MBD Driven Tolerance Analysis

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3DMC 3D METROLOGY CONFERENCE

mtc where progress happens

mtc

MTC: Who Are We?

- Opened in 2011
- Independent RTO
- To bridge the “valley of death” – the gap between academia and industry
- Prove innovative manufacturing ideas
- Manufacturing system solutions
- Training & Skills
- Part of the High Value Manufacturing Catapult

UNIVERSITY OF BIRMINGHAM

Loughborough University

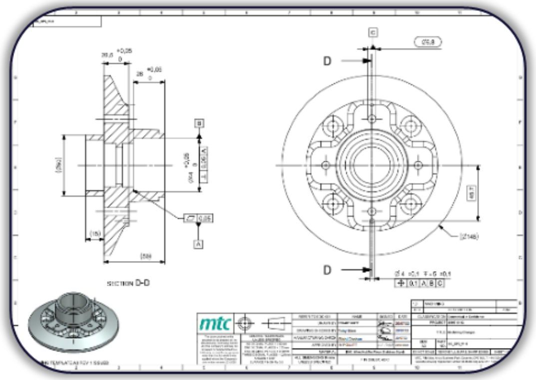
The University of Nottingham

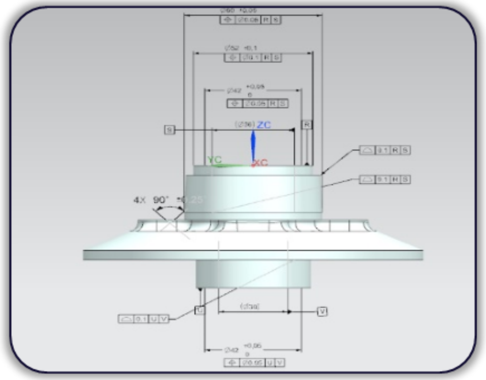
Introduction

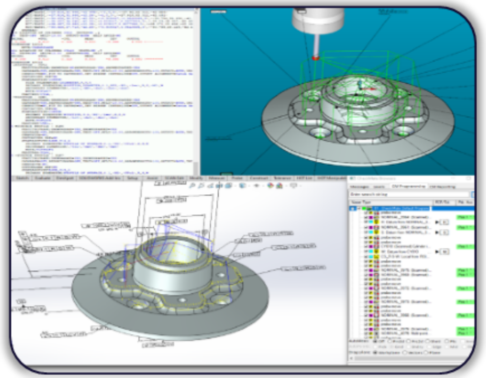
What is Model Based Definition?

Model Based Definition (MBD) is the CAD model, with embedded product manufacturing information (PMI), that defines how to make and inspect a part or assembly.

When an organisation creates a digital thread, enabling advanced software tools to re-use MBD throughout a manufacturing process chain, they become a **Model Based Enterprise (MBE).**







Technical Drawings and Data Pack

- Drawing centric;
- Physical authority;
- Paper-based / paper-on-glass;
- Human-readable

Model Based Definition

- Model centric;
- Digital authority;
- Semantically linked GD&T and PMI;
- Human & Machine-readable;

Model Based Enterprise

- Digital thread;
- Downstream consumption of digital information;
- Through-life data traceability

Benefits of MBE

Quality & Communication

- Single authoritative digital model
- Configuration & Data management
- Enhanced data traceability

Design Capability & Productivity Tools

- GD&T advisers
- Tolerance allocation automation
- Tolerance & Variation analysis

Manufacturing Capability & Productivity

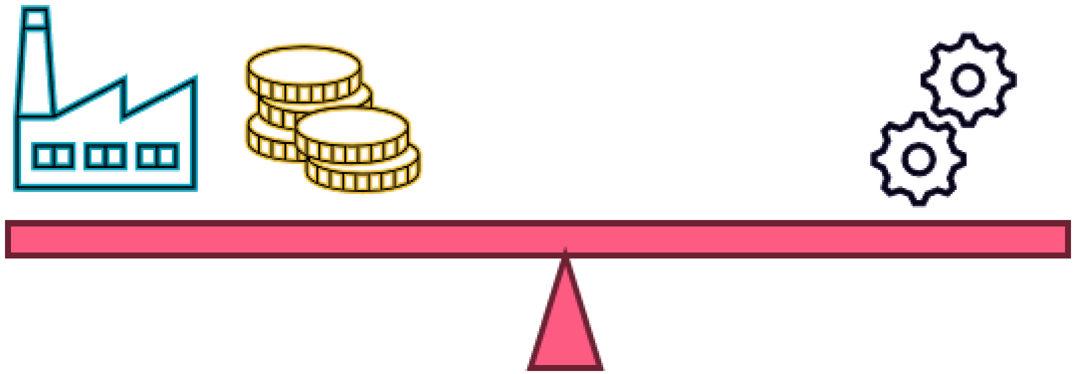
- Partial automation of Inspection & Manufacturing programming
- Reduced manual misinterpretation & effort duplication

Tolerance Analysis

- **Product success depends on the application of tolerances:**
  - They control fit, form and function;
  - It's a balance between function and manufacturability.

- **Tolerance stack-up and variation analysis are often:**
  - Iterative and complex, manual processes;
  - Time consuming and error prone.

