MAPOD case study - EDF feedback and perspectives

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Abstract

This paper gives EDF experience on a MAPOD study that was conducted to assess NDT performance on Steam Generator tube inspection between 2014 and 2016. It reviews different aspects on a case study, concerning both theoretical and practical issues.
The conclusions of the paper deal with the amount of work required:

1- MAPOD allows an increase in the management of the real process performance: knowing where the margins are enables to do additional measurements in order to reduce uncertainties due to a lack of knowledge

2- But simulated POD is very demanding in terms of inputs: both the statistic laws to model the inputs, which are not required in a deterministic approach, and complementary experimental data, such as noise density, are necessary to assess the operational POD. This additional information and the way to implement it in the global model is subjected to controversy.

3 – We expected sensitivity studies to help the consensus, by proving the robustness of the POD assessment. But the first (and preliminary) results showed it was not the case: the ranking of the influent parameters changes dramatically with the sensitivity indicator retained. When considering a given value of the defect or the total POD curves, the results are very different in terms of ranking. Furthermore, the inputs that are ranked “high impact” or on the contrary “low impact” do not always convince NDT experts.

4- Therefore, additional work is necessary to strengthen the POD assessment and to convince the qualification body.

5- We conclude that MAPOD may be too demanding for a qualification goal. Unless the POD curve is implemented in a more global maintenance policy, such as Risk Informed In Service Inspection or ROC analysis, we suggest that assessing a point value, even in a deterministic frame, is sufficient for an industrial purpose.

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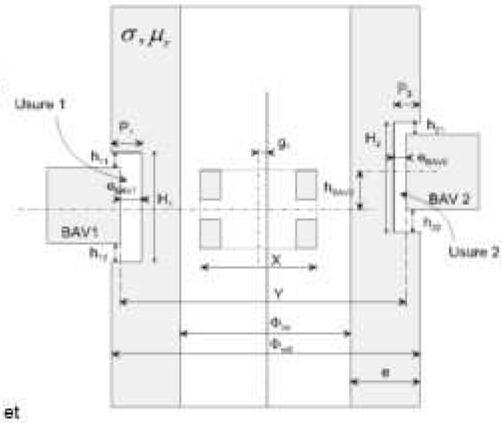
Context

- In 2013, EDF showed some interest in assessing the potential of the POD frame to strengthen the French NDT qualification process for the inspection of nuclear components
  - Deterministic. Main objective : to assess the influent parameters contribution to the signal, add their contributions and determine the procedure threshold: give the guaranty that the defect will be detected
  - Some statistics is used to add the influent parameters contribution
  - No demand on Human Factor (qualification of an automated process is the main target)
- Real case study / SG AVB wear/ ET / 3D FEM code
  - R&D project with high skills in FEM and statistics
- Basic case study / defect in a pipe / cooling line / UT / 2D CIVA
  - (simplified case taken from a former study by CEA/G. Ribay)
  - Basic statistics analysis
- My objective here is to share my preliminary conclusions

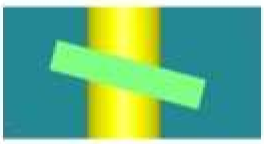
Content

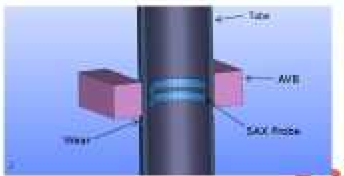
Case study – Inputs

- Pipe thickness *E : Normal law*
- Wear1 : distance between the AVB and the top/bottom of wear h_{11} et h_{12}, depth P_1 : *Uniform laws*
- Wear 2 : h_{21} h_{22} and P_2 : *Uniform laws*
- Offset of the 2 wear : $hBAV_2$: *Uniform*
- Inclination of AVB with regards to the pipe inc_1 et inc_2
- Gap between AVB and wear : $eBAV_1$ et $eBAV_2$: *Uniform laws*



