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HOT ROLLING OF STEEL – GENERATION 6.0*

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Abstract

Today we are talking about Industry 4.0, as the latest revolution of industrial processes and progress, considering that the steam engine (Industry 1.0), railways and cars, mass production in the 1920th (2.0), Industrial Automation (3.0), and finally integrated manufacturing, integrated communication, and internet (4.0) can be seen as the state-of-the-art situation in industry, nowadays. Similar to the Industry progress, we can approach the rolling process of material, which started about 150 years ago in a very basic way. Steam engine- and belt driven-mills were very operators' intensive, brutal and risky to operate. Mechanical improvements brought throughput, safety and quantity, as also quality of the products. The rolling of steel, in particular of rails, beams, rebar, strip (focus in this paper) and plate has enabled the large scale transport and travel, the building of bridges and buildings, the manufacturing of ships and cars. From single stands to continuous rolling trains the production and quality of mills increased significantly. From ingots and blooms to slabs, we have to admit a big jump in which has changed the face of the world significantly. Thin Slab Rolling has revolutionized the output and the throughput of rolling mills (Generation 3.0 to 5.0). Finally, Endless Rolling, has boosted the quality and quantity of rolling mill processes and permitted nowadays to enter in market niches which were not thinkable a decade ago. Mastering the automation and applying reliable systems (mechanical and electronically) of drives, actuators and sensors, as also communication and information interchange to all levels of automation are the success factors of such complex mills, we call herein after "Rolling Mills of Generation 6.0".

Key words: Hot rolling; Steel; Generations of mills; Generation 6.0.

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1 INTRODUCTION AND HISTORY - The Hot Strip Mill

David Landes in his path-breaking survey of technological innovation in Western Europe explained that: *"the wide strip mill was the most important single advance in iron and steel technology in the interwar period".*
In the American literature tributes to the WSM (wide strip mill) are more generous. In his multi-volume study of the American iron and steel industry, Hogan records: *"…the continuous strip mill was one of the greatest advances in steel making since the development of the open hearth process".*
Many authors emphasize the crucial enabling role of WSMs for the automobile industry. In 1963, Fisher in his *The Epic of Steel* emphatically wrote:

> *"…it was the automobile that led the way into the new America, which came into being in the present century. The motor vehicle evoked one of the steel industry's most important technological changes. Because of the universality of sheet steel, it has more to do than any other steel product – than any other manufacturing material – in creating the new America. Sheet steel was the magic carpet on which America rode to new adventures in living".* [1]

