OPTIMISATION OF NOZZLE ARRANGEMENTS ON DESCALING HEADERS

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ABSTRACT

The demand for improved product quality and increased productivity has focused attention on the need for more efficient systems of hydraulic descaling. Nozzle characteristics have been investigated and test procedures developed to measure spray patterns and impact. Improved nozzle characteristics and an optimization of the spray header design result in higher efficiency of the complete system . There are also important operational benefits saving energy and improving product quality which are the objectives when a descaling header is designed. The nozzle manufacturer must have detailed knowledge of the performance of the nozzles under operation conditions and the system design.

Of particular concern are :

1. Nozzle spray characteristics
2. Variables of impact
3. Design parameters of an optimal nozzle arrangement on a descaling header
4. Special solutions for descaling in plate mills, profile rolling and for forged products
5. Conclusion

The paper will focus on these four points in connection with new nozzle types and supporting components and will draw a conclusion at the end.
Figure 1 shows a typical nozzle arrangement and a list of terms and symbols which are used hereafter.

1. NOZZLE SPRAY CHARACTERISTICS

1.1 SPRAY ANGLE

Hydraulic descaling nozzles are normally flat (jet) spray nozzles. The exact definition of the spray characteristics such as spray angle, spray thickness and impact distribution together with the specification of the operation parameters are the first two steps when a spray nozzle is designed. The standardization of descaling nozzles based on the nominal spray angle was introduced many years ago and has proved to be advantageous with regard to header design flexibility and product availability. Four (4) spray angles describing the width of the spray are now very common. These are 22°, 26° , 30° and 40° nozzle tips each available in 13 standard flow sizes (Table I). In order to achieve the above mentioned design flexibility, the spray width is identical for all nozzle tip sizes at identical pressures and spray heights.

1.2 SPRAY THICKNESS

The spray thickness (also often called spray depth) describes the width in the minor axis of the spray. The technical evolution of descaling nozzles reduced the spray depth by almost 50% compared early designs. However, this was only possible with the aid of stabilizers and optimized internal flow conditions of all nozzle components such as those of a “Scalemaster High Performance”. In modern installations with spray heights around 80mm spray depths ranges between 3 and 4mm only (Fig.2).

The impact distribution over the width and thickness of spray can be measured precisely and documented (Fig.2) as described in great details by my Mr. Stafan Schürman in his paper “Measurement and mathematical approximation of the impact of descaling nozzles” presented during the Hydraulic Descaling Conference in 2000. This tool is essential for the design not only of the nozzles but also for a nozzle arrangement on a header as we will hear later in this paper. It goes without saying that the nozzle manufacturer is aiming to achieve an impact distribution as even as possible over the entire width of the spray.

2. VARIABLES OF IMPACT

The impact created by the water jet on the target surface is the predominant factor for effective descaling. The correct definition of the impact is force F in Newton applied over an area A in mm² (Equation 1):

$$\text{Equation 1:} \quad \frac{\text{F in Newton}}{\text{A in mm}^2} = \text{Impact N / mm}^2$$

2.1 AREA OF IMPACT

Having selected one particular nozzle type (size and spray angle) the force depends only on the water pressure respectively on the water flow. If the water pressure is fixed and limited as in many existing installations the only variable to play with, is the area of impact. As Equation 1 suggests, the smaller the area the higher the impact. The spray angle and the spray thickness are the two nozzle design parameters which effect the area of impact. The spray thickness depends on the quality of the internal design of all spray nozzle components. Recent developments have lead to a further reduction of the spray depth by improving and extending the internal water flow zone geometry and reducing the stabilizer wing thickness (Fig.3). A more laminar water flow providing a sharper spray jet with a higher impact was the result.

2.2 SPRAY HEIGHT

The spray height (vertical distance between nozzle orifice and target surface) as a system design parameter plays an important role as it has a direct and strong effect on the spray width, and hence on the area of impact. Due to the typical convergence of every spray jet it is unfortunately not possible to apply a simple trigonometrical equation to describe the change of the spray width as a function of the spray height in order to calculate the area of impact. Furthermore, the convergence differs from one nominal spray angle (22°, 26°, 30° and 40°) to the other and also depends on the water pressure. Figure 4 shows this effect with a rule of thumb of how effective the spray height can influence the impact without putting one additional KW power into the system. Real descaling experiments with a silicon steel test sample under conditions typical for descalers in a thin slab plant were conducted. With a 26° Scalemaster nozzle at a pressure of 240bars and a flow of 27,9 l/min a reduction of the spray

height from 136mm to 90mm resulted in a reduction of remaining scale from 24,9% (Fig.5)to 16,2% (Fig.6).
In practice one can never utilize the full increase of impact as per the rule of thumb because the spray width narrows and more smaller nozzles become necessary to cover the entire width of the rolled stock (Fig.7). Nevertheless, significant improvements could be achieved in both product quality and cost savings in existing rolling mills by reducing the spray height.
Some of these success stories were presented here by mill operators during the last three Hydraulic Descaling Conferences.

