and medium train speeds, the sensitivity of the locomotive pantograph is such that a wide variation in pantograph pressure, flexibility of the catenary system, changes of gradient and ' hard spots ' can be tolerated without causing loss of contact or poor current collection. This is not the case at speeds in excess of approximately 50 m.p.h. when pressure variations tend to increase rapidly. These factors affect not only the general design parameters for the overhead equipment but require a much more precise determination of the performance data regarding the positioning and magnitude of concentrated masses in span, their mutual interaction, natural frequency of the catenary oscillation, etc.

Much useful information has been provided from test runs with the London Midland Region catenary test coach which has served to illustrate, amongst other points, the more uniform elasticity obtained with compound catenary construction. The operation of the test coach and experimentation with the catenary is, however, severly limited by reason of normal commercial operation, lack of access and cost. Prompted by the desire to increase the tempo of development, a test site, fig.6, was laid down at Prescot in 1954 consisting of four types of overhead equipment installed parallel to each other and supported on special structures to enable height and structure spacing to be varied. It was also necessary to design special instrumentation for the work to be carried out. Continuous records have been maintained of conductor tensions, temperatures, height variations and ambient conditions which in combination with other data has enabled a full static evaluation of the various forms of construction to be prepared. The problem of extending this work to embrace dynamic performance appeared for a considerable period to be insoluble until recent mathematical research showed conclusively that the production of a scale model was feasible and determined the scale constants.

Plans for a model testing station rapidly followed and it is now in an advanced stage of construction at Tolworth (see fig.7). The movement of the overhead equipment is measured electronically and by high speed photography at controlled temperatures. Thus we are now in a position to predict from model experiments up to scaled speeds of 100 m.p.h., detailed performance characteristics which may be checked mathematically and verified by full scale observation. If by so doing we are able to develop simpler, cheaper and more efficient forms of overhead equipment the research expenditure will indeed have been justified.

4 Conclusions

The combined physical and electrical properties of the resinous materials in a variety of forms have already led to the introduction of new components in the catenary system. Their further exploitation offers promise of substantial technical advances and economies, particularly for high-voltage A.C. systems.

New processes, with standardisation and simplification of components and designs, are reducing manufacturing costs and facilitating erection and maintenance.

New components and assemblies are making for simpler and cheaper constructions, with improved performance.

The dynamic model is proving a powerful tool, to support static test equipment, in the study of characteristics and performance of catenary systems and pantographs in combination.

Together, these developments are already demonstrating their value. In the authors' view, their further pursuit is likely to lead to significant simplification of catenary systems, to reductions in first cost of equipment and the civil work associated with electrification, and to easing of the problems of maintenance.

SUMMARY

The first 50 c/s A.C. railway electrification in Britain was an experimental project completed in March 1953. Development work on overhead equipment has been continued and extended, in parallel with British Railways' current electrification schemes, to embrace new materials and improved techniques.

Resin bonded glass fibre is finding increasing use for insulation: other materials indicate further fields for exploration. New processes are aiding the preparation of improved designs taking advantage of the reduced pollution hazards in rural areas.

Some of the developments are being applied: others are being pursued and have yet to be proved. Future lines for enquiry are indicated and aid in high speed studies is expected from a dynamically equivalent scale model of the catenary system and pantograph.

It is concluded that these developments will permit simpler erection methods, reduced costs and improved high speed performance.

RÉSUMÉ

La première électrification 50 Hz de chemins de fer en Grande-Bretagne fut un projet expérimentalé complété en Mars 1953. Les développements préliminaires sur les équipements des caténaires ont été continués et étendus parallèlement aux projects d'électrification en cours des Chemins de fer britanniques pour embrasser de nouveaux matériaux et des techniques améliorées.

Le tissu de verre imprégné de résine trouve un emploi croissant pour des isolations. D'autres matériaux conduisent à d'autres champs d'exploration. De nouveaux procédés aident la préparation des fabrications améliorées en utilisant la probabilité réduite de pollution dans les régions rurales.

