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CONCEPTUAL DESIGN STUDY ON ALUMINIUM WIRE DRAWING AND STRANDED CABLE PRODUCTION

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Vienna, 1989

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EXPLANATORY NOTES

References to dollars ($) are to United States dollars, unless otherwise stated.

References to tonnes are to metric tonnes, unless otherwise specified.

In tables:

Totals may not add precisely because of rounding.

A hyphen indicates that the item is not applicable.

An em dash (—) indicates that the amount is nil or negligible.

Two dots (. .) indicate that data are not available or are not separately reported.

The following abbreviations are used in this publication:

AA Aluminium Association

IEC International Electrotechnical Commission

DIN Deutsche Industrie-Norm (German industrial standards)

An E- prefixed to the name of a material (for example, E-AlMgSi) means that the material is used for electrotechnical applications.

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Introduction

A. Background

The present study is designed to assist investors and experts in developing a primary aluminium processing industry based on the production of stranded electric cable. Such a development effort is usually intended to replace semi-finished imports by domestic production relying on locally available resources and labour, with the ultimate aim of retaining the profit resulting from the price gap between domestically produced aluminium ingots and semi-finished imports. An additional benefit is that domestic market demand can be satisfied at a lower price with greater flexibility by producers having more direct connections with both raw material suppliers and domestic consumers. This is especially true for countries having bauxite resources and reduction plants. Such a situation confronts many developing countries, which as a group hold the bulk of world bauxite and energy resources, but which use them only in part or not at all.

An investor in a position to establish a plant in a developing country and possessing the required financial means still has other problems to overcome. It is difficult to choose the plant operating capacity best suited to the prevailing technical and economic conditions. The production units of up-to-date plants usually have high capacities, sometimes exceeding local market demand. The establishment of the production capacity required by the domestic market may not be feasible because production equipment of very small capacity does not exist and the available equipment cannot be economically operated at low levels of demand.

The manufacture of electric conductors seems more advantageous, however, because the stages of drawing and stranded wire production can be built up from relatively small units with individual capacities of a few hundred tonnes per annum and responding more closely to local market demand.

The same does not apply to wire-rod manufacturing, where the production capacity of the cast rolling equipment requires development steps of from 10,000 to 20,000 tonnes per annum. The sudden surplus of products appearing shortly after plant start-up but not demanded by the domestic market can be exported, preferably to neighbouring countries. A newly commissioned plant experiencing initial difficulties will have to face severe export trade constraints. The difficulty of marketing the products may deter investors from starting a new line of production, although such difficulties can be overcome by adequate preparation and careful project implementation.

Despite all the difficulties confronting it, the aluminium industry in developing countries has generally been found to grow faster than the economy as a whole and to have mostly positive effects. Moreover, despite the fluctuating price of primary aluminium ingot, the prices of semi-finished aluminium products are relatively stable. Experience shows that under difficult market conditions, even at the lowest price of primary ingot, high-quality semi-finished products manufactured at high productivity rates, that is, at low production cost, can be marketed at prices that bring an adequate profit for the manufacturers. That point is borne out by comparing the figures in table 1

Table 1. Average 1985 prices of aluminium ingot and selected semi-finished products

Item	*Average 1985 price (dollars per tonne)*
Ingot, Al 99.5	1 050
Wire rod, E-Al 99.5	1 130
Wire rod, E-AlMgSi 0.5	1 160
Rolled strip or plate	1 656
Foil	1 950
Extruded sections	1 690
Drawn products (Al 99.5)	1 450
Drawn products (alloyed)	1 625
Anodized extruded sections	1 880
Castings	2 550
Stranded cables	1 430-1 770

At a certain stage of industrial growth, industries will be established at ever greater distances from energy sources, and electricity must be transmitted to remote places of consumption. In general, countries begin by using imports to meet their needs, but later they gradually start to tap domestic resources to build up a production base.

In countries where copper is abundant, it will be used to make conductors, and where bauxite is available and there is an aluminium smelting capability, conductors will be based on aluminium. In the latter case, domestic stranded cable production will also be based on aluminium. Domestic demand can be met in countries where no aluminium is available by establishing stranded aluminium cable plants for the processing of imported aluminium. Purchased wire rod may be used by both the stranded cable plant, with a product mix based on market demand, and by the wire-drawing plant that supplies it.

B. Summary

This study deals with the establishment of a stranded cable production industry. It provides information on the equipment and technologies applied, and on personnel, energy and other requirements. Various alternatives for wire-rod production starting from purchased aluminium ingot are described. To help determine the feasibility of a proposed project, examples are given of the selection of plant capacities, of investment cost estimates and of the calculation of other cost factors.

In chapter I the applications of aluminium and copper in the electric power industry are discussed and the types of aluminium conductor described. The latter include unalloyed aluminium (E-Al 99.5), alloyed aluminium (E-AlMgSi 0.5), steel-cored aluminium and steel-cored alloyed aluminium

stranded cables. The chemical composition and mechanical and electrical properties of conductors, as well as the methods of measurement of those parameters, are described. The structure of stranded cables, including the core and surrounding layers, the characteristics of stranding and related recommendations of the International Electrotechnical Commission are considered. Other electrotechnical applications of aluminium are also noted in chapter I.

Wire-rod production is introduced in chapter II. Possible methods of wire-rod production are rolling, extrusion and cast rolling. Cast rolling is now the most widely used process. The operations of a wire-rod casting shop are described. The molten metal can be supplied either from the pot-room or by melting ingots. Metal-cleaning, alloying and equipment selection are dealt with. Since the smallest feasible production capacity involves a single cast rolling machine, wire-rod plants based on Properzi casters, types 6E and 7E, with capacities of 10,000, 15,000 and 20,000 tonnes per annum, are examined. Investment cost estimates and personnel, energy, materials and utilities requirements are also considered.

Data on wire-drawing plants are given in chapter III. The calculation of drawing parameters is covered in the section dealing with the theory and practice of wire-drawing. Technical parameters of slip-drawing and slip-free drawing equipment are listed, and wire requirements noted. Equipment, investment cost estimates and personnel and material requirements are determined, and equipment layouts presented, for plants with capacities of 5,000, 10,000 and 20,000 tonnes per annum. Data for a cable plant with an optimum capacity of 2,500 tonnes per annum, which requires a minimum of investment, are also included.

Stranded wire plants are discussed in chapter IV. Stranded cables, production technology and the selection and characteristics of equipment, including tubular and basket-type wire equipment and their respective fields of application, are described. The basic capacity is taken to be 5,000 tonnes per annum and a plant is considered for a selected product mix. Equipment is selected, personnel and material requirements are determined, and the respective investment costs are estimated for capacities of 10,000 and 20,000 tonnes per annum and for the minimum economic capacity of 2,500 tonnes per annum. The possible layout of equipment is also presented.

Energy supplies (electricity, gas and coal), utility systems, waste-water treatment, environmental protection, packaging, storage, transport and maintenance are dealt with in chapter V. The equipment, material and personnel requirements of auxiliary units of plants with capacities of 2,500, 5,000, 10,000 and 20,000 tonnes per annum are determined. Data on energy and utilities supplies are summarized in tables, and an investment cost estimate is included.

Three complete works are discussed in chapter VI. The first two are wire-drawing and cabling plants with capacities of 2,500 and 5,000 tonnes per annum, the third is a complex including a wire-rod plant, a drawing plant and a stranded wire plant with a capacity of 10,000 tonnes per annum. The establishment of the works is described and layouts are presented. The numbers of persons required for the operation of the works are 86, 220 and 380, in accordance with the rising output levels.

Chapter VII is concerned with investment decision-making. Direct investment costs, including the costs of production and auxiliary facilities, are summarized for all capacity variants. Phase income estimates are calculated for the capacity variants and production costs and profits determined. An implementation schedule is also given.

I. Application of aluminium in the electric power industry

A. The materials of overhead transmission lines in developed and developing countries

The conductor material of overhead transmission lines used to be copper. Since 1910 countries short of copper resources have sought to replace copper with more abundantly available material. Remarkable results were achieved by France, Germany and Hungary up to 1940. In the period following the Second World War nearly all countries with a developed industry understood the technical and economic advantages of using aluminium in power transmission and therefore started to use that material. At present, aluminium is considered to be not a substitute for copper but rather an economically and technically better solution than the application of copper. The major portion of conductor materials for overhead transmission lines is therefore made of aluminium.

The transmission lines used in the electric power industry consist of approximately 90 per cent of overhead transmission lines and 10 per cent of cables. In developed countries the lengths of power lines operated at various tension levels are estimated as follows: nearly 50 per cent of the total length of all overhead transmission lines operate at below 1 kV of tension; about 40 per cent at from 1 to 35 kV; and about 10 per cent at above 35 kV. Those percentages do not reflect the ratios of conductor materials used for the various rated overhead transmission lines, since the higher the rated operating voltage, the greater the cross-section of built-in materials and the larger the quantity of materials used.

The types of overhead transmission lines used at various voltage levels are as follows:

(a) Below voltages of 1 kV, aluminium stranded conductors are used;

(b) Above voltages of 1 kV, alloyed and unalloyed aluminium stranded conductors, steel-reinforced, are used.

From the changes that have occurred in recent years the following conclusions may be drawn concerning the widespread application of various types of overhead transmission lines:

(a) Mainly below voltages of 1 kV, but even up to 35 kV, the application of insulated overhead cables is increasing;

(b) Above voltages of 1 kV, alloyed aluminium stranded conductors show definite gains over steel-reinforced aluminium stranded conductors.

The reason for the first change lies in the increasing importance attached to environmental concerns. In populated areas it is much easier to install overhead transmission lines. The cables can be fixed to walls and other supporting structures, without disturbing the environment as much as conventional transmission lines. Insulated overhead cables can also be repaired under tension and new branchings established without interrupting energy supplies.

There are several reasons why aluminium alloys are preferable to other transmission line materials. Alloyed aluminium conductors are economically more advantageous than steel-reinforced stranded aluminium conductors because their slightly lower conductivity is compensated for by the greater mechanical strength of the line. An alloyed aluminium overhead line having the same conductive characteristics as a steel-reinforced transmission line will be lighter, thus compensating for its higher cost by the low cost of its supporting structures. Alloyed aluminium conductors have a more homogeneous structure than steel-reinforced stranded conductors, their accessories and elements are simpler and cheaper, and less work is required to install such a power line.

The steel core of the reinforced stranded aluminium conductors may become corroded at the steel-aluminium interface, a risk that can be only temporarily averted by tin-plating the steel core. Alloyed aluminium transmission lines offer better corrosion resistance.

1. *Aluminium conductors*

The purity of unalloyed aluminium used in electrotechnical fields of application is required to be a minimum of 99.5 per cent. In addition, the permitted amount of impurities (chromium, titanium, vanadium and manganese) detrimental to the conductivity of the aluminium is limited, and special measures are taken during the production process to maintain them at a sufficiently low level.

The tensile strength of conductors made of commercial-grade aluminium is low even in a hard-drawn state. Greater tensile strength can be achieved by adding suitable alloying elements to aluminium that do not produce detrimental effects on conductivity. Alloying elements forming solid solutions are known to exert such effects on conductivity. The solution is to add alloying elements that form precipitates in the base metal after tempering (through high-temperature tension-releasing heat treatment followed by rapid cooling), thus increasing the strength of the alloy. The aluminium-magnesium-silicon (AlMgSi) 0.5 alloy, containing approximately 0.5 per cent magnesium and 0.5 per cent silicon, has been developed in that way.

Table 2 summarizes the composition of most widely used conductor materials based on the Deutsche Industrie Normen (DIN) and the standards of the Aluminium Association (AA). Alloys meant for electrotechnical applications are designated by means of an "E" prefixed to the name of the alloy.

The diameters of aluminium conductor wires used for the manufacture of stranded power transmission lines vary from 1.5 to 5 mm, but only one diameter is chosen for a given stranded structure. The tolerances of wire diameters are the following:

Diameter (mm)	*Tolerance (mm)*
1.5-2.5	±0.025
2.5-3.0	±0.030
3.0-4.0	±0.040
4.0-5.0	±0.050

Table 2. Chemical composition of most widely used conductor materials

(Percentages)

										Other constituents	
Standard and designation	*Aluminium (minimum)*	*Chromium*	*Copper*	*Iron*	*Magnesium*	*Manganese*	*Silicon*	*Titanium*	*Zinc*	*Individual amounts*	*Total*
Din E-Al	99.50	..	0.02	0.40	0.05	[a]	0.25	[a]	0.05	..	0.03
AA 1350 (EC)	99.50	0.01	0.05	0.40	..	0.01	0.10	..	0.05	0.03	0.10
DIN E-AlMgSi 0.5	..	..	0.05	0.10-0.30	0.10-0.30	0.05	0.30-0.60	..	0.10	0.03	0.10
AA 6101	[b]	0.03	0.01	0.50	0.35-0.80	0.03	0.30-0.70	..	0.10	0.03[c]	0.10

Note: Maximum value is indicated where only one figure is given.

[a] Cr + Mn + Ti + V (Chromium + Manganese + Titanium + Vanadium) = 0.03 per cent (maximum).

[b] The percentage of aluminium is the remaining amount required to make a total of 100 per cent.

[c] Boron = 0.06 per cent (maximum).

The elementary strands of a conductor stranded of two wires should not have any extension. In stranded conductor structures with a higher number of elementary strands the individual wires may have extensions, but the minimum distance between the extensions of two different wires should be 15 m.

Regulations concerning the physical, mechanical, electrical and other characteristics of conductor wires are published by the International Electrotechnical Commission (IEC). Thus, IEC publication No. 111 applies for unalloyed aluminium stranded conductors, while IEC publication No. 104 applies for alloyed aluminium conductors.

Table 3. Mechanical and electrical properties of conductor materials

		Mechanical properties		*Electrical properties at 20°C*	
Material quality and standard code	*State of the material*[a]	*Tensile strenghth (R_m) (N/mm^2)*	*Elongation ($L_o = 200$) (percentage)*	*Specific resistivity (maximum) ($ohm \cdot mm^2/m$)*	*Specific conductivity (minimum) ($m/ohm \cdot mm^2$)*
E-Al (99.5)	F7-1	95-100	12	0.028010	35.700
E-Al (99.5)	F7-2	105-120	10	0.028010	35.700
E-Al (99.5)	F9	115-130	8	0.028010	35.700
E-Al (99.5)	F13-F17	159-193	2	0.028264	35.380
AA 1350	H12	83-117	..	0.028035	35.670
AA 1350	H14	103-138	..	0.028080	35.610
AA 1350	H16	117-150	..	0.028126	35.550
E-AlMgSi 0.5 (AA 6101)	F17	160-190	18	0.3300-0.0341	29.300-30.300
E-AlMgSi 0.5	F22	294[b]	4	0.032790	30.497

[a]Fx and Hx are the standard means of designating the temper of materials. F7-1 corresponds to the diameter range of 01.0-03.5 mm, and F7-2 to that of 00.2-01.0 mm.

[b]According to IEC publication No. 104, the tensile strength should be not less than 300 N/mm^2.

Table 3 shows the mechanical and electric properties of several conductors whose composition and quality are based on DIN and AA. The resistivity value depends on temperature. That relationship is defined by the following equation:

$$R_{20} = R_T \cdot \frac{1}{1 + a\,(T-20)}$$

where R_{20} = resistivity at 20°C

R_T = resistivity at T°C

a = temperature coefficient of resistance
(for unalloyed aluminium, 0.00403/°C)
(for alloyed aluminium, 0.0036/°C)

In practice, resistance is generally measured between 10°C and 30°C, and the value referring to 20°C is calculated by the above formula. Another important characteristic of wires is the coefficient of linear thermal expansion. Its value is 0.000023/°C.

2. *Stranded conductors*

Stranded conductors are made by stranding two or more elementary wires into one or more concentric layers. The stranded conductors may consist of aluminium, aluminium alloy or steel-reinforced aluminium.

Aluminium stranded conductors are used as overhead transmission lines at voltages mainly below 1 kV, since in populated areas the supporting towers are closely spaced and strict mechanical requirements do not therefore arise. The relevant requirements are summarized in IEC publication No. 207.

The lay ratio is the ratio of the axial length of a complete turn of the helix formed by an individual wire in a stranded conductor to the external diameter of the helix. Table 4 shows the lay ratio of several stranded conductors having various layers in accordance with the recommendations of IEC. The number of conductors in a stranded structure is always one more than the number of conductors in the individual layers because one conductor is the core of the stranded structure and it is not included in the layers.

The tensile strength of the individual wires within the stranded conductor slightly decreases during the cabling operation, but the decrease should not exceed 5 per cent. Where there are strict requirements relating to mechanical properties (for example, where the distance between two consecutive supporting towers is greater than 50 m), steel-reinforced aluminium stranded conductors are chosen. These types of overhead transmission line can be used for 1 kV up to any practical voltage. The requirements relating to that type of conductor are summarized in IEC publication No. 209.

Steel-reinforced stranded aluminium conductors include a concentrically arranged core consisting of one or more zinc-plated steel wires surrounded by one or more aluminium layers of equal cross-section. Lay ratios of such conductor structures are provided in table 5 according to IEC publication No. 209.

After a 5 per cent decrease in the tensile strength of the individual wires the value should remain within the range specified by the standards. The final modulus of elasticity and the coefficient of linear expansion for the conductors are summarized in table 6.

Alloyed aluminium stranded conductors are used in the same fields of application as steel-reinforced aluminium stranded conductors, as previously noted. Their respective general characteristics, as outlined in IEC publication No. 208, are similar or identical to those of unalloyed aluminium stranded conductors. For lay ratios the data summarized in table 4 should be considered. The minimal tensile strength of the individual wires should exceed the figure of 3×10^8 Pa before and after cabling.

Steel-reinforced alloyed aluminium stranded conductors are used when there are extreme mechanical requirements. Heavy-duty requirements are mainly the result of climatic conditions, such as high wind speeds, high rates of frosting (ice formation) and the spanning of large distances over rivers, narrows and valleys. Such requirements are dealt with in IEC publication No. 210. The lay ratios are given in table 4 and the final modulus of elasticity and the coefficient of linear expansion in table 6.

3. *Conductor adaptations for electric power transmission*

Since insulated overhead cables can be simply and quickly installed, they account for a large share in the electrification of the countryside and outlying areas where underground cable remains uneconomical because of its tenfold cost increase and low consumer concentration.

There are two types of insulated overhead cable structures. One is a system developed in Belgium, France and the United States of America, in which the

Table 4. Lay rations for unalloyed aluminium stranded conductors

Number of wires in conductor	Lay ratio									
	6-wire layer		12-wire layer		18-wire layer		24-wire layer		30-wire layer	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
7	10	14	—	—	—	—	—	—	—	—
19	10	16	10	14	—	—	—	—	—	—
37	10	17	10	16	10	14	—	—	—	—
61	10	17	10	16	10	15	10	14	—	—
91	10	17	10	16	10	15	10	14	10	13

Note: For purposes of calculation, the mean lay ratio shall be taken as the arithmetic average of the relevant minimum and maximum values given in this table.

Table 5. Lay ratios for steel-reinforced aluminium stranded conductors

Number of wires		Ratio of aluminium to steel wire diameter	Lay ratios for steel core				Lay ratios for aluminium wire					
			6-wire layer		12-wire layer		Outside layer		Layer immediately beneath outside layer		Innermost layer of conductors with three aluminium wire layers	
Aluminium	Steel		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
6	1	1.000	—	—	—	—	10	14	—	—	—	—
6	7	3.000	13	28	—	—	10	14	—	—	—	—
12	7	1.000	13	28	—	—	10	14	—	—	—	—
18	1	1.000	—	—	—	—	10	14	10	16	—	—
24	7	1.500	13	28	—	—	10	14	10	16	—	—
26	7	1.286	13	28	—	—	10	14	10	16	—	—
28	7	1.125	13	28	—	—	10	14	10	16	—	—
30	7	1.000	13	28	—	—	10	14	10	16	—	—
30	19	1.666	13	28	12	24	10	14	10	16	—	—
32	19	1.500	13	28	12	24	10	14	10	16	—	—
54	7	1.000	13	28	—	—	10	14	10	16	10	17
54	19	1.666	13	28	12	24	10	14	10	16	10	17

Note: For purposes of calculation, the mean lay ratio shall be taken as the arithmetic average of the relevant minimum and maximum values given in this table.

Table 6. Final modulus of elasticity and coefficient of linear expansion for steel-reinforced aluminium stranded conductors

Number of wires		*Final modulus of elasticity*	*Coefficient of linear expansion*
Aluminium	*Steel*	*(10^6 Pa)*[a]	*($°C^{-1} \times 10^{-6}$)*
6	1	81 000	19.1
6	7	77 000	19.8
12	7	107 000	15.3
18	1	67 000	21.2
24	7	74 000	19.6
26	7	77 000	18.9
28	7	79 000	18.4
30	7	82 000	17.8
30	19	80 000	18.0
32	19	82 000	17.8
54	7	70 000	19.3
54	19	68 000	19.4

Note: Quoted modulus values may be regarded as accurate to within ±3,000 × 10^6 Pa, and as applying to coductors stressed to between 15 and 50 per cent of the ultimate strength of the conductor. Coefficients of linear expansion have been calculated from final modulus values for the aluminium and steel components of the conductors, using coefficients of 23.0×10^{-6}/°C and 11.5×10^{-6}/°C for aluminium and steel, respectively.

[a] Pa (pascal) = 1 newton/m^2 (unit of pressure).

three phase conductors are made of unalloyed aluminium and the neutral conductor is made of alloyed aluminium designed so that it can support the total weight of the conductor system.

The second type is a system developed in the Federal Republic of Germany and Sweden, in which the three phase conductors and the neutral conductor are made of unalloyed aluminium, have the same cross-section and are twisted into a bunch. The insulation of each of the stranded conductors uses either high-density polyethylene or cross-linked polyethylene.

Insulating material having a thickness of from 1 to 2 millimetres must meet the following requirements: resistance to ultraviolet radiation; resistance to corrosion caused by salty fog from the sea or by chemically aggressive atmospheric conditions; and no significant change in electrical and mechanical properties in the temperature range from −40°C to +80°C. There is no IEC recommendation for insulated overhead cables. It has been found that the cross-sections of stranded aluminium conductors—which must be individually insulated with polyethylene—can be 25, 35, 50, 70 and 95 square millimetres, and that four conductors (three phase and one neutral) or more (three phase, neutral, street lighting and signal cable conductors) can be twisted together into a bunch.

The stranded conductors referred to thus far may be regarded as standard, commonly used types. Nevertheless, certain manufacturers have patented processes designed to decrease electricity losses or the rate of corrosion.

To avoid the danger of corrosion of steel-reinforced aluminium stranded conductors, increasing use is being made of Alumoweld wire composites, in which the steel wire has an aluminium cover with a thickness of from 0.5 to 1.5 millimetres. The aluminium cover protects the steel core from corrosion and improves electric conduction. Furthermore, it decreases the amount of extra losses due to the alternating magnetization of the steel core. To decrease such losses, stranded structures of an uneven number of three or more layers are used. Within those structures the number of ampere-turns twisted to the left and to the right are compensated, thus making the steel core practically unmagnetized.

The properties of aluminium conductors built into housing and industrial establishments are described in IEC publication No. 121. Use is made of soft materials with a strength of 10^8 pascals at an elongation of 20 per cent. The diameter of the individual wires exceeds 1 millimetre and the surface is insulated with plastic having a thickness of less than 1 millimetre.

B. Aluminium conductor materials in the generation, transformation, transmission and consumption of electric power

The bulk of aluminium consumption by the electrotechnical industry is used in the manufacture of the above-mentioned types of conductox. The fields of application described below represent a smaller but not negligible amount of aluminium consumption, and it would be useful to consider the possibility of such applications in countries manufacturing electric conductors.

1. Aluminium busbars

The high-current conductors of switchgears and transformer stations are the busbars. The majority of busbars are made of aluminium. Low- and medium-tension busbars have rectangular cross-sections of from 12×2 mm^2 to 200×15 mm^2. The material used in the busbars is either E-Al 99.5 (extruded or hard aluminium) or E-AlMgSi alloy when there are higher mechanical requirements. The requirements of alloyed aluminium are summarized in IEC publication No. 114. They include the following: resistivity at 20°C is 0.0325 ohm metres as the highest permitted value; minimum tensile strength is 2×10^8 pascals, at a maximum elongation of 8 per cent.

Tubular busbars are used for the transmission of high tensions, since the electromagnetic penetration depth into aluminium at a frequency of 50-60 Hz is about 15 mm. The use of a busbar with a diameter of twice this figure would therefore be uneconomical. The tubular structure provides further advantages from a mechanical point of view. Tubular busbars having a diameter of 32 mm and a wall thickness of 2 mm are widely used, but in certain cases they are also made with larger dimensions.

2. Underground cables

Underground cables consist of insulated conductors fitted with extra protection that enables them to be laid into walls, cable trenches or underground. Such cables are generally unable to carry their own weight and have to be laid. This is an advantageous field of application for aluminium, since in most cases there are no special mechanical requirements. Cables for voltages of up to 1 kV can have a stranded structure or a solid circular or segmented cross-section. Only stranded structures may be used for voltages above 1 kV. Cable manufacture has until recently been mainly for voltages of up to 1 kV, but cables to be used at voltages in the range of 1-35 kV have begun to appear. The amount of cable produced for voltages above 110 kV is smaller, but it cannot be neglected because there is a tenfold price difference between such cable and stranded overhead power transmission lines performing the same tasks.

The cable insulation used in the voltage range of 1-35 kV is generally polyethylene. Above 35 kV polyethylene insulators are not widely used, being replaced instead by oil-paper insulators. At the highest operating voltages (400 kV and above), the application of sulphur hexafluoride (SF_6) gas-insulated cables is spreading. The tubular conductor of those cables is made of E-Al 99.5, with a cover of E-AlMgSi alloy. Conductors of the latter type are capable of high-power underground transmission.

Telecommunications cables usually have conductors of small cross-section (under 1 mm^2) that are difficult to make using aluminium. A further difficulty is that reliable connections can be ensured only at high costs. For those reasons aluminium is not as widely used in telecommunications as would seem feasible.

3. *Rotating machines*

There have been efforts to use aluminium as the armature material of rotating machines, but insulated aluminium conductors are not widely used since they would increase the weight and price of the equipment. Die-cast aluminium is widely used as the armature conductor material of induction motors. The small-size housing of rotating machines is also widely manufactured by precise cutting of extruded aluminium.