- **Modern software, combined with MBD can:**
  - Improve communication of design intent;
  - Reduce complexity Reduce errors;
  - Yield dramatic time savings.

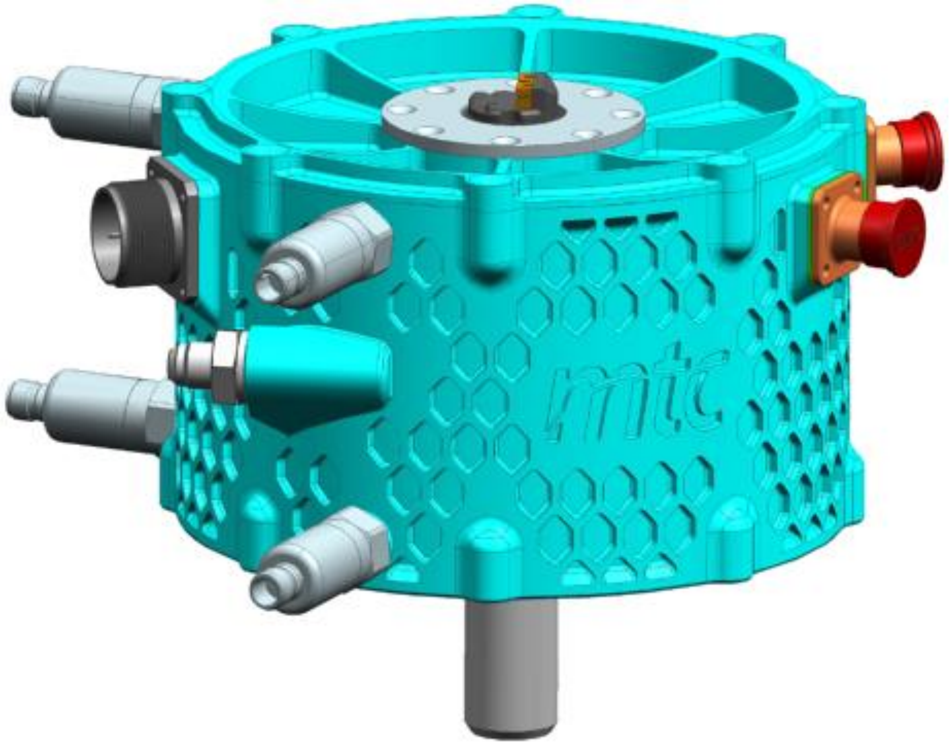


Case Studies

Future Electric Motor Systems (FEMS4)

- **MTC objective:**
  - Design, manufacture, and experimentally validate a high performing electric motor combining several advanced manufacturing methods.

- **This is an ideal case study for tolerance analysis as it has:**
  - CAD and manufacturing drawings;
  - Physical components;
  - Varying manufacturing process capabilities;
  - Tight tolerances;
  - Common industrial tolerance stack challenges;



CAD of FEMS Motor

Case Studies

1D Example Stack

1D Motor Spring Tension:

- 6 distinct components;
- Creates an envelope for a Wave Spring to seat;
- Ensures pre-loading is maintained in operation;

A		B		C		
Main Casing 116 +-0.10	−	NDE Plate 1 +-0.25	−	Spring Carrier 5.42 +-0.1	=	Casing Assy 109.58 +-0.45
D Shaft 80 +-0.10	+	E Bearing 13 -0.06	+	E Bearing 13 -0.06	=	D Shaft 106 +0.10/-0.22