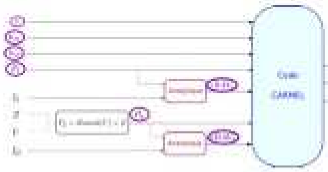
Picture of the inclination of AVB : parameters inc_1 et inc_2

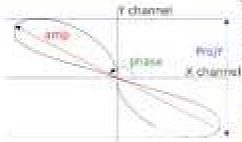




Sampling and FEM computational code (Carmel_3D)

The main contributors to NDT signal variations are modeled through statistical distributions





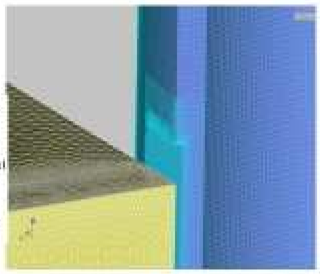
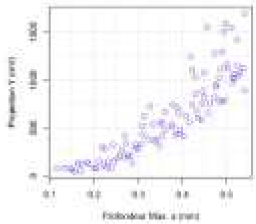


Illustration of the mesh in the numerical model of NDT simulation

LHS sampling : between 50 and 100 calculations

L. Maurice, V. Costan, and P. Thomas. Axial probe eddy current inspection of steam generator tubes near anti-vibration bars: performance evaluation using finite element modeling. JRC-NDE, 2013.



Example of result : 100 calculations with Carmel_3D

Content

1. The Case studie
2. **Theoretical issues**
3. Practical issues
4. Preliminary conclusions

Issues

- To implement the Berens model, some assumptions are demanded
  - What if they are not fulfilled ?
  - Can we relax the constraints ?

- FEM calculation may be very demanding (long and costly)
  - Is it feasible to have a sound POD with a reduced number of calculations ?
  - How can we use metamodels for POD assessments ?

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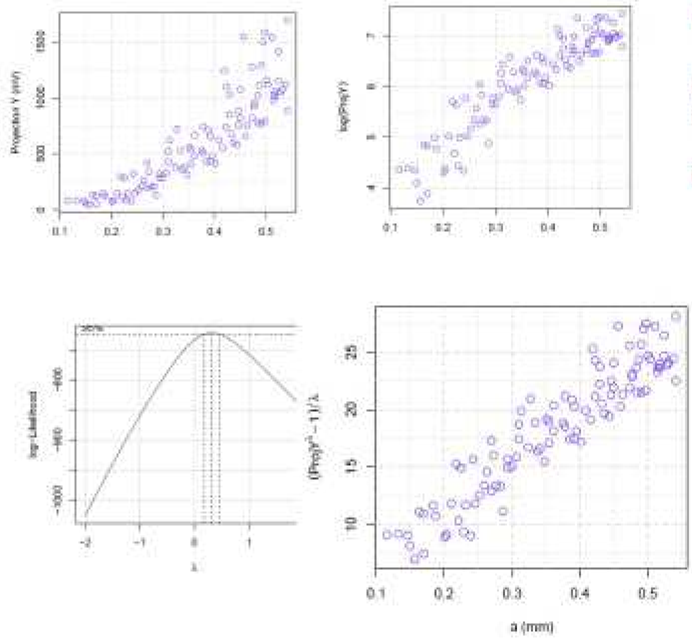
A- Box-Cox transformation to optimize the regression



- $y_{ProjY} = (Proj_Y^{\lambda} - 1)/\lambda$ si $\lambda \neq 0$
- $\log(Proj_Y)$ si $\lambda = 0$
- $\lim_{\lambda \to 0} (Proj_Y - 1)/\lambda = \log(Proj_Y)$
- λ computed by writing the Log-Likelihood

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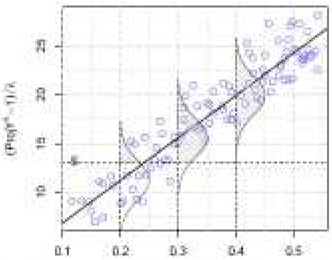
A- POD with Berens

