

# Quality criteria of robustness analyses in electrodynamics

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## Outline

- Computer aided magnetic circuit calculation of motors at ED and the challenges in robust motor design
- Assessment of quality criteria of robustness evaluations
  - Influence of tolerance distributions on robustness analyses
  - Convergence of CoP's

## Electrical Drives (ED)

- Part of the business sector Automotive Technology of the Robert Bosch GmbH
- Development and manufacturing of electrical drives for automotive applications, e.g.:



Window Lifter

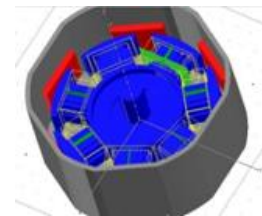


Engine Cooling



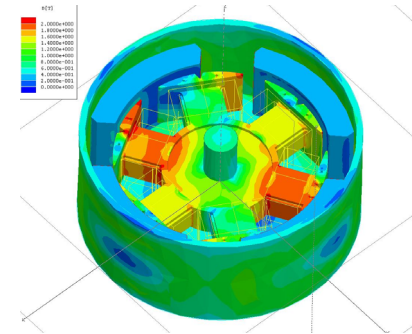
Wiper Systems

- Head Office in Bühl (Baden)
- Department ED/EED – engineering of electrical drives
  - Design and optimization of the motor magnetic circuits



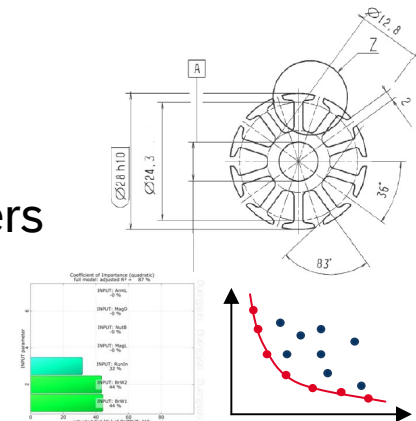
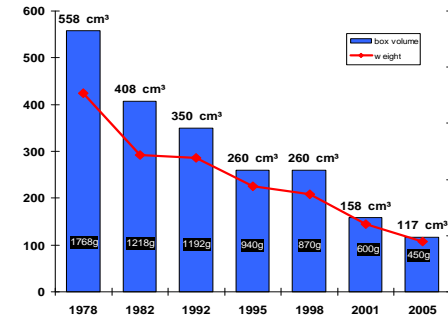
## Computer aided magnetic circuit design at ED

- Magnetic circuit design considers:
  - Motor characteristics, demagnetization, forces, losses, ...
- The following computer models are used:
  - Electromagnetic field calculations via geometry based 2D/3D finite element calculation (FEA)
  - Analytical commutation calculations
- Interaction with other domains:
  - Forces and torques → NVH, static structural analysis
  - Losses → Thermal



## Motivation

- Increased focus on reduction of weight and volume
  - Need of motor topologies with higher number of poles having a higher sensitivity to tolerances
- Vision:
  - Find an optimal and robust design of the magnetic circuit of the motor based on accurate and fast calculations
- Requirements:
  - Fully parameterized and automated motor simulation tool based on a unique data format of input parameters
  - Methodology of optimization algorithms and robustness analysis

