The recent developments of aluminium conductors in France in public distribution and industrial plants

PIERRE JACOMET

IN 1964, the total French consumption of aluminium amounted to 226 000 tons, out of which electricity, including electrodomestic appliances and electronic radio, used up 42 000 tons, i.e. about 18·5%. The conductors to which particular attention is given in this paper represent 20 000 tons, which is a little less than 9% of the total French consumption. These are divided as follows:

Bare conductors for overhead lines:

Aluminium-steel reinforced	8 000 tons yearly (aluminium content)
Almelec	4 500 tons yearly (alloy)
Insulated cables	5 600 tons yearly (aluminium)
Bus-bars	1 900 tons yearly.

The use of aluminium as conductor is now generalized in the overhead and underground transmission and distribution networks of Electricite de France (the French National Electricity Utility), as well as in all the indoor and outdoor leads of the hydraulic, thermic and atomic generating stations. Aluminium is already extensively used in factory equipment and for feeding large living units.

During the period 1939–1948 when aluminium totally replaced copper, the quality of materials, and of insulating materials in particular, was deteriorating. Numerous mishaps were reported and aluminium used anywhere and anyhow left very unpleasant memories. The specific case of house wiring was characterized at that time by unsuitable sharp-ended screw terminals; aluminium plug pins, and joints achieved by splicing or soldering with corroding fluxes, such practices being absolutely prohibited. Aluminium was then a mere substiution product, in the worst meaning of the term.

Then there was the period 1948–1958 during which aluminium had to make a name for itself, no longer as a substitute, but as a serious competitor, provided its fields of application be carefully defined and indispensable equipment and connection means developed to suitability. Finally, since 1958, we are facing a generalization of aluminium in public distribution (overhead lines and underground cables) and are now in a phase of active expansion in the field of low voltage.

Since economy is finally the evident incentive, we have been led to establish in the past the ratio $\frac{P_C}{P_A}$ for which aluminium is of interest in each of the vast fields of power transmission, designating by:

P_C the price per kilo of 3 mm diameter copper wire and
P_A the price per kilo of 4 mm diameter aluminium wire.

Both prices are published weekly in the French specialized papers, thus allowing the ratio to be known at any time. Knowing that, with an equal conductibility, one kilogram of aluminium replaces one kilogram of copper, we found that, as a first approximation, aluminium is of interest when:

$\frac{P_C}{P_A} > 0{\cdot}5$ for bus-bars

$\frac{P_C}{P_A} > 0{\cdot}6$ for high-voltage transmission lines

$\frac{P_C}{P_A} > 0{\cdot}7$–$0{\cdot}8$ for cables insulated with impregnated paper and pvc

$\frac{P_C}{P_A} > 0{\cdot}8$ for distribution lines.

The curve of this ratio starting from the year 1903 emphasizes the benefit resulting from the use of aluminium in the four fields mentioned (Fig. 1) as well as the grounds for this use. The savings have become

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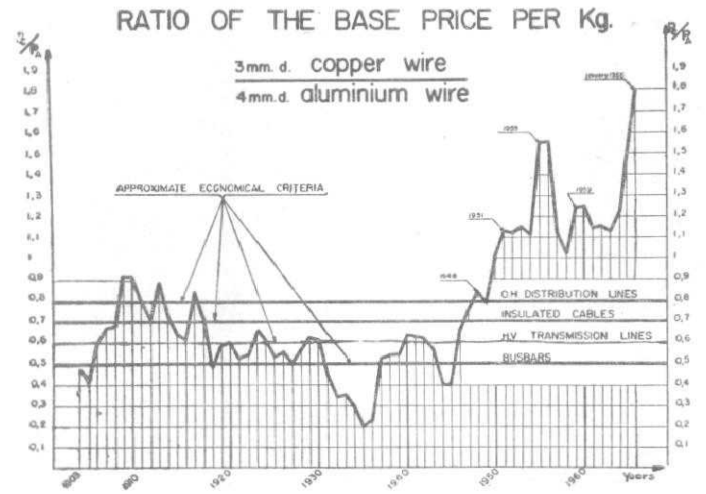
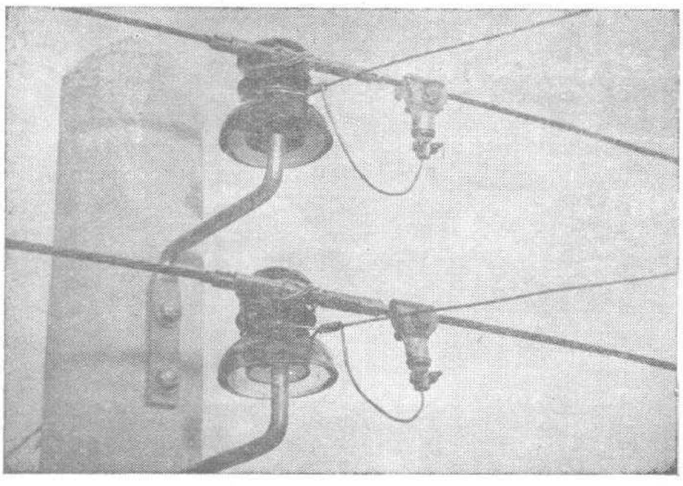


1 *Fluctuations of the 2 mm Cu wire price to 4 mm Al wire price ratio*

quite substantial since the year 1950, with peaks in 1955–1956 and at the present time. The other two financial advantages which are connected to aluminium, i.e. stability of rates and foreign currency savings for the countries that import copper. Considering the present ratio in France : 1·83, the replacement of 40 000 tons of copper by 20 000 tons of aluminium means currency savings of about £10 000 000. It is therefore obvious that in countries such as India and France, aluminium is bound to make further progress and to consolidate its present position.

Let us now examine the way followed in France during the last few years, stressing the points capable of bringing a contribution or a partial solution to India's present economic concerns.