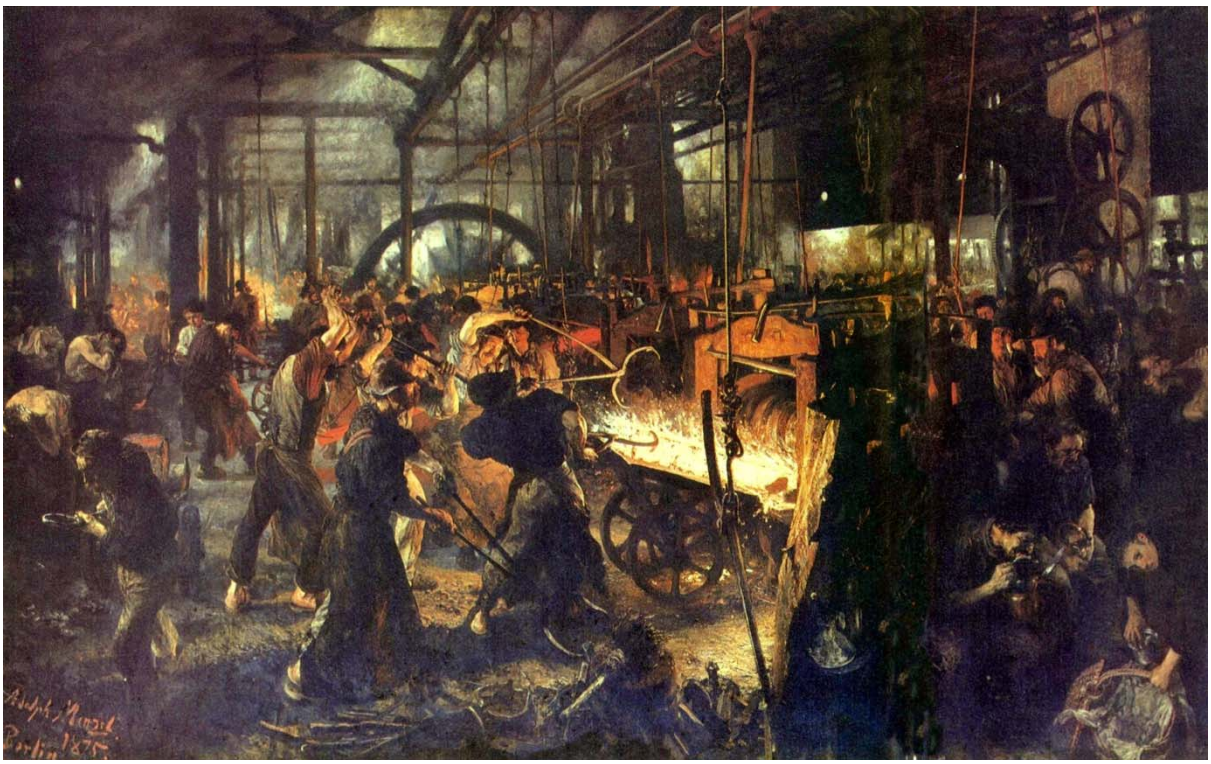


Figure 1: Historical Process Picture "DAS EISENWALZWERK" (Adolf Friedrich Erdmann von Menzel @ Berliner - Altes Museum / around 1875) during Industrial Revolution 2.0. and Rolling - Generation 0.0.

The continuous WSM was a shift from a simple to a "complex" technology. Steam driven hand mills were all of a piece: both the steam engine drive and the mill stands were made up of castings and simple machined moving parts.
An important innovation of this mill was the 4-high stand that allowed the work rolls to be small, supported by large diameter backup rolls – so that much greater reductions could be achieved on a single pass.

2 PROCESS TECHNOLOGIES (Generation 1 to Generation 5)

In order to be able to understand the trends in process technologies, it makes sense to take a look at the history of these technologies – in this case, the history of hot strip production.
In a paper at the Stahl Institut VDEh (Verein Deutscher Eisenhuetten) Stahl und Eisen Nr. 122 (2002), a group of authors describes 5 generations of mill types [2].

	Time Period	Operating Mode	Raw Material	Capacity Mio t/a	Thickness mm	Number of Finishing Stands	Automation	
Generation I	1926 - 1960	semi continuous	ingots slabs	1.5 - 2.5	> 2.5	6	hand / manual	 Youngstown USA
Generation II	1960 - 1970	semi continuous	ingots slabs	3 - 4	> 1.5	6	semi automatic	 Krupp Dortmund, GER
Generation III	1970 - 1980	fully continuous	ingot slabs continuous casting	5 - 6	> 0.8	7 - 9	semi automatic	 HSM Chiba No. 3, JP
Generation IV	1980 -	semi continuous "three-quarter" continuous	continuous casting	5 - 6	> 1.2	7	fully automatic	 Shagang HSM, China
Generation V	1990 -	CSP ISP Conroll DSC	thin slabs	1.5 - 2.5	> 0.8	5 - 7	fully automatic	 AK Mansfield, USA

Figure 2: Generations of Strip Rolling (Generation 1 to 5), summarized by VAI [3]

Casting and rolling are still de-coupled in all these 5 generations.

2.2 New Steel Grades

As a material, steel continues to have a high value – steel is modern. The development of steel grades has by far not yet reached its end. The market, together with its product requirements and competing materials, like for example aluminum, drive this continuous development.
Developments in the dual and multi-phase steels are worth special mention. Mill technologies accompany these developments. Sometimes, the plant builders also take part in the steel grade development, with the vision of building a “metallurgical perfect” mill.
It’s also worth to say that in the last 20 years the mechanical strength of hot rolled steel has doubled from about 300 Mpa to nowadays 600 to 700 Mpa as an average (for car material and HSS applications – mills).