2.3 SPRAY ANGLE
For a given nozzle size, water pressure and spray height the influence of the spray angle on the impact is also quite significant because the area of impact is also changing (Fig.8).

2.4 WATER PRESSURE AND FLOW
It is common knowledge that the water pressure is approximately proportional to the impact and that this goes for the water flow, too. More detailed investigations have shown the following results:

- Since the spray thickness tends to narrow at higher pressures it can be said that the impact rises 2,1 times if the water pressure is doubled for a particular nozzle.
- Since the spray thickness tends to widen with the nozzles size it can be said that the if the nozzle is increased so that flow is doubled at a particular water pressure, the impact rises only by a factor of approximately 1,85.

A direct comparison with different water pressures show the influence of this parameter on the impact in Table II.

3. DESIGN PARAMETERS OF AN OPTIMAL NOZZLE ARRANGEMENT ON A DESCALING HEADER

It is very clear that the best spray nozzle can not fulfil the expectations when certain important design principles are not followed when a descaling header is designed.

3.1 SPRAY JET OVERLAP
For a uniform descaling over the entire width of the rolled stock it is essential to secure also a uniform impact of all jets spraying in one row. The nozzle spacing with the pitches between them is not only directly related to the spray height and spray angle, but also to the overlap of two adjacent spray jets. As illustrated in Fig.2 every descaling nozzle shows a certain unavoidable drop of the impact at both edges of the spray jet. The characteristic of this “Edge Drop” depends mainly on the spray angle, whereas the wider the spray angle the larger the width of the edge drop. The nozzle manufacturer should maintain one edge drop characteristic throughout all nozzle sizes belonging to one spray angle family.
The width of the overlap of two adjacent spray jets must be equal to the width of the edge drop. Nozzles of different manufacturers, however also show different edge drops with either sharper or softer characteristics. Consequently it is important to define the edge drop for every nozzle respectively nozzle family allowing the header designer to work with this data.
Undescaled stripes on the surface can be caused by excessive overlap. In such a case the spray jet of the nozzle sitting further behind the adjacent one creates a water layer on the surface

which reduces the impact in the overlap area drastically (Fig. 9). A phenomena which can be seen quite often and shown in Figure 10. No imprint on the lead plate of the front spray jet is visible caused by this effect. In this case the inclination angle was also too big.
If the overlap is too small, or if there is a gap where no water impinges directly on the surface, stripes of remaining scale will eventually lead to rolled in scale.
The nozzle offset angle of 15° against the centre axis of the header pipe is already built into the nozzle tips. This feature prevents that spray jets of one row collide with each other.

3.2 INCLINATION ANGLE

The inclination (lead) angle has been discussed in various papers during previous conferences but it is still a subject of debates. The effect of the area of impact has already been described above. It is also a fact that with the increase of the inclination angle both the spray width and the spray thickness are increased as well. Hence the area of impact increases, consequently lowering the impact. Measurements confirmed a drop of impact of approximately 18% if the inclination is increased from 15° to 30°. A vertical spray would be ideal in terms of impact, however in practise it is desired that the water loaded with scale particles is directed against the material flow (rolling direction) in order to prevent carry over into the roll bite. On the other hand the descaling water should not travel too far upstream, for instance into the furnace. This can easily happen with inclination angles set at more than 15°.

4. SPECIAL SOLUTIONS FOR DESCALING IN PLATE MILLS, PROFILE ROLLING AND FOR FORGED PRODUCTS

4.1 WATER STOP VALVE

The use of the low water pressure pre-fill function is a standard feature in a modern descaling system in order to eliminate hydraulic shock (water hammers) when initiating high pressure spraying through an open header. However, the low pressure water continuously charged through the open descaling nozzles can cause negative metallurgical effects due to the undesired cooling especially when rolling critical plates (API-pipe or stainless steel grades) during thermo mechanical control processes.
The installation of a check valve (Water Stop Valve WSV) in front of every descaling nozzle prevents water flowing through the nozzles below a water pressure of 8-10bars (Fig.11).

<u>The features and benefits of this product are:</u>

- Only 2 WSV basic versions for all Scalemaster nozzles, Mini and HP types
- Every WSV comes with a filter
- Valve and stabilizer units separate allowing to use standard stabilizers
- Material completely made from stainless steel
- Metallic sealing
- No significant changes of nozzle spray characteristics (width, thickness, distribution))
- Very low impact loss of only approx. 13% (with medium nozzle flow size)
- Very low water flow loss of only approx. 5% (with medium nozzle flow size)
- No modifications of header required
- Very large internal free passages for clogging free operation
- Simple design, all components easy to replace

<u>Typical applications for the WSV :</u>

- Plate mills (finishing and mill descalers)
- Conventional hot strip mills rolling stainless steel where descaling does not take place during every pass (FSB)
- Steckel mills
- All installations having water hammer problems because of non existing pre-fill systems
- When water saving is a criteria even during low pressure bypass charging