4. *Transformers and reactors*

The use of aluminium as the conductor material of transformer coils is primarily an economic question relating to manufacturing and operating costs. The borderline range for the use of copper or aluminium is from 2 to 6.3 MVA (the rate applied varies from country to country), with the use of aluminium becoming economic below that range. The shape of conductors with a cross-sectional area of less than 10 mm^2 is circular, and for one exceeding 10 mm^2 it is rectangular. The requirements relating to composition and mechanical and physical properties of E-Al 99.5 aluminium conductor materials are the same as those previously indicated. The requirements for conductors built into choke reactors are the same as those for transformer conductors. Aluminium is generally used in the coils even at the highest power rates.

5. *Condensers*

The increasing application of solid-state components in advanced control technologies has made it necessary to install ever greater condenser capacities into electric networks. Aluminium has achieved widespread use in that field. Sufficiently small-sized, reliable and high-capacity condensers can be made from foil with a thickness of from 5 to 8 microns, recently developed electrolyte materials and polypropylene insulator materials. Such condensers can operate reliably in ambient temperatures of from −40°C to +50°C. The purity of aluminium used in the manufacture of foil needed for condensers is 99.9 per cent. Recent technological developments have made it possible to reach the rated power of 400 kilovolt-amperes per unit, which relates to 8 kilovolt-amperes per litre of specific rated power.

Applications of power condensers include the following: improvement of phase factor (cosine phi); carrier frequency and sonic frequency feedback of electric power networks; filtering of harmonic currents generated by solid-state components; and starting motors. In the field of telecommunications, polypropylene insulated condensers are being gradually replaced by condensers that have an aluminium film on the insulator material instead of individual foil layers.

6. Electrotechnical application of aluminium for non-conductive purposes

Aluminium is used in electrotechnical applications not only for conductive purposes. Aluminium-enclosed or aluminium-clad electric equipment is commonly installed in low-tension networks. Castings and aluminium plates are usual elements of enclosed or claded equipment even at medium voltages (from 1 to 35 kV). For the cladings of high-tension equipment, aluminium castings and tubular structures of alloyed aluminium are commonly used. Reflector plates and street lampposts are also made of aluminium.

Because aluminium provides electromagnetic shielding, is anticorrosive and may be aesthetically shaped, it is often used as the construction material for casings, covers and other parts of instruments, telecommunications equipment and computers. Aluminium walls of varying thicknesses provide shielding against low and high amperage disturbances. Cooling fins of diodes and trisitors used in high-power electrotechnology are made from aluminium plates or specially designed extruded aluminium sections.

II. Wire-rod manufacturing

A. Manufacturing processes and equipment

Wire rod is the stock from which cold-drawn conductors are made. Unalloyed aluminium wire rods can be produced starting from molten metal or ingots by hot-working.

1. Characteristics of wire rod

The quality of the wire rod stock is determined by five fundamental factors, namely chemical composition, dimensions, surface quality, metallurgical state and electrical properties. The chemical composition of the wire rod should match the standardized composition of drawn wire and the electric conductor as end-product. The standardized chemical composition of unalloyed and alloyed aluminium is described in chapter I, section A.

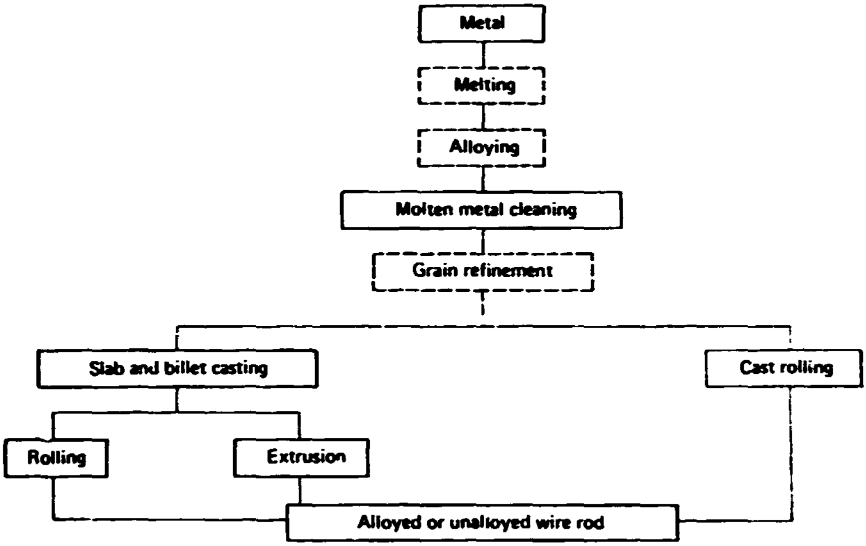
The wire rod has a circular cross-section with a diameter of from 7.5 to 16 mm. Further processing of the wire rod requires that the tolerances of the nominal diameter should be small. Similarly, it is essential to maintain the circular shape of the wire rod. To keep within the maximum permitted ovality, the difference between the maximum and minimum diameters of the same cross-section should not exceed 5 per cent of the nominal diameter.

The internal structure of wire rod should be uniformly fine-grained. It should not contain any metallic or non-metallic inclusion because the latter can lead to ruptures during further processing. The basic material should be worked so that further processing would be tolerated. Such a ductile state can be achieved during the production process (for example, with unalloyed rod produced by continuous casting) or by further heat treatment (for example, with alloyed rod produced by continuous casting).

The surface of wire rod should be free of any defects generated by casting or working (such as pressing and rolling), including cracking, scaling, notching, cavities, penetrations, inclusions or corrosion. Since the required properties of electric conductor end-products will vary according to the specific field of application, the properties of wire rods must also be varied. The properties of wire rod may be changed to meet different requirements by altering the following conditions or processes: preparation of charge and alloying; casting conditions; initial and final temperature of hot-working; extent and mode of deformation; and conditions of cooling after hot-working.

There are currently three well-known methods of wire rod manufacture, namely rolling, extrusion and cast-rolling. The basic steps involved in these technologies are shown in figure I. Steps framed in broken lines represent alternative operations depending on whether the casting shop starts with solid or molten metal, or whether alloyed or unalloyed metal is required.

Figure 1. Wire-rod fabrication methods



A continuous casting-rolling process is currently used to manufacture the major portion (from 90 to 95 per cent) of wire rod [1]. This is easily understandable because such a technology eliminates the need to remelt solid metal when starting from molten metal and saves the cost of reheating and preheating the workpieces. In the combined continuous casting-rolling operation the weight of coils can be increased, thus increasing the productivity of further processing steps.

The manufacture of wire rod by the process of rolling or extrusion is an old-fashioned technology that is applied only as a compromise solution. Those processes will therefore be given only brief consideration below.

2. *Wire-rod manufacture by rolling*

Rolling-mills for the production of wire rod are located in areas where there is no aluminium smelting capacity nearby (perhaps not even in the same country), and where large amounts of wire rod were needed in the 1950s and 1960s. As a rule, the rolling-mills were designed to process wire bars having dimensions of 100 × 100 × 1,300-2,700 mm and a mass of from 35 to 75 kg. The capacity of such a plant can reach as much as 20,000 to 60,000 tonnes per year.

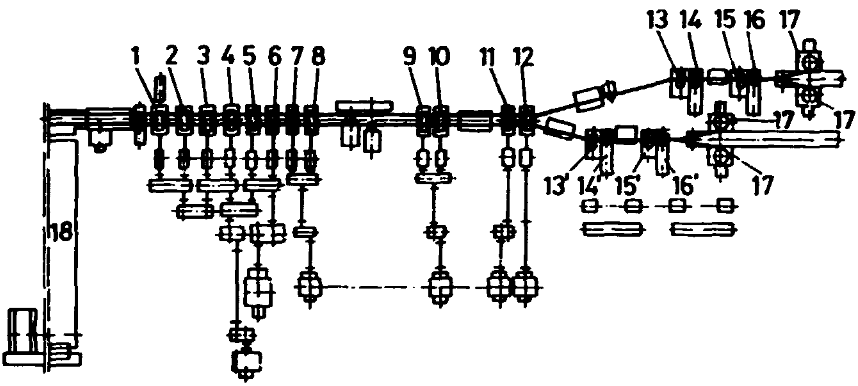
Wire-rod rolling-mills usually have several (8 to 16) roll stands classified as initial, medium and final rolling units, which in some cases have a so-called ready-making roll group (including rolling-mills with a common drive in simple arrangement), depending on the functions and structure of the stands. Mills having the same function within the plant may be built with a common drive unit.

The working rolls have a two-high arrangement, the axes being vertical or horizontal. The rolls used for the working of aluminium wire bar are etched. The etched shapes rotating towards each other will finally give the required shape and size of wire rod.

In older plants the final roll stands were placed beside each other and the wire rod was taken from one roll stand the other either by a mechanical device or by the operator. In more up-to-date plants the final roll stands are placed one after the other in a "tandem" arrangement.

Figure II shows the theoretical arrangement of a continuous rolling mill. Wire bar is preheated up to 480°C in pusher-type furnaces (18). It is then rolled by the initial roll stands (1-8) and passes to the medium or intermediate roll stands (9-12), which are capable of rolling two wire bars in parallel. The final rolling-mill (13-16) has a dual arrangement for handling one wire rod at a time. The last unit in both branches is a coiler and transporter system (17).

Figure II. Continuous aluminium rod mill



3. *Wire-rod manufacture by extrusion*

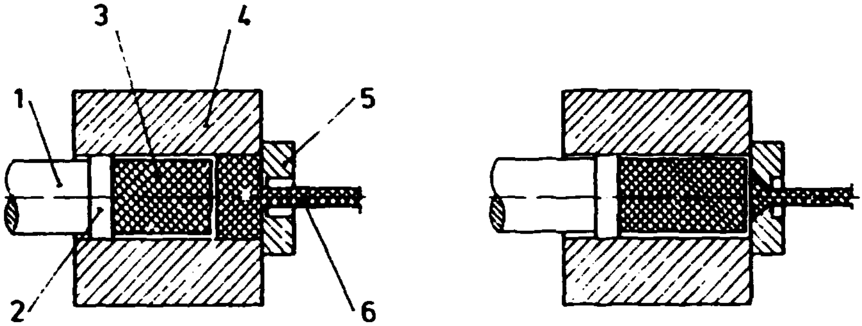
The method of wire-rod manufacture by extrusion is currently applied only where free extrusion capacity is available and the quantity of wire rod required is small (only a few thousand tonnes) [2]. The application of extrusion technology for the manufacture of wire rod is based on the welding of wires by hot extrusion [3]. The weight of coils that can be produced by using that technology is greater than the weights attainable using the technology described in the preceding section. It is significant that hot extrusion of aluminium wire rod is a flexible process that can be applied for small production series, while wire-rod rolling-mills can be used only for large production series.

Figure III (see [3]) illustrates the process of infinite extrusion. The direct extrusion of one wire bar onto another is possible when requirements are not too strict (figure III(A)). Since extrusion causes the tailpiece of the billet to become rich in contaminants that lower the conductivity of the wire and inhibit welding, the tailpiece has to be removed. Two consecutive billets must therefore be welded together by means of a tool having a welding chamber (figure III(B)).

4. *Wire-rod manufacture by cast rolling*

Casting and rolling is the fundamental manufacturing process for alloyed and unalloyed wire rod. A rod of large cross-section is cast in a special casting

Figure III. Infinite extrusion of aluminium



A. With standard tool

B. With tool having weld chamber

Key:
1 Press rod
2 Press disc
3 Billet
4 Recipient
5 Tool
6 Wire

machine, then fed directly into a multi-roll stand at the end of which the wire rod having the required diameter is coiled. Examples of production lines of this type are given in table 7 [4].

All the regularly used wire qualities, in particular E-Al 99.5, E-Al 99.7 and E-AlMgSi 0.5, can be manufactured with the equipment covered in table 7. The weight of the coils varies between 800 and 3,000 kg, depending on the diameter of the wire rod.

Table 7. Characteristics of aluminium wire-rod cast roiling lines

	Sample production lines[a]				
Characteristics	*(1)*	*(2)*	*(3)*	*Properzi No. 7*	*Properzi No. 8*
Cross-section of rod (mm²)	2 250	2 000	2 500	2 184	3 120
Production capacity (tonnes/h)	4	4	5	4	5-8
Number of roll stands	10[b]	10[b]	2[b] + 12[b]	15[c]	17[c]
Diameter of wire rod (mm)	9.5	9.5	9.5	9.5	9.5

[a]Supplier names provided on request by the Department of Industrial operations of UNIDO, Metallurgical Industries Branch.

[b]Two-high arrangement (in 90° turns).

[c]Triangular arrangement.

The supply of molten metal to the casting shop is the first element that may significantly influence the technology to be applied, the equipment to be used and the product cost. A choice between two possibilities may therefore arise. The first possibility is that the casting shop may receive molten metal from the pot-rooms. In that case a simpler and smaller battery of furnaces having the following functions will be sufficient:

(a) Collection and homogenization of molten metal arriving from the pot-rooms at temperatures of from 850°C to 950°C;

(b) Cooling of metal having a temperature above 750°C by adding clean solid waste;

(c) Establishing the required chemical composition;

(d) Cleaning and skimming metal prior to casting, adjustment of the casting temperature and maintaining the required rate of casting. Those operations can be carried out in a separate furnace, called the holding or casting furnace.

The furnaces are not used for melting, and the casting rate is generally about 4 tonnes per hour. A reverberatory furnace with a capacity of from 10 to 25 tonnes and an energy consumption of from 60 to 80 kWh per tonne will therefore meet the requirements.

Depending on local conditions, the collection and homogenization of molten metal can be carried out in one furnace and casting done from another, but with proper planning all operations could be performed in the same furnace unit. Since the major requirement is the continuous operation of the casting and rolling equipment, two furnace units are usually installed to ensure the supply of molten metal for one casting and rolling line.

The second possibility is that the solid metal may have to be melted. That would involve the following major steps: charging the furnace and melting the stock; achieving the correct chemical composition; treating the molten metal; adjusting the casting temperature, cleaning and skimming the metal; and, finally, casting. Those tasks are usually performed by two types of furnace. Melting furnaces of high thermal input capacity, that is, high melting rate, are used to melt the solid metal charge and to treat it with chlorine-generating compounds. Casting furnaces are used for the preparation and casting of molten metal.

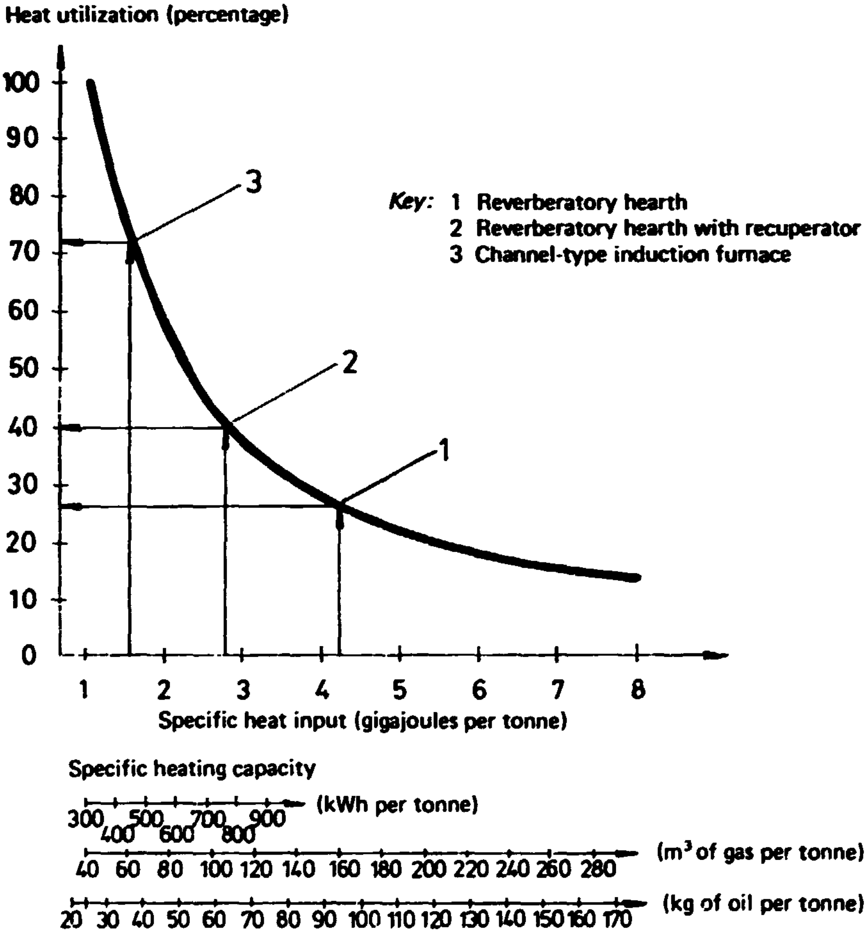
Besides the required melting rate, the availability of energy (electricity, gas or oil) is also an important factor in the selection of the melting furnace. Figure IV ([5], p. 179) shows the heat utilization rates of a melting furnace. For 100 per cent efficiency of utilization, the theoretical amount of energy needed to melt one tonne of aluminium and to heat it up to 710°C is 1.112 gigajoules per tonne.

Energy-saving has become a major concern. As a general rule, every increase of 100°C in the temperature of air produces an average of 5 per cent in fuel savings. One condition for energy-saving is heat recovery through the perheating of combustion air by heat from the flue gases. Several useful examples are cited in [6].

An electric resistance furnace that can be tilted to both sides has the following characteristics:

Capacity	10 tonnes
Depth of bath	600 mm
Nominal heating capacity:	
In delta connection	240 kW
In star connection	80 kW
Rated heating voltage	50 Hz, 380 V
Operating voltage	220 V
Hydraulic tilting unit:	
Rated power of pump motor	10 kW
Capacity of pump	36 l/min
Oil pressure	100 bars
Refractory lining (where in touch with molten metal)	Magnesite

Figure IV. Heat utilization of melting furnaces



The main technical parameters of a casting furnace designed for tilting are the following:

Capacity	25 tonnes
Depth of bath	650 mm
Surface area of bath	21 m^2
Fuel	Oil or natural gas
Number of burners	2

The furnaces should be selected so as to maintain the required operating rate of the casting and rolling equipment, thus avoiding the down times resulting from a lack of molten metal or alloy changes. Since the furnace capacity not regularly needed by the cast rolling equipment can be utilized for the casting of slabs or billets, it is advisable to install a slab or billet caster in addition to the cast rolling unit. A description of such a unit is given in [3].

Molten metal coming directly from the pot-room has a temperature too high for casting, and its impurity level is usually acceptable. Even if solid metal is used, the impurity level of the "frozen" metal is higher than the level permitted in the end-product. The concentration of impurities, such as oxides, inclusions, hydrogen and sodium, will have to be reduced. In a high-quality metal the impurity level is low. To achieve that result the melt has to be cleaned and a portion of the impurities removed.

Several metal-cleaning processes have been developed, the most important of which are described below:

(a) After fluxing and skimming, molten metal is left to rest for from 2 to 4 hours. This is a passive method that does not guarantee the required degree of cleaning, and that demands extra furnace capacity and plant space;

(b) The metal may be cleaned by using the following agents, singly or in combination: a neutral (inert) gas such as nitrogen or argon; an active cleaning gas such as chlorine; or an agent generating or producing the same effects as an active cleaning gas. The cleaning operation is carried out in a furnace or a ladle;

(c) The melt may be subjected to intermittent vacuum treatment. This method, which requires expensive equipment, is especially suitable for reducing the hydrogen content;

(d) The best results have been achieved with the increasingly widespread type of equipment that operates on a principle of cleaning "in line". With such equipment cleaning takes place closest to the place of freezing of the metal.

Continuous metal-cleaning equipment can be classified into two main groups according to the mechanism of cleaning. The two groups can be identified by their differing techniques: on the one hand, inert gas (nitrogen or argon) and the active cleaning gas (chlorine) are charged against the flow of molten metal; on the other, the gases are injected into the melt via one or more rotating mixer heads. An example of the above-mentioned techniques is provided by the spinning nozzle inert flotation process, which has been in use since 1974.

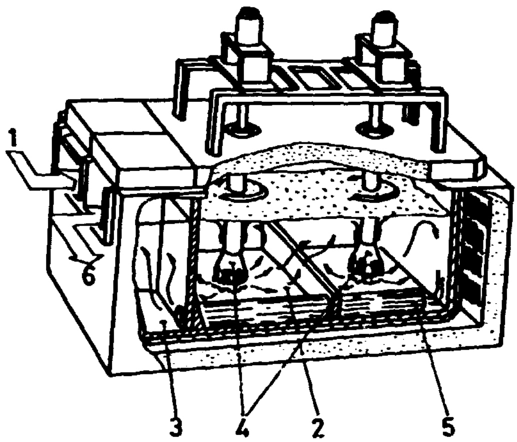
Figure V shows a twin-rotor variant. The unit consists of a system of chambers placed in a container made of refractories and lined with graphite. Heating elements are built in between the outer wall and the graphite lining. Two spinning nozzles reach into the melt from below and the cleaning gas (usually very clean nitrogen and from 1 to 5 per cent chlorine) enters the cleaning chamber via the axes of the rotating heads. Finely dispersed gas bubbles physically remove the hydrogen and oxides by lifting them to the surface of the melt, while chlorine reacts with other impurities such as sodium).

The cleaning capacity of a continuous metal-cleaning unit with only one spinning nozzle is 10 tonnes per hour, while a unit with two spinning nozzles can clean 20 tonnes of metal per hour. Built-in heating capacity is 30 kilowatts, and the dispersing-mixer head rotates at 380 revolutions per minute. The practical results achieved with such a unit using a gas mixture of 99 per cent nitrogen and 1 per cent chlorine are as follows:

Condition of metal	*Hydrogen (g per gram of aluminium)*	*Oxygen (ppm)*	*Sodium (ppm)*
Before treatment	0.12-0.20	20-30	20-30
After treatment	0.06-0.08	5-10	5

Increasing the chlorine content (for example, up to 3 per cent) would decrease the sodium content to from 1 to 2 parts per million. The various metal-cleaning processes are usually applied in combination, especially when the metal is known to have a high impurity level, which occurs when metal

Figure V. Continuous metal-cleaning equipment designed for the spinning nozzle inert flotation process



Key: 1 Metal feed from casting furnace
2 Cleaning chamber
3 Casting chamber
4 Gas injector and mixer
5 Passage for cleaned metal
6 Metal discharge to casting

from electrolysis is directly transported to the casting shop. The sodium content of such a metal can reach from 80 to 120 parts per million prior to cleaning. Metals having such a high level of impurities are usually pretreated by resting or adding from 1.5 to 3 kilograms per tonne of hexachloroethane to the melt prior to filtering. When pretreatment of the molten metal is not possible, the chlorine content of the cleaning gas mixture should be increased (for example, up to a maximum of 30 per cent). Since chlorine is harmful to human beings and to the environment, all chlorine storage and charging facilities and exhaust systems (stacks, neutralizers) must be designed in accordance with the regulations of the country concerned.

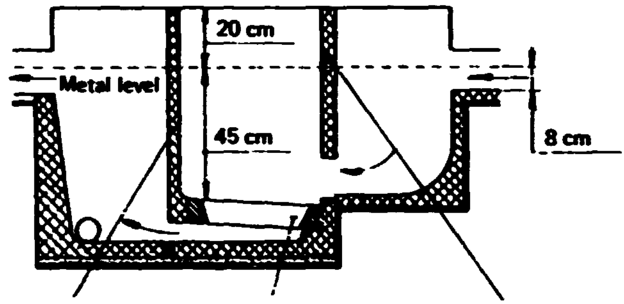
Vanadium and titanium impurities that lower the conductivity of wire rod will have to be removed from the molten metal. Such impurities may be removed in one of the following ways:

(a) Boron containing flux is added to the electrolysing pots;

(b) An aluminium-boron master alloy containing from 1 to 2 per cent of boron is charged into the molten metal. Boron reacts with vanadium and titanium to form compounds with a high melting point that either settle or can be filtered out.

As a further cleaning step ceramic filter plates consisting mainly of aluminium oxide (80-85 per cent of Al_2O_3) have been developed and used for the removal of coarse non-metallic inclusions. Ceramic filter plates of that type (for example, with dimensions of 23 cm × 23 cm × 5 cm, a porosity of from 85 to 90 per cent and an average of 12 pores per linear centimetre) are placed into the metal flow at an adequate position in the casting trough (see figure VI).

Figure VI. Arrangement of ceramic filter plate in casting channel



One square metre of ceramic filter plate with a thickness of 50 millimetres can process in a lifetime from 100 to 200 tonnes. On the basis of tests carried out with that type of filter, inclusions of more than 5 microns are filtered out. The sodium content is decreased by only 20 to 40 per cent, provided the initial value is from 20 to 50 parts per million, and the hydrogen content is not decreased by the filter at all. For the production of wire rod the metal to be cast should have the following maximum impurities:

Hydrogen	0.12 g per gram of aluminium
Sodium	0.10 ppm

Such low impurity levels can be ensured only by the combined application of various cleaning processes.

