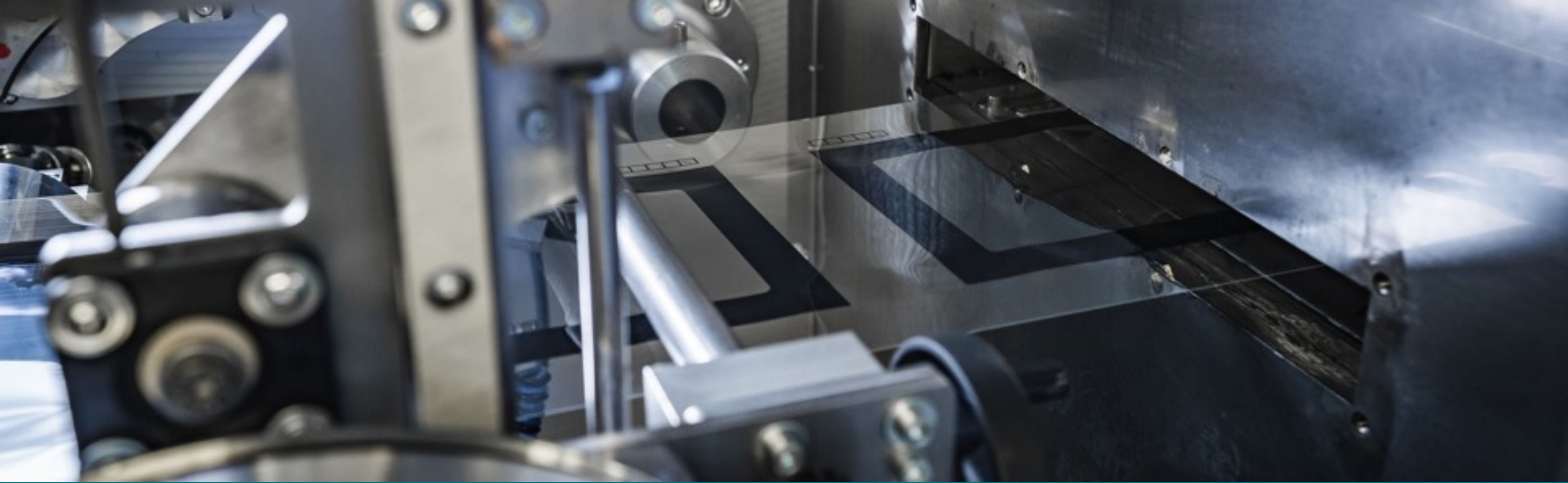


Coatema Slot Dies

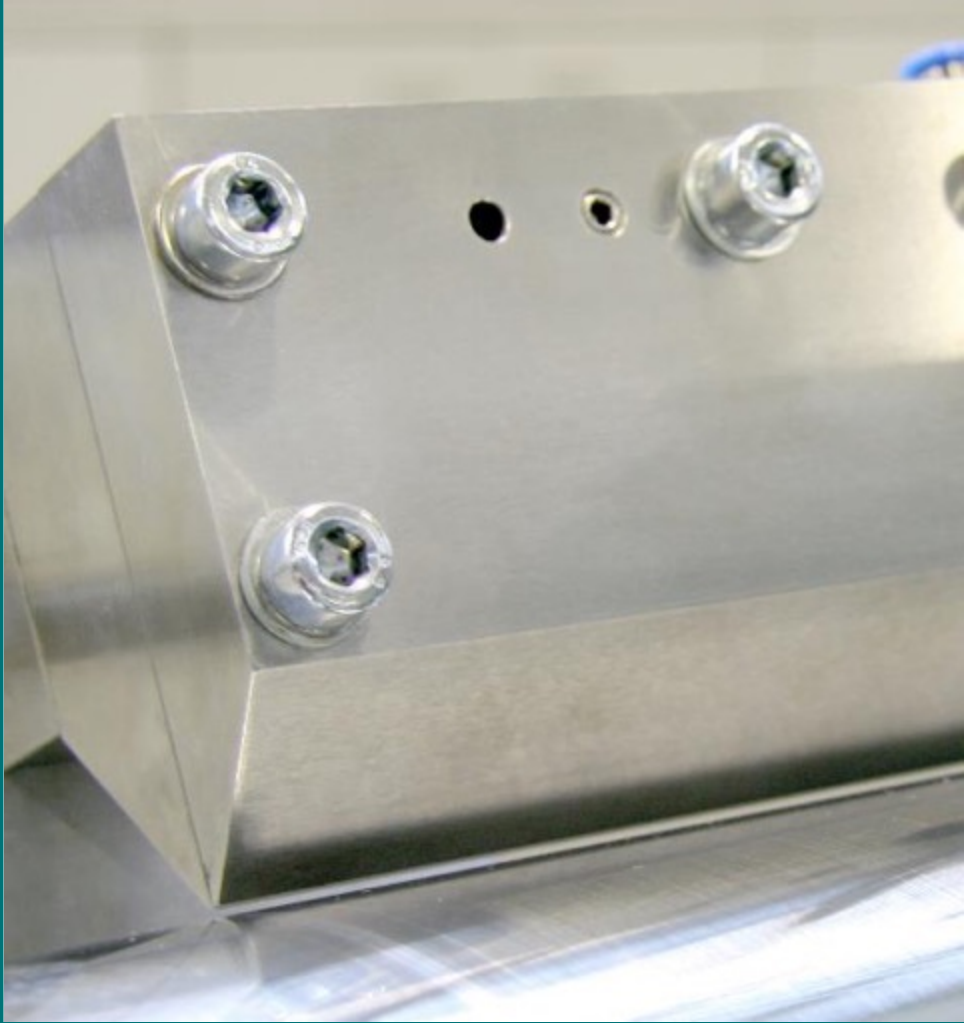
Coatema

08/03/2023

MEMBER OF ATH

7.

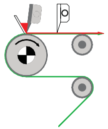
Slot die coating

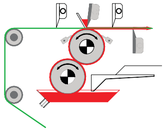


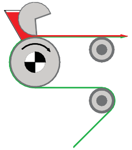
Coating parameters

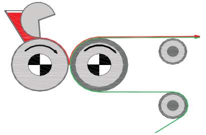
Ink properties	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate speed ✓ Layer thickness ✓ Coating accuracy	✓ Process layout ✓ Tension control system ✓ Material guiding system ✓ Inline parameter control ✓ Quality control	✓ Convection drying ✓ Contact drying ✓ Infrared drying ✓ Sintering ✓ NIR ✓ High frequency ✓ UV crosslinking systems
Substrate	**Pretreatment**	**Environment**	**Finishing**
✓ Surface tension ✓ Dimension stability ✓ Surface structure ✓ Contact angle	✓ Corona ✓ Plasma ✓ Cleaning	✓ Humidity ✓ Temperature ✓ Inert conditions	✓ Calendaring ✓ Embossing ✓ Slitting

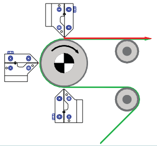
Coating systems

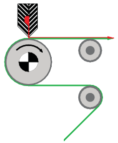

Knife system

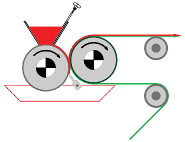

Double side coating system

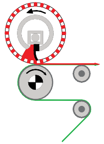

Commabar system

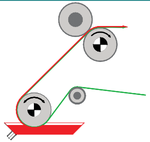

Reverse commabar system

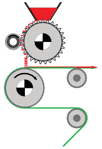

Slot die system

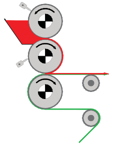

Curtain coating system

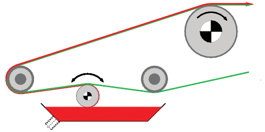

Case knife system

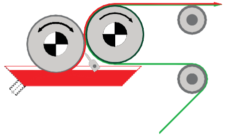

Rotary screen system

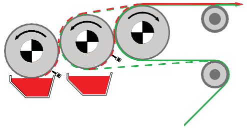

Dipping system (Foulard)

