Comparison between experimental and simulated velocities in a MPW geometry

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Outline

1. Overview
2. Experimental setup
3. Simulations of the process
4. Sensitivity analysis
5. Correlation between simulation and experiment
6. Conclusion

OVERVIEW

Overview – About Bmax

Developer and provider of advanced metal processing using High Pulse Power:

- Electro-HydroForming (EHF)
- Magnetic Pulse Forming and crimping (MPF MPC)
- Magnetic Pulse Welding (MPW)

Strong technical support

- **Multiphysics simulations**
- **High velocity material characterization**

Bmax France
Toulouse

Overview - Simulation stakes

Stakes of Simulation

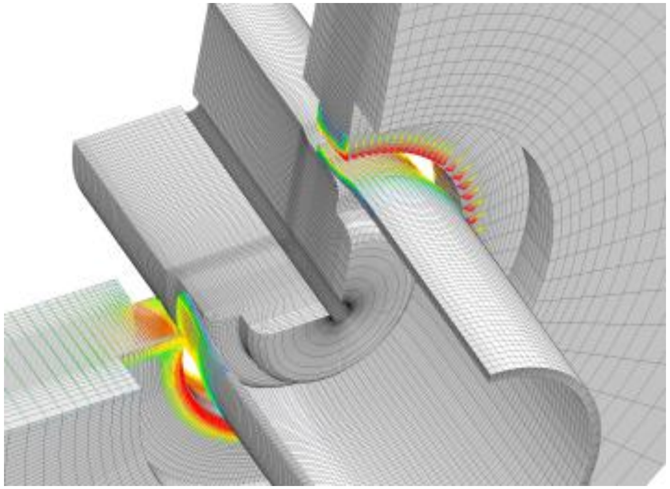
- Propose predictive processes (required by most companies)
- Respond faster to customers
- Reduce development costs

Objectives

- Predict parts feasibility
- Optimize processes and components (coils, dies)
- Limit the number of experiments
- Understand physics

Necessary step

- Assess the correlation between experiments and simulation, especially for velocities



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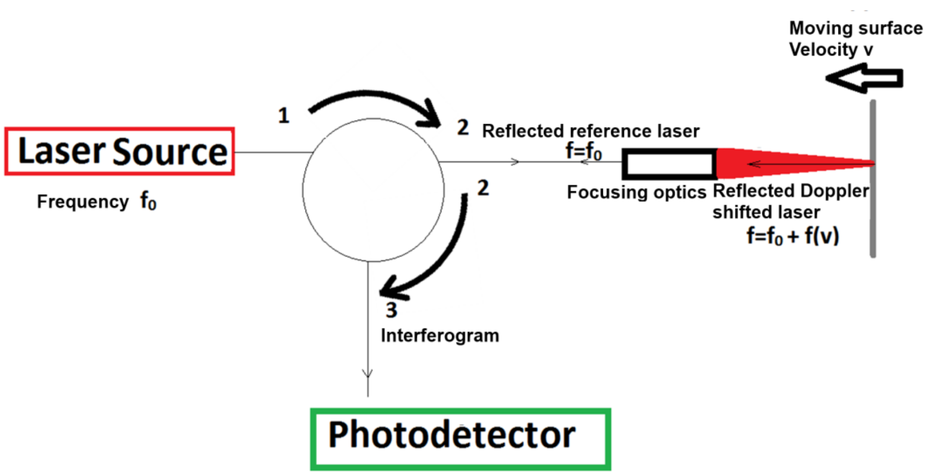
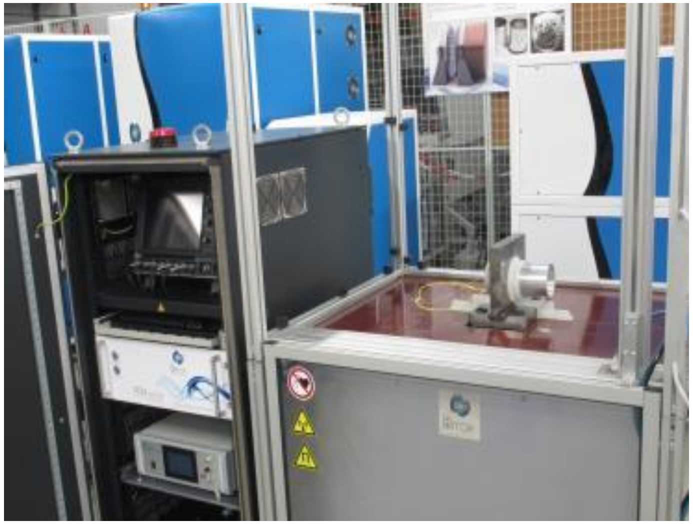
EXPERIMENTAL SETUP

