Fast Simulation - Assisted Shape Correction after Machining

Ramiro Mena[1*,2,3], Stéphane Guinard[1], José V. Aguado[2] and Antonio Huerta[3]
[1] Airbus SAS, France (ramiro-francisco.mena-andrade@airbus.com)
[2] ICI-HPC Institut de Calcul Intensif at Ecole Centrale de Nantes, France
[3] Laboratori de Calcul Numeric (LaCaN) at Universitat Politecnica de Catalunya, Spain

Problem description

- Distortion in aeronautical parts [a]
  - Subject: large and thick-walled aluminum forgings
    - ⋆ (+) produce complex geometries in an economical way
    - ⋆ (-) present residual stresses (RS)
  - Problem: important distortions
    - ⋆ arise after machining
    - ⋆ reconfiguration at stress and geometry level
  - Solution: Reshaping
    - ⋆ (-) highly manual process that requires skilled workers
    - ⋆ (-) contributes to increment the final manufacturing cost
  - Project's goal: to explore the use Model Order Reduction (ROM) techniques applied to the reshaping problem.

[a] A descriptive video of the project can be found in the following QR code

Research questions

For the reshaping process, we would like to know:

1. What is the influence of the initial RS for reshaping?
2. Which are the most important technological parameters?
3. How to simulate consecutive operations and provide an answer in real-time?

Problem Setup

Geometry: T shaped beam (based on the cruciform)
Operation: Bending straightening
Material: AA7010 (previously characterized)

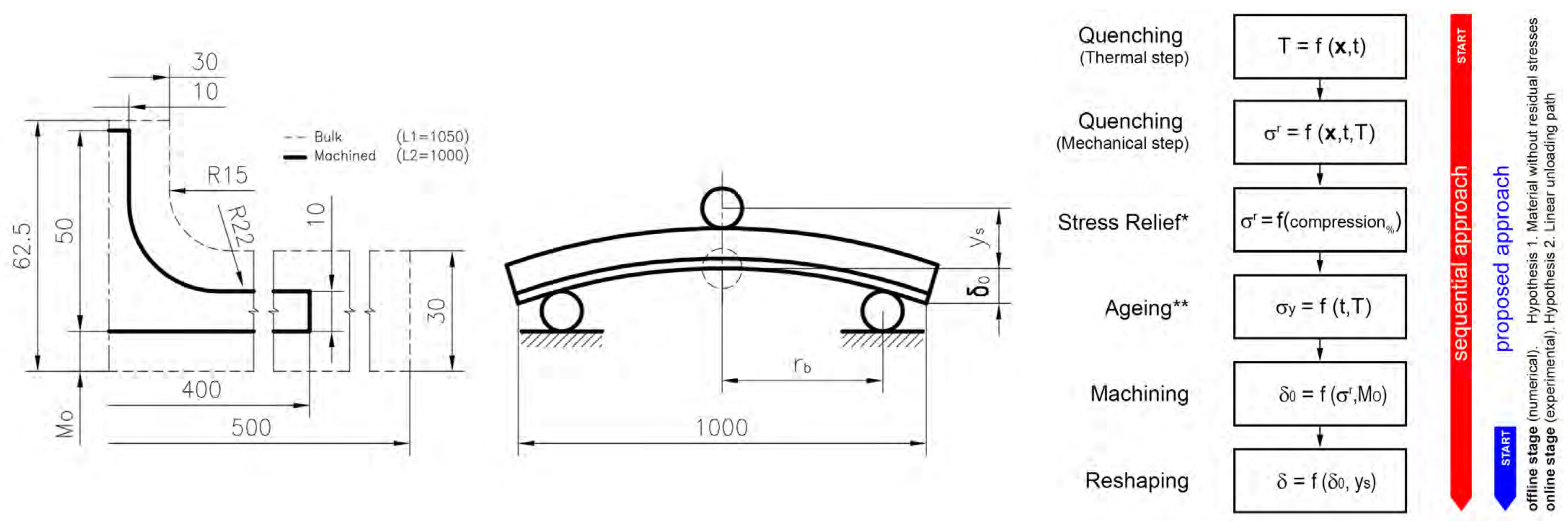

Fig. 1: Problem setup: geometry definition (left), parameters for bending straightening (centre) and simulation strategies (right).