2 *Tapping Cu house-service wire from Al l.v. secondary conductor*

Development of almelec in the o.h. lines of the 225, 380 and 750 kV transmission network

In France the homogeneous almelec conductor was first developed in the distribution of medium and low voltage networks. The almelec used in France since 1928 is a heat treated alloy containing 0·6% Si and 0·7% Mg. The guaranteed ultimate tensile strength of the wires is of 33 kg/sq.mm and their yield strength equals about 70% of this value. Its maximum resistivity at 20°C is of 0·0325 ohm. sq./mm/m. Like the other foreign alloys of the same family, it has been the subject of a first IEC international recommendation N° 104 concerning wires. A second one, dealing with cables, is now being printed. The advantages of this cable compared to steel-cored aluminium (SCA or ACSR) are the following ones :

Technically

A greater hardness, about twice that of aluminium, that gives it a better mechanical behaviour, during erection as in operation ;

A composition homogeneity that leads to :

- a simplification of sleeves and especially of dead-ends ;
- a higher yield strength which results in a better resistance to loads ;
- a greater detorsion inertness : this facilitates erection and in particular tension-stringing of large conductors ;
- an increased corrosion resistance, that combined with greasing (now generalized in France), permits to store such cables and to locate them in all regions, including the sea-coast areas where they perform remarkably.

A greater lightness (gain of about 30 to 35%) together with a high mechanical resistance leading to a higher strength/weight ratio.

Economically

Without taking a higher scrap value into account, comparison may be schematized as follows in the present construction practice of French lines :

- An extra high voltage, where conductors have substantially the same conductibility (for example usual 380 kV 570 sq. mm almelec and 617 sq.mm steel-cored aluminium conductors), the slightly higher cost of the almelec conductor (reduced, in practice, by transportation and paying-out savings) is the more counterbalanced as the line shows more angle and dead-end towers and, therefore, a more sinuous route ;
- At high voltage, where conductors have the same cross-section, because of the existing standards (i.e. almelec or steel-cored aluminium 228 sq.mm conductors, commonly used in 63 kV), the higher purchase price is nearly balanced by savings on

Joule losses : a benet on supports remains then in favour of almelec, benefit which is to be determined in each particular case, whether the gain results from lightenig angle or dead-end towers, at equal parameter (as at extra high voltage), or from a reduction of sags leading to a gain on the height of supports, in the case of same EDS.

In short, it can be stated that, in spite of a slightly higher purchase cost, all surveys unanimously point out the real technical and economical advantages of almelec. This favourable appraisal caused a new Electricite de France trend to gradually replace steel-cored aluminium by almelec conductors on the transmission network. Almelec was used there for the first time in 1955 on a 63 kV line as a homogeneous conductor of 708 sq.mm. Since then, its use has extended to the 225 kV and 380 kV lines for which the 366, 570, 851 and 1 200 sq. mm conductors have been standardized. In 1965, almelec clearly over-scored steel-cored aluminium, with 5 300 tons against 2 500 tons for the latter. A 1 600 sq.mm. conductor is under fabrication to equip an experimental 750 kV line.

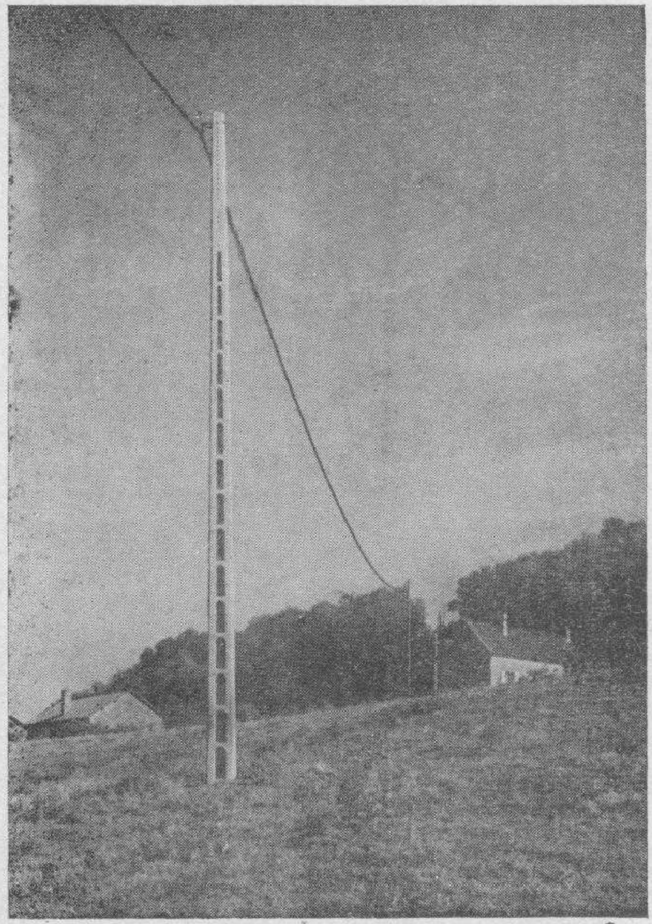
Use of aluminium pre-assembled insulated cables in low-voltage overhead distribution networks

Public distribution of low-voltage electric power traditionally requires bare conductors on pole implanted in the ground or on small structures directly fixed on the front part of the houses. When these conductors have aluminium as their main component, the small-gauge service drop cables leading the consumers to the line remain always in copper, and the jointing is performed by means of special aluminium to copper tap connectors (Fig. 2). The overhead lines of such a design for a number of years have given fully satisfactory service.

The utilization of pre-assembled cables in low-voltage o.h. lines as secondary cables introduced new and often economical possibilities in this field, while it offered unquestionable advantages, especially for the utility. Such cable consists of a steel-cored aluminium conductor neutral-messenger, generally insulated, around which the aluminium phase conductors, also insulated, are cabled and, if necessary, those of public lighting.

