Transfer function approach based on simulation results for the determination of POD curves

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Motivation

POD curves are obtained thru expensive and time consuming experimental campaigns

Objective

To use simulation results to help reducing cost of the POD curve

Two approaches (1):

• Full model assisted POD
• Transfer Function

(1) MAPOD Group http://www.cnnde.iastate.edu/MAPOD/
Outline

• Transfer Function (TF) approach

• Application case

• Proposed methodology to compute POD curves

• Results

• Conclusion and perspectives
This work is based on the Transfer Function (TF) approach applied by C. Harding and All(2).

The aim is to generate a POD curve for natural defects in complex geometries by analysis of a combination of data from natural and artificial defects in simplified and complex geometries.

POD Transfer Function Approach

K. Smith, Pratt & Whitney, Palm Springs, CA, February 2005
MAPOD WG

Step 1
Flat Plates

CRACKS

\[
\text{Crack response} = \frac{m_x}{m_n + b_n}
\]

NOTCHES

\[
\text{Notch response} = \frac{10m_x + b_n}{10m_n + b_n}
\]

Lab data to control variability

Step 2

Complex Geometry

Notch size

Variability Data

Step 3

Step 4

Crack Response

Notch Response

\[
\frac{m_x + b_n}{m_n + b_n}
\]

Lab data to control variability

Crack size
POD Transfer Function Approach

Linearity assumption

\[
\frac{m_c x_c + b_c}{10 m_n x_n + b_n}
\]
Our goal: to apply TF approach to the following problem

Given a POD curve for an inspection process and simulated NDT data, generate a new POD curve for similar inspection of similar components but with different material properties.

This work has been done in the framework of the PICASSO project http://www.picasso-ndt.eu/
## Use case: HFET of fatigue cracks in Titanium

<table>
<thead>
<tr>
<th>Part</th>
<th>NDT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material:</strong> Titanium (TA6V)</td>
<td><strong>Configuration:</strong> High Frequency Eddy Currents Testing (HFET)</td>
</tr>
<tr>
<td><strong>Geometry:</strong> Flat areas</td>
<td><strong>Probe:</strong> Pencil probe (2MHz)</td>
</tr>
<tr>
<td><strong>Defects:</strong> Fatigue cracks</td>
<td><strong>Conditions:</strong> In-service (manual)</td>
</tr>
</tbody>
</table>

How do we obtain our simulated data set?

The simulation supported POD approach: uncertainty propagation

Input parameters:
- Part
  - Dimensions
  - Conductivity
- Probe
  - Dimensions
  - Number of turns
  - Frequency
- Inspection
  - Start scan position
  - Scan increment
  - Lift-off
- Flaw
  - Shape
  - Length
  - Height
  - Width

Signal response data analysis and POD curve estimation

First saturated data
Exp=3.4 mm
Simul=2.9 mm

All cracks are detected
Exp=1.4 mm
Simul=1.55 mm

Data on Titanium

\[
\begin{align*}
\alpha_{90}^{\exp} &= 1.5 \text{mm} \\
\alpha_{90/95}^{\exp} &= 1.8 \text{mm} \\
\alpha_{90}^{\text{simu,EC}} &= 1.5 \text{mm} \\
\alpha_{90/95}^{\text{simu,EC}} &= 1.7 \text{mm}
\end{align*}
\]

First validation of the simulation supported POD approach.

We will use simulation results (green dots) for our study.

Methodology

POD config. A (HFET on Ti)

known

POD config. B (HFET on Al)

unknown

Use simulation

Ti simulation

Al simulation
deterministic

\[
\frac{\hat{a}_{\text{exp},\text{Ti}}(\alpha)}{\hat{a}_{\text{sim},\text{Ti}}(\alpha)} = \frac{\hat{a}_{\text{exp},\text{Al}}(\alpha)}{\hat{a}_{\text{sim},\text{Al}}(\alpha)}
\]

\[
\frac{\text{Ti}_{\text{ref}}}{\text{Al}_{\text{trans}}} = \frac{\text{Ti}_{\text{sim}}}{\text{Al}_{\text{sim}}}
\]
Datasets for the study

- Reference data for Ti: simulated data **with** uncertainty sources (realistic values)
- Simulated data for Ti and Al: simulated data **without** uncertainty sources (deterministic simulation)

- Validation data: simulated data for Al **with** uncertainty sources (same as Ti)
Methodology for the application of the transfer function to our application case

- **Step 1**: Computing linear regression parameters for simulated NDT data Ti_sim and Al_sim.

Adapt methodology for piecewise linearity!!!
Step 1’ : Computing **piecewise** linear regressions parameters for simulated NDT data Ti_notch and Al_notch

\[
\begin{align*}
\beta_{0}\text{low}, & \quad \beta_{1}\text{low}, \quad \delta_{\text{low}}^{2} \\
\beta_{0}\text{high}, & \quad \beta_{1}\text{high}, \quad \delta_{\text{high}}^{2}
\end{align*}
\]

Computation of a piecewise transfer function
Step 2: Computing a **piecewise** Transfer Function

**Hypothesis**: ratios of signals are the same in Titanium and Aluminium

**Lower part** transfer function

\[
\begin{align*}
\beta_{0,low,exp,Al} &= \beta_{0,low,exp,Ti} + \beta_{0,low,sim,Al} - \beta_{0,low,sim,Ti} \\
\beta_{1,low,exp,Al} &= \beta_{1,low,exp,Ti} + \beta_{1,low,sim,Al} - \beta_{1,low,sim,Ti} \\
\delta_{low,exp,Al}^2 &= \delta_{low,exp,Ti}^2
\end{align*}
\]

**Upper part** transfer function

\[
\begin{align*}
\beta_{0,high,exp,Al} &= \beta_{0,high,exp,Ti} + \beta_{0,high,sim,Al} - \beta_{0,high,sim,Ti} \\
\beta_{1,high,exp,Al} &= \beta_{1,high,exp,Ti} + \beta_{1,high,sim,Al} - \beta_{1,high,sim,Ti} \\
\delta_{high,exp,Al}^2 &= \delta_{high,exp,Ti}^2
\end{align*}
\]

**Lower part** of the POD

**Upper part** of the POD

Computation of a mixture POD
Step 3: Applying the Transfer Function to Titanium with fatigue cracks

Better fit of the piecewise TF signal to the validation dataset
### Step 4: Computing a mixture POD

**Difficulty**: we need to mix the POD curves obtained for each part of the TF.

**Methodology**: computation of 2 POD curves (one obtained by application of the TF for the small crack length values, the other one for large crack length) and mixture of the 2 curves in between.

For illustration
Step 5 : Computing the mixture POD for fatigue cracks in Al. and validation

TF POD fits well with validation POD when both computed with piecewise linear approach
Conclusion and perspectives

• A transfer function approach has been proposed to obtain POD curve in Aluminium based on simulation data in Titanium and Aluminium.

• This new approach shows how linear methods can be extended to account for piecewise linear relationships between signal and crack length.

• The new methodology requires linear piecewise signal fitting.

• An heuristic method has been proposed to compute a piecewise/mixture POD.

• The perspectives of this work are:
  – To take into account variability in the transfer function (our approach was assuming that the variability was the same in titanium and aluminium when determined by transfer function).
  – To provide a theoretical framework (Bayesian?) for mixture modelling of POD.
  – To validate the approach on experimental data.
Thanks for your attention