2.3 High Product Quality

Hot-rolling mill managers face an increasing demand for high-quality products which will remain at a high level and will grow even further. Among these are the geometric properties, such as uniformity and replicability of width, thickness, profile and flatness. Surface properties are equally important, since damage to the hot-rolled

strip is permanent. Suitability of strip for automobile skin production is a step that is already determined in the hot strip mill.
Only future-oriented technologies we can meet such requirements. Mastering the process, the Automation the quantity and the quality are for sure the ingredients to build and to run such mills.

3 HOT STRIP MILLS - GENERATION 5 and 6.0

If we have a look to the new technologies, we have to admit that NUCOR and ARVEDI are the frontrunner in entering into new machinery and processes.
The "X"SP Rolling can be seen (more or less) as an endless process which refer to all the applied technologies on the market, such as CSP (**C**ompact **S**trip **P**roduction), ISP (**I**nline **S**trip **P**roduction), QSP (**Q**uality **S**trip **P**roduction) and ESP (**E**ndless **S**trip **P**roduction).
SMS, Danieli and Siemens VAI (nowadays PRIMETALS, which is a joint venture of MHI and Siemens) are the possible suppliers, but also Japanese companies are involved in these technologies (e.g. MHI).
Production of advanced steel grades are well described by "SMS´ 20 years of CSP®" and care about higher throughput, good quality to be competitive in a demanding market situation which require highest development towards sophisticated applications. It has to be said clearly, that the most successful continuous strip production of the fifth generation is by far the SMS' CSP process, with more than 30 installations worldwide. These CSP plants could set the standards regarding:

- mechanical properties
- surface sensitive requirements

SMS has further developed their CSP mills in endless mode [5], which we can attribute to Generation 6.0 in future.