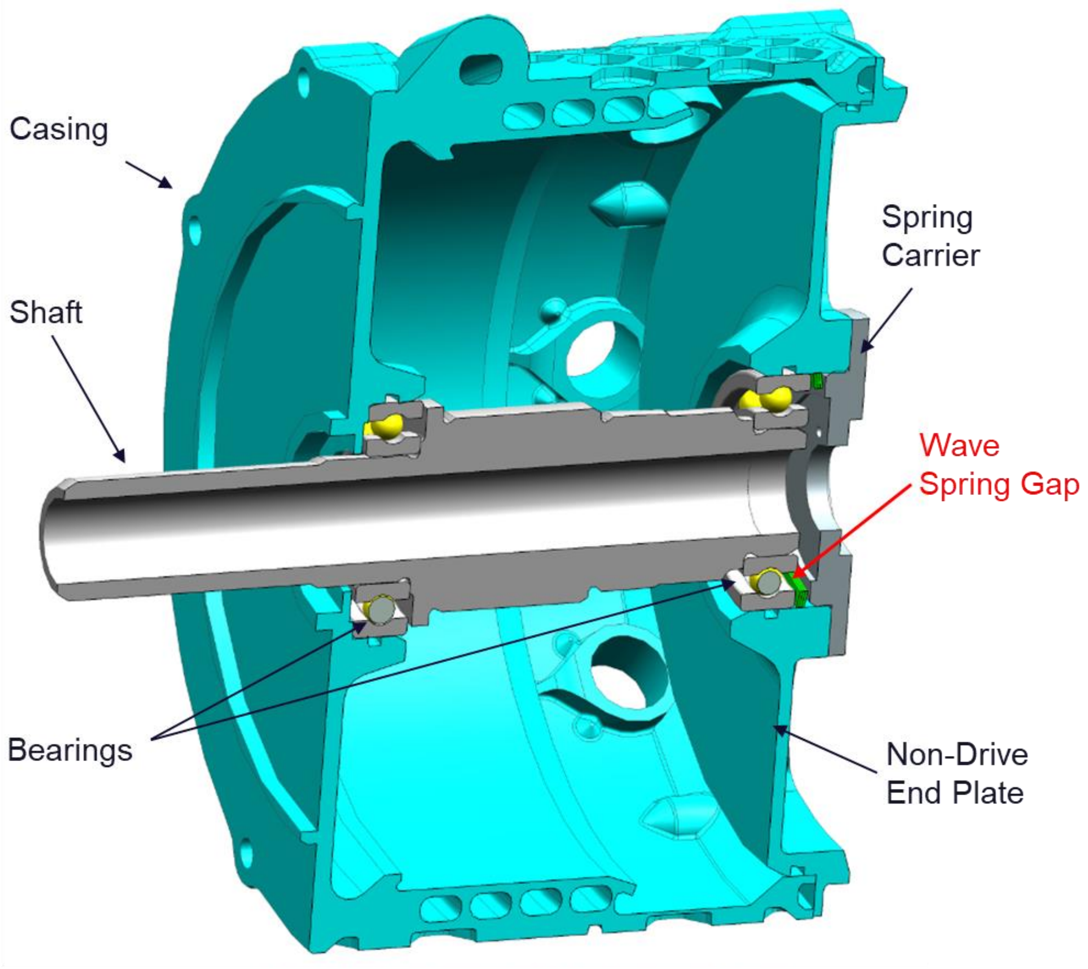
Clearance:

3.58mm Nominal

3.03mm Tightest Fit

4.25mm Loosest Fit

Error prone, Manual stack calculation for the simple case of the spring gap.



CAD of FEMS4 Motor showing contributing components to stack.

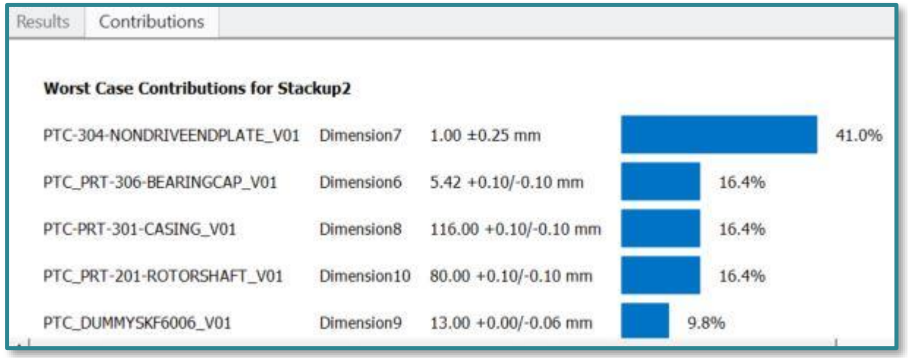
Case Studies

1D Example Stack

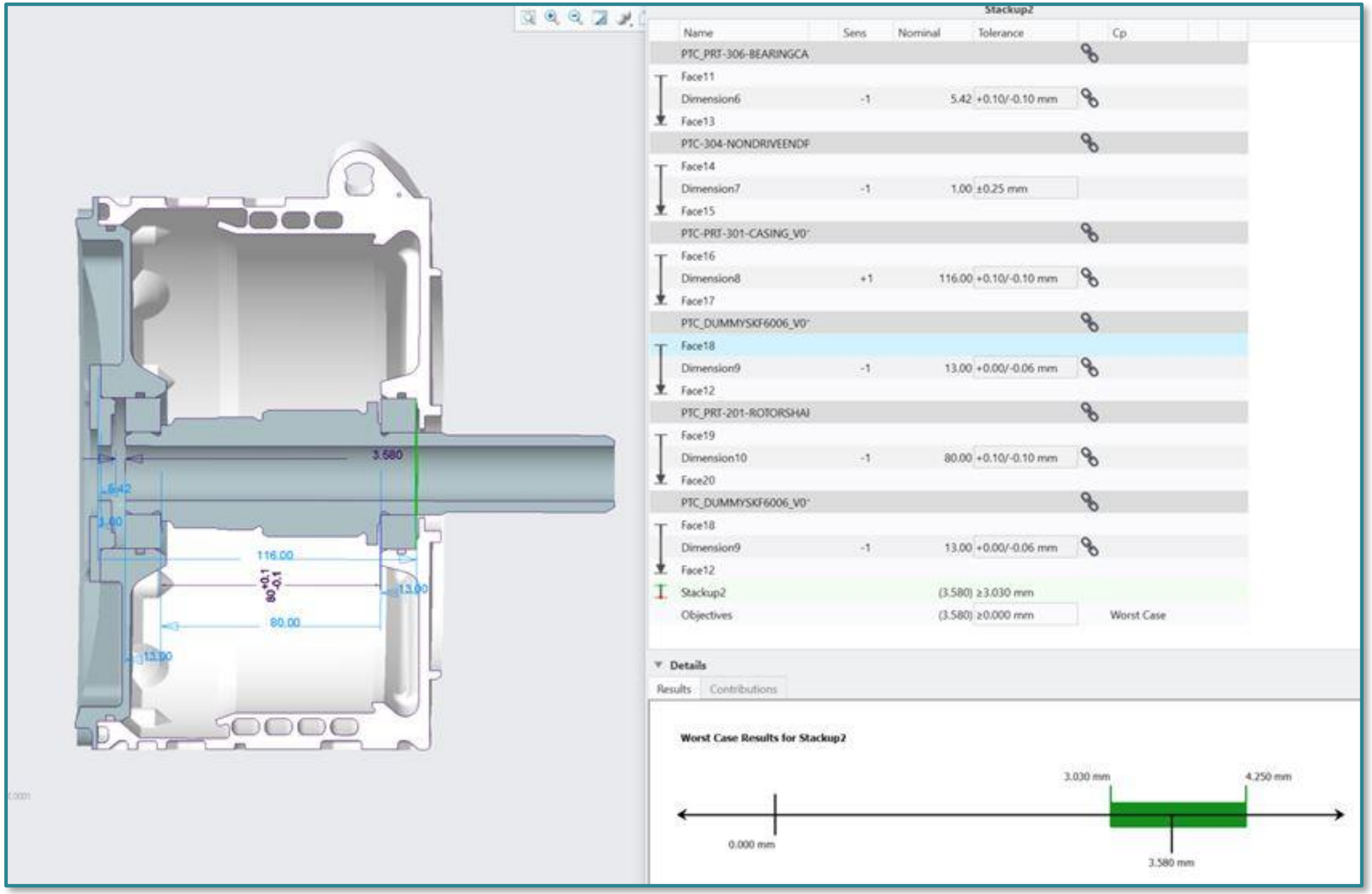
Top Level Findings:

- Instant each feature’s tolerances;
- Removes engineer, or BMS held spreadsheets;
- Eradicates human error.

Mins	Hrs	Days



Spring Gap Contributors obtained using Creo’s EZ Tol analyser



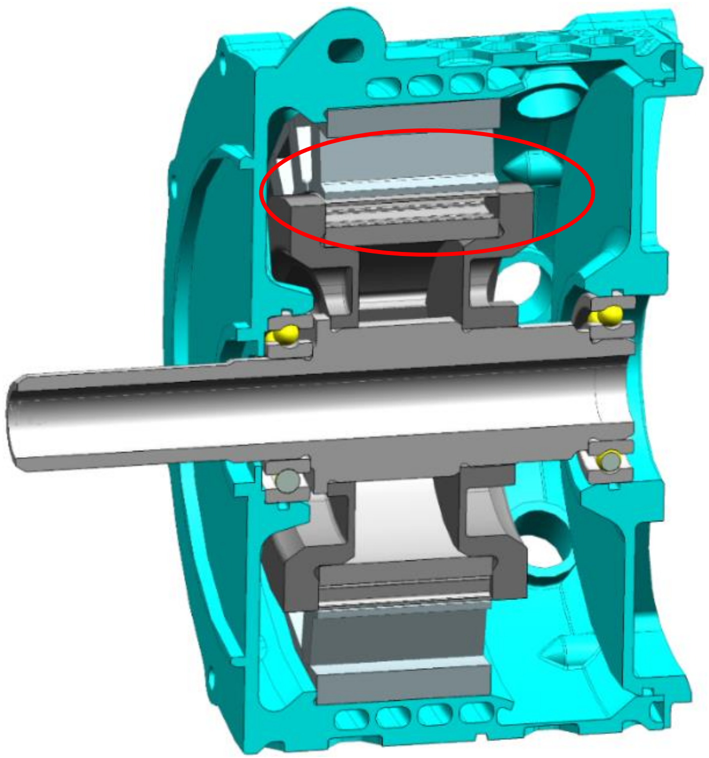
Spring Gap Worst Case Results obtained using Creo’s EZ Tol analyser

