SIMULATION AND OPTIMISATION OF A WIPING KNIFE ON THE LAB SCALE

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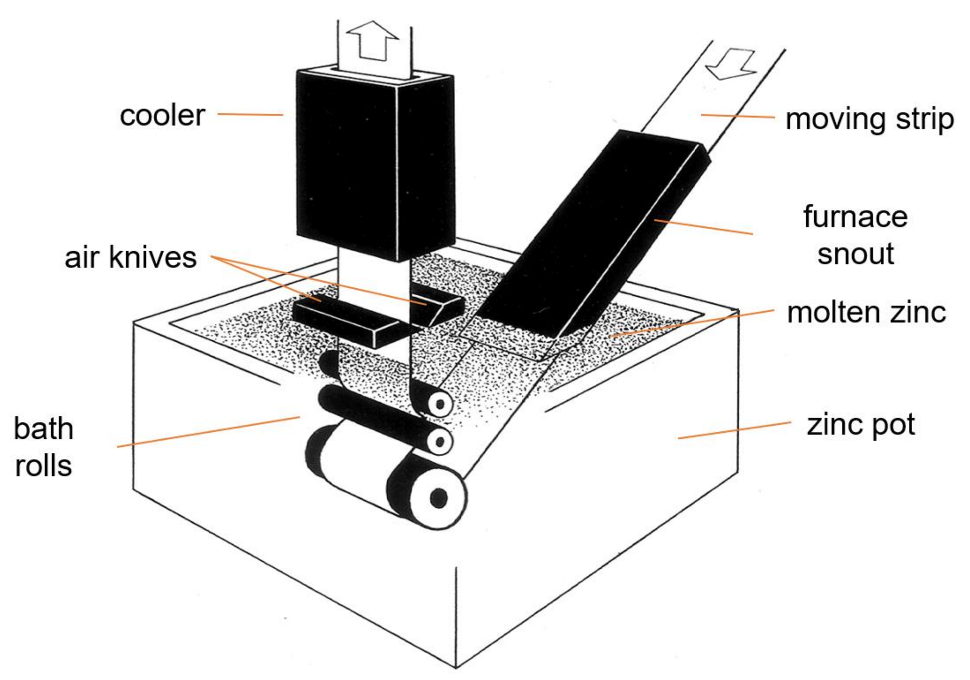
Gas jet wiping during hot dip galvanizing [1, 2, 3, 4]

- Heat treated steel strip continuously passing through zinc bath and dragging up molten zinc on the surface.
- Film thickness is usually much thicker and inhomogeneous than customer request.
- A pair of two high-speed opposing plane jets adjust the film thickness by removing any excess molten zinc.
- Coating thickness is reduced to few micrometers, referred to as gas jet wiping.
- Nitrogen or compressed air is applied for the gas jet, the nozzle is commonly called air-knife.

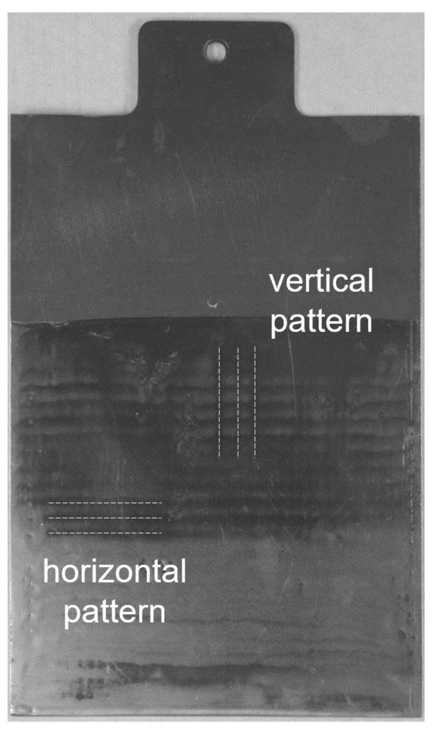


Schematic view of galvanizing process.

Galvanizing simulator of Salzgitter

- Research and simulate the galvanizing process of steel sheet on a lab scale.
- Air-knives applied to wipe down excess molten zinc just like on industrial lines.
- Existing air-knives designed solidly and used for years.
- Coating thickness from 7 µm on, but variation of about ± 20 %.
- Sample appearance, especially waviness, and thickness homogeneity improvable.

