Sonderdruck aus „MPT International" Volume 23 (2000), Heft 5, Seite 92-96
Nachdruck verboten. **Verlag Stahleisen GmbH,** Düsseldorf

Optimization of descaling nozzles in a hot strip mill

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In hot rolling, the surface quality of the finished strip depends on the performance of the descaling equipment in the roughing and finishing trains. The design of descaling systems and nozzles has been improved over the years step by step, thus increasing the kinetic energy of the spray water and enabling reproducible spray patterns. At Thyssen Krupp's hot strip mill in Bochum the descalers have been modernized several times since 1992. Thus downgrading of hot strip due to scars could be reduced by more than 50%.

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Design of descaling equipment

Descaling mechanism. In hot rolling, efficient descaling is of major importance to the quality of the finished product. Descaling equipment today has to be efficient, reliable and cost-effective.

In descaling, the surface of the rolled material is impacted by high-speed water jets with a defined spray pattern. During descaling, a typical sequence of physical mechanisms takes effect, some of them in parallel [1]:
- breaking of the scale layer by the high impact energy of the water spray,
- detachment of the scale layer through differential shrinkage of metal and scale during shock cooling,
- blasting off of the scale through explosion-like evaporation of the water droplets beneath the scale layer, and
- removal of the detached scale through inclined orientation of the spray.

Basic factors for efficient descaling. A descaling process can only be described as efficient if cost aspects are included in its design. Cost-effectiveness comes from two elements, both of which have to be provided to achieve an optimum solution:
- precision nozzles, and
- optimized nozzle arrangement.

The most important demand that a nozzle manufacturer has to meet, next to high operational reliability, is the guarantee of the following parameters:
- spray water distribution,
- pressure distribution of the spray,
- spray width,
- spray depth, and
- flow rate.

These parameters form the basis for specific spray properties which are indispensable in descaling. Quality of manufacture is extremely important in descaling nozzles, especially with regard to the precision of the internal contours.

As part of the nozzle manufacturer's quality management, the close dimensional tolerances needed to achieve reliable spray patterns are produced with state-of-the-art manufacturing equipment. This ensures reproducible production conditions in the nozzle's application.

Computerized measuring equipment in conjunction with special nozzle layout software make it possible to make reliable predictions of the properties of a descaling system, **figure 1.**

This program provides on-screen configurations of diverse nozzle layouts and operating conditions, together with graphics of spray patterns and calculations of all parameters. These are automatically recalculated after changes.

The physically induced convergence of the edge sprays means that different effective spray angles can be selected depending on spray height and spray pressure. This function is recorded in a large number of reproducible measurements and is implemented in the descaling program.

The most important of the many nozzle parameters is ***impact,*** which is expressed as the quotient of spray force and area of coverage in N/mm^2.

Designs with various objectives, e.g. higher impact, or reduced spray water or pump energy, can thus be made available quickly in printed form.

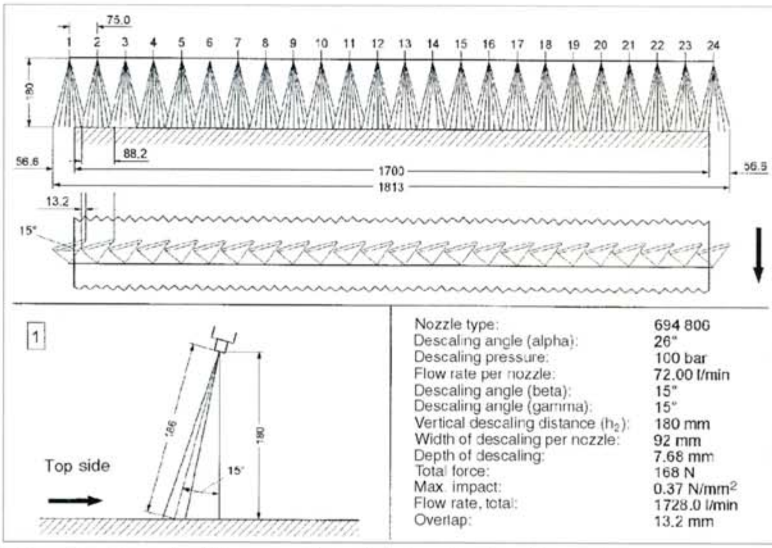

Figure 1. Example of the computerized design of a descaling system

Nozzle-specific parameters and design of descaling systems. Effective nozzle design calls for knowledge of which function can be used to influence impact by varying the parameters.

Spray pressure, nozzle size and spray angle are linear in their effect on impact; spray height has an exponential component because irrespective of the spray angle two dimensions are changed simultaneously: spray width and spray depth.

Spray height is therefore the most effective parameter. Halving the distance between nozzle and strip surface increases impact by a factor of roughly four.