Case Studies

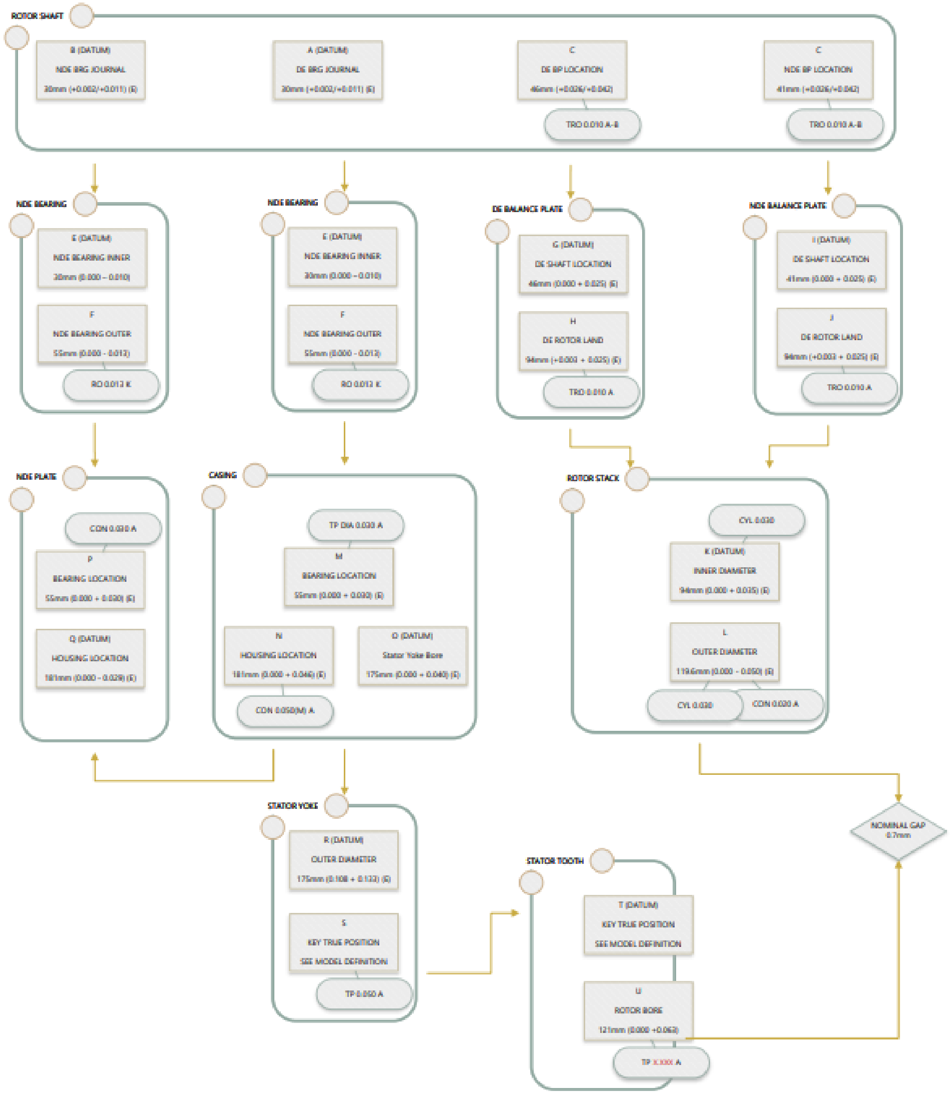
3D Example Stack

- **3D Motor Running Clearance:**
  - Between the Rotor and the Stator;
  - 37 tolerance allocations contribute to this clearance, identified from 9 components.

- **Identified Findings:**
  - Features that had a greater effect on running clearance;
  - Over 2000 simulations ensured other features always constrained the assembly;
  - Analysis was too complex for excel based tools.



CAD of FEMS4 Motor showing location of running clearance.



Map of tolerance stack being assessed.

Case Studies

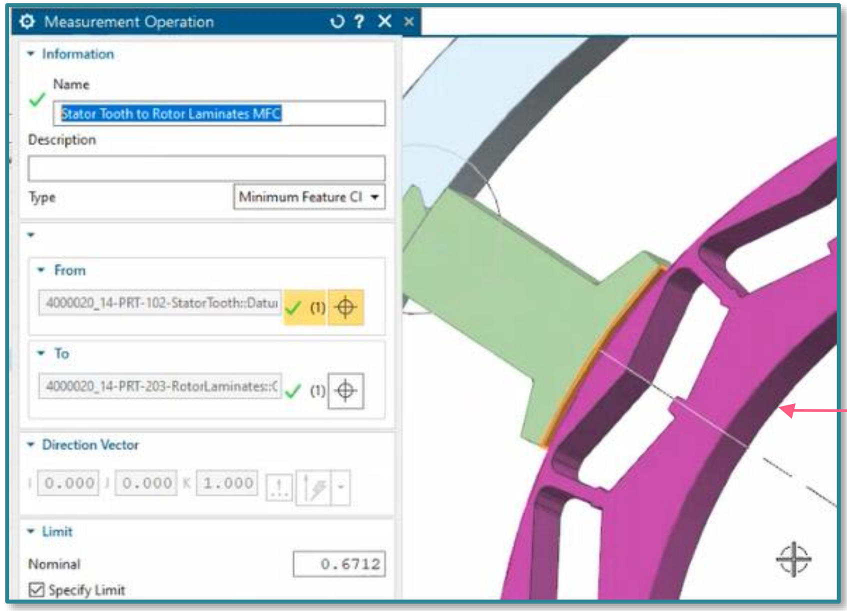
3D Example Stack

➢ Running Clearance, Heating & Interference Effects:

- ➢ Each fit plays a key role in determining measurement actuals. Options for fits include:
  - ➢ Centering;
  - ➢ Float;
  - ➢ Bias.

