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Development and capabilities of X-JET air knives, the new generation of Danieli-Kohler air wiping equipment
Why to develop a new air knife?

Requests of the modern HDG market:

Increase plant productivity:
- increase galvanizing speed for automotive lines up to 200 mpm
- increase galvanizing speed for commercial lines > 200 mpm

Reduce Zinc consumption:
- low coating weights at high speed (Z100, Z80, Z70)
- strict coating weights control accuracy

Increase Quality / Reduce production costs:
- on-board gap & width adjustment systems
- automatic lip cleaner
The market is asking further and further for low coating weights and higher line speeds.

The combination of minimum coating weight and high process speed asks for more demanding wiping performance of the Air-Knives system.
### Nozzle Computational Fluid Dynamics

<table>
<thead>
<tr>
<th>Model</th>
<th>Turbulence description</th>
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<tbody>
<tr>
<td>RANS</td>
<td>k-ε 2 equations : k-ε</td>
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<tr>
<td></td>
<td>v²f 4 equations : k-ε, wall normal turbulent stress v, its dissipation f at walls</td>
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<tr>
<td>RSM</td>
<td>6 equations : Reynolds stresses tensor</td>
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<tr>
<td>LES</td>
<td>2d Direct down to grid scale - Smagorinsky-Lilly subgrid - 1 cell thickness</td>
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<tr>
<td></td>
<td>3d Direct down to grid scale - Smagorinsky-Lilly subgrid - Thickness 2xGap</td>
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<th>Model</th>
<th>Anisotropy resolution</th>
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<tr>
<td>RANS</td>
<td>k-ε None</td>
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<td></td>
<td>v²f Approximate</td>
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<td>Explicit</td>
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![Graph showing static pressure vs. distance from jet axis](image)

![Graph showing velocity magnitude](image)

![Graph showing pressure](image)
Experimental Device – Validation – Nozzle Development

**STUDY AND PROTOTYPE TESTING**
1. EXP validation of LES approach
2. LES numerical study of several solutions
3. EXP test of best solutions

**CRITERIA**
for maximum wiping performance:
1. Higher $P$ peak and narrower $P$ bell $\rightarrow$ higher $\frac{dP}{dX}$ pressure gradient
2. Higher Shear Stress peak
Air Knife Design

At nozzle pressure and temperature transducers
Gap & width adjustment
Angle regulation
Lip cleaner
Air Knife Laboratory Testing

Nozzle dimensional check - Transversal jet uniformity characterization
Pressure regulation respose time – Knife displacement caused by jet
Thermal regime check - Mechanical actuators test
MM Ravenna HDGL#2 – Before Revamping
MM Ravenna HDGL#2 – New Air Knife Equipment

- New air knife nozzles (gap & width adjustment)
- New elevator positioners
- New edge baffles
- Existing blowers
- Existing special piping
- Existing submerged rolls
- Modified sink roll arms
- Modified automation system

New contactless edge baffles
Existing special piping
Angle regulation
MM Ravenna HDGL#2 – Revamping Results

Average production data (Coating Weight vs Line Speed) before and after revamping (circle points) in Marcegaglia HDGL #2 compared with other European HDGL lines (square points).

- **Average Line Speed** increased by 9%.
- **Average Coating Weight** decreased by 15%.

**Coating Weight Data:**
- Before revamping: 147.4 g/m² at 130.1 m/min
- After revamping: 125.3 g/m² at 141.7 m/min

**Comparative Analysis:**
- **280 to 180 m/min**
- **270 to 160 m/min**

**Process Observations:**
- **Edge splashing** using conventional equipment at high speed.
- **No border splashing** observed after revamping.
Performance Improvement from Gen.2 to Gen.3

The X-JET made a jump into the most critical area, that is the high speed – low coating weight area.

There is still margin to investigate the ultimate wiping limit of this nozzles with higher feeding pressure and reduced distance to strip.
Wiping Model

- **Input (wiping conditions)**
  - Strip speed, thickness, roughness
  - Bath temperature and pH content
  - Electrode gap, workstation, angle, strip distance, height over bath
  - Gas composition, temperature, pressure at valve and the regulating valve

- **Database**
  - Jet wiping profiles DB
    - Shear stress, pressure, and heat transfer coefficients profiles as a function of bath gap, workstation, angle, strip distance, gas composition, temperature, pressure at valve
  - Physical properties DB
    - Film density, viscosity, latent heat, Thermal conductivity as a function of temperature and composition
  - Gas supply pressure losses DB
    - Pressure drop from compressor to bath and gas flow rate as a function of gap, pressure at valve and gas temperature

- **Film-Fluid-Dynamics Model**
- **Film-Thermal Model**

- **Prediction**
  - Coating profile, velocity, weight coating and strip temperature

- **Coating (Point)**
  - Coating [g/m²/each]
  - 2 g/m²/each

- **Model Over-estimation Error (%)**

- **Figure**
  - Diagram showing various parameters and their relationships.

- **Table**
  - Parameters and their values:
    - **Wiping gas**
      - Air
      - Nitrogen
    - **Temperature [°C]**
      - 20
    - **Knife setup**
      - Gap (mm): 1.0
      - Angle (deg): 0.0
      - Distance (mm): 5.0
      - Knife height (mm): 400
      - Undershift: 0.00 mm
    - **Strip & Bath**
      - Strip thickness (mm): 0.5
      - Bath temperature (°C): 480
    - **Model**
      - Pressure at valve (bar): 60
      - Simulation height after knife (mm): 400

- **Buttons**
  - Calculate
  - Reset
  - Model output
  - Save journal
  - Save figures
Coated Samples Analysis

**PROFILOMETER**: surface roughness characterization

**SEM-EDXS**: coated samples section analysis
Coated Samples Analysis

GDOES: species concentration within coating thickness
Research and development about Zinc Wiping equipment is still in progress. *DANIELI* research is focused on wiping process, but not limited to it.

**Direct measurement of knifes-to-strip distance.**
Multiple point measurement along the strip width, utilizing eddy current sensors.

**Benefits:**
- additional feed-back for Coating Weight close loop control
- additional feed-forward correction for Coating Weight regulation
- automatic functions such as optimal air knife positioning sequences
- measure of strip cross-bow shape
- cross-bow correction by automated positioning of corrector roll intermesh
- characterization of strip vibration modes

The ultimate limit of the **X-Jet nozzles** has still margin to be investigated.
- feeding with higher air pressure and working at reduced strip to nozzle distance
Future Developments (2/2)

Strip stabilization
→ research about strip electromagnetic stabilizer is in progress.

Alternatives to the conventional Air wiping technology such as the magnetic wiping
→ Lorentz force acting directly on the film (no media, no splashing; no oxidation; no noise; no cooling of metal film)
→ combined action of magnetic field & air wiping

New types of Coating
→ application of wiping technology and modeling to the new types of coating (Zn-Al-Mg; Zn-Al-Mg-Si;.....)