# PROPERZI UPDATES THE CCR (CONTINUOUS CASTING & ROLLING) TECHNOLOGY WITH NEW ROLLING STANDS

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Dr. Eng. Carmelo Maria Brocato
Continuus-Properzi S.p.A., Via Cosimo del Fante 10, Milan 20122, Italy

**Abstract**

CRU reported that some 10% of world aluminium production in 2006 was converted directly into wire and rod products – equivalent to 3.4 million mt. As the technology of rod production has evolved to include electrical conductor (6xxx and 8xxx series), low tensile 1370 H8 and complex mechanical alloys, it has been determined that the quality of the rod is improved by making higher area reductions in the first rolling stands. The Properzi three-roll concept results in a nearly perfect balance of lateral spread and longitudinal displacement of the metal during each reduction step. This concept is achieved by a Roughing Mill and a Finishing Mill operating in tandem. All Properzi Finishing Mills are of traditional three-roll construction using rolling rolls of 270mm or 180mm. This paper illustrates the current state of the art of the rolling technology in response to the specific requests/needs of the wire industry and how the use of new rolling stands improves the quality of the rod.

## 1. Preamble

According to Metal Bulletin and other prominent journals of the Aluminium Industry, the worldwide production of aluminium in year 2007 was in the range of 38,000,000mt. The previous year 2006 was some 33,900,000mt. The analysts are comfortable in thinking that the expected trend can be 40,000,000mt in 2008 and over than 42,000,000mt in 2009 (source MBR –Primary Aluminium & Alumina Monthly).
According to ALCOA (Source – paper presented at CRU Wire and Cable Conference June 11, 2007) the portion of aluminium converted into rod was some 3.4-3.5 million of mt in year 2006. During the same year, demand for aluminium rod in North America and Europe was over 1.2 million mt/year. China's aluminium rod demand was over 1.6 million mt/year.
Aluminium rod is produced all over the world and is considered a commodity. In other words, a product which is quoted on the Metal Exchange Market, with standard characteristics, ruled by competent authority ASTM or EN and practically constant price worldwide, depending on : "demand v/s offer".
Continuus-Properzi of Milan-Italy is the originator of the continuous casting and direct rolling of non ferrous metal and is still the major supplier of equipment for producing non ferrous rod (aluminium, copper, zinc, lead).

## 2. Characteristics of the Rod

Nowadays, the rod users are accustomed to "handle" the rod with a nominal diameter of 9.53mm. In some countries, especially in India, there are several producers who supply rod of 7.6mm. Other diameters of commercial interest/use are 12mm and 15mm, and larger diameters such as 18mm and 25mm. The aluminium rod is supplied in coils. There are two main categories of available coils.

a) The <u>tight coils</u>, which are produced when the line is equipped with Automatic Twin Reel Coiler. The rod is coiled loop by loop by means of the torque control of the coiler motor.


**Figure 1 – tight coil**

The coiler motor is synchronized with the rolling mill motor so as to have a mechanical constant parameter of the rod.

Aluminium coils reach a weight of 2,000kg-2,500kg. In some countries, especially North America and Canada, there are some Properzi rod lines equipped to produce jumbo coils of 3,800kg. The coils are supplied PET or steel strapped, with or without plastic cover.

b) The <u>loose coils</u>, which can be either concentric or orbital (rosette type). They are obtained in two different ways with or without a loop-forming pipe.

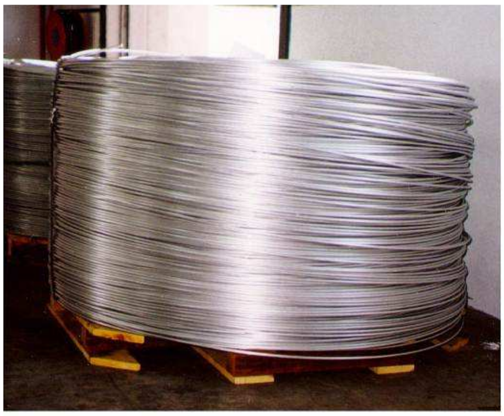


**Figure 2 – loose coil**

<u>Without loop-forming pipe</u> – Loops are naturally formed by effect of the force of fall; the diameter variation is obtained by modifying the height of the loop exit.