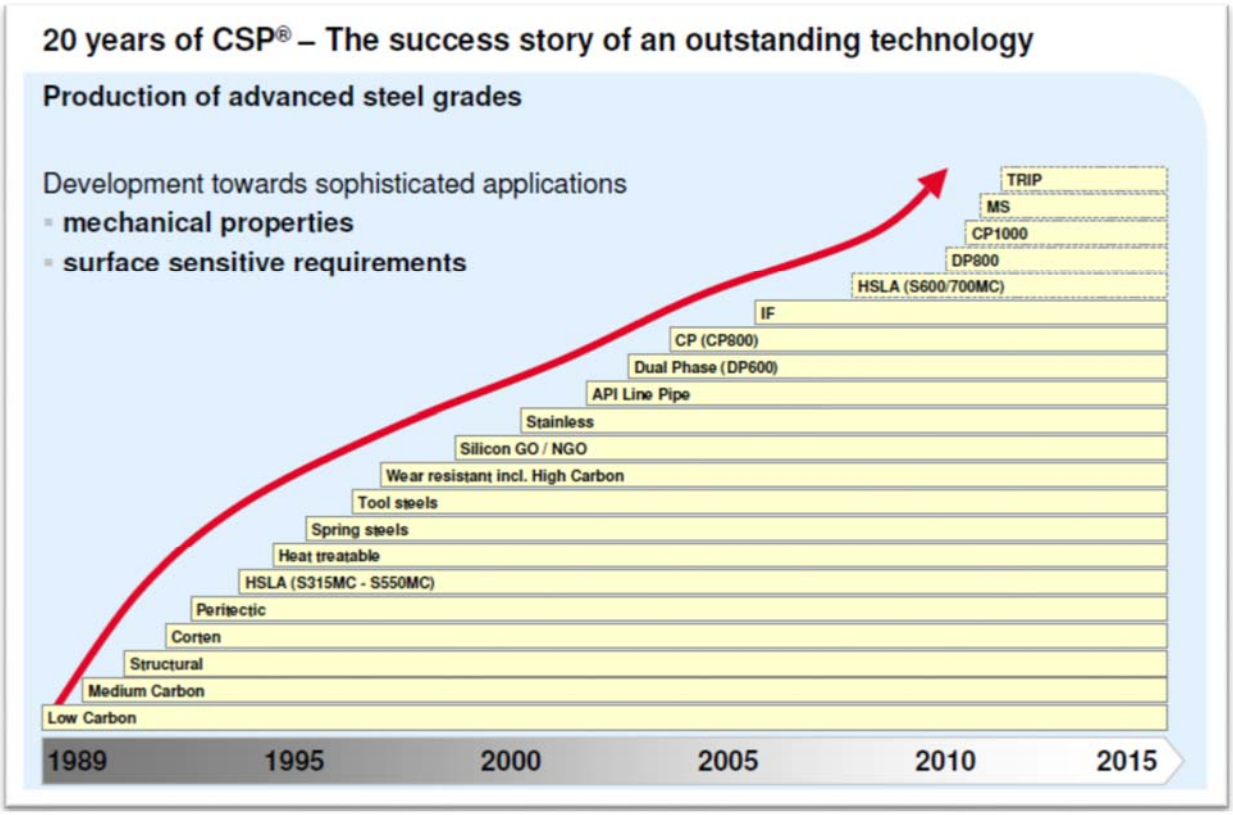


Figure 3: SMS CSP Development in the last 20 years [5]

To talk about modern hot rolling processes (Generation 4.0 to 6.0) we have to consider following methods of processing:

- Continuous rolling of normal slabs (200 to 250mm thick)
- Continuous rolling of thick slabs, up to 400mm (for higher grades, e.g. API grades, which need more passes to be applied)
- Continuous (batch or endless) rolling of thin and medium slabs (50 to 150 mm thickness) for highest throughput and good quality.
- Continuous Near-Net-Shape Casting and Rolling to achieve minimum times of processing, a reasonable throughput and good quality, e.g. Castrip® at Nucor / USA plants, and BCT (Belt Casting Technology) at Salzgitter / Germany.

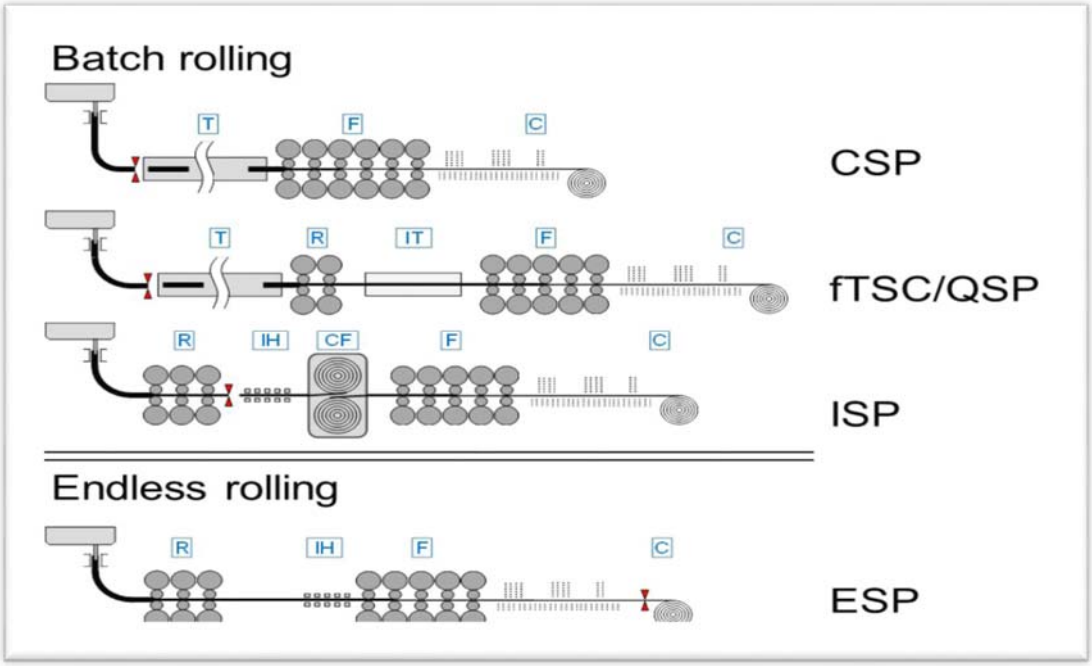


Figure 4: The evolution of the TSCR technology. The principal elements of the plant are defined as follows: C – cooling/coiling; CF – Cremona – furnace; F – finishing mill; IH – inductive heater; IT – intermediate treatment (heated transfer table or cooling); R – roughing mill; T – tunnel furnace.

