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Innovations for Coiling of Modern Hot Rolled Flat Materials

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The given report represents an analysis of modern technological hot strip rolling lines in terms of development direction of equipment and technologies for coiling of hot rolled strips with the target to relieve the choice of the line of modernization of existing equipment or planning of new one, including the coiling technology. There is given a description of the main factors influencing the deterioration of strip head end quality in the commencement of the coiling process and methods to avoiding these. There are described key parameters for technological engineering of down coilers with the goal to achieve the production of high quality coils. There is given a large coverage of the issue of the new generation type of down coilers – "Power Coiler" for coiling of high-strength pipe steel grades, group "X" (X100-X120).

Keywords: HOT STRIP MILL, DOWN COILER, POWER COILER, FORCE CONTROL OF WRAPPER ROLLS, STEP CONTROL OF WRAPPER ROLLS, COILING QUALITY, HIGH-STRENGTH PIPE STEEL, ESP PLANT, COILING OF NARROW STRIPS, COILING OF THE HIGH-STRENGTH MATERIALS, COILING OF THE ULTRA THIN MATERIALS

1. Overview

Currently the range of rolled alloys is being broadened on account of the increasing demand for products with advanced mechanical properties. The constant improvement of wide-strip hot-rolling mill and cooling lines cannot disregard the department, in which the rolled products that have the necessary properties achieved at the cooling line are being coiled.

For this reason there are appearing several directions for the development of technologies and mechatronic packages for hot-rolled strip coiling departments.

- Coiling of strips with smaller widths (up to 800 mm).
- Coiling of ultra-fine strips (down to 0.8 mm) with longer coiling time.
- Coiling of strips with normal widths (800-2100 mm) with limited material strength and thickness pattern.
- Coiling of strips with normal widths (800-2100 mm) with enhanced material strength and thickness pattern (Power Coiler).

2. Down Coilers common operation description

2.1. Technological datas

The optimum strip tension between pinch rolls and mandrel is one of the basic parameters for achieving excellent coil quality. On the one hand, the optimum tension must prevent from strip oscillations (which straight away would affect the coil quality) between mandrel and pinch rolls (for high-strength steel qualities) and, on the other hand, the tension must be low enough not to reduce the strip width in the same section of the line (for "soft" strips). There are different formulas to identify the optimum (necessary) and the maximum (possible) tension. In general, these formulas are empiric and being optimized in practice. The strip tension depends on the following parameters:

$$F_{tension} = f(R_e; h; w; k),$$

where $F_{tension}$ – tension force between mandrel and pinch rolls, [N]; R_e – yield strength of the material at coiling temperature, [N/mm²]; h – strip thickness, [mm]; w – strip width, [mm]; k – factor being corrected during down coiler operation for achieving the optimum coiling quality, [-].

The second basic parameter for designing down coilers is the drive power for mandrel, wrapper rolls and pinch rolls. This parameter in turn depends on:

- $F_{tension}$ and maximum coil diameter.
- Necessary bending work.
- Acceleration / Deceleration.

The third basic parameter is the strip coiling speed. In particular these are the maximum coiling start speed and the maximum steady-process speed.

2.2. Actions for reducing strip damage at strip head end

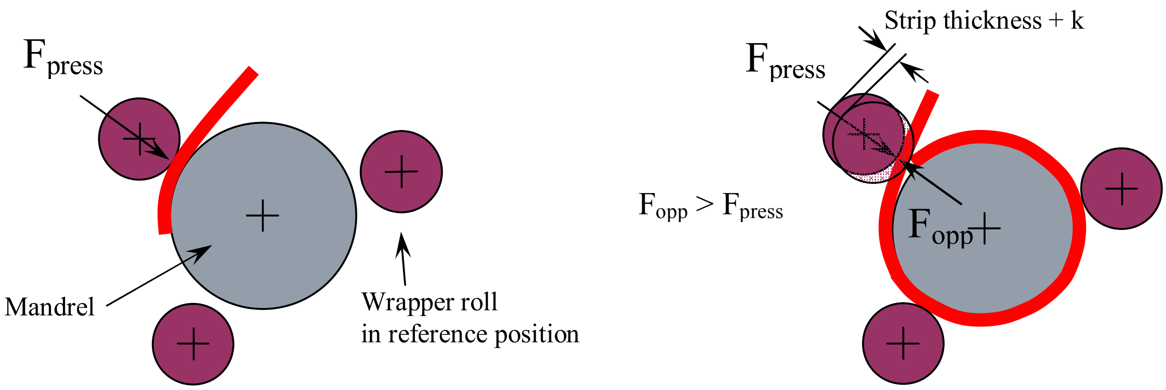
Unlike their precursors, state-of-the-art down coilers is fully hydraulically operated. This makes it possible to improve the automatic control quality for the down coiler components. The hydraulic system has two circuits: circuit 1-125 bar; circuit 2-290 bar. The second circuit is used for fast regulation of the necessary components, such as wrapper and pinch rolls as well as side guides.