This means that to optimize cost-efficiency the spray distance should be as short as possible, although in practice heat loss and strip speed have to be considered.

The design of the descaling system has to be based on the type of scale encountered. Most of the primary scale arises in the furnace. To allow furnace scale to be removed easily, the furnaces are operated with an oxidizing atmosphere, which produces a thick, dry, easily removable scale. If the scale layer is thick, cooling produces differential shrinkage of scale and metal. Tangential shear forces occur at the boundary layer which cause the scale to crack [2].

With thin, firmly adhering scale the situation is different. This adhesive scale also occurs in oxidizing furnace atmospheres on high-alloy and low-carbon steels. Owing to the firm adhesion of the thin scale layer it is not easy to utilize shrinkage in scale removal. Breaking and flushing are required in this case, calling for higher impact and lower water coverage per unit area. This means the spray distance must be short and small nozzles must be used [2].

Impact measuring techniques. Highly sensitive measuring equipment is needed to optimize parameters such as flow rate, spray angle and spray quality in nozzle production.

The principle of impact measurement is shown schematically in **figure 2.** A pressure transducer moving on a precision slide passes without slip at a defined speed through a spray at a pressure of, for example, 150 bar. The velocity of the water as it exits the nozzle, v_0, is roughly 170 m/s. On its path through the spray the transducer picks up several thousand measuring pulses which are converted by computer into a three-dimensional image.

The dominant factor in designing and assessing descaling nozzles is impact and its trapezoidal distribution pattern, **figure 3.**

This distribution pattern, which is indispensable for descaling, is achieved by special contours inside the nozzle. A computerized measuring unit delivers a three-dimensional image of the sprayed surface. Other parameters measured simultaneously are spray pressure, flow rate and total spray force.

Descaling nozzles

Different types of nozzles are used in the roughing and finishing trains of the Bochum hot strip mill. Their design and properties are described in general below.

FUH4 nozzle. This nozzle has a dovetail-type lock, **figure 4.** This design has proved particularly practical for connecting nipple and nozzle for the following reasons:

- The nozzle is inserted sideways into the dovetail guide, ensuring the correct position of the nozzle on the header and virtually ruling out incorrect fitting.
- The twist of the spray relative to the axis of the pipe is guaranteed after each nozzle change.

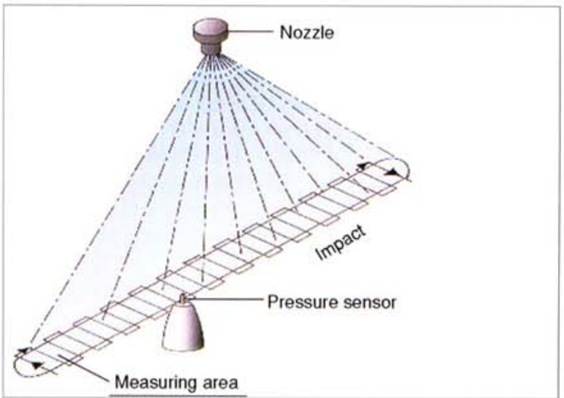

Figure 2. Impact measurement

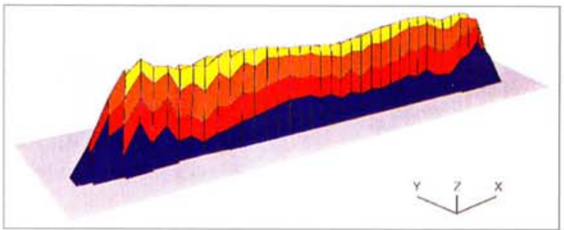

Figure 3. 3-dimensional distribution of descaling impact

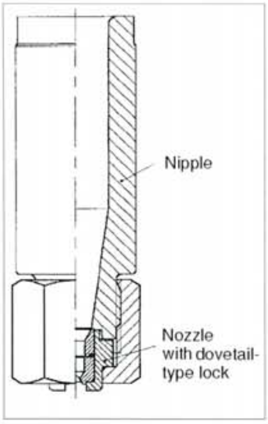

Figure 4. FUH4 descaling nozzle

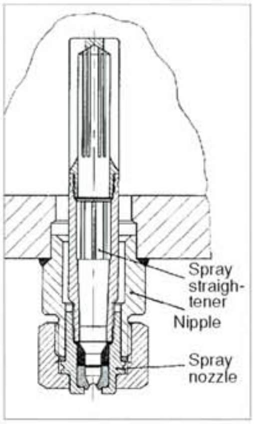

Figure 5. Scalemaster descaling nozzle

The twist angle on the descaling equipment in the Bochum hot strip mill is 15° in order to prevent interference between the edge sprays of adjacent nozzles.