Y = BoxCox($Proj_Y$) is the signal after the BoxCox transformation

Y= $\beta_0 + \beta_1$.P1 + ε, with ε=N(0,σ^2)

ε models the residuals (the distance from data to the model)



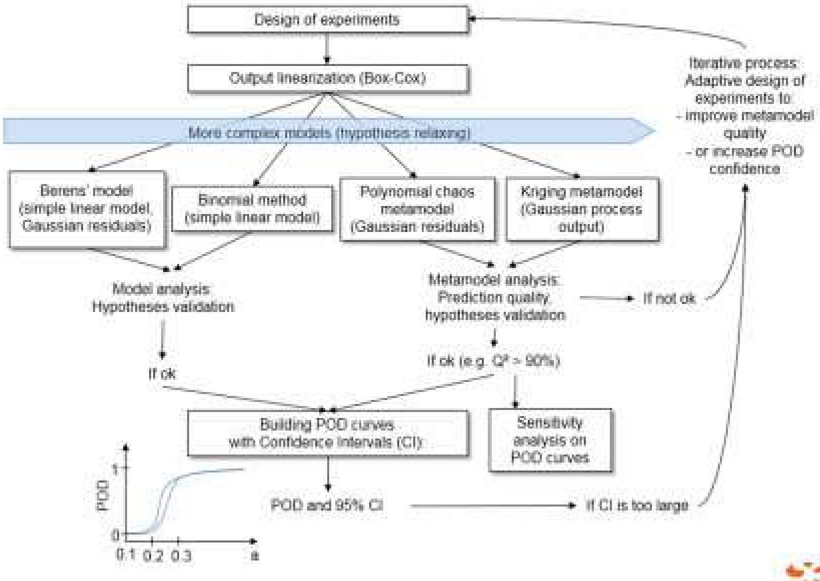
- The POD is computed through the usual formula :

$$\text{PoD}(P_1) = P(\beta_0 + \beta_1 P + \varepsilon > S) = \Phi\left(\frac{S - \beta_0 - \beta_1 P}{\sigma}\right)$$

B – Example of a metamodel

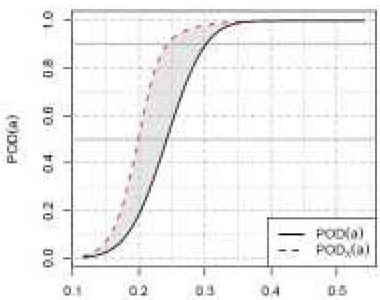
- Y_{projy} (a,X) = $\beta_0 + \beta_1$.a + Z(x,a), with :
  - Z(x,a) – the Gaussian process with a given covariance kernel (parameters).
  - Their estimation provides also an assessment of the variance σ^2 which gives an estimate of the variations of Y_{projy}, around the linear regression : $Beta_0$ + $Beta_1$.a
    - X = Influent Parameters vector = (e, a, e_{BAV1}, e_{BAV2}, h_1, h_2...)
    - a = max (P1,P2) in the case of two wear
- The main differences between the 2 models are the followings :
  - Berens : Errors don't change with the value of a. The impact on parameters on the signal Y is constant
  - With the metamodel, the distance of the values Y_{projy} (a,X) to the regression depends on X and a : the impact of all the parameters differs with the wear depth
  - We can assess how the parameters and the wear change the distance to the mean regression line
- Quality indicators
  - Indicators to assess the relevancy of the surrogate model are available and tell us about it's quality. If quality is poor, additional FEM calculations is required