4.2 MICRO SCALEMASTER

During the early stages of the development of hydraulic descaling nozzles a very robust and large set of components with outer diameters well beyond 40mm was the solution for spray heights often greater than 300mm. Today the plant requirements changed significantly for :

- Thin slab plants were the rate of slab cooling during descaling had to be reduced
- Descaling of sections (heavy medium & light), rails and rounds which is now common
- Descaling of forged products

All these applications have in common the requirement for small outer nozzle dimensions suitable for spray heights between 50 and 100mm. Moreover, it is desirable to keep the welding nipple diameter of the descaling nozzle to a minimum which reduces the "Swiss Cheese Perforation Effect" on headers and spray rings especially with small nozzle pitches. The Micro-Scalemaster outer welding nipple diameter of only 16mm (Standart-Scalemaster 43,5mm, Mini-Scalemaster 27mm) allows complicated spray ring designs (Fig.12). It also helps to reduce the header pipe wall thickness for flat product descaling in thin slab rolling mills. This is a remarkable cost saving factor.

5. CONCLUSION

The successful introduction of surface detection systems in rolling mills confronted the rolling mills, the mill designers and the nozzle manufacturers with more descaling system issues than ever before.
The formation of scale caused by complex thermochemical mechanisms are influenced by the chemical properties of the steel and the upstream production processes such as continuous casting and reheating. Hence, not every rolled in scale problem can be solved by optimising the nozzle and header arrangement. However, experience has shown that a systematic problem solving approach is necessary to identify shortcomings of a descaling system and to eliminate them. The points discussed in this paper shall serve as a guide line. They shall also help to distinguish between facts and pure theories. The facts described have been established through real measurements and have been confirmed by numerous plant installations.
The new products such as the Scalemaster High Performance, the Micro Scalemaster and Water Stop Valve are solutions for the state of the art rolling mills. They are indispensable components for the production of high quality steel at competitive costs.

References :

1.) Büchele W, New Developments in Descaling Hot-Rolled Products, MPT Intn. 5/1995
2.) Schürmann S, Measurement and Mathematical Approximation of the Impact of Descaling Nozzles, Hydraulic Descaling Conference, London 9/2000
3.) Wolf M.M, Scale Formation and Descaling in Cont. Casting and Hot Rolling, I&SM 1/2000