The nipple houses a long, slender inlet cone which connects steplessly with a guide sleeve upstream of the nozzle orifice. The spray water is focused by a continuously tapering cross section and delivered to the nozzle. The aim is to eliminate turbulence and energy losses as far as possible.

This ensures that the water leaves the nozzle in a sharply defined reproducible spray pattern with defined properties.

Scalemaster nozzle. The Scalemaster series, **figure 5**, is a major development for the descaling area. The task of the descaling nozzle is to convert the energy of the spray water into kinetic energy with as little pressure loss as possible. Impact on the strip surface is a key parameter in the removal of scale. The spray nozzle therefore has to turn the water into a high-performance tool with a high degree of efficiency.

In contrast to the side-fitting FUH4 nozzle the Scalemaster nozzle is inserted axially into the nipple. It is locked by a two-point socket. The most important component in this nozzle system is the stainless steel spray straightener. This is positioned at an optimized distance ahead of the nozzle and secured against axial movement and rotation. The precision of this straightener is crucial to the quality of the spray patterns, which include a "vertical" hard-outline pattern. The eight flow chambers formed by the straightener must have exactly the same cross-section to produce a symmetrical spray pattern. Stability and low flow resistance are other important properties.

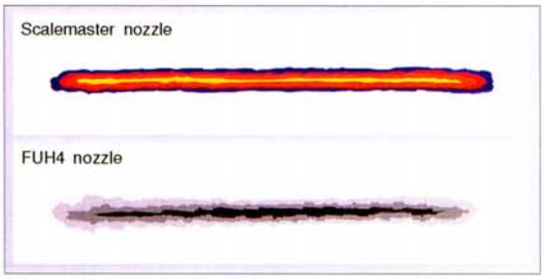

Figure 6. Spray depths of Scalemaster and FUH4 nozzles

Therefore, at the heart of the Scalemaster system there is a spray straightener ahead of every nozzle to smooth out turbulence and minimize energy losses on the decisive section of the flow path. This means that even with difficult flow conditions, e.g. sharp deflections, the quality of the spray pattern is independent of the position of the nozzle in the header because disruptions are minimized by the spray straightener upstream of each single nozzle.

The increased efficiency of Scalemaster lies in achieving a smaller spray depth with a largely turbulence-free flow. The impact is higher the smaller the area of coverage onto which the water volume is projected. **Figure 6** shows the typical differences in spray depths between FUH4 and Scalemaster nozzles. The reduction in spray depth with Scalemaster nozzles compared with FUH nozzles is approximately 30%.

Mini Scalemaster nozzles. The Mini Scalemaster series is a nozzle system that produces an identical spray pattern to that of the "big" Scalemaster system due to the use of the same nozzle inserts. The "mini" part of the name relates solely to the outer form of the individual components – nozzle, nipple, spray straightener and cap. The more slender form makes it possible to space nozzles more closely in the header and to achieve shorter spray heights in this way.

Scalemaster HP. In the course of further improvements to nozzle efficiency the Scalemaster HP series was developed. HP stands for "high performance" and even better conversion of spray water energy into high kinetic energy. Spray depth has been reduced further thanks to a number of optimization measures in the inlet area. HP versions are available for both the Scalemaster and the Mini Scalemaster. The nozzle material in the Scalemaster HP series is cemented carbide. A long-life version has been developed for equipment subject to particularly heavy nozzle wear, due to high concentrations of abrasives in the spray water for example.

Descaling equipment in the Bochum hot strip mill

The Thyssen Krupp wide hot strip mill in Bochum is a semi-continuous mill consisting of three reheating furnaces, a reversing roughing mill with upstream edger, a coilbox with coil furnace, a seven-stand finishing train and three downcoilers. The product range is roughly one third stainless and two thirds carbon steel grades. **Figure 7** gives a schematic overview of the descaling equipment.

In *descaler 1* in the roughing train the primary furnace scale is removed at a pressure of 125 bar by Scalemaster nozzles mounted on an upper and a lower header. In the entry and exit sections of the roughing mill there are additional FUH4 nozzles, also operating at a pressure of 125 bar.

In *descaler 2* in the entry to the finishing train the hot strip is descaled at a pressure of 110 bar by Mini Scalemaster HP nozzles mounted on two upper and two lower headers. Another 110 bar spray group – also fitted with Mini Scalemaster HP nozzles – is situated directly ahead of the first finishing stand.

Downstream of the first three stands of the finishing train there are 55 bar *interstand cooling systems* using Mini Scalemaster HP nozzles which lower the surface temperature of the strip and largely prevent the formation of secondary scale [3].