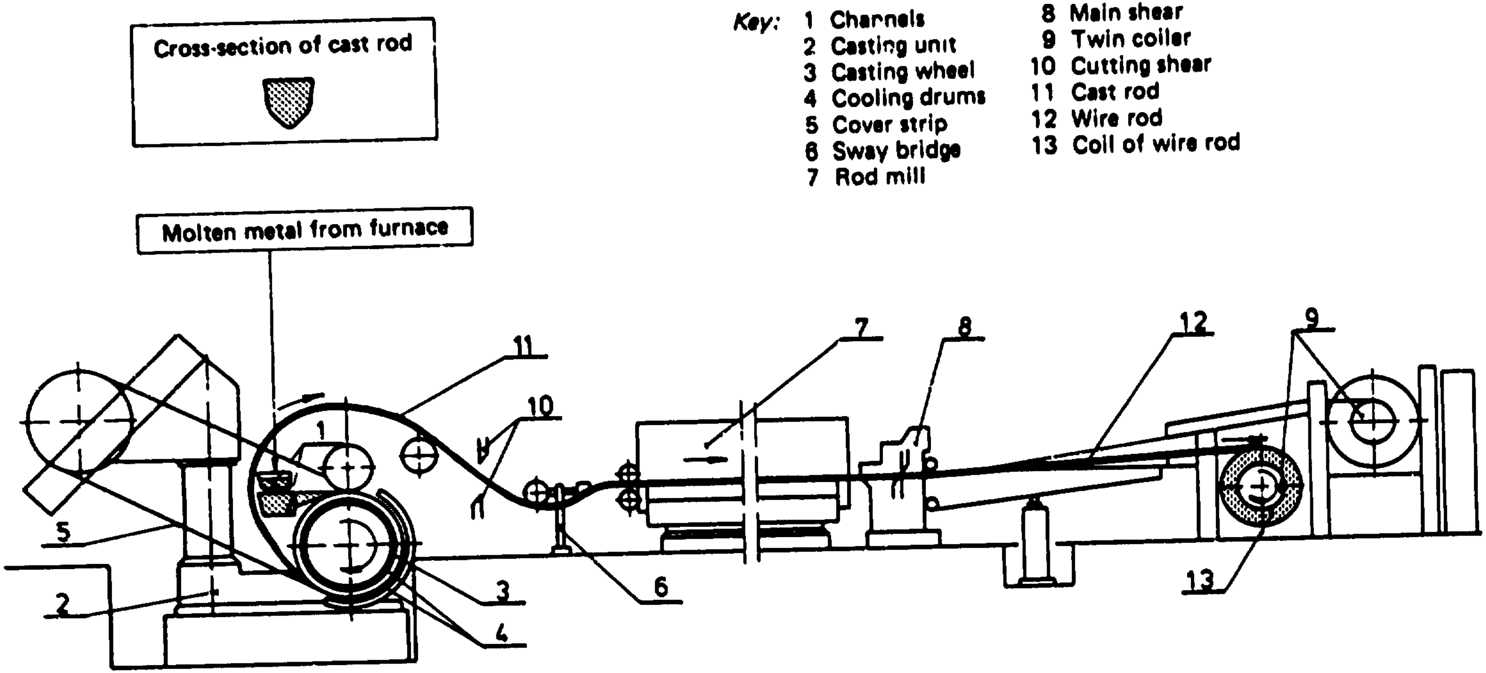
Proper alloying and grain refinement are required for the cast rolling of alloyed wire rod. Alloying is done by charging metallic magnesium and an aluminium-silicon master alloy containing from 10 to 20 per cent of silicon. An aluminium-titanium-boron master alloy containing 5 per cent of titanium and up to 1 per cent of boron is used for grain refinement. The master alloy can be fed to the furnace in the form of small ingots (from 3 to 4 kilograms per tonne of aluminium) or continuously in the form of wire amounting to from 1.5 to 2 kilograms per tonne. The aluminium-titanium-boron wire should be fed into the casting trough at such a distance from the place of solidification that the intermetallic particles serving as the nuclei for crystallization may be uniformly dispersed.

Cast rolling lines form the principal equipment of the casting shop. The varied technologies are dealt with in detail in [7]. A widely used type of continuous cast rolling equipment, named Properzi after the inventor, is produced by a firm in Italy. The four lines of equipment currently produced are, in increasing order of capacity, as follows:

Mini 8 (similar to the 6E)
8/13 (similar to the 7E)
1800-8/17
2000-8/17

The Properzi casting and rolling line is illustrated in figure VII.

Figure VII. Continuous casting unit for Properzi wire rod



The rod-casting machine has a water-cooled casting wheel, the crown of which is machined for the rod to be cast and is covered by a steel band. Molten metal fed into the trough machined into the wheel solidifies as a result of the cooling effect of the rotating wheel and covering steel band. Solidified rod leaves the casting wheel and passes onto the rolling line. The casting machine is further equipped with a metal transfer trough, a casting plate and a structure supporting the casting machine and the cast rod.

It is essential to maintain a constant level of molten metal in the casting trough, especially when casting alloyed rod. That can best be ensured by horizontal metal feeding, in which, for example, molten metal flows through a needle valve and a balanced buoy into the last chamber of the casting channel. Adjustment of the balancing weight ensures precise control of the metal level and automatic metal feed.

The casting wheel of the machine is made of high-quality and high-conductivity electrolytic copper. For the casting of unalloyed aluminium rods the material of the casting wheel is either unalloyed copper or copper alloyed with chromium and zirconium and hardened by cold-working in the former case and by heat treatment in the latter. For the casting of alloyed aluminium rods the casting wheel is made of copper alloyed with silver.

The material of the casting wheel may contain only very small quantities (from 100 to 200 parts per million) of oxides or oxygen. The surface of the casting wheel in touch with aluminium should be absolutely smooth and polished.

Cooling of the casting wheel is achieved by two rows of water jets on the inside and one row on the outside. Cooling water is required at a rate of from 40 to 60 cubic metres per hour at a pressure of from 3 to 4 bars. Scaling should be avoided.

The cavity of the mould on the casting wheel has to be lubricated with oil prior to casting. A blank rod is placed into the mould before casting, molten metal is fed until it reaches the blank rod, and the casting wheel is then started. The blank rod helps to ensure that the whole length of the aluminium rod will be put to valuable use.

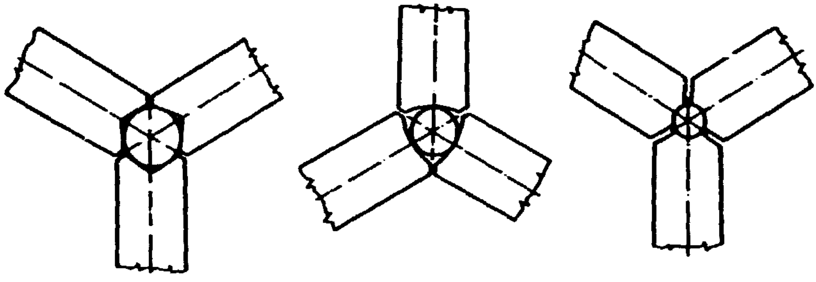
The rolling line consists of from 13 to 17 mill stands. The Properzi rolling-mill contains three work rolls in each of the roll stands. The work rolls are positioned at 120° with respect to each other. The cavities milled into the work rolls together form the designed shape and determine the rate of deformation and the dimensions of the rod.

The cavities formed by the work rolls alternate between hexagonal and triangular up to roll stand number 10. Even-numbered roll stands give triangular, and odd-numbered roll stands hexagonal, shape to the wire rod being formed. Final rolling is always done by odd-numbered roll stands. Even-numbered roll stands before the odd-numbered ones that do the final rolling have triangular cavities that smooth the surface of the wire rod. The work rolls in any two consecutive roll stands are rotated by 60° in order to roll down the edges of the wire rod formed in the previous roll stand. Cavities and roll stands are illustrated in figure VIII.

A pass schedule calculated for 17 roll stands is summarized in table 8.

The elongation factor is the ratio of the cross-sections of the wire rod entering and leaving the same roll stand. Deforming force, torque and power requirements can be determined on the basis of relationships involving section rolling. The number of revolutions of the work rolls in a certain group of roll stands being fixed and the elongation factors theoretically constant, the roll

Figure VIII. Sketch of mill stands and voids in the Properzi process



a b c

Key: a Hexagonal void
b Stretching or flattening triangle
c Circle

Table 8. Pass schedule for a Properzi line 7E

Rod and number of roll stands	*Shape of cavity*	*Cross-section of rolled wire rod (mm²)*	*Diameter of wire rod (mm)*	*Elongation factor*
Rod	Trapezoid	2 184	—	—
1	Hexagonal	1 862	—	1.170
2	Triangular	1 465	—	1.280
3	Hexagonal	1 145	—	1.280
4	Triangular	895	—	1.275
5	Hexagonal	711	—	1.275
6	Triangular	565	—	1.265
7	Hexagonal	445	—	1.265
8	Triangular	352	—	1.265
9	Hexagonal	280	—	1.265
10	Smoothing triangle	211	—	1.265
11	Circular	176	15.01	1.265
12	Smoothing triangle	140	—	1.253
13	Circular	112	11.95	1.253
14	Smoothing triangle	89	—	1.253
15	Circular	71	9.53	1.253
16	Smoothing triangle	56	—	1.253
17	Circular	45	7.6	1.253

stands can be driven by a single direct-current motor. The complete rolling-mill line can be synchronized by the casting wheel. That is accomplished when the cast rod passes over an arched tilting set of rollers, the position of which provides the signal for fine synchronization.

The work roll area of roll stands is closed and divided into two compartments by fittings. One of the compartments takes part in the circulation of lubricants for the drive gears and bearings, the other helps the circulation of the cooling emulsion for the work rolls. The two types of lubricants should never mix.

The oil content of the emulsion (the cooling lubricant for the work rolls) is from 10 to 15 per cent and is directed to the entry rollers and work rolls. The rate of feeding the emulsion to the first work roll stand when starting should be small to prevent the rod from slipping. To achieve the required mechanical properties of the wire rod, the amount and temperature of the emulsion will have to be controlled during rolling.

The temperature of the emulsion varies between 40°C when taken in for cooling and 80°C when leaving the work roll area. The emulsion is filtered with a band-type filter. The capacity of the emulsion storage tank and that of the transfer pump depend on the size of the rolling-mill. The capacity of the cooling system of the whole rolling-mill should be based on an entry temperature of the rod of about 480°C and an exit temperature of about 290°C. The amount of heat to be discharged can be determined from the temperature difference of about 200°C and the weight of metal passing through the equipment in one hour. A charge of emulsion should be changed after from 1 to 1.5 months of operation.

Coiling wire rod at a temperature of about 250°C directly after leaving the rolling mill would cause irregular cooling of the coil, since the inside of the coil could be at a higher temperature than the outside in case of open-air cooling. Since this irregularity in cooling would impair the mechanical and electrical properties of the wire rod, up-to-date wire-rod manufacturing lines have a cooling unit installed between the rolling-mill and the coiler. The cooling unit is designed to lower the temperature of the wire rod to about 100°C.

The coiling of wire rod can be done by coilers having horizontal axes or by basket-type coilers. The coilers usually have two drums and automatically switch from one drum to the other when the first one is full. The pre-adjusted weight of a coil is between 800 and 3,000 kilograms.

For further processing the coiling of unalloyed wire rods must be tight, especially where no intermediate cooler is built between the rolling mill and the coiler, and that of alloyed wire rods must be loose, in order to let water reach all threads during the following hardening steps, thereby producing more uniform mechanical properties. The pitch of coil threads is from 3 to 4 millimetres higher than the diameter of the wire rod. Coils of wire rod have to be packed for long-distance transport prior to further processing. Figure IX shows alternative methods of packing wire-rod coils for land and marine transport.

The quality control of applied technologies and manufactured products is a never-ending task. In addition to the measurement of dimensions and temperature, the analysis of chemical composition and the testing of electrical and mechanical properties are to be performed regularly.

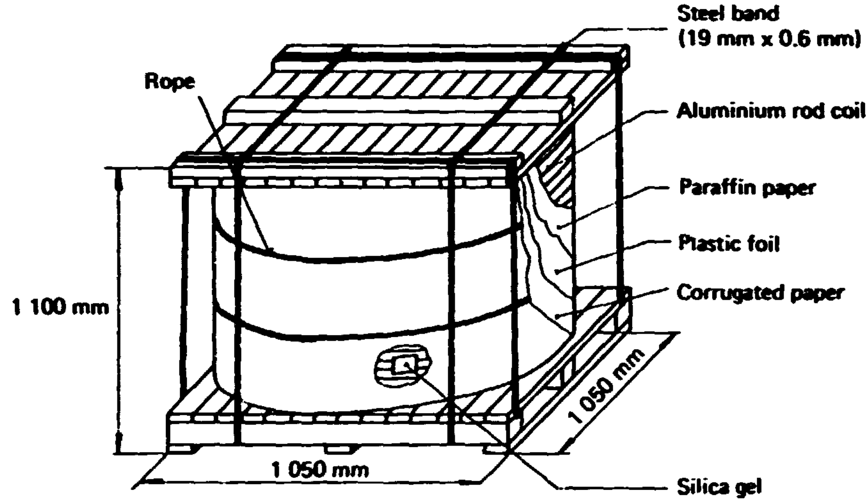
B. Technology and equipment for wire-rod casting plant

1. Product mix

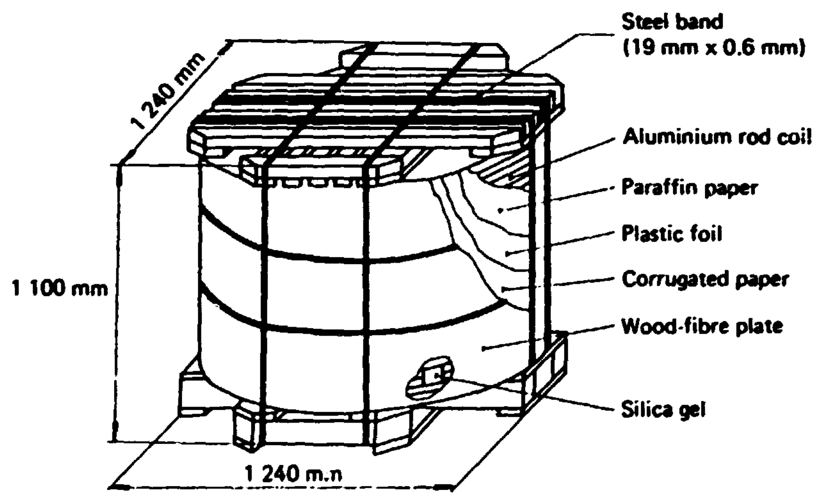
The quantity and mix of products are basically determined by market demand, but there exists a lower limit of capacity below which economic production cannot be achieved.

The wire-drawing and stranding capacities to be installed have to be determined on the basis of the wire-rod demand and optimum economic capacity. Various required levels of production are given in table 9.

Figure IX. Packing of wire-rod coils



A. For land transport



B. For marine transport

2. *Key equipment and description of plant*

The major parameters of currently available Properzi-type wire-rod lines are summed up in table 10. A comparison of tables 9 and 10 shows that no economic wire-rod man·.acturing capacity can be installed for a required wire-drawing and twisting capacity of 5,125 tonnes per annum. In such a case it seems more prudent to purchase the wire rod or to set up the smallest economically viable wire-rod manufacturing unit and to sell the extra amount

Table 9. Annual wire-rod production requirements

(Tonnes per annum)

Total	*Production requirements*	
	Alloyed	*Unalloyed*
	A. *Drawn wire*[a]	
2 500	1 250 (50)	1 250 (50)
5 000	2 500 (50)	2 500 (50)
10 000	3 000 (30)	7 000 (70)
20 000	4 000 (20)	16 000 (80)
	B. *Cast and rolled wire rod*	
	E-AlMgSi 0.5	*E-Al 99.5*
2 562	1 287	1 275
5 125	2 575	2 550
10 230	3 090	7 140
20 440	4 120	16 320

Note: Because of waste, 1.03 kg of alloyed wire rod, or 1.02 kg of unalloyed wire rod, is required for the production of 1 kg of drawn wire.

[a]Figures in parantheses indicate percentages.

on the domestic or external market. It is estimated that from 1983 to 1985 the selling price of unalloyed wire rod per tonne was from $200 to $250 higher than that of aluminium ingot, regardless of the level of purchases or sales of wire rod.

Provided the capacity of the wire-drawing plant and the amount of wire rod that can be exported reach a total of 9,000 tonnes per annum, that is, two-thirds of the capacity of the smallest wire-rod manufacturing line, it may be feasible to install Properzi line 6E. Provided the domestic and external demand for wire rod can reach the amount of 15,000 tonnes per annum in a not too distant future, the feasibility of initially installing Properzi line 7E should be considered.

When calculating capacity it should be borne in mind that the amount of wire rod made of aluminium-magnesium-silicon alloy could be from 20 to 35 per cent less than that of unalloyed wire rod (see [7]). Table 10 indicates the number of operators required for the Properzi wire-rod manufacturing lines. The number of operators can be grouped as follows: chief operator, casters, coiler operators, furnace operators and general aid. Calculation of the number of working hours has been based on three eight-hour shifts per day, five days per week and 50 weeks per year. Auxiliary operations depend on the degree of utilization of the manufacturing line, which may vary from 70 to 92 per cent (see [7]). The present writers have found the degree of utilization to be 82 per cent.

In 1986 the approximate prices of various Properzi-type wire-rod manufacturing lines were as follows:

Type of manufacturing line	*Price (dollars)*
6E—Mini 8	1,560,000
7E—8/13	2,400,000
1800—8/17	4,100,000
2000—8/17	4,500,000

Table 10. Technical characteristics of Properzi wire-rod cast rolling lines

Item	*Unit*	*Type of line and specifications*			
		6E - Mini 8	*7E - 8/13*	*1800 - 8/17*	*2000 - 8/17*
Cross-section of rod	mm^2	1 130	2 163	3 472	3 472
Diameter of casting wheel	mm	1 400	1 400	1 800	2 000
Diameter of wire rod	mm	Stand 13: 7.60	Stand 13: 9.53	Stand 17: 7.60	Stand 17: 7.60
		Stand 11: 9.53	Stand 11: 11.95	Stand 15: 9.53	Stand 15: 9.53
		Stand 9: 11.95	Stand 9: 15.01	Stand 13: 11.95	Stand 13: 11.95
		Stand 7: 15.01		Stand 11: 15.01	Stand 11: 15.01
Power of drive motor	kW	235	368	588	735
Nominal casting rate	kg/h	2 800	4 500	8 000	9 100
Degree of utilization	Percentage	82	82	82	82
Number of working hours per year		6 000	6 000	6 000	6 000
Yearly production					
(E-Al 99.5, diameter of 9.53 mm)	Tonnes per year	13 776	22 140	39 360	44 772
Number of persons per shift		4	5	5	5
Man-hours per tonne		1.74	1.35	0.76	0.67

The following main technological steps are to be carried out in a wire-rod plant: supply of molten metal from pot-rooms or from solid charge by melting; alloying, including microalloying and grain refinement; cleaning of the melt; casting and rolling of the rod; coiling; hardening and drying of alloyed wire rod, operations which can also be carried out in the wire-drawing plant; quality control; and packaging.

(a) Supply of molten metal

For molten metal transported from a nearby electrolysis plant two electric resistance furnaces should be installed, each with a capacity of from 10 to 20 tonnes, depending on the capacity of the cast rolling line. That is the most common arrangement of Properzi cast rolling lines. Usually the range of products of an aluminium smelter is broadened by installing a cast rolling line for wire rod as an addition to slab and billet casting and narrow- and wide-strip casting. The advantage of such an arrangement is the direct utilization of the heat content of molten metal, although that requires the existence of an adequate industrial infrastructure.

When only solid metal is available, a melting operation is required to supply molten metal to the wire-rod plant. For proper utilization of the main production equipment, it is important to have a cycle time for the melting furnaces to match the operating schedule of the cast rolling line. Melting furnace capacity can be increased gradually by installing several smaller units when the final capacity of the cast rolling line cannot be utilized. In such a case, higher investment and operating costs should be expected because of the greater number of smaller units.

The cost of remelting ingots is significant. The specific cost of remelting ranges from $40 to $50 per tonne, including fuel consumption as indicated in figure IV, with all depreciation costs supposing a depreciation period of 10 years, maintenance and operating costs, and a 2 per cent melting loss as a result of oxidation of molten metal.

(b) Alloying

When the casting shop receives molten metal from a nearby pot-room, the sequence of operations will be as follows:

(a) Charging silicon containing the master alloy (AlSi 12) to the bottom of the furnace, for E-AlMgSi 0.5 only;

(b) Pouring molten metal into the furnace;

(c) Cooling the melt to 760°C (for example, by charging solid metal of appropriate composition);

(d) Mixing metallic magnesium, for E-AlMgSi 0.5 only;

(e) Sample-taking for chemical analysis;

(f) Correcting alloy content (for example, magnesium, silicon), for E-AlMgSi 0.5 only;

(g) Mixing, treatment and skimming.

In a casting shop starting with solid metal, all the constituents of the metal charge, including alloying elements and additives, will be melted in the melting furnace. The charging of magnesium, sample-taking for further chemical analysis and correcting the alloy composition are also usually carried out in that furnace, and only the ready metal is transferred to the casting furnace.

The level of impurities (titanium and vanadium) that lower the conductivity of metal is generally higher in the pot-room metal than permitted. That can be remedied by charging boron-containing flux (for example, borax) into the metal in the pot. The quantity to be charged is from [illegible] to 3 kilograms per tonne.

Improved workability and strength of the end-product made of alloyed materials is ensured by charging grain-refining compounds such as AlTi5B1 into the melt. Grain-refining master alloy can be charged into the metal in the form of ingots or of wire 9 mm in diameter fed into the metal-transfer trough just before the metal-cleaning unit. Controlled and uniform feeding of grain-refining wire is done by a specially designed device.

(c) Cleaning the melt

The prepared melt is treated with chlorine-generating flux either in the casting furnace for casting shops starting with solid metal or in the collecting furnace for casting shops operating with molten metal. The amount of chlorine-generating flux used, for example hexachloroethane, is from 1 to 4 kilograms per tonne. Since the impurity content of the melt after treatment is usually too high, further cleaning of the metal is necessary. It is done in a cleaning unit installed between the casting furnace and the casting wheel. Some well-known units can provide a cleaning capacity of more than 10 tonnes per hour. Material requirements of the casting shop are given in table 11 for the previously determined capacity levels.

Table 11. Annual material requirements of a casting shop

(Tonnes per annum)

	Material requirements based on annual production and distribution					
	Total of 10,000		*Total of 15,000*		*Total of 20,000*	
Material	*Unalloyed 7,000*	*Alloyed 3,000*	*Unalloyed 11,500*	*Alloyed 3,450*	*Unalloyed 16,000*	*Alloyed 4,000*
Molten metal from pot-room	10 230[a]		15 335[a]		20 440[a]	
Master alloy AlB3 (3 % B)	24	—	40	—	56	—
AlTi5B1	—	12	—	14	—	16
AlSi12	—	125	—	144	—	166
Metallic Mg	—	16	—	19	—	22
Aluflux EV[b]	5		8		10	
Aluflux H[b]	30		45		60	

[a]The amount of molten metal from the pot-room should be increased by the melting loss. The rate of melting loss varies from 1 to 4 per cent, depending on melting conditions and charge.

[b]Type of refining flux.

(d) Quality control

Quality control covers the chemical composition, shape, surface characteristics and mechanical and electrical properties of the end-products. That requires regular examination of samples taken at certain stages of production. In general, the following kinds of sample are taken and examined:

(a) Samples from the metal bath in the furnace, to determine chemical composition after alloying and correction, and from the metal transfer trough at the beginning, in the middle and at the end of casting;

(b) Samples from the end of each of the coils, in order to determine mechanical and electrical properties;

(c) Samples from the coils, to determine shape and surface quality at certain stages of production.

A spectrograph is used for chemical analysis, an electron microscope is preferred for structural analysis, and equipment for performing tensile tests, twisting and bending is used for mechanical tests. Regular control of the production process requires appropriate dip-tube pyrometers and touch pyrometers and other measuring instruments.

3. *Major technical and operating parameters*

For guidance concerning the supply of plant equipment, major technical and operating parameters are listed below for one tonne of production. They are average figures that may vary to a large extent depending on local conditions.

Parameters	*Units per tonne of aluminium*
Heating requirements	
For melting: Heating oil	80-100 kg
Natural gas	130 m^3
For holding: Electric power	110 kW
Natural gas	20 m^3
Electric power for driving	75 kW
N_2 gas for metal cleaning	2 m^3 (at 20°C and 1 bar)
Cl_2 gas for metal cleaning (up to 10 per cent chlorine content of gas mixture)	360 g
Hexachloroethane for metal cleaning (in pill or powder form)	3-4 kg
Compressed air	30 m^3 (at 20°C and 1 bar)
Emulsion: For E-Al 99.5	0.5 kg
For E-AlMgSi 0.5	2-3 kg
Lubricating oil	0.1 kg
Cooling water: Recycled	22.5 m^3
As make-up water	0.5 m^3
	Tonnes of alluminium
Lifetime of casting wheel:	
Of ordinary copper	800-1,000 per piece
Of special alloy	4,000-6,000 per piece
Lifetime of steel band	20-60 per piece
Lifetime of work rolls:	
Of steel (without regrinding)	7,500 per set
Of tungsten carbide (without regrinding)	30,000 per set

Personnel requirements depend greatly on the extent to which the production plant relies on auxiliary units (for major maintenance, transport, in-laboratory tests, analysis etc.) and the continuous operation of the

Table 12. Estimated personnel of casting shop

Activity or type of personnel	Number of shifts	Personnel required for different levels of wire-rod production: 10,000 tonnes per annum	20,000 tonnes per annum
Casting and rolling line	3	12	15
Melting	3	6	6
Maintenance	1	3	4
Maintenance staff on duty	3	3	3
Transport	1	2	4
Technician	1	2	2
Plant engineer	1	1	1
Administration	1	1	1
Plant manager	1	1	1
Total		31	37

Note: Estimates are given for the casting shop of a plant receiving molten metal. When a solid charge is used, a further nine persons should be added for the melting operations (or 31 + 9 = 40 persons for a capacity of 10,000 tonnes per annum).

production line can be ensured (by continuous material supply), and on the capacity of the production line (since higher-capacity lines have higher productivity). The personnel requirements of a plant starting operations from molten metal, with further processing of the wire rod in a nearby wire-drawing plant to which the wire rod can be transported without packaging, are given in table 12.

The plant will have to keep a stock of reserve materials to ensure uninterrupted operation. The amount of aluminium stock greatly depends on the availability of the metal, on whether the technology is based on solid or liquid metal, on the location of the drawing plant, on whether the wire rod is to be exported or not etc. The aluminium stock can be best estimated in terms of the number of production days, as shown in table 13. When liquid metal is used, only the alloying elements have to be stocked.

A few other possibilities may also exist. Greater reserves of production capacity may result in keeping smaller stocks. It is very important to speed up transport from the plant. That requires a labour force for quality control, packaging, transport, material handling etc., and the organization of production in accordance with transport needs.

The stock of spare parts has a value of from 3 to 10 per cent of the value of the equipment used, depending on the degree of complexity of the equipment and the availability of spare parts. A larger stock of spare parts should be kept in developing countries located far away from the country of the equipment manufacturer.

Table 13. Estimated aluminium stock

	Required stock expressed in terms of production days					
	Drawing plant nearby (packaging not required)			Drawing plant far away (packaging required)		
Type of metal supply	Before melting	Wire rod	Total	Before melting	Wire rod	Total
Molten metal	1	—	1	1	3	4
Solid charge	7	—	7	7	3	10

A plant should have a complete set of tools and dies for all its main products. There should be a three-months stock of other tools and auxiliary materials, such as lubricants, casting dies, covering bands for casting wheels and work rolls, but an even larger stock of materials and tools less frequently used can be maintained.