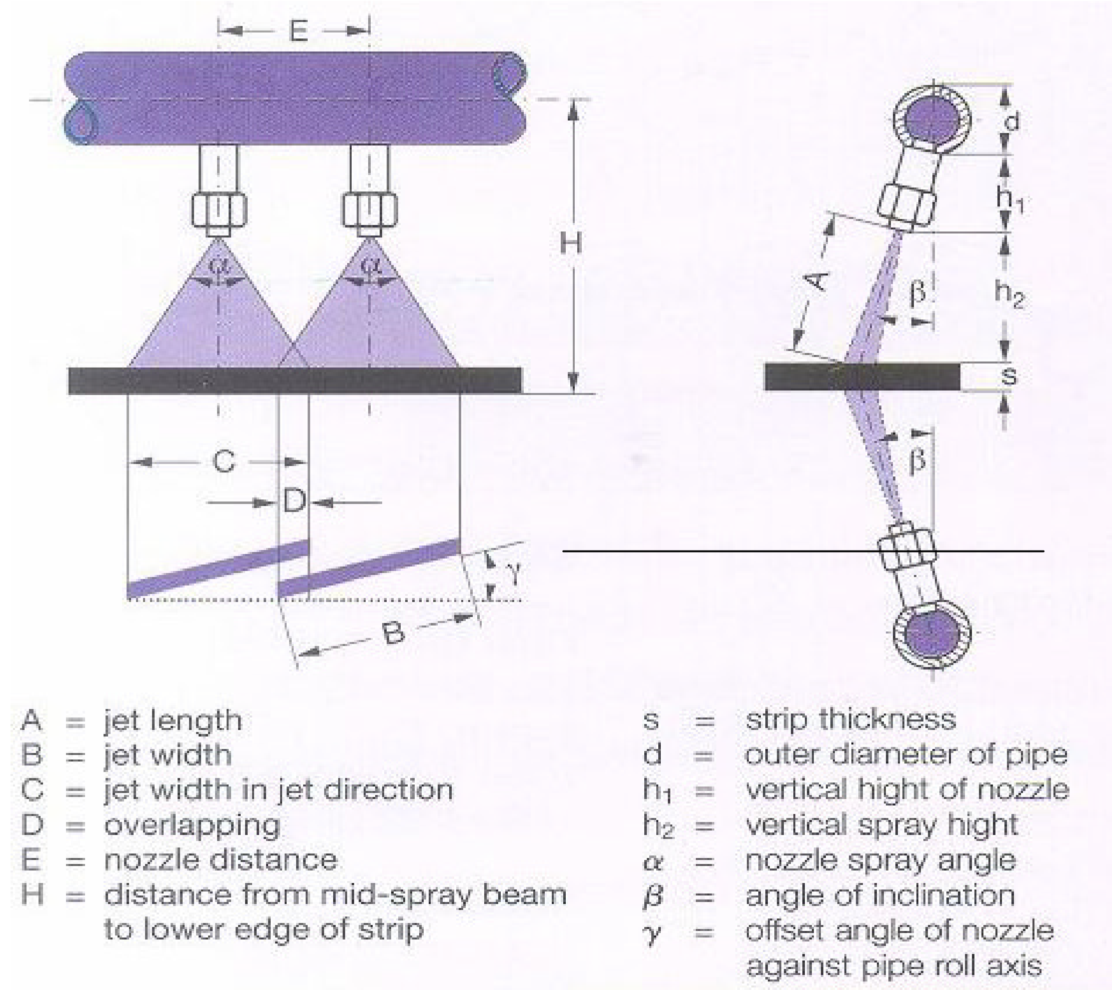


Fig.1: Nozzle arrangement with list of terms and symbols

Flow rate for water ($\dot{V}$)					
p = 100 bar (1450 psi)		p = 200 bar (2900 psi)		p = 400 bar (5800 psi)	
[l/min]	[US Gall./min]	[l/min]	[US Gall./min]	[l/min]	[US Gall./min]
12,00	3,17	16,97	4,50	24,00	6,34
15,00	3,96	21,21	5,60	30,00	7,92
18,00	4,76	25,46	6,73	36,00	9,52
23,00	6,08	35,53	9,39	46,00	12,16
28,00	7,40	39,60	10,46	56,00	14,80
36,00	9,51	50,91	13,45	72,00	19,02
45,00	11,89	63,64	16,81	90,00	23,78
58,00	15,32	82,02	21,67	116,00	30,64
72,00	19,02	101,82	26,90	144,00	38,04
89,00	23,51	125,87	33,25	178,00	47,02
112,00	29,59	158,39	41,85	224,00	59,18
125,00	33,03	176,78	46,70	250,00	66,06
134,00	35,40	189,50	50,07	268,00	70,80

Table I: Scalemaster sizes each available with 22°, 26°, 30° and 40°

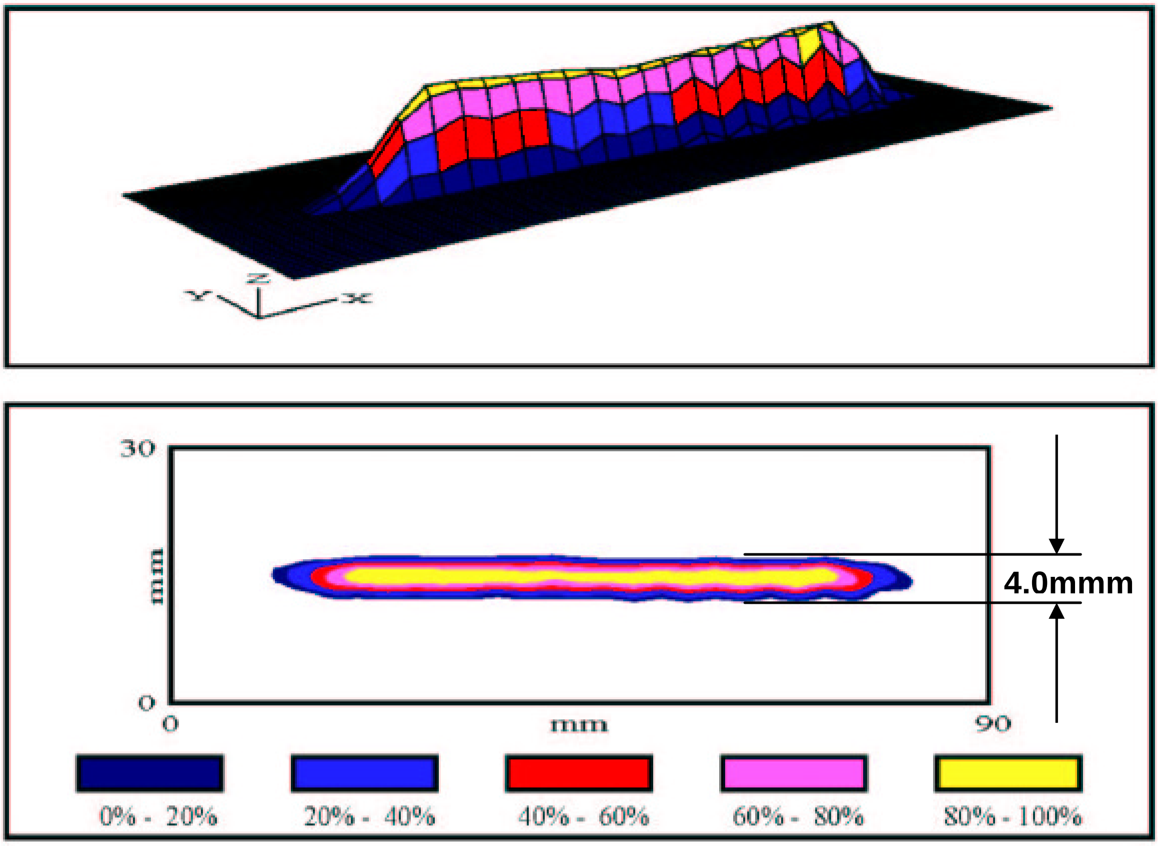


Fig. 2: Impact measurement of Scalemaster HP, 40° with 90 l/min at 400bar, max. impact 2,3N/mm at 80mm spray height, spray thickness 4,0mm

