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Steel Pressure Pipe for the Hydro-electric Plant "La Bissorte".

Le tuyau d'acier de l'usine hydro-électrique de "La Bissorte".

Stahldruckrohr des Kraftwerkes „La Bissorte".

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Steel tubing has quite recently played a prominent part in the arrangement of the hydro-electric power station at "La Bissorte", whose delivery pipe carrying the water to the turbines is made entirely of steel from its very starting point (that is, from the source of supply) and this delivery pipe is one of the outstanding modern pipe lines, not only on account of the height of the head under which it operates and which exceeds 1,000 metres, but also on account of the energy developed, which works out at 100,000 h. p.

It would therefore seem opportune to submit a few facts about the installation of this piping, which is remarkable both for the originality and for the boldness of its design.

Description of the Pipe Line.

The entire installation is of metal, its length being 3,037 metres, no less than 3,800 tons of steel was used for its construction. It starts at the Barrage, or dam, at an altitude of 2,028 and finishes at an altitude of 936. The level of the dam is 2,082; if account be taken of the hydraulic recoil produced by the turbines, the piping of the lower portion is subjected to the very heavy pressure of 132 kg per sq. centimetre.

Diameters have been calculated for a volume of 7.5 cubic metres per second.

The pipe line consists of two main parts:

One part with a small gradient over a length of 1,080 metres with a diameter of 1.8 m, is installed entirely in a passage cut in the rock; the tubes are electrically welded and equipped from the very start with all the necessary cocks, valves and safety devices.

The other part has a steep gradient over a length of 1,957 metres; some of the pipes along this portion are water gas welded, their diameter being 1.4 m, and the remainder are armoured. The diameters of these latter are 1.4 and 1.3 m. and the remainder are armoured. The diameters of these latter are 1,4 and 1,3 m.

These also are fitted from the start with valves and safety appliances.

These two main parts are united in an equalising chimney shaft with a diameter of 2.5 m and height of 70 metres situated in a vertical pit cut out of the rock.

The lower end of the pipe line, which before reaching the power station crosses the Mont Cenis railway line from France to Italy, is terminated by a collector fitted with three branch pipes, each of which feeds a 34,700 h. p. turbine.

The erection of the pipe line was exceedingly complicated owing to the very steep gradients of the slopes and the individual weight of each piece of tube. Some of the latter actually weigh as much as 15 tons.

The power of pressure piping is expressed by the product HD^2 (H being the height of the head, D the mean characteristic diameter).

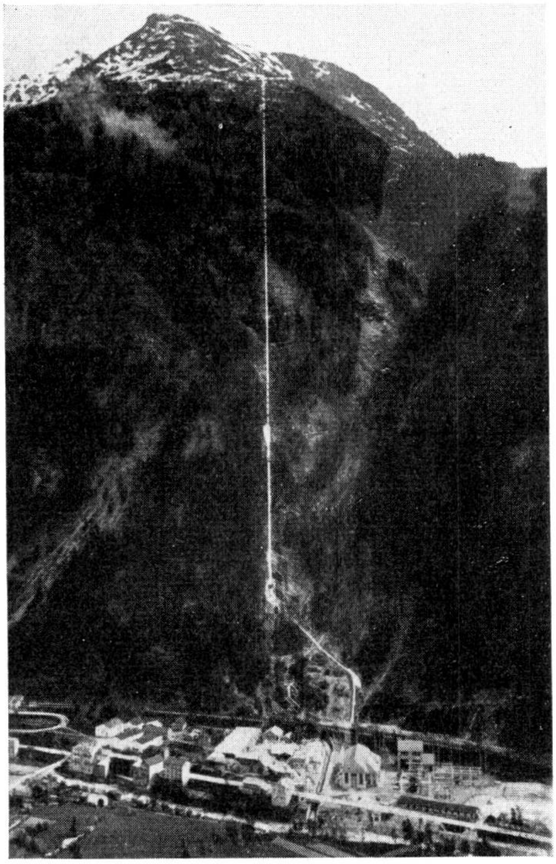

Fig. 1.
"La Bissorte" Pressure Pipeline. General view.

The pipe line of "La Bissorte" is remarkable from this point of view and sets up a record with $HD^2 = 2360$.

Its dimensions were calculated to resist an atmospheric vacuum and a static pressure corresponding to the maximum level of water in the reservoir plus either a 15 per cent. linear overpressure due to hydraulic recoil when closing the turbines, or to overpressure resulting from hydraulic recoil caused by oscillations which would produce a uniform overload of 55 m, admitting for each the maximum value of the two overloads in question.