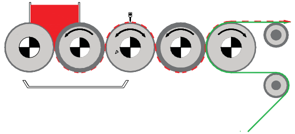

Powder scattering system


Reverse roll coating system

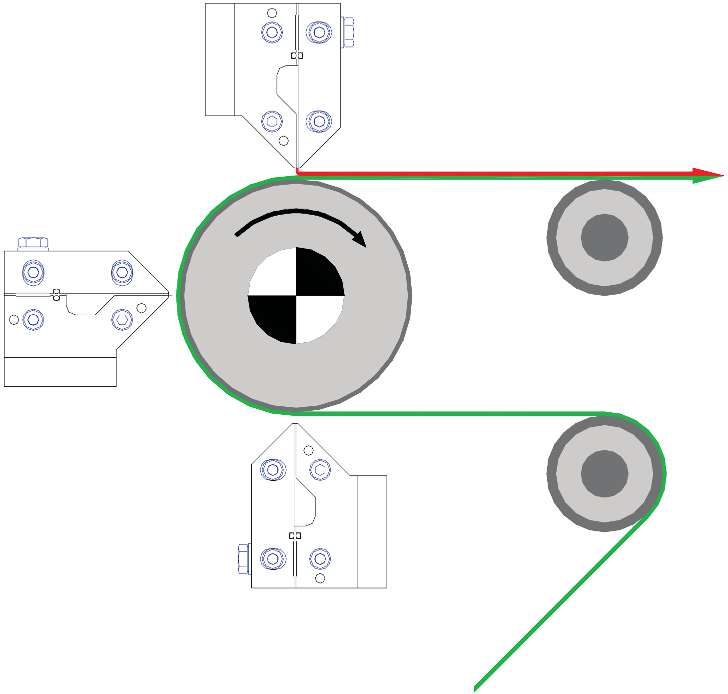

Micro roller coating system


2-roller coating system


3-roller combi coating system


5-roller coating system

Basics of slot die coating – range of parameters



Coating speed
✓ 0.1 – >1000 m/min

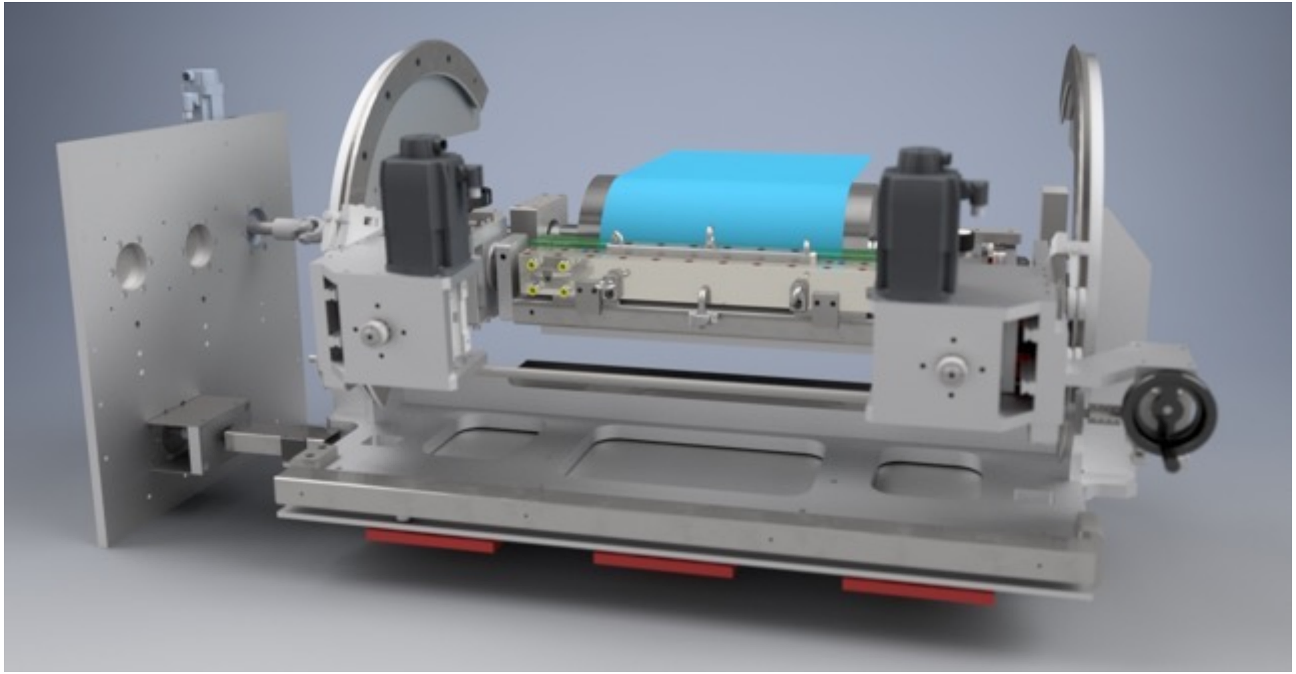
Ink viscosity
✓ 1 – 300 000 mPas

Layer thickness (dry)
✓ 0.1 – >200 µm

Coating accuracy
✓ <1% (2 – 5%)