The insulating material must, of course, offer all guarantees of stability (weatherproof, resistance of ultraviolet rays, abrasion, etc.) and is made of thermoplastic or elastomer components such as polyethylene, neoprene, vinyl chloride, etc. The following must be brought to the credit of pre-assembled cables :

increase of load-carrying ability, because of its lower reactance than open wire of the same size :
greater reliability through suppression of hazardous contacts between phases :
reduction of the height of poles, since phase to phase spacing is lessened and, furthermore, clearances can be reduced, owing to cable insulation ;
reduction of stringing costs, as only one cable is handled ;

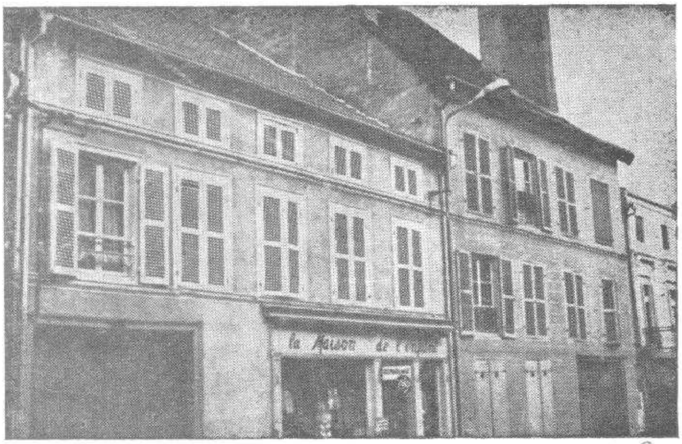


3 *Aluminium self-supporting pre-assembled cable feeding pumping station*

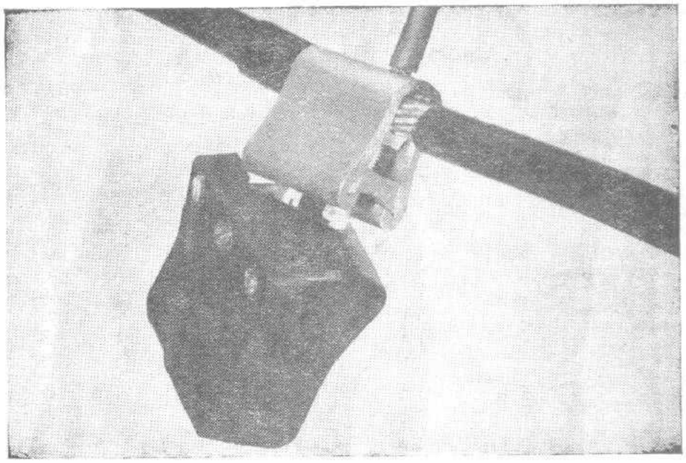
suppression of electric hazards for crew, since tap connections are easy to achieve with hot conductors ;
easy power increments, independent from previous distribution ;
great improvement, from the aesthetic point of view, compared with the overhead lines they replace, without it should be necessary to go to costly underground distribution.

These cables can be used in several fields :

city and rural lines on brackets or poles, with self-supporting neutral-messenger. This practice is, among others, of an obvious interest in wooded areas, where expensive tree trimming is thus avoided and outages by falling branches are considerably reduced. In areas where frosting is frequent, the use of one cable instead of four open wires results in a reduction of loads in the ratio of about 4 to 1.



4 *Aluminium pre-assembled secondary laid on front of houses*



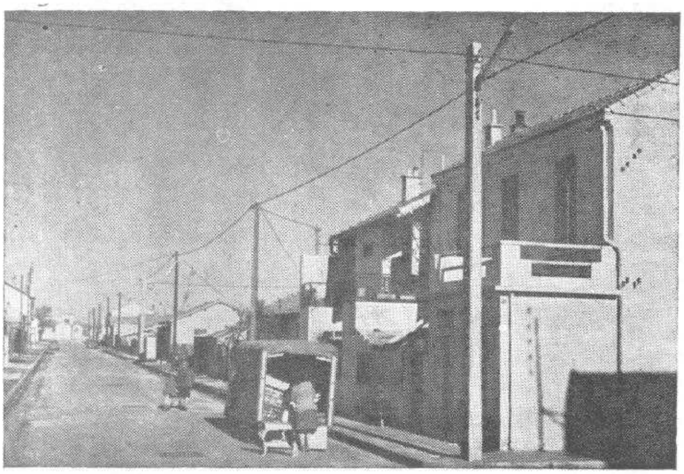
6 *Saddle tap for connecting insulated copper house-service wire to aluminium pre-assembled secondary cable ; note the insulating shroud filled with grease*

networks on frontages according to 3 main versatilities : cable clamped approximately every 10m to brackets sealed in the house walls. The method, where cable is about 12 cm distant from the front part of the house, is particularly cheap, but restricted to streets where the houses are of a homogeneous architecture ;

cable with non-supporting neutral conductor, fixed approximately every 80 cm to the walls at a distance of about 5 cm from them ;

cable similar to the latter, but fixed closely to the walls, where it can be better hidden.

Mixed constructions on poles frontages may also be designed. Figures 3 to 5 show some aspects of these new networks which have their own specifications and settled an already important market. The tappings consist of a bronze connector tin-plated inserted in an insulating encapsulation filled with sealing neutral grease. Like in the traditional low-voltage secondary lines, the service drop wire remains in copper, since protection of the aluminium to copper joint is sufficiently provided by the grease and the cap (Fig. 6).



5 *Alumtnium self-supporting pre-assembled cable network on Mediterranean sea-coast*

Aluminium in industrial plants

Insulated cables

For numerous years, the presence of aluminium in insulated cable has been limited to public distribution underground networks, where its generalization was achieved at medium voltage as early as in 1958 and is now underway at low voltage of supplying large housing blocks ; this application involves some 3 000 km of paper insulated, lead-covered cable or sometimes, at low voltage, with an aluminium sheath used as a neutral conductor. At the same time, a reversion to aluminium could be witnessed in the industrial plants whence it had nearly disappeared after the end of World War II.

