DEVELOPMENTS IN RUBBER AND RUBBER COMPOSITES—2

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COLIN W. EVANS

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M.Phil., F.P.R.I., F.I.R.I., A.R.T.C.S., F.Inst.Pet.

Formerly Technical Director, Dunlop Limited, Gateshead, UK
Chairman, International Standards Organisation Committee, Rubber and Plastics Products
Chairman, Rubber Industry Standards Committee, British Standards Institution

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DEVELOPMENTS IN RUBBER AND RUBBER COMPOSITES—2

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PREFACE

This volume, the second in the series dealing with rubber and rubber composites and associated topics, describes and updates further products and branches of the rubber industry, namely cables, footwear, sports goods and latex products, while other sections deal with hazards and health and safety at work advice and short fibre reinforced elastomeric composite materials. The theme of miscellaneous and unusual applications of rubber and rubber-like materials has also been continued. Each chapter is written by a well-known specialist in the field under discussion.

Mention is made, although obviously within classified limits, of current and up-to-date techniques in the various topics discussed and, where possible, a look is taken into the future.

Thanks are expressed to all the contributors and their companies for permission to publish and also for the various illustrations which are separately acknowledged in the text. Thanks are also expressed to my secretary Miss Patricia McLeman and to my wife for her usual jovial, happy and helpful advice and encouragement.

COLIN W. EVANS

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LIST OF CONTRIBUTORS

A. R. Carter

Shoe and Allied Trades Research Association, Satra House, Rockingham Road, Kettering, Northants NN16 9JH, UK

T. Eccersley

Chemicals and Textiles Division, Department of Trade, Ashdown House, 123 Victoria Street, London SW1E 6RB, UK

C. W. Evans

Formerly Technical Director, Dunlop Limited, Hydraulic Hose Division, Earlsway, Team Valley, Gateshead NE8 1YR, UK

A. Ford

Bayer UK Limited, Bayer House, Manchester Road, Broadheath, Altrincham WA14 5PF, UK

R. C. Haines

Dunlop Sports Company Limited, 97 Bridge Road, Horbury, Wakefield, West Yorkshire WF4 5NN, UK

G. Lawson

Rubber and Plastics Research Association of Great Britain, Shawbury, Shrewsbury, Shropshire SY4 4NR, UK

R. E. Whittaker

Shoe and Allied Trades Research Association, Satra House, Rockingham Road, Kettering, Northants NN16 9JH, UK

Chapter 1

CABLES

C. W. EVANS

Formerly Technical Director, Dunlop Limited, Gateshead, UK

SUMMARY

The uses and types of cables have been divided into industry applications, and include oil, coal mining and quarrying, transport, shipbuilding, domestic and power distribution. Present and future applications within these parameters are discussed, together with materials, standards and specifications and the latest trends in manufacturing processes and engineering plant and equipment.

1 INTRODUCTION

Like most other products, electric cables have to be designed to meet specific requirements to accommodate the special needs of the industry to which they are to be supplied. For the purposes of this chapter, current and future usages in these major industries will include:

(a) the oil industry;
(b) the coal-mining and quarrying industries;
(c) transport;
(d) shipbuilding;
(e) domestic and miscellaneous applications;
(f) power distribution.

Other areas include telecommunications, electronics and aerospace, but the very high degree of specialisation to which cables are used in these applications is considered to be too limited in interest, and they are therefore not discussed. This omission, however, is not intended to imply a lessening of these important usages, as these too are very important cable outlets.

Before the Second World War natural rubber was used to the full and was in plentiful supply, with grades of excellent electrical properties readily available. In the mid-1930s Duprene[1] became available and was used where oil resistance and good weathering and environmental properties were needed. This of course was the name given to the early neoprenes[1] which today are classified as 'CR' rubbers. During the war years, home-produced PVC came on stream and GR-S, the forerunner of SBR, became available, at first slowly and then in ever-increasing quantities. The use of elastomeric materials for cables in the immediate post-war years was rather slow, partly because of the presence of thermoplastics and also because of their non-availability.

Since then, however, and especially today, the future is very bright because of many new polymers and also because of new processing technologies, such as new types of continuous vulcanisation and the availability of polymers in powdered and particulate forms.

The use of electric cables in various industries will now be considered.

2 THE OIL INDUSTRY

2.1 Offshore Installations

The main areas of cable installations within the oil and natural gas industries at the present time and in the foreseeable future lie in the oil-drilling and exploration rigs in the offshore areas, together with the deep-sea production platforms. In these connections, it is not surprising that the cable industry has come to think of these floating monsters either as ships, or indeed as large ships sitting on the sea bed. There is one big difference, however, and that is that there is a greater fire risk on an oil platform than on an ordinary vessel, and because of this the need is for fire-resistant cables similar to those used by the navies of the world. Some of the designs for this still use PVC both for insulation and sheath. Additionally, fire retardance is considered to be a very important factor, with cable sheaths having high oxygen index ratings to ensure maximum resistance to flame propagation to other parts of the rig. Continuous research into compounds is an ever-present task.