Fig. 3: Scalemaster HP (High Performance) with optimised internal flow geometry

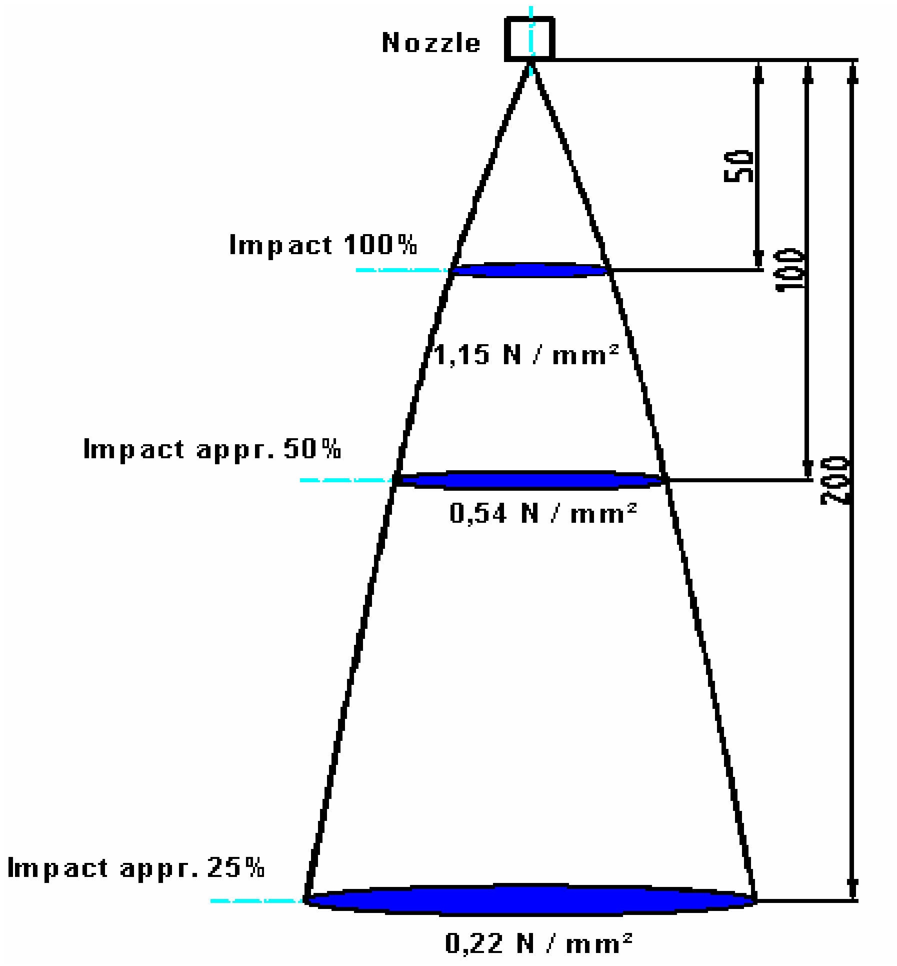
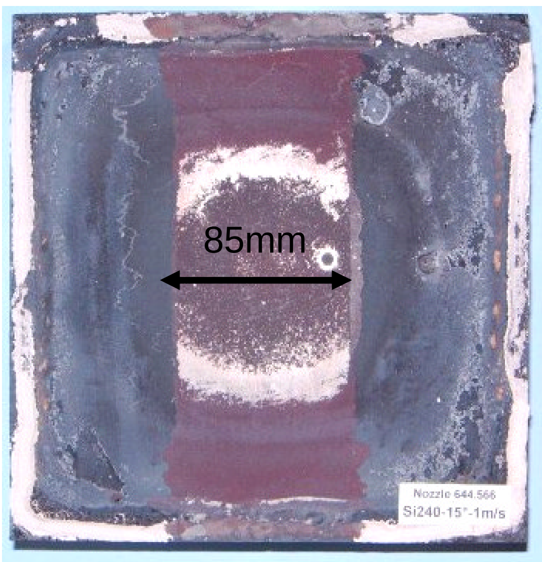
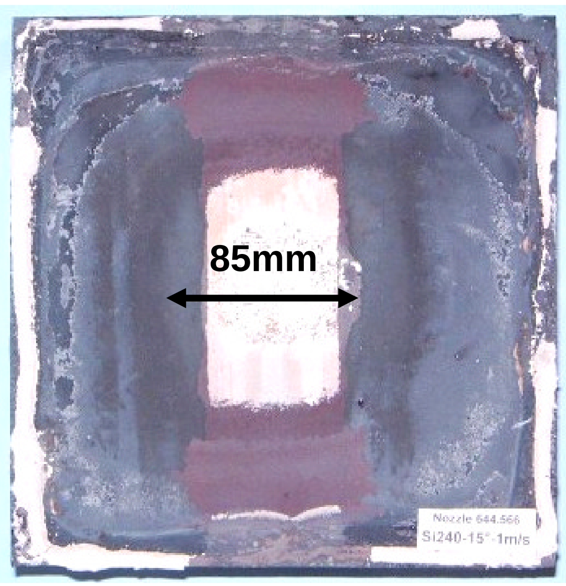