The fatigue strengths under these maximum pressures would be the following:

8 kg/cm² for the metal plate,

24 kg/mm² for the spiral reinforcement,

2 kg/cm² for the pressure of the masonry work which acts as an anchor block.

The sheet metal used for the pipes was Siemens-Martin extra mild steel with a 35 kg/mm² tensile strength and 30 per cent. longitudinal pull respectively. The reinforcement to armour the tubes is made of treated special Siemens Martin steel having minimum coefficients of 90 kg/mm² tensile strength, 60 kg/mm² limit of elasticity and 8 per cent. longitudinal pull.

Low gradient section.

This part includes:

Anchor piece of pipe with inside diameter 1.8 m from the outlet gallery (altitude 2028.86) to the sluice chamber (altitude 2028.78) with a gradient of 0.001 m per metre, made of electrically welded tubes with walls 12 mm thick, length of each section of piping 9 metres, these assembled on the site by socket joints and butt welded with the electric arc.

The tubes in the passage or gallery are entirely concreted in order to form an anchoring plug and to be absolutely water tight. After concreting, pressure injections were carried out through the wall of the sheet metal along the whole of the concrete plug.

A pipe line of 1.8 m inside diameter and 1 000 metres long, leading from the sluice chamber (altitude 2028.78) to the spherical valve fitted at the point where the steel slope (altitude 2015.36) starts with a gradient of 0.0134 m per metre, erected entirely inside a gallery large enough to ensure the passage of inspectors and attendants and access to the regulating flap.

This pipe line of electrically welded tubes 8 and 9 mm thick and in sectional lengths of 9 metres, was assembled on the site of erection by sleeve joints and rivets.

Reinforcement hoops, at intervals of 3 metres, reduce the effects of fluctuating atmospheric pressure.

Two intermediate anchoring blocks which keep the bends in position, ensure strength which is further increased by pedestals of masonry work with steel saddles. The pedestals or supports are placed at equal distances of 9 metres.

There are no expansion joints in the pipe line, altough the bends are anchored in position. The reason for this is that temperature fluctuations within the gallery are but very slight.

Equalizing shaft.

This has a diameter of 2.5 m and branches just above the point where the low gradient section meets the steep gradient portion.

The equalizing chamber includes a horizontal part placed inside a gallery 62 metres long and another 65 metres high situated in a vertical shaft.

It is made of arc welded tubes with walls 8 to 15 mm thick, the section lengths are each 6 m, they were assembled in situ, rivets being used for the horizontal part and welding for the vertical part. Each tube of the horizontal portion rests on a masonry pillar and has a steel saddle. The tubes in the vertical part are surrounded by concrete which fills in the space between metal and rock.

Steep gradient section.

This part includes:

Tubes welded by water gas — inside diameter 1.4 m length 522 metres up to level 1,704 metres, passing in turn through the horizontal passage or gallery, then through the gallery inclined at a gradient of 0.849 m per metre over a length of 229 metres and then reaching the open air.

This section, which has no expansion joints, is made of water gas welded tubes 11 to 39 mm thick; they were assembled on the site of erection by socket jointing and riveting.

The bends are joined to the straight pieces of piping by tongued flanges and bolts.

The blocks of masonry are spaced along the profile of the water conduct in such a way as to leave the bends free to play their part in equalizing the longitudinal stresses due to temperature fluctuations.

In the spaces between the blocks, the pipe line rests on masonry pillars situated at intervals of 12 metres and fitted with steel saddles.

A section of armoured tubes with an inside diameter of 1.4 m, length 152 metres up to an altitude of 1,632 metres.

This section is erected in the open air.

It is made of plates 12 mm thick, spiral reinforcing 60×22 to 60×26; the tubes were assembled in situ by riveted sleeve joints and by special sliding joints, one for every three tubes.

All the bends are held down on masonry blocks and connected to the straight pipes by sliding joints.

The straight parts are also fixed to the intermediate blocks at intervals of 19 metres; in these spaces the pipe line rests on pillars 6.40 metres apart and with steel saddles. Between each block that is, at equal distances of 19 metres free expansion of the pipe line is secured by sliding joints which do the work of expansion joints of short dilatation range.

A section of armoured tubes, inside diameter 1.3 m, with riveted sleeve joints, length of tubing 827 metres up to a height of 1,120. This section passes first of all into the passage and then out into the open.