Results and Discussion (1/2)

For bending straightening, we need to determine the final shape of the part after performing a cycle of loading and unloading. Therefore, the displacement field $\mathbf{u}(\mathbf{x};\mu)$ for a given set of parameters μ is the field of interest.

In the studied case, μ is composed by the initial distortion δ_0, the position of the bottom roller r_b and the imposed vertical stroke y_s.

$$\mu = (\delta_0, r_b, y_s) \tag{1}$$

When $\mathbf{u}(\mathbf{x};\mu)$ is reconstructed for all the parametric domain, the remaining distortion δ can be found as a post-processing operation as:

$$\delta(\mu) = \max_{\mathbf{x}} [\mathbf{u}(\mathbf{x};\mu)] - \min_{\mathbf{x}} [\mathbf{u}(\mathbf{x};\mu)] \tag{2}$$

For all the possible reshaping configurations, we are mainly interested to know the optimum stroke y_s^{opt} that, for a fixed set of parameters (δ_0, r_b) will minimize the remaining distortion δ in the structural part.

$$y_s^{opt} = \arg\min_{y_s} [\delta(\mu)] \tag{3}$$

Effect of the initial Residual Stresses during reshaping

- By using the initial distortion δ_0 as the main input and considering the part under the Residual Stress Free (RSF) hypothesis, it is possible to mimic the remaining distortion δ evolution of the system with residual stresses (RS) [1].
- There is an offset Δ between the system with residual stresses (RS) and the residual stress free configuration (RSF) and it can be found experimentally by considering a linear unloading path in the force-displacement diagram [2].

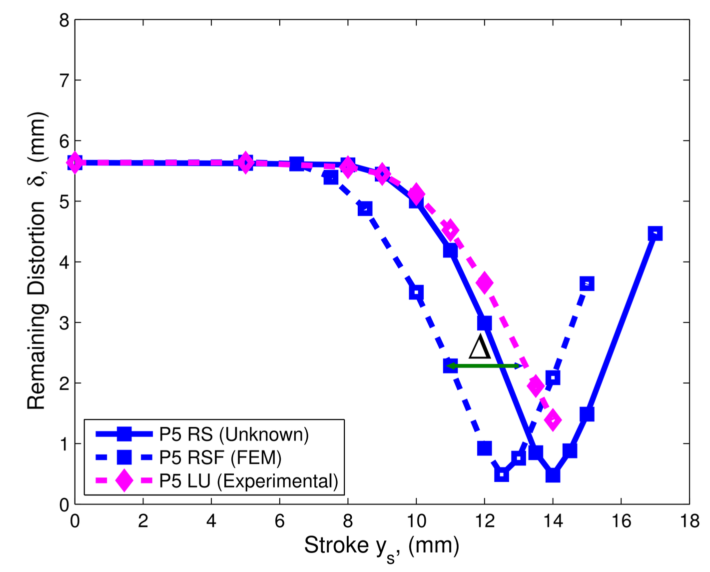

Fig. 2: Remaining distortion δ evolution for a given stroke y_s: sequential vs proposed approach

Results and Discussion (2/2)

Multi-parametric ROM study of bending straightening

- Reshaping is solved under the Sparse Subspace Learning (SSL) formulation [3, 4].
- The problem of not knowing beforehand δ_0 is overcome by including it as a parameter.
- δ_0 is the starting point for reshaping and it determines the setup for the technological parameters r_b and y_s.