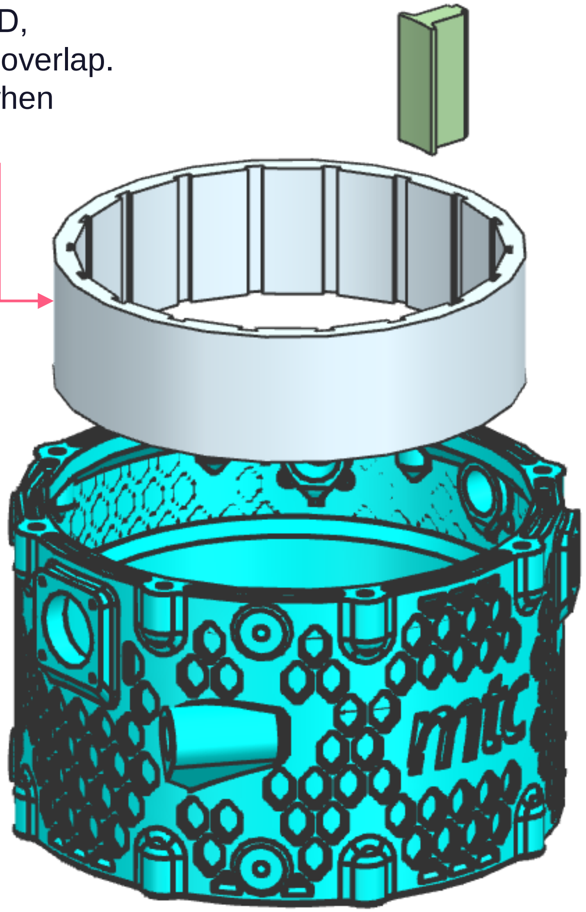
Float and Bias require clearance between objects to function.

OD "centered" to casing ID, interference produces an overlap. Interference will reduce when component are offset.



A screen capture from NX highlighting the running clearance between the Rotor Laminate and Stator Tooth

ID "centered" to Balance Plate OD's, interference produces an overlap. Interference will reduce when components are offset.

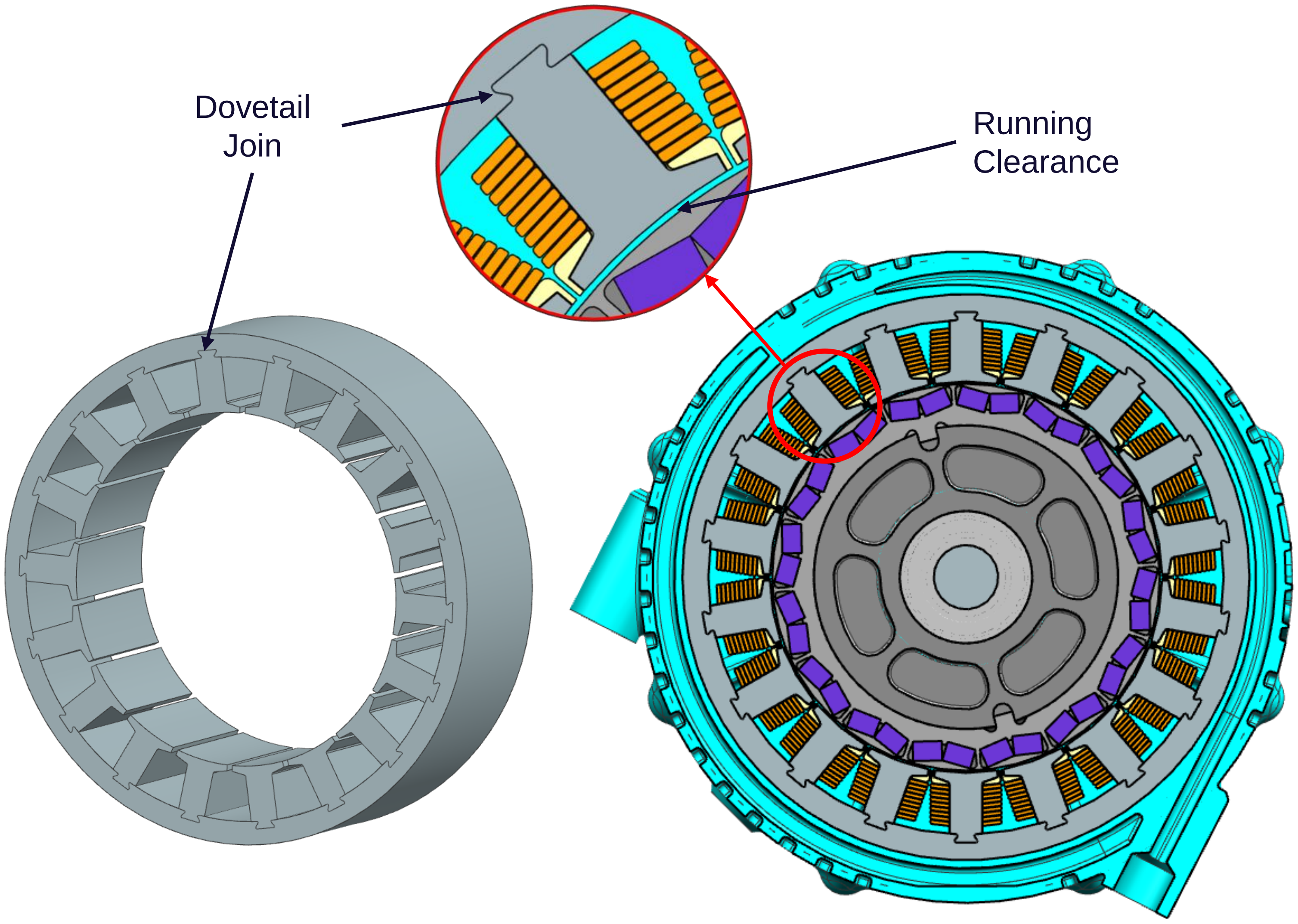


Assembly model of FEMS Motor

Case Studies

3D Motor Running Clearance

- **3D Motor Running Clearance:**
  - Dovetail joint between the stator tooth and stator ring.
  - Designer's assumptions / preferences can lead to dramatic implications at manufacturing & inspection;
  - Wire EDM manufacturing method,
  - Datum features;
  - Critical diameter;
  - Tight tolerances.