Certains développements sont en application, d'autres sont poursuivis et sont encore à prouver. Les grandes lignes futures des investigations sont indiquées. On croit que les études en grandes vitesses seront aidés par un modèle à échelle réduite, dynamiquement équivalent à un système de caténaires et de pantographe.

ZUSAMMENFASSUNG

Die erste 50 Hz Wechselstrom – Elektrifizierung in Grossbritannien, vollendet in 1954, war ein Versuchsprojekt. Die in März 1953 Entwicklungsarbeit an der Oberleitungsausrüstung wurde gleichzeitig mit den laufenden Elektrifizierungsprojekten der 'British Railways' fortgeführt und ausgedehnt mit der Absicht, neue Materialien und verbesserte Ausführungsarten anzuwenden.

Harzgebundene Glasfasern finden für Isolationszwecke in zunehmendem Masse Anwendung, andere Materialien werden weiter erforscht. Neue Verfahren unterstützen die Vorbereitung von verbesserten Konstruktionen, die die verminderten Verunreinigungs-Gefahren in Landgegenden ausnützen.

Einige dieser Entwicklungen werden bereits angewendet, andere werden verfolgt und müssen noch ihre Eignung erweisen. Zukünftige Linien für Untersuchungen werden aufgezeigt. Hilfe in Studien mit hohen Geschwindigkeiten wird von einem dynamisch equivalenten, masstabgetreuen Oberleitungs- und Stromabnehmer-Modell erwartet.

Es wird gefolgert, dass diese Entwicklungen einfachere Montagemethoden, kleinere Kosten und bessere Leistungen bei hohen Geschwindigkeiten erlauben werden.

RESUMEN

La primera electrificación de los ferrocarriles a base de corriente alterna de 50 ciclos que se realizó en la Gran Bretaña fué una instalación de carácter experimental que se llevó a cabo en Marzo 1953. Se continuó ampliando el trabajo en torno a las líneas de contacto aéreo, a la par de los actuales proyectos de electrificación de los Ferrocarriles Británicos, que entrañó el empleo de nuevos materiales y diseños perfeccionados.

La fibra de vidrio impregnada de resina se usa cada vez como agente de aislamiento: otros materiales ofrecen halagüeñas perspectivas que merecen estudio. Los nuevos procedimientos constiuyen una valiosa ayuda en la preparación y perfeccionamiento de los diseños, aprovechándose de los menores peligros de contaminación que se dan en las zonas rurales.

Algunos de los descubrimientos logrados ya se han aplicado, pero otros, todavía en proceso de exploración, tienen que dar aún resultados satisfactorios en la práctica. Se indican las bases sobre las que se debe fundar el estudio futuro y el empleo de un modelo de sistema catenario y pantógrafo a escala reducida dinámicamente equivalente no podrá por menos de ser una valiosa ayuda en el estudio de alta velocidad.

En conclusión, estos avances permitirán recurrir a métodos más simples de instalación, reducir el volumen de costos y mejorar el rendimiento a elevada velocidad.