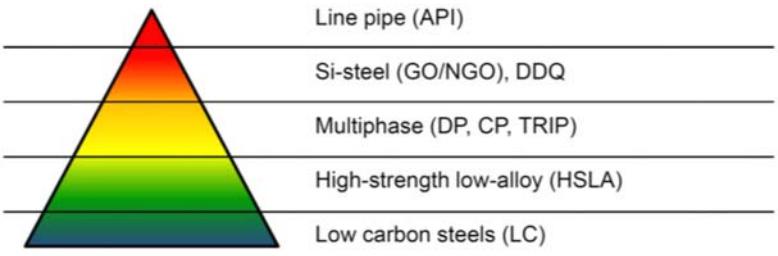
3.1 The Arvedi ESP Process for the Production of High Quality Steel Grades – Hot Rolling Generation 6.0

The indisputable ecological and economic advantages of TSCR (Thin Slab Cast and Rolling) technologies for the production of commodity steel grades are further multiplied by an increasing share of high quality steel grades in the production mix. HSLA steels, medium and high carbon steels as well as dual phase steels already have a share of more than 25% of the annual Arvedi ESP production in Cremona. TSCR processes in general and the Arvedi ESP process in particular have a high potential for the production of quality demanding steel grades like electrical steel, complex phase steel grades and line pipe steels (API grades).
In a quality pyramid for typical hot rolled strip steel grades, low carbon steels (LC) form the basis: they are relatively easy to cast at a high casting speed and the quality demands are limited to homogeneous mechanical properties and a homogeneous microstructure as well as a sound surface.
The quality demands for microalloyed LC steel grades (HSLA steel grades) are somewhat higher but still moderate: internal soundness becomes more important as the formation of coarse primary nitrides and carbo-nitrides in segregations has to be

avoided. The higher casting speed in TSCR results in a shorter time of the strand surface at elevated temperature and thus suppresses the precipitation of nitrides, carbides or carbon-nitrides along grain boundaries. For the Arvedi ESP process, the absence of a tunnel furnace shortens the time between meniscus and recrystallisation in the first stand of the high reduction mill to less than 4 minutes. The premature precipitation of Nb(C,N) is suppressed. The efficiency of microalloying elements is thus higher than that of other TSCR processes. Moreover, the use of Ti for the control of grain growth is unnecessary, which is an additional advantage with respect to the castability of steels.

A further interesting field of application of the Arvedi ESP technology is high-strength or ultra-high-strength multi-phase steels. In contrast with the ferritic microstructure of LC steels and microalloyed LC steels, multiphase steel consists of either ferrite/martensite mixtures (dual phase steels), a ferrite/martensite/retained austenite microstructure (TRIP steels) or ferritic/bainitic/martensitic structures (complex phase steels). Multi-phase steel grades have a higher carbon content and commonly also higher manganese and silicon content. In high-speed continuous casting the hypo-peritectic range is generally avoided, whereas hyper-peritectic (medium carbon) steels proved to be suitable for the TSCR process. In the Arvedi ESP process, the bow-type caster with funnel-shaped mould provides stable operating conditions. The high degree of deformation due to two-step rolling in the high reduction mill and finishing mill in the Arvedi ESP process provides excellent conditions for the homogenization of the microstructure in the hot rolled strip.

One of the most demanding flat products is line pipe steel for sour gas applications. The low content of residuals and tramp elements together with highest demands on the homogeneity of the product additionally challenges steel plants and rolling mills. The advantages of the Arvedi ESP technology regarding homogeneity and the precise adjustment of the mechanical properties have recently been reported. [7]



	Quality attributes						
	Cleanliness	Internal quality				Surface quality	
		Centre segregation	Hot tearing	Homogeneous mec. properties	Homogeneous microstructure	Defects*)	Surface Decarburizing
Relevance of process step for quality attribute							
Steel making	▲▲▲	(▲)				(▲)	
Continuous Casting	▲▲	▲▲▲	▲▲▲	▲	▲	▲▲▲	▲
Hot rolling	(▲)	(▲)	(▲)	▲▲▲	▲▲▲	▲▲▲	▲▲▲
Relevance of quality characteristics for product demands							
LC				▲		▲	
HSLA	▲	▲	▲	▲	▲	▲▲	▲
MP	▲▲	▲▲▲	▲▲	▲▲▲	▲▲▲	▲▲	▲▲▲
Si-steel, DDQ	▲▲▲	▲	▲	▲▲▲	▲▲▲	▲▲▲	
API	▲▲▲	▲▲▲	▲▲▲	▲▲▲	▲▲▲	▲▲▲	▲▲▲