Velocity measurement – PDV system Principle

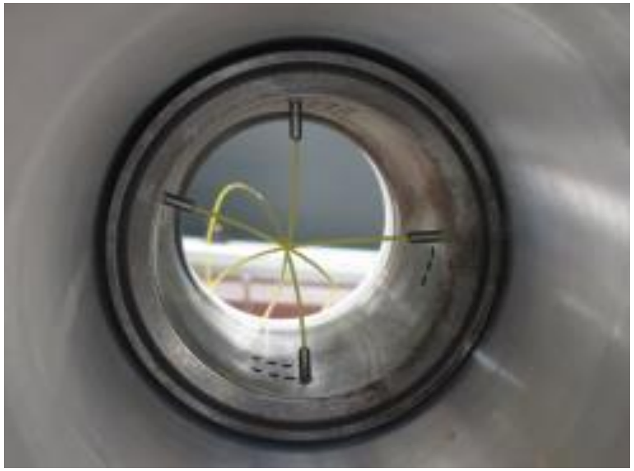


- Collaboration with IUL (Dortmund) and OSU (Columbus, Ohio)
- Fully integrated, off-the-shelf 3U rack solution available from Bmax
- 4 measurement channels, up to ~ 800 m/s measured velocities
- Cheaper and much easier to use than VISAR

Velocity measurement – MPW configuration



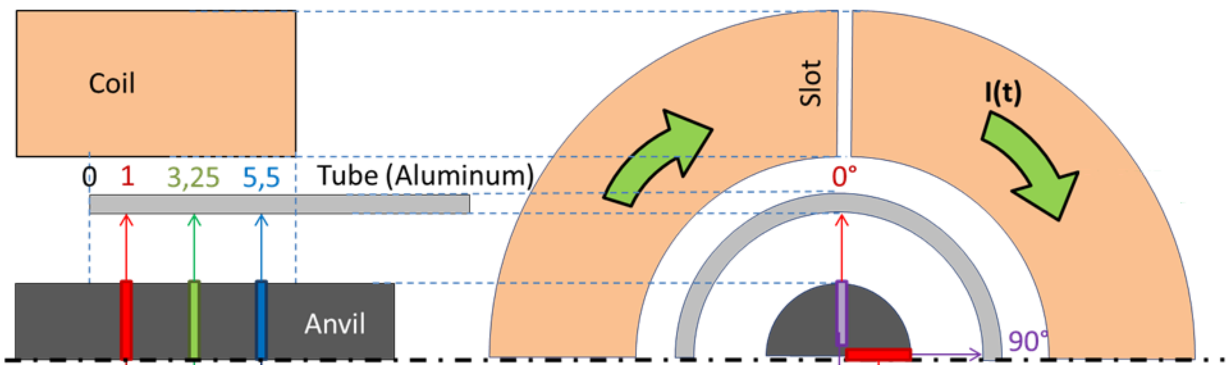
PDV system integrated in a mobile Faraday cage



View of the different measurement angles and positions

SIMULATION OF THE PROCESS

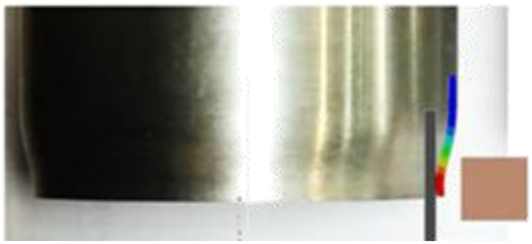
Simulation of a MPW configuration



Tube geometry:

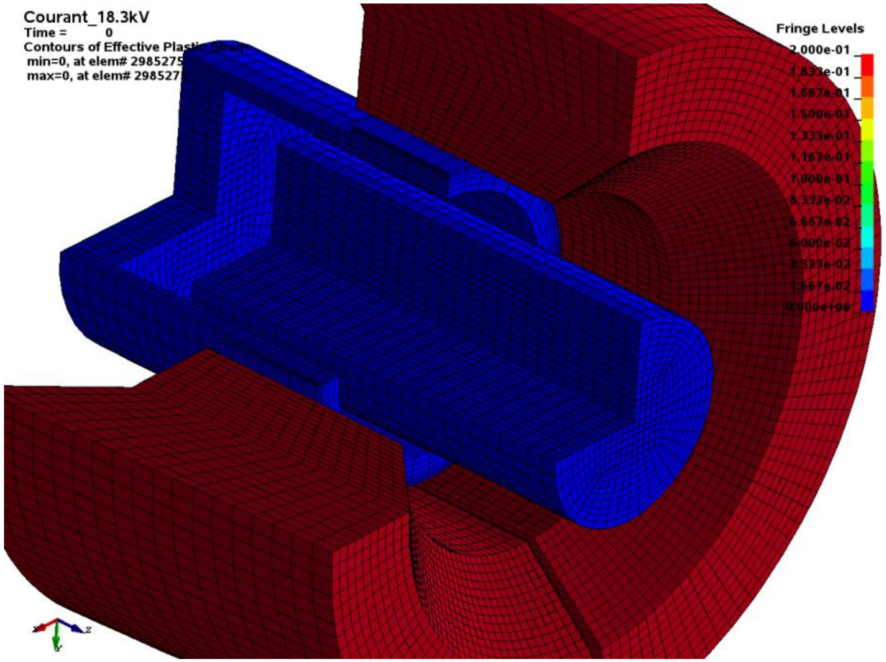
- 2 mm thick
- Outer diameter 80 mm
- Working length 7.5 mm