At medium voltage indeed, factory distribution mains consist mostly of single or three core cables insulated with elastomers or plastics. These are firm and permanent leads that are set up once for all by specialized crew.

As they are also quite economical, there is no wonder that their use gradually spreads to all industries : motor-car, steel, chemical works, etc.

At low voltage, the service features pertaining to factories are noticeably different : the aluminium cable that often acts as a power feeder between a switchboard and a motor must be able to face :

rather frequent disassembling of terminals for maintenance operations ;

fast replacements which in case of trouble increase the risks of poor re-assembling ;

the necessity of connecting to terminals that, in

the case of motor, are often copper threaded rods placed in very small casings.
a polyvalent personnel, not necessarily familiar with the particularities of aluminium.

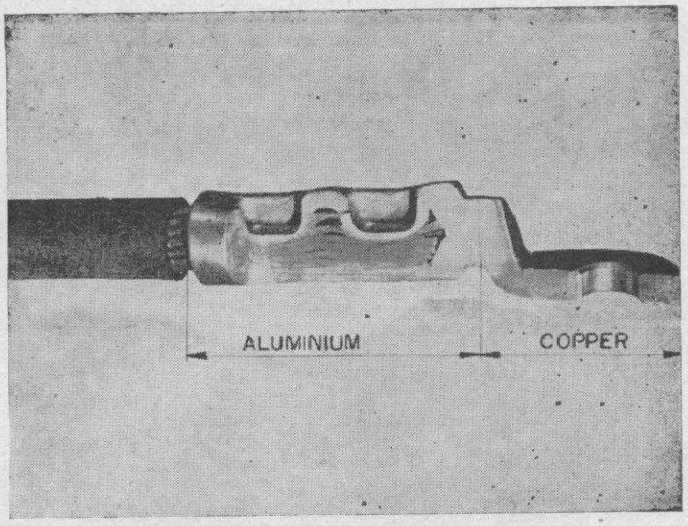
These requirements are now met, particularly by use of copper-lug indent crimped terminations (Fig. 7) that limit the connecting problem to mere contacts of a copper-lug to a copper terminal which the equipment is designed for and the maintenance crew know quite well (Fig. 8). This factor played an important part in the recent trend for industrial plants to take the benefit of important savings through the use of aluminium (10% to 50% according to the type of cable of equivalent conductibility considered).

Apart from indentation, it is also possible to use bolted terminals and joints, numerous items of which equip service panels after they have successfully met severe electrical-load cycling tests. The larger diameter of aluminium conductors may be objectionable concerning their connection to motors and switchgear; adequate glands and terminals casings of suitable dimensions should then be provided. A successful means to reduce this diameter is to choose non-stranded conductors, consisting of a solid circular or sector-shaped core, even more economical than the usual cables. The great malleability of annealed aluminium gives these solid conductors a pliability that is quite suitable for most industrial cables. When great flexibility and lightness are both seeked, 'aluflex' or 'souplau' are used; these have been especially developed for the manufacturing of flexible cables. The 'Caravelle' aircraft is wired with such cables (40 to 84 sq. mm cables) and so are more than 150 electric locomotives, as well as floating cables and electric furnaces. The present tendency for all these cables favours aluminium for sizes equal to or larger than 35 sq. mm, a limit which is stated by our national regulations.

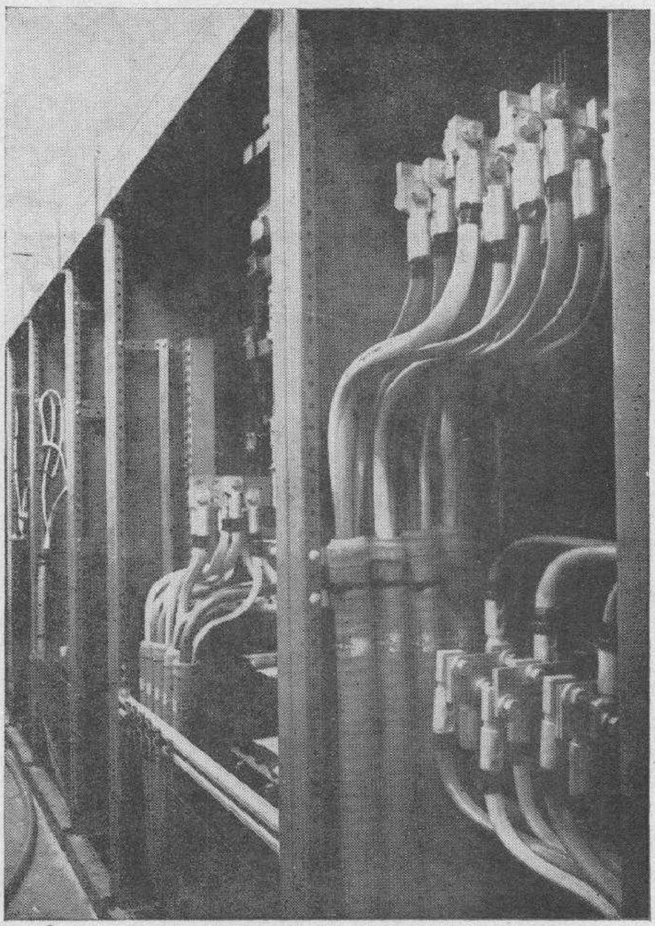
It was not deemed relevant to think of aluminium, at the present time, for smaller wires and house wiring as long as this first step has not been achieved, and especially as long as domestic accessories terminals have not been suited to this use, which represents a major difficulty.