<u>With loop-forming pipe</u> – This method is similar to orbital coils but with fixed pallets, concentric to the loop-forming axis.

Orbital Coils

Coils are obtained by laying loops made by a rotating loop-forming pipe, synchronized with the rolling line, which lays the loops on a suitable rotating pallet having an axis of revolution different from the one used to form the loops (axis eccentricity).

Such coils can reach a weight of 2,000kg (exception made for very few customers who produce coils of 4,000kg which are delivered to the final customers very near to the factory).

In principle, we can say that loose coils have better attitude to be de-coiled, but lower attitude to cope with long transportation, as compared to tight coils.

The following paragraph disserts about the various commercial uses of the aluminium rod.

## 3. Commercial Uses of the Aluminium Rod

Table I summarizes the most common commercial applications of the aluminium rod, worldwide.

**Table I**

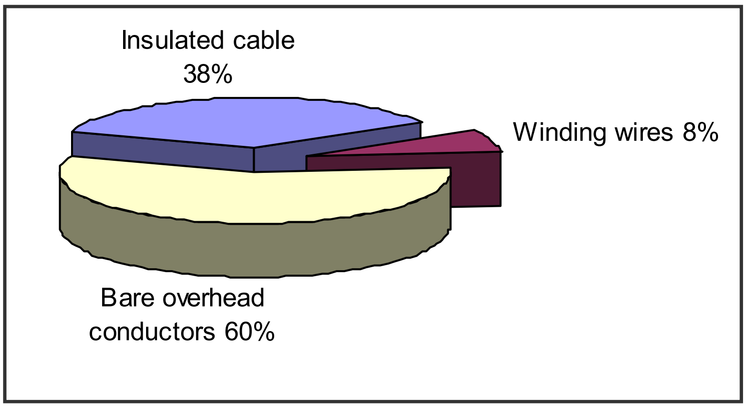
| | |
|---|---|
| Welding Wire | 4043, 4047, 5154, 5356 |
| Zipper Wire | 5056, 5086 |
| Fasteners | 5052, 5056, 5086, 6061, 6063 |
| Insect Screen | 5056, 5154 |
| Rivets (Non-Aircraft) | 1050, 5052, 5056, 5086, 5154, 5754, 6061 |
| Eke/Conductors Alloy Wire | 1200, 1350, 5005, 6101, 6201, 8175, 8176 |
| De-ox | Pure aluminium >96% Purity |
| Tie And Utility Wire | 1100, 3105, 5052, 5056 |
| Screw Machine Stock | 2011, 2017, 2024 |
| Nails | 5056, 6061 |
| Fence | 3003, 3105, 6061 |
| Antennas | 5052 |
| Impact Extrusion | 1050, 3003, 6063, 6061 |

The vast majority of the produced rod (some 80%-85%) serves for the electrical applications (cables and conductors), while the balance quantity is devoted to the so-called mechanical applications, ranging from the welding wire through the de-ox and others.

Let's focus our attention on the rod used for the electrical applications.

This portion can be further divided in the following sub-systems:

**Table II**




- Insulated cable 38%
- Winding wires 8%
- Bare overhead conductors 60%

There are two major projects that will give a remarkable boost to the wire industry during the next coming years. These two projects are:

a) The Arab Grid Project, which foresees the interconnection of GCC Countries with Libya, Tunisia, Egypt and Jordan.

b) The Electricity Act, which will involve the realization of some 60,000km of cables, for bringing power to all the villages of the vast territory of India. The implementation of this project has already started.