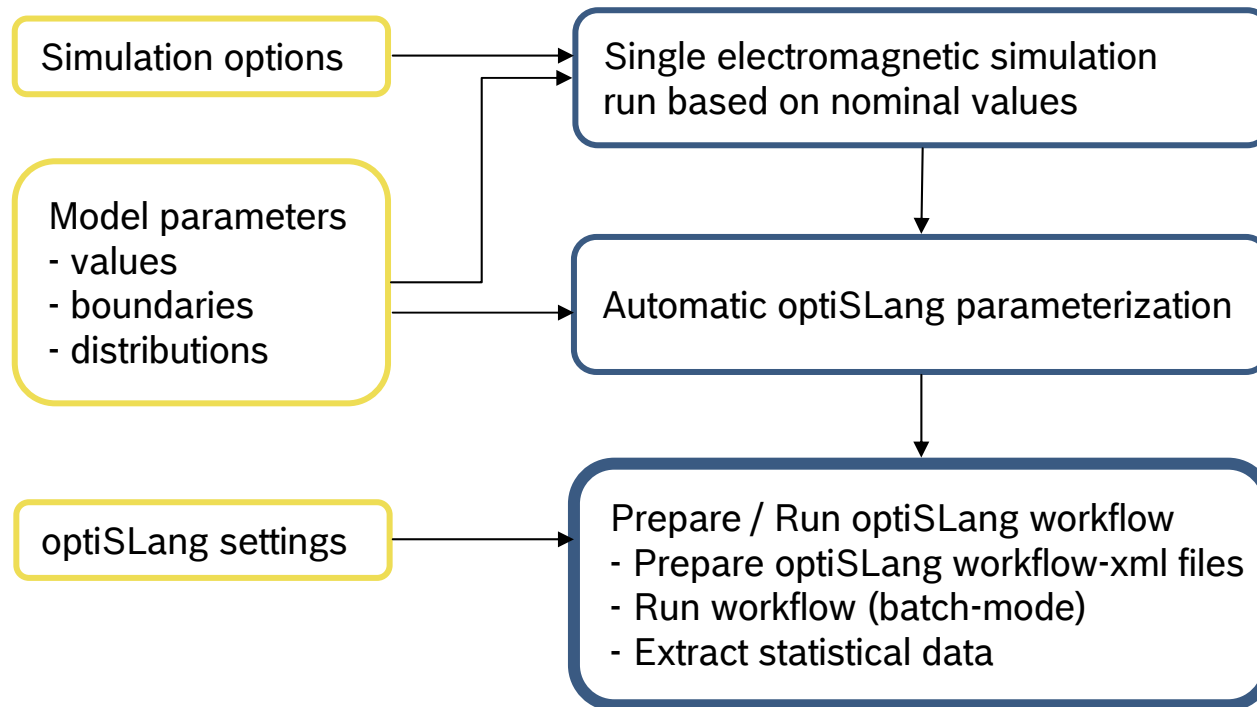


## Requirements on robustness analysis

- Reliable detection of cause-effect relationships in order to find important tolerance parameters
- Robust optimization requires CAE process to be accurate
  - Sufficient quality of model and parameterization is necessary
- Robust optimization requires a very high computational effort
  - Efficient use is necessary
- Goals:
  - To assess quality criteria of robustness analysis
    1. Variance of robustness analyses
    2. Influence of input tolerance distribution (sigma level)
    3. Required number of design evaluations
  - To provide an automatic workflow for calculating these factors

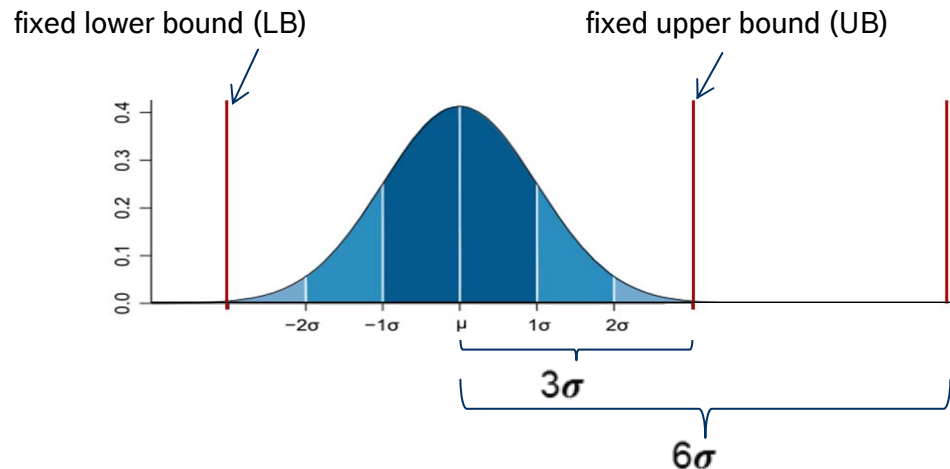
## Concept of automatic workflow

- Together with the ED-automatic CAE-Solver, an automatic optiSLang workflow has been prepared in Matlab