It is made of plates 12 to 20 mm thick and with reinforced spiral casing 60×24 to 80×48. The length of the tubes, the method of assemblage and the bolting appliances are identical with those of the preceding section.

A section of armoured tubes, inside diameter 1.3 m, fitted with sliding joints, length of pipe line 451 metres, leads to the collector (altitude 936.70 m) erected partly:

— in the open, partly

— on a metal footbridge (crossing the "Bissorte" torrent) and partly:

— in the interior of a metal-plated passage under the railway line.

It is made of tubes 22 and 24 mm thick with spiral reinforcement 90×48 to 100×54. The tubes are assembled by sliding joints.

Just as in the preceding sections, this part of the pipe line also has its bends clamped and the straight parts are fixed at intervals of 19 metres, free expansion between the clamped parts being ensured by sliding joints. Furthermore, the pipe line rests on pillars with steel saddles; the distance between the pillars is 6.4 m.

A collector with inside diameter 1.3 m — 1.1 m — 0.8 m horizontal, length 38 metres including three branch pipes for connecting the line to the turbines.

It is entirely encased (except for the bifurcated parts) in a block of masonry which forms part of the foundations of the power station. The tubes are armoured, thickness of the metal being 35 mm; they are assembled by collars and the branch pipes are of cast steel.

Method of construction.

The construction included mainly the manufacture of tubes of certain lengths and of three different types:

Electric arc welded tubes,
Water gas welded tubes,
Armoured tubes.

The raw material was submitted first of all to the Steel Works for approval by a special Checking Department placed under the direct supervision of the Superintendent of the work. On arrival at the workshops they were checked up by their casting and series numbers and thereupon sorted and arranged in lots according to their kind and size.

Index cards referring to their manufacture were then filled in, mentioning dimensions of the various parts and their reference marks. All the manufacturing operations were given in full on these cards, so that by consulting them a strict control could be kept on the whole course of manufacture of any tube.

Electric arc welded tubes.

The manufacture of these tubes was carried out according to the usual sequence: planing, bevelling, bending, welding, hydraulic testing, machining and painting.

In view of the comparatively light thickness of the metal, the bending was effected while the metal was in a cold state and by means of a vertical hydraulic press. Coated electrodes were used for the electric arc welding and melted into V-bevelled joints after which heat treatment was applied to the apex of the V. Longitudinal welds were automatically machined, while the transversal welds were hand made.

Water gas welded tubes.

The operations of planing, bevelling and bending were carried out as in the preceding case. The gas for the water gas welds was obtained by pouring water vapour on incandescent coke. This gas, having a high content of hydrogen and carbon monoxide, has reducing properties and when it burns has a deoxidising effect. When welding the ends of the plates these are made to overlap each other and no deposit metal is applied. The ends of the metal which overlap are brought to a white welding heat by the reducing flame of the blowpipes heated by water gas and air. After this they are hammered.

These welds lead to deformation of the tube, induce high internal stresses and overheat the metal. In order to eliminate these stresses and improve the metal in the welding zone, the shape of the tube which has just been made is corrected by annealing at a temperature of 950^0 (the temperature being controlled by a pyrometer).

Advantage is taken of the annealing operation to place the red hot tube in a special re-shaping machine. This operation is effected very rapidly because it must be terminated before the temperature of the tube drops below 500^0. After

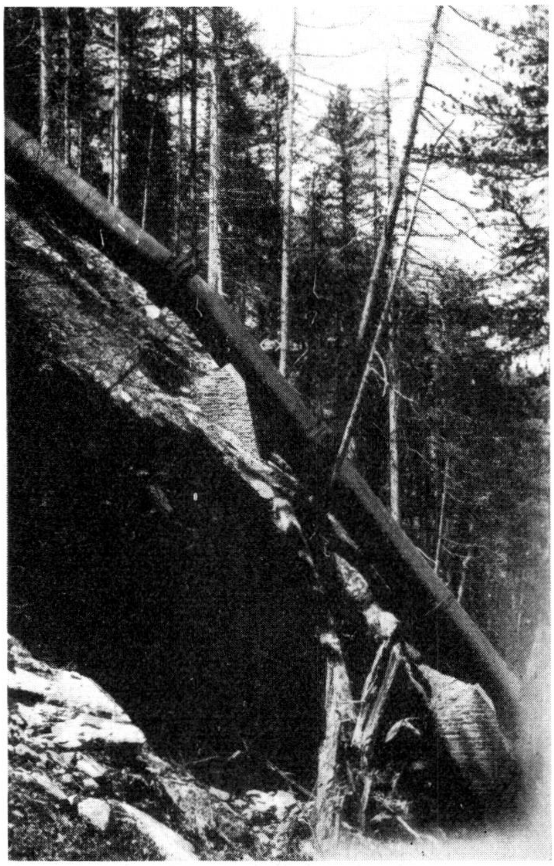

Fig. 2.
Water-gas welded portion öf pipeline at level 1810.

the operations of annealing and re-shaping, flanging machine is used and while the metal is still hot the ends of the tubes are widened to facilitate their assemblage.