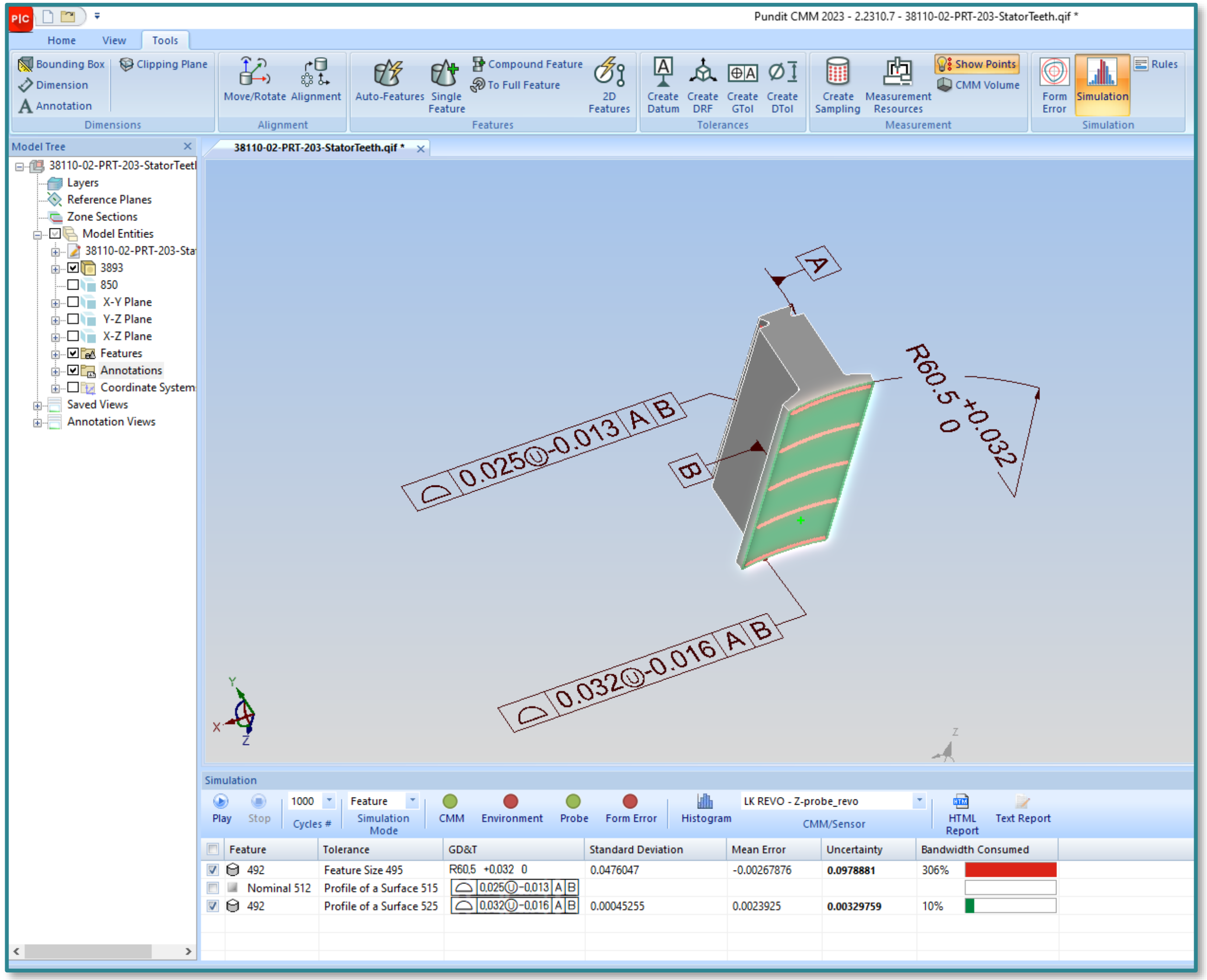


Case Studies

3D Example – Design for inspection

➢ Measurement Uncertainty Assessment:

- ➢ MBD driven tool: Pundit CMM: Capvidia
  - ➢ QIF, STEP 242, JT, Native;
- ➢ Critical partial radius: 32 µm tolerance;
- ➢ **> 300%** tolerance consumption, based on simulated mid range CMM.
- ➢ GD&T correction to surface profile consumed only **10%;** Same radial zone size.