Busbars

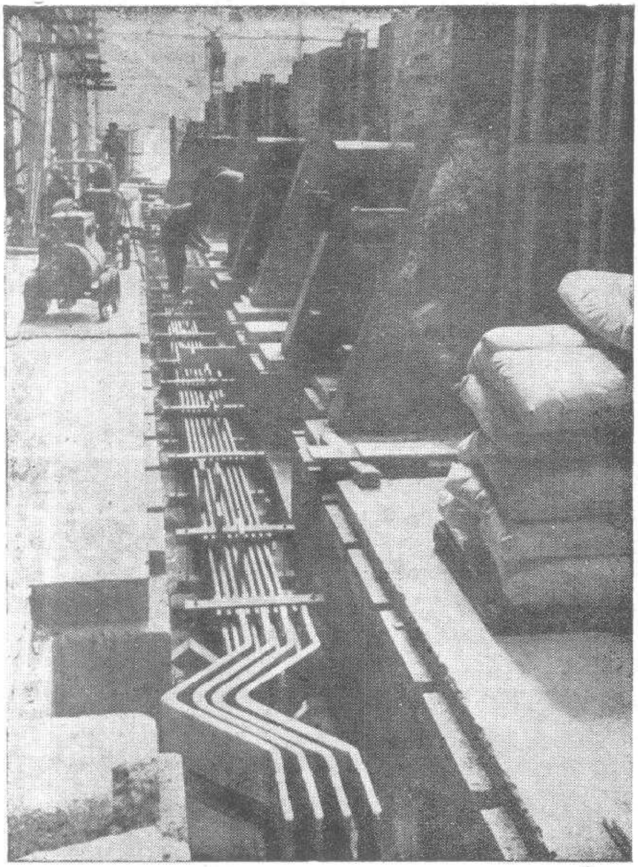
After its use had become popular in generator-transformer links of generations (channels and half-octogon sections) as well as in outdoor sub-stations (tubular or stranded conductors), aluminium turned also to industrial equipments, in order to increase its market possibilities. In the field of heavy currents, aluminium buses are the most advisable choice, at the present time, since they raise the least technical and technological problems, together with the greatest money saving. These conductors, easy to join, allow savings from about 65 to 75% on connections cost, in comparison with equal conductibility copper. The possibility of larger spans, the lightness of conductors and, in numerous instances, specialized joining processes such as MIG welding, result in additional gains both on transporta-



7 *Indent-crimped terminal consisting of aluminium body cold-welded to copper lug*



8 *Indent-crimped terminals on low voltage cable with aluminium conductor and sheath*



9 *10 000-A busbars feeding graphitization furnaces ; note expansion joints*

tion and on assembling. The horizontal continuous casting, therefore in large length, performed directly from the aluminium smelting furnace, gives maximum money saving for rectangular bars the cross-section of which extend from 100×10 mm for the smallest to 600×160 mm or 700×120 mm for the heaviest ones, with d.c. current-carrying capacities of many 10 000 amperes.

Because of such favourable conditions, aluminium was gradually admitted in numerous factories (supplying rolling mills, workshops distribution, busbar trunking systems) belonging to steel, paper, car industries, etc. and was likely to finally extend to electric furnaces as well as to electrolytic plants other than the ones producing aluminium, in spite of the initial reluctance of the maintenance electricians.

With respect to electric furnaces, up to a few years ago, very few heavy power ones were fed by aluminium low voltage leads. Today, it has been introduced in corundum furnaces (800, 1 500 and 3 500 kVA units), carbide and iron-alloys furnaces (9 000 to 20 000 kVA units), graphitizing furnaces from 1 500 to 9 000 kVA, and numerous 50 to 125 kW resistance or induction furnaces operating in varous industries.

In electrochemistry, the fear of possible corrosions had, in the past, always kept aluminium away from aqueous electrolysis rooms where, like in chlorine fabrication, the atmosphere could be deemed particularly aggressive. However, an experiment conducted on 120 t of bars in a Pechiney—Saint-Gobain factory, proved that the use of heavy rectangular bars is technically suitable, if necessary with a protection against accidental leakage of soda or mercury. Numerous installations have been witnessed since in chemical industry : from chlorine, aluminium infiltrated fluorine, hydrogen, silver and even copper electrolysis plants. It was, of course, already commonly used in fabrication of chlorate, perchlorate and perborate.

In electrolytic treatment plants, where fears of corrosion and joining problems were similar, a parallel development was recorded, and aluminium bus is operating in important industrial installations for tin-plating steel strips, etching and polishing stainless steel besides smaller copper, nickel and chromium-plating plants.

Earth circuits

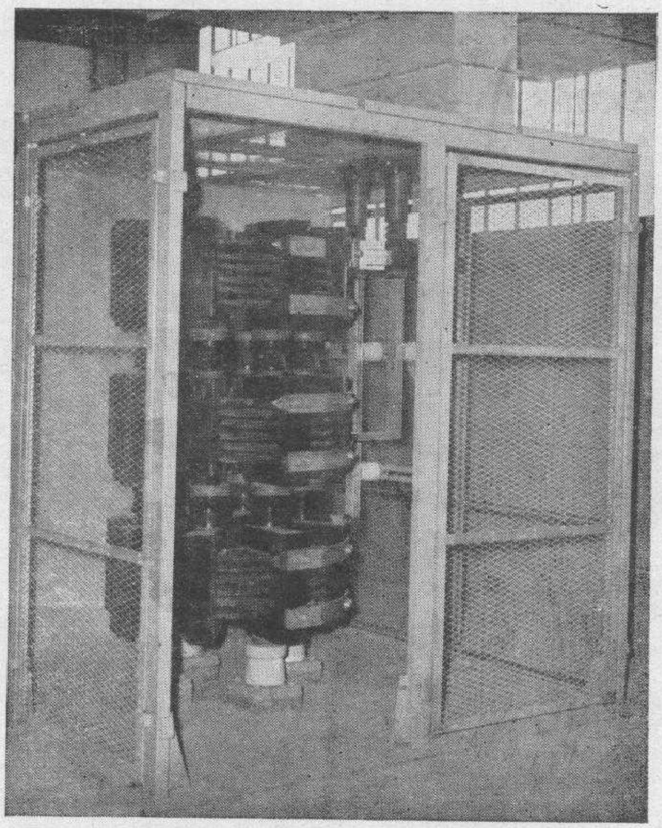
Bars and rods of smaller area can be produced on a very large length directly from the smelting furnace and a casting wheel. This is the way Properzi wire is manufactured, such a wire being used as a rough material for wiredrawing, but also possibly for earth circuits wirings. French regulations explicitly include aluminium for circuits above ground level (because unprotected aluminium must not be buried) : multiple applications thereof exist, namely in sub-stations, hydro-electric stations and industrial plants.