In the event of a fire, sufficient time must be available to enable the workers in the vicinity to take to the boats and evacuate the premises, so anything that can be done to delay the spread of the fire is an obvious help and necessity.

European technology favours the use of EPR-insulated and CSP-sheathed cables for ships, and thus also on the drilling rigs, as these are considered to be ships for this purpose. Vertical runs of cable of up to 150 m can occur on occasion and it is because of this that sheath compounds are specified to have oxygen indices which can be even higher than 31, to limit flame propagation.

The early rigs installed in the North Sea were gas production platforms and were very small in comparison with today's and tomorrow's oil rigs. Indeed the facilities available on modern rigs can be likened to those of a small town's electrical requirements. Installations capable of 70 MW per platform are quite common. Therefore, depending upon the basic electrical design requirements, this can be distributed at British, American or European standard voltages between 3.3 kV and 15 kV, and it is now common practice for cables for these voltages to be used on modern platforms, together with the lower voltage distribution and control cables.

Medium voltage on American designed rigs is usually catered for by 5 kV crosslinked polyethylene insulated cables, but elsewhere EPR-insulated screened cables are generally used, irrespective of whether the main cabling is PVC or EPR insulated.[2]

Elastomeric cables are often preferred for their greater flexibility in situations where cables must be drawn into ducts after assembly of the platforms, and in some cases where their continuous temperature rating of 85 °C allows smaller conductor sizes to be used.

Historically, cables used on the early gas production rigs, where only relatively small power requirements were required for lights and small motors, etc., had mainly PVC only for both insulation and armoured sheathing in the 400–600 voltage range. The early oil production platforms which followed the gas exploration and production eras had electrical generation capabilities of several megawatts and rapidly developed in size to 70 MW.

It is usual for an oil production platform to function first as a drilling platform, and whilst the drilling equipment can be driven mechanically it is more frequently driven and controlled electrically via cables to the drill rig tower. These cables range from multiple small-core constructions up to single-core cables of 300 mm^2 conductor cross-section. Of necessity they have to be very robust and flexible to allow movement of the rig to new positions after the completion of each well.

Flexible armoured cables have been developed for this,[2] and these have been based in construction on mining cables. The flexible conductors are EPR insulated with very heavy-duty PCP sheath, armoured, and then a further PCP sheath. Additionally, as well as this application such cables also have widespread uses, ranging from reeling drum installations to helicopter starter leads.

Mention has been made earlier of the requirements and need for flame-retardant properties in cables used on oil rigs. This is to allow the cables to operate and function normally for an adequate time should a fire occur. Some cables have been designed which are capable of 20 min operation at 650°C with no risk of conductor to conductor short-circuit.[2]

In the smaller size range these essential cables are usually insulated with silcone rubber, and for sizes upwards of 25 mm^2 cross-section, EPR-insulated CSP-sheathed braid-armoured cables to BS 6883 are quite suitable. The outer portion of CSP and armour gives adequate fire protection for a satisfactory period of time to the inner EPR insulation.

Silicone-insulated cables are also suitable in such hot areas as flare stacks, where they are used with ignition equipment and to navigation lights and other aids.

2.2 Submarine Cables

Additional to the offshore applications on the rigs themselves, submarine cables are used between the platforms in a group, as such a set-up offers an alternative to generation on individual platforms. Historically, paper-insulated and lead-covered cables were used, but modern technology has replaced these with elastomeric cables, despite the fact that paper insulation is unrivalled for high voltage and high current applications. Elastomeric insulated cables have proved satisfactory in areas as high as 84 kV AC, as they have the advantage of lighter weight because of the absence of lead, which in turn also permits longer lengths even up to 10 km in one piece.

One of the more difficult operations in very high voltage cable manufacture over the years has been the formation and elimination of voids at the insulation/screen interface. This produces ionisation discharges and ultimate cable breakdown. EPR insulation is ideal for submarine cable insulation because of its excellent resistance to ozone produced by partial discharges and electrochemical treeing. Triple extrusion techniques have been developed whereby both conductor and core screens are extruded in the same operation as the insulation.

The flexibility of submarine cables is an essential feature of their construction and the only positive way of achieving this is by the use of cables based on elastomeric materials. Such cables were used when articulated flare towers, pivoted on the sea bed and allowed to move under the influence of wind and wave, were introduced.[3] At that time (1975) the working stress under which EPR-insulated submarine cable insulations were required to operate was a maximum of 2·5–3·0 kV/mm with a maximum conductor temperature of 85 °C. However, because of this flexibility it is necessary during the laying of these cables on the sea bed to have a slight tension from the laying vessel in order to prevent loops being formed which ultimately cause kinking.