The ends of the tubes are then polished on a lathe, after which follow hydraulic tests, machining and painting.

With regard to the pipe line at "La Bissorte", the longitudinal welds were carried out in a special automatic machine suitable for tubes with a diameter of 3 m and a length of 6.50 m, and in which hammering can be done by a compressed air rammer. The transversal welds were executed by hand hammering and the shift of workers included on occasion three operators for hammering the heavy plates.

Annealing was effected in a large furnace fed by gazogene and of such dimensions that tubes of 3 m diameter and 6.50 m length could be dealt with.

Temperature was checked permanently by a recording pyrometer kept in the foreman's office.

Four-cylinder bending machines were used for re-shaping or curving. These were arranged so as to allow of the welds being rolled as soon as operations started.

Armoured tubes.

As this is a novel system not applied before 1925, it might not be out of place to describe the process, which is one that is commonly practised by armament manufacturers when making heavy guns.

The operation when dealing with tubes is briefly the following:

Assuming the tube to be of appropriate steel the contents of which are known, with local thicknesses calculated in such a way that after the reinforcement, the

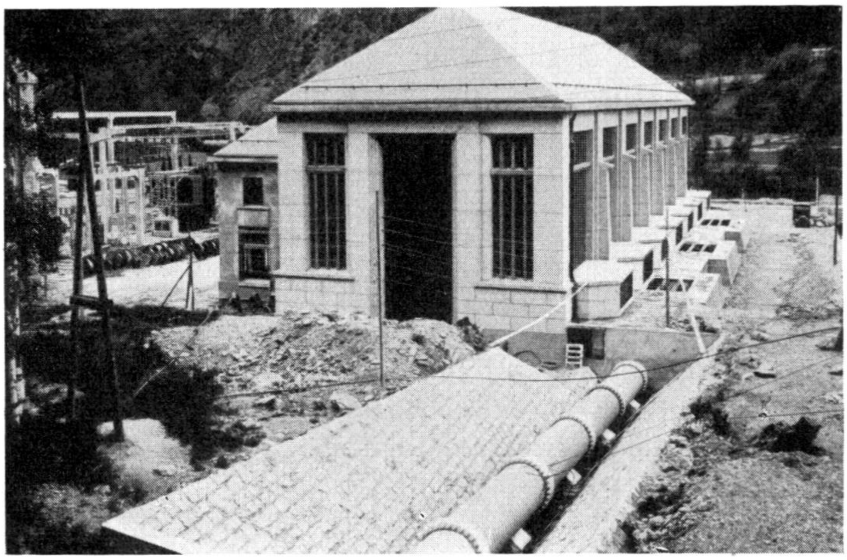

Fig. 3.
Pressure Pipeline on arrival at powerhouse.

cannon will be made of one single piece of metal (without addition of outer spiral reinforcing).

In its original state, the tube could not comply with the service conditions laid down for the muzzle designed.

The resistance necessary to fulfil its aim not being attained, it is secured by self-reinforcement and the increased strength is exactly determined and checked by the operation itself.

Assuming further that a powerful hydraulic press is available and that it communicates with the interior of the tube, the two extremities are then closed down by an absolutely watertight joint.

The liquid under pressure is poured into this tube while the pressure is gradually increased up to a point at which it slightly exceeds the figure corresponding to the limit of elasticity of the tube, remaining however, definitely below breaking point.

The pressure is maintained for a certain period at this degree and then gradually dropped until it corresponds with that of atmospheric pressure.

The tube which is expanded beyond its limit of elasticity maintains distortion permanently, while the component metal becomes harder and denser.

This kind of hydraulic expansion induces a tensile state in the outside layers of the tube while the internal layers are subjected to compression.

This complicated phenomenon is called self-reinforcement because it gives the impression of the tube having acquired increased strength without any outer force intervening.

There is no need to dwell further on this technical aspect of artillery manufacture nor to go into the manifold uses to which this new process has been put.

