Modern rail rolling technologies

In several areas of the world, the production of rails is increasing due to interest generated by the market for high-speed and/or high-load railways. Rail quality requirements are very demanding, and rolling processes and technologies must adapt to the new challenges in order to provide rail rollers with efficient and profitable plants. The latest rail mill designs and technologies are described.

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The market for new railroads and the modification of existing railway lines has become increasingly active in recent years as its cost-effectiveness and relative ease of operation for short to medium distances make railway transportation convenient for both freight and passenger transport.

Among the worldwide investments announced or known during the first half of 2013 were:

- Mexico to spend $24bn in infrastructure, including railways
- Russian Railways poised to consume 1,000,000t/yr of rails
- Britain to make the biggest rail investment in more than 100 years, with £30bn in 2014-2020
- California High-Speed Rail Authority approved by Transportation Board for a new line
- Brazil launched a rail package in 2012 which foresees R$91bn expenditure for 10,000km of railways.

For passenger transportation, high speeds (over 200km/h) are often requested – with some cruising speeds exceeding 350km/h. On the other hand, freight transportation requires large load capability. Long freight trains with more than 100 cars (the ‘mile train’) are not uncommon for commodities like minerals and crops, and the individual axle load has been increasing from typically 25t to 40-50t.

Both high speed and heavy haul transportation call for premium grade rails with strict quality requirements, with wear resistance, rolling contact fatigue, vibration, dynamic loads and rail linear tolerances being some of the issues that have to be addressed. Rail operators therefore want high-quality rail solutions that are flexible and that help increase operational profitability.

There is intensive research into improving rail performance, improving the features of existing steel grades and microstructures, as well as developing new ones. In the field of freight or mixed freight-passenger railways, the most common rails use non-alloyed low
strength pearlitic steel. However, since the requirements of high wear resistance and contact fatigue are increasing, pearlitic steels are being further improved, while new alloy grade rails with bainitic or pearlitic/bainitic structures are being developed (see Figure 1).

KEY REQUIREMENTS OF MODERN MILLS
A modern installation for rail rolling must be able to address all market requests for both freight and passenger application, yet offer high operational flexibility, accuracy, efficiency and quick change of production with minimum downtime. Therefore rail producers must have a plant capable of efficient production of a wide range of grades, sizes and lengths with quick automatic setup operations, self-adaptability of use, intelligent process control system and sustainable costs.

In particular, rail manufacturers want to:
- Cater to all rail market segments, and fulfill all international rail standards
- Improve the product quality and the operation reliability
- Reduce operational costs
- Be capable in some cases also to roll sections, typically medium (up to 300mm) or large sizes, eg, beams and channels.

ROLLING MILL LAYOUT
For mills that only produce rails or rails and sections up to 300mm, the state-of-the-art layout comprises two EVO reversing breakdown mills (BDMs), a 5 to 7-stand continuous universal mill, in-line heat treatment, cooling bed with a pre-cambering system, straightening system and ancillary systems such as sawing units, hot marking, stacking and binding, and control systems.

With this type of configuration, rails up to 120m in length may be rolled continuously.

For mills that produce rails and heavy sections over 300mm, the most practical layout is an EVO breakdown mill followed by a 3+1 tandem intermediate and finishing universal mill (see Figure 2).

REVERSING EVO BREAKDOWN STANDS
Whether the initial feed material is bloom/billet or a form-cast blank, it is first descaled and then rolled through a reversing EVO breakdown mill down to the necessary leader pass while applying a sufficient reduction ratio required for finishing rolling (see Figure 3).

EVO breakdown stands typically offer roll diameters of 600-1,400mm and side-guard manipulators. In the case of rail mills, the typical roll working diameter is 800-1,000mm, with a barrel length of approximately 2,000mm. In mills with two breakdown stands, the roll
sizes are identical to minimise spares. An optimum setup also includes hydraulically balanced rolls, electric motors to adjust the gap, transducers and load cells. Four-row taper roller bearings support the radial loads, and two-row thrust taper roller bearings support the axial loads. With free-floating chocks the distribution of the load on the bearings is more uniform, so their life is extended and maintenance stoppages are reduced.