Machine windings

The present economic features are particularly favourable to bare or insulated aluminium conductors in power transmission connections. Now, to examine the situation in electrical machines and equipment, space requirements are predominant here. Since a given magnetic circuit cannot accommodate so many ampere/turns with aluminium as with copper, the aluminium-wound machine, with equal ratings, power losses, temperature rise, etc. will inevitably be bulkier. That is why, at present time, in the yet favourable case of distribution transformers ranging from 500 to 10 000 kVA, the savings on coils is counteracted by the increased dimensions of the whole. It can therefore be stated that, with the possible exception of furnace transformers with heavy-current secondary winding, the situation does not favour economically aluminium windings in the case of rotating machines and power transformers, due to the presence of magnetic circuits.

The only important application deals with rotor cages of industrial induction motors whose bars come directly from die-casting together with the end rings and cooling fins. This method of fabrication by gravity-die or pressure-die casting according to the runs involved, is now widely adopted, because it is simple, rapid and cheap. Some special windings are also commonly made of aluminium, i.e. capacitors with foil or tape, coreless reactors with cables or rectangular bars (Fig. 10), coils of nuclear physics apparatus, such as particle accelerators, electromagnets and Wilson chambers. For example, the European Council for Nuclear Research possesses, in Meyrin, near Geneva, a 600 MeV synchro-cyclotron and a large 25 GeV synchrotron, both provided with aluminium windings : the whole represents 180 t of hollow 99·7% purity aluminium conductors, rectangular shaped, produced in long lengths by extrusion. Thus, for the next years, such a stabilized situation can only lead to normal developments resulting from the foreseeable increase in number of the above-listed equipment or machines. That is the reason why, in this field, we turned to other possibilities, which seem to be more attractive.

The demand for anodised conductors by a continuous process, is approximately 300 tons annually. The insulant that develops on the conductor is pliant and adhesive alumina, 5 microns thick. This oxide film is inert and heat-resistant, even at high temperatures of about 400 to 500°C. The breakdown voltage of approximately 100 V may be increased to 200 V pursuant to varnish impregnation. Besides the negligible thickness of this insulant and its remarkable heat-resisting property, these conductors offer the advantages (a) insensitiveness to nuclear radiations, (b) an overall weight reduction of about 50% on the coils and, simultaneously, saving ranging from 15 to 30% over the price of a conventional winding. Among the main applications, mention may be made of electromagnetic brake coils with round or flat wires (for rolling mills and heavy truck driving—(Fig. 11), lifting magnets, electromagnetic pumps, various transformer or auto-transformer windings, etc.



10 *Dry-type reactor wound with aluminium stranded conductor, operating in a large French generating station*

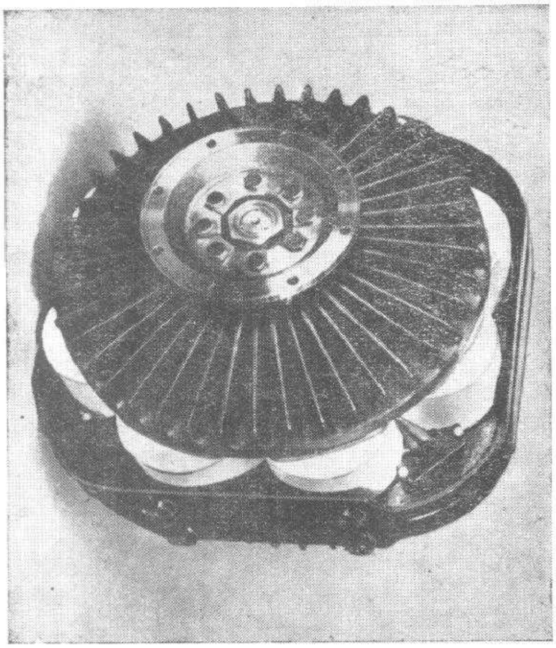
Strip windings

The principle of this new method, suggested by capacitor windings and developed for a few years in the USA, is well known nowadays. It consists in replacing the round wire with an electrically equivalent strip of the largest possible width, rolled on itself together with a sheet of insulating material. The available space is thus much better filled, which generally permits to place an increased area of conductor with the same iron core. Besides weight and cost savings, this type of coil winding offers the following advantages :