We will merely bear in mind two main points:

1) The fact that in the case of the tube under consideration, it has been permanently distorted without reaching breaking point and under a known pressure which exceeds its original limit of elasticity and it is thus enabled to withstand any further renewal of this same pressure without any permanent deformation being produced. It has thus acquired a limit of elasticity which is higher than that which it possessed in the first instance.

This therefore represents a change of mechanical properties.

For instance, self-reinforcement, carried out under precisely determined conditions, will be found in the case of a tube thus hardened to have increased its limit of elasticity by one-third and its tensile resistance by 8 per cent.

As a matter of fact, by means of this self-reinforcement, a steel tube of new metal can be manufactured to dimensions which can be definitely calculated and so comply with certain service requirements.

2) The application is of particular interest in that the pressure produced by the desired hardening represents simultaneously a proof of resistance which is both very great and very exact, since it corresponds to the service pressure affected by a multiplier which, ceasing to be theoretical, has taken on a definite value. Manufacture and control are thus carried out by a single process and the final product offers absolutely scientific guarantees of resistance and lightness while the process itself is a remarkably inexpensive one.

The service conditions which have to be complied with by pressure pipe lines are obviously not identical with those set up for tubes used in the manufacture of heavy guns.

But what has been said above about self-reinforcement of these guns explains the application of a process of the same kind to pressure piping.

The aim is the same: namely, that of securing the best combination, in the circumstances, of resistance and ligthness together with controlled scientific guarantees.

A self-reinforced tube required for pressure piping consists of:

— — — a tube, generally of welded steel plate, which forms the inside wall, the thickness of the latter being a fraction of that necessary for an ordinary tube possessing the same resistance, and:

— — — reinforcement rings equally spaced along the outside surface of the wall.

These rings are of rectangular section, rolled, weldless, made of steel treated for robustness, and having a limit of elasticity which is considerably higher than that of the tube sheet metal, this being an essential condition when reinforcing by this process.

The next point is to see how the manufacturing process will endow the wall of the tube and the rings with a combination of stresses which will provide a solution to the problem of resistance combined with lightness.

The outside diameter of the wall of the tube is slightly less than the inside diameter of the rings; these can thus be placed at appropriate distances when the metal is cold.

A strong hydraulic press is brought to bear on the two ends and these are closed so as to be absolutely watertight.

Pressure is increased progressively until it is twice the running pressure (static pressure plus overpressure) required when the tube will be in commission.

This maximum pressure is called "pressure of reinforcement", and once it is reached it is maintained for a period of a minute and then allowed to drop to running pressure. The tube and rings are then hammered, any control or other measures which may be necessary follow on, and the wall is examined to see whether it has behaved satisfactorily during the period of deformation. Pressure is then increased up to the rate of reinforcing pressure, and this is maintained for at least five minutes.

The operation of reinforcement and the pressure tests can then be considered as terminated.

Il would be well to add a few observations to this brief exposition in order to emphasise the usefulness of this manufacturing process:

1) The progressively increasing action causes the wall of the tube to expand and it then begins to adhere to the rings.

Pressure goes on rising, the tube tends to expand the rings and the metal is then found to be in a state of tension.

After a definite drop of pressure, the wall of the tube which has exceeded its original limit of elasticity becomes permanently deformed; it acquires a new limit of elasticity, higher than the previous one and is strengthened by the self-reinforcement. Meanwhile, the rings, owing to the great tensile strength of their component metal, have undergone elastic deformation only and set up a tightening of the outside wall analogous to that which would be produced by the contraction of rings fitted to the tube when in a hot state.

2) The experiment proves that, where strength while in commission is the same, a tube which was self-reinforced in this way would weigh half what an ordinary welded tube weighs.

3) The process offers a great advantage in that the metal can be watched in its various stages of manufacture; the strains it undergoes can be followed with the help of suitable apparatus, and action taken if necessary in order to adjust the pressure of the reinforcement required so as to obtain the best nominal conditions.

4) Finally, the manufacturing process supplies all the tests required to check the results obtained.

When the operation has been concluded, the self-reinforced tube is a guarantee of strength equal to at least twice the working pressure aimed at because this guaranteed pressure has made its production possible.

The pressure tests made after erection will thus be required only for controlling the leakproof properties of the joints assembling the various tubes.

5) As a matter of fact the self-reinforced tubes might be compared to weldless tubes, that is, they are very robust.