A quick-change car device allows the stand holder with worn rolls to be quickly removed and replaced with the new rolls. Hydraulic capsules on the bottom roll are used for roll wear compensation and anti-jamming. Despite its relatively large size, the whole mill has a compact design so that mill spring is kept within very small limits.

The development of automation protocols enable modern generations of EVO mills to operate with a high degree of automation, so guaranteeing a consistent product quality while ensuring the highest safety to both personnel and components.

The reversing BDM does not require large foundations typical of the old 3-Hi design, and tilting roller tables are not necessary, which results in a compact installation. Modern inverter-driven variable speed motors make the rolling speed control easier and minimise energy consumption.

**CONTINUOUS FINISHING UNIVERSAL MILL**

In this design, the universal mill reduces the leader pass to the final rail shape through a sequence of continuous passes using five to seven universal/horizontal Red Ring stands. This allows for a fast and easy conversion between universal and horizontal configuration. The same configuration may be adopted for sections up to 300mm.

The continuous finishing universal mill is advantageous for:

- High production rates
- High reliability of rolling (off-line stands are preset)
- Smooth rolling process with less equipment maintenance
- Excellent rail shape control (one edging pass after each universal pass)
- Better control of roll wear, longer roll life and fewer roll changes
- Lower rail heat losses with lower power consumption and better tolerances
- No need to change stand as line is set up after each pass
- Reduced downtime for stand changes with a quick-change device.

**3+1 TANDEM INTERMEDIATE AND FINISHING UNIVERSAL MILL**

This is the most modern concept for large sections and rails. The intermediate group comprises three stands arranged in universal-horizontal-universal configuration which operate in reversing mode, followed by a single pass universal finishing stand. The key advantage of this configuration is that the fourth stand is kept open (or off-line) during reversing intermediate rolling, then closed (or moved in-line) only to apply the final single finishing pass. As the reduction applied during finishing is very small, the rolling stresses and the consequent roll wear are reduced, which enables fewer roll changes and a beneficial impact on productivity.

In a 3-stand universal configuration, where the final stand is used for both reversing and finishing rolling, the lifetime of its rolls would not normally exceed 1,000t. With the 3+1 solution, the roll life in the final stand is expected to reach 2,000-3,000t. Because commonly rolled campaigns for rails and sections average 2,000-2,500t, finishing stand changes during the campaign are largely unnecessary.

The reduction of required changing stops with the consequent increase of hours availability (up to 4%), leads to an increase of productivity (5% in case of a nominal yearly value of 1Mt), which rapidly pays off the cost of the additional stand. For the same reason, despite the additional stand, the total number of rolls in the warehouse does not increase significantly.
The service life in the track and switch systems is especially determined by rolling contact fatigue (RCF) that can generate surface damage such as cracks which, over time, impair the functional properties of the rail. Damage removal by grinding and refurbishing are lengthy and costly operations so, in order to extend the rail service life, it is necessary to improve RCF resistance.

Currently, about 80% of the world rail market is served by standard grade rails with a predominantly pearlite microstructure with an ultimate tensile strength (UTS) below ~1,000MPa (see Figure 4).

As higher UTS is conducive to improved RCF resistance, stronger rail materials continue to be developed. In pearlitic steels, UTS is increased by reducing the spacing between the cementite lamellae, which may be obtained by adding costly alloying elements or through head hardening.

Bainitic rails show superior qualities in terms of RCF resistance, are performing well in heavy haul railroads, and market share is increasing. The initiation time of RCF damage is longer in bainitic rails, and it may be further prolonged with an increase of UTS (up to approximately 1,500MPa), which may be obtained with heat treatment. Therefore, with both pearlitic and bainitic (or combination of the two) microstructures, UTS values may be increased by suitable heat treatment (head hardening).