Material data	
MATERIAL	Al6060 T6
Density	2700 kg/m3
Young modulus	69.5 GPa
Poisson ratio	0.33
Yield stress Re	150 MPa
Max elongation A%	12 %
Ultimate tensile strength Rm	215 Mpa
Electrical conductivity	31.6 MS/m



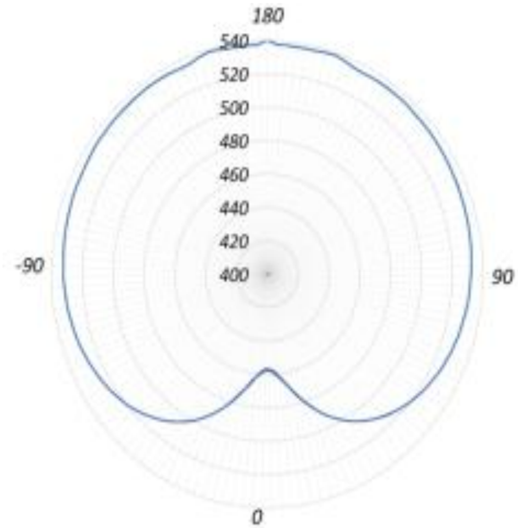
Outer tube after shot & Corresponding numerical deformed shape (Contours = Displacement)

3D Simulations – Example of coil slot influence



3D effects can be predicted on 3D simulations.

Coil slot decreases locally the velocity



Radial velocity depending on angular location

Initial numerical simulation

- Hypotheses
  - 2D axisymmetric model with measured current as input
  - Bilinear elastoplastic constitutive law
  - Burgess resistivity model

- Simulation input parameters
  - Element formulation
  - Measured current
  - Tube position
  - Constitutive law (yield stress, tangent modulus)

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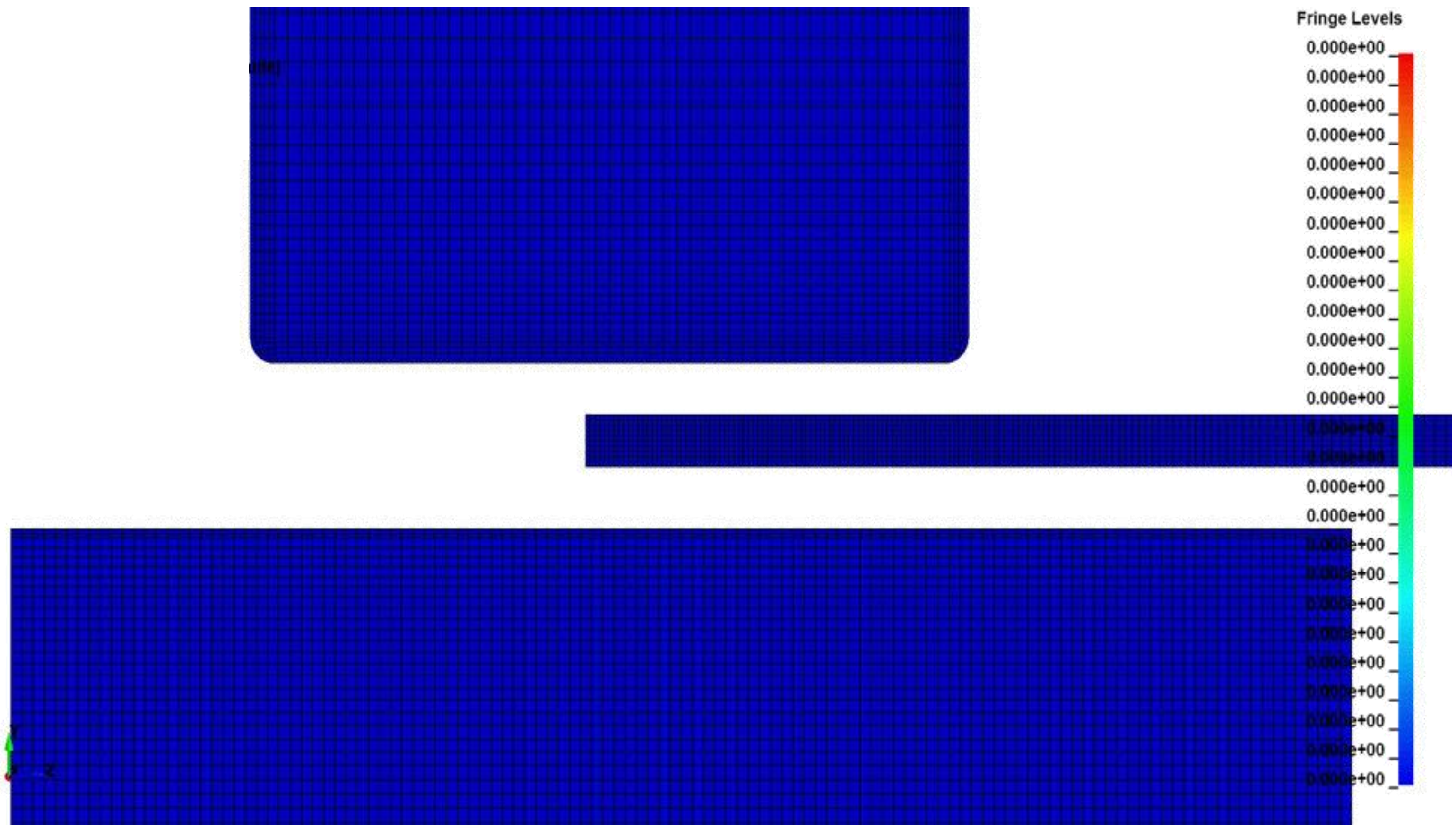
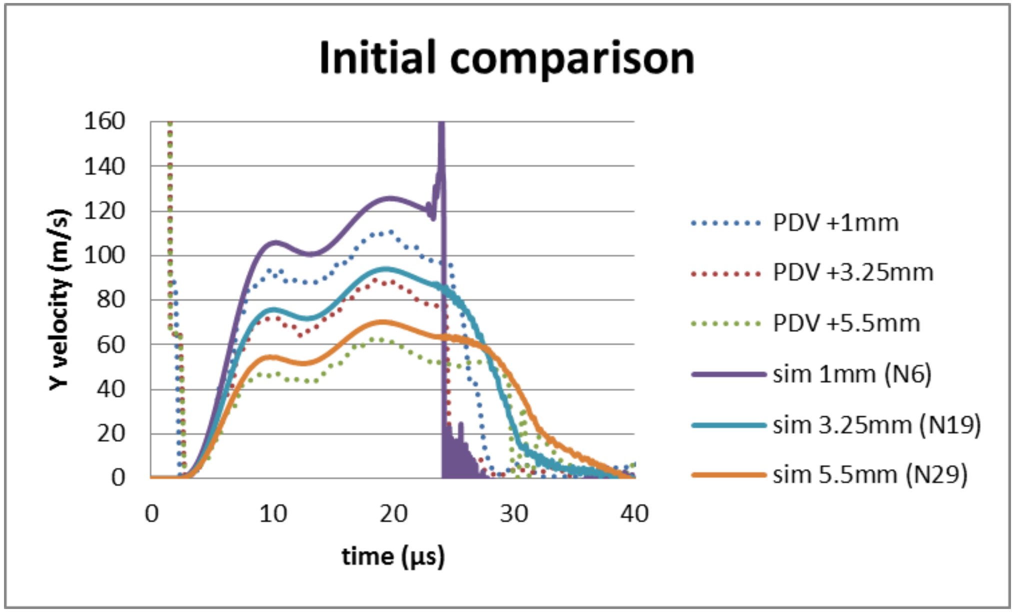
2D axisymmetric coupled simulation of the process