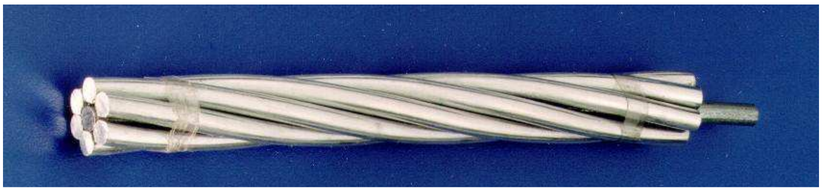


**Figure 3 – basic ACSR**

The figure 3 represents a very basic ACSR (Aluminium Conductor Steel Reinforced) conductor, where a certain number of aluminium wires (rod drawn in the drawing machines) of diameter 2.7mm or 3.2mm are stranded around a steel core. Therefore, the rod supplied must be capable of further transformation (reduction in diameter in drawing machine and twisting in stranding machine) and above all must be capable of transporting the electric power.

**Figure 4 – pylon and wires under snow**

Corrosion resistance and mechanical strength are requested for a reliable exercise of the power line. Figure 4 shows for instance a pylon and wires subject to the load of snow.

The continuous improvements of Properzi CCR (**C**ontinuous **C**asting & **R**olling) lines have allowed the cable and wire industry to use more and more sophisticated raw material (the rod) and produce lighter and stronger cable with better conductivity.

The following paragraphs analyze more in detail the needs of the cable industry and the current state of the art as well as the improvements made in our CCR lines to satisfy the wire and cable producers' needs.

**4. The Electric Power – An Expensive Utility**

It is commonly well-known that the electric power is generated in power stations that can be thermoelectric or hydro and then is transported and distributed trough the wire network. During the years, the industry has worked towards the minimization of the power loss associated to the power transportation and the increase of the intensity of current per square mm of cable and conductors.

If we consider a single conductor the power loss is completely transformed into heat according to the Joule Law, expressed by the following equation:

i) $P = RI^2$

Where:

- P is the dissipated power expressed in [W]
- R is the resistance of the conductor depending on material, length and shape, expressed in [Ω]
- I is the current intensity expressed in [A]

Yet, the resistance R depends on several parameters according to the equation:

ii)$R = \rho \, l/s$

Where:

- $\rho$ is the resistivity of the material [$\Omega mm^2/m$] -
- l is the length of the conductor [m]
- s is the cross section area of the conductor [$mm^2$]

For many years, the power transmission lines have been designed using ACSR (Aluminium Conductors Steel Reinforced) considering an average of 53-55% on copper (the reference international annealed copper standard has a conductivity equal to 100 IACS). The big overhead wires were composed of pure aluminium, but due to the poor tensile strength of the pure aluminium, it was necessary to use an internal core wire steel made for the mechanical properties, and of course, the active strand was aluminium made.

This system presented two big disadvantages: a) High weight per A/h transmitted; b) Serious problem of corrosion.

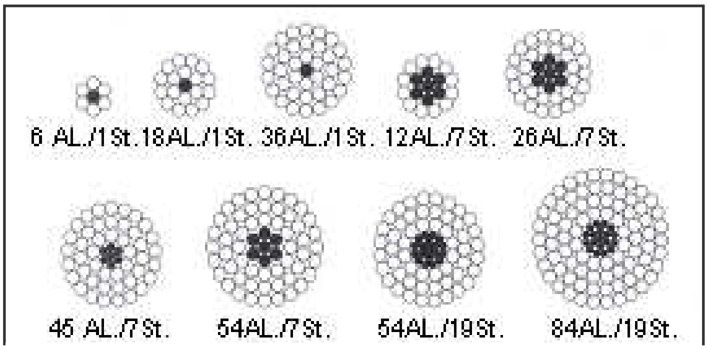



**Figure 5 –types of ACSR**

After the first Oil Shock (Kippur War – 1973) the cost of energy has grown dramatically and therefore the cable industry has become more conscious about the cost of energy loss, looking for new materials and new strategies. At the same time the growing demand of power has imposed the optimization of the power transmission on the existing infrastructure.