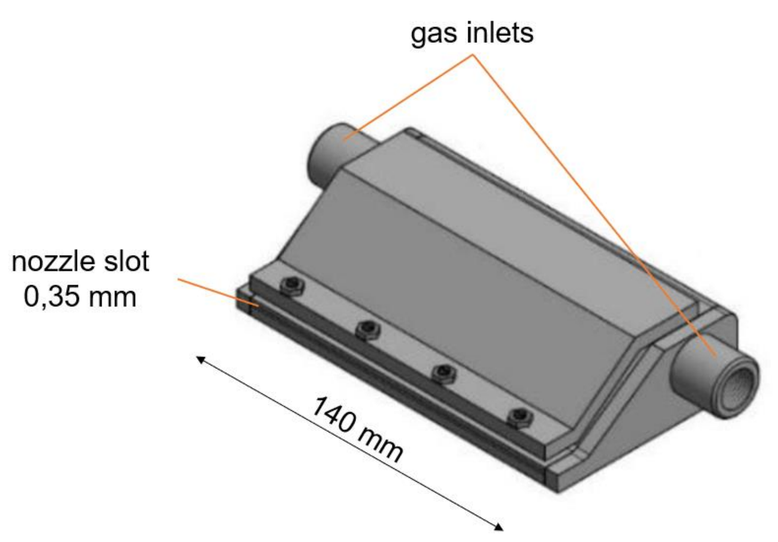
Galvanizing simulator of SZMF.



Galvanized sample with wavy coating.

Numerical Modeling

- Structured mesh with hexahedron-elements, unstructured mesh only for complex shapes as for the final design.
- Element number between 550.000 and 750.000
- Set value for incoming mass flow of N2 as initial condition for transient simulation, exponentially increasing to prevent dynamic influx effects.
- Boundary conditions of nozzle exit: atmospheric pressure, temperature 295 K, 200 – 250 m/s
- Turbulence model: SST
- Evaluation of flow condition by streamline, velocity vector visualization, flow velocity over time and turbulence intensity Tu.



Schematic view of the existing nozzle.

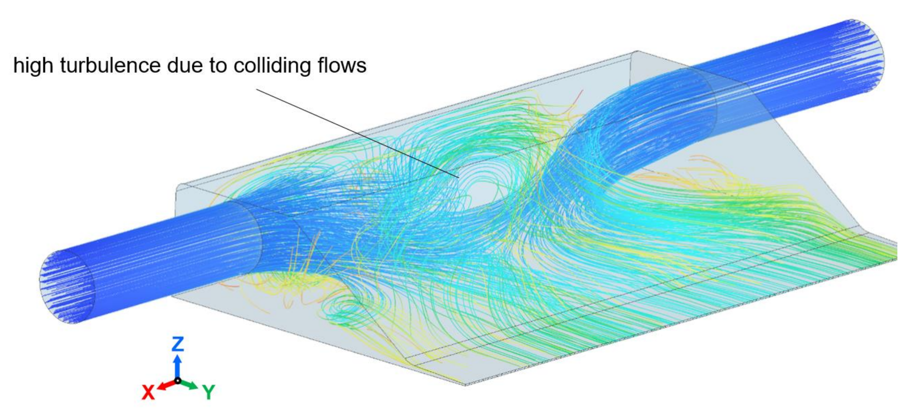
$$Tu = \frac{U'}{U} = \frac{\sqrt{\frac{1}{3}\left(u'^2_x + u'^2_y + u'^2_z\right)}}{\sqrt{u_x^2 + u_y^2 + u_z^2}}$$

$$u'^2_{x,y,z} = \frac{1}{1-n}\sum_{i=1}^{n}\left(u_i - \bar{u}_i\right)^2$$

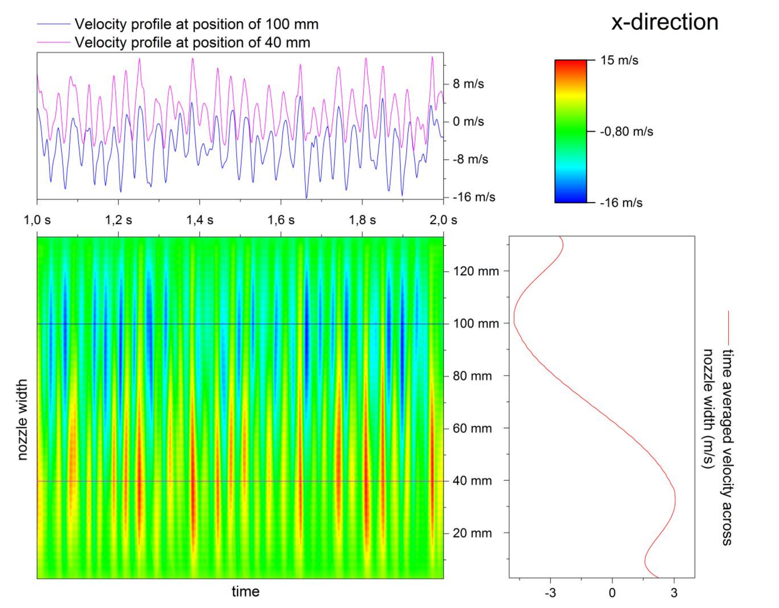
Turbulence intensity Tu relates velocity fluctuations U' to average velocity U, small values indicating a less turbulent flow condition.