## Influence of sigma-level on robustness analysis

- Information about mean values and tolerances (drawings)
- Less information about variance and distribution of the parameters



$$\sigma_L = \frac{UB - \mu}{\sigma} = \frac{\mu - LB}{\sigma} \rightarrow \sigma = \frac{UB - \mu}{\sigma_L}$$

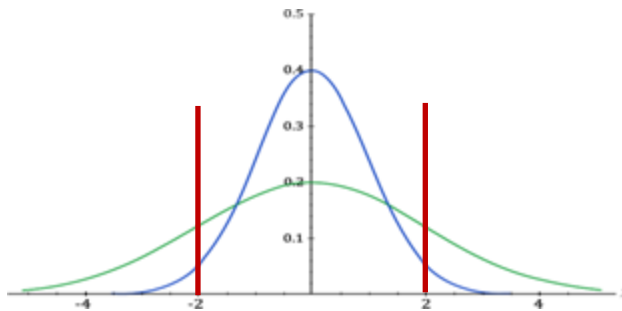
$\mu$  = mean value,  $\sigma$  = standard deviation,  $\sigma_L$  = sigma level



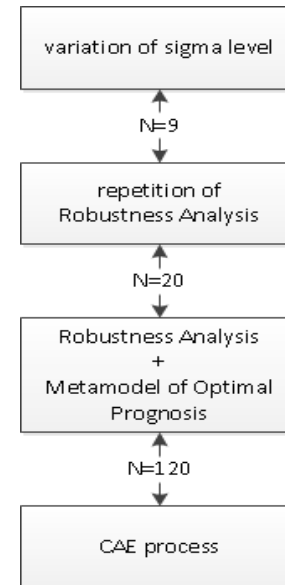
## Influence of sigma-level on robustness analysis

→ Which influence has the sigma-level of input parameter distributions on the robustness analyses (RA)?

- Variation of sigma levels ( $\sigma_L$ )