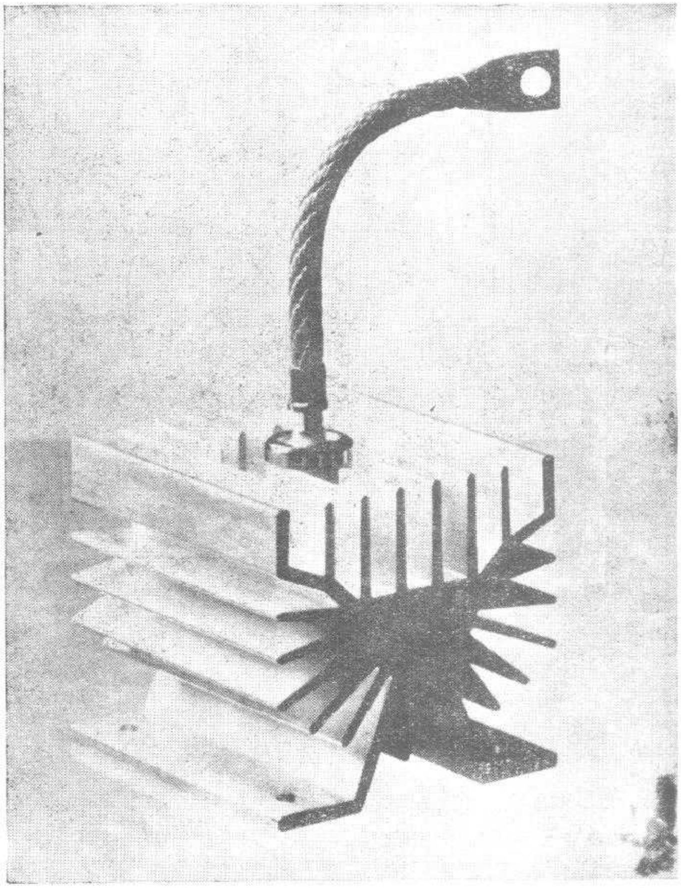
- Such windings are more compact, nearly indestructible.
- The edges of each turn have access to the outside of the coil, hence avoiding hot spots.
- The ability for this strip to provide good heat dissipation is particularly attractive for small coils, entirely sealed.
- Voltage between turns is the only one to be taken into account for the choice of the insulant thickness. Therefore, the size of the winding may be reduced over conventional coils where higher voltages between layers are to be considered.
- Various conventional insulants are used : paper, epoxy resin, mylar, etc.
- The material which should finally be retained for each specific case depends on the requirements set by operating temperature, hence from ambient features and prescribed current densities. For devices designed for operation at high temperature, it is possible to use anodized strips with insulated edges, at least for thicknesses down to 60 microns.

Besides power units of which we know only one American sample (15/20 MVA transformer), it appears possible to divide roughly the most interesting appplications of aluminium strip windings for the future into two groups :

- medium or small power devices : such is the case of pole transformers from 10 to 25 kVA where aluminium strip winding provides strength and weight, space and cost savings ;
- very low power devices at low or very low voltage : this is a very extensive field where the series to be produced, the classes of insulating materials, the economic comparisons vary to a large extent according to the type of apparatus considered : horns, relays, inductances, radio—TV transformers, etc.



11 *Truck electromagnetic brake wound with anodised aluminium wire ; one of the complete coils*



12 *Finned extruded heat sink on Si-rectifier diode*

In France, the anodized strip is, at the present time, more popular than strips insulated with paper or varnish coatings, particularly in the case of lifting magnets. The development of these various windings was made possible by the achievement of new jointing processes such as cold welding and iron-soldering with non-corrosive fluxes, which permit easy terminations through copper lugs, wires or tapes.

Cryogenic winding is an entirely new development, now under way : substitution of copper by refined aluminium working at very low temperature, utilizing the fact that the residual resistivity of pure aluminium is much lower than that of copper. The French industry is now in the process of building a 20 MVA "cryotransformer" operating at liquid hydrogen temperature. This project is operated jointly by three French industrial companies : Alsthom for the electrical part, Air Liquid for the cryogenic part, and Pechiney for the refined aluminium. The present process used by Pechiney (three-layers electrolytic refining) gives a metal of average grade 99·995% ; by selection, one can reach 99·998%. But a new process is under development, which is expected to give an aluminium of 99·999% purity, or better. With this metal, the resistivity at 20° K will be about $\frac{1}{1000}$ of its value at room temperature. This high increase in conductivity allows a big reduction of the size of the windings and of the whole transformer, which overcompensates the cost of the cryogenic machine : hence a reduction on the total investment. Another favourable factor is the reduction in losses, and correspondingly in the operating costs. If the transformer project is successful, another project will be made for an alternator. Of course, in the field of low temperature, a challenge to refined aluminium comes from the supraconductors. The latter are superior for d.c. in some cases : but for a.c., in the present or foreseeable state of the technique, they are not satisfactory.

Electrical equipment

Although this matter is somewhat beyond the scope of the present survey, it should not be left out as it represents a huge bulk of tons. In this very extensive field it is pertinent, at first, to point out the market that electrical equipment and fittings offer to cast aluminium alloys, Al-Si in most cases. To consider only some of the most typical applications, mention may be made, of motor stator bodies and apparatus frames, equipment casings and watertight socket-outlets, parts of high voltage switchgear and circuit-breakers, terminal caps, heads of transformer bushings, turbo-generator end-winding covers, etc. without omitting all the aluminium conductor accessories, i.e. clamps, connectors, bus supports, etc.

The present trend in France, is to replace steel bolts by aluminium alloy bolts, especially for outdoor fittings (o.h. lines and sub-stations connectors). There are two reasons for it: on the one hand, the high resistance of aluminium in atmospheric expositions as well as to chemical attacks; allowing an easy disassembly, even after a very long period of service and, on the other hand, the same coefficient of expansion, which improves the quality of electrical contacts. An aluminium alloy containing 4–5% Zn, 2·6–3% Mg and 0·6–1% Cu is utilized for this purpose, and its minimum mechanical characteistics are the following:

Ultimate tensile strength	47 kg/sq. mm
Yield strength (0·2% elong.)	40 kg/sq. mm
Elongation	8%

These bolts are cold or hot forged and protected by anodization, sealing and grease impregnation.

When a manufacturer seeks lightness, non-magnetism, chemical resistance, thermal conductivity, excellent appearance, good reflectiveness, etc. he is most of time led to think of aluminium and its alloys; that is why reflectors, meters, domestic apparatus, small devices, etc. commonly include cut, pressed, forged or machined parts, sheets (especially when steel requires an expensive protective coating), bars, pipes and structural shapes made of light metal. Even lampholders can be economically manufactured with pressed, anodized and coloured 3% Mg alloy.