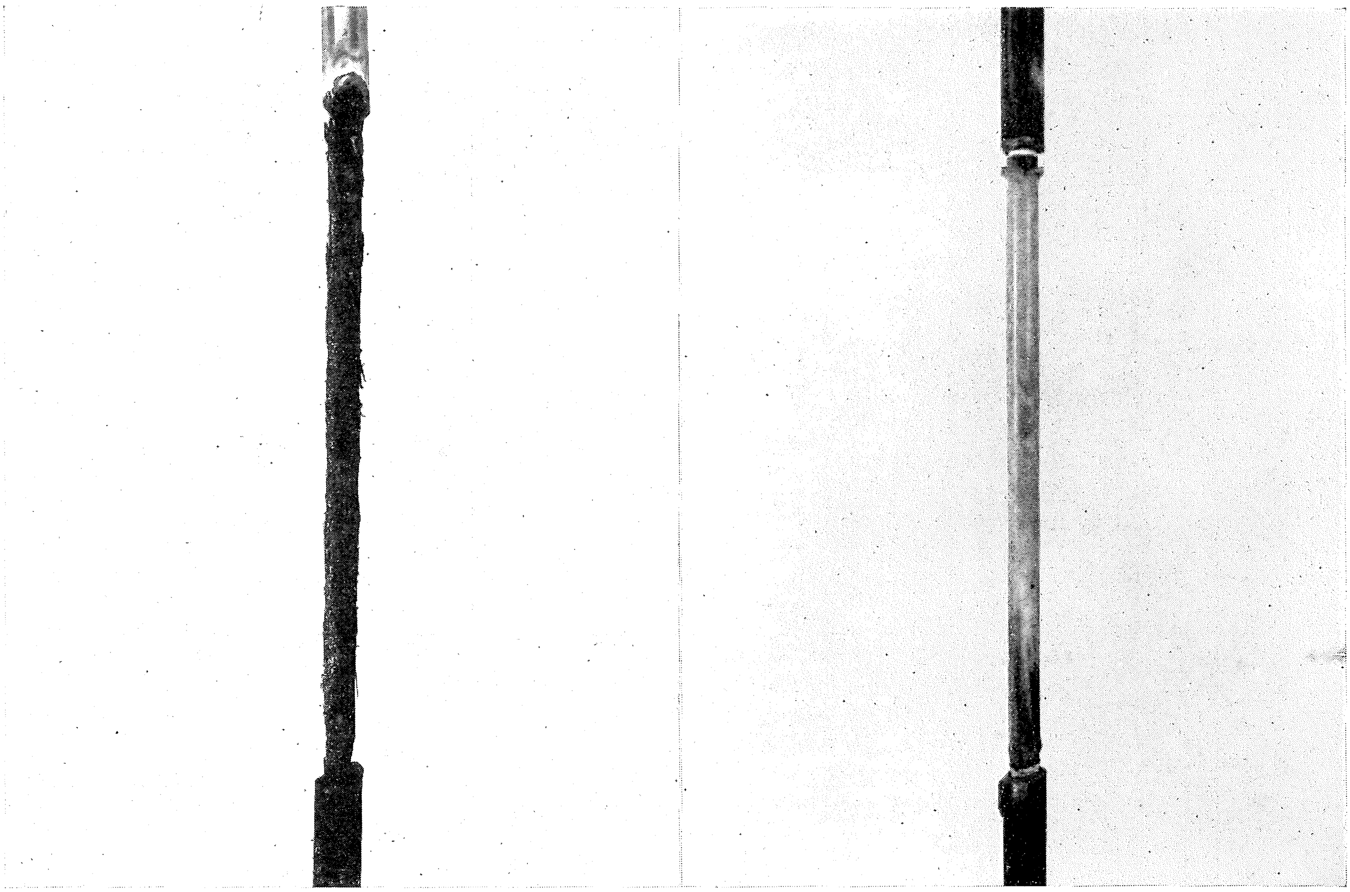

Fig.1 Glass fibre samples after arc tests
(a) Sample without P.T.F.E. sleeve
(b) Sample protected by P.T.F.E. sleeve