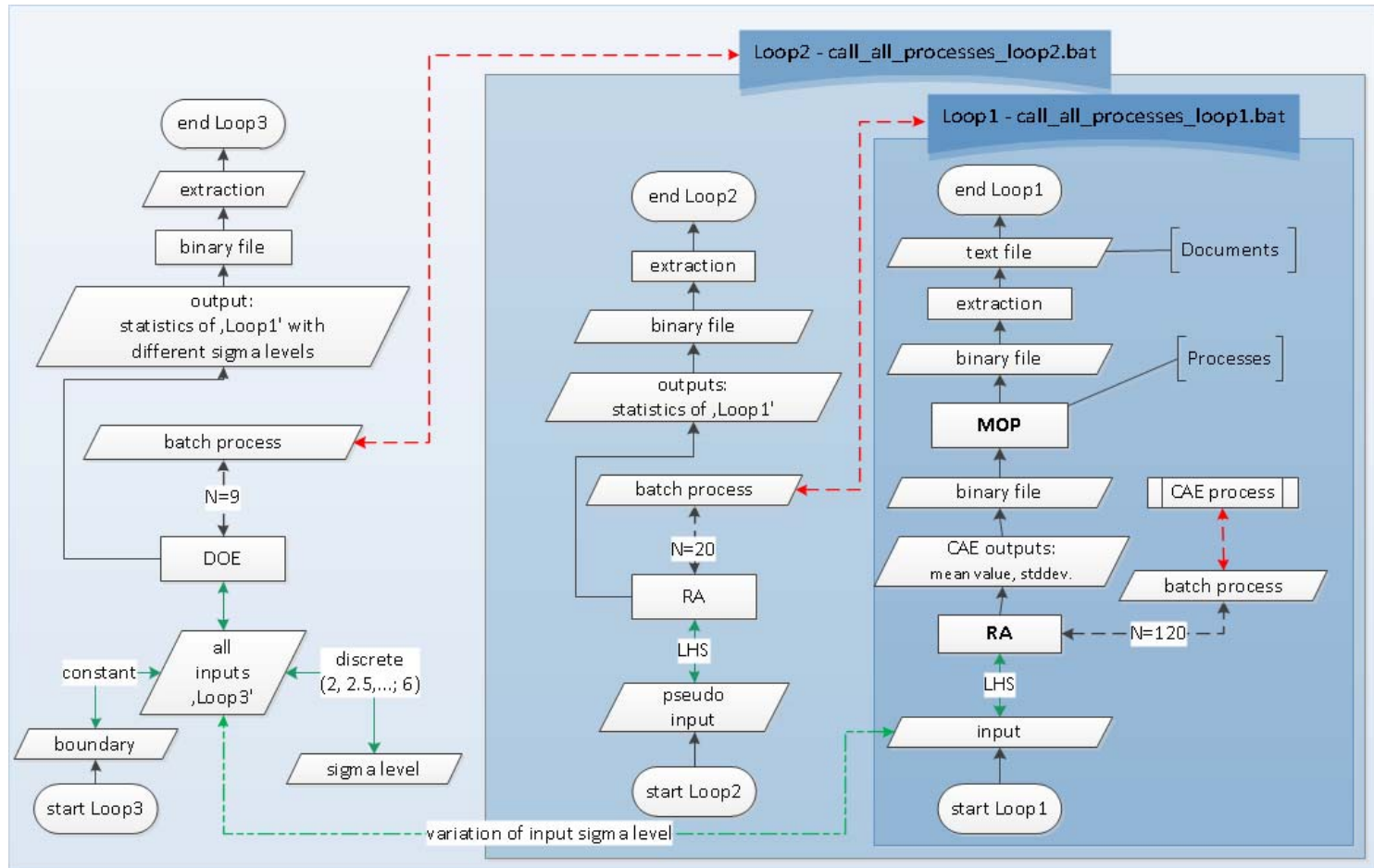


- Robustness analysis workflow for each  $\sigma_L$
- Repetition of robustness analysis