If, with respect to transmission tower members and substation frames, a study is to be made in each case according to the scheduled location and the possible savings on manufacturing, transportation, erection and maintenance, however, in other fields, the wide variety of shapes easy to produce by extrusion with a die cost quite advisable may be the basis of new designs, as shown in Fig. 12: among other possibilities, full or tubular sections can be extruded with shapes meeting specific requirements, bulbs, stiffeners, fins, slides, dovetails or other features which simplify assembling operations, increase the moment of inertia or heat transfers and, in short, make the use of aluminium really functional and competitive.

In conclusion, it may be stated that, after having been for numerous years a mere substitute (transmission lines excluded, however) aluminium has now become, thanks to important technical improvements and to the help of more and more favourable economic situation, a great electrical metal, competing strongly with the other materials in the big game of industrial expansion. Acknowledgment is to be made to the engineers of our country and particularly to those of Electricite de France whose sound-minded enthusiasm for new designs as well as steady concern to build at the best price although meeting safety requirements, have kept this national utility away from hazardous supplies, repeatedly difficult, unstable and expensive, intricated by consequent financial discomfort and other fever peaks. This example, followed more and more extensively by private industry, forecast the future important widening of aluminium acceptance in the fields we just mentioned, provided we don't slacken our efforts for promotion, technical improvements and technological popularization. The same should certainly happen in India since, in a situation that, in many respects, may be compared to France a few years ago, India already turned deliberately towards aluminium.

Discussions

Mr **K. C. Choudhuri** (R.D.S.O., Chittaranjan): I would like to know if aluminium overhead transmission lines have been used in the French Railways for electric traction; if so what is the route kilometrage covered by such conductors.

Mr **P. Jacomet** (Author): Our overhead traction lines are not made of aluminium. On the Lyon-Marseilles line we have used aluminium feeders. During the last war we used traction lines made of aluminium and steel and the pantograph used to brush against the steel. This practice was abandoned because at that time aluminium was not cheaper but now that the price structure has changed the question can certainly be reviewed.

Mr **L. J. Balasundaram** (NML): In some of the samples shown to us it appears that aluminium has been joined to aluminium and to copper by pressure welding. Could Mr Jacomet give details about the pressure and temperature used for joining. Did pressure welding have any effect on the conductivity of the pressure welded zone and if so what was the remedy used?

Mr **Jacomet** : Two discs, one of copper and the other of aluminium, with their surfaces properly cleaned, are brought together rapidly in a press at a pressure of about 1 000 kg/mm^2. There is diffusion of atoms on both sides. This is then heated to 300°C and punched. The temperature has to be very strictly controlled, otherwise the joint becomes brittle and breaks as glass. Pressure welding does not affect electrical conductivity at all.

Mr **I. C. Joseph** (Larsen and Toubro Ltd., Bombay) : For low voltage distribution switch boards while changing over to aluminium we are anxious about creep at the joints. Has Mr Jacomet any comments to add about creep at pressure joints in aluminium with particular reference to the reduction of pressure at the contact ?

Mr **Jacomet** : Joints satisfy certain definite conditions. For the contact surface we take 10 amps/cm^2 and contact pressure should not exceed 1 kg/mm^2. In these conditions creep is avoided. On behalf of the French Electricity Board, Aluminium Francais have done considerable work on the thermal cycling of these joints to determine creep behaviour.

Mr **R. Padmanabhan,** (TISCO, Jamshedpur) : I would like to know if any special grease is used in all these contacts.

Dr **Rajendra Kumar** (NML) : Aluminium wires which are being used for domestic wiring purposes are in the hard drawn condition and therefore do not permit even slight handling ; they break and continuity of the electric line is lost. I feel that immense advantages will accrue to the domestic aluminium conductors if they are used in the fully annealed condition. Would the representatives of aluminium industry please comment on this aspect ?

Mr **N. Gopalkrishnan,** (Indian Aluminium Company, Calcutta) : We fully agree that for domestic wiring aluminium wire should be in the fully annealed condition. The specification 3/4 hard temper in the Indian Standards is incorrect and we have already taken up the matter for suitable modification. We also feel that for house wiring a single aluminium conductor is to be preferred to the stranded construction. The size of such single conductors of rating equivalent to the existing copper wires—will permit their use with the existing brass terminals.

In reply to Mr Padmanabhan there are various brands of grease which can be used for the protection of electrical joints. I may suggest ESSO Multipurpose Grease H and Caltex, Multipak 2 which are both available in India. In this connection and in reply to the references made by Mr Jacomet I may add that aluminium house wiring has been found very suitable in India. Installations about 10 years old were recently inspected and found to be perfect. No bi-metallic corrosion whatsoever has occurred between the aluminium wires and the brass terminals—even without protection by grease—even in locations in Bombay and Cochin under marine atmosphere.

In the field of electrical windings a lot of discussion took place on anodised aluminium wire. In its absence in India we have introduced enamelled aluminium wire to replace enamelled copper wire. It is now being made by 6 or 7 units in the country and has successfully been employed to wind chokes for fluorescent tubes. Trials in winding small motors (as for fans) have been undertaken with very encouraging results and experiments are being extended to larger motors.

Cast aluminium rotors are being used in India in all small motors and are being tried now for motors up to 30 H.P.

Lampholders and lampcaps are also being made in aluminium in India entirely dispensing with brass.

Finned extruded heat sinks for Si-rectifier diodes, as illustrated in Mr Jacomet's paper can also be made in India and interest in similar sections has also been shown in this country.

Finally, with reference to Mr Choudhuri's question, trials are being conducted at present by Railway Electrification Project, Calcutta, with NICCO and our own organisation with aluminium alloy (INDAL D 50 S corresponding to E 91 E of BS 2898) grooved overhead wire. For the pantograph wearing strip, a softer aluminium alloy is being considered.