Useful data on operating costs of Properzi-type aluminium wire-rod cast rolling lines are given in [7]. The data are based on 25 years of observation and on the investment experience of more than 120 Properzi cast rolling lines. To eliminate the distorting effects of aluminium price fluctuations, the original figures expressed in dollars have been recalculated to take into account the percentage distribution of processing costs (the latter does not include prices of materials). The figures contained in table 14 refer to a plant starting with molten metal, where there is no melting loss to calculate, and only E-Al 99.5 material is processed. The payback period has been taken as 10 years for the calculation of depreciation.

Table 14. Estimated operating costs of Properzi-type wire-rod production lines

(Percentage)

	Type of production line			
Cost factor	*6E*	*7E*	*1800-8/17*	*2000-8/17*
Wages of operators	27.3	23.4	16.9	15.8
Wages of maintenance personnel	9.3	9.5	8.9	8.8
Management and control	10.5	7.0	4.8	4.4
Auxiliary materials	6.4	7.0	8.9	9.6
Maintenance materials	5.8	4.4	4.8	4.4
Electricity	4.1	4.4	5.6	6.1
Fuels	7.0	5.7	6.4	6.1
Depreciation	22.0	33.5	38.7	39.5
Others	7.6	5.1	4.8	5.3
Total	100.0	100.0	100.0	100.0
Ratio of operating costs of other types with respect to type 6E	100.0	91.9	72.1	66.3

4. *Investment data*

Selected production equipment and investment cost estimates for a wire-rod plant starting with molten metal are given in table 15. Figure X shows the arrangement of equipment in the plant.

Selected production equipment and investment cost estimates for a wire-rod plant using solid charge are given in table 16. Figure XI shows the arrangement of equipment in the plant.

The tables do not include the costs involved in procuring the plant site, in particular the purchase price of land and infrastrucutre investment, which can vary so much that each case should be considered individually. In order to operate a plant other financial resources are required, such as working capital for metal stock and spare parts, which amounts to from 15 to 25 per cent of the investment cost.

In table 17 the investment costs of Properzi lines 6E and 7E are compared for total capacity utilization.

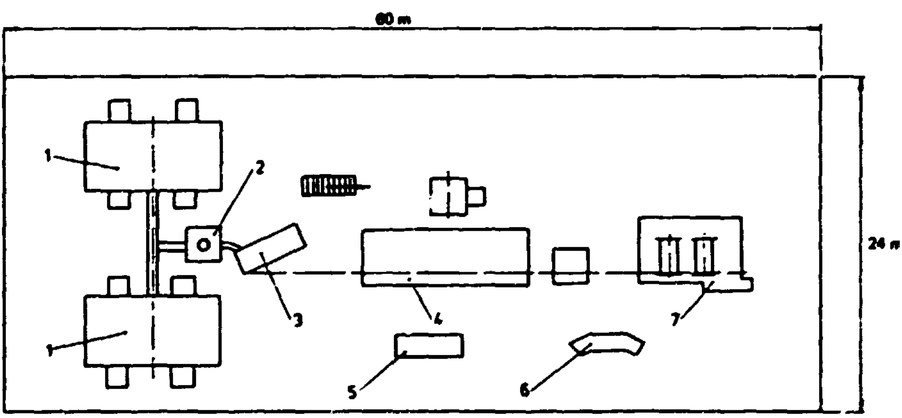
Table 15. Investment cost estimate for plant operating with molten metal

(Thousands of dollars)

		Investment costs based on wire-rod requirements					
		10 000 tonnes per annum		*15 000 tonnes per annum*		*20 000 tonnes per annum*	
Item	*Unit price*	*Number of units*	*Cost*	*Number of units*	*Cost*	*Number of units*	*Cost*
Electric resistance furnace (12 tonnes)	280	2	560	2	560	—	—
Fuel-fired reverberatory collecting furnace (25 tonnes)	400	—	—	—	—	2	800
Continuous metal-cleaning equipment with accessories	350	1	350	1	350	1	350
Grain-refining unit with wire feeder	10	1	10	1	10	1	10
Cast rolling machine, type 6E	1 340	1	1 430	—	—	—	—
Cast rolling machine, type 7E	2 400	—	—	1	2 400	1	2 400
Quality control and office equipment	—	—	100	—	150	—	200
Transport units (indoors)	—	—	100	—	150	—	200
Building, 24 m × 60 m	300[a]	—	430[a]	—	430[a]	—	430[a]
Erection	—	—	340	—	450	—	550
Others (engineering, know-how etc.)	—	—	200	—	250	—	300
Total	—	—	3 520	—	4 750	—	5 240

[a]Dollars per square metre.

Figure X. Arrangement of equipment in wire-rod plant operating with molten metal



Key: 1 Casting furnace
2 Continuous metal-cleaning unit
3 Casting machine
4 Rod mill
5 Control panel
6 Control panel
7 Coiler

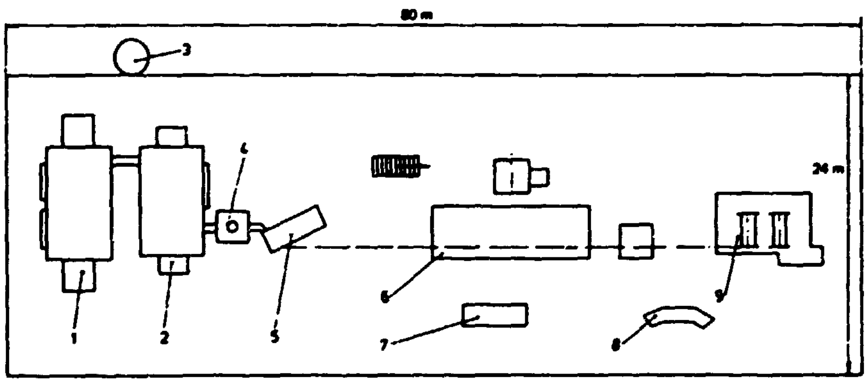
Table 16. Investment cost estimate for plant operating with solid charge

(Thousands of dollars)

Equipment and facilities	*Unit price*	*Estimates based on wire-rod requirements*					
		10 000 tonnes per annum		*15 000 tonnes per annum*		*20 000 tonnes per annum*	
		Number of units	*Cost*	*Number of units*	*Cost*	*Number of units*	*Cost*
Fuel-fired melting furnace (capacity of 28 tonnes, melting rate of 5.4 tonnes per hour)	1 230	1	1 230	1	1 230	1	1 230
Fuel-fired casting (25 tonnes)	400	1	400	1	400	1	400
Continuous metal-cleaning equipment with accessories	350	1	350	1	350	1	350
Grain-refining unit with wire feeder	10	1	10	1	10	1	10
Cast rolling machine, type 6E	1 430	1	1 430	—	—	—	—
Cast rolling machine, type 7E	2 400	—	—	1	2 400	1	2 400
Quality control and office equipment	. .	. .	100	. .	150	. .	200
Transport equipment (indoors)	. .	. .	100	. .	150	. .	200
Building, 24 m × 80 m	300[a]	—	580[a]	—	580[a]	—	580[a]
Erection	. .	. .	340	. .	450	. .	550
Others (engineering, know-how etc.)	. .	. .	230	. .	270	. .	300
Total	—	—	4 770	—	5 990	—	6 220

[a]Dollars per square metre.

Figure XI. Arrangement of equipment in plant operating with solid metal



Key: 1 Melting furnace
2 Casting furnace
3 Stack
4 Metal-cleaning unit
5 Casting machine
6 Rod mill
7 Control panel
8 Control panel
9 Coiler

Table 17. Comparison of investment costs

Item	Properzi cast rolling line			
	Type 6E		Type 7E	
	Molten metal	Solid charge	Molten metal	Solid charge
Investment cost (thousands of dollars)	3 870	5 150	5 330	6 390
Capacity (tonnes per annum)	13 776	13 776	22 140	22 140
Investment cost (dollars per tonne per year)	281	374	241	289

Trends in investment and operating costs, as reflected in tables 14 and 17, show the advantages of plants having higher productivity.

Names and addresses of major equipment suppliers will be provided on request by the Department of Industrial Operations of UNIDO, Metallurgical Industries Branch.

III. Wire-drawing

A. Production processes and applied equipment

Unalloyed and alloyed wires are obtained from hot-worked wire rod by further cold-working, usually through wire-drawing. Most cold-drawn wires are processed into electric conductors of various types.

1. *Characteristics of drawn wires*

Data on the chemical composition of unalloyed and alloyed aluminium wires used in the manufacture of power transmission lines are given in table 2, and the mechanical and electric properties of conductor materials are summarized in table 3. A very important characteristic of wires and cables is their tendency to show fatigue when subjected to stress. Bending tests are carried out to determine the failure point. Such tests involve coiling and decoiling the wire around a cylinder of a specified diameter. Wires should withstand a certain number of bending operations without failure. That number is eight for E-Al 99.5 and four for E-AlMgSi 0.5.

2. *Wire-drawing technology and equipment*

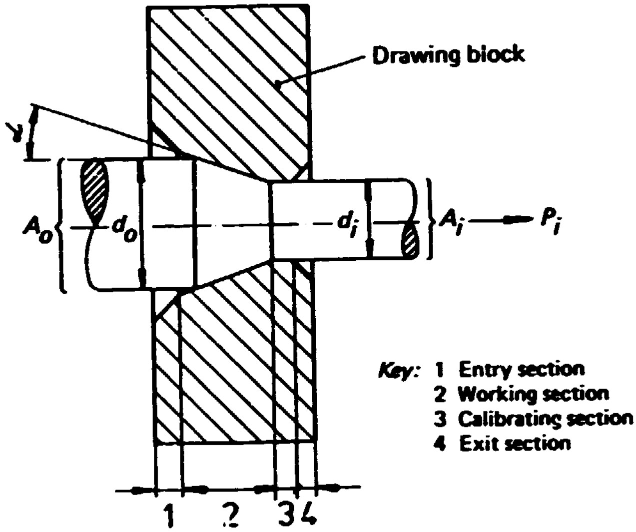
A number of innovations in wire-drawing technologies and equipment have not yet been applied in mass production. Although not described in detail here, those innovations have been covered extensively in [8].

Some technologies have already passed the level of laboratory and pilot-plant experiments. Thus, a firm in Italy has developed a new wire-rolling line that is available and ready for use in plant operations. The production line is equipped with from 10 to 12 roll stands with calibrated work rolls in triangular arrangement. The wire-rod mill starts from wire rod having a diameter of 9.5 millimetres, which it rolls down at a high speed (up to 50 metres per second) to wire of 1.5 millimetres in diameter.

Despite recent developments, traditional wire-drawing technologies dominate industrial practice in the production of electric conductors. Such technologies and the related equipment are described below. The deformation resulting from wire-drawing is illustrated in figure XI1.

In accordance with the decreasing diameter of the opening in the drawing block, the diameter of the entering wire decreases from an initial diameter of d_o to an exit diameter of d_t, and the cross-section of the wire decreases from A_o to A_t. The decrease is caused by the action of drawing force P_t, during which the frictional forces generated between the surface of the wire and that of the

Figure XII. Sketch of wire-drawing



drawing block are of great importance. The cone half-angle of the drawing-block plays an important role in the working process. For aluminium drawing the angle, a, is as follows [4]:

Diameter of wire (millimetres)	*Cone angle (2a)*
15-6.00	22°-26°
6-3.00	18°-22°
3-0.15	16°-20°

According to [4], the magnitude of the required drawing force can be determined by the following formula:

$$P_i = (A_{n-1} - A_n) \cdot (1 + \frac{f}{a})\, k_{fm}$$

where A_{n-1} and A_n are the cross-sections, in square millimetres, before and after a drawing stage

f is the coefficient of friction, ≈ 0.05

a is the cone half-angle of the drawing-block, in radians (see figure XII)

k_{fm} is the medium metalworking strength, in N/mm^2, or

$$K_{fm} = \frac{R_{m.n-1} + R_{m.n}}{2}$$

where $R_{m.n-1}$ and $R_{m.n}$ are tensile strengths, in N/mm^2, before and after the drawing stage

The tensile stress generated in the wire by the tensile force transmitted by the drawing disc or drawing drum can be expressed as:

$$\sigma_{zi} = \frac{P_i}{A_i}$$

When the magnitude of the stress approaches the tensile strength of the wire (R_m), the latter may easily break. The number that indicates how many times the tensile strength of the wire is higher than the drawing force is called the safety factor (K_z), values of which are listed in table 18.

Table 18. Values of safety factor K_Z

Diameter of wire (millimetres)	*Safety factor* K_Z
10.0-5.0	1.40-1.45
5.0-1.0	1.45-1.50
1.0-0.4	1.50-1.60
0.4-0.1	1.70-2.00
0.1-0.01	2.20-2.50

The equipment performing the drawing operation may be of several types. In terms of drawing technology, there may be slip-drawing or slip-free drawing equipment, based on single-stage or multi-stage design.

Wire-drawing equipment can be grouped according to the field of application or the range of the wire diameter, which for aluminium is as follows:

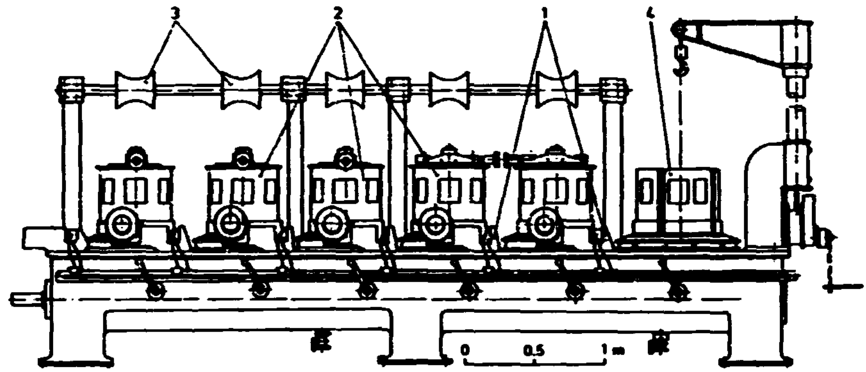
Kind of wire	*Range of wire diameter (millimetres)*
Wire rod	16.0-4.5
Medium wire	4.5-1.0
Thin wire	1.0-0.4
Fine wire	0.4-0.1
Microwire	<0.1

Aluminium conductor wire is drawn in multi-stage wire-drawing machines, that is, the wire passes through a number of consecutive drawing blocks. The number of drawing stages is determined by the quality of the material, the required final diameter and the mechanical properties of the wire. In most cases the number of stages ranges from 10 to 20. Figure XIII shows a six-stage slip-free drawing machine. In multi-stage drawing machines each of the drawing drums has an individual drive and the drawing blocks are located between two consecutive drums. The machines are also called collecting drawing machines, since aluminium wire is collected on the drawing drums. A further characteristic is that the difference in the speed of any two drums causes the wire to be subjected to twisting, which can lead to breakage.

Figure XIV illustrates a twin-drummed collecting drawing machine designed to reduce the risk of wire breakage. Such a risk is eliminated by the use of slip drawing machines. The peripheral speed of the drawing discs of the machines is chosen to ensure that it is always from 5 to 12 per cent higher than the actual speed of the wire leaving the drawing block. In such a drawing machine the wire continuously slips around the perimeter of the discs, which results in wear and heat generation. Safe operation of such high-speed equipment is therefore feasible only through high-quality cooling and lubrication [9].

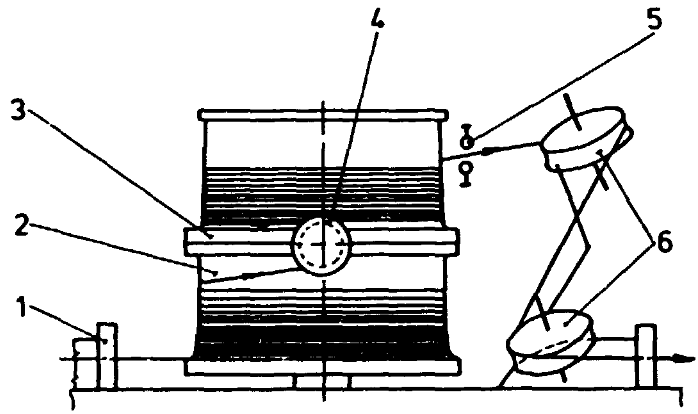
The adaptability of multi-stage slip-drawing machines is shown by the wide range of products that can be made by eliminating selected drawing discs

Figure XIII. Six-stage slip-free drawing machine



Key: 1 Drawing tools
2 Drawing drums
3 Wire-guiding roll
4 Feeding stand

Figure XIV. Twin-drum rapid drawing machine



Key: 1 Drawing block
2 Drawing drum
3 Free running drum
4 Wire-guiding disc
5 Collection control
6 Guide discs

and blocks. The operation of slip-drawing machines is based on the principle of continuity, as reflected in the following formula:

$$A_1 \times v_1 = A_2 \times v_2 = A_3 \times v_3 = A_n \times v_n = \text{Constant}$$

where A_1 *to* A_n are the cross sections of wire exiting from the drawing blocks

v_1 to v_n are the speeds of wire twisting around the drawing discs

Calculating the productivity of the drawing operation is based on the mass of material drawn and coiled onto a drum (or disc) in one second. The hourly production is then given by the following relationship:

$$G_{th} = 2.827 \times \gamma \times v_K \times d_K^2 \text{ (kg/h)}$$

where γ = Density (for aluminium, 2.7×10^3 kg/m³)
V_K = Drawing (coiling) speed (m/s)
d_K = Diameter of wire when coiling (mm)

For aluminium, the relationship takes the form:

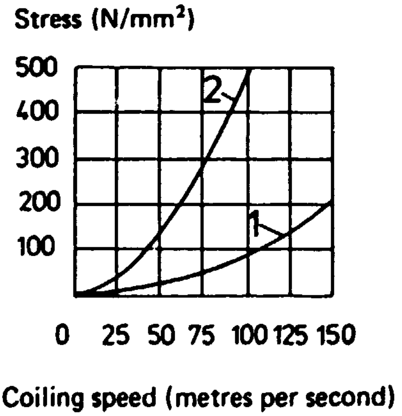
$$G_{th} = 7.66 \times v_K \times d_K^2 \text{ (kg/h)}$$

Since the theoretical level of productivity cannot be maintained for a long time in practice, a factor or utilization rate of 0.8 is applied. Thus, the practical performance is given by:

$$G_{ph} = 0.8 \times G_{th} \text{ (kg/h)}$$

Performance is directly related to the speed of drawing, the increase of which may help to solve certain technical problems. For example, increasing the speed of coiling would create such stresses within the wire that it would tend to break off (see figure XV, curve 1). Similar stresses are generated in the locking section of the coil, the diameter of which may reach 2.5 times the diameter of the cylindrical section (the number of revolutions per minute of the coiler is highest at the beginning of coiling). Curve 2 of figure XV shows the stresses generated in the perimeter of the coil. The great slope of stress curves underlines the need for proper selection of coil materials and vibration-free mounting of coils, especially at high speeds.

Figure XV. Stresses generated in wire-drawing



In installing high-speed wire-drawing machines care should be taken to ensure close tolerances and vibration-free operation. Dynamic balancing of rotating parts, uninterrupted lubrication and cooling processes require attention. The drawing speed of the most up-to-date wire-drawing machines may reach from 50 to 60 metres per second.

The electric motor used to drive the wire-drawing machine should have the following characteristics: a short, interrupted start for threading; slow and soft starting; short but uniform acceleration up to operating speed; adjustability of rotating speed (revolutions per minute) and of optimal drawing speed according to the quality of the drawn wire and the prevailing technical conditions; and an emergency stop (in case of accident or malfunction).

In multi-stage drawing the diameter of drawn wire decreases with the decreasing diameter of the drawing blocks. The planned decrease in diameter is included in the pass schedule. Apart from the material properties and characteristics of the drawing machine, the following should be considered when preparing a pass schedule:

$$\lambda = \frac{v_{d,n}}{v_{d,n-1}} \text{ and } \mu = \frac{A_n}{A_{n-1}}$$

where: v_{d1} to $v_{d,n}$ are the speeds measured at the perimeter of the drawing discs

A_1 to A_n are the cross-sections of wire exiting from the drawing blocks

μ is the coefficient of elongation

λ is the ratio of speeds measured on the perimeter of any two consecutive drawing disks

For the drawing of medium and thin wire and for slip drawing machines the value of λ varies from 1.10 to 1.20. The following relationship is also important:

$$\mu = (1.01-1.04) \cdot \lambda$$

Pass schedules can be prepared on the basis of a constant μ for the coefficient of elongation (in the case of highly ductile materials) or a gradually decreasing value of μ (mainly for materials that harden fast).

The fact that the calibrating part (see figure XII) of the drawing block gradually wears off, leading to changes in the final dimensions and hence in the cross-section of the drawn wire, should also be taken into account. The length of the cylindrical calibrating section is from 20 to 30 per cent of the diameter in the case of aluminium [10].

3. *Heat treatment*

Aluminium wires of E-Al 99.5 quality are generally used in a hard state. They are therefore usually not heat-treated, hence there is no need for annealing. The end-products can be manufactured in a single process, even at a high reduction rate (with a 95 per cent decrease in cross-section). Thus production technology is simple.

Heat treatment plays an important role in the production technology used to make alloyed wires of E-AlMgSi 0.5 quality. Coils of wire rod are further processed through the proper combination of heat treatment and cold-working, along the following general lines: stress-releasing heat treatment and chilling in water; drying; cold-working (wire-drawing); and annealing (tempering).

Stress-releasing heat treatment involves holding coils of E-AlMgSi 0.5 quality at a temperature of from 550°C to 560°C for the required period of time. For that purpose the most widely used furnace has electric resistance heating and internal lifting hooks. Cycle time in that type of furnace is about eight hours, depending on the weight of the coils.

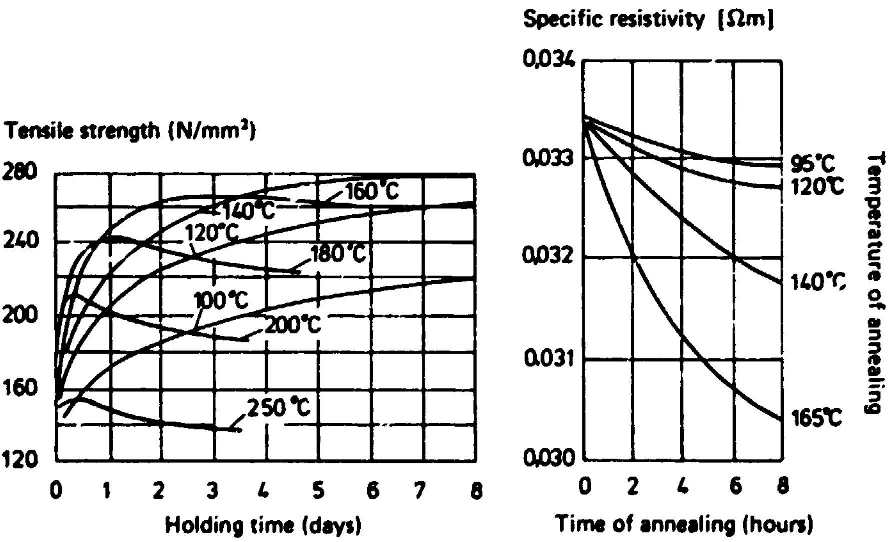
Chilling is carried out in the water basin located directly beneath the heat-treating furnace. The water basin has a capacity of from 10 to 12 m^3. The coil is sunk into the basin within 15 to 20 seconds after the bottom of the furnace is opened. The water is agitated by jetting compressed air into it at a pressure of about two bars. The coils are lifted out of the basin after cooling, stored in an appropriate place to let the water drip off and dried to avoid corrosion during further storage. Drying is done in a chamber-type furnace operated at a temperature of from 130°C to 135°C. Four hours are required for drying (of one-tonne coils). Wire rod of E-AlMgSi 0.5 quality will have the following properties after heat treatment:

Tensile strength	160-190 N/mm^2
Elongation	18 per cent

Annealing finishes the process of heat treatment following the cold-drawing of wire. Heat treatment is carried out in chamber-type or in car-bottom furnaces. Coils are charged into the furnace either on spools or without spools. Figure XVI (A) shows the change in tensile strength of wire heat-treated at 530°C, as a function of temperature and the time of annealing. The optimal temperature of annealing is around 160°C. A relatively high tensile strength can be achieved within a short time at that temperature.

As a result of annealing the electric resistance of wire decreases (owing partly to segregation and partly to softening), as shown in figure XVI (B).

Figure XVI. Effects of annealing on heat-treated alloy



A. Effect of annealing temperature and holding time on the tensile stregth of alloy E-AlMgSi 0.5

B. Effect of annealing conditions on specific resistivity

New technologies are being developed [11] using the latest metallographic innovations relating to heat treatment and E-AlMgSi 0.5 (AA 6201) production technology. The most important feature of the new technologies is that dissolution of the Mg_2Si phase occurs during wire-rod cast rolling and improves alloy strength, thus eliminating stress-releasing heat treatment and hardening as individual steps. By comparison, the continuously heat-treated alloy process even eliminates annealing, through thermomechanical hot-rolling after wire-rod casting, as reflected in table 19, which outlines the steps involved in both the traditional and the new processes.

Table 19 makes it clear why the operating costs associated with the new processes are lower. The relative processing costs are reflected in table 20.

Table 19. Traditional and new processes for the production of E-AlMgSi 0.5 alloyed wire[a]

Traditional process	*New process*	*Continuously heat-treated alloy process*
Continuous cast rolling	Continuous cast rolling with stress-releasing heat treatment	Continuous casting and thermomechanical rolling
Stress-releasing heat treatment	—	—
Drying	—	—
Wire drawing	Wire deawing	Wire drawing
Annealing	Annealing	—
Twisting	Twisting	Twisting

[a]See [11].