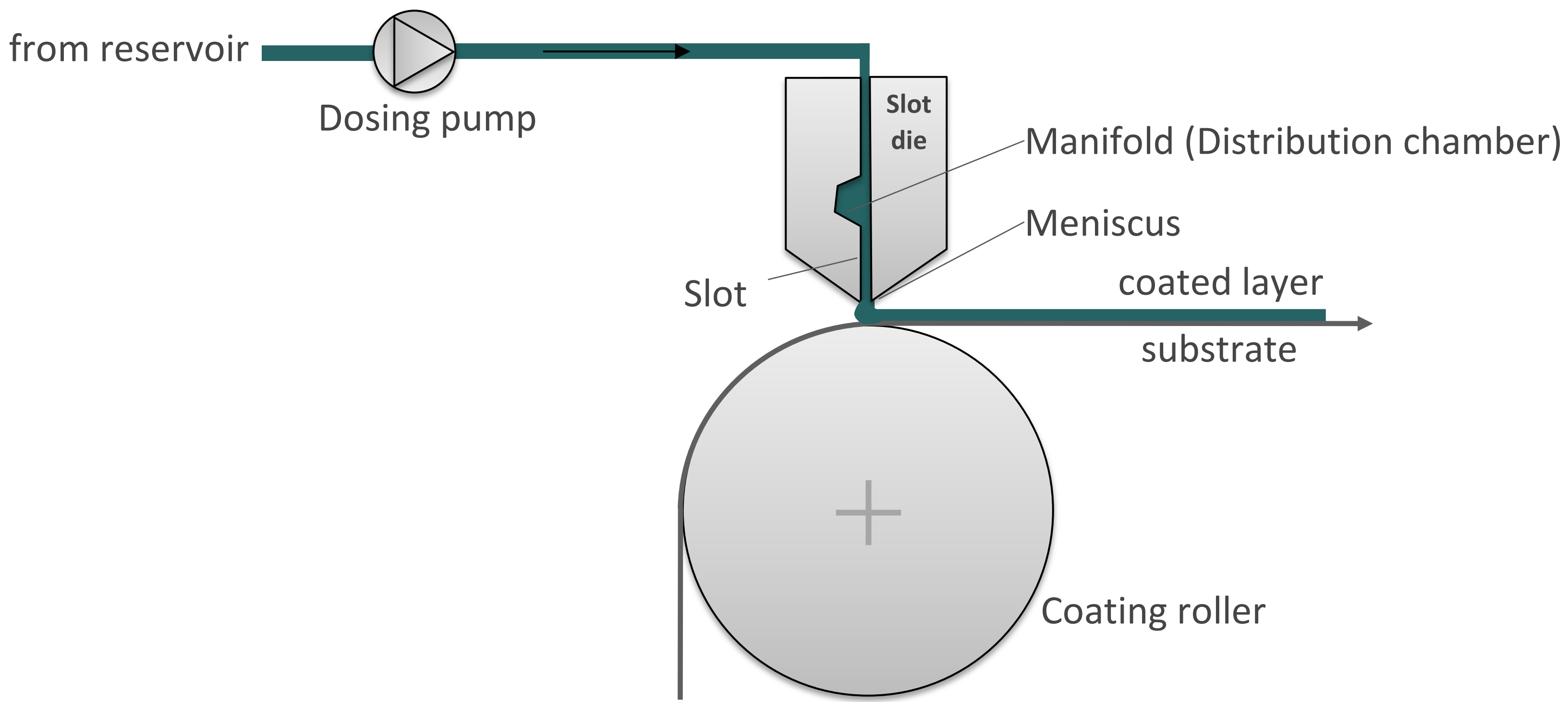
Coating width
✓ up to approx. 3 m

Basic principle

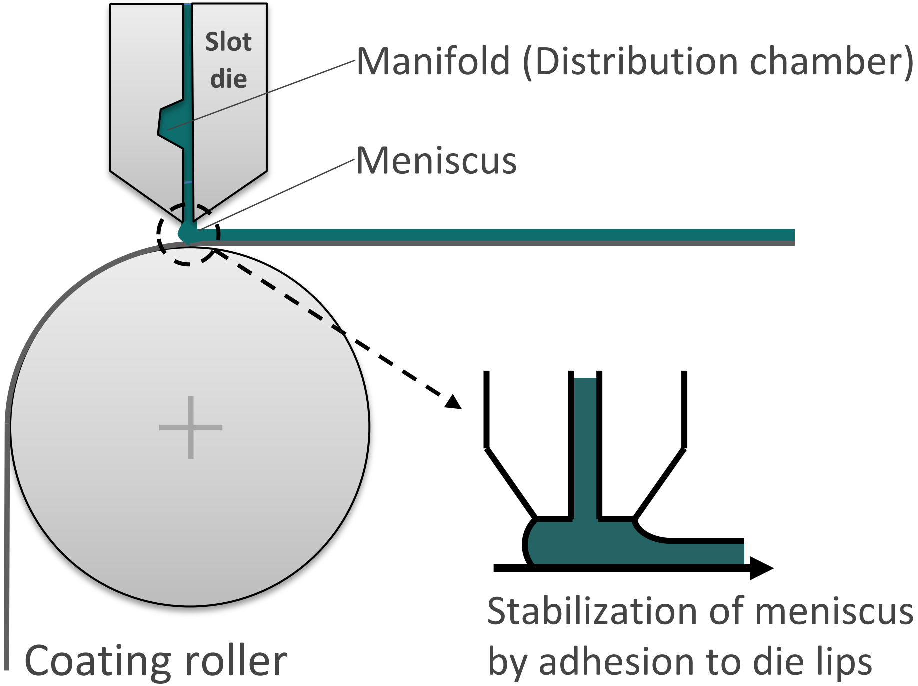


Basic principle

Basic principle



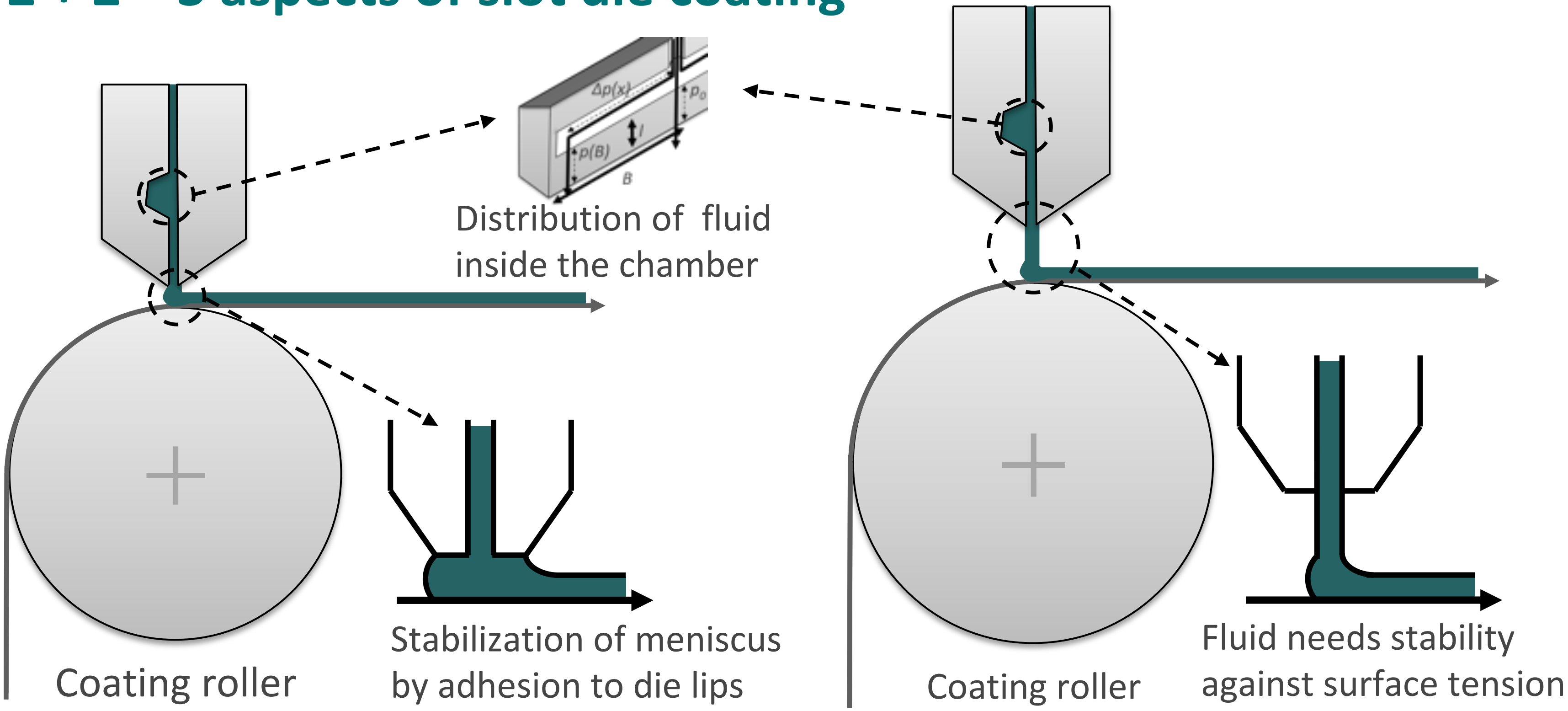
Bead mode



Stabilization of meniscus by adhesion to die lips

- ✓ Meniscus is formed between die lips and substrate
- ✓ Adhesive stabilization of meniscus by die lips
- ✓ Very low minimum flow rate possible
- ✓ For a stable process the range of rheological parameters is limited
- ✓ Preferrably for low coating speed

2 + 2 = 3 aspects of slot die coating



Theoretical background – „Basic“ fluid dynamics for advances geometries

$$\oint \rho v dA = 0$$

Continuity equation (conservation of mass)

Any flow of liquids is described by a set of differential equations:

To describe the meniscus flow of a slot die means, to solve these differential equations for given boundary conditions.

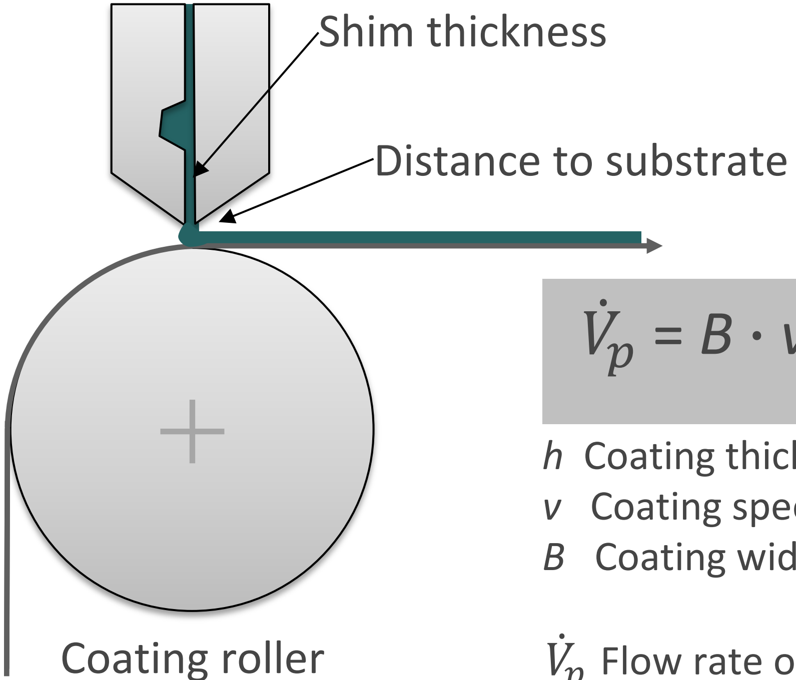
Can be done by appropriate computer programs.

$$\frac{\partial v}{\partial t} + (v\nabla)\, v = \frac{(-\nabla p + \eta \Delta v + f)}{\rho}$$

Navier-Stokes-equations (equations of motion for incompressible fluids, ρ = const)

Δ, ∇= differential operators

Theoretical background



$$\dot{V}_p = B \cdot v \cdot h$$

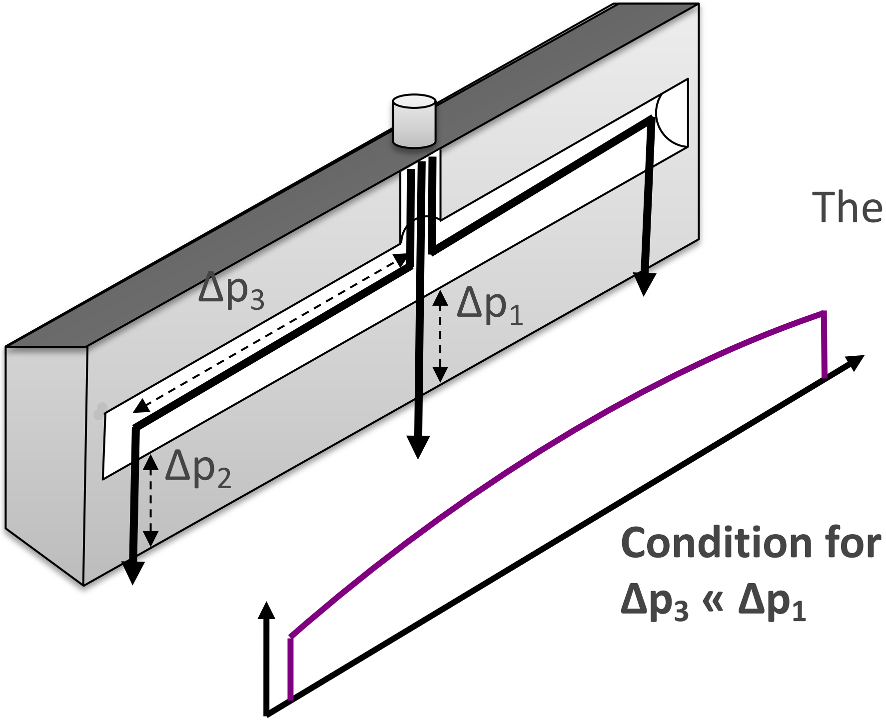
h Coating thickness wet
v Coating speed
B Coating width

$\dot{V}_p$ Flow rate of the pump

Contrary to a widespread misunderstanding the wet coating thickness does not depend on the shim thickness.

Shim thickness and distance to substrate only help to stabilize the meniscus.

Why should a slot die coat homogeneously?

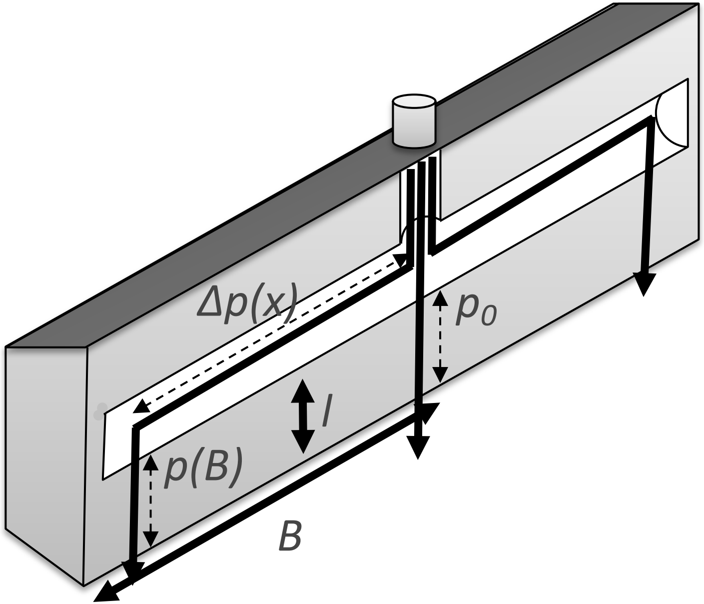


Theoretical thickness profile

Condition for good profile

$\Delta p_3 \ll \Delta p_1$

Fluids in the manifold: 1.5D approximation



Pressure drop Δp(x) via pumping through finitely sized distribution chamber leads to:

Theoretical pressure profile:

$$p(x) = p_0 \cdot \frac{\cosh \frac{W-x}{\lambda}}{\cosh \frac{W}{\lambda}}$$

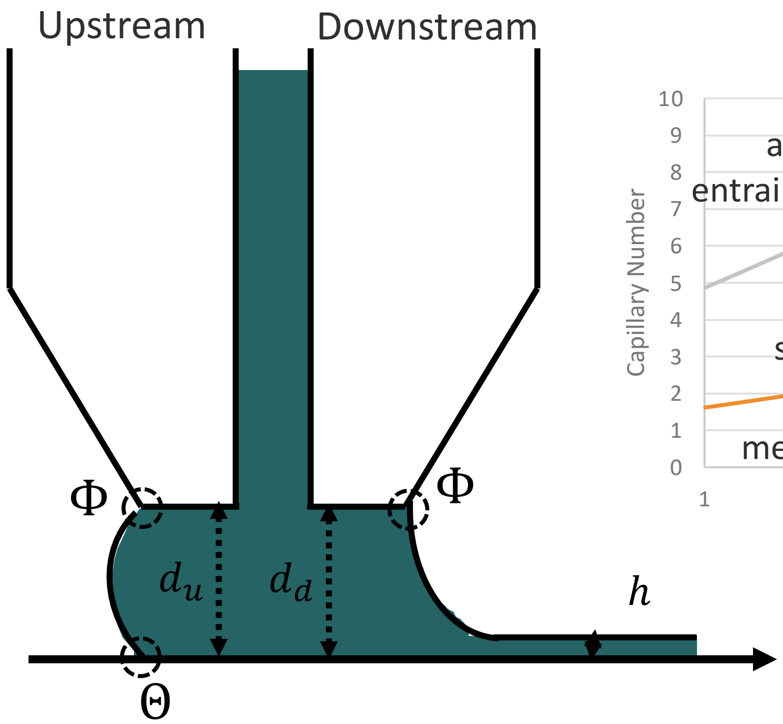
Theoretical thickness profile:

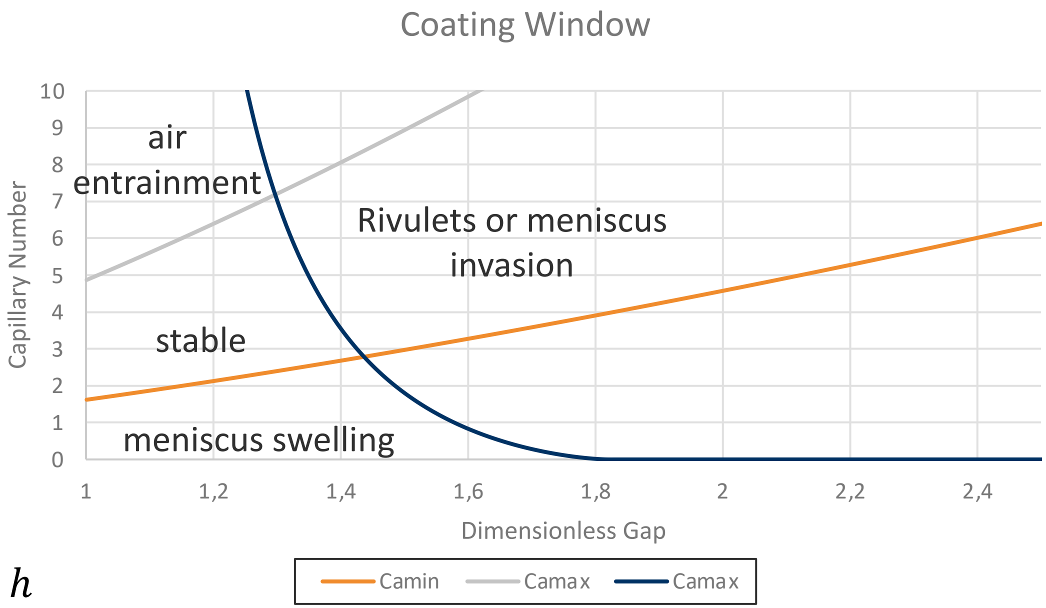
$$h(x) = \frac{B \cdot h_0}{\lambda} \cdot \frac{\cosh \frac{W-x}{\lambda}}{\sinh \frac{W}{\lambda}}$$

$$\lambda = \sqrt{\frac{3\pi \cdot l \cdot r^4}{2\delta^3}}$$

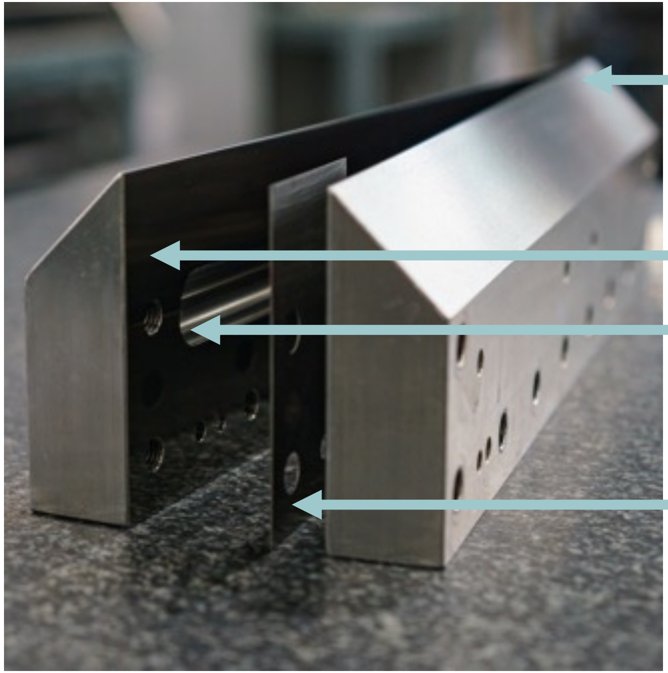
„slot die geometry parameter“

Calculation of the meniscus stability





Coatema standard layout – one design among many available



Lips

Slot area

Manifold

Shim

Improving the coating profile

- ✓ Large manifold, long slot area, highly parallel lips (standard)
- ✓ Coat hanger design
  - ✓ Profile is compensated by a tilted manifold
  - ✓ Conical manifold cross section to keep flow speed constant (optional to prevent precipitation)
  - ✓ Works perfect for adequate rheology only
- ✓ Slot width adjustment
  - ✓ Slot width is locally narrowed or widened to adjust the local flow resistence
  - ✓ Slot width can be modified by microns only. So despite adjustability the die has nevertheless to be highly precise and a sufficient manifold volume is necessary (the adjustment is a fine tuning only)

Increasing homogenity: Coat hanger design

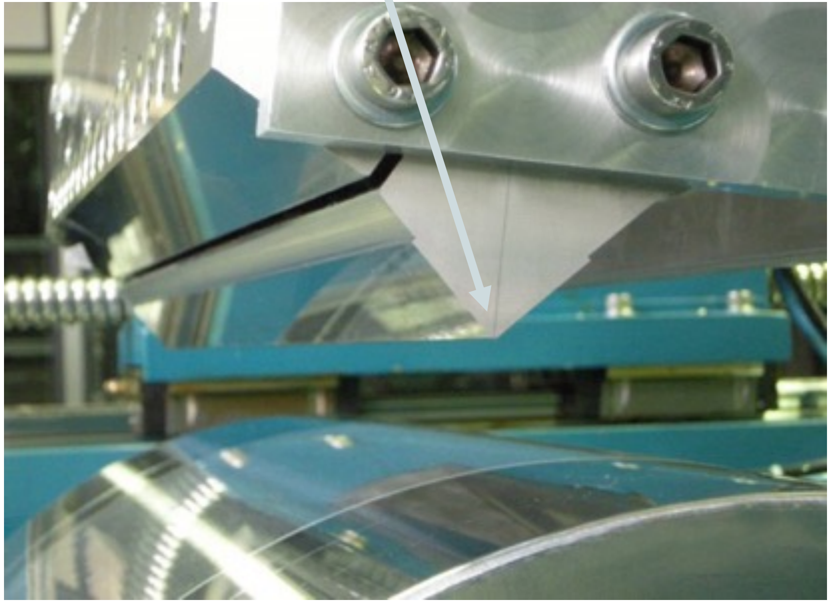
Manifold small
to minimize dead
volume
(optional conical
to prevent
precipitation)

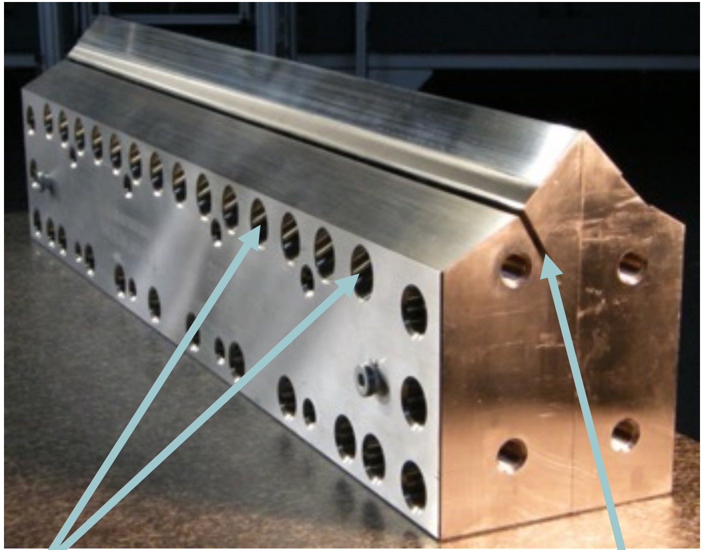
Tilted manifold
to correct the
pressure profile

Long slot area

Increasing homogeneity: The last 1 %

slot (shim edge)