It is a fact that cable making and hose manufacture are very similar. This is certainly true with regard to the plant used,[4] which includes compound mixing,[4,5] extrusion, braiding, continuous vulcanisation and lead-covering processes and operations. It is therefore not surprising that an entirely new and up-to-the-minute development, of so-called 'umbilicals' or 'bundles' of hoses, cables, and combinations of both, has been developed for such applications, as the means of controlling the blow-out preventer stacks on drill ships and downhole logging of oil wells. The cables are modest in size and voltage, but have to be sufficiently robust to withstand extremes of temperature and pressure, and winds and seas of extreme violence. Hence they are armoured with high tensile strength steel wire.

The application of the cable-making technique of helical lay-up associated with submarine and other power cables ensures bundle flexibility without undue strain on the assembly, a vital factor in bundles used for blow-out preventer control purposes. This type of bundle normally consists of textile-reinforced thermoplastic-type hydraulic high-pressure hoses consolidated into a single unit, with a thermoplastic protective over-sheath, usually of PU. Such hoses have a very low volumetric expansion.

Umbilicals for production wellhead control may be electromechanical and are normally double wire armoured for ballast and mechanical protection purposes on the sea bed. Production wellhead control bundles can be manufactured in lengths up to 2000 m, depending upon size and number of hoses and cables.[6]

New handling and production techniques had to be developed in order to manufacture the bundles, especially the long length ones. Much larger spools of textile yarn had to be made and used so that the textile joins in the braid were fewer in number, i.e. further apart, and in this area also special splicing techniques had to be introduced in order to keep the braiding knots at very minimal levels. The textile portion of the hose reinforcement of such a high-pressure hose would normally be of high tensile steel-wire braid, but obviously as the environment is salt water this was not possible, so a specially prepared Aramid yarn was used.[7] Each length of hose has a lining of nylon with a cover of either nylon, polyurethane or PVC, depending on the exact operating conditions.

Prior to the introduction of the laid-up umbilical, single hoses were used and were tied together if more than one length was required, but this was far from satisfactory and was even hazardous in application, as loose hoses around an oil platform and floating in a North Sea swell is not good practice. In order to obtain a neat and compact laid-up bundle without twist, it was necessary to resort to cable technology and the laid-up hoses and cables were in turn covered with a thick sheath of PU, although other materials including PVC can be used as necessary.

2.3 Shore-Based Installations

In oil refineries the power requirements are very different from those used in general industry. The main difference is the possible presence of oil spillage into the ground, and any cables buried in such conditions have to be capable of withstanding such adverse conditions.[8] Even the best of oil-resistant polymers will swell to varying degrees and eventually allow oil to pass through and travel along the conductor to the terminations. Some plasticiser extraction is also fairly certain, and this can produce brittleness. Thus the cable will have only a limited life. The only sure way of preventing this oil seepage is to protect the cable cores with a metal barrier such as a lead or aluminium sheath.

Elsewhere the oil industry has parallel oil drilling and exploration work continuing on land as well as offshore, but this has not presented too great problems to the cable maker. The majority of cables in use have well-proven track records and are performing well, and this also applies to tanker terminals, refinery extensions and gas-processing plants. These are basically paper-insulated lead-covered cables, but EPR tends to be preferred for the voltage range 5–33 kV. Cables for lower voltage applications may be paper or PVC insulation with lead covering, but where oil and other hydrocarbon seepage is not present, PVC insulation and sheaths with armouring are increasing in use.

The rig and platform yards either use paper or are EPR insulated, the trend being for the latter type at high voltages with PVC-insulated and armoured cables for the lower voltage range.

However, the newer development of concrete structures has produced a more novel application. When the lower portion of a concrete structure has been completed in an excavated basin on the land, it is floated out for completion just offshore. The concrete pumps have to run continuously and the electrical linkage is maintained via an 11 kV EPR-insulated cable which can be either supported on a pontoon bridge between the structure and the shore, or along a line of buoys or by a submarine cable. This could well be a future area where the integral hose flotation system used for oil suction and discharge purposes for hoses could perhaps be built into and around the cable with the elimination of other flotation necessities.

3 COAL MINING AND QUARRYING

Cables used for mining and quarrying purposes have to be extremely robust with great flexibility, and additionally those used in underground mining have to have special fire-resistant properties as well as some conductivity or rather anti-static properties included in the sheathing compounds.