Consequently, their use for pressure piping has proved to be very great when their calibre exceeds that of unwelded tubes, and also in cases where ordinary welded tubes are not strong enough or require such thickness that they would be eliminated by considerations of weight or manufacturing problems.

The main operation of manufacture of the self-reinforced tubes is thus seen to be that of strengthening, a process which at the same time constitutes a hydraulic test at a pressure which is at least double that of the maximum working pressure (static pressure plus overpressure).

The result is that the most important plant for the construction of self-reinforced tubes is a hydraulic testing press which can deal with large dimensions when pressure piping such as that of "La Bissorte" has to be manufactured.

A very important point on which we must insist concerns the control of the stresses in the material which can be effected thanks to the method of manufacturing self-reinforcing tubes.

Before applying pressure, a certain number of tensometers are placed on the rings, these tensometers being distributed uniformly along the length of the tube which is to be reinforced.

While the process of reinforcing ensues, the first thing to do is to record the pressure when bringing the wall into contact with the rings, then the tension of the rings under increasing pressure up to the pressure of reinforcement, then under decreasing pressure to the working pressure, then again under the reinforcing pressure and under the operating or working pressure and finally, with the pressure at nil, so as to control the degree of tightening of the rings on the wall.

While these operations are proceeding, the pressure of reinforcement calculated as necessary to carry out the nominal tensions can be corrected in good time.

This control, effected during the process of manufacture or when systematic experiments are being carried out, has shown that the real stresses correspond with the nominal ones very satisfactorily and it proves that a very wide margin exists between the limit of elasticity of the reinforcement rings and their maximum tension as a result of the reinforcement pressure.

The wall of self-reinforced tubes is generally made of extra mild steel having the following coefficients:

Tensile strength	$\geqslant$ 34 kg/mm^2
Limit of elasticity	$\geqslant$ 19 kg/mm^2
Longitudinal pull	$\geqslant$ 30 %
Mesnager notching action . .	$\geqslant$ 7 kg/cm^2
Permissible stress	8 kg/mm^2

or of special very ductile steel with the following coefficients:

Tensile strength	$\geqslant$ 54 kg/mm^2
Limit of elasticity	$\geqslant$ 36 kg/mm^2
Longitudinal pull	$\geqslant$ 20 %
Mesnager notching action . .	$\geqslant$ 7 kg/cm^2
Permissible stress	12 kg/mm^2.

In the first of these cases, the reinforcement rings were made of treated steel with the following mechanical properties:

Tensile strength	$\geqslant$ 90 kg/mm^2
Limit of elasticity	$\geqslant$ 60 kg/mm^2
Longitudinal pull	$\geqslant$ 8 %
Mesnager notching action . .	$\geqslant$ 4 kg/cm^2
Permissible stress	24 kg/mm^2

and in the second case they were made of treated special steel having the following properties:

Tensile strength	$\geqslant$ 115 kg/mm^2
Limit of elasticity	$\geqslant$ 95 kg/mm^2
Longitudinal pull	$\geqslant$ 6 %
Mesnager notching action . .	$\geqslant$ 5 kg/cm^2
Permissible stress	36 kg/mm^2.

The average fatigue strength of a self-reinforced tube calculated in proportion to the total section of the wall and the reinforcement ring is 16 kg/mm^2 in the first case, and 24 kg/mm^2 in the second. This means that a tube made in this way has a weight which is half that of an ordinary tube whose resistance coefficients would be 8 and 12 kg/mm^2 respectively.

The advantage of using self-reinforcing tubes is not limited solely to pressure piping with a very high head of water, for experience has shown that it is an economic proposition to use them from the time when maximum working pressure reaches 320 metres, but that their limit of utilisation is far wider in certain specific cases and also when the question of safety is of very special importance.

Besides the saving made on the initial cost when self-reinforced tubes are used and the great security they offer, these self-reinforced tubes have another advantage for those who operate hydro-electric works.

This appliance offers, in fact, the advantage of reducing considerably the hydraulic recoil owing to the large diametral expansion of the tubes under the effect of internal pressure consequent upon the degree of fatigue strength that can be admitted for the metal of which it is made.

As a matter of fact the hydraulic recoil depends on the speed or velocity of wave propagation and diminishes with the value of the latter.

The velocity in the case of steel tubes has the following coefficients:

$$a = \frac{9.900}{\sqrt{48.3 + 0.5\,\frac{D}{e}}} \quad \text{now: } \frac{D}{e} = \frac{2R}{p} \quad \text{therefore: } a = \frac{9.900}{\sqrt{48.3 + \frac{R}{p}}}$$

taking for instance:

— internal pressure: . . . $p = 1000$ m of water or 1 kg/mm^2
— degree of fatigue strength: $R = 8$ kg/mm^2 for ordinary tube,
$R = 16$ kg/mm^2 for self-reinforced tube.