Differential adjustment screws

space for bending the die lip

Increasing homogeneity: The last 1 % automatized

Computerized adjustment of slot width or gap width

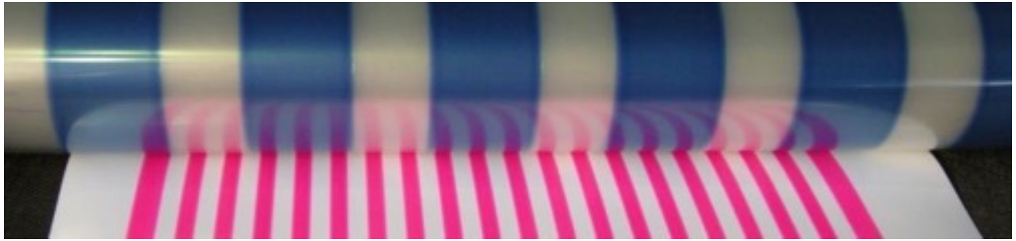
Slot width: for uniformity

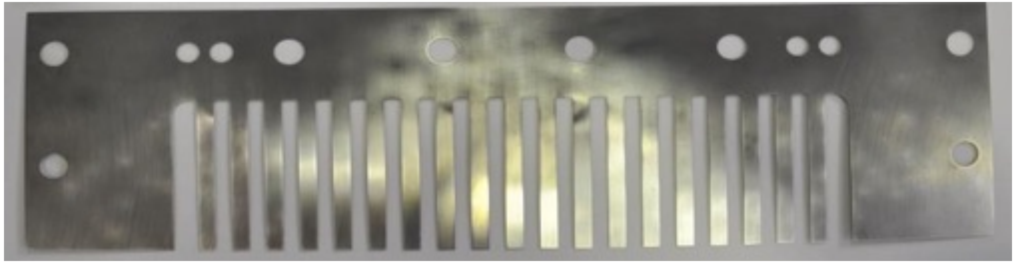
Gap width: for very small coating windows

Structured coating – levels of complexity

		Current status
1	Full area, homogeneous	Requirements are met, thickness profile variation of 0.5 %
2	Stripes downweb	Requirements are met, good edge definition
3	Stripes crossweb (intermittent coating)	Requirements are partially met, edge definition of 0.5 – 1 mm depending on liquid
4	Arbitrary patterns	Requirements are not met, concepts for realization exist, research project is going on