The source of electrical current in a mine is usually down a pit shaft and then along the roadway to the pit face. The cables in the pit shaft are cleated to the sides and are thus fixed permanently in a vertical position. They must resist water seepage and must not contain any ingredient that will flow out of the end of the cable. In order to resist occasional and external damage as well as to bear the strain of their own vertical weight in the pit shaft, double wire armouring is usually applied within the construction. A typical construction is one of plasticised PVC for installation with galvanised wire armouring impregnated with a no-flux bitumen and PVC outer sheathing. These cables operate at 3·3 kV, and after the shaft usually carry on along the roadway as far as the gate end, where the voltage is reduced to 550 V or 1·1 kV. As the pit face advances, of course the gate follows, so the 3·3 kV cable is lengthened from time to time. From the gate, pliable cable armouring is used and the final cables to and at the face are the trailer cables. The flexible cables supply power to the conveyors as well as for permanent lighting and battery recharging. Very often they are installed alongside and parallel to the coal conveyors, where apart from cut damage due to rocks and coal, etc., there is also the hazard of crushing, hence the need for flexible conductors, rubber insulation, flexible wire armouring and a very tough sheath of PCP.

Trailing cables also carry current from the end of the armoured cables to the cutting and drilling machinery at the actual coal face, and the operating conditions here are obviously very arduous, as not only do they have to withstand crushing but they have to be pulled and dragged around over rough rocks, etc., where they get bent and twisted into all kinds of unnatural contortions, and so have rather limited life cycles when compared with normal service conditions elsewhere. Short-circuits can occur due to conductor breakage and puncturing of the insulation, thus causing shorts and possible fire hazards due to arcing.

This is obviously very dangerous since if methane gas happens to be present, an explosion could occur. Therefore, on these cables each power core is individually screened either with a copper–nylon braid or more recently with conductive rubber. This must have a resistivity of less than $10\,\Omega^2/\text{cm}$, and hold this resistivity despite severe flexing, otherwise the circuit breakers will not operate and shut off the current.

The need for high tear and cutting strength is obvious in a coal mine, as is the need for fire resistance, and even no-afterglow requirements are now built into many mining specifications world-wide. This is to ensure that the cable will not re-ignite after the flame has been extinguished. In the future it is quite likely that even higher voltages will be used at the coal face, but the limiting factor on this is the availability of flameproof transformers and switchgear of adequate safety factor. The cable industry has already developed the insulation compounds and design features of such cables.

4 TRANSPORT

Much of the recent and foreseeable development work on cables for transport has been in the field of the railways, including underground trains. In this latter connection, considerable effort has been expended world-wide in an attempt to develop a so-called ‘smokeless cable’. This is a cable which when burned does not emit any smoke or toxic fumes. The smoke hazard is extremely important, not really because of its toxic danger, but because of the fear and panic it brings to the average traveller in a confined area such as a tunnel. In conventional PVC cables, during burning, copious black smoke together with a high level of hydrochloric acid gas is produced and this latter is a very nasty irritant to the respiratory system. Borates have been found to be effective in reducing smoke.[8]

The solving of this problem became urgent because many towns and cities world-wide have decided to install underground passenger travel systems as a solution to their traffic congestion and energy problems, and the underground transport engineers were faced with the possible problems of cable fires in the tunnels.

One way of minimising this is in the cable development[2] incorporating elastomeric compounds where the insulation can be flammable, but if burnt will produce neither dense smoke nor irritant gases. Over the laid-up cores a specially designed elastomeric filling compound having flame-retardant properties is applied. The function of this is to protect the insulation from external flame. The outer sheath is a flame-retardant silicone rubber. Very impressive results are being obtained with such cable constructions.

Another nuisance and possible hazard in underground train tunnels is the accumulation of brake dust and metal filings along the cables which are cleated to the tunnel walls, as this can catch fire owing to sparks or static. The fires then creep slowly along the cable unless checked. One way of stopping this was the use of asbestos braiding over the cable, but this is not now considered a healthy thing to do, owing to the possibility of asbestosis. However, materials other than asbestos can now be used in this connection.

Another large and very important area on the railways for cables is on the locomotive. This has occurred since the demise of steam in favour of diesel and electric traction locomotives. 'Diesel' locomotives contain more electric cables than may be realised. In fact, they should really be called diesel-electrical, since the diesel engine is used to drive dynamos and alternators to generate the power that is used for the final drive. Additionally, large air blowers are electrically driven to keep the engines cool and current is also required for the lighting and heating of the carriages. To make life difficult for the cable designers the cables also have to be resistant to diesel oil, and internal combustion engines are not particularly clean in operation, throwing oil about all over the place. One has only to look at the average diesel locomotive in use today anywhere in the world to see this. A railway diesel locomotive could almost be described as a small power station on wheels. Despite the cooling fans, operating temperatures in the confined space available in a railway diesel locomotive are high, and cables have to be rated for 85 °C operation. To date not all the required properties can be met at one and the same time, since elastomers are not available to cover the whole gamut of requirements simultaneously.