In the first case: $a = 1320$ metres and:
in the second case: $a = 1230$ metres,
which confirms what has just been stated.

The self-reinforced tubes which constitute the larger part of the pressure piping of "La Bissorte" were constructed of gas welded tubes. In order to

Fig. 4.
Armoured portion of entering inclined gallery at level 1220.

obtain great homogeneity at the time of self-reinforcing, the precaution was taken of making each tube with sheet metal belonging to the same casting.

While self-reinforcing proceeded the rings and welds were hammered vigorously.

On the other hand, for a certain number of tubes, measurements on wall and rings were effected from a pressure starting at nil to the reinforcement pressure and inversely by aid of Huggenberger tensometers. By this means it was possible to verify that the real and nominal resistances were in line.

At the time of reinforcing, strong calibration plates were fitted to the ends of the tubes and thus perfectly calibrated elements were obtained and the machining could be done along lines of repetition work without final touching up of the plates of the couplers fixed to the ends of the tubes.

The plates at the ends of a certain number of tubes were welded to these with the electric arc, and additional pressure tests were carried out to ensure the leakproof properties and soundness of these welds.

Painting in the workshops.

Before despatching the tubes they were brushed, the slag was removed and they were then tarred inside and out while in a hot state.

Before tarring was effected, the tubes were heated with powerful gas blow-pipes at a temperature of about 80^0, and then plunged into a large tank of tar previously raised to the same temperature. When taken out of the tank they were found after the tar had dripped off them to be impregnated with a protective coat of tar which adhered very closely to the tube.

Inspection.

The inspection of the manufactured tubes was carried out on the one hand by the Contractor's Permanent Checking Department, which was responsible for effecting this control during manufacture by cutting off sample test pieces, checking the welds, applying hydraulic tests and verifying the dimensions, while, on the other hand, intermittent checking was effected by another Department under the Superintendent of the work.

Each tube was stamped and a report drawn up on the results of the inspection; particular attention was paid to the hydraulic pressure.

Hydraulic test.

The hydraulic test which is the main operation in the manufacture of self-reinforced tubes is the most important operation in the revision and inspection of pressure piping, since it determines the minimum coefficient of practical safety.

All the tubes of the pressure piping at "La Bissorte" have been tested for double the maximum pressure (static pressure plus overpressure) that they have to withstand when in commission.

To that end a "hydraulic test pressure" of 3 500 tons[1] capable of testing tubes up to 3 m diameter and 13 metres in length was used.

We have already explained how the hydraulic test was carried out at the same time as the self-reinforcing operation for the self-reinforced tubes.

When testing electric arc welded tubes or water gas welded tubes, the pressure was raised in the first place to double the maximum working pressure and kept there for a minute, then lowered to the working pressure at which the welds were thoroughly hammered; after that the testing pressure was maintained for at least five minutes.

The finished tubes were then taken to the site by motor lorry and in such quantities as were required for erection.

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[1] The load of 3500 tons corresponds to the hydraulic thrust on the press rams in the course of tests made with that portion of tubes below 264 kg/cm^2.

Erecting the tubes.

The first and most important of the problems to be solved in order to carry out the work of erection satisfactorily was that of transporting the tubes to the final site; here the weight of the various parts, the uneven ground over which they had to be transported and the very steep gradient of the slope, to which must be added the presence of the bends in a horizontal position and the inclined galleries presented great complications.

The following was the solution selected:

Transport by overhead cable of all the elements for the region lying between levels 1030 m and 2015 m, and in addition to this special plant was provided for lowering the tubes for each gallery in this zone.

Transport on an inclined plane of the elements in the region situated between levels 945 m and 1030 m.

No special difficulty was encountered when erecting the section situated just below that just mentioned, because the slope was a gradual one and access therefore easier.

The programme depended on the following factors:

- the transporting capacity of the overhead cable;
- need for carrying out simultaneously the laying of the piping and the civil engineering work;
- impossibility of increasing the shifts on account of risks of accident.

The work had to be divided into two sections.

The first included that carried out in the region between 1030 m and 1650 m and the section between the power house (inclusive of the collector) to the third anchorage block.

The second section was not so heavy, and it was here that the work was terminated by joining the pressure piping on the low gradient to the three turbines.