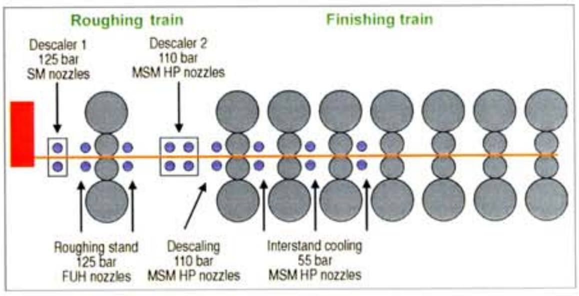

Figure 7. Bochum hot strip mill; layout of the descaling equipment

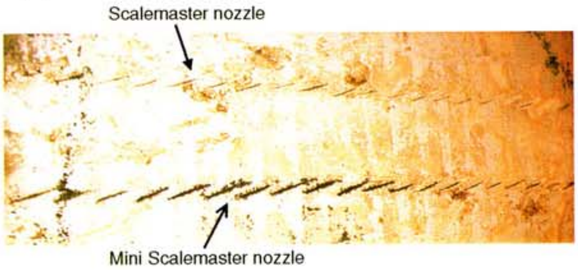

Figure 8. Photographs of the descaling patterns of Scalemaster nozzles and Mini Scalemaster nozzles in the Bochum hot strip mill

Modernization of the descaling equipment. In recent years extensive modernization measures have been carried out on the descaling equipment in the roughing and finishing trains in close cooperation with the nozzle manufacturer Lechler, **table 1**. The aim of the modernization was to increase the impact ***without*** changing the spray pressure.

Table 1 compares nozzle type, number of headers, number of nozzles per header, flow rate, spray pressure, nozzle angle, nozzle-to-strip distance and impact for the individual modernization stages, starting with the original configuration of descalers 1 and 2. Simply by changing the nozzle type and the nozzle-to-strip distance by means of an additional adapter it was possible to increase the impact of descaling by around 35% in the roughing mill and 60% in the finishing train.

As an example, **figure 8,** gives the higher descaling effect of Mini Scalemaster nozzles with adapters compared with Scalemaster nozzles based on spray patterns photographed in production.

Downgrading of hot strip product due to scale scars has been reduced by a total of 55% thanks to the modernization of the descaling equipment, **figure 9.**

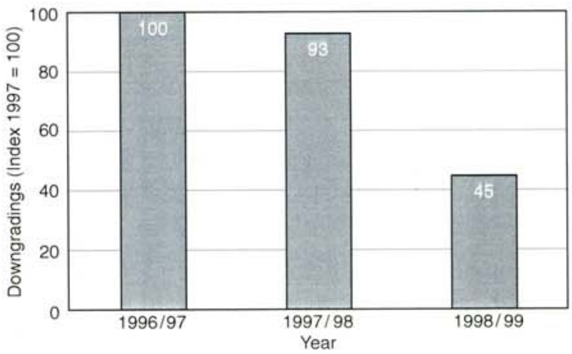

Figure 9. Development of downgradings of hot strip due to scale scars in the Bochum works (Index 1997 = 100)

The work described was only possible thanks to very close cooperation between nozzle manufacturer, production, maintenance and revamping departments. ■

References

[1] *Büchele, W.:* Stahl und Eisen 115 (1995) No. 10, p. 71/72.
[2] *Kroll, A.:* Stahl und Eisen 119 (1999) No. 9, p. 89/93.
[3] *Becker, E.-U.; Degner, M.; Thiemann, G.; Voss, G.:* Stahl und Eisen 119 (1999) No. 8, p. 107/110.

Descaler 1: Roughing mill Year	1997		1998	
Spray bar top/bottom Nozzle type	Top FUH 666.906.12	Bottom FUH 666.887.12	Top Scalemaster 694.906.27	Bottom Scalemaster 694.887.27
Number of headers	1	1	1	1
Number of nozzles per header	30	30	30	30
Flow rate [l/min]	139.75	139.75	139.75	139.75
Spray pressure [bar]	125	125	125	125
Nozzle angle [°]	16	16	16	16
Distance nozzle/strip (index 1997 = 100)	100	100	100	100
Impact (index 1997 = 100)	100	100	133	138
Descaler 2: Finishing mill Year	1992	1993	1998	1999
Nozzle type	FUH4 666.806.12	Scalemaster 694.806.27	Mini Scalemaster 644.807.27 (with adapter)	Mini Scalemaster HP 642.807.27 (with adapter)
Number of headers	2 top / 2 bottom	2 top / 2 bottom	2 top / 2 bottom	2 top / 2 bottom
Number of nozzles per header	24	24	24	24
Flow rate [l/min]	72	72	72	72
Spray pressure [bar]	110	110	110	110
Nozzle angle [°]	15	15	15	15
Distance nozzle / strip (index 1992 = 100)	Top: 100; Bottom: 100	Top: 100; Bottom: 100	Top: 84; Bottom: 90	Top 84; Bottom: 90
Impact (index 1992 = 100)	100	130	145	160

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