Level 2 – downweb stripes

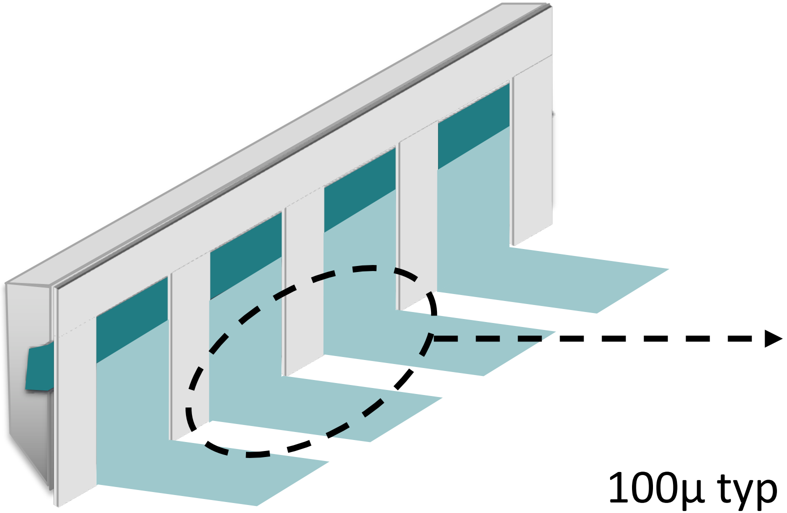




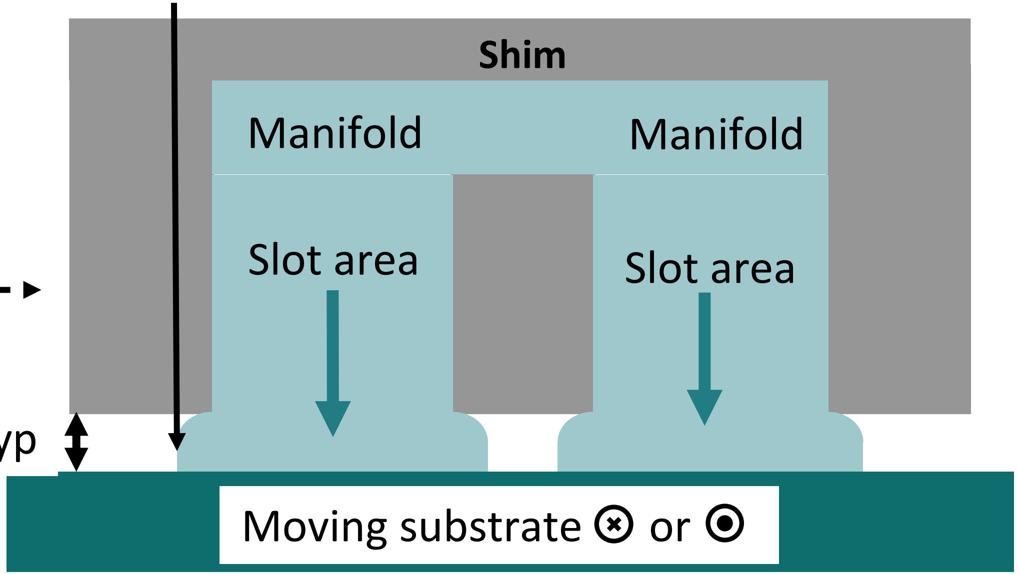
Downweb stripes of different width …

… are made by appropriate shims, lasercut from steel or kapton

Level 2 – downweb stripes

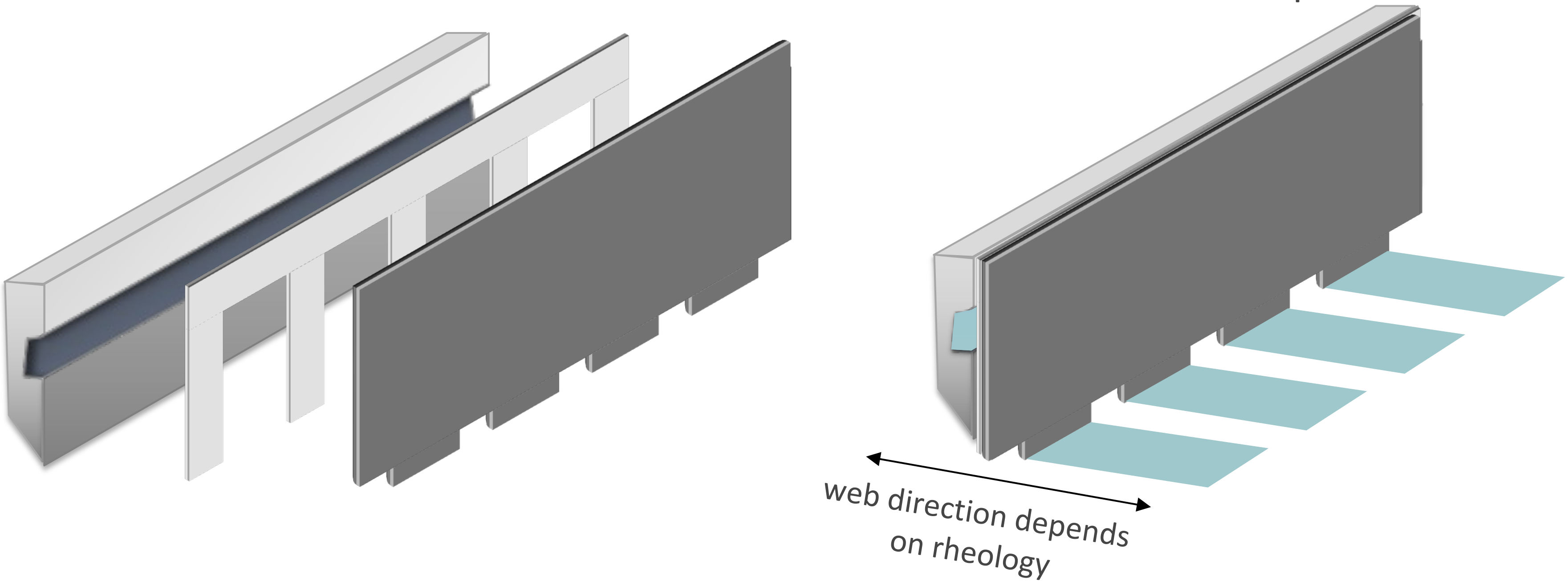


Problem:
Stripe widening by capillary forces at the edges of the shim teeth

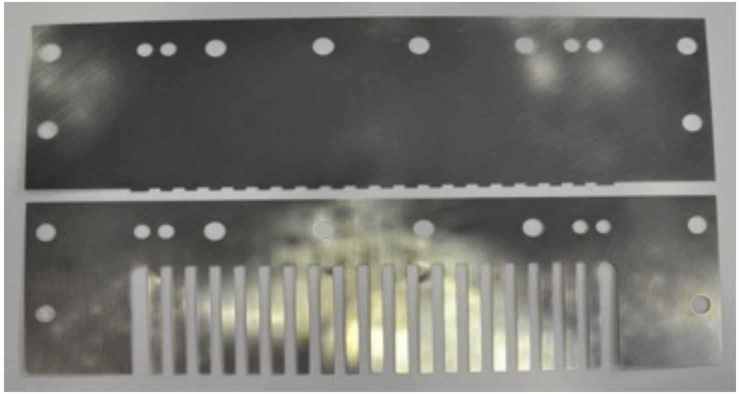


Level 2 – downweb stripes

Manifold + Shim + Meniscus guide = well defined stripes



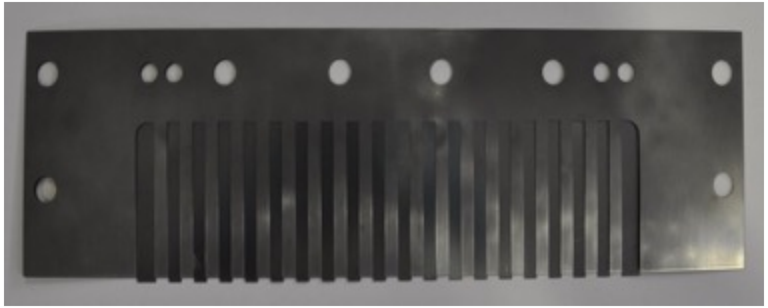
Level 2 – downweb stripes

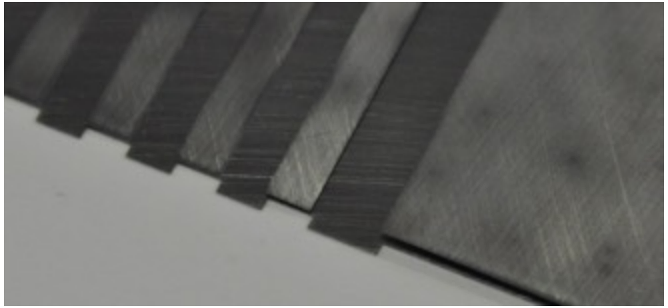


Meniscus guide

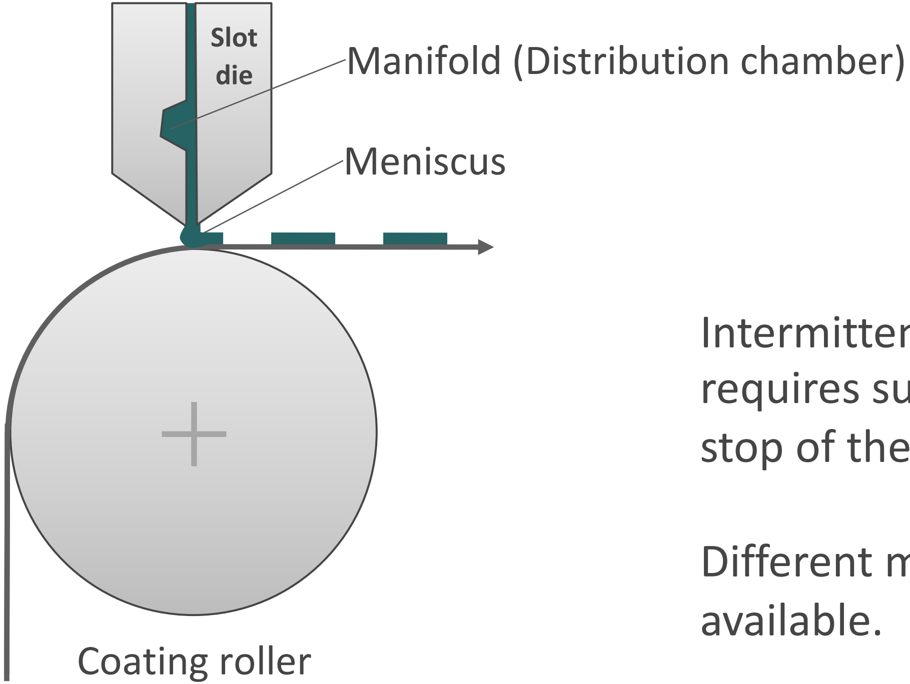
Shim

Meniscus guide + shim





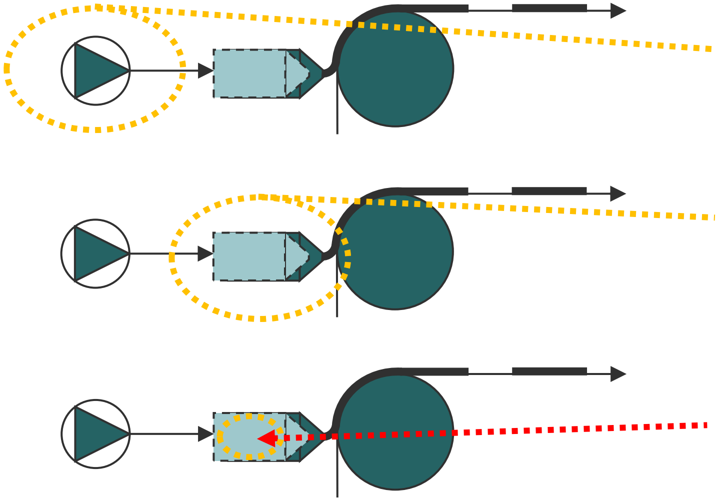
Structured coating – crossweb stripes (intermittent)



Intermittent coating requires sudden start / stop of the fluid flow.

Different methods are available.

Standard techniques for intermittent coating



Pump:
stop – reverse – restart

Slot die body:
move back – move forth to minimum gap – move back to working gap (wedge procedure)

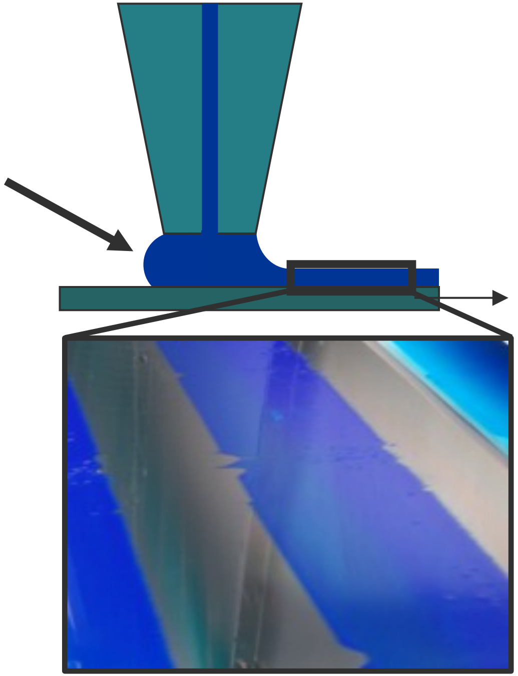
Slot die internal:
stop and redirect the flow by shutters and valves. Pump flow continues, die flow stops.

All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge defintion is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

Structured coating – reason for bad edges at low viscosity

- ✓ Mensicus has to be interrupted
- ✓ Low viscous liquids do not break along a straight line
- ✓ Meniscus has to be sucked back and restored
- ✓ Speed is of essence

→ For low viscosity, all of the three methods are too slow and too indirect



PI-SCALE
SHAPING THE FUTURE IN OLED LIGHTING

PHOTONICS21
PHOTONICS PUBLIC PRIVATE PARTNERSHIP

Structured coating – new concepts for low viscosity liquids

Two new concepts allow to interrupt and restore the meniscus much faster:

✓ **Double chamber slot die**
with modified chamber geometry and Piezo driven suck back pump

✓ **Switching lip slot die**
with a Piezo driven lip opening mechanism that sucks back the meniscus right where it is

PI-SCALE
SHAPING THE FUTURE IN OLED LIGHTING

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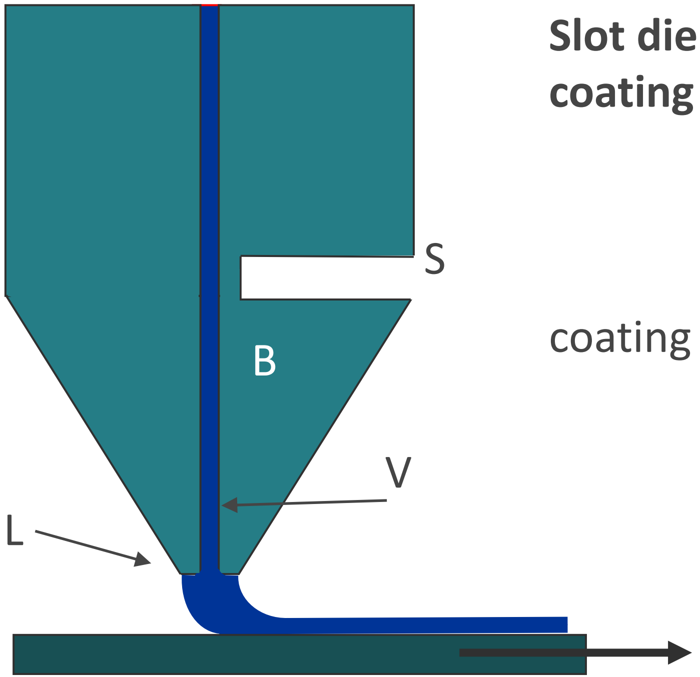
Structured coating – the switching slot die lip



Slot die with movable lips:
coating mode

coating works as usual

L lip
V slot volume
B bendable lip
S bending slot

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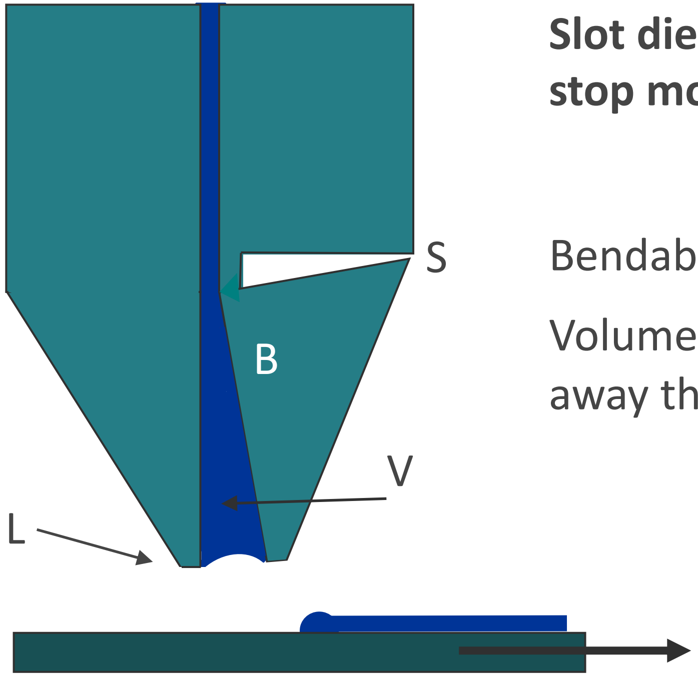
Structured coating – the switching slot die lip