For such considerations the main parameters are the temperature of the conductors and the mechanical stresses of the wire. They determine the existing reserves in transmission capacity limited by the maximum allowed temperature of the metals and the critical sag and ground clearance. The new strategies of the wire and cable industries are reflected in the maximization of the transportable power on existing infrastructures or the minimization of the necessary number of pylons in case of the lines. The above inputs have found three main different follow-up:

a) development of new alloys reflecting the best compromise between tensile strength and conductivity. This is to realize AAAC (All Aluminium Alloys Conductors) in a way to eliminate the heavy steel core from the conductors. The wires have an almost double tensile strength as compared to pure aluminium and a satisfactory conductivity, having the resistivity higher by about 10% than pure aluminium. Some of the most used alloys are:

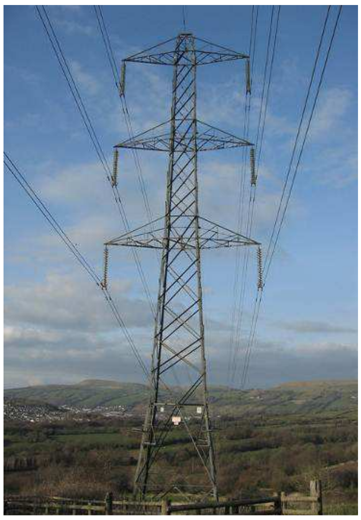


**Figure 6 – pylon tower**

AA6101 Rod with conductivity up to 53% IACS, and UTS (Ultimate Tensile Strength) up to 220 $N/mm^2$.

AA6201 Rod with conductivity up to 52.0% IACS, and UTS up to 300 $N/mm^2$.

AA5005 Rod with a minimum conductivity of 53.8% IACS, and UTS up to 200 $N/mm^2$.

AA8017 Rod with a minimum conductivity of 58.5% up to 60.8% IACS, and UTS up to 140 $N/mm^2$.

b) development of new alloys resulting in SAG resistant conductors. Alloys of Mg and Zr.

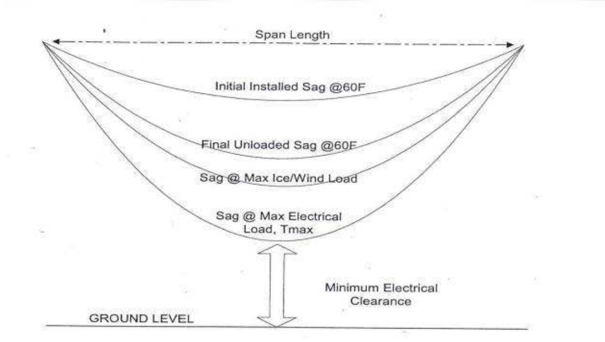



**Figure 7 – SAG development**

TAL, ZTAL, XTAL.

These alloys are applied in steel reinforced overhead line conductors, allowing the line capacity to be increased by 50 to 100%. Depending on the alloy, the maximum allowable temperatures are between 150°C and 230°C. Peak temperatures may vary between 180°C and 310°C. These conductors have a limited sag effect compared with others.

c) use of AA1370 in H8 temper (soft wire) for the manufacturing of conductors type ACCC (Aluminium Conductors Composite Core). The conductor consists of a carbon fiber wire with a typical tensile strength of 1500 $N/mm^2$, around which aluminium wires are wound. In order to optimize the filling of the apparent cross section area of the conductor, the wires are profiled instead of having a circular cross section area. ACCC conductor can significantly increase the capacity of an existing power corridor without requiring the necessary modifications to existing structures, as would be necessary if a larger conventional cable was used to increase the required capacity.

**Figure 8 - ACCC**

## 5. Recent Improvements on Properzi Rod Production Lines

In the previous paragraphs we have seen that the wire and cable sector is more and more demanding, and that the improvements in the casting and rolling lines have allowed the wire and cable industry to explore the boundary of new applications. While it was quite easy to produce (commercial) pure aluminium rod, the production of aluminium alloy rod requires the best advanced machinery, starting from the furnaces down to the coiler, and high technical know-how.