Fig.4: Effect of spray height on impact for a Standard Scalemaster with a flow of 25,5 l/min at 200bars and 26°

<table>
<tr><td colspan="2">Silicon steel descaled with Mini Scalemaster 644.566.27 at 240bars, speed 1,0m/sec</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig. 5: Test plate, descaled at a spray height of 136mm. Remaining scale 24,9%</td><td>Fig. 6: Test plate, descaled at a spray height of 90mm. Remaining scale 16,2%</td></tr>
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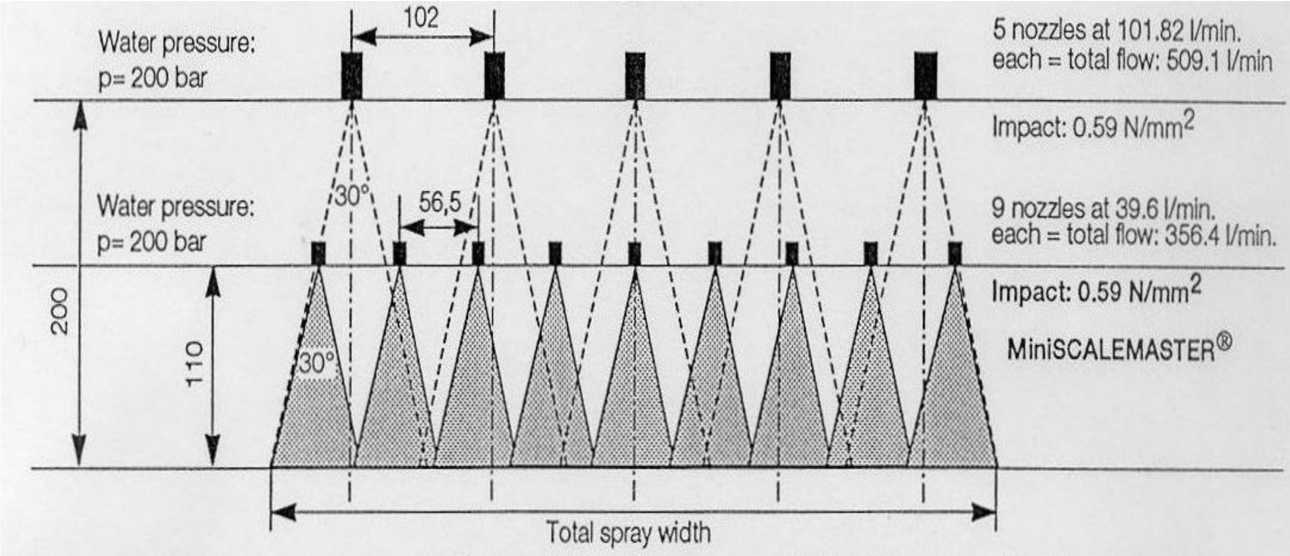
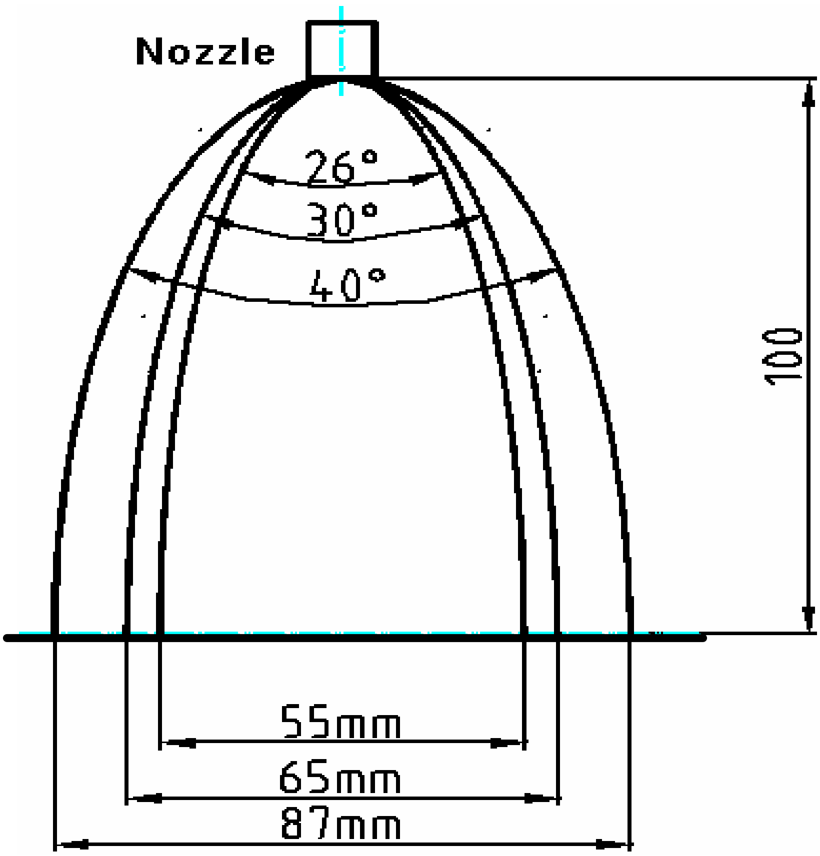