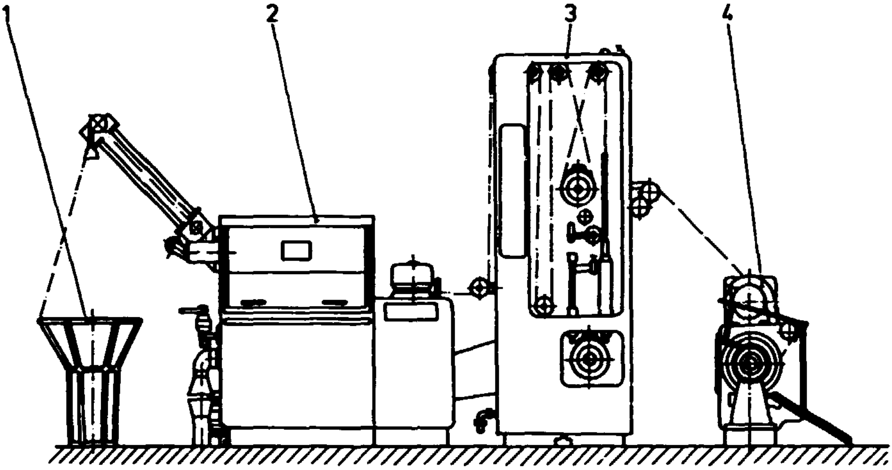
Table 20. Percentage distribution of wire-processing costs[a]

Process steps	*Traditional process*	*New process*	*Continuously heat-treated alloy process*
Melting, casting and rolling	37.0	37.0	37.4
Stress-releasing heat treatment and hardening	29.5	—	—
Packaging and in-plant transportation	0.7	0.7	0.7
Wire-drawing	25.1	25.1	25.1
Annealing	7.7	7.7	—
Total	100.0	70.0	63.2

[a]See [11].

Another promising development involves the connection of the unit performing partial or full annealing to the wire-drawing equipment, as shown in figure XVII. The use of such continuous annealing units in the production of aluminium wire has only recently begun. In addition to speeding up the production process and having a lower investment cost, continuous annealing units consume less energy than a traditional heat-treating furnace. Both lines of development are promising; as their operational safety improves, the processing technologies should assume increasing importance when investment decisions are made.

Figure XVII. Multi-stage slip drawing machine combined with continuous heat-treating unit



Key: 1 Decoiler
2 Drawing machine
3 Continuous annealing unit
4 Coiler

4. *Auxiliary equipment and materials*

By sharpening the end of the wire rod the diameter is reduced to facilitate threading into the drawing block. The tail end of one coil is welded to the front end of the next coil to ensure continuous operation and to avoid repeated threading. The ends of the wire are joined by electric resistance welding when breakage occurs. Bosses generated by melting and welding will have to be removed. Mechanical qualities are improved in the welding region by cold-upsetting in order to avoid further breakage of the wire. It may become necessary to recoil the wire, to clean its surface and the packaging and to include the associated equipment in the plant.

The tool of wire-drawing is the drawing block (see figure XII). The material of the drawing block for alloyed and unalloyed aluminium wire is usually tungsten carbide inserted into a steel frame of standard quality. That applies for diameters down to 0.4 millimetres. Wires of smaller diameter are drawn with drawing-blocks made of industrial diamond.

Since the opening of the drawing block that determines the diameter of the existing wire changes continuously, the diameter of the wire also changes. The requirements relating to the dimensional tolerance of the wire determines when the tool has to be exchanged or can be ground to another size. Drawing blocks made of hard metal can be reground eight times, those made of industrial diamond from 4 to 6 times. Table 21 shows the performance expected from drawing blocks in terms of length and weight of aluminium wire between two consecutive regrindings.

Table 21. Performance of drawing blocks between two consecutive regrinding operations

Parameter (millimeters)	*Length of wire (kilometres)*	*Weight of wire (kilograms)*
Hard metal block		
d_K = 10.0-1.0	400	$852 \cdot d_K^2$
d_K = 1.0-0.4	200	$426 \cdot d_K^2$
Diamond block		
d_K = 1.0-0.4	14 000	$29\,800 \cdot d_K^2$
d_K = 0.4-0.2	17 000	$36\,200 \cdot d_K^2$
d_K = 0.2-0.1	20 000	$42\,600 \cdot d_K^2$

Note: d_K = diameter of wire leaving the drawing block.

Smaller plants need not seek to acquire an independent capability to manufacture or regrind drawing blocks, which can be purchased in reliable quality from expert suppliers. Nevertheless, plants should ensure continuous quality control and proper storage of drawing blocks and, if possible, the evaluation of their expected life span.

A very important auxiliary material for slip drawing machines is the lubricating-cooling fluid. Specialized suppliers offer a wide range of concentrates for this water-based solution. A detailed study of frictional and lubricating processes is presented in [12].

5. *Special wires*

The metallurgical characteristics of aluminium conductor wires and development trends are given in [13]. Metal-cleaning (for further reducing iron and silicon content) and the use of various advanced technologies help to produce traditional unalloyed conductor wires with improved conductivity and more homogeneous properties. The elevated temperatures caused by short circuits reduce the strength of overhead power transmission lines, resulting in greater deflection between consoles. To counteract the effects of higher temperatures manufacturers are trying to increase the heat resistance of wire materials. That can be achieved by microalloying without reducing conductivity.

A wide range of development activities are being carried out to improve the quality of unalloyed, insulated wires. Wires hardened by drawing are difficult to work. They often break, and because of the high degree of relaxation the joints become loose, leading to an increase in transition resistance and other problems. The various methods of solving such problems include the following: alloying (for example, through the use of conductor wires of increased iron content); partial heat treatment; or galvanic surface coating (using, for example, the nickel-piating process).

Conductor wires made of high-purity aluminum are classified in a separate group. Their fields of application are summarized in table 22, a brief description of the production technology for high-purity conductor wires is given in table 23.

Table 22. Fields of application of high-purity (Al 99.99, Al 99.999) aluminium wires

Type of material	*Diameter range*	*Applications*
Al 99.99	4-0.4 mm	Metal vapouring for reflecting surfaces
Al 99.999	6-0.4 mm	Metal vapouring for electrotechnical purposes
Al 99.99	300-125 m	Terminal outlet of semi-conductor elements
Al 99.999	300-125 m	Terminal outlet of semi-conductor elements
AlSi 1	100-25 m	Terminal outlet of semi-conductor elements

Table 23. Production technology for high-purity aluminium wires

	Material and diameter range					
	Aluminium 99.99		*Aluminium 99.999*		*Aluminium-silicon 1 Ø 100-25 m*	
Operation	*Ø 10-1.5 mm*	*Ø 1.5-1 mm*	*Ø 6-1.5 mm*	*Ø 1.5-0.1 mm*	*Al 99.99*	*Al 99.999*
Wire-rod casting by Properzi line	+	+	—	—	—	—
Zone refining	—	—	+	+	—	—
Alloying	—	—	—	—	+	+
Extrusion	—	—	+	+	+	+
Rough drawing	+	+	+	+	+	+
Annealing	—	—	—	—	+	+
Fine drawing	—	+	—	+	+	+
Annealing	—	—	—	—	+	+
Microdrawing	—	—	—	—	+	+
Surface cleaning	+	+	+	+	+	+
Recoiling	—	+	—	+	+	+
Packaging	+	+	+	+	+	+

Note: + indicates that the operation described is applied to the specified material and diameter range.
— indicates that the operation described is not applied to the specified material and diameter range.

B. Technology and equipment of wire-drawing plant

1. Product mix and quantitative requirements

On the basis of the requirements of the cabling plant and of the data contained in table 8, a drawing plant having a capacity of 5,000 tonnes per annum should prepare for the production of the quantities and types of wire indicated in table 24.

Table 23 shows that the product for both qualities of material has a diameter of 2.5 mm.

Although the capacity and type of equipment should be selected in accordance with the above-mentioned requirements, drawing machines and heat-treating units are capable of being adapted to handle new dimensions.

2. Key equipment and description of plant

The increasing requirements relating to the surface quality of wires makes it necessary to install slip drawing machines in the plant. The major parameters

Table 24. Recommended production of wire-drawing plant

(tonnes per annum)

Diameter of wire (mm)	Production level for selected materials and voltage capacity			
	E-Al 99.5			E-AlMgSi 0.5
	120 kV network	1 kV network	Total	20-35 kV
1.7	60	—	60	—
2.5	480	1 185	1 665	2 125
2.8	140	65	169	375
3.5	606	—	606	—
Total			2 500	2 500

of some drawing machines are given in table 25. Price and space requirements of machines listed in table 24 include those of auxiliary units, such as rotating or stationary feeders, wire collectors, rotating cranes for spools, lubricant supply units, noise damping covers and electric switchboards.

Table 25. Main characteristics of drawing machines

Parameters	Specifications		
Number of drawing stages	13	11	9
Type of drawing machine	Slip drawing	Slip drawing	Slip drawing
Maximum entry diameter (mm)	10	9.5	9.5
Alloy	E-AlMgSi	E-Al 99.5	E-Al 99.5 E-AlMgSi
Exit diameter (mm)	1.7-3	1-3.5	1.8-3.5
Percentage reduction in stages	26	28	43-26
Maximum drawing speed (m/s)	25	20	10
Power of main drive motor (kW)	300	190	9 × 22.5
Average exit diameter (mm)	2.5	2.6	2.5
Capacity at average diameter, G_{ph}[a] (kg/h)	837	725	355
Space requirement together with auxiliary units			
Length (m)	16	15	16
Width (m)	7	7.5	6
Estimated price (thousands of dollars)	460	90	210

[a] $G_{ph} = 0.7 \cdot 7.66 \cdot v_{max} \cdot d_K^2$

where V_{max} = maximum coiling speed

d_k = coiling diameter of wire

The pass schedule will not be dealt with in detail here, since information on the subject is readily available. Traditional technology will be applied in a new plant equipped with heat-treating furnaces for alloyed wire production. The most widely used and simplest furnaces are described in table 26.

For the calculation of furnace capacity the useful production time available yearly has been taken to be 5,760 hours. The required auxiliary equipment for the plant is as follows: sharpeners; welding equipment; upsetting presses; waste coilers; scales; packing presses; material testing equipment (for tensile, twisting and bending tests); and transport equipment.

Table 26. Characteristics of heat-treating furnaces

Parameters	*Hardening furnace*	*Drying furnace*	*Annealing furnace*
Maximum temperature (°C)	600	200	350
Operating temperature (°C)	550	135	165
Temperature accuracy (°C)	±5	±5	±2
Coil diameter (m)	1.25 × 0.85	1.25 × 0.85	[a]
Weight of coil (kg)	1 100	1 100	..
Rated power (kW)	140	210	180
Heat-treating time (h)	7	4	8.5
Weight of charge (kg)	1 100	8 800	7 000
Dimensions (m)			
Length	2	7.1	10.50
Width	2	3.7	2.00
Height	1.25	2.0	1.25
Capacity (tonnes per annum)	900	10 000	4 500
Estimated price (thousands of dollars)	90	105	105

[a] Wire coiled on spool.

3. Requirements of wire-drawing plant

The most important technical and operating parameters of the wire-drawing plant are listed below:

Material requirement:

For wire of E-Al 99.5 quality	1.02 tonne of stock per tonne produced
For wire of E-AlMgSi quality	1.03 per tonne of stock per tonne produced

Auxiliary materials:

Oils, lubricant	1 kg per tonne
Drawing block	1 block per 10 tonnes

Electric energy:

For E-Al 99.5	200 kWh per tonne
For E-AlMgSi	730 kWh per tonne

Industrial water: 5 m^3 per tonne

Compressed air: 40 m^3 per tonne

The energy and material requirements of the wire-drawing plant are summarized in table 27 on the basis of the above data.

Table 27. Energy and material requirements of wire-drawing plant

Item	*Requirements based on plant capacity* 5,000	10,000	20,000
Stock material (tonnes)	5 100	10 200	20 400
Drawing oil (tonnes)	15	30	60
Drawing block (number of pieces)	500	1 000	2 000
Electric energy (MWh per year)	2 350	3 590	6 150
Industrial water (thousands of m^3 per year)	25	50	100
Compressed air (thousands of m^3 per year)	200	400	800

As previously noted, for a drawing plant with a capacity of up to 5,000 tonnes per annum there is no need to establish an individual wire-rod cast rolling plant because it could not be economically operated. In such a case the stock material (aluminium wire rod) of the wire-drawing plant should be purchased. The condition of the materials is a very important economic factor. It is essential for the production of alloyed wires to use hardened wire rod of E-AlMgSi quality. That simplifies the technology of the wire-drawing plant, lowers the amount of material stock required and helps to avoid the installation of drying and hardening capacities. The estimated aluminium stock required for daily production of a wire-drawing plant is given in table 28.

Table 28. Daily aluminium stock requirements of wire-drawing plant

	Material	
Distance of supplier and condition of material	*E-Al 99.5 (tonnes)*	*E-AlMgSi (tonnes)*
Nearby wire-rod plant		
Heat-treated	—	3
Without heat treatment	2	5
Far-away wire-rod plant		
Heat-treated	—	10
Without heat treatment	8	12

On the basis of the ratio of alloyed and unalloyed products in the production schedule and the ratio of dimensions within groups of products, a wire-drawing plant with a capacity of 5,000 tonnes per annum should be installed with two drawing machines to be operated in two shifts per day. Hardening furnaces are to be operated in three shifts, which is also justified by the need to conserve energy.

In further stages of plant development it is advisable to operate the drawing machines in three shifts (continuously) as well. This determines the personnel requirements of the plant, as reflected in table 29. Personnel requirements for maintenance and in-plant transportation will be indicated later. The operators of wire-drawing machines should be trained workers, while maintenance requires skilled workers.

Table 29. Personnel requirements of wire-drawing plant

	Requirements based on plant capacity (tonnes per annum)			
Type of personnel	*2,500*	*5,000*	*10,000*	*20,000*
Supervisors	—	3	5	7
Direct labour	8	14	23	37
Persons on duty	3	4	6	12
Laboratory	1	4	6	8
Total	12	25	40	

4. *Investment costs*

Table 30 provides data on the investment costs of wire-drawing plants. The arrangement of equipment follows the pace of expansion, which may be by as little as from 1,000 to 2,000 tonnes per annum.

Table 30. Investment costs of wire-drawing plant

Item	*Unit price (thousands of dollars)*	*Costs based on capacity variants* — *2,500 tonnes per annum*: *Number of units*	*Value (thousands of dollars)*	*5,000 tonnes per annum*: *Number of units*	*Value (thousands of dollars)*	*10,000 tonnes per annum*: *Number of units*	*Value (thousands of dollars)*	*20,000 tonnes per annum*: *Number of units*	*Value (thousands of dollars)*
11-stage slip drawing machine for E-Al	90	—	—	1	90	1	90	2	180
13-stage slip-drawing machine for E-AlMgSi	460	1	460	1	460	2	920	3	1 380
Hardening furnace	90	1	90	3	270	4	360	5	450
Drying furnace	105	—	—	1	105	1	105	1	105
Annealing furnace	105	1	105	1	105	1	105	1	105
Sharpening, welding and upsetting machines	—	—	25	—	30	—	40	—	80
Drawing-block supply	—	—	15	—	20	—	30	—	50
Materials handling (indoors)	—	—	40	—	60	—	80	—	150
Materials testing	—	—	40	—	50	—	50	—	70
Other equipment (packeting press etc.)	—	—	15	—	20	—	25	—	40
Erection[a]	—	—	85	—	300	—	350	—	500
Production building	300[b]	—	[c]	—	300[b]	—	380[b]	—	520[b]
Other costs (engineering, know-how, management during erection etc.)	—	—	70	—	150	—	200	—	250
Total costs			945		1 960		2 735		3 880

[a]Approximately 20 per cent of machinery investment costs.

[b]Dollars per square metre.

[c]Shared with cabling plant (see table 35).

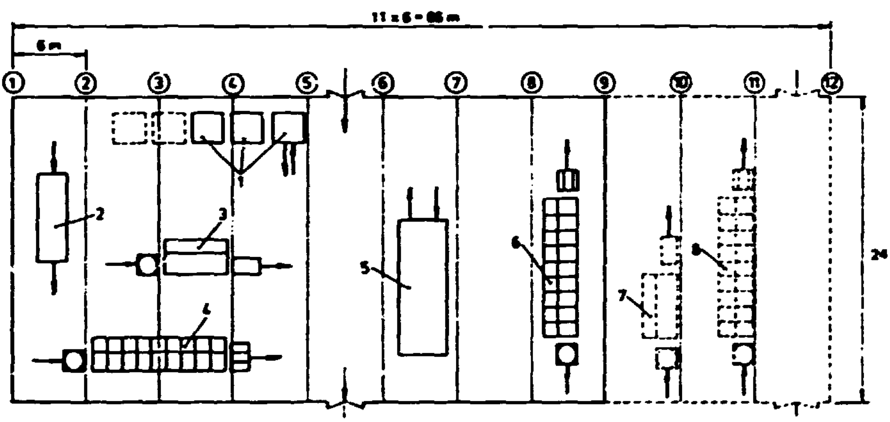
The equipment should be installed in a light steel-structured building, without overhead crane, of the following dimensions:

For a capacity of 5,000 tonnes per annum:	24 m × 36 m
For a capacity of 10,000 tonnes per annum:	24 m × 48 m
For a capacity of 20,000 tonnes per annum:	24 m × 66 m

The equipment of the wire-drawing plant is installed in the same building as that of the cabling plant for the 2,500-tonnes-per-annum capacity variant. The internal height of the building depends on the heights of the hardening furnaces. On that basis, the useful internal height of the production building is approximately 5 metres. No special measures need to be taken for fire protection and lighting. A practical example of the equipment layout in a drawing plant is given in figure XVIII.

The Department of Industrial Operations of UNIDO, Metallurgical Industries Branch, will provide on request the names and addresses of major equipment suppliers.

Figure XVIII. Equipment layout of drawing plant operation at various capacities



Capacity variants: 5 000 tonnes per annum, columns 1 to 7;
10 000 tonnes per annum, columns 1 to 9;
20 000 tonnes per annum, columns 1 to 12.

Key:
1 Hardening furnace
2 Drying furnace
3 Slip drawing machine (for E-Al 99.5)
4 Slip drawing machine (for E-AlMgSi 0.5)
5 Annealing furnace
6 Slip drawing machine
7 Slip drawing machine
8 Slip drawing machine

IV. Production of electric stranded conductors

A. General description

Stranded conductors for overhead power transmission lines are made of unalloyed aluminium of E-Al 99.5 quality or aluminium alloyed with magnesium and silicon. The operation of cabling produces a structure consisting of a core around which layers of alternately turned wires are placed. The wires making up the different layers have the same diameters, except for stranded wires reinforced by a steel core or made of alloyed aluminium wires. In the case of stranded wires reinforced by steel, the core may be of a single wire or may be a stranded structure itself. The steel core is usually galvanized for corrosion resistance. Resistance to corrosion can further be increased by filling the gaps between individual lines with grease.

1. Types of stranded conductors

A stranded conductor can be cabled without any geometrical conditions. Such a method, called irregular stranding, is used when several wires of different diameters or insulated wires of the same diameter are cabled together and then hung from walls, poles or other supporting structures in industrial areas or for overhead cables.

Regular cabling means that one or more layers of wire having the same diameter are twisted (cabled) around a core. Cabling in adjacent layers is always in opposite directions. The number of wires having the same diameter in layers is 6, 12, 18, 24 etc. for overhead line conductors. The core of the stranded wire can be a single wire having the same diameter as any other wire in the surrounding layers, or the core can be a stranded structure itself. Thus, the one-layer system consists of seven wires, the two-layers system of 19 wires and the three-layer system of 37 wires. The requirements relating to unalloyed and alloyed aluminium conductor wires have been published by IEC.

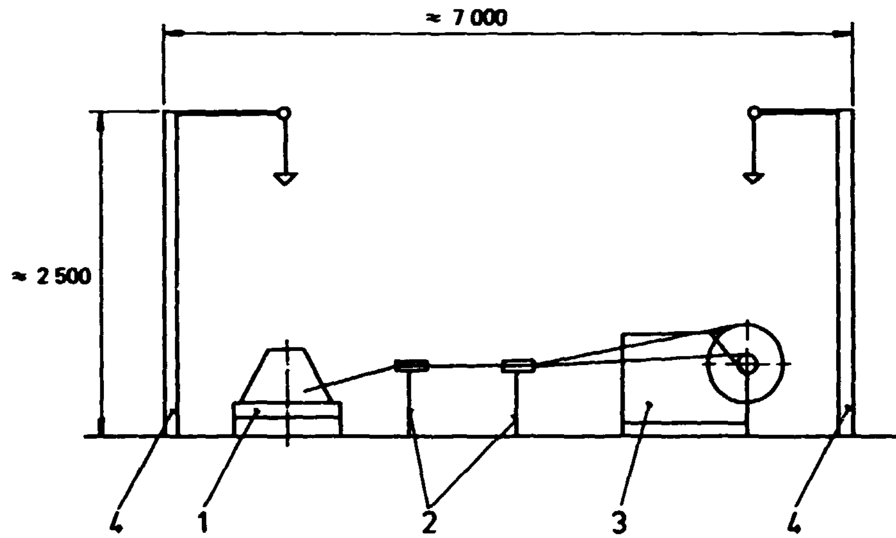
The aluminium wires of steel-reinforced aluminium stranded conductors are cabled around the core in layers and alternating directions. The steel core may be a single steel wire or may consist of a stranded structure of several steel wires. According to IEC regulations, the core may consist of one, seven or 19 individual wires. The tensile strength of galvanized steel wire is 1,300 newtons per square metre and the ultimate elongation is 4 per cent. The diameter of steel wires making up the core ranges from 1.5 to 3 millimetres. Requirements relating to the geometry and mechanical and physical properties of cables are summarized in chapter I.

2. Production technology

Materials required for production are unalloyed and alloyed aluminium wires, galvanized steel wires, drums made of wood or metal, paper, wooden lagging material, spooling and grease. Aluminium wire is received either in coils or on the spools of the stranding machine. Wire arriving in coils should be recoiled onto the spools of the machine. About 300 kilograms of wire can be coiled onto a spool having a diameter of from 400 to 800 millimetres. Steel wire arriving in coils will also have to be recoiled onto the spools of the stranding machine.

A typical recoiling machine is shown in figure XIX. The recoiler has a DC drive (20 kilowatts) with stepless speed control in the speed range of from 5 to 10 metres per second. The diameter of steel wire that can be recoiled ranges between 1.7 and 5 millimetres. The machine requires 10 × 2.5 square metres of space.

Figure XIX. Sketch of recoiler



Key: 1 Preparation stand
2 Guide rollers
3 Spooling machine
4 Coil and spool handling device

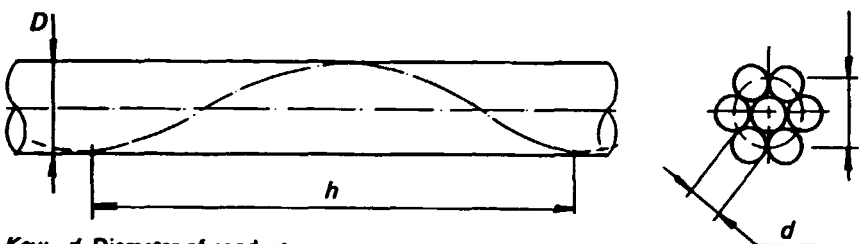
Metallic drums are used in the cabling plant with an outer diameter of from 1 to 2.2 m. The drums are supplied with the stranding machines by the machine suppliers. Wooden drums are manufactured for transporting end-products. The drums are usually produced by the auxiliary plants of the cabling plant. Outer diameters of the drums are between 1 and 2.2 metres, with a width of from 650 to 1,200 millimetres.

The main packaging material is paper impregnated with paraffin, which protects the stranded conductor from damage and lowers the chance of humidity penetrating to the wires. The paper has a specific weight of from 100 to 120 grams per square metre. Pine wood, typically from 25 to 50 millimetres thick, is used for laggings. Deals are mounted onto the perimeter of the coil drums to protect stranded wire from mechanical damage. Steel-reinforced aluminium stranded wires are manufactured with total or partial grease filling according to the order of the customer for corrosion resistance. The filling grease is smeared on the wire during the cabling operation.

Individual wires are placed by each other helically onto the surface of a cylinder by simultaneous straight-line and uniform rotating movements. Speed of motion in a straight line is the same as the speed of extraction of the stranded wire. That speed and the number of revolutions per minute determine the length of lay. Wire breakage should be avoided, since the use of broken wire is not permitted by the strictest regulations. Less stringent regulations allow for joining the ends of wire, either by cold-welding or less frequently by butt-welding. Cabling of aluminium, alloyed aluminium, steel and steel-reinforced stranded conductors is carried out in the same way.

Figure XX shows a few applied terms and abbreviations. The value of the diameter *d* of the conductor to be cabled is regulated by standards or regulations. The outer diameter *D* of the stranded conductor is an odd multiple of the number of layers and the diameter of the wire. The length of lay is the length of whorl.

Figure XX. Signs and terms relating to overhead power transmission lines



Key: *d* Diameter of conductor
D Outer diameter of layer
h Length of lay

The lay ratio, denoted by *m*, is the ratio of the length of lay *h* and the outer diameter *D* of the layer. The lay ratio is smaller towards the outer lays. The required length of wire for one length of lay can easily be calculated. For one revolution of the cabling machine the length of stranded conductor produced is equal to the length of lay. Cabling speed is given by the following relationship:

$$V = h \times n \text{ (m/s)}$$

where h = length of lay in metres

n = revolutions per second of cabling machine

The consecutive layers of a stranded conductor are cabled in alternating directions, the outer being cabled to the right, a requirement made by customers and end-users because all devices and connecting units follow that rule. The stranded conductor has a layer cabled to the right when the direction of the wires is the same as the direction of the mid-portion of the letter *Z*; it is to the left when the direction of the wires is the same as the direction of the mid-portion of the letter "*S*".

According to the established standards the lays of the stranded conductor should be closed and the individual wires in contact with each other. The number of spools to be put into individual units of the cabling machine follow the rule for regular concentric wire build-up (1 + 6 + 12 + 18). The production length of the stranded conductor should be established in the contract between the manufacturer and the customer. A deviation of ±5 per cent from the contracted length is permissible. The dimensions of the cable drum required for transporting the stranded conductor depend on the cable length. The cable drum is classified according to its outer diameter, and its dimensions and design are standardized.

Optimal production length from the viewpoint of the manufacturer is that which produces an equal number of drums with one charge of wires on the cabling machine. Fully charged spools are capable of producing several production lengths of stranded conductors.