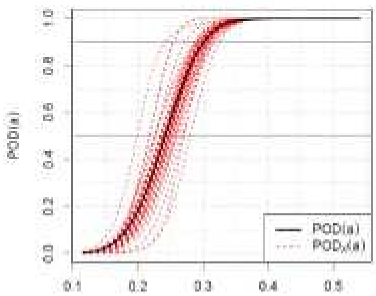
C - Generic method for POD assessments



D – Sensitivity Indicator

- Example with $POD_X(a)$ when the vector X is fixed at a given value.
- The quantity $Diff_X$ ($DiffX = ||PoD(a) - PoD_X(a)||^2$, $||f(a)||^2 = \int f(a)^2 da$) measures the distance to the mean POD by the means of the gray surface.
- The higher $Diff_X$, the more having fixed X is important.
- But $Diff_X$ depends on X. We show examples of different $POD_X(a)$ for other values on X.
- Total variability due to X is computed by the expected value $V = E(Diff_X)$





D – Sensitivity Indicator

- Several sensitivity indicators can be computed
- They address the all curve
- We give the example of the simple Sobol indicators, which have been built for the POD functions on the grounds of the variance theory

- $PODX_i$ (a): what would have been the average POD if the i[th] parameter was constant?
- $PODX_{-i}$ (a) : what would have been the average POD if only the i[th] parameter was random?

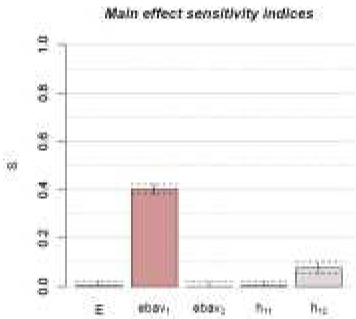
$$
\begin{aligned}
PoD_X(a) &= \mathbb{P}(Y_{ProjY} > s \mid a, X), \\
PoD_{X_i}(a) &= \mathbb{P}(Y_{ProjY} > s \mid a, X_i), \\
PoD_{X_{-i}}(a) &= \mathbb{P}(Y_{ProjY} > s \mid a, X_{-i}), \\
D &= \mathbb{E}\|PoD(a) - PoD_X(a)\|^2
\end{aligned}
$$

with $\|.\|$ the euclidean norm. PoD Sobol' indices are then defined by:

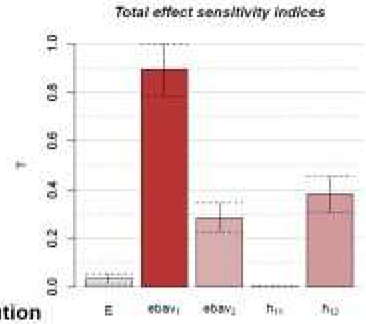
$$
\begin{aligned}
S_i^{PoD} &= \frac{\mathbb{E}\|PoD(a) - PoD_{X_i}(a)\|^2}{D}, \\
T_i^{PoD} &= \frac{\mathbb{E}\|PoD_X(a) - PoD_{X_{-i}}(a)\|^2}{D}.
\end{aligned}
$$

D - Sobol indices – Example of results

Effect of one parameter only



Total effect - Contribution of a parameter in interaction with the others. Thee sum of all the contributions exceeds 1



The understanding of the ranking and the evolution from the main effect to the total effect is not obvious

The thickness E has a very low influence, which seems surprising

Theoretical results

- It is possible to build a generic model dealing with all the possible cases
- With a very low calculation budget, the results were considered acceptable (the mean POD, the quality indicator for the metamodel)
- We can use statistical tools to assess the parameters sensitivity to the POD function: it enables the ranking of the inputs

- Reference : L. Le Gratiet, B. Iooss, T. Browne, G. Blatman, S. Cordeiro, B. Goursaud, Model assisted POD curves : new statistical tools and progressive methodology, Journal of Non destructive evaluation, 36:8, 2017

Content

Issues

- How to choose the relevant inputs for the calculations
  - Which parameters are to be considered ?
  - Which laws to describe the parameters ?
- How to deal with the qualification body
- How to include experimental data (probe variation, metallurgical noise, reel wear/crack vs. simulated)
- How to address the sizing issue from the POD?