Precisely on these grounds, Siemens decided to take this technology one step forward with the Induction Dual Phase Rail Hardening (idRHa+) process, developed in cooperation with Centro Sviluppo Materiali (CSM). This process was developed through extensive use of integrated numerical modelling and validated through extensive experimental trials in the pilot unit of CSM’s laboratories (see Figures 5 and 6).

idRHa+ is the most advanced rail head-hardening system currently available, its main strengths being its outstanding process performances and the easy adaptation to different conditions (layout, production rates, material and cooling requirements; see Figure 7). Modelling allows the precise control of the cooling process around the rail outer profile to obtain the desired microstructure and hardness distribution across the rail section. This approach allows rail rollers to simulate the whole process and test in advance rail samples through different cooling models, so that the head-hardening line can be quickly ramped to nominal production, and its performance obtained with full consistency and reliability.

The technological features of the 3+1 mill make use of state-of-art automation. The under-load gap hydraulic adjustment is derived from flat rolling technology and the fully automated stand change protocol reduces the total change time to less than 20 minutes, while improving safety conditions. The overall footprint required for the installation is also small, as the fourth stand is located immediately after the reversing stands.

**IDRHA+ RAIL HEAD HARDENING**

With the increase in performance demands as described earlier, it is evident how crucial it is to increase the properties of the rail-wheel contact area. This may be reached by a proper combination of hardness of the outer rail head surface, with a good toughness of the head core. This is obtained by controlling the amount of decomposed austenite in the outer and inner parts of the rail head.

![Fig 5 Pilot unit at CSM](image1)

![Fig 6 Rail sample showing sample points](image2)

![Fig 7 idRHa+ adapts to different production routes](image3)

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**idRHa+ features and operation** The first zone of idRHa+ is equipped with an induction heating system, which serves for the selective adjustment of the rail temperature after rolling. The temperature is equalised along the rail longitudinal dimension, while the desired temperature gradients may be obtained across the rail transverse section.
The system can heat the rail from ambient temperature in off-line application and consists of a series of high-power induction modules, with split top and bottom coils powered by individual digital phase converters. The number and location of the heating units depend on productivity, rail sizes and grades, while the total installed power is 30-35kW per t/h of rolled rails. Their design grants an efficient transfer of high power density to the rail in a short time and space. In on-line application, the rails are already hot as they arrive from the in-line mill where they were either heated at the initial billet or blank furnace, or heated as a result of deformation work during rolling. In these cases the heating power required for the induction system will be reduced, as it will mainly serve for temperature equalisation of rail across its cross-section and along its length.

The cooling zone contains several modules (see Figure 8), each equipped with a set of interchangeable cooling devices (spraying nozzles with mist-atomisers of different media or air-jet blades) which apply the required cooling protocols.

Depending on the processed grade, the rail surface temperature is normally 750-1,000°C at the entry and 300-650°C at the exit, with the cooling speed adjustable in the range of 0.5-40°C/s in accordance with the required microstructure and mechanical characteristics (see Figure 9).

Temperatures are continuously monitored by pyrometers or thermo-scan cameras, and are used by the process control system to apply the fine regulation of selective use of cooling modules, cooling media pressure and flow rate values, off-set distance of spraying nozzles and rail running speed in order to correct dynamically any recognised thermal heterogeneity along the rail length and across the rail section.

Each module may be stand-alone or coupled with others. Pre-set process protocols, with heating and cooling rates and temperature profiles, are stored in the process control system as a function of grade and characteristics.

Embedded in the process control system are several thermal, mechanical and metallurgical models, such as austenite decomposition with microstructure prediction, precipitation behaviour, thermal evolution with transformation heat calculation, mechanical properties prediction and deformation behaviour. Through the application of the process models, the control system manages and predicts the process and the product parameters according to:

- Actual chemistry
- Desired microstructure
- Desired mechanical characteristics, like hardness and strength
- Hot rolling mill setup and procedures (eg, stand layout, thermo-controlled rolling)
- Expected temperature in defined profile points (head, web and foot) and along the length (head, centre, tail)
- Expected austenite decomposition rate and transformation temperature.

The pre-set cooling strategy is then fine-tuned, taking into account the actual parameters, measured or predicted with integrative data during the rail process route. The use of the most suitable cooling rate and its working parameters (eg, pressure and flow rate) are determined for each module according to the optimised process strategy suggested by the process models. Once validated, the process protocols are stored in the control system for easy recipe management.