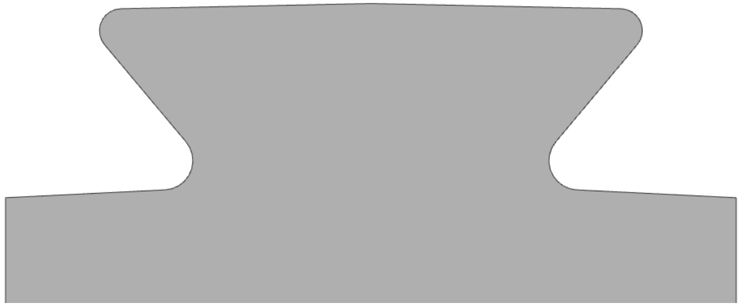


Screen capture from Pundit CMM portraying the measurement uncertainty derived from alternative tolerance allocation approaches

Case Studies

3D Example – Design for inspection

- **Datum features:**
  - Surface profile pushes emphasis onto Datums;
  - Unstable datums in the original design;
    - Purely design preference / assumptions;
  - How is the part made?
    - Wire EDM
    - Manufacturability unchanged.



Old stator tooth design

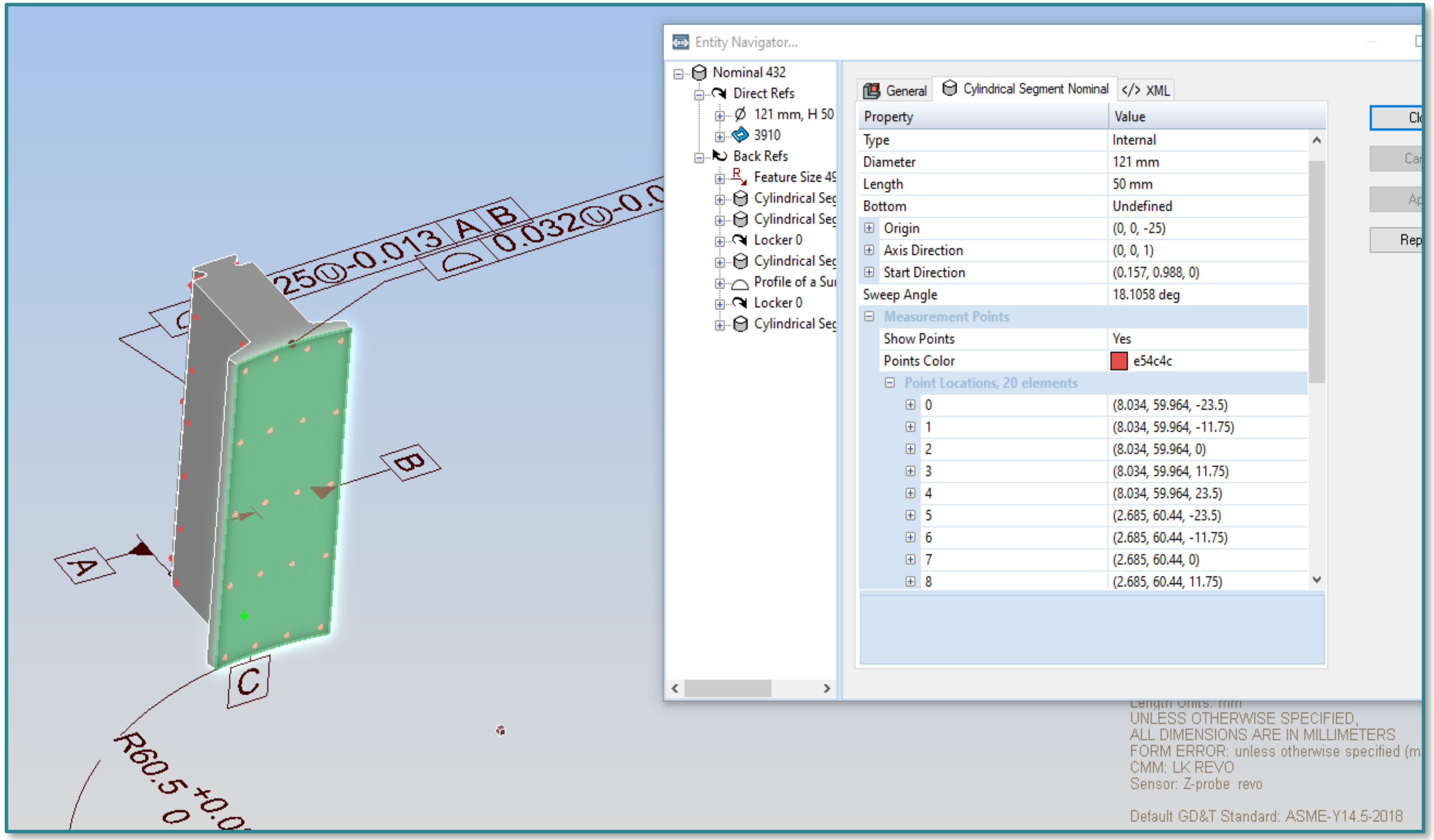
New stator tooth design

Mins	Hrs	Days

Case Studies

Data driven inspection workflow

- **Digital thread for inspection:**
  - Uncertainty evaluation provides optimal measurement strategy;
  - QIF exported the previously defined measurement target points in readiness for component inspection.
  - GOM ATOS 5 inspection;
    - 18 parts, assessing process capability;
    - Target points auto extracted;
    - GD&T evaluation automation with MBD.