Fig. 7: Example of two nozzle arrangements at different spray heights with identical impact and significant reduction of water flow



Spray angle	Impact
26°	**100%**
30°	**88%**
40°	**69%**

Fig. 8: Change of spray width and impact at different spray angles

Scalemaster Type	Spray angle °	Water pressure bars	Water flow I/min	Spray jet width mm	Spray jet Thickness mm	Total force N	Max. Impact N/mm²
694.566.27	26	100	18,00	57	3,80	42	0,26
694.566.27	26	200	25,50	58	3,60	84	0,54
694.566.27	26	300	31,20	58	3,40	126	0,84
694.566.27	26	400	36,00	59	3,20	167	1,17

Table II : Influence of water pressure on impact

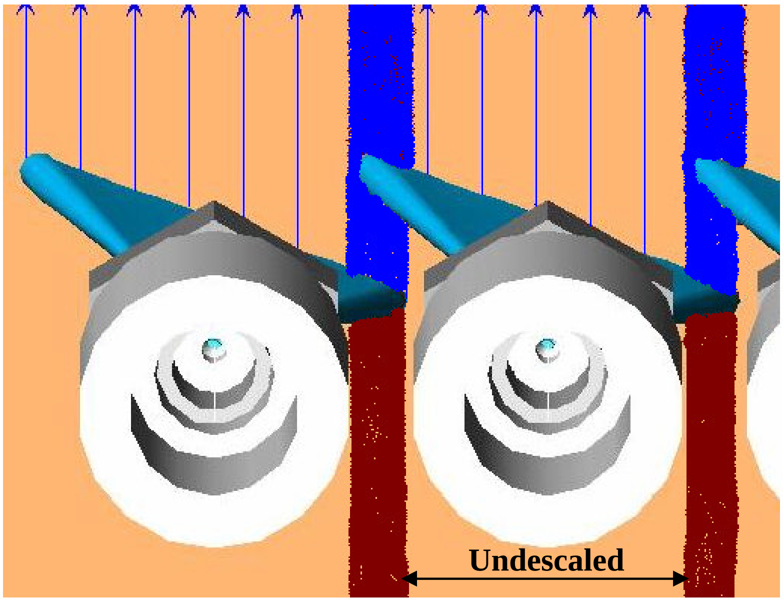


Fig. 9: Water layer effect caused by overlap being too big

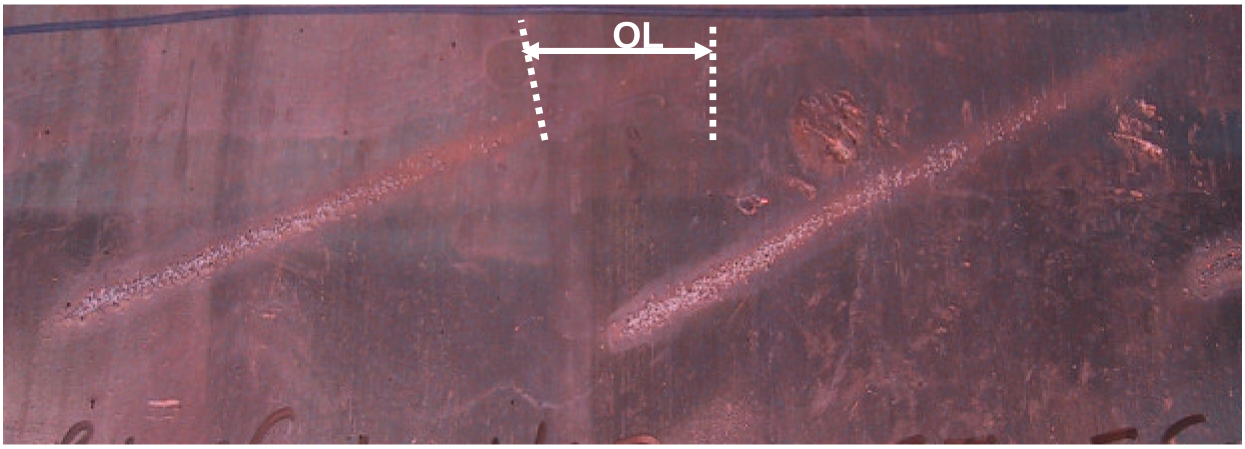


Fig.10: No imprint on lead plate in the excessive overlap area “OL”