Slot die with movable lips:
stop mode

Bendable lip B flips open

Volume V increases and sucks away the meniscus

L lip
V slot volume
B bendable lip
S bending slot

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PHOTONICS[21]
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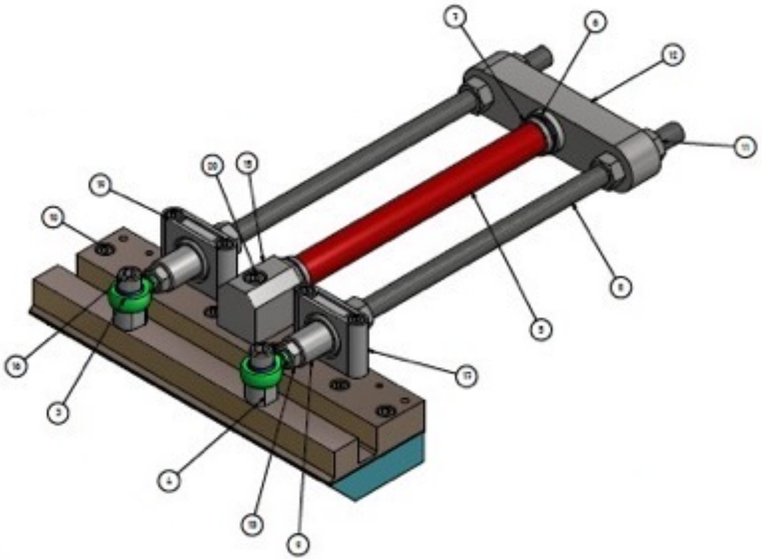
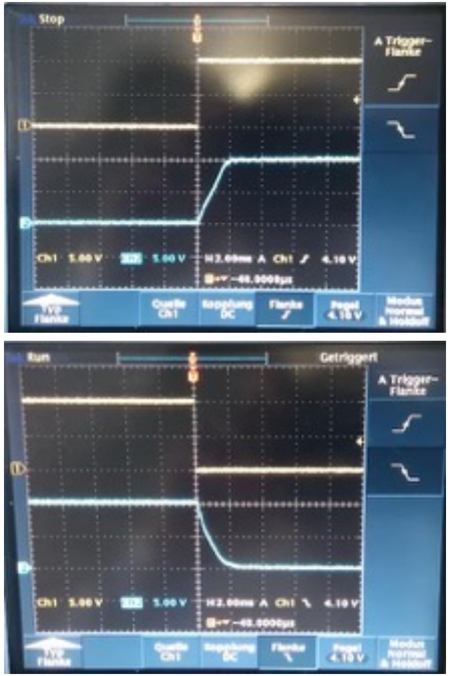
Structured coating – technical implementation with Piezo-Drive



Extremely fast action:
within few ms from coating to stop mode and vice versa

Control Voltage

Piezo Response



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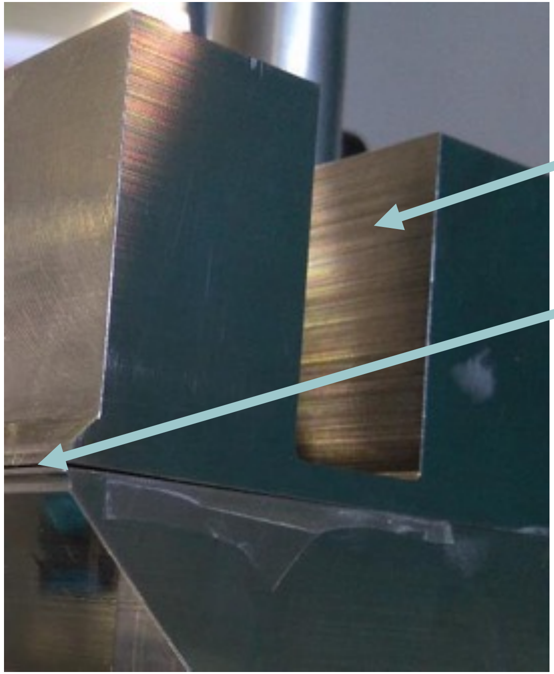
Structured coating – technical implementation with bendable lips

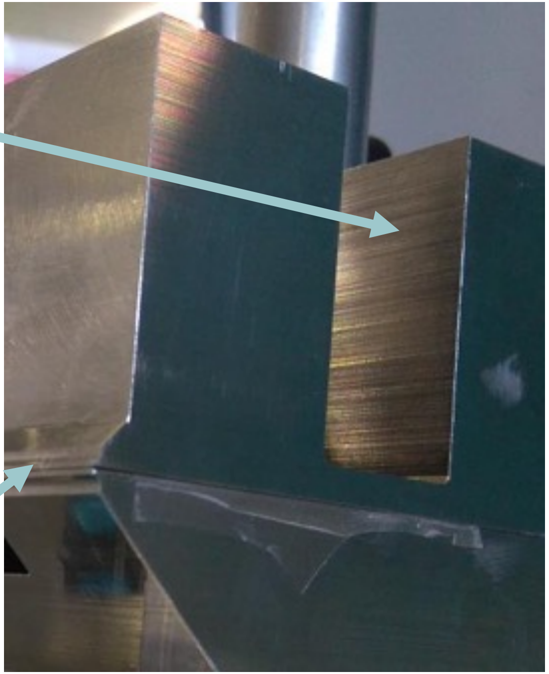


Bending slot

Lips open

Difference is 300 µm only

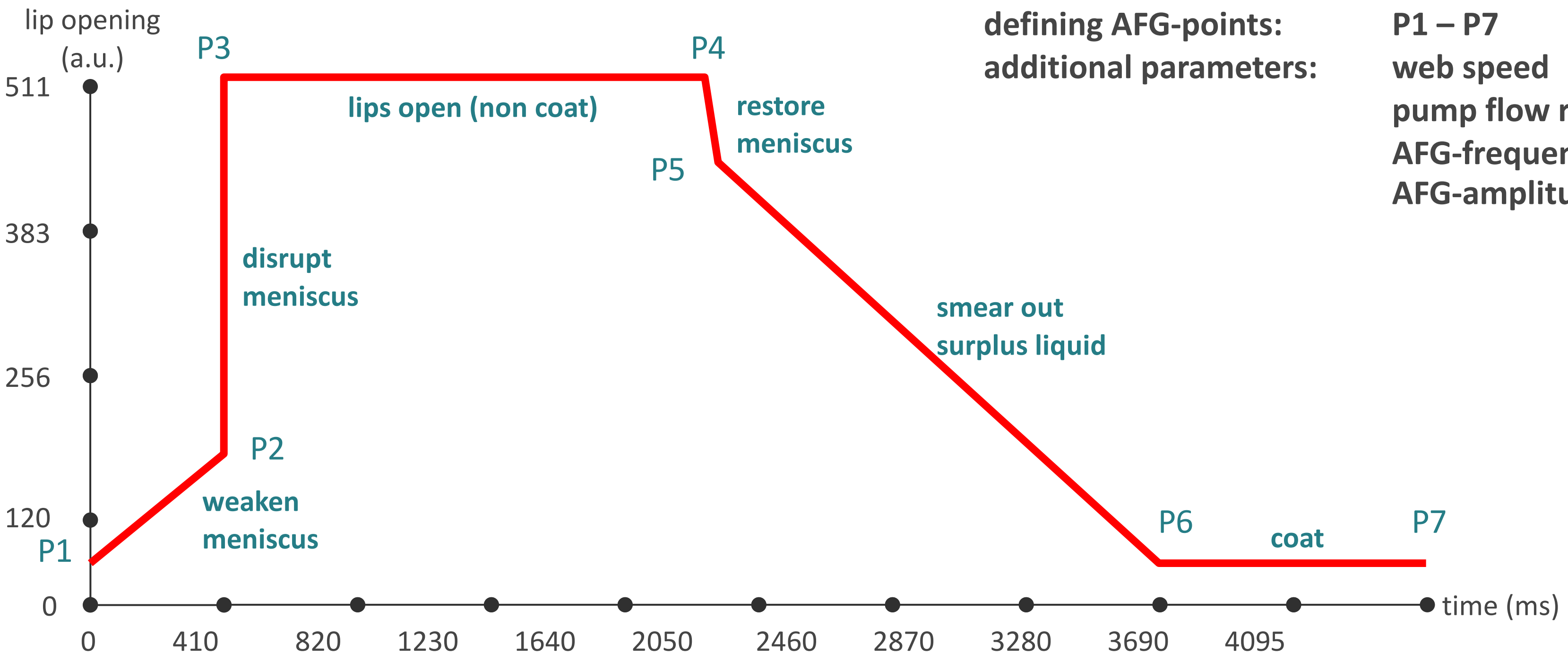
Lips closed



Technical implementation with bendable lips in action

Coatema®
Coating Machinery GmbH

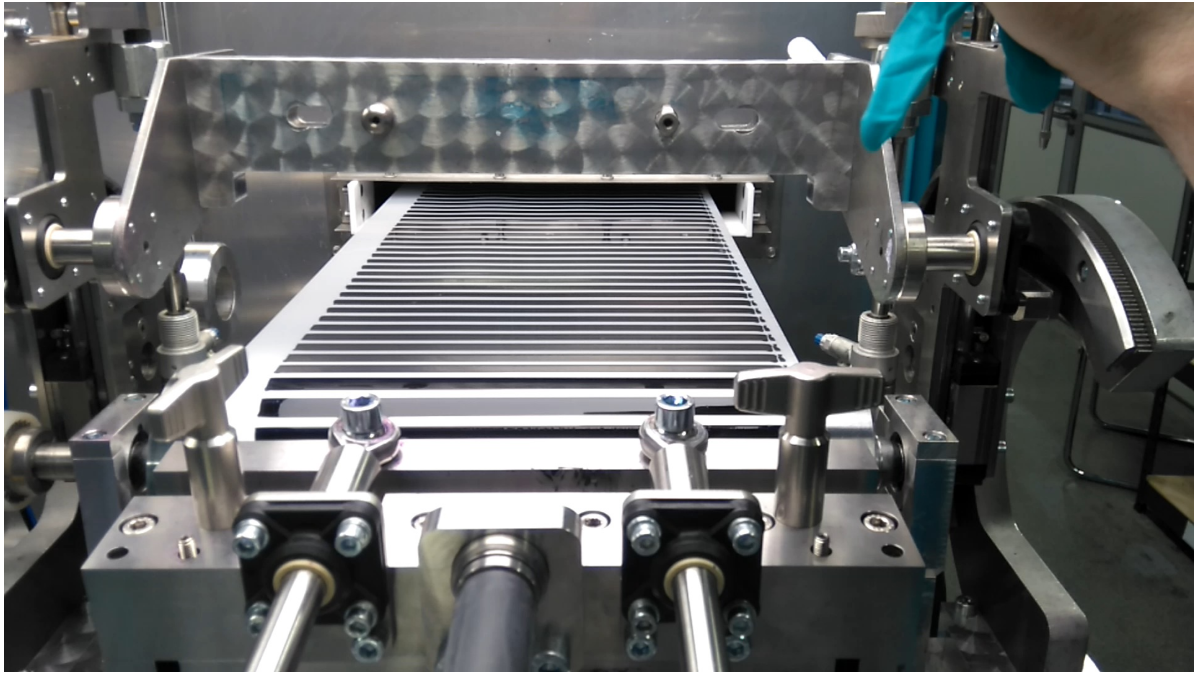
Structured coating – stages of lip motion