*) cracks, oszillation marks, slag gripping, pinholes, blowholes

Figure 5: Quality pyramid for typical hot rolled strip steel grades

A breakthrough, which results in a new, sixth generation (Generation 6.0 to say it in modern terms) of hot-strip production, stands on the brink of its industrial implementation. Arvedi and Siemens VAI have built the world's first plant for endless strip production. The line has been built in Cremona and was commissioned in 2009.

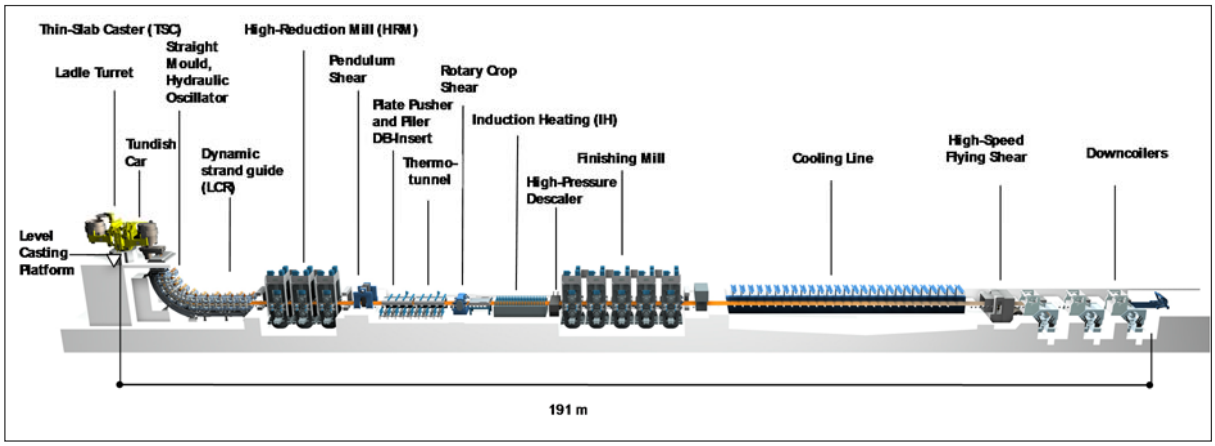


Figure 6: ESP Plant of ARVEDI / Cremona (representative for Rolling 6.0)

The total length only amounts to 190 meters and industrial strip thicknesses of less than 1 mm can be produced. An annual capacity of 2 million tons can be achieved with one strand. The Arvedi ESP concept sets the new benchmark in the area of compound plants.

Figure 7: ABM group (32 visitors) has visited the Arvedi facility in Cremona / Italy in June 2011.

Recently, the Chinese producer Rizhao, has invested in five Arvedi ESPs which will start production in 2015 and 2016. The mills are appropriate for producing ultra thin hot strip with 0,8mm thickness, whereof the width is:

- 1600 mm wide – three lines
- 1300 mm wide – two lines

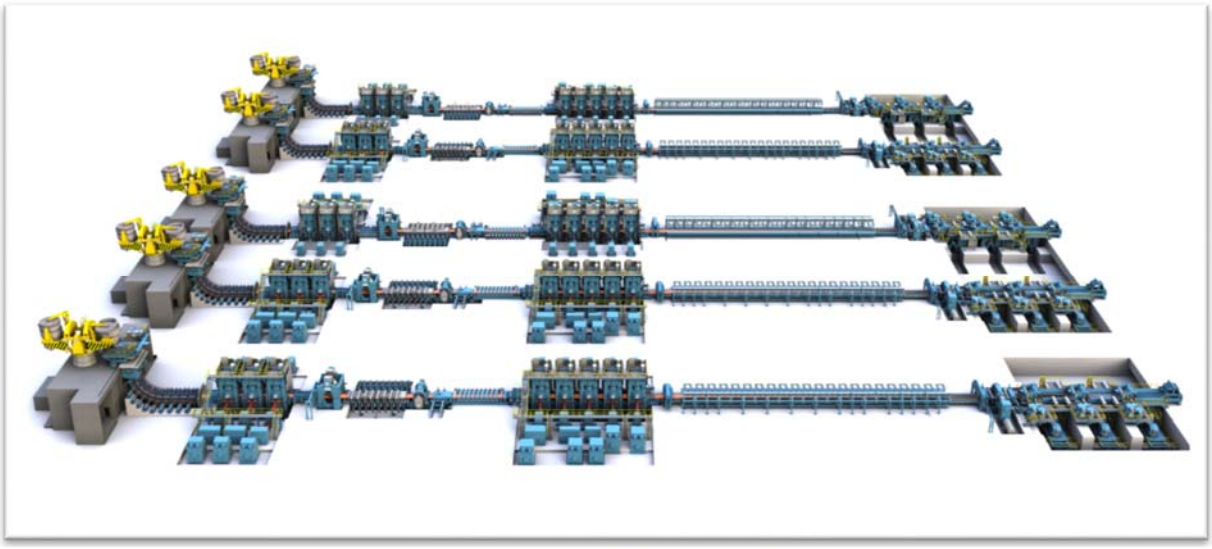


Figure 8: Arvedi ESP in China at Rizhao – five lines in parallel [8]

Italian supplier Danieli has a similar market approach with their QSP, fTSR and ETR (Generation 6.0) Technology, in terms of batch, semi endless and endless rolling.

	1. QSP	*2. fTSR*	*3. ETR*
Mill Configuration	2(1)RM+HTT+5(6)FM	2RM+4(5)FM	3RM+IH+5FM
Nominal production (tpy)	1,700,000 / 2,000,000 with 1 strand	1,500,000 / 1,700,000 with 1 strand	1,700,000 / 2,000,000 with 1 strand
	3,200,000 / 3,600,000 with 2 strands	2,800,000 / 3,200,000 with 2 strands	-
Slab thickness (mm)	90 (70)	70 (50)	80
Strip thickness (mm)	1.0 (0.9) - 19.0	1.0 (0.8) - 15.0	0.8 - 8.0
Strip width (mm)	900 - 1550	900 - 1550	900 - 1550
Plant length (m) from caster mould to downcoiler	480 (for 2 strands layout)	410 (for 2 strands layout)	220
Steel grades	Carbon steels, IF, HSLA, API grades up to X80, Silicon GO and NGO, Peritectic, DP and TRIP	Carbon steels, IF, API grades, HSLA, Peritectic, Silicon NGO, DP and TRIP	Carbon steels, IF, HSLA, Peritectic, DP and TRIP
Strip quality	Excellent	Excellent	Commercial
Thermo mechanical rolling	Possible	Limited	No
Ferritic Rolling	Possible	Possible	No
Rolling Mode	Coil to Coil	Coil to Coil (Semi-endless)	Coil to Coil Endless

Figure 9: Danieli (Mini) Mill Configurations – Mill Type Comparisons [6]

New technologies do not stop at classical mills. Thin Strip casting and Rolling, casting, Conroll, Caststrip, Stripcast, Eurostrip, Horizontal Belt Strip Casting (HBSC) at Salzgitter, etc. were and are the future prospects for new and revolutionary process methods entering in new market niches and quality segments.

4 CONCLUSION

Hot rolling of steel strip is living through its 5thand 6thGeneration and new and important developments are on the way. The discontinuous mill will be more and more replaced by continuous mills. Automation systems release the stress on the operators and guarantee the best quality and performance. In the area of (backup

and work) roll-materials a continuous development can be registered. Environmental friendly mills are the “issue of today” and any saved kilowatt-hour helps to get the production costs down [4].

It is perhaps time to reflect and to put firmly on the map what has been a long and important chapter in the history of technology in the 20th century and to eagerly await what the near and medium future will bring on new features, measures and technologies.

Generation 6.0 of strip rolling is the future way to cope with investment- and operation-costs, to achieve a high throughput with lesser strip thicknesses by maintaining highest quality standards, and all these under maximum sustainability. A breakthrough of a new process takes at least two decades and it seems that now we can call the “X”SP Process (CSP, ISP, QSP and ESP) which progressed from batch- and semi-endless-mode to a new rolling generation: “Generation 6.0”, the endless rolling of strip.

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