Initial numerical simulation

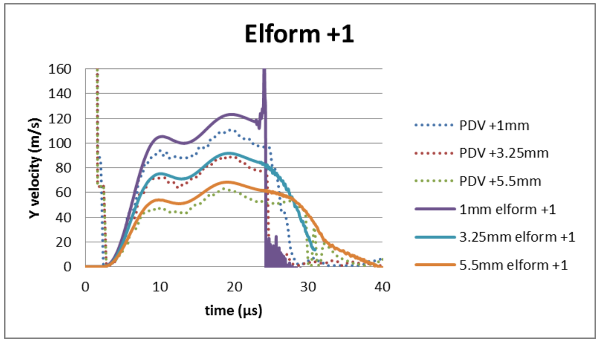


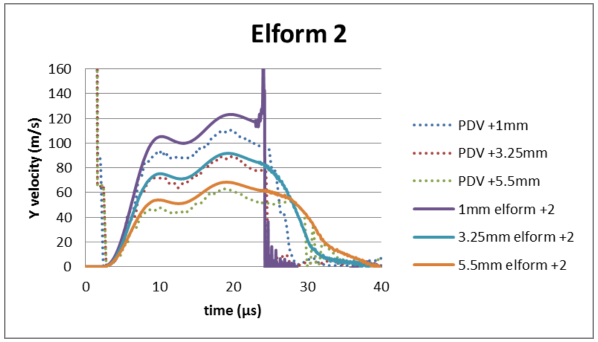
- Observations
  - Global shape is OK
  - Overestimated simulated velocities compared to measured ones
  - Non constant differences indicates overestimated angle at 1 mm and less differences for the other positions

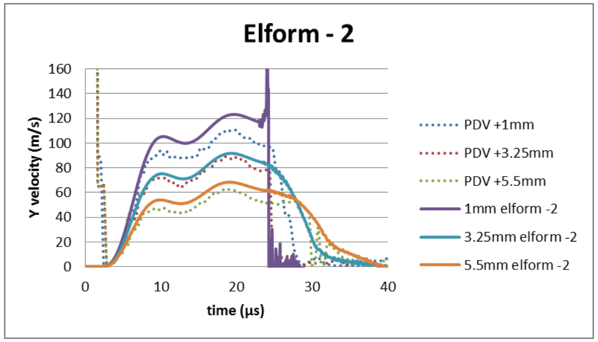
SENSITIVITY ANALYSIS

Sensitivity analysis – Element formulation

- Different element formulations available
  - Constant stress solid element (Elform +1)
  - Fully integrated S/R solid (Elform 2)
  - Fully integrated S/R solid intended for elements with poor aspect ratio, accurate (Elform -2)