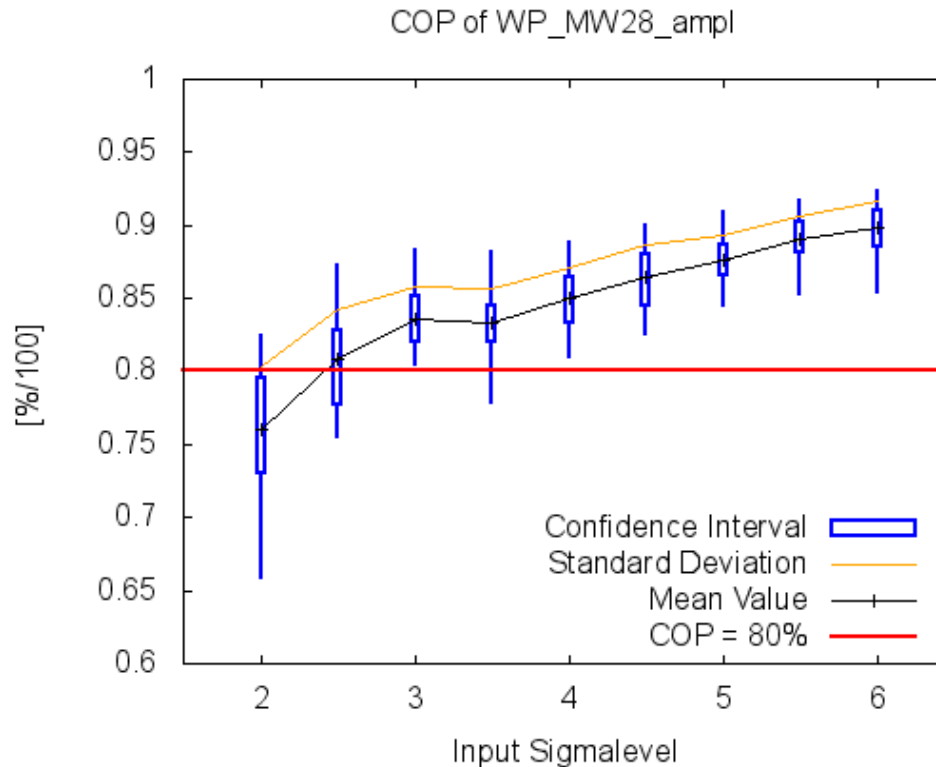


→ Allows evaluation of statistical behaviour of the method of robustness analysis including MoP