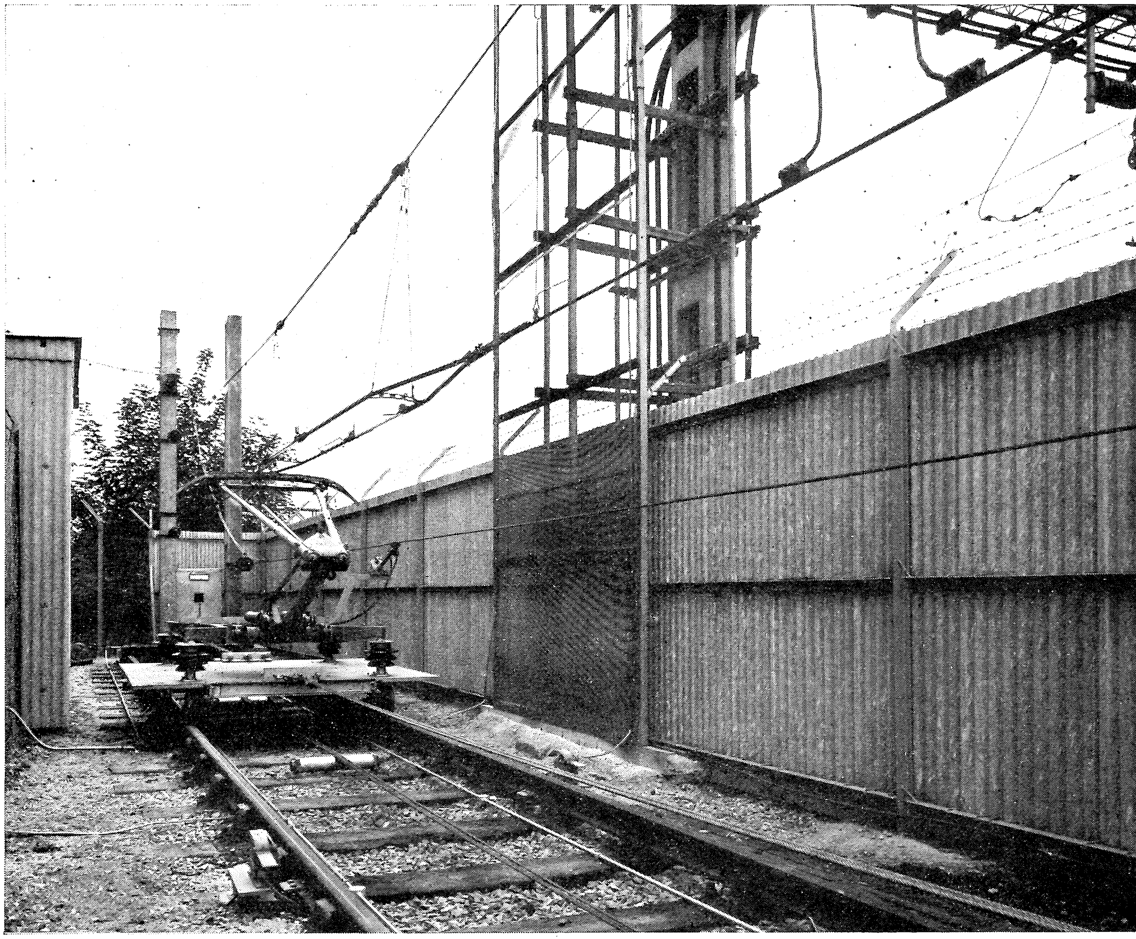

Fig.2 The new glass fibre section insulator undergoing power arc tests at Wilmslow