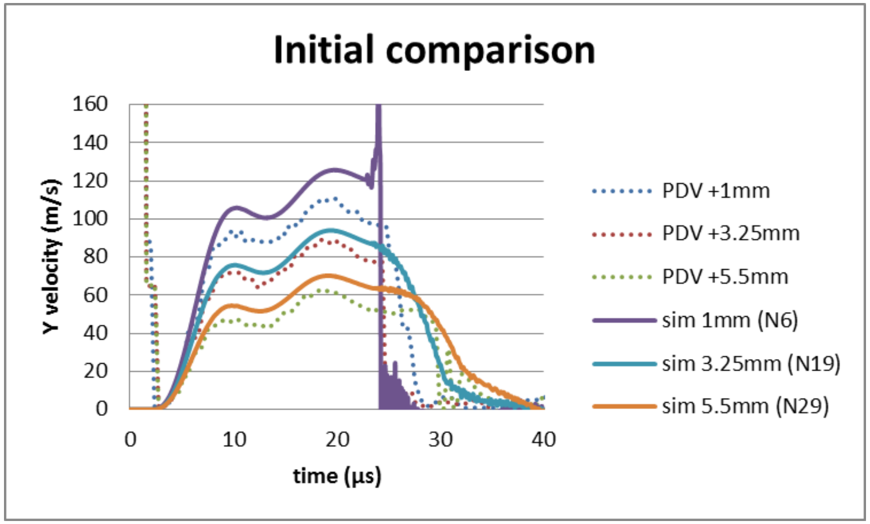


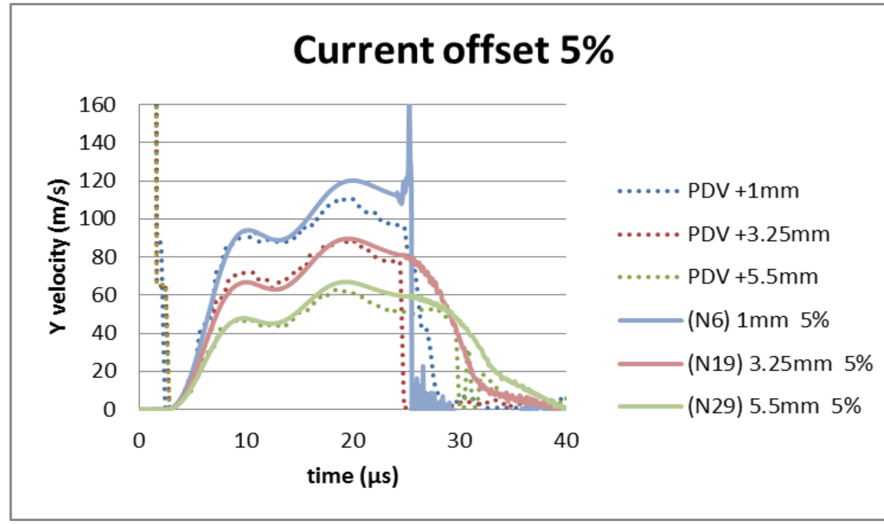




- Element formulation has no influence on the results

Sensitivity analysis – Measured current





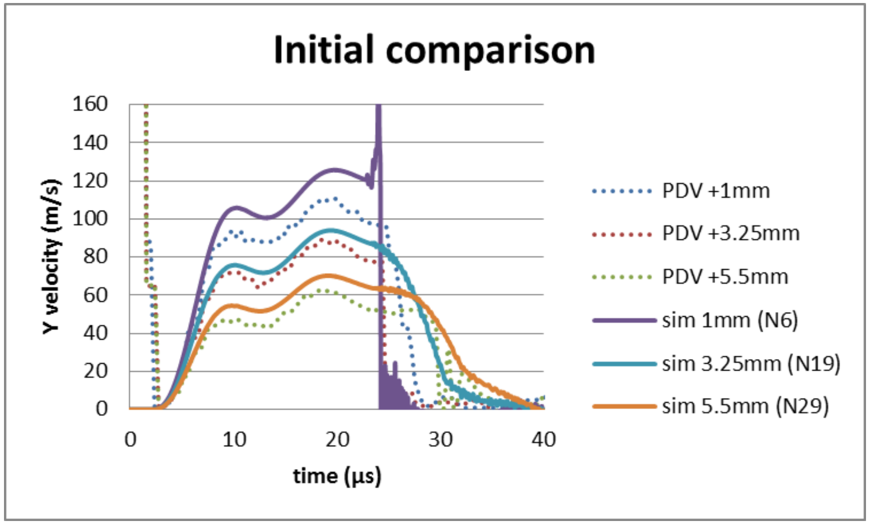
A 5% offset is a realistic possible error due to the following uncertainties:

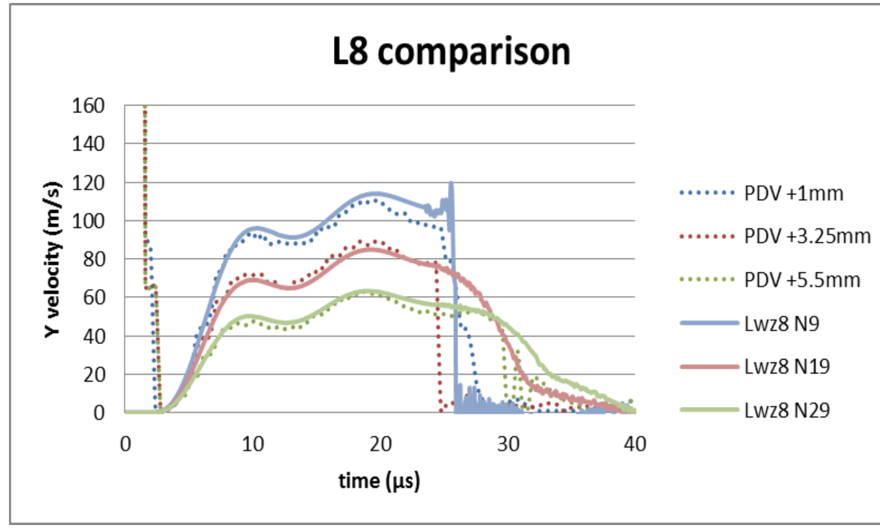
- We calibrated our current measurement and showed a 4 % uncertainty.
- Noise due to capacitive coupling (recently reduced to 2 %)

5 % decrease in current amplitude induces a 13 % decrease in the first velocity peak

- Accurate current measurement is critical for the process simulation

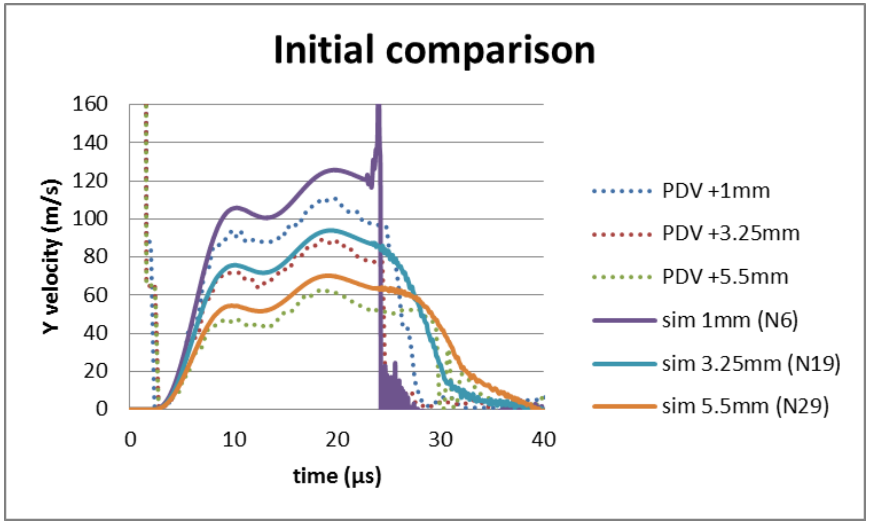
Sensitivity analysis – Working length

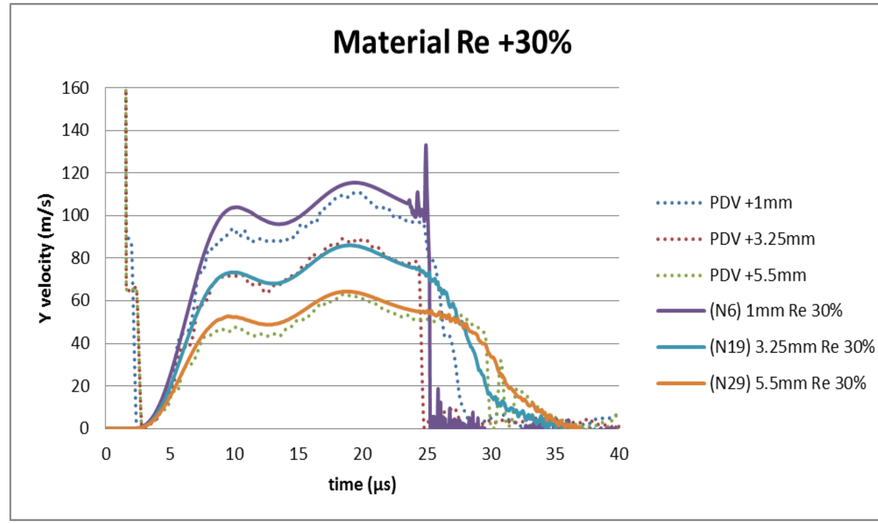




- Adding 0.5 mm to the working length (+7 %) reduces the measured velocities by 10 %
- Accurate positioning is critical to the process simulation