The most remarkable improvements realized to achieve a high and repeatable quality of the rod are identified in the following areas:

### 5.1 Metal Treatment and TiBAl Feeder

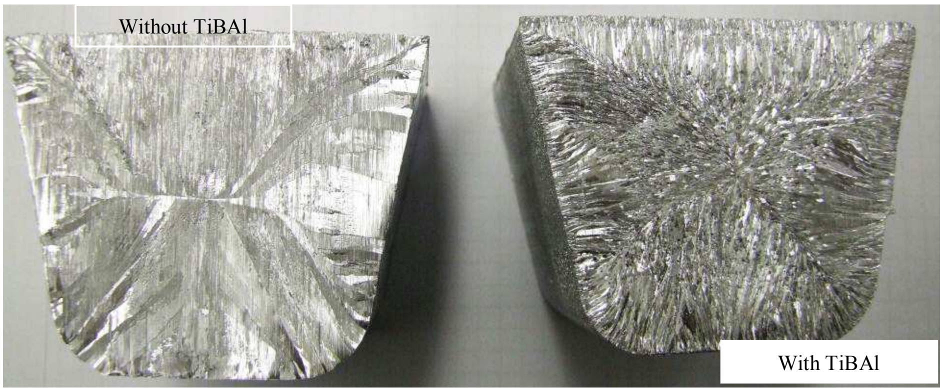



**Figure 9 – cast bar cross section area**

The in line filtering and degassing system, blowing Nitrogen or Argon as a mechanical mean to reduce the Hydrogen content, allows to reduce inclusions content and hydrogen content in such a quantity that it does not affect the drawing operations down to the smallest diameter.

For producing quality rod it is also important the system to inoculate the fine refining means, commonly known as TiBAl, especially when the final product is AA 6xxx (Al-Mg-Si) or AA5xxx (Al-Mg).

Figure 9 shows a cast bar produced with the same casting machine processing molten metal not treated with TiBAl (left-hand side) and processed with TiBAl (right-hand side). It is quite evident, considering that the produced rod will subjected to heavy mechanical stress in the subsequent drawing operations, that as finer is the grain size as better is the mechanical behavior of the rod in the drawing operations.

**5.2 Improvements on the Casting Machine – Casting Parameters Easily Repeatable**

The casting machine is the heart of the rod production line. The liquid metal is solidified in the casting wheel in a shape of a continuous cast bar that is then processed into the rolling mill down to the requested diameter of 9.5mm, or 12mm, or any commercial diameter foreseen in the rolling sequence. The casting wheel can be seen as a rotating heat exchanger where the liquid metal is quickly solidified inside the rotating continuous mold, under the effect of the cooling water distributed, in a controlled and repeatable manner, by a series of adjustable and calibrated spray nozzles placed externally to the casting wheel throughout an arc of 210°. One directs cooling water to the bottom of the rotating ring mould, a second row of nozzles directs the cooling water flow to the steel belt and two additional rows of spray nozzles direct their cooling water onto the outer sidewalls of the copper ring mould. When the CCR line is meant to produce complex alloys of 5xxx-6xxx or 8xxx series, the volume (flow) of cooling water to the spray cooling manifolds is controllable in its entirety, per each manifold, through self contained metering valves to provide very precise and repeatable control of the flow of the cooling means. Production variables, including casting wheel speed, flow of the cooling water in each manifold, emulsion flow in the rolling mill, in Properzi's most recent design and sophisticated wire rod plants are PLC/computer monitored and controlled, with the ability of adjusting these variables as per specific recipes for each grade of pure aluminium and aluminium alloy to be produced. All key components are connected to a data highway to allow for meaningful data acquisition. Space does not allow listing the various sizes of lines currently available or describe their diversity and different specialized applications. Basically, Properzi CCR lines sizes range from 1.3 ton per hour of 3.2mm wire or 9.5mm wire rod from a bar cross section of 800mm$^2$, to 15 tons per hour of 9.5mm to 30mm wire rod from a cast bar having a cross sectional area of 5,500mm$^2$.