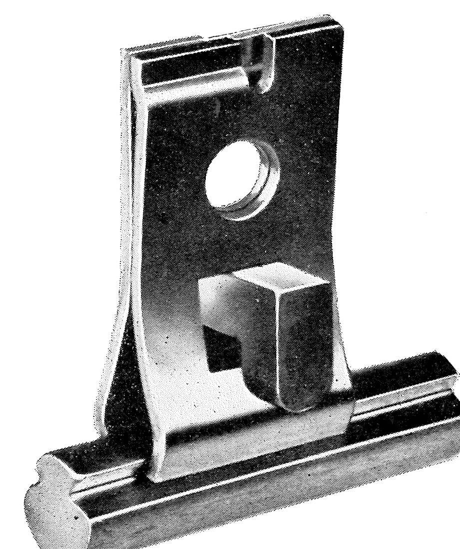

Fig.3 Contact wire dropper dip

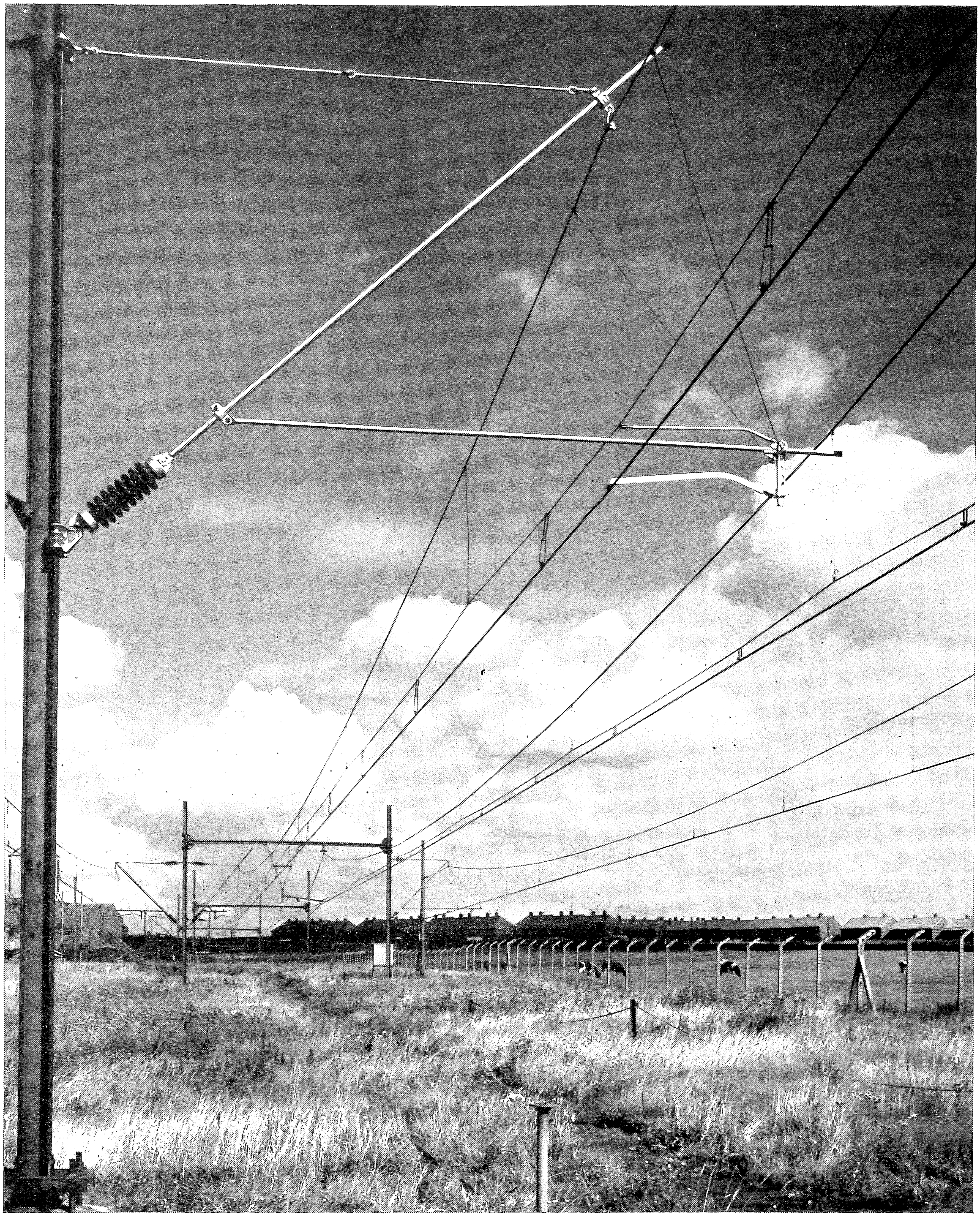

Fig.4 The new design cantilever as used with compound catenary equipment