The erection work was started at four places, but work preceeded simultaneously on two out of four at most; when work was checked or there was a breakdown on one section, operations were at once continued on one of the others. This method proved necessary in particular whenever a gallery was entered or working shifts and masons had to relieve one another.

From the time erecting was started an initial experiment was made with hydraulic pressure on one of the first sections laid and rivets made on the site capable of meeting a normal working pressure of 100 kg/cm^2 were tested for leakage.

A second test, this time more exhaustive, was made after all the self-reinforced tubes (the collector included) had been erected, in other words, the whole section from the power station (level 936.7 m) to level 1715 m.

These tests aimed in the first place at verifying that the joints were leakproof and then of controlling the strength of the pressure piping and the anchorage blocks when subjected to the maximum pressures which the piping would have to stand in the long run.

The pipe line was first filled by little streams of water from above; pressure was increased by means of an electropump set up in the power station; this delivered the water direct to the collector. Pressure gauges were placed at the two ends of the section under test.

On the first day pressure reached 115 kg/cm² in the collector, then on the second day 124 kg and on the third 132 kg. At that time the pressure registered by the manometer placed on the upper part was 54 kg/cm².

As compared with the static pressure the over-pressure induced in the section under test was 15% in the collector and 50% in the upper part.

The test, which was a very severe one, in particular for the upper parts of the section tested, gave rise to no observations. Thanks to the tests it was possible to ascertain that the joints and rivets were all perfectly leakproof and that the clamping blocks, when subjected to very high stresses, stood absolutely firm.

As soon as erection had been completed the piping was cleaned and then given a coat of bituminous paint.

The inside paint which had been passed at the Works but damaged during erection was touched up; those parts which were exposed to the air were given a coat of paint and two coats were given to the parts inside the passage.

The lower part in the neighbourhood of the power station was furthermore given an additional coat of aluminium paint.

In October 1934 the whole plant was ready to be put in commission and the hydro-electric works started working in May 1935, from which time it has given ample proof of the beneficial effects of its well regulated power.

Summary.

The plant at the Bissorte Falls, which consumes a volume of 7.5 m³ under a head of 1150 metres, develops energy to the extent of 100,000 h. p.

It consists of one single turbine pipe line having a diameter of 1.3 m at the base and 1.8 in the upper part.

3,800 tons of steel were used to construct this turbine pipe line, which has a total length of 3.037 metres. It feeds three turbines of 34,700 h p. each.

When work is normal the tubes of the lower part are subjected to a maximum pressure of 132 kg/cm².

Thanks to the introduction of self-reinforced tubes into the design, this pipe line has been constructed in such a way that it offers perfect guarantees from the point of view of design and execution, together with very great advantages from the economic point of view.

The self-reinforced tubes consist of cylindrical tubing and reinforcement rings, these latter have an internal diameter which is slightly greater than the diameter of the tube in question.

In order to ensure the rings being a tight fit on the tubes, the process applied is not the hot one as that would eliminate the possibility of using treated high tensile steel for the rings, but a process carried out while metal is in the cold state, namely, by extending the wall obtained by applying a certain pressure, called "reinforcement pressure", to the inside of the tube.

The advantages of this process of self-reinforcement are many:

1. The permanent deformation to which the tube is subjected does not deprive the latter of any of its good characteristics; on the contrary, it endows it with new qualities inherent in self-reinforcement.
2. The self-reinforcing pressure required so that the tube may become self-reinforced constitutes at the same time a very severe resistance test. By one and the same operation the tube is manufactured and controlled at a pressure which is at least twice its maximum working pressure.
3. Controll of fatigue strength of the metal can easily be effected by help of appropriate appliances.
4. From the point of view of saving, the reduced thickness of the wall and the use of unwelded reinforcement rings made of steel treated to resist high pressures allows of reducing the amount of metal required, that is, of weight, very considerably.
5. With this type of tube the hydraulic recoil is greater reduced.

A large number of pipelines have been constructed with self-reinforced tubes, among them being the following:

Les Sept-Laux	(1050 metres)	
Le Lac Mort	(625 metres)	
Le Vintrou	(276 metres)	diameter of 2.00 m
Escaldès	(492 metres)	
Eylie	(1040 metres).	

La Bissorte was put in commission in May 1935 and has confirmed the excellence of this new technique applied to turbine pipe lines and devised by M. Georges Ferrand, Delegate-Member of the Board of the Dauphiné Company for Investigation and Erection, at Grenoble.