The wrapper rolls belong to the main down coiler components. They are used for forming the bending and pushing corridor for the strip, when it starts being wrapped around the mandrel. The wrapper rolls have two operation modes:

- a. Force Control (**Figure 1**)
- b. Step Control (**Figure 2**)

In **Force Control (Figure 1)** mode, when the first layer is wrapped, the link together with the roll are pressed against the strip with the defined necessary minimum force and then it is pushed up by the strip with each wrap by the amount of the strip thickness (**Figure 1a** – coiling start, **1b** – after first wrap). The difficulty consists in identifying the force, with which the wrapper roll has to be pressed against the strip, because on the one hand the force must be sufficient to achieve good coiling quality and on the other hand this force must not cause damages to the strip (in case of extra fine and "soft" materials). This force must be less than the push-off force (F_{opp}), which is generated by the strip after each wrap ($F_{opp} > F_{press}$).

Step Control (Figure 2) is activated after the first wrap, shortly before the strip head-end reaches the particular roll the second or third time, the latter is raised from the strip by the amount of the strip thickness plus a value fixed proportionally to the strip thickness.



a b

Figure 1. Principle of force control by wrapper rolls: *a* – coiling start; *b* – after first wrap

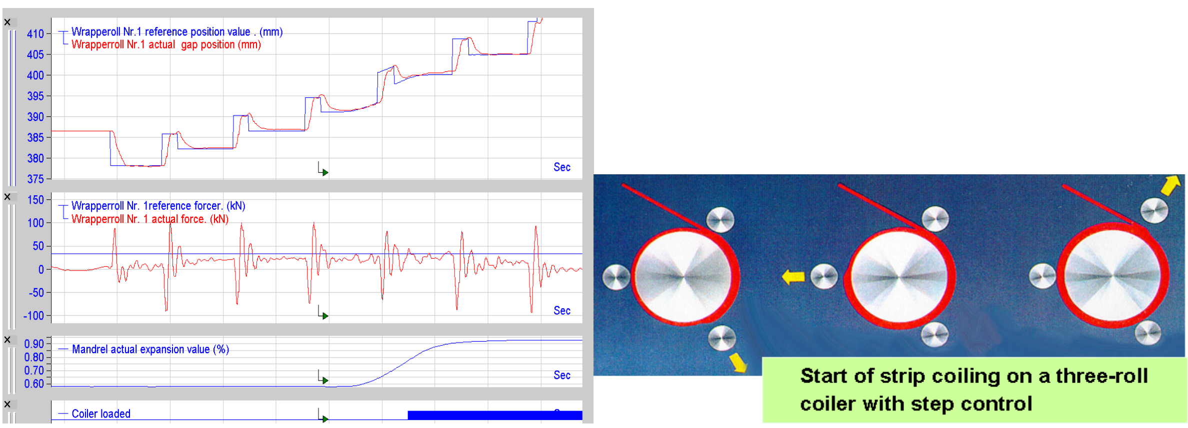


Figure 2. Principle of step control by wrapper rolls

After the head-end has passed the roll, the latter is swiveled onto the strip again (Step Control). This procedure is repeated until strip tension has been built up and the rolls have been pivoted to their outer end position. This is normally the case after three or four wraps.

The main advantage of the Step Control mode is that it makes it possible to reduce strip surface damages caused by the edge of the strip head end that is being pressed into the subsequent wraps. At the same time, a reduced expansion force is used in the mandrel in order to reduce the pressure on the strip head end from inside of the system. In general, the Step Control mode is activated for strip gauges starting from 2 mm. This has to do with the the high coiling start speed.