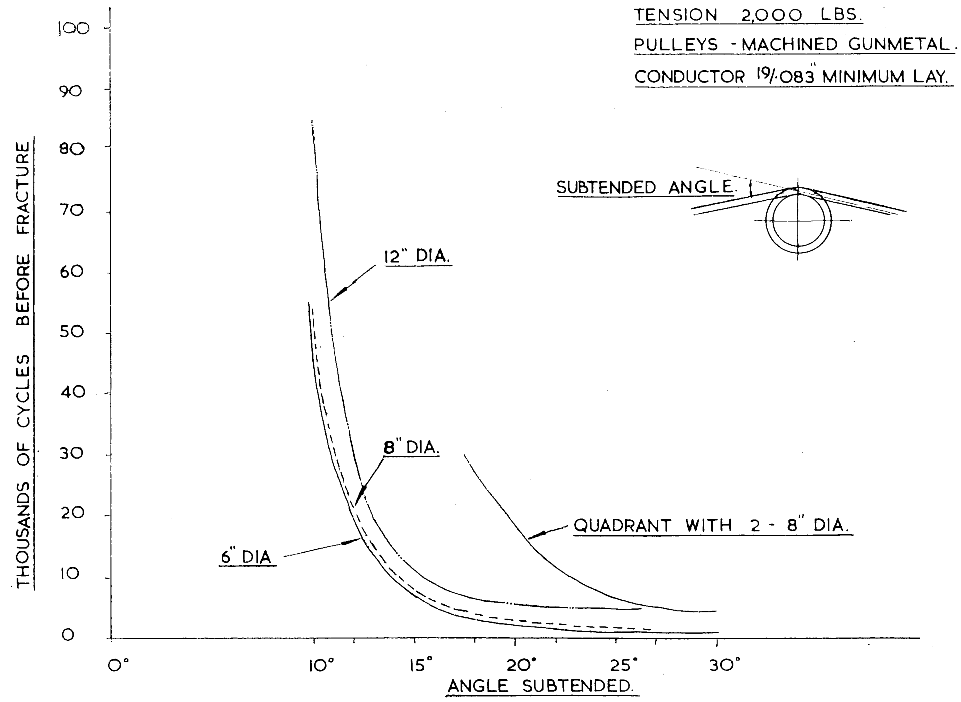

Fig.5 Tests with catenary suspension rollers. Graph showing relationship between subtended angle and test life for three sizes of catenary suspension roller