Stranded conductors for overhead power transmission lines can be produced on two basic types of cabling machines, the tubular type or the cage type. For the tubular type, the spools charged with wire are put in supporting cradles inside a high-strength steel tube, mounted on bearings so that the cradles remain stationary, the tube rotating about them. The tube holds rollers on which run the individual wires building up the stranded conductor. The wires are forced to the right place by a distributing platen. High rotating speeds (from 7 to 14 revolutions per second) can be achieved by such a machine because the spools are located on the axis of rotation. A further advantage of the machine is that the wires are not distorted during the cabling operation, hence no extra stresses are generated in the wires. A disadvantage of the equipment is that the wires may be damaged when passing through the surface of the tube. Another disadvantage is the length of the machines, since the spools are placed one after the other. Tubular stranders are recommended for stranded structures of the 1 + 6 type. A tubular-type strander unit is illustrated in figure XXI(A). The machine requires a space of 24 m × 4 m, and has a drive motor of 45 kilowatts.

Cage-type stranding machines have as many carriages as the number of wires to be cabled into one structure. The spools are placed onto the mantle of the carriage basket, thus removing the great rotating masses far away (at a radius of from 500 to 800 millimetres) from the centre of rotation. That is why the cage-type machines cannot be operated at high speed (maximum speeds are from 2 to 3 revolutions per second). Guiding the wires is handled smoothly with this type of machine. Wires are reeled off the spindles with a constant deceleration, and even the most complicated stranded conductors can be manufactured in a single stage.

A disadvantage of this type of equipment is that the wires are distorted during the cabling operation, with mechanical stresses remaining in the structure. A cage-type cabling machine is illustrated in figure XXI(B). The space requirement is 45 m × 4 m, and the power of the drive motor is 45 kW.

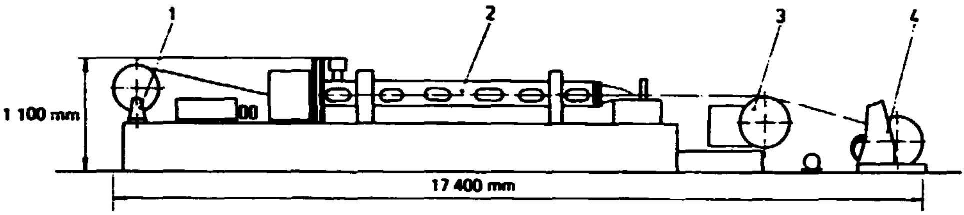
The raw materials of the cabling plant may be hard or annealed, but in all cases they are ready for further processing. There is no need to install a heat-treating capability in the plant.

3. *Quality control*

Contracts for the supply of stranded conductors are based on a series of standards. Customers usually specify additional special requirements. To meet the required standards, the cabling plant controls the quality of incoming materials on arrival, the production process and the quality of the end-product.

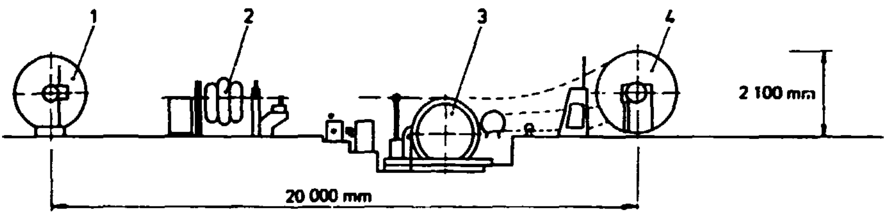
Figure XXI. Equipment for the production of overhead conductors

A. Tubular type stranding machine



Key: 1 Feeding stand
2 Stranding tube
3 Pulling device
4 Coiler

B. Cage type stranding machine



Key: 1 Feeding machine
2 Cabling cage
3 Pulling device
4 Coiler

Random quality control tests are carried out by means of spectrometry. Random tensile tests are also carried out on samples 200 millimetres in length. Electric resistance is measured by the Thomson bridge method. To calculate the specific conductivity of the wire, its cross-section is determined from the weight of 1 metre of wire, the specific density being taken as 2.69 kilograms per cubic metre. Measurements are taken at 20°C. When they are taken at different temperatures, the results will have to be corrected according to the method described in chapter I.

The product surface should be smooth and free of mechanical damage. The dimensions are measured and checked in accordance with the prescribed tolerances. In-production quality control is limited to dimensional and surface checks. Quality control of the end-product should ensure the consistency of the rated dimensions and the quality of the steel and aluminium wires. That requirement is met by measuring the product and by visual inspection of the cabling. An established method of control has been to check a sample of from 3 to 10 metres in length taken from the cable drum. Wires are disentangled from the cable and the number of layers, the direction of cabling and the fitting of wires and lays are checked.

Breakage of individual wires should not occur at 80 per cent of the calculated tensile force. During loading up to 95 per cent of the calculated tensile force, a maximum of one seventh of the total number of individual wires are allowed to break. The tensile strength of wires disentangled from the cable should not be less than 95 per cent of the original value. Tensile force is calculated for single metal (aluminium and alloyed aluminium stranded conductors) structures as follows:

$$F = 0.95 \cdot \frac{\pi}{4} \cdot d^2 \cdot R \cdot n$$

where F = tensile force (N)
d = diameter of conductor (mm)
R = tensile strength of conductor (N/mm^2)
n = number of wires

For twin metal (aluminium and alloyed aluminium conductors steel-reinforced) structures tensile force is calculated as follows:

$$F = \frac{\pi}{4} \cdot (d_s^2 \cdot R_s \cdot n_s + d_{Al}^2 \cdot R_{Al} \cdot n_{Al})$$

where R_s = specific tensile strength for a 1 per cent elongation of steel wire (N/mm^2)

R_{Al} = tensile strength of aluminium wire (N/mm^2)

d_{Al} and d_s = diameters of aluminium and steel conductors (mm)

n_{Al} and n_s = number of aluminium and steel conductors

The weights of stranded conductors are also measured. Deviation from the figure calculated for a length of one kilometre should not be more than ±2.5 per cent. Electrotechnical properties such as resistance and conductivity are determined.

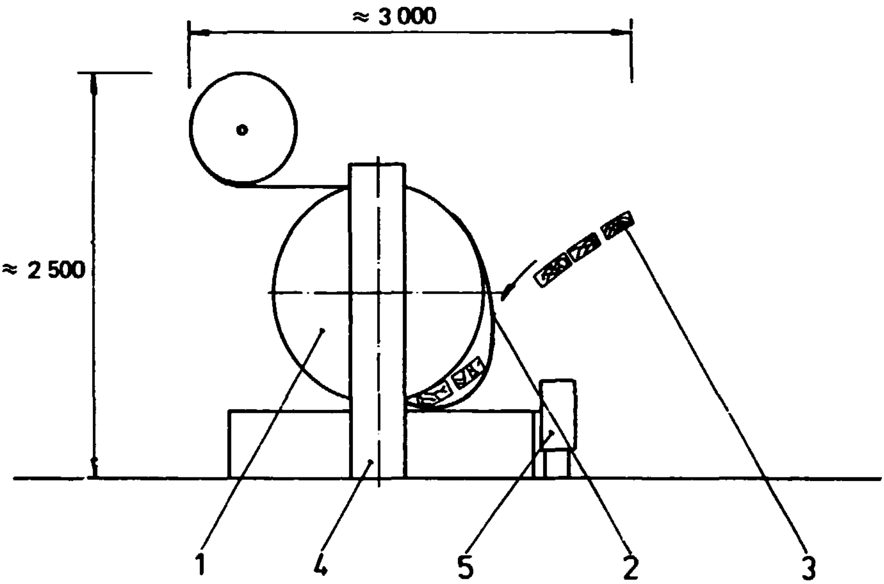
Behaviour under short-term and long-term current load is tested in wind tunnels simulating real conditions. Short-circuiting loading capacity is tested at temperatures relating to various climatic conditions (from 80-150°C) and at various current intensities for different periods of time, depending on the structure of the conductor. Creeping, or elongation under long-term load, is measured on a special apparatus designed for the even loading of the sample.

4. *Packaging*

Testing of the products is followed by the last step of the process, namely packaging. The function of packaging is to ensure that the product is safe from outer mechanical damage and to protect it from moisture and contaminants. Proper and aesthetic packaging is a good advertisement for the manufacturer and increases the confidence of the customers. Determination of in-plant transport routes is a related concern. Proper selection of internal transport routes is important not only for the sake of saving space and time, but also for the protection of the products by avoiding crashes and accidents.

The process of packaging starts in the storage area of empty drums, where the core of the drums with a diameter of from 1 to 2 metres will be covered with two layers of paraffin-impregnated paper. The rim of the drums is covered with plastic material. Drums are then transported to the cabling plant and put onto the coiling devices. After coiling, the surface of the stranded conductor will be covered with polyethylene foil which is fixed to the perimeter of the drum. After weighing, the full drums will be bridged. The polyethylene covering the surface of the coil will be covered with paraffin-impregnated paper and wood. Those operations are usually carried out by machinery (see figure XXII). The equipment is capable of packaging drums having an outer diameter of from 1 to 2 metres and a weight of from 3 to 4 tonnes. The space requirement is 6 m × 4 m per machine.

Figure XXII. Packaging machine for bridging



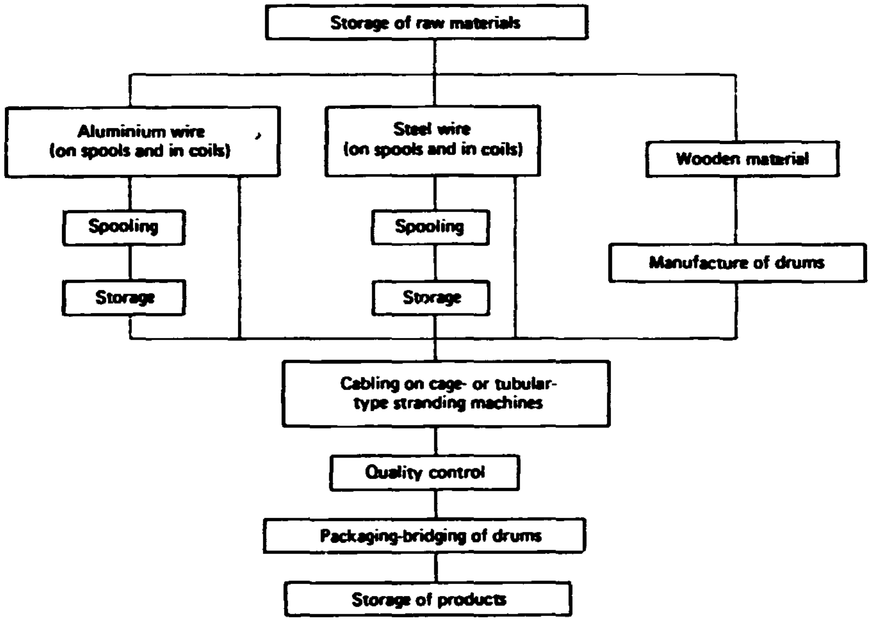
Key: 1 Drum to be packaged
2 Steel band
3 Deals
4 Coiler stand
5 Jackhammer

B. Technology and equipment of a cabling plant

1. Description of plant and production process

The technology of the plant will be determined by the product mix and the level of output. The product mix is determined on the basis of world statistics of current production and consumption. The average product mix may depend to a great extent on the circumstances of industrial development of a country, such as whether industry has already, or has not yet, started to develop together with electrification, or whether electrification has been completed and the market is saturated. The design of a proposed plant may be modified to take such factors into account, but an existing plant built to produce a variety of products is capable of considerable flexibility in response to proportional shifts or even to slight variations in capacity. Certain steps of operations carried out in a cabling plant are shown in figure XXIII.

Figure XXIII. Technological operations of cabling plant



Determination of plant capacity is based on statistical data, taking into account the production capacities of related plants. Thus the base capacity for a wire stranding plant has been selected as 5,000 tonnes per annum. Multiples of that capacity, that is, 10,000 and 20,000 tonnes per annum, have also been considered.

Since the capacity of the key equipment, the cabling machines, can be increased or changed in 100-tonne steps, the capacity of the plant can also be changed in smaller steps. An economically viable variant requiring a minimum of investment has therefore been chosen for study. The capacity of that variant is approximately 2,500 tonnes per annum. The calculations made for the variant are based on the assumption that the drawing and stranding plants are operated as one unit and that other savings will prove possible because such a preliminary stage of cable production is generally undertaken as part of the activities of an existing plant.

The product mix taken for the selection of equipment is summarized in tables 31, 32 and 33 for capacities of 2,500, 5,000 and 10,000 tonnes per annum, respectively. For the variant of 20,000 tonnes per annum the products are the same, the ratio within a type of stranded conductor is the same, and the ratio of alloyed to unalloyed aluminium is 20 : 80.

For the selection of equipment the following points should be kept in mind:

(a) Productivity should exceed 0.3 metres per second;

(b) Specific energy consumption should be below 0.2 kWh per square metre of machine foundation space;

(c) Bearings with a long life span and other parts subject to wear and tear should have a lifetime of 20,000 operating hours;

Table 31. Selected product mix of cabling plant with a capacity of 2,500 tonnes per annum

Type of wire	*Cross-section of cable (square millimetres)*	*Structure of stranded conductor (millimetres)*	*Output (tonnes per annum)*	*Aluminium conductor (tonnes per annum)*	*Steel conductor (tonnes per annum)*	*Product breakdown (percentage)*	*Ratio of cable length in kilometres to drum diameter in millimetres*
Steel and aluminium	95[a] + 16[b]	7 × Ø1.7 + 26 × Ø2.5	385	270	115	43	4/1 500
Steel and aluminium	250[a] + 40[b]	7 × Ø2.8 + 26 × Ø3.5	510	355	155	57	3/1 800
Subtotal			895	625	270	100	
Aluminium	50	7 × Ø3	280	280	—	45	4/1 200
Aluminium	95	19 × Ø2.5	312	312	—	50	4/1 500
Aluminium	120	19 × Ø2.8	33	33	—	5	3/1 500
Subtotal			625	625	—	100	
Alloyed aluminium	50	7 × Ø3	438	438	—	35	4/1 200
Alloyed aluminium	95	19 × Ø2.5	625	625	—	50	4/1 500
Alloyed aluminium	120	19 × Ø2.8	125	125	—	10	3/1 500
Alloyed aluminium	240	37 × Ø2.9	62	62	—	5	3/1 800
Subtotal			1 250	1 250	—	100	
Total			2 770	2 500	270		

Note: The ratio of alloyed to unalloyed aluminium is 50:50.

[a]Refers to the steel core.

[b]Refers to the aluminium section.

Table 32. Selected product mix of cabling plant with a capacity of 5,000 tonnes per annum

Type of wire	*Cross section (square millimetres)*	*Structure of stranded conductor (millimetres)*	*Output (tonnes per annum)*	*Aluminium conductor (tonnes per annum)*	*Steel conductor (tonnes per annum)*	*Product breakdown (percentage)*
Steel and aluminium	95[a] + 16[b]	7 × Ø1.7 + 26 × Ø2.5	770	540	230	43
Steel and aluminium	250[a] + 40[b]	7 × Ø2.8 + 26 × Ø3.5	1 020	710	310	57
Subtotal			1 790	1 250	540	100
Aluminium	50	7 × Ø3	560	560	—	45
Aluminium	95	19 × Ø2.5	625	625	—	50
Aluminium	120	19 × Ø2.8	65	65	—	5
Subtotal			1 250	1 250	540	100
Alloyed aluminium	50	7 × Ø3	875	875	—	35
Alloyed aluminium	95	19 × Ø2.5	1 250	1 250	—	50
Alloyed aluminium	120	19 × Ø2.8	250	250	—	10
Alloyed aluminium	240	37 × Ø2.9	125	125	—	5
Subtotal			2 500	2 500	—	100
Total			5 540	5 000	540	

Note: The ratio of alloyed to unalloyed aluminium is 50:50.

[a]Refers to the steel core.

[b]Refers to the aluminium section.

Table 33. Selected product mix of cabling plant with a capacity of 10,000 tonnes per annum

Type of wire	*Cross section (square millimetres)*	*Structure of stranded conductor (millimetres)*	*Output (tonnes per annum)*	*Aluminium conductor (tonnes per annum)*	*Steel conductor (tonnes per annum)*	*Product breakdown (percentage)*
Steel and aluminium	95[a] + 16[b]	7 × Ø1.7 + 26 × Ø2.5	2 156	1 500	656	43
Steel and aluminium	250[a] + 40[b]	7 × Ø2.8 + 26 × Ø3.5	2 856	2 000	856	57
Subtotal			5 012	3 500	1 512	100
Aluminium	50	7 × Ø3	1 570	1 570	—	45
Aluminium	95	19 × Ø2.5	1 750	1 750	—	50
Aluminium	120	19 × Ø2.8	180	180	—	5
Subtotal			3 500	3 500	—	100
Alloyed aluminium	50	7 × Ø3	1 050	1 050	—	35
Alloyed aluminium	95	19 × Ø2.5	1 500	1 500	—	50
Alloyed aluminium	120	19 × Ø2.8	300	300	—	10
Alloyed aluminium	240	37 × Ø2.9	150	150	—	5
Subtotal			3 000	3 000	—	100
Total			11 512	10 000	1 512	

Note: The ratio of alloyed to unalloyed aluminium is 30:70.

[a]Refers to the steel core.

[b]Refers to the aluminium section.

(*d*) Manual handling time should not be more than 15 per cent of machining time (exchange of spools and drums);

(*e*) In case of wire breakage there should be a quick stop (for example, within five seconds).

Additional information is given below on the two basic types of cabling machines.

Tubular stranders are used for the production of simpler (1 + 6 wires) stranded conductor structures (see figure XXI(A)). All types of stranded conductors can be produced on tubular stranders in the pitch range of from 40 to 250 millimetres. The cabling tube with alternating directions can accommodate six spools. The end-product can be coiled onto drums having outer diameters of from 1 to 1.6 metres. The capacity of a unit is from 800 to 1,500 metres per hour.

Cage-type cabling machines (see figure XXI(B)) are used for more complicated (12 to 91 wires) stranded structures. All types of cable can be produced in the pitch range of from 50 to 500 millimetres. The direction of rotation of carriages can be changed and the carriages can accommodate spools with diameters of from 630 to 1,600 millimetres. End-products are coiled onto drums with an outer diameter of from 800 to 2,600 millimetres. The capacity of a unit ranges from 300 to 1,200 metres per hour.

Cabling machines are equipped with their own spools. Wire arriving in coils should be recoiled onto those spools using the equipment shown in figure XIX. Random tests of geometrical, mechanical and physical properties are carried out. Ready-made stranded conductors are subjected to stringent quality control, and tests are conducted on geometrical, structural and mechanical properties, and on electric resistance and behaviour. The end-products are then packaged using polyethylene foils, paraffin-impregnated paper and lagging. Both operations are performed by the type of machinery shown in figure XXII.

In-plant transportation of materials, drums and spools necessary for production is performed either by trucks or by carts moving on fixed tracks. Manual handling is important. Automated systems and even robots are used in more up-to-date plants for storage and handling of spools. They are, however, not proposed in the first stage of development because of their high investment cost ($500,000 per unit) and complexity.

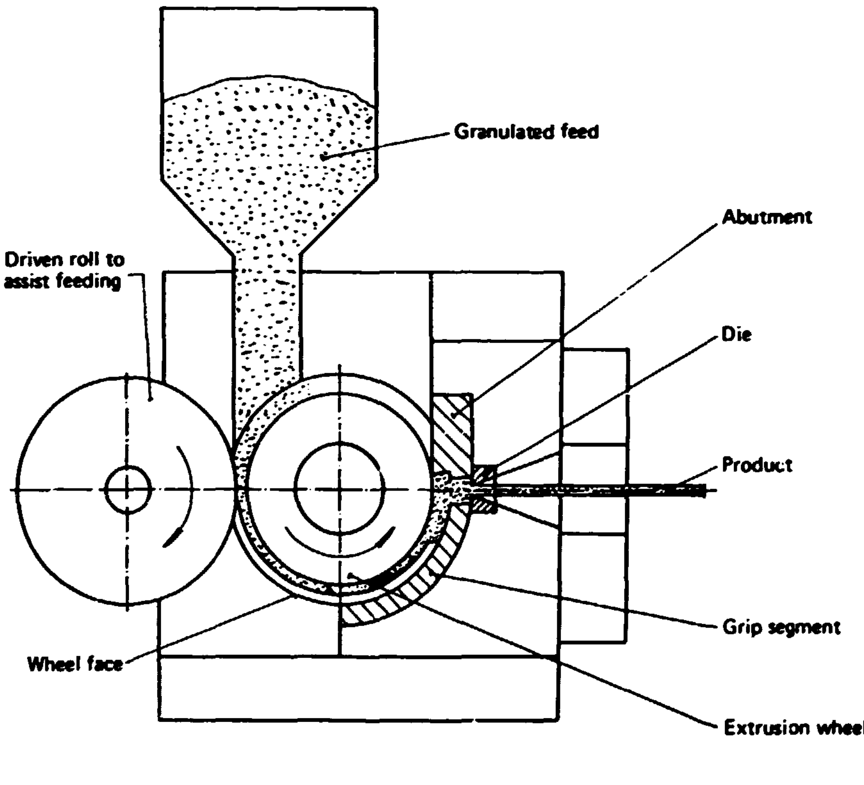
Production materials are stored close to the place of use. Spare parts are stored in covered and uncovered storage areas. The quantity of materials to be stored is determined by availability and storage capacity. In the present case, it is assumed that the drawing plant is located in the neighbourhood. Stocks can therefore be small and flexible modifications of the production programme are possible. The level of reserve stocks would be as follows:

Reserve stocks	*Period covered (days)*
Alloyed and unalloyed aluminium wire	7
Steel wire	20
Drums	15
Pinewood deals	20
Grease	20

The storage capacity of the end-products is calculated to cover five days.

Some scrap is generated during the production of cables. There are several ways of recycling or selling scrap. After packaging aluminium wire the scrap can be remelted in the furnaces of the casting shop or may be sold. Cutting the scrap down to pieces of from 2 to 3 millimetres enables it to be used for the reduction of steels. It can also be recycled by means of a new process called the Conform process (see figure XXIV). In this process, granules of aluminium are extruded by the action of a rotating tool. Because of the high working rate and generated temperatures, aluminium welds together and can produce even complicated shapes of excellent surface quality. Other wastes can be sold or discarded.

Figure XXIV. The Conform process



Some wastes generated in the plant cannot be deposited in ordinary waste storage areas because they are harmful to the environment. These include various oil residues, oily rugs used for the cleaning of machines, reagents discarded by the laboratory and sulphuric acid from the batteries of trucks. Acids may be discharged into the sewage system after careful neutralization. All other materials should be stored in closed containers and periodically destroyed (for example, by incineration).

The operations of a cabling plant exert no harmful effects on the environment. The plant equipment is installed in a light-structured building without overhead crane. The surface area of the buildings are 1,800 m², 3,464 m², 6,912 m², and 14,400 m², depending on production capacity. A separate building includes drum and maintenance workshops, baths, wardrobes and offices. Empty drums are stored to receive raw materials, and a separate area is reserved for stocks of end-products.

2. *Technical and operating characteristics*

The figures mentioned below will help to determine the amount of equipment and the number of employees required:

(a) To produce 1 tonne of stranded conductors, 770 kilograms of aluminium and 345 kilograms of steel are required (including the generation of 10 per cent and 15 per cent of scrap);

(b) Tubular stranding equipment requires 3.9 hours per tonne of product; a cage-type cabling machine requires 2.3 hours per tonne of product and 2.4 hours per tonne for bridging;

(c) On the basis of a three-shift system, and taking into account State and religious holidays as well as two days off per week, the yearly working time is 5,400 hours, or 225 days.

Estimates of plant personnel requirements are given in table 34.

Table 34. Plant personnel requirements

	Number of employees based on plant capacity in tonnes per annum			
Category of employee	*2,500*	*5,000*	*10,000*	*20,000*
Management	2	5	7	10
Technician, laboratory chemist	4	8	15	24
Skilled workers	16	20	47	90
Unskilled workers	15	27	59	116
Total	37	60	120	240

3. *Investment data, equipment and costs*

Investment cost estimates for cabling plants are summarized in table 35, which includes a list of equipment and the number of units required. The equipment layout for plants with capacities of 2,500 and 10,000 tonnes per annum are shown in figures XXV and XXVI.

The Department of Industrial Operations of UNIDO, Metallurgical Industries Branch, will provide on request the names and addresses of major equipment suppliers.

Table 35. Investment cost estimates of cabling plants

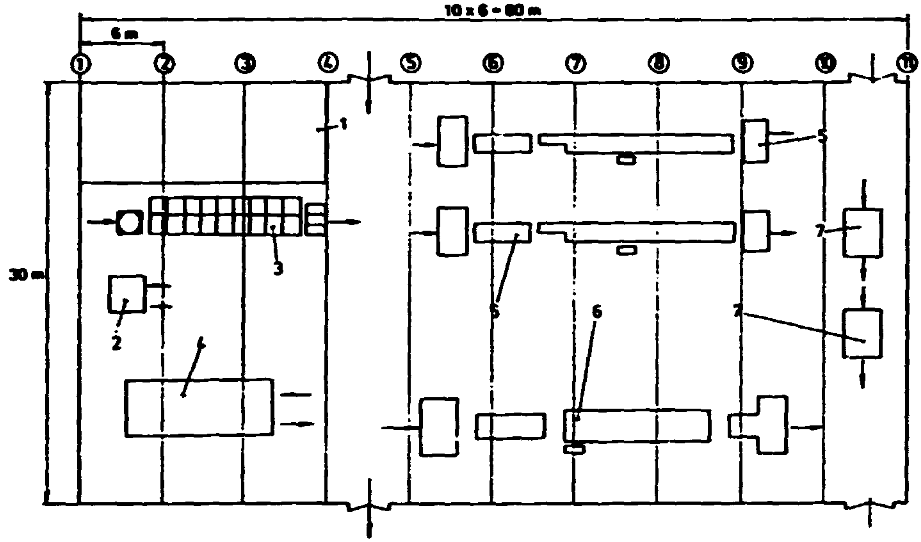
(Thousands of dollars)

Equipment and facilities	*Unit price*	*Estimates based on plant capacity* — *2,500 tonnes per annum* — *Number of units*	*Cost*	*5,000 tonnes per annum* — *Number of units*	*Cost*	*10,000 tonnes per annum* — *Number of units*	*Cost*	*20,000 tonnes per annum* — *Number of units*	*Cost*
Recoiler	150	—	—	1	150	2	300	4	600
Tubular strander machine	220	2	440	5	1 100	9	1 980	18	3 960
Cage-type machine (with one drum)	350	1	350	3	1 050	4	1 400	8	2 800
Cage-type machine (with two drums)	450	—	—	2	900	3	1 350	7	3 150
Drum packaging unit	120	2	240	5	600	8	960	13	1 560
Quality control equipment	—	—	100	—	450	—	450	—	650
Transport equipment (indoors)	—	—	80	—	100	—	150	—	350
Building	300[a]	—	540[a, b]	—	1 030[a]	—	2 070[a]	—	4 140[a]
Drum plant, workshops etc.	—	—	—	—	460	—	750	—	1 120
Erection	—	—	200	—	400	—	510	—	1 100
Others (know-how, engineering etc.)	—	—	200	—	500	—	675	—	1 240
Total costs			2 [illegible]90		6 740		10 595		20 670

[a]Dollars per square metre.