This guarantees the active application of an ideal cooling path along the whole rail length and across the whole cross section. Very strict characteristic variation can be obtained avoiding formation of zone with too high or too low hardness and avoiding any undesired microstructure. idRHa+ can process rail sizes up to 75kg/m, including asymmetrical. While idRHa+ is expected to deliver unsurpassed performance in terms of flexibility and reliability for seamless rails up to 120m in length, its flexibility...
may also be adapted to process shorter lengths in both in-line and off-line applications. As of July 2013, two contracts including the supply of idRHa+ process and equipment are ongoing (China and Kazakhstan).

**GAUGING AND IN-LINE INSPECTION**

The rail profile is continuously monitored before the rail enters the cooling bed, using a static ProScan optical profile gauge (see Figure 10) which uses 2D cameras and lasers to determine the profile with a typical accuracy of +/- 0.1mm. The measured data allow for the automatic adjustment of rolling parameters and can automatically spot surface defects. ProScan may be effectively complemented by a surface defect detection module that reads the temperature differential of the edges of the defect. The module is enclosed in the ProScan body and is capable of detecting all surface defects such as rolled-in scale, well-defined dents and scratches.

**PRE-CAMBERING OF RAILS**

In some cases, depending mainly on rail temperature, grade and shape, during cooling on the bed the rail will show a marked tendency to bulge outwards on its head side. If this bending effect is too large, the subsequent straightening process becomes too difficult and also produces excessive stresses on the rail and the straightening equipment. This may be critical, especially for long rails (over 100m), such as those used in high-speed passenger railways, which have very tight requirements for straightness and residual stress.

To prevent this, the EVO pre-cambering system applies an opposite inward bend on the rail at the entrance of the cooling bed, by means of active cars with hydraulic grippers (see Figure 11).

Each car travels individually programmable distances that allow for the application of different pre-camber patterns. The pre-camber patterns are calculated by cooling numerical models for different rail parameters and validated by experimental trials. EVO pre-cambering allows the rails to be sufficiently straight when entering the straighteners to reduce the straightening force and residual stresses.

**STRAIGHTENING SYSTEMS**

High-speed trains call for extremely tight tolerances of linearity and rail shape, and low levels of internal residual stress. Before entering the straightening area, a hydraulically operated manipulator positions the rail onto its foot and ensures entry to the straightening machines.

The typical straightening line for rails (see Figure 12) comprises horizontal and vertical straightening machines in a rigid frame containing two staggered rows of rollers. Hydraulic capsules are used, which significantly benefits the compactness of installation and speed of under-load roll regulation.
The roller position and centreline is adjustable according to the rail size and section modulus, and a hydraulic counterbalance eliminates backlash. The rollers are mounted in a removable cassette for quick changing so that the cassette can be automatically removed and replaced with a standby cassette. A suction system removes the scale.

**SAWING EQUIPMENT**

Sawing (see Figure 13) is preferred to shearing to achieve the desired length for hot-cut rails as it eliminates the deformation of rail ends and provides better cut quality and precision. Depending on factors, including noise limitation and campaign duration, either metallic or abrasive hot saws can be used. During sawing, the rail is clamped at both sides of the wheel, whose movement can be either pendulum or linear.

For abrasive cutting, the wheel wear is automatically compensated by adjusting the approach stroke while its peripheral speed may be made constant by the inverter-driven motor. Saws are also used for nose and tail cropping and sampling, with automatic crop and sample discharge systems. As swarf is collected in a bin, a separate dust removal and filtering system is provided with abrasive sawing equipment. The metallic disc sawing equipment is encased in a sound-proof cover. The final cut-to-measure of the rail is done by saw with cementite carbide inserts, and may be integrated with the drilling station.

**SUMMARY**

Rail production is increasing in quantity and quality due to the interest generated by high-speed and high-load railways. Rail rollers must meet demanding quality requirements with modern rolling processes and technologies, so to be able to run efficient and profitable operations.

Siemens has developed and supplied technologies and rail mills that are state-of-the-art in terms of mill flexibility, operating cost and rail quality. 

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