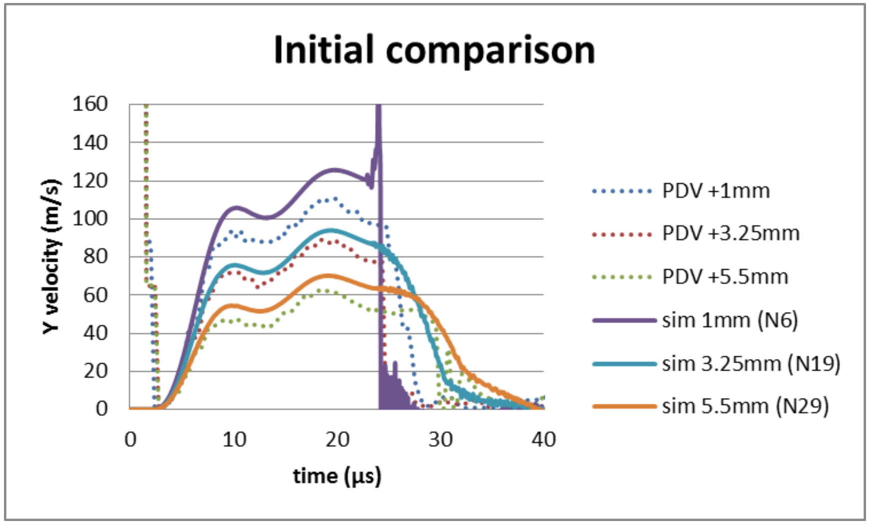
Sensitivity analysis –Yield stress

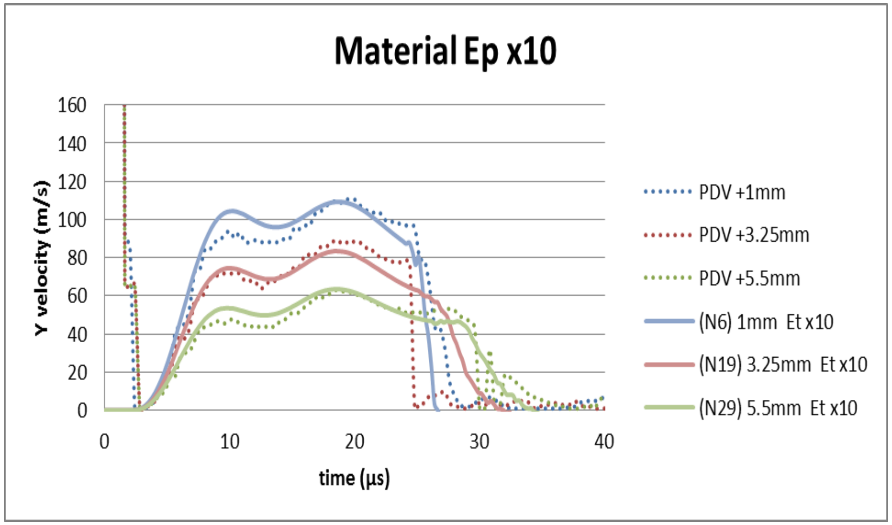




- First velocity peak isn't affected by the yield stress
- A realistic 30 % increase of the yield stress decreases the second velocity peak by 9 %
- Plastic strain occurs only later during loading (after 10 µs)

Sensitivity analysis – Tangent Modulus





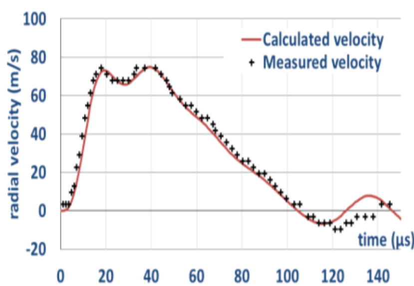
- An unrealistic change (x10) leads to little influence in simulated velocity
- Only second velocity peak decreases by 14 %

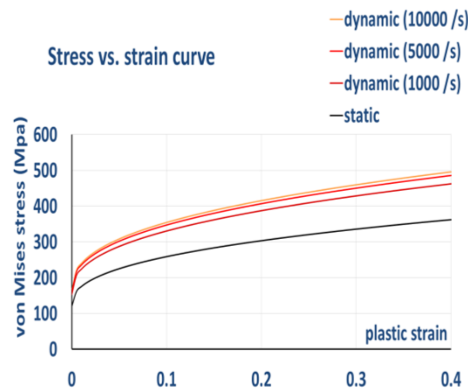
High strain rate material behavior

Ph.D. in High Speed Dynamics ending this year with 2 laboratories specialized in forming and high strain rates behavior

ELASTO-VISCOPLASTIC CONSTITUTIVE LAWS

Innovative test bed based on PDV to evaluate the parameters of strain rate dependent constitutive laws



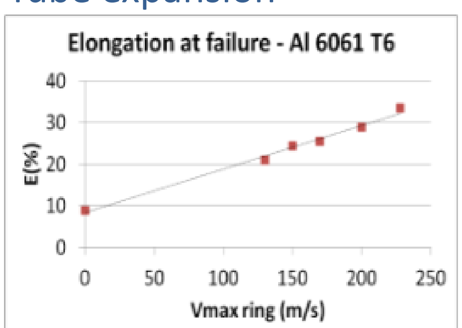


$Ex: Modified \quad Johnson-cook$

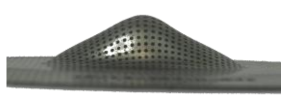
$$\sigma = \left[A + B\varepsilon^{n}\right]\left[1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^{p}\right]$$