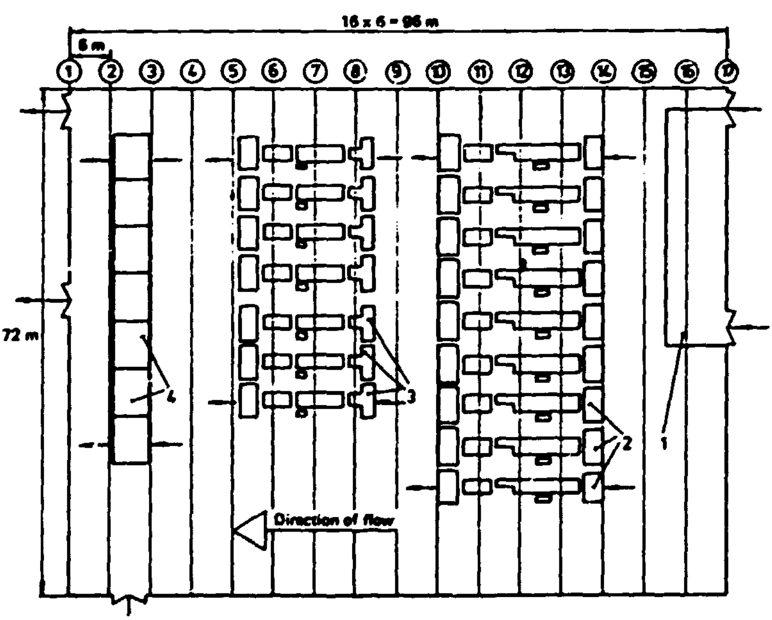
[b]Shared with wire-drawing plant.

Figure XXV. Equipment layout of drawing and cabling plant with a capacity of 2,500 tonnes per annum



Key:
1 Storage area for raw materials
2 Hardening furnace
3 Slip drawing machine
4 Annealing furnace
5 Fast strander machines
6 Cage-type stranding machine
7 Storage area for finished products

Figure XXVI. Equipment layout of cabling plant with a capacity of 10,000 tonnes per annum



Key:
1 Storage
2 Fast strander machines
3 Cage-type stranding machines
4 Drums packaging units

V. Auxiliary plant units

Auxiliary plant units are selected to suit the capacity alternatives of wire-rod plants, wire-drawing plants and cabling plants designed on the basis of the following three principal variants:

(a) Under one variant the wire-drawing and cabling plants use purchased wire rod and have a capacity of 5,000 tonnes per annum that can be expanded to 20,000 tonnes per annum;

(b) Under another variant the wire-rod cast rolling shop uses purchased aluminium ingot and has a capacity of 10,000 tonnes per annum that can be expanded to 20,000 tonnes per annum. This plant is to be established at the same location as the above-mentioned one;

(c) Under the third variant a wire-drawing and cabling plant with a capacity of approximately 2,500 tonnes per annum and operating with purchased wire rod is to be established in an existing plant, hence it does not require an individual energy receiving and distribution system. Since the existing utility supplies satisfy the requirements of such a plant, only the extra needs are determined. Higher-capacity variants should be taken into consideration when the capacity of the utility supply system is increased.

Close co-operation between various fields of engineering is essential for the proper connection between auxiliary plants and production plants, as well as for designing the plants to ensure their optimal functioning and economic success.

A. Energy supply and requirements

1. Energy supply and utility systems

(a) Electric energy

An external power supply system is an essential aspect of site selection. A three-phase electric power supply system with a frequency of 50 hertz at medium or high tension (from 6 to 120 kilovolts) is necessary. The use of a main transformer is advisable when the voltage of the network exceeds 10 kilovolts. This transformer supplies the internal medium-voltage distribution system of the plant.

The voltage of internal power distribution is from 6 to 10 kilovolts. Medium- to low-tension (from 6 to 0.4 kilovolts) transformers are installed at the centre of gravity of consumption, that is, in the plant buildings, supplying a voltage of 3 × 380 volts required for the plant equipment. Voltage fluctuation at the connection points should not be more than +5 per cent to −15 per cent. Waste of energy should be lowered by the installation of phase-improving condenser batteries providing for a value of cosine phi (phase factor) of from 0.95 to 1.

The in-plant medium-voltage power distribution network contains aluminium cables in an insulated system for safety reasons. Contact protection of low-voltage consumers is achieved by neutral grounding. The medium- to low-voltage transformers with aluminium windings (air insulated and dry) should have a capacity range of from 1 to 1.6 megavolt-amperes for indoor operation. Power supply and distribution networks and the various transformers require continuous attention and should be operated by specially-trained skilled workers. For safety reasons a separate transformer and power distribution unit (operating at low voltage) should be installed for plant lighting and for the supply of plant control units independently of the production equipment.

(b) Fuels

The fuels used in plant operations should be selected according to the requirements of the wire-rod casting shop using solid charge. The most suitable fuel for metal melting is natural gas, but oil-fired melting furnaces can also be installed when there is no natural gas supply line in the vicinity of the plant. Casting furnaces can be gas-fired or electrically heated.

When selecting fuels the heating of offices and social facilities should be considered as well as the workshops. Natural gas should be used whenever possible. For the heating of buildings and offices, oil or coal can be used when natural gas is not available.

When using natural gas the plant receives it from the external supply network at medium pressure, that is, from 6 to 10 bars. The pressure of natural gas is generally reduced to 2 bars (the pressure of the internal distribution network) at the gas supply station. Natural gas at reduced pressure is supplied to the consumers (boilers, furnaces etc.). The gas supply station should be equipped with devices for the measurement of volume and other parameters, as well as with safety and alarm systems. The natural gas pipe-train should be supported by columns, but usually the same route should be selected as for the other utility supply systems. Operation of the natural gas supply system does not require continuous handling, but a group of specially trained maintenance personnel should be kept on duty in case of an emergency.

An appropriate unloading and storage facility should be installed when using fuel oil. Oil is supplied by pumps to the consumers through pipelines. Storage capacity should be designed to maintain from 3 to 10 days of oil consumption, including peak levels, and taking into account the continuity of supply and the capacity and availability of transport facilities. Oil can be transported by road or railway tankers. Coal-firing may be considered only for heating purposes, depending on local circumstances. The open-air storage area should have a capacity of from 10 to 20 days in winter. Petrol and diesel oil should be stored for the operation of in-plant transport vehicles (trucks etc.). The capacity of storage facilities should follow local practice.

(c) Steam and hot water

The energy required for heating, the amount of which depends on climatic conditions, can be economically supplied by a boiler unit. Supersaturated steam supplied by the boiler at a pressure of from 6 to 10 bars is transported by pipe-trains to the heating apparatus through heating centrals located in individual buildings.

The heating of production workshops can be achieved by blowing hot air into the building or by hot-water central heating servicing also social facilities (wardrobes and bathrooms), offices etc. Production buildings can be directly heated by gas when available on a continuous, reliable basis. Hot water for washing should be supplied by high-capacity steam-heated or direct gas-fired water-heaters.

The battery of boilers should include machinery of various capacities in order to provide for the most economic supply of heating energy in both summer and winter. When using coal-fired boilers, the waste generated by the drum manufacturing plant can be recycled. Equipment for the supply of steam and energy should include the necessary instrumentation for economic and safe operation and control. Operation of a battery of boilers requires the continuous presence of the operating personnel.

(d) Compressed air

A central compressor station should be established for the supply of compressed air to the consumers at a pressure of from 4 to 6 bars. The compressor station should be equipped with the necessary cooling, cleaning and filtering units, and include several units to provide spare capacity. Compressed air is transported by pipeline to the points of consumption. The pipeline network consists of main lines and branches within the buildings. The volume of supplied and consumed compressed air should be measured to ensure the efficient operation of the system. The operation of compressors requires continuous attention.

(e) Water

The wire-rod casting shop is the greatest consumer of water, requiring a degree of hardness of from 3 to 5 NK°, a temperature of from 20°C to 25°C, and a pressure of from 4 to 6 bars for the casting of molten metal. Water consumption is also increased by the cooling of various items of equipment (parts of machines subjected to intense heat, bearings, hydraulic systems etc.). Cooling water should have the above-mentioned parameters, and it must be clean because the least amount of contaminants (such as oil) decreases the heat-transfer capacity of water. The water may eventually be used to supply boilers and to wash equipment (cars, trucks etc.).

Drinking water supplies require separate facilities. When plenty of water of the required quality is available, it may be used only once; when there is an external drinking water network, it suffices to connect the plant pipe-train to the external system. When water is to be supplied from ground level or underground sources, the water pressure should be maintained by building a water tower and operating supply and pressure pumps.

A closed-circuit system can water-cool equipment in areas where little water is available. Water that is heated up by the equipment has to be cooled down in cooling towers. A temperature decrease of 10°C can be achieved in that way. In an appropriately equipped closed circuit, make-up water can be as low as 10 per cent of recycled water. Depending on the quality of make-up water, the incoming water may require some treatment.

To meet the established water quality standards, it may be necessary to build a water reservoir with a capacity equivalent to a few days' consumption. Pumps for the water supply system should be installed in separate buildings near the cooling and water towers and the water reservoir so as to provide spare pump capacity. Measurement and control of the water volume and parameters should be carried out to ensure cost-efficient operation of the system.

2. *Required energy and utility supplies*

Energy needs will be determined by the product mix, the volume of production and the technological parameters. The amount of indirect consumption will be influenced by the size of the buildings, climatic conditions, the number of personnel, the availability of water etc. Electric energy, natural gas, heating, water and compressed air requirements of plants of varying capacity are indicated in table 36.

The energy equivalent may be used in calculating the specific energy requirements of plants. Natural gas, with a lower heating value of 36 megajoules per cubic metre, is particularly useful. The figures given in table 36 are valid for a plant where aluminium is melted in natural-gas-fired melting furnaces, where the fuel used for heating (in boilers, for example) is natural gas, and where cooling water is recycled several times by means of cooling towers. On the whole, for the different types of energy required (electric energy, natural gas etc.), the coincidence factor can be taken as 0.9.

3. *Technical specifications, investment cost estimates and layout of energy supply facilities*

A list of equipment needed for facilities supplying energy and other utilities is given in table 37. Figures XXVII and XVIII show the layout of these facilities.

B. Maintenance

Proper maintenance requires a decision at the initial stage of project implementation on the equipment, technology, personnel and organization scheme needed for the timely performance of repair work. Planned preventive maintenance using repair methods that depend on the state of the equipment seems best suited for the maintenance of production equipment with the technology currently available. That requires the establishment of an appropriate system of technical inspection.

A time-dependent maintenance system is proposed for equipment (hoisting equipment, vehicles etc.), of which the checking, repair or maintenance time is measured by inspectors. The operating and maintenance instructions given by the supplier of the equipment should be strictly followed and the lessons of experience gained during operation applied. The number of persons required for maintenance may be from 20 to 25 per cent of the operating personnel. From 25 to 30 per cent of total maintenance work can be performed by external labour, thus decreasing the number of full-time employees required.

Table 36. Plant energy and utility requirements for selected capacity variants

Type of plant	Capacity (10 tonnes/year)	Electric energy (MWh/year)	Plant required for plant operation (Megawatts)	Natural gas: Equipment (10 m^3/year)	Natural gas: Heating (m^3/year)	Natural gas: Total (m^3/h)	Industrial water (10 m^3/year)	Industrial water (m^3/h)	Drinking water (10 m^3/year)	Drinking water (m^3/h)	Compressed air (10 m^3/year)	Compressed air (m^3/h)
Wire-rod cast rolling shop	10	1 850	0.43	1 300	83	360	400	80	20	[illegible]	300	60
	20	3 700	0.86	2 600	83	700	800	160	25	6	500	100
Wire-drawing plant	2.5	1 500	0.34	—	15	6	12	2	5	2	70	15
	5	2 300	0.54	—	30	12	25	5	7	3	200	40
	10	3 600	0.84	—	50	20	50	10	9	4	400	80
	20	6 100	1.40	—	100	40	100	20	11	5	800	160
Cabling plant	2.5	2 000	0.45	—	75	30	23	6	71	32	180	35
	5	3 500	[illegible]	—	150	60	50	10	125	39	250	50
	10	7 000	1.6	—	300	120	100	20	149	59	500	100
	20	14 000	3.30	—	600	240	200	40	184	65	1 000	200
Drum manufacturing plant	2.5	500	0.11	—	60	25	6	1	7	3	—	—
	5	850	0.20	—	100	40	10	3	9	4	—	—
	10	1 700	0.40	—	200	70	20	5	11	5	—	—
	20	3 400	0.80	—	250	100	40	10	13	6	—	—
Auxiliary plant (utilities, boilers, maintenance)	2.5	600	0.12	—	20	8	6	1	7	3	15	3
	5	1 000	0.25	—	50	20	10	2	9	4	25	5
	10	1 300	0.30	—	70	30	20	3	11	5	40	8
	20	1 500	0.40	—	100	40	30	4	13	6	60	12
Others (offices, storage etc.)	20	400	0.20	—	50	20	—	—	4	2	—	—
Totals	2.5	4 600	1.0	—	170	69	47	10	90	40	265	48
	5	7 650	1.8	—	330	132	95	20	150	50	475	86
	10	15 450	3.4	1 300	753	600	590	118	200	70	1 240	224
	20	29 100	6.3	2 600	1 183	1 140	1 170	234	250	90	2 360	425

Note: The figures referring to capacities of 10,000 and 20,000 tonnes per annum for auxiliary plants and in the totals include the requirements of wire-rod casting plants.

Table 37. Equipment needed for facilities supplying energy and other utilities to wire-rod cast rolling, wire-drawing and cabling plants with a capacity of 10,000 tonnes per annum

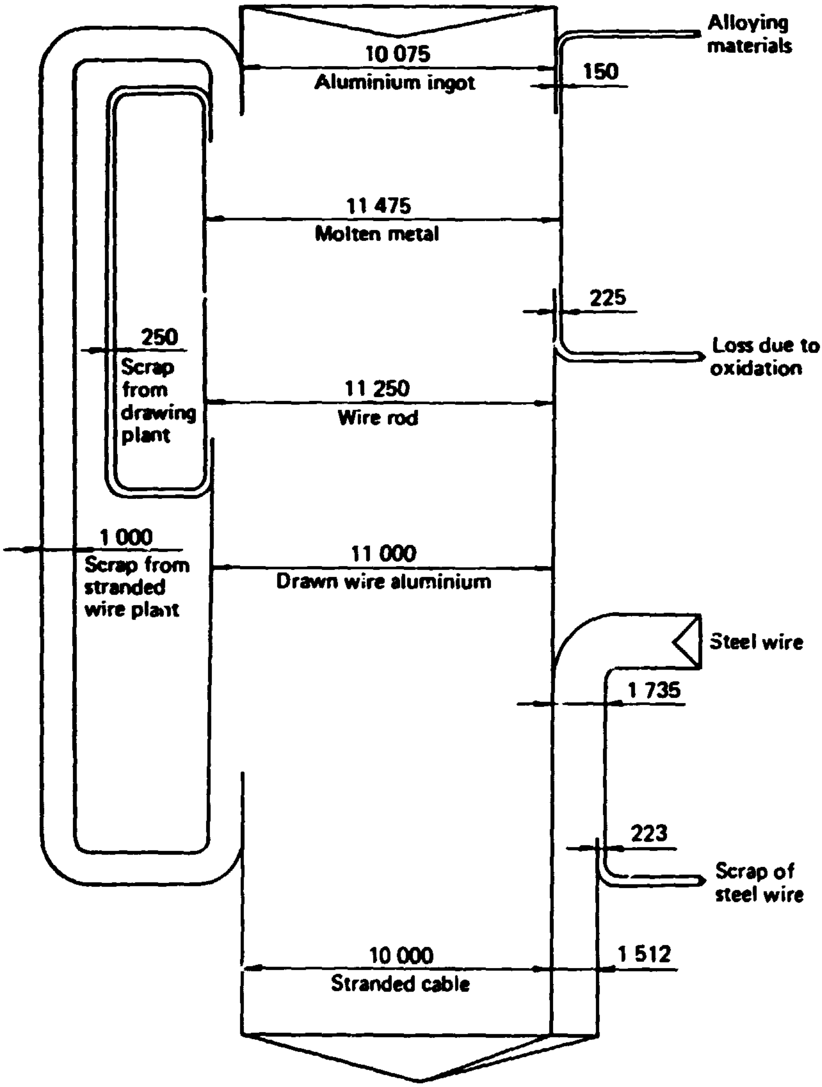
Technical specifications	*Number of units*	*Investment cost (thousands of dollars)*		*Area required (square metres)*	*Operating personnel*	*Remarks*
		Equipment	*Buildings*			
1. Electric energy supply						
Main transformer: capacity, 6.3 MVA; secondary voltage, 6.3 kV; open-air design	2	..	..	..	..	Four transformers required for plant with a capacity of 3,000 tonnes per annum
6 kV distribution board in cladding	15	..	..	..	..	
Phase-improving condenser battery, 3 × 500 v, unit capacity of 150 kVa	8	..	..	..	..	
6.3 kV to 0.4 kV transformers, unit power of 1 MW, complete with secondary distributor	8	..	..	..	..	
Cables: 10 kV	2[a]	..	..	..	..	Requires continuous attendance
1 kV	5[a]	..	..	..	..	
Subtotal	—	500	70	450	5	
2. Natural gas supply						
Gas supply station with a connection capacity of 1,000 m^3/h	1	..	..	..	..	Does not require continuous attendance and operation
Main pipe-train	0.2[a]	..	..	..	..	
Subtotal		120	20	69	2	
3. Boiler and heat supply						
Gas-fired steam boiler, capacity of 5 tonnes/h, with combustion air supply system and steam at a pressure of 6 bars in saturation	2	..	..	..	..	Requires continuous attendance and operation
Steam pipe-train	1[a]	..	..	..	..	
Subtotal	—	400	170	600	6	

4. *Compressed air supply*						
Air compressors with a capacity of 250 m^3/h, complete with drying and cooling equipment	2	..	..	..	..	Continuous attendance and operation required; unit capacity of compressors for plant with a capacity of 5,000 tonnes per annum is 100 m^3/h
Main pipe-train	1[a]	..	..	..	..	
Subtotal	—	150	20	64	5	
5. *Water supply*						
Circulating pump, delivery head of 60 m, supply capacity of 1,000 l/m	6	..	..	..	..	For plant with a capacity of 5,000 tonnes per annum, 3 circulating pumps required
Water treatment unit with a capacity of 20 m^3/h	1	..	..	..	..	
Water tower, 40 m in height, volume of 200 m^3	1	..	..	..	..	Requires continuous attendance
Cooling tower, hydraulic capacity of 200 m^3/h, temperature step of 10°C	2	..	..	..	..	For the plant with a capacity of 5,000 tonnes per annum, 1 cooling tower required
Water reservoir of 500 m^3	2	..	..	..	..	
Water pipe-train	1[a]	..	..	..	..	
Building for pumps and other services	..	..	..	..	..	
Subtotal	—	260	330	686	5	
6. *Environmental protection* (Sewage and rain-water drainage)						
Drainage system	3[a]	..	..	..	..	
Sewage collecting basin and oil trap	..	..	..	..	..	Does not require continuous attendance and operation
Subtotal	—	140	250	250	2	
Total	—	1 570	860	2 110	25	

Note. The number of employees required for attending and operating utility systems and auxiliary plants may be reduced by adopting sound management policies.

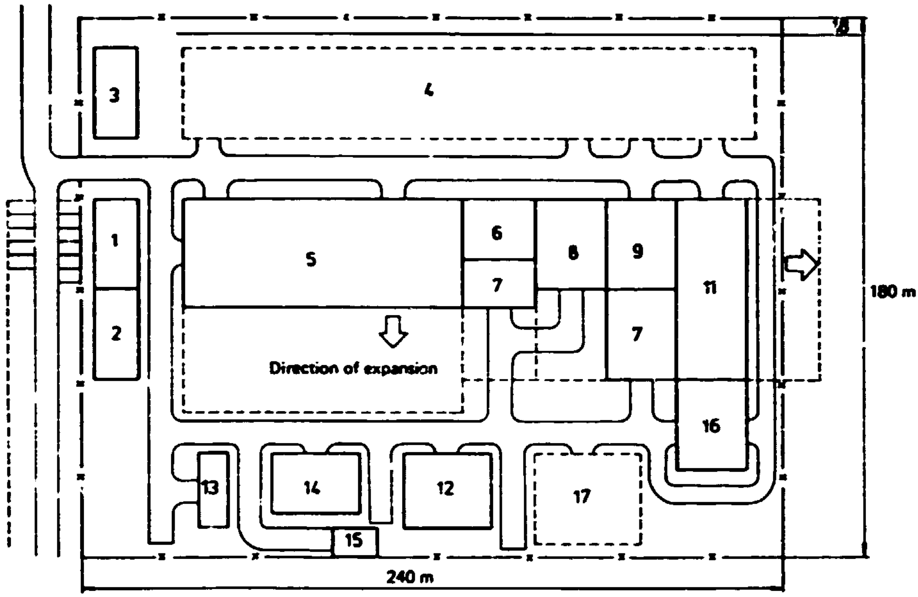
[a]Length in kilometres

Figure XXVII. Material flow-sheet of works with a capacity of 10,000 tonnes per annum, including wire rod plant, drawing plant and stranded cable plant



The establishment of small metalworking and machining workshops is recommended for the manufacture and repair of certain items of equipment required for maintenance and operation. At the same time, a stock of more complicated, specialized spare parts and equipment (such as main pieces or subassemblies) should be held in reserve. The following equipment should be covered in the planned preventive maintenance scheme: industrial furnaces and service systems (melting, casting and heat-treating furnaces); metallurgical production and machining equipment and woodworking machines (wire-rod cast rolling line, wire-drawing machines, cabling machines, saws etc.);

Figure XXVIII. Layout of drawing plant and cable plant with a capacity of 5,000 tonnes per annum



Key:
1 Management offices
2 Social building
3 Electric power station
4 Storage area for raw materials, wood, empty drums and finished products
5 Cabling plant
6 Intermediate storage
7 Storage of auxiliary materials
8 Wire-drawing plant
9 Storage for wire rod
10 Wire-rod cast rolling shop
11 Drum-manufacturing shop
12 Water and compressed-air supply
13 Sewage treatment
14 Boilers
15 Natural gas supply station
16 Maintenance work shop
17 Waste storage or deposit
18 Railway tracks

containers, vessels, pipe-trains, pumps, fans and compressors; transport facilities, vehicles, trucks and hoisting equipment; boilers and service facilities; buildings and related mechanical facilities; and electric energy supply and distribution systems, signalling systems and transformers.

On-site maintenance work requires testing and checking the equipment, assembly and disassembly (exchange of malfunctioning or worn-out parts), and technical and safety measurements and checks. The maintenance of wire-drawing equipment requires special attention. Of decisive importance is the condition of lubricating parts and elements, and product quality depends on the surface quality of guide and feedback rollers. In addition to the maintenance of drive units, the spindles must be regularly balanced (dynamically and statically). The condition of the lubricating devices of cabling machines is also highly important.

The maintenance of drawing blocks made of hard metals, tungsten carbide, diamond or industrial diamond poses special problems. Grinding and polishing machinery is required for maintenance drawing blocks, in addition to diamond powder or diamond paste for regrinding. The workshop is used to prepare the drawing blocks for operations in accordance with the pass schedule. Drawing blocks should be stored on shelves adjacent to the maintenance workshop, and a detailed record of their use should be kept.

The following three categories of maintenance personnel are required: mechanical maintenance (machinist and locksmith), from 55 to 60 per cent of total; electric maintenance (electrician, locksmith, electronics technician), from 30 to 35 per cent of total; and building maintenance, from 5 to 10 per cent of total. Practical experience has shown the yearly cost of maintenance to amount to from 5 to 7 per cent of the value of fixed assets.

The surface area of the central maintenance workshop should measure from 3 to 5 square metres per worker, with extra room for machining equipment. The machining workshop should house lathes, milling machines, horizontal drills, universal grinders etc. The mechanical workshop should be equipped with gas and electric welding units, saws and pipe-bending and -cutting machines. The electric workshop should contain instruments for the measurement of current, voltage, power, resistance etc., and oscilloscopes and equipment for trouble-shooting. The following special equipment is also required: spark machining equipment, grinder, heat-treating furnaces, and dynamic and static balancing equipment.

It would be impractical to install maintenance and repair capacity for activities that are rarely performed or that require special skills. Such activities include relining furnaces and boilers, recoiling electric motors, repairing vehicles, the manufacture of cabling tools and a large volume of building work. The decision on the installation of capacity for maintenance and regrinding of drawing blocks will depend on local and plant conditions.

The technical management of the plant should include engineering or other personnel responsible for keeping records of spare parts, the orderly filing of documents and small design modifications. The layout of maintenance facilities is shown in figures XXVII and XXVIII.

C. Materials handling and storage

1. Materials handling

(a) Within the production building

Since materials handling in the production building forms part of the production process, it is described in the sections dealing with production technology.

(b) Between production buildings and plant sites

The problem of transporting ingots and alloying materials into plants working with a solid charge has to be dealt with. Stacked and bound ingots and master alloys are moved by fork-lift trucks. The same fork-lift trucks can handle scrap packed in boxes or containers. Ingots, master alloys and scrap are charged into the furnaces by trucks equipped with a special rotating head.

Coils of wire rod arrive on wooden pallets that can also be handled by the fork-lift trucks. The coils of wire rod must be handled in such a way as to prevent contact with humidity, because the drawing block is harmed by corrosion due to humidity. Fork-lift trucks can be used to move materials between drawing and cabling plants. Wire kept on spools in the cabling plant can be transported and protected during storage by means of transport lines and frameworks.