## Influence of sigma-level on robustness analysis

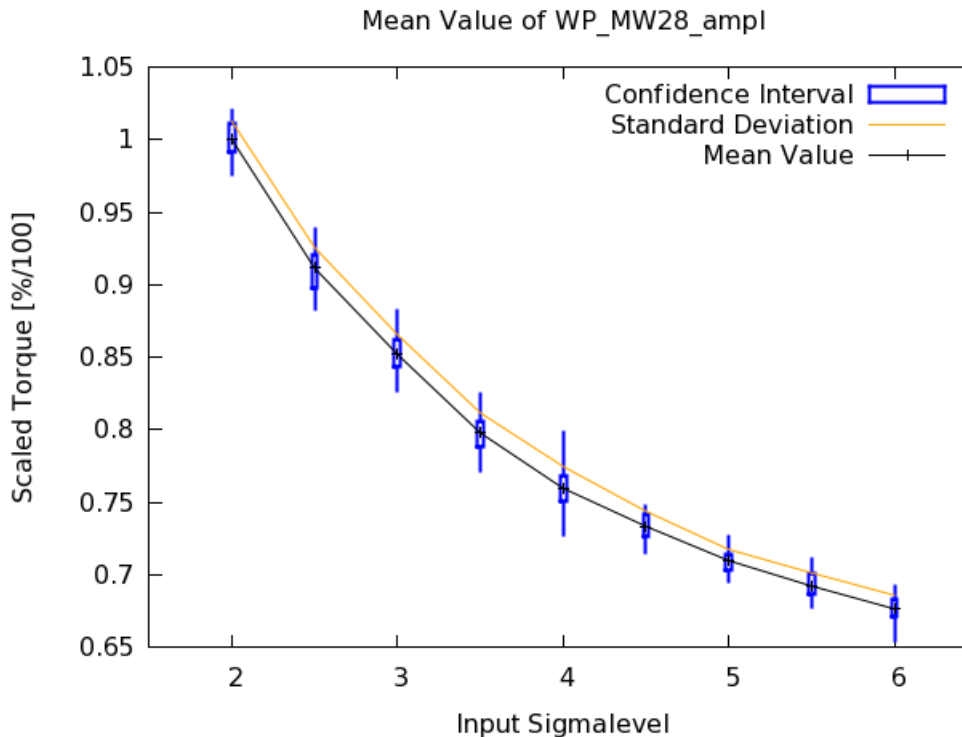


## Influence of sigma-level on robustness analysis



→ Detect model problems of low CoP's

## Influence of sigma-level on robustness analysis



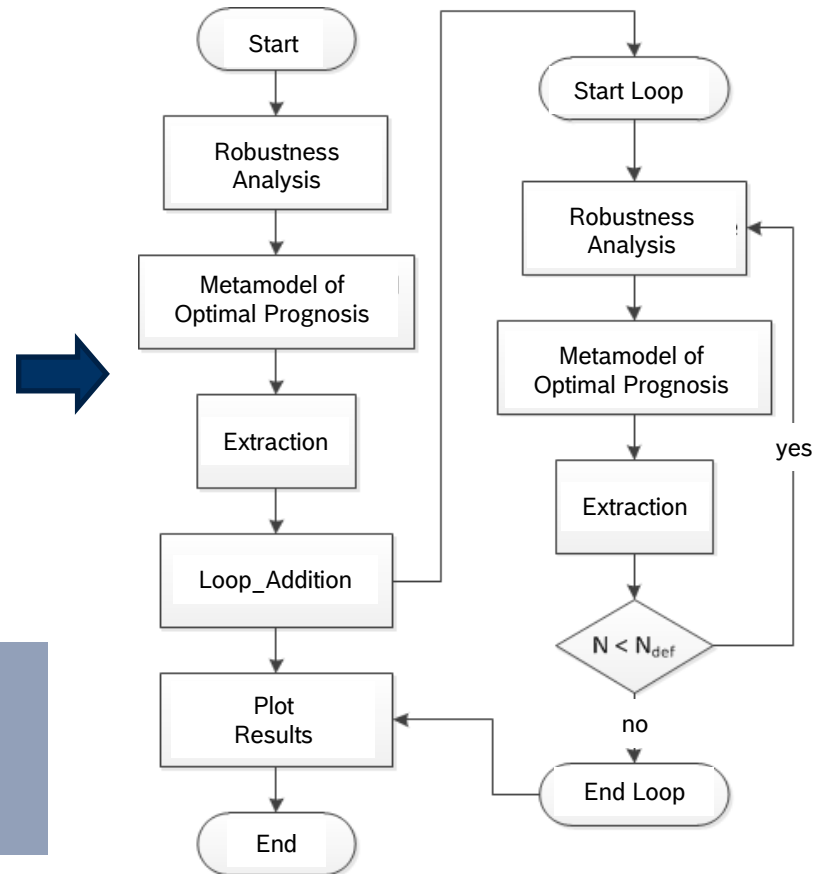
→ Evaluate influence of distributions with different sigma-levels

## Required number of calculations of RA

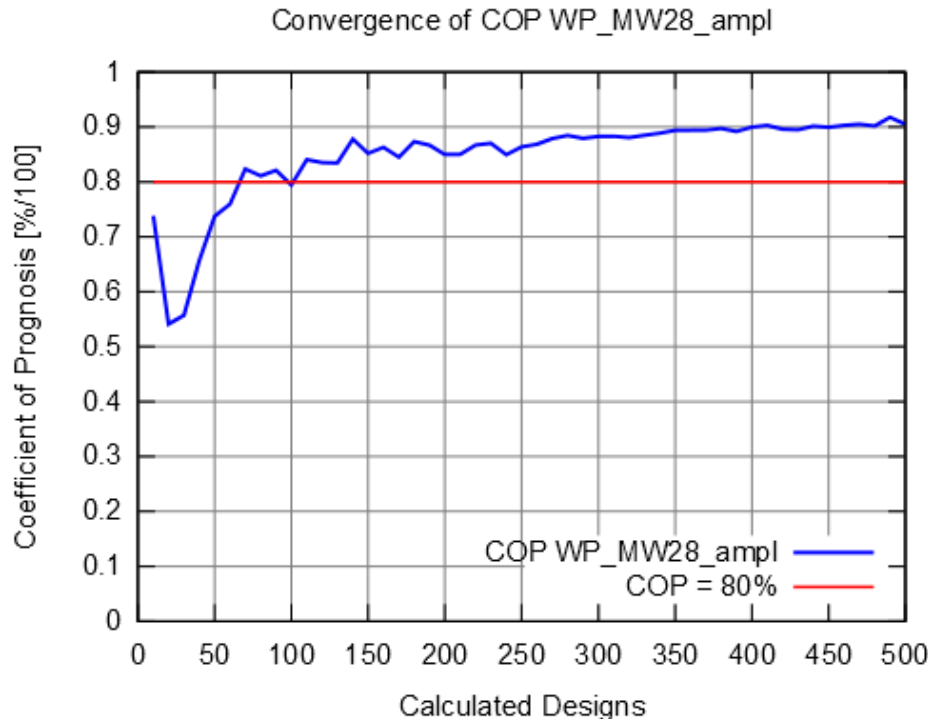
→ Find best compromise of run time and quality of the robustness analysis