Present air-knife design

- Highly turbulent flow inside the nozzle.
- Collision of incoming flows, creating chaotic conditions caused by feeding from both sides.
- Wide variations of gas flow at nozzle exit.
- Fluctuations in x-direction particularly strong due to missing measures of flow deflection and vortex reduction.
- Turbulence intensity is biggest at nozzle centre for the same reason.
- Presumed fluidic disadvantages confirmed.



Streamline visualization of gas flow inside present air-knife (respresentive snapshot, colour gradient stands for different runtime of flow).



Time dependent flow velocity in x-direction at the nozzle exit.

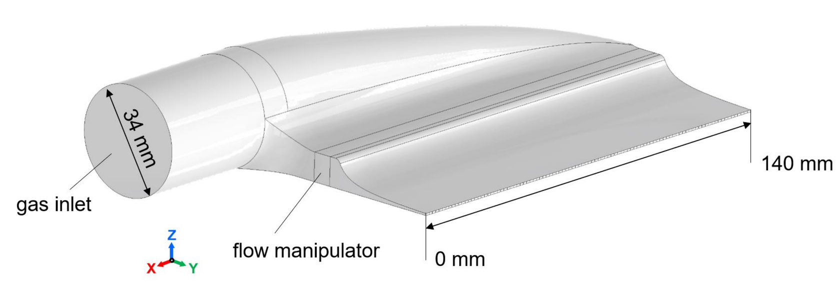
New air-knife design

Fluidic features

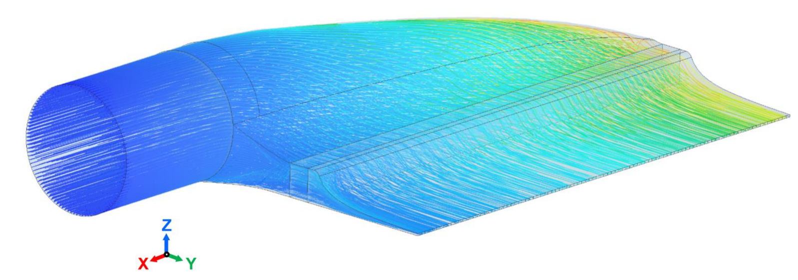
- Gas feeding from one side to avoid flow collision.
- Increased cross-section of feeding pipe to reduce flow velocity causing less turbulence.
- Tapered distribution chamber to compensate the decreasing volume flow (radius decreases as per root function, so that cross-section decreases linear).
- Rounded edges to minimize vortices, especially directly at inlet and end of chamber.
- Flow manipulator to reduce turbulence and straighten the flow after deflection.
- Exit channel with nonlinear convergent contour accelerates gas flow as constantly as possible.