3. Types of Down coilers

3.1. Down Coiler for coiling of narrow strips (width up to 800 mm)

For strips with smaller widths, light-weight down coilers are used. (All components intended for strip coiling have a reduced width). One of such hot-rolling sheet mill shops is operated at Hoesch Hohenlimburg/GERMANY (**Figure 3**). The narrow strip down coiler installed at this plant has following characteristics:

Down coiler type – 3 wrapper-roll type. Hoesch Hohenlimburg/GERMANY	
Max/Min strip width, [mm]	715/150
Max/Min strip thickness, [mm]	17/1
Max hot yield stress, [N/mm²]	1000
Min coiling temperature, [°C]	300
Max. coil weight, [to]	15
Max. coil diameter, [mm]	2,000
Mandrel ø max, [mm]	500
Total motor power of pinch roll unit, [kW]	2 x 450
Mandrel motor power, [kW]	1,500
Max strip tension, [kN]	60

The outstanding feature of these down coilers is that the strip coiling start speed can be up to 15.5 m/s.

Figure 3. Down coiler at Hoesch Hohenlimburg/GERMANY

3.2. DC for coiling of the high-strength materials (with limited max. thicknesses by max. hot yield point) and width of 800-2100 mm

Currently, different down coiler combinations are used for coiling normal-width strips: with three and four wrapper rolls.

One of the latest experiences in the supply of down coilers for high-strength alloys ($R_e \leq 1300$ N/mm²) made by SIEMENS VAI is the supply of state-of-the-art down coilers to the hot-rolling mill shop at VA Stahl, Linz (AUSTRIA), **Figure 4**.

Down coiler type–3 wrapper-roll type. Linz (AUSTRIA)	
Max strip width, [mm]	1780
Max/Min strip thickness, [mm]	20/1,2
Max hot yield stress, [N/mm²]*	1300
Min coiling temperature, [°C]	100
Max. coil weight, [to]	36
Max. coil diameter, [mm]	2,300
Total motor power of pinch roll unit, [kW]	2 x 750
Mandrel ø max, [mm]	762
Mandrel motor power, [kW]	1,500
Max strip tension, [kN]	353

* (max. thickness – 8 mm at max. strip width)

Figure 4. Down coiler at VOEST Alpine Stahl, Linz (AUSTRIA)

Practical technological experiments in high-strength coiling (R_e = 900 ÷ 1300 N/mm²) have shown that the main criteria for achieving high coiling quality (not to mention high-speed automation and sufficient equipment power) are the following three:

- The strip must have high flatness
- The strip must have a homogeneous structure (mechanical properties) over its full length/width
- The equipment (including drives) must be able to create sufficient tension between pinch rolls and mandrel, especially after tailing out from the finishing mill.

Figure 5. Material: Alform 1100 (Hot yield stress up to 1300 N/mm². Thickness – 8 mm. Coiling temperature app. 115°C)

3.3. DC for coiling of the ultra thin materials in the endless strip production (ESP-Plant)

Lately there is a growing interest in ESP plants, in which liquid alloy is being cast, rolled, cooled and coiled in one operation, without interrupting the casting and rolling cycle in the rolling line (**Figure 6**). In such a process the strip is separated just in front of the down coiler group. The minimum strip thickness currently achieved at such plants is 0.8 mm. The outstanding feature of the coiling process consists in the following:

- Guaranteed strip guidance to the pinch rolls and further to the mandrel. As rolling of ultra fine strips involves high speeds and strip thickness reduction also reduces the specific weight of the strip, the strip behaviour on the roller table is unpredictable.
- The coiling time for one strip can be up to 5 minutes (while the regular time is no more than 2.5 minutes). This increases the time, during which the hot coil is remaining on the mandrel, one of the most important down coiler components, and leads to undesirable heating of the mandrel.
- Fast carry-over of strips between two pinch roll units
- Increased wear of the side guides as the fine strip is cutting into it during coiling.

For the above reasons the down coilers used for strip coiling at such plants must consider these technological particularities.

3.4. DC for coiling of the high-strength materials. Power Coiler

As at regular wide-strip mills the high-strength steel quality range (up to X100) is being extended and the maximum strip thickness is being increased up to 25.4 mm, a new down coiler design has been developed under the label "Power Coiler" (**Figure 7**). The major objective of this development was to create process conditions at strip coiling start that would make it possible not to coil a strip having an uncooled head end (at the maximum possible strip thickness), which in turn would eliminate structural discontinuity and corresponding mechanical properties at the strip head and tail ends. The idea was to create the conditions necessary for strip pre-bending before the required tension between pinch rolls and mandrel is built up, which would make it easier to wrap the first strip layers around the mandrel without considerably increasing the energy demands of the down coiler drive.