The interest of having Peer Reviews

❑Two half day meetings with experts on different fields : maintenance, calculation and design (mechanical computation), NDT, R&D (NDT FEM model)

❑ Preparation work to provide information to the experts
- ✓ NDT (Input assessments, global assessments, explanation of the process)
- ✓ R&D (FEM calculation results)

❑ No research for potential biases : share of information on
- ✓ Configurations : scenarios
- ✓ Main parameters
- ✓ Statistical functions (poor knowledge)
- ✓ Look for a consensus

❑ The objective was reached
- ✓ The experts needed to exchange all together before answering the questionnaire
- ✓ Their choices were pretty close
- ✓ Very poor statistical background among French engineers

The questions of the choice of the elicited parameters

Be aware of the needs : it is not because you need an input that you should ask abruptly for it

The thickness E and the shift h_{11}/h_{12} were elicitated separately, as two geometric possible influence on the probe signal

- ❑ E is well known, easy to assess, we hade data
- ❑ h_{11}/h_{12} are unknown : elicited with regards to the probe influence area. Over 10mm, the probe does not measure the influence. Thus 10mm was chosen as a maximum value for the shift between wear highest point and the AVB top

❑In fact, ET signal is proportional to the volume. With the maximum values chosen for E and h_{11}/h_{12}, the impact of h_{11}/h_{12} is automatically much higher : a strong influence can derive from a poor knowledge.

❑It is important to come back to the experts with this information

- ✓ If they keep their advice, one should not retain the thickness as a parameter. E can be taken with its nominal value.
- ✓ It is a good way to challenge the experts

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Peer Review on the input and Qualification Body – a process to build

Perspectives

- ❑ The process could be generalized, even for deterministic studies
- ❑ The purpose is to reduce the qualification effort, by focusing on the main relevant parameters
- ❑The process is still to build

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The good points

- POD results are robust : no matter the model, the results are very close (even though assumptions are not fulfilled)
- One can build a generic model for all the possible cases & the tools to assess sensitivity which allow the ranking of the inputs

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Several points of attention

- Have the relevant output from modeling is not obvious as it is with experimental data
  - Some explanations :
    - numerous actors involved
    - the modeling of a real process is often difficult
  - Examples
    - Several sources of influence to the signal: AVB, wear,
    - Calibration for UT technique
  - ➢ An NDT analyst must check that the information provided is relevant
- The ranking almost always raises questions : the ranking order of the parameters changes significantly depending on the indicator retained :
  - a given value of the abscissa, such as a_{90},
  - the complete POD curve...
  - and the indicator itself (main effect, total effect)

Several points of attention

- Some input parameters seem to have been over estimated : you may not know a parameter (its maximum value) but you know it cannot be so much influent on the POD
  - a feedback process with the expert, providing the results is necessary
  - The choice of the parameters to elicitate needs an exchange between NDT analyst and the modeling expert : the discussion can help avoiding useless calculations
- The confidence on the POD (90% confident curve) should be addressed after all experimental inputs were added : probe, noise, real defect vs modeled
- EDF pursues the effort but on simplified cases in order to determine and share a process with the Qualification Body
  - The main goal is to rank the input influent parameters

POD for NDT qualification: too luxurious?

- A complete MAPOD study is a big effort
  - It needs high skills in several fields, at least : modeling, NDT signal analysis, statistics
  - Each must go much further than expected towards the other fields to have correct final results
- Using the POD just for the qualification purpose seems an excessive effort
- It is relevant when connected to other considerations such as
  - Field experience : ROC analysis may help finding the best threshold that keeps the objective in terms of defect and reduces the number of false calls
  - RI-ISI : if the maintenance relies on probabilistic criteria, the full POD is required
- But a point value (such as a deterministic assessment) may be enough information for NDT qualification

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