Results of CFD-Simulation

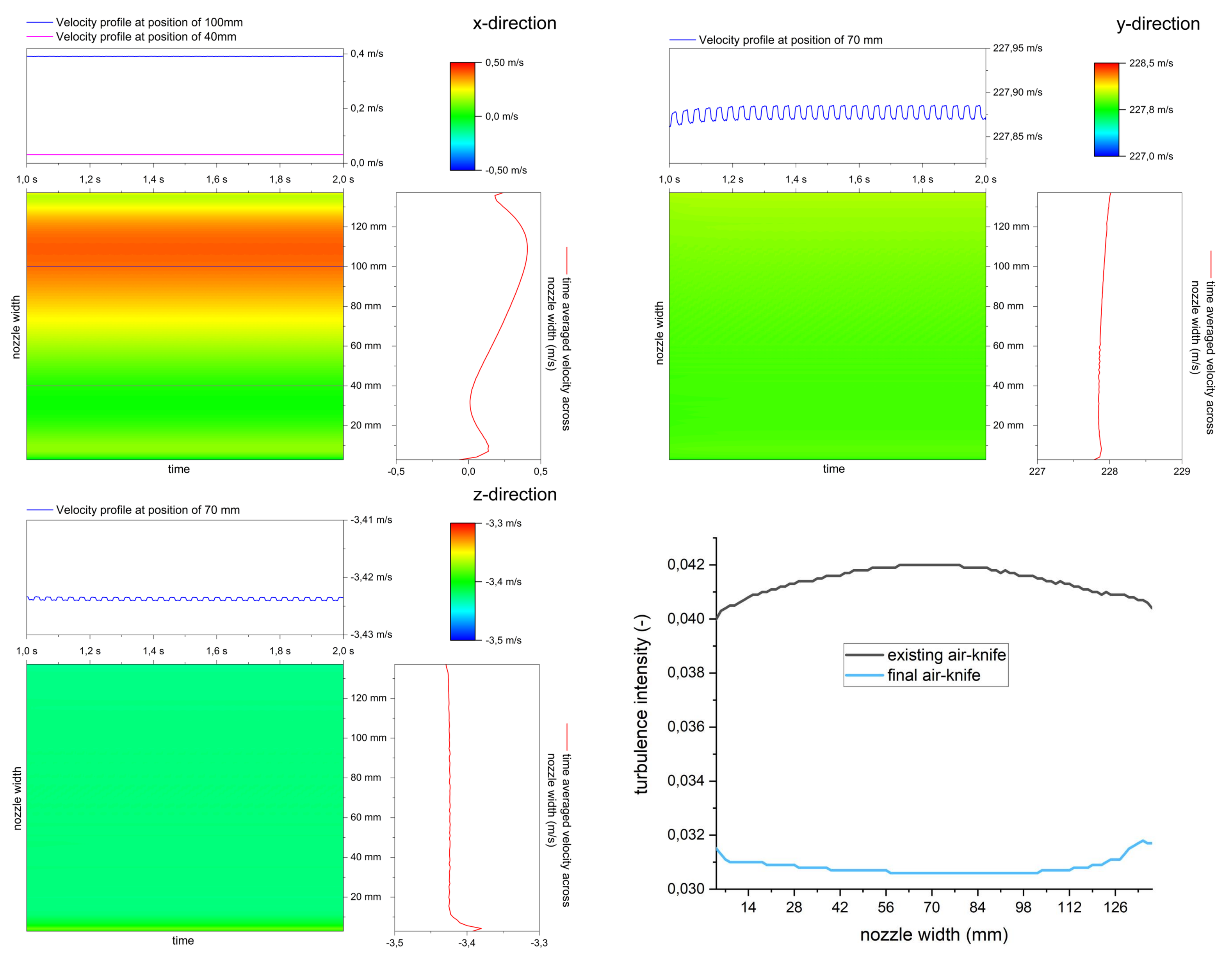
- Very steady flow without large vortices inside the nozzle.
- At nozzle exit homogeneous velocity in main direction (y-coordinate) over time and across width.
- Cross flows and their fluctuations reduced significantly (x- & z-coordinate).
- Turbulence intensity reduced by almost 25 %.



Flow volume of new air-knife design..



Streamline visualization of gas flow inside new air-knife (respresentive snapshot, colour gradients represent different runtime of flow).



Time dependent flow velocity (x-, y- and z-direction) and turbulence intensity.

Conclusions

- Fluidic optimisation potential of the existing air-knife of the galvanizing simulator was identified by using transient RANS simulation.
- Present design lacks fluidic measures for soft flow deflection, turbulence reduction and smooth flow acceleration towards nozzle exit.
- Based on the findings a new air-knife design was developed, which shows almost 25 % less turbulence and a much more even flow.. Velocity variations could be reduced by several orders of magnitude.
- Several fluidic measures like one-side feeding, tapered distribution chamber, flow manipulator and exit channel nonlinear convergent contour are applied to the new design.

References

1) J.A. THORNTON, M.F. GRAFF, Metallurgical Transactions B 7B (1976), p.607.
2) C.H. ELLEN, C.V. TU, Journal of Fluids Engineering 106 (1984), p.399.
3) E.O. TUCK, Physics of Fluids 26 (1983), p 2352.
4) M. DUBOIS, Proc. 8th Int. Conf. on Zinc and Zinc Alloy Coated Steel Sheet, Genova (2011)