- Robustness Analysis (using LHS with 10 Samples)
- Extraction of CoP
- Loop of RA (ALHS by increasing  $N$  until  $N_{\text{def}} = 500$  Samples)
- Extraction of CoP's

→ Allows evaluation of convergence of statistical data depending on number of design evaluations

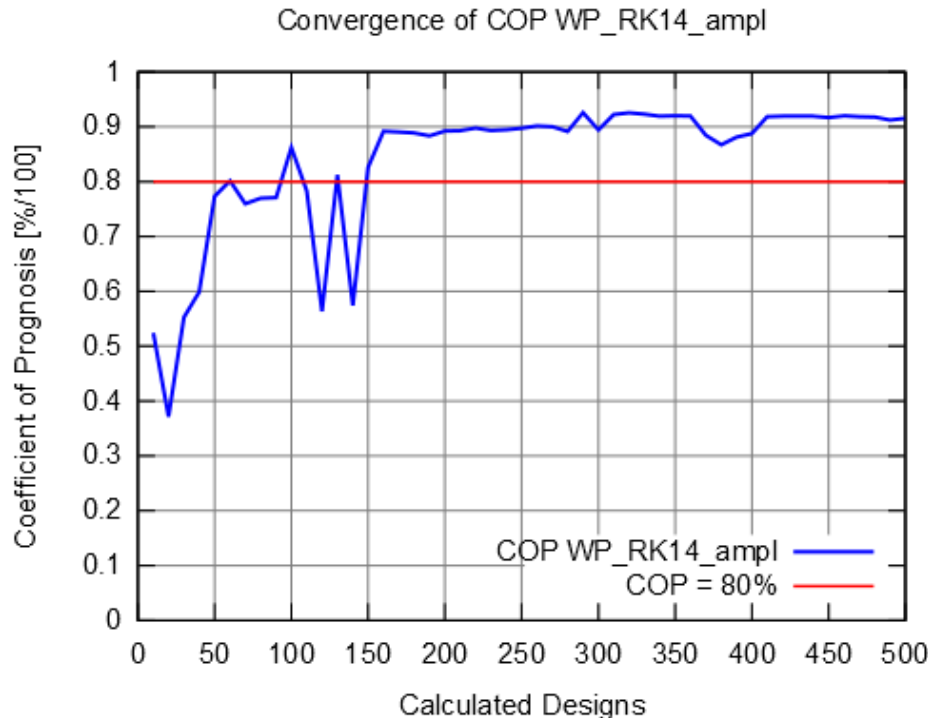


## Required number of calculations of RA



→ Evaluation of convergence of the CoP's of the output values allows to decide about the required number of iterations

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## Summary

- ➔ Reliable application of the method of robustness analysis is essential for robust design optimization
- ➔ Automated workflow of testing settings of robustness analyses allows the calculation of quality criteria
  - Convergence of CoP's due to number of design evaluations
  - Evaluate influence of distributions with different sigma levels
- ➔ The presented work forms a fundamental support for motor developers in setting suitable parameters to carry out robustness analyses