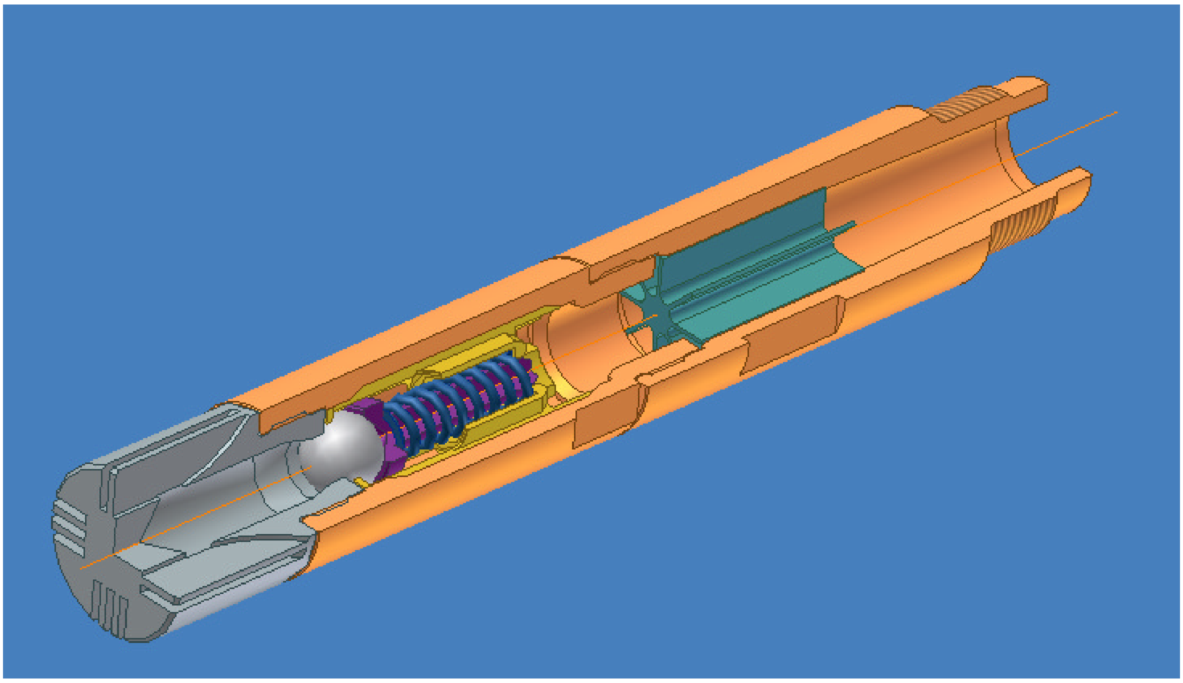


Fig. 11: Water Stop Valve WSV prevents undesired cooling of plates and strips

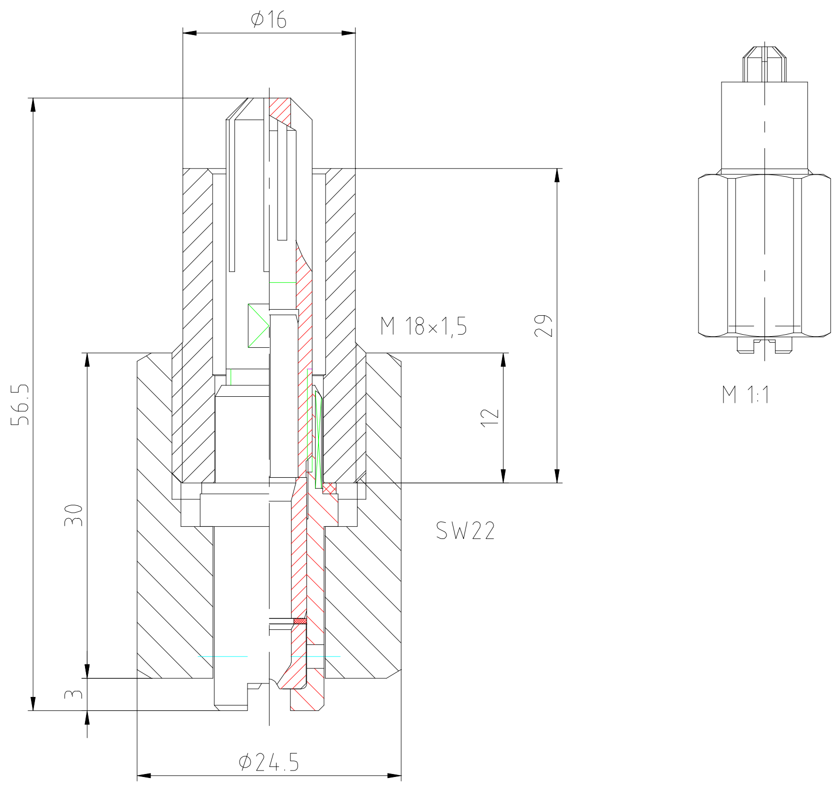


Fig. 12: The robust Micro Scalemaster with small dimensions