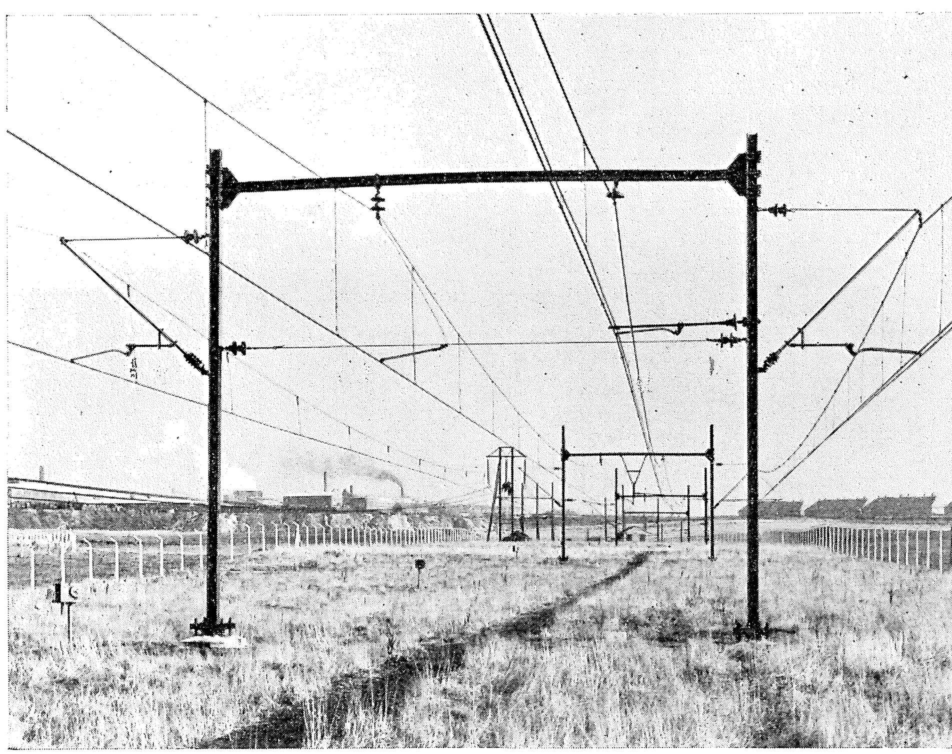

Fig.6 The Experimental Establishment at Rye Hey, Prescot

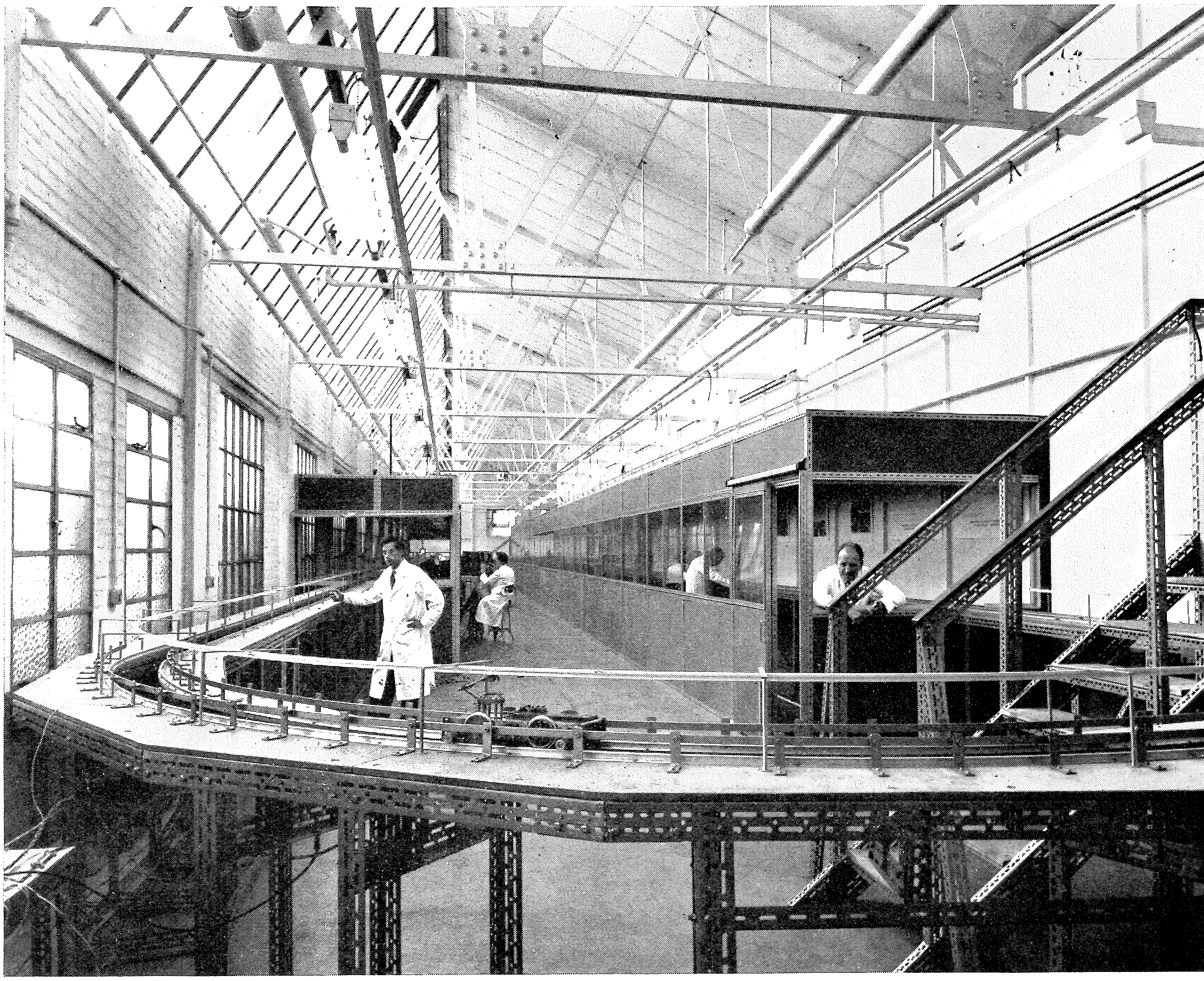

Fig.7 A view of the dynamically equivalent scale model of overhead equipment at Tolworth

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