The end-products are moved by fork-lift trucks or by overhead cranes when available. When railway cars are used for transporting the goods, the drums to be carried by the same wagon should be lined up and loaded by crane. Rail cars should have a wooden bottom and the drums should be fixed with joists and wedges. Fork-lift trucks and other devices should be provided for handling auxiliary materials, spare parts, wooden platens and drums used for packing, tools etc.

The following equipment is needed for materials handling in a wire plant with a capacity of 10,000 tonnes per annum and including a wire-rod cast rolling shop, a wire-drawing shop and a cabling plant:

Equipment	*Number of units*
Flat platform truck, capacity of 2 tonnes	2
Flat platform truck, capacity of 3 tonnes	2
Fork-lift trucks, capacities of from 2.5 to 3.2 tonnes	4
Fork-lift trucks, capacity of 5 tonnes	2
Fork-lift truck, capacity of 10 tonnes	1
Trucks with rotating head for the charging of furnaces	2

The purchase price of the various transport trucks amounts to from 5 to 7 per cent of the investment cost of production equipment. Passage ways and plant roads of from 8 to 10 metres in width should be built to ensure uninterrupted materials handling, loading and unloading.

2. *Storage*

Requirements for the storage of raw materials for the wire-rod cast rolling plant are described below. Ingots of from 15 to 20 kilograms each are supplied in stacks of from 1 to 1.5 tonnes. Fork-lift trucks can easily store and transport the stacks and charge them into the furnaces. The production of semi-continuously cast T-bars has recently been spreading. Metal in this form is highly advantageous, because large quantities of it can be stored in relatively small areas. Coils of wire rod should be stored when the wire drawing plant uses purchased wire rod. Coils are stored on pallets in stacks of three. The storage area of coils should be closed, covered and protected from rain.

The area required for the storage of finished products is based on established storage guidelines. Moreover, the number of drums will depend on the need to provide four square metres of space for each drum, and to ensure their accessibility. Drums may be stored on any paved open area with rain-water drainage. Empty drums should also be stored, the number of which will be equal to the number of drums containing finished cables. The area required to store an empty drum is approximately two square metres. Steel wire can be stored in coils requiring a relatively small indoor storage area, preferably in the production building.

Provision should be made for the collection, packing and storage of scrap formed during production and the storage of wood required for the manufacture of drums. An area is provided for that purpose near the workshop for the manufacture of drums and in the production building itself. Drawing spools also need storage space, and intermediate storage of drawn wire is provided for between the wire-drawing and the cabling plants. Wire is stored on frames of aluminium, steel or wood. The following are additional storage requirements:

(a) Auxiliary materials such as wall-lining materials for furnaces should be stored in moisture-free areas;

(b) Special attention should be given to the proper storage of drawing blocks;

(c) Spare parts for repairs and maintenance should be centrally stored for each plant, on the basis of an appropriate storage and recording system;

(d) Wooden platens, scrap containers, packaging materials (paraffin-impregnated paper, polyethylene foil, cardboard etc.) and deals for bridging should be carefully stored.

D. Packaging

A number of materials require packing in the course of the production process starting with ingots and leading to stranded cables.

Cast and rolled wire rod must be packaged when the total production of the wire-rod cast rolling plant is not used by a nearby wire-drawing and cabling complex. The purpose of packaging is to protect the wire rod from humidity and mechanical damage. Coils of wire rod are placed between two wooden plates in an upright position, then covered with paraffin-impregnated paper, polyethylene foil and cardboard, as well as plywood. The wooden plates are bound with steel bands. The operation is performed as part of the production process. An example of packaging for long-distance transport is shown in figure IX. It is also possible to pack the coils of wire rod only in polyvinyl-chloride foil or in steel bands when the coils are to be transported in a dry region to a nearby plant.

The primary finished products of the cabling plant are the stranded electric conductors and sometimes wire for cables. Those products are transported on drums made of steel or wood. The empty drum is covered with a few layers of paraffin-impregnated paper and cardboard. After the drum is filled with stranded conductor, the coil is fixed with a band and covered with paraffin-impregnated paper, polyethylene foil and deals. The drum slowly rotates on the drum-packaging machine (shown in figure XXII) while air-hammers nail the deals on the rim.

E. Environmental protection and water drainage

The atmosphere is directly contaminated by materials generated by the production and auxiliary processes carried out in the cast rolling shop and the boilers. Flue gases are generated by the gas-fired melting and casting furnaces and the boilers, and chlorine-containing gases escape from the casting shop, depending on the metal-cleaning technology used. Care should be taken to neutralize chlorine-containing dust and flue gases.

Contaminants are also generated during the water cycle. They are primarily oils and greases that mix with water when washing cars or cooling cast metal, or that escape from the lubricating-cooling system of machines (when changing emulsions or due to leakage). Oils and greases originating from the washing and running of cars contaminate rain-water drainage. The subject of water treatm is also related to the deposit and treatment of sewage.

Solid wastes are generated mainly during the packaging operation in the form of wood, paper and polyethylene foil. There are no hazardous, poisonous wastes. The environment can be adequately protected by the proper operation of production equipment.

The proper fuel-air ratio in the furnaces and boiler should be ensured by controlled firing systems to improve combustion. Flue gases generated by the furnaces and boiler should be exhausted through stacks or chimneys at a height of from 20 to 60 metres, depending on local requirements and regulations. Flue gases containing chlorinated compounds may be extracted through stacks with a suitable internal lining. Chlorine should not be allowed to escape into the atmosphere of the production buildings.

Generated waste water should be deposited in separate compartments, depending on the type of contaminant. Sewage should be drained in a closed ductwork and transferred to a collecting ductwork. In the absence of a central sewage transfer system, local drying and transport in tank cars may be a realistic solution.

Industrial waste water and rain-water can be transferred by a common ducting system. Before passing industrial waste water into the drainage system, its oil content should be reduced to the level required by local regulations. When water is used several times (in a closed circuit or recirculating system), it may be necessary to skim off the oil from the water before passing it to the collecting system. In simpler cases, oil may be skimmed off in a basin when it floats on the surface of the water. In such cases the emulsions used for the cooling and lubrication of equipment may not be mixed into the waste water. These emulsions will have to be transported in separate tankers, since the establishment of an individual separating plant would be uneconomical, given the small quantities concerned. Wood and paper wastes can be burnt in coal-fired boilers, otherwise solid waste dumps outside the plant area will have to be provided.

Facilities for the protection of the environment do not require continuous attendance, but regular checks should be carried out. The investment costs of various plants and facilities are summarized in table 38.

Table 38. Direct capital costs[a] based on selected capacity variants

		Costs in thousands of dollars				
Item	*Capacity variant[b] (tonnes per annum)*	*Civil engineering*	*Equipment*	*Erection*	*Miscellaneous*	*Total*
Wire-rod cast rolling plant using solid charge	10 000[c]	580	3 620	340	230	4 770
Wire-drawing and cabling plant	2 500	540	2 000	285	210	3 035
	5 000	1 790	5 560	700	650	8 700
	10 000	3 200	8 395	890	875	13 360
	20 000	5 780	15 680	1 600	1 490	24 550
Maintenance	5 000 to 20 000	80	180	40	40	340
	10 000[d]	100	260	50	50	460

Table 38. *(continued)*

Item	*Capacity variant*[b] *(tonnes per annum)*	*Costs in thousands of dollars*				
		Civil engineering	*Equipment*	*Erection*	*Miscellaneous*	*Total*
Auxiliary plants (electric energy supply, boilers, natural gas, compressed air, water supply, waste-water treatment)	2 500	50	100	50	50	250
	5 000	440	980	130	130	1 680
	10 000	770	1 200	140	160	2 270
	20 000	925	1 730	170	230	3 055
	10 000[b]	860	1 400	170	230	2 660
Materials handling, storage and woodprocessing	2 500	..	..	..	..	300
	5 000 to 20 000	300	440	20	60	820
	10 000[d]	250	500	20	60	830
Offices, social facilities, roads etc.	2 500	..	..	..	..	200
	5 000 to 20 000	850	250	20	80	1 200
Total	2 500	590	2 100	335	260	3 785
	5 000	3 460	7 410	910	960	12 740
	10 000	5 200	10 465	1 110	1 215	17 990
	20 000	7 935	18 280	1 850	1 900	29 965
	10 000[d]	5 840	14 425	1 490	1 525	23 280

[a]Costs related to plant site and miscellaneous overhead costs are excluded (land, customs, transport, interest, external utilities etc.).

[b]For wire-drawing and cabling plant, unless otherwise stated.

[c]Wire-rod cast rolling plant.

[d]Wire-rod, wire-drawing and cabling plant.

VI. Plant management and organization

The three basic capacity variants among the several production plants that have been discussed so far will now be considered more closely. In one of the variants, a wire-drawing and stranding plant operating with purchased wire rod at a capacity of 2,500 tonnes per annum is integrated into an existing plant. In another variant, a wire-drawing and stranding plant with a capacity of 5,000 tonnes per annum operates with purchased wire rod. In the third variant, a wire-rod cast rolling plant working with ingot supplies a wire-drawing and stranding plant operating at a capacity of 10,000 tonnes per annum. The last two variants are supposed to be individual plants. The equipment layout for the first variant is shown in figure XXV; that of the second and third variants are illustrated in figures XXVII and XXVIII, respectively.

The first variant is adopted when local demand, or the increase in demand, for electric conductor wires is low, and the required quantity can be supplied by equipping an existing plant with a few wire-drawing and stranding machines. In the first stage, stranding machines are usually installed and drawn wire is purchased. In the second stage, wire-drawing machines can be installed, providing a greater degree of flexibility with little extra investment. The starting material in the second stage is wire rod. The minimum economic capacity of such plants is from 2,000 to 2,500 tonnes per annum, considering the performance, price, energy and other requirements of wire-drawing and stranding equipment.

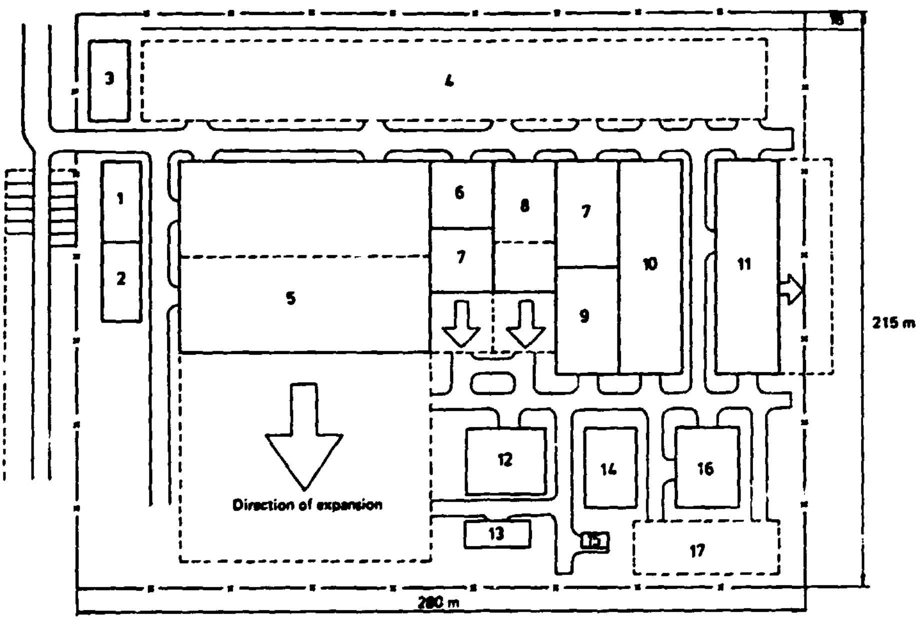
The second variant may be adopted by a developing country that decides to manufacture the wires and cables required for its electrification. The first step would be to establish a cable plant using purchased wire. The installation of a wire-drawing plant may be justified by the need to respond better to market demand, to employ more domestic workers and to reduce production costs. The widest range of market demand can be satisfied by such a plant using purchased wire rod. The capacity of 5,000 tonnes per annum is an average figure based on initial demand and the most economical conditions of operation.

The third variant may occur when the above-mentioned drawing plant begins to expand and to purchase aluminium ingot to produce wire rod in a cast rolling shop. This solution allows greater flexibility in responding to market demand and promotes the use of a cheaper raw material (aluminium ingot), the domestic labour force and other resources.

The cable works including an aluminium smelter can be started in order to further process molten metal directly into wire rod. The cast rolling facility may be installed in the existing casting shop of the aluminium smelter or located further away, depending on the availability of labour, the market etc. It is more economical and advantageous to start production of wire rod from molten metal, although in practice it is often started from solid metal. The latter possibility has been selected in order to illustrate all the facilities required to built up a complex.

At a later stage the wire-drawing and cabling plants are established to carry out further processing of wire rod produced by the cast rolling plant. Initially, the processing capacity can be less than what is required to process all the wire rod, hence a part of it will have to be marketed. The capacity of the wire-drawing and cabling plants increases with market demand up to the capacity determined by the wire-rod cast rolling plant. The material flow-sheet of a complex cable works with a capacity of 10,000 tonnes per annum is shown in figure XXIX.

Figure XXIX. Layout of wire-rod plant, stranded wire plant and drawing plant with a capacity of 10,000 tonnes per annum



Key:
1 Management offices
2 Social building
3 Electric power station
4 Storage area for raw materials, wood, empty drums and finished products
5 Cabling plant
6 Intermediate storage
7 Storage of auxiliary materials
8 Wire-drawing plant
9 Storage for wire rod
10 Wire-rod cast rolling shop
11 Drum-manufacturing shop
12 Water and compressed-air supply
13 Sewage treatment
14 Boilers
15 Natural gas supply station
16 Maintenance work shop
17 Waste storage or deposit
18 Railway tracks

The capacity of the complex with the aluminium smelter is 10,000 tonnes per annum, but total capacity including the processing of steel is 11,512 tonnes per annum of stranded conductor. This generates a gross income of $17,798,000 on the basis of the product mix proposed in table 33 and of 1985 prices. The following average prices of stranded conductors have been taken into account:

Type of conductor	*Dollar price per tonne*
Steel and aluminium stranded structures 1 + 6; 7 + 26	1,455
7 + 36	1,435
Stranded structure of E-Al 99.5 quality	1,585
Stranded structure of E-AlMgSi 0.5 quality	1,750

The personnel requirements of such a plant are shown in table 39, which is based on a three-shift working schedule in the production plants, one or two shifts in the utilities and auxiliary plants, a 24-hour workday and five days of operation per week. If holidays and illnesses are taken into account, the total number of employees should be increased by 15 per cent to 86, 220 and 390 persons for the three variants.

Table 39. Personnel requirements for selected capacity variants

(Number of persons employed)

Item	*Personnel requirements based on capacity variant*		
	2,500 tonnes per annum	*5,000 tonnes per annum*	*10,000 tonnes per annum*
Wire-rod cast rolling plant	—	—	40
Wire-drawing plant	12	25	40
Cabling plant	25	60	120
Energy and other utilities	8	23	23
Maintenance	16	50	70
Packaging and storage	14	30	40
Water treatment, environmental protection	—	4	6
Total	75	192	339

The uninterrupted operation of the plants depends on a number of factors. Although a detailed discussion of all the factors is beyond the scope of this study, three of them must be briefly considered because of their decisive role in plant operations.

Manufacturing processes are carried out in each plant using highly sophisticated, automatic equipment. The quality and quantity of the products, hence the economic health of the plants, is determined by the condition of the tools and machines and the amount of time spent in production. The equipment should therefore be kept in operation during as much of the useful working time as possible, making the fullest use of the speed, capacity and other parameters specified by the suppliers. This can be achieved only when skilled workers using the proper equipment are able to accomplish their tasks according to a planned preventive maintenance schedule. It will require a co-ordinated effort in the fields of mechanics, electricity and automation. A department set up to undertake such an effort would require the closest co-operation, from the beginning of plant operations, among its members, its expert advisers and the equipment suppliers.

Apart from the condition of the equipment the technology applied determines product quality and the economic viability of operations. In most cases technology for the plant is provided by the equipment suppliers, but it is still advisable to maintain a separate department of technology within the plant, for the following reasons:

(a) Even the most able engineer cannot cope with all the details of every problem;

(b) The product mix will not remain identical to that for which the plant was originally designed, hence new technologies must be continuously developed;

(c) Quality requirements gradually increase for all products;

(d) Production costs must be steadily decreased.

A strong department of technology with a staff of well-trained and experienced experts can apply and adapt plant equipment to changing external conditions, incorporate the latest innovations into the production process, exchange know-how at the international level and, finally, develop advanced technologies and quality control systems.

Special attention should be paid to marketing. When new production capacity is introduced the supply of certain products suddenly increases and far exceeds the demand and rate of growth of the domestic market or industry. A team of marketing analysts will have to examine those questions preferably before the establishment of the plant, but certainly not later than the start of production. A knowledge of the potential of domestic plants and market demand is essential.

New products should be developed for new fields of application, including processing technologies. Complex systems worked out by the plant should be marketed. Selling the products at realistic prices can be ensured through close co-operation between the plant and the customers in the period of production run-up.

VII. Investment decisions and implementation schedule

The proposed plant layouts are shown in figures XXVII and XXVIII. Alternative layouts may be considered depending on local circumstances. It is important to leave enough space for future plant expansion, including auxiliary plants. The estimated direct capital costs based on capacity levels are given in table 38. The table summarizes the investment costs required to establish a complex including auxiliary plants, an energy supply system etc. Costs related to the purchase or acquisition of land and miscellaneous overhead costs are excluded. On the basis of the data given in table 38, an economic analysis of the complex can be made if the phase price is related to the investment costs. The phase price is the difference between the price of the purchased product (aluminium ingot or wire rod) and the price of the end-products (stranded aluminium conductor). That difference is considered to be the additional value produced by the plant. The sum of yearly additional values is obtained when the phase price is multiplied by the number of products. By relating this sum to the respective direct capital costs the economic outlook for the variant may be assessed. Such a simple and informative economic calculation will now be made, on the basis of 1985 world market prices, for the capacity variants dealt with in this study (see table 40).

Table 40. Phase income estimates according to investment level

(Thousands of dollars)

Plant and capacity (tonnes per annum)	*Capital costs*	*Price income*	*Cost of metal*	*Phase income*	*Ratio of phase income to capital costs*
Wire-drawing and cabling plants (2,500)	3 785	3 865	2 863	1 002	0.27
Wire-drawing and cabling plants (5,000)	12 740	7 730	5 725	2 005	0.16
Wire-drawing and cabling plants (10,000)	17 990	15 460	11 450	4 010	0.22
Wire-drawing and cabling plants (20,000)	29.965	30 920	22 900	8 020	0.27
Wire-rod, wire-drawing and cabling plants (10,000)	23 280	15 460	10 500	4 960	0.21

The average price of stranded aluminium conductor is $1,546 per tonne, that of aluminium ingot $1,050 per tonne, and that of aluminium wire rod $1,145 per tonne (excluding transport costs). To simplify the calculations, only the rated capacity for aluminium and the aluminium content of stranded structures have been taken into account.

Table 40 shows that the ratio of produced additional value to the direct capital cost improves as the capacity of wire-drawing and cabling plants increases. There is an intermediate value of the ratio for a complex including a wire-rod casting and rolling plant and wire-drawing and cabling plants with a capacity of 10,000 tonnes per annum.

The establishment of a plant with a capacity of 2,500 tonnes per annum within an existing complex gives a good investment ratio similar to that of a plant with a capacity of 20,000 tonnes per annum. The ratio can be further improved when equipment is installed in existing buildings, thus eliminating building costs of approximately $500,000. Additional capacity increases by that means would be counter-productive, because apart from the required extra investment in equipment, the cost of expanding the utility supply systems will also worsen the ratio. The number of persons required for the operation of the plant will increase together with operating costs.

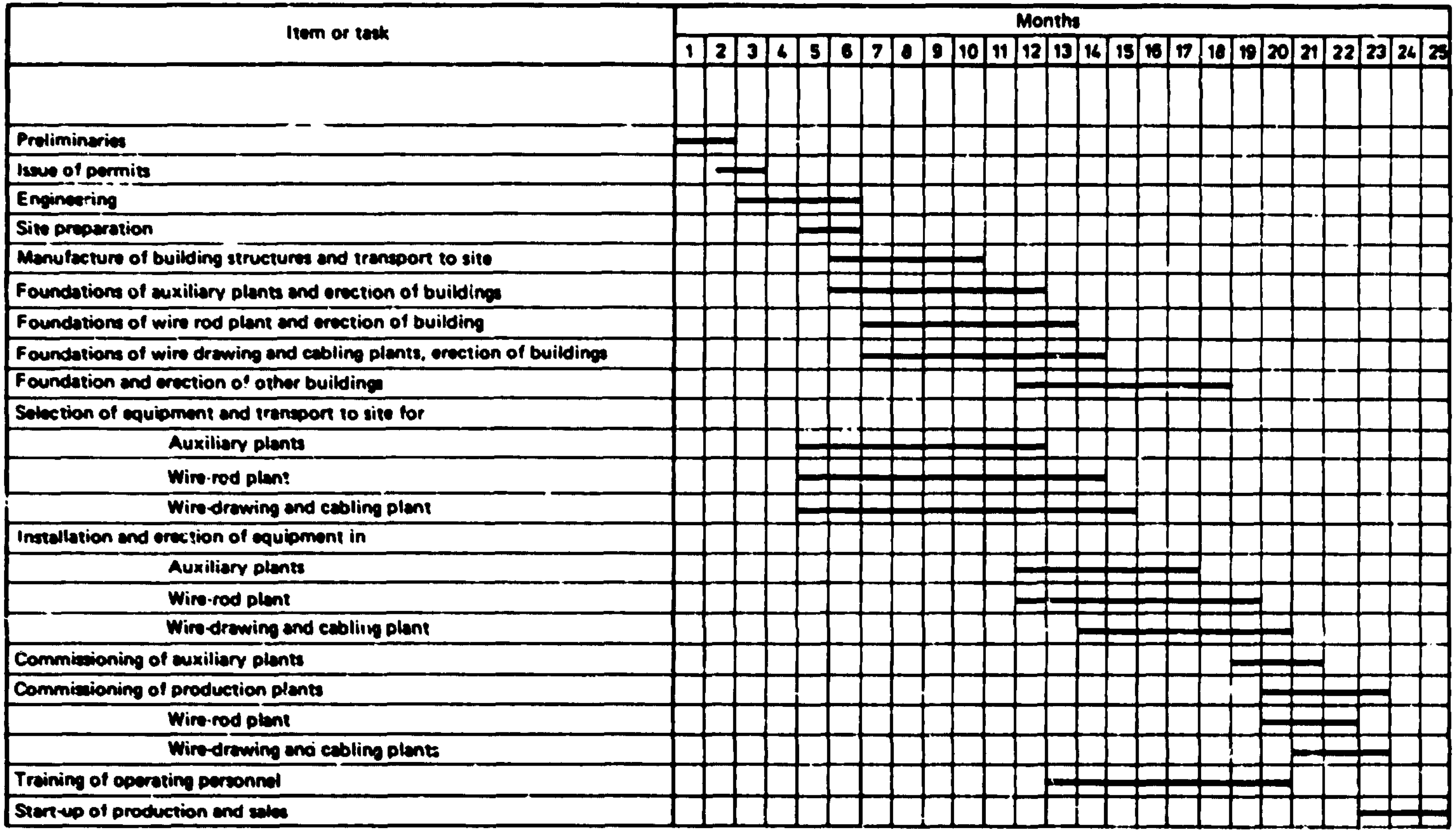
The above calculations are only preliminary, and cannot replace profit calculations based on real data. Similarly, although the market prospects of the end-products will greatly influence the economic performance of the plant, they are not analysed here. It may be hepful to analyse production costs and to relate them to the sales price. The calculation for a complex consisting of a wire-rod cast rolling plant and wire-drawing and cabling plants with a capacity of 10,000 tonnes per annum is outlined below:

Cost factor	*Dollar cost per tonne of output*
Aluminium raw materials (with 2 per cent loss due to oxidation)	1,071
Electric energy, unit price of $12 per MWh	24
Auxiliary materials, tools	22
Maintenance, 3 per cent of value of equipment ($15,380 × 0.03 = $461,400; $461,400/10,000 tonnes = $46/t)	46
Costs of drum manufacture	18
Wages ($300 per month for 200 persons)	72
Costs of working capital (10 per cent interest rate on working capital of $1,500,000)	30
Depreciation of fixed assets at 6 per cent per year ($23,170,000 × 0 06 = $1,390,200 per year)	139
Interest payable on imported equipment, after deduction for inflation, on the basis of an interest rate of 6 per cent ($8,290,000 × 0.06 = $497,400 per year)	50
Total costs	1,472

The above calculation shows that the complex makes a slight profit on the basis of 1985 world market prices, since the production costs are $1,472 per tonne and the sales price is $1,546 per tonne, with a profit of $74 per tonne. The dominant cost factor is the depreciation of fixed assets, hence the lower the direct capital cost of an investment for a certain production level, the more profitable it is. Further difficulties may be faced when in the first year of production only 50 to 80 per cent of the products can be marketed.

At the decision-making stage, a detailed study should be carried out with special emphasis on site selection and the availability of raw materials, utilities, infrastructure, labour and management skills. The amount of fixed assets and working capital should be estimated in domestic and foreign currencies. An analysis should be prepared of both domestic and possible foreign market demand, and of the product mix required to meet that demand.

Figure XXX. Implementation schedule for a wire-rod casting plant, wire-drawing plant and cabling plant with a capacity of 10,000 tonnes per annum



If the preliminary studies outlined above justify the project, then a feasibility (or pre-investment) study should be prepared, preferably by a consulting company. In the study the following aspects should be considered for one, two or, in special cases, more project alternatives: project background and history, including the cost of preparatory studies and investigations, demand and market analysis, with sales forecasting, and the relationship of marketing to the production programme and plant capacity; production materials and inputs, with cost estimate; site selection and local conditions; engineering; labour and organization; implementation schedule; and financial evaluation (total production and investment costs and sources of financing), with the calculation of the pay-back period, the simple rate of return, the net present value and the internal rate of return, and including break-even analysis and sensitivity analysis.

Economic evaluations can be performed using computers and purchased software packages. Detailed consideration of the above aspects is also useful when the project is supported by government decisions on economic development. The project implementation period may be as little as two years if it is well organized and co-ordinated, and if full advantage is taken of the services of consultants and suppliers. Figure XXX provides an example of an implementation schedule for a wire-rod cast rolling plant, a wire-drawing plant and a cabling plant.

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