A demonstration of the multi-parametric solution is presented in the QR code

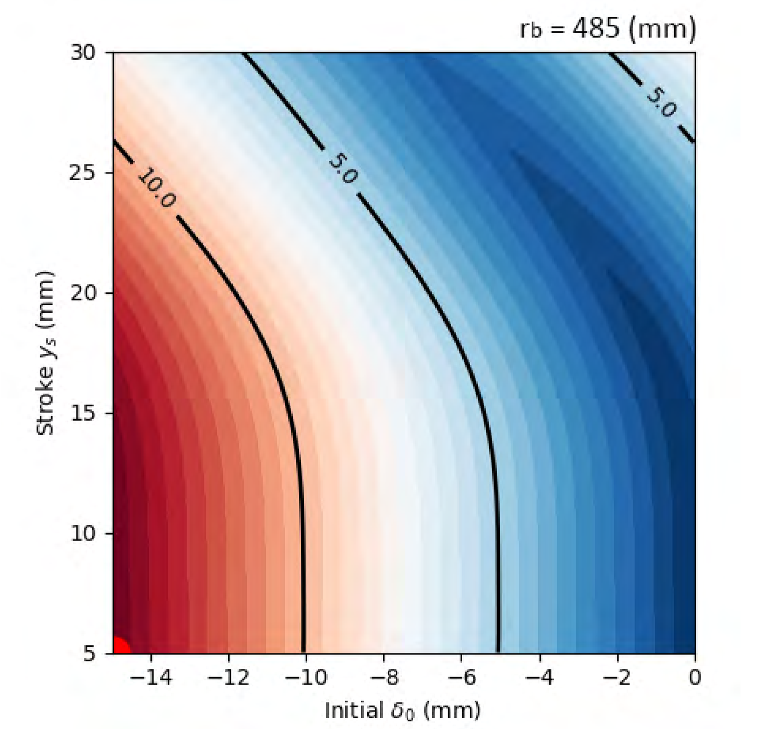

Fig. 3: Response surface: Remaining distortion $\delta = f(\delta_0, y_s, r_b|_{r_b=485})$

Evaluation of multiple reshaping operations via MOR

- Different strategies can be evaluated before selecting the optimum configuration.
- The main limitation of the three-point bending straightening operation is that it can only induce a triangular displacement field to counteract a wavy shape.
- For each repaired wave n, $2n$ smaller waves are generated by manipulating the part with $2n-1$ operations.

The remaining distortion δ after each reshaping operation can be visualized in the QR code

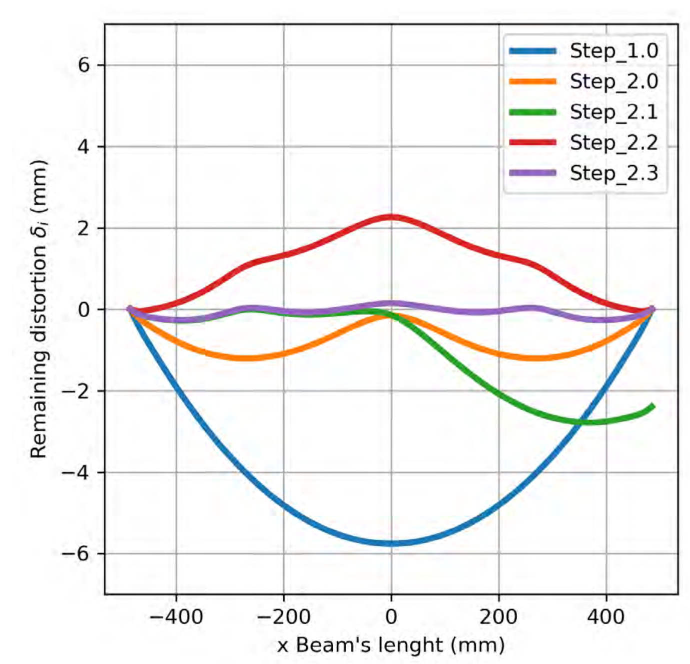

Fig. 4: Remaining distortion δ evolution during two reshaping steps

Conclusions

- The industry is willing to have new tools to solve problems that nowadays are treated in an empirical way. Reshaping of large thick structural parts is an example of how MOR can be applied to an open problem, especially the SSL, allows to perform a multi-parametric study to test different *what-if* scenarios in a cost-effective way and, thanks to its non-intrusiveness, acts as a bridge to join MOR with the available third-party FEM solutions.

Acknowledgements
This project is part of the Marie Skłodowska-Curie ITN-ETN AdMoRe funded by the European Union Horizon 2020 research and innovation program with grant number 675919.

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