**Figure 10 – casting machine**

**5.3 Improvements in the Rolling Operations – The Rolling Train**

The quality of the produced rod also depends on the distribution of the reductions per pass adopted in the rolling mill. High reductions by 28% ~ 33% in the cast bar area in the first stands of the sequence, while the bar is more hot and malleable, remove all visible traces of bar internal porosity. Roll stands making a traditional area reduction of 20% ~ 25% followed in-line to produce whatever final rod diameter was required. For this reason the rolling mills of middle and high capacity of the last generation are made up of two rolling mills operating in tandem: one first section made up of a sequence of two-roll stands (up to five stands) to perform the high reduction mentioned above, and one second section made up of the traditional Properzi three-roll rolling stands, giving the classic Properzi triangle/round deformation sequence.

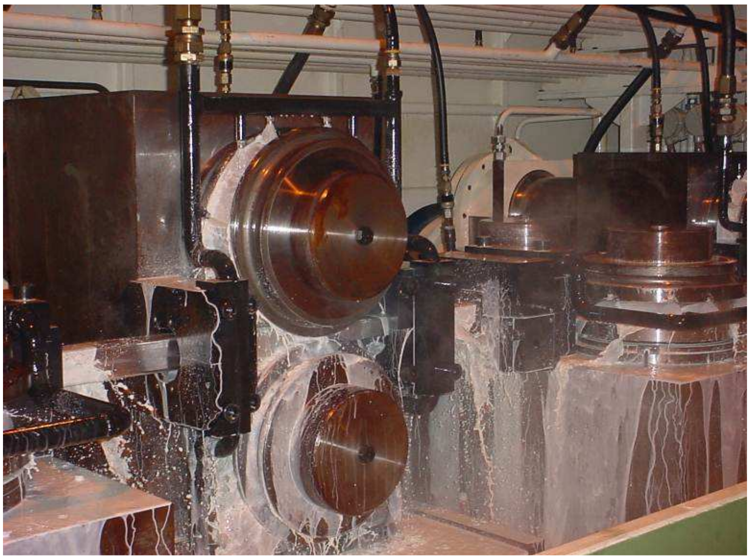


**Figure 11 – roughing mill**

The stands of the first section (roughing mill) are individually driven by variable speed motors, while the stands of the second section (finishing mill) are actuated by one variable speed motor only. The combination of two rolling mills operating in tandem, in perfect synchronization, has been possible thanks to the tremendous advances in electrical controls.

The correct calibration of the rolls of the finishing mill, actuated in a repeatable way with the use of dedicated optical projector, allows excellent results in terms of roundness of the produced rod. The three-roll concept results in a near perfect balance of lateral spread and longitudinal displacement of the metal during each reduction step. The three-roll rolling mills have two different sizes of stands. The mod. 9 stands have working rolls with a theoretical diameter of 270mm, while in the mod. 9N stands the working rolls have a theoretical diameter of 180mm. Properzi is presently designing new stands where the rolling rolls shall have a theoretical diameter of 230mm approximately, with the aim of replacing both the mod. 9 and the mod. 9N.

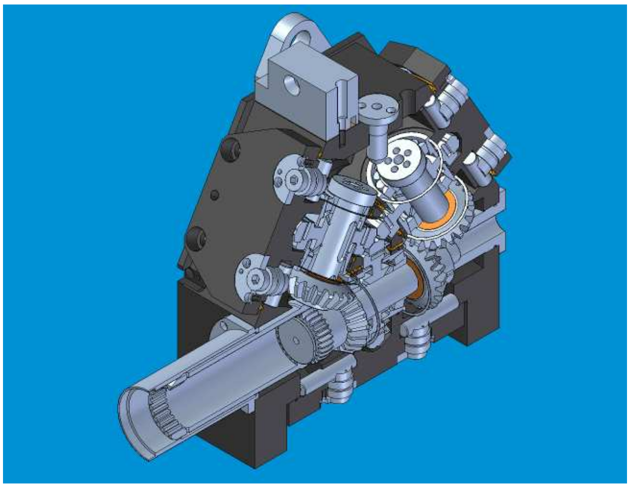


**Figure 12 – view of mod. 9N stand**

**5.4 Improvements in the Coiling Operations**

The quality and the geometry of the coil influence the subsequent unwinding operations and therefore the possible drawing speed. Researches and efforts have been done to develop a coiler able to:

- wind the rod with a minimum possible tension
- have repeatable control of the loops layering

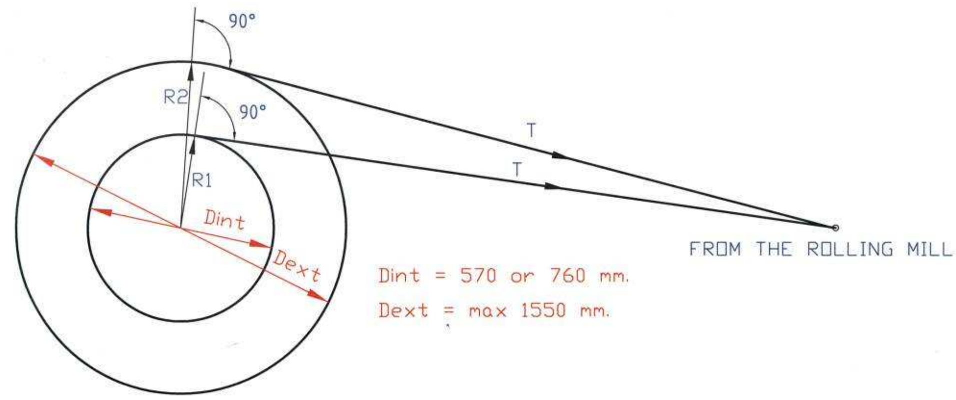



**Figure 13 – indicative scheme of the reel**

During the coiling operations the temperature of the rod ranges between 150 and 80°C depending on the alloy being cast. The lower is the winding tension, the lower are the changes in rod diameter. We have achieved the very low tensioning of 10 ÷ 20 N/mm$^2$ during coiling. Looking at figure 13, it is quite evident that while the winding the coil goes from a radius $R_2$ up to the final diameter $R_1$. Since the tension applied to the rod, $T_1$ shall be always equal to the tension $T_2$ it comes that:

$Mf = T_1R$ (Mf is the torque applied to the reel expressed in [Nm]; T is the tension applied to the rod, expressed in [N]; R is the radius of the coil, which grows during the coiling operations. It is expressed in [m] ).

Therefore the torque of the motor shall be automatically reduced once the diameter of the coil increases due to the addition of further loops. Also the angular speed of the reel is automatically reduced once the diameter of the reel increases, since the speed of the incoming rod (speed of the mill) is constant.

The following equation, summarize this concept:

$$Mf = T1\ V/\varpi \longrightarrow Mf\ \varpi = Cost.$$

($\varpi$ is the angular speed of the reel expressed in [rad/s], V is the rectilinear speed of the rod exiting from the rolling mill expressed in [m/s])

The above equation reveals that the reel of the coiler shall be accurately controlled in power. The absorbed power of the motor of the reel shall be theoretically constant. We have presently neglected that weight of the reel increases during the coiling operations.

**Figure 14 – view of an automatic twin reel coiler**

A new electric fleeter system is proposed to obtain coils with higher precision, composed by well aligned loops. The fleeters' movement is powered by brushless motors and the type of winding (even or random) can be selected directly in the HMI of the machine. Each finished coil can have a standard weight of 2-2.5mt. For reducing the handling operations the large size machines are equipped with automatic strapping and automatic unloading of the reels.

**6. Conclusions**

The many above mentioned successful achievements have resulted in improved quality on a repetitive basis as well as improved production costs for all aluminium and aluminium alloy wire rod produced.

The rod can be supplied in tight coils suitable for long transportation, but also in form of loose coils, and the process is monitored in all the critical phase to guarantee the repeatability.

The technology advances in casting, rolling and coiling allowed the wire industry to produce on industrial basis special alloys for a better and more efficient service of the power lines.

We continue to strive for even better quality, productivity and development of new aluminium alloy wire rod.

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