FORMING LIMITS

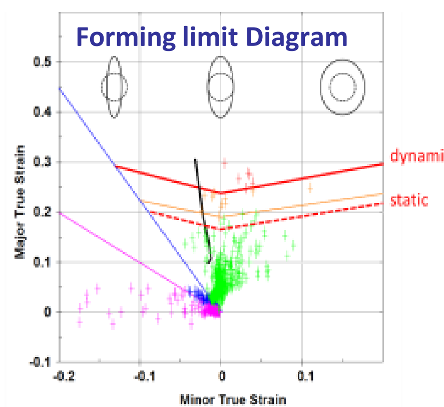
Tube expansion



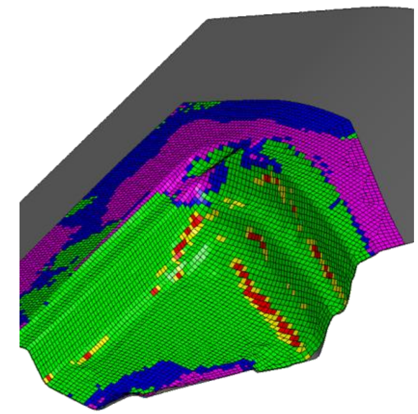
Elliptic open dies



Hemispheric dies



3D SIMULATIONS

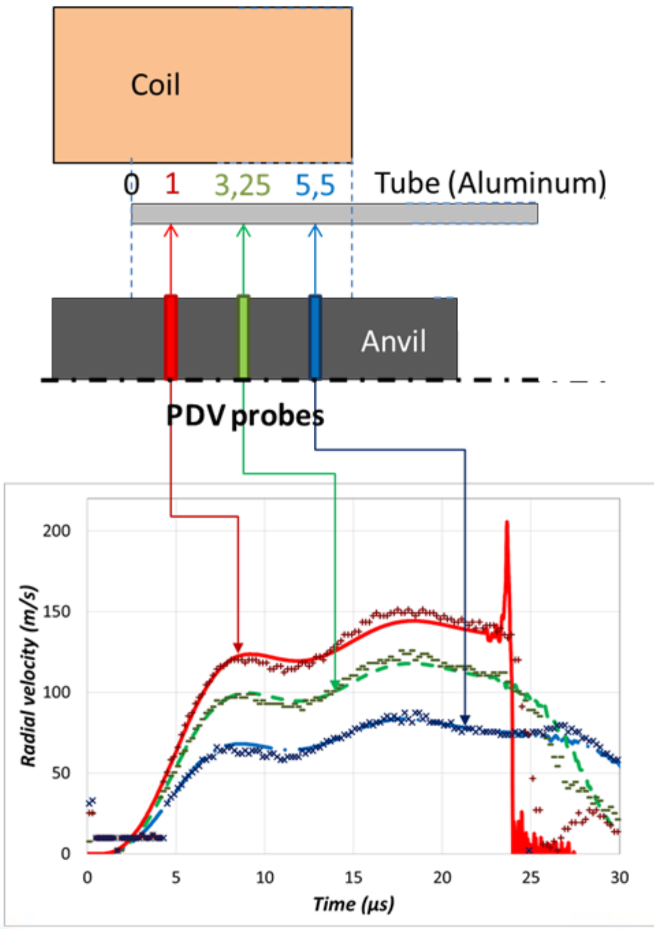


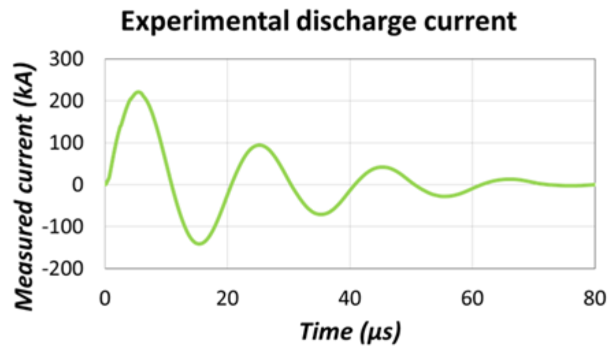
Formability key

Cracks	
Risk of cracks	
Good	
Wrinkling tendency	
Wrinkles	

CORRELATION BETWEEN SIMULATION AND EXPERIMENT

Correlation between simulation and experiment





- Main changes
  - New test with better current measurement
  - Modified Johnson-Cook model with parameters from M. Beusink Master's thesis (Measurements and simulations on the (dynamic) properties of aluminium alloy AA6060
- Much better agreement

Conclusion

- As previously shown, the major factor for the sensitivity analysis are, in order of importance:
  - Measured current
  - Positioning
  - Yield stress

Paramètre	Variation du paramètre	Variation sur la vitesse simulée	
		1er pic	2ème pic
Measured current	5 %	13 %	13 %
Positioning	7 %	10 %	10 %
Yield stress	30 %	0 %	9 %

- Given experimental uncertainties, the simulation reproduces quite well the velocities.
- This correlation is a necessary basis for predictive forming simulation of complex parts.