defining AFG-points: **P1 – P7**

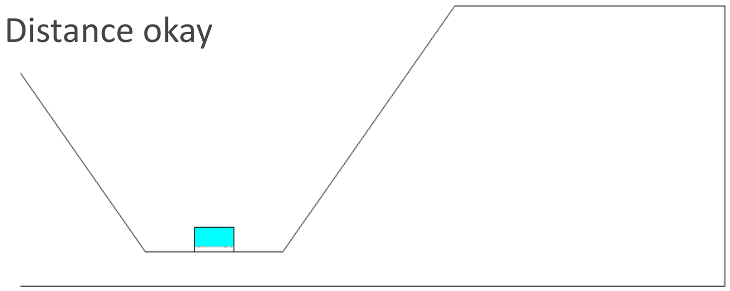
additional parameters: **web speed**
pump flow rate
AFG-frequency
AFG-amplitude

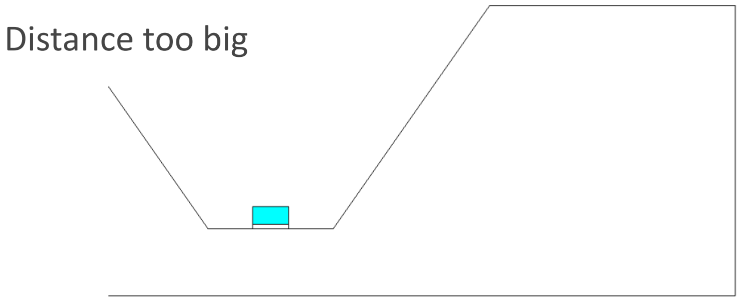
Structured coating – ongoing trials: stripe coating of fuel cell paste



Simulation of anode Coating

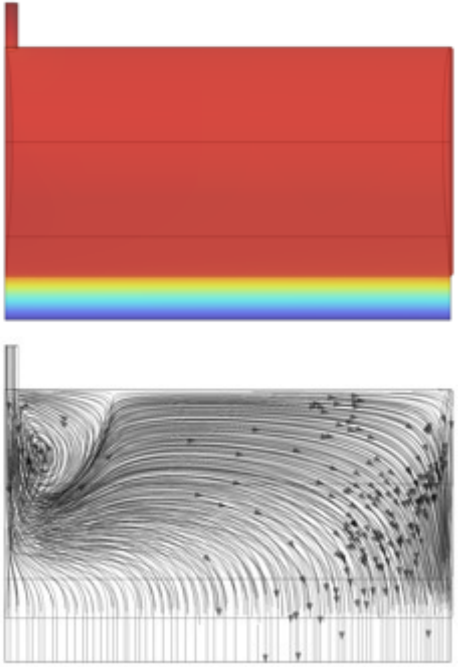
- ✓ Example for anode electrode coating
- ✓ Fluid data taken from real world (shear-thinning power law fluid)
- ✓ Process parameters for 90m/min 400µm coating and 300mm width
- ✓ No “fancy” slot-die “just” Coatema standard



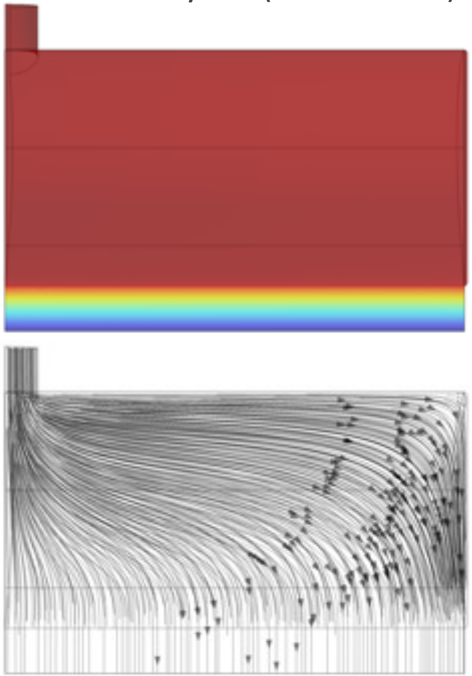


Streamlines and pressure distribution

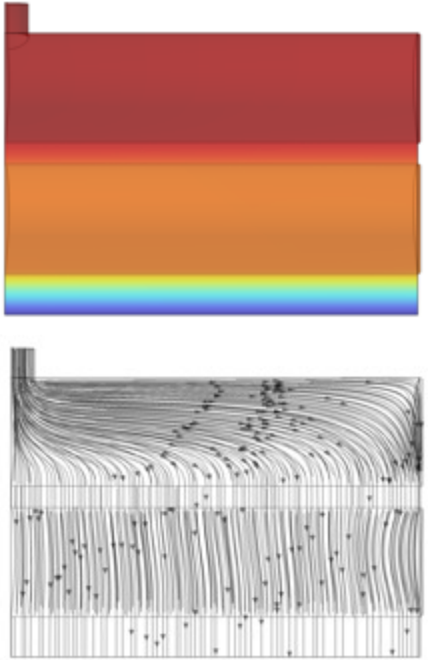
Single Chamber with too small inlet (4mm)



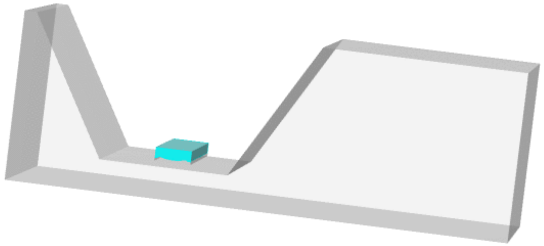
Single Chamber with correct chamber layout (10mm inlet)

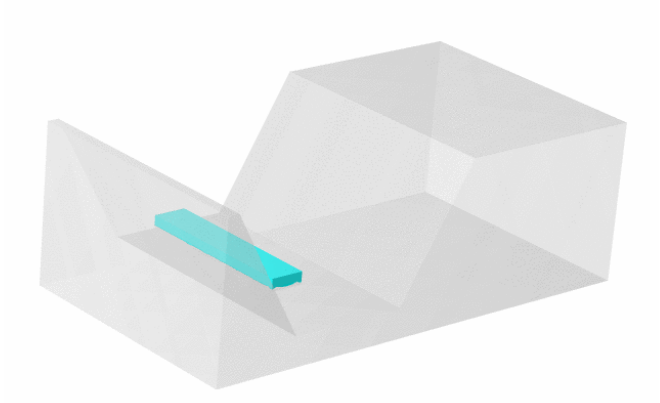


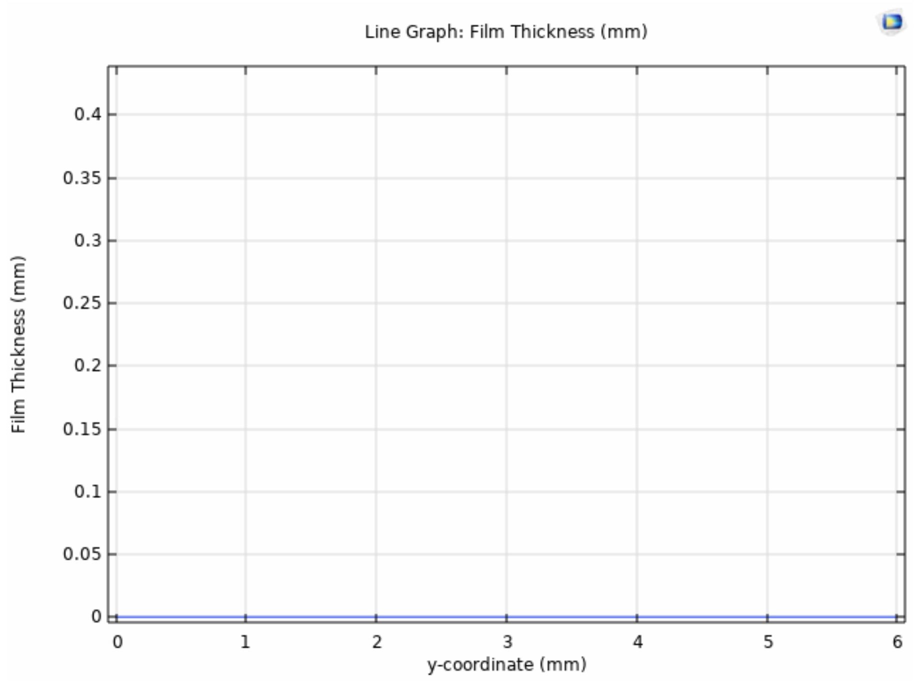
Dual chamber slot die (8mm inlet same dead volume)



Meniscus makes or breaks Homogeneity







Thank you

Roseller Straße 4 ▪ 41539 Dormagen ▪ Germany
T +49 21 33 97 84 - 0 ▪ info@coatema.de

www.coatema.com

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