For that end it was proposed to use an optimum arrangement consisting of a hold-down roller and a pinch roll unit in combination with the first wrapper roll and the mandrel. For bending the strip around the mandrel, the first wrapper roll has been equipped with an additional auxiliary roller. Additionally the double wrapper roll has now a new function, namely the same the pinch roll unit, i.e. to push the strip around the mandrel.

For identifying the necessary wrapper rolls forces for all above listed plants, numerous simulation experiments have been carried out to engineer the coiling process (**Figure 8**).

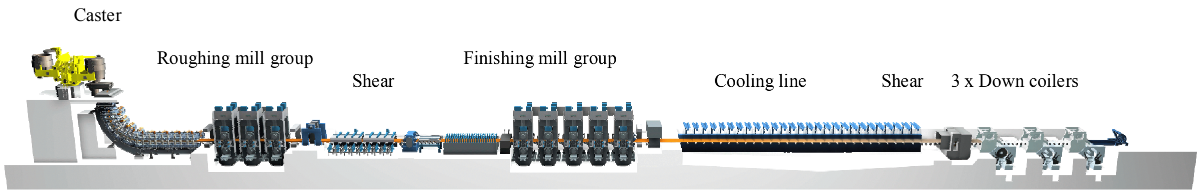


Figure 6. Layout of ESP (endless strip production) plant

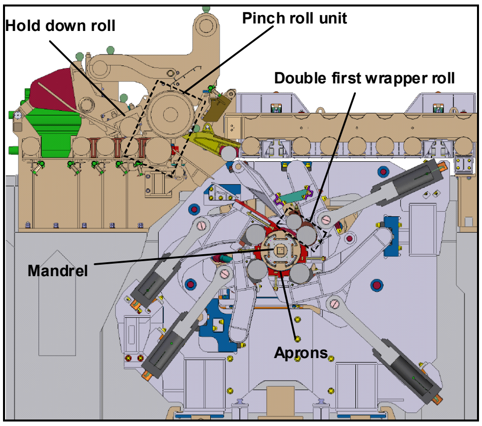


Figure 7. Functional chart of Power Coiler

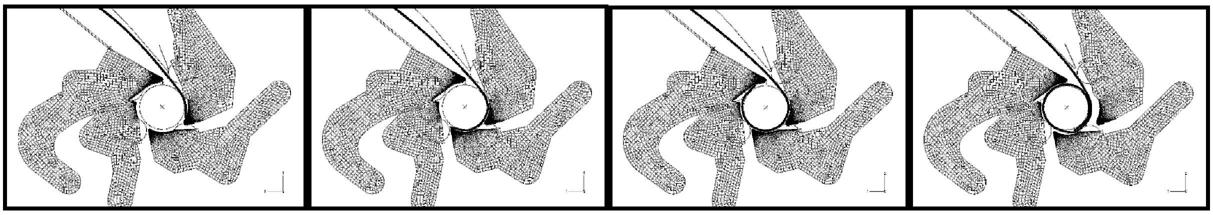


Figure 8. Simulation of coiling processes with Power Coiler at beginning of coiling

The results of these investigations have been proven in practice at the 2100 mm wide-strip mill lately built and started up by Siemens VAI in Krakow (Poland). Coiling tests with a not completely cooled head end were carried out for X80 materials and for 15, 20 and 25 (**Figure 9**) mm thicknesses. The test results are listed in table below.

Strip thickness, [mm]	Strip width, [mm]	Uncooled head, [m]	Uncooled tail, [m]
15	1900	1	0
20	1900	2	2
25	1900	2	3

The most powerful Power Coiler is actually erected in Severstal (RUSSIA), where X100 steel grades will be coiled at 25,4 thickness (**Figure 10**).

Figure 9. Material: X80 (Thickness – app. 25 mm. Width app. 1900 mm)

Down coiler type 4 wrapper-roll type (Power Coiler). Severstal (RUSSIA).			
Max strip width, [mm]	1850	Max. coil diameter, [mm]	2,300
Max/Min strip thickness, [mm]	25.4/1.2	Total motor power of pinch roll unit, [kW]	2 x 700
Max hot yield stress, [N/mm²]	600	Mandrel ø max, [mm]	850
Min coiling temperature, [°C]	450	Mandrel motor power, [kW]	1,670
Max. coil weight, [to]	47	Max strip tension, [kN]	272

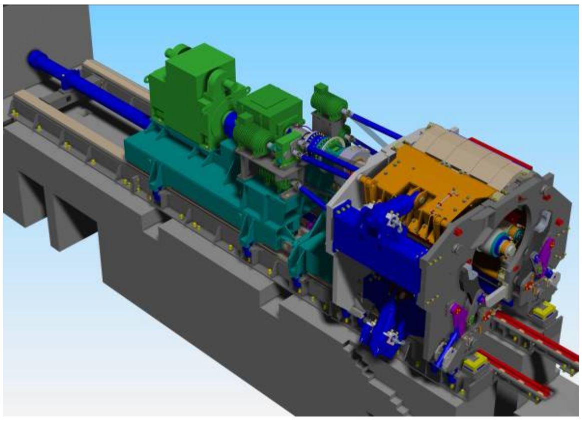


Figure 10. Power Coiler at SEVERSTAL, Cherepovets (RUSSIA)

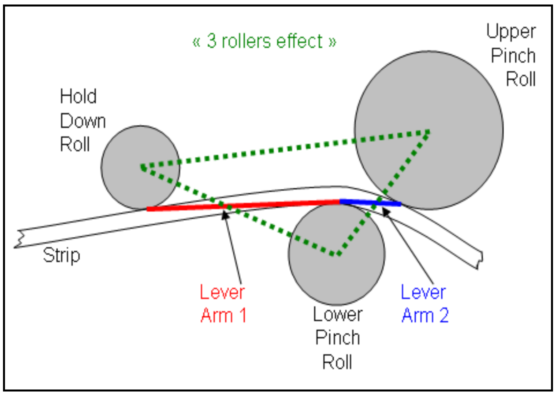


Figure 11. Functional chart of strip pre-bending in pinch roll unit

Taking the above said into consideration the Power Coiler has the following advantages:

- High-strength steel (such as X100) thick strip (up to 25.4 mm) coiling is possible thanks to:
  - ✓ Controlled hold down roll, that improves the coiling behaviour at the head and tail end of the strip.
  - ✓ Pre-bending of strip at pinch roll unit and hold down roll (**Figure 11**).
  - ✓ Auxiliary roller at the first wrapper roll, which makes strip bending around the mandrel easier.
  - ✓ "Pinch mode" for double Wrapper Roll Nr. 1
- Shorter uncooled strip head and tail ends (at maximum strip thickness and width). The question if it is possible to reduce these uncooled parts to zero length (at a strip thickness of 25.4 mm) still needs to be investigated
- Reduced power requirements for initial strip windings due to pre-bending of strip with the pinch-roll and initial wrapper-roll unit
- Coiling of complete thickness spectrum of the normal hot strip mills (1.2-25.4 mm)
- Improved operating safety for thin strips due to 4-roller design with reduced apron lengths. The

innovative Power Coiler solutions can be characterized as a milestone in improved coiling of high-strength pipe grades (API) in common with conventional materials in a wide range of strip thicknesses and widths.

Conclusions

The paper discusses the main preconditions for ensuring good strip coiling quality. A method for reducing damage of the strip head end at the beginning of the coiling process (Step Control) is described. Development tendencies of modern plate rolling lines are examined with respect to coiling. Recommendations are given for the further development of modern coiler technologies.

Some objectives of future down coiler development for hot-rolled sheet coiling are the following:

- Development of a coiling technology and coiling equipment for such steel qualities as X120 (for a maximum thickness of 25.4 mm and a maximum width of 2100 mm)
- Cut-down of the change time of such equipment like pinch roll unit and mandrel. Siemens VAI has developed an automatic pinch roll change technology which cuts down change time from 2.5h to app. 10 min. First implementation will be realized at Allegheny Technologies (USA).

Новые идеи для намотки современных горячекатаных листовых материалов

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при участии Миничмаер Р., Шмоллер Ф. Х., Сейлингер А.

В данной работе был произведен анализ современных технологических линий горячей прокатки листа с точки зрения направления развития оборудования и технологий для намотки горячекатаной полосы, с целью облегчить выбор направления модернизации существующего или планировании нового оборудования и технологий смотки. Описаны основные факторы, влияющие на ухудшение качества головной части полосы в начале намотки и методы их устранения. Описаны основные параметры необходимые для технологического проектирования моталок с целью получения бунта высокого качества. Детально раскрыта тема нового поколения моталок типа "Power Coiler" для намотки высокопрочных трубных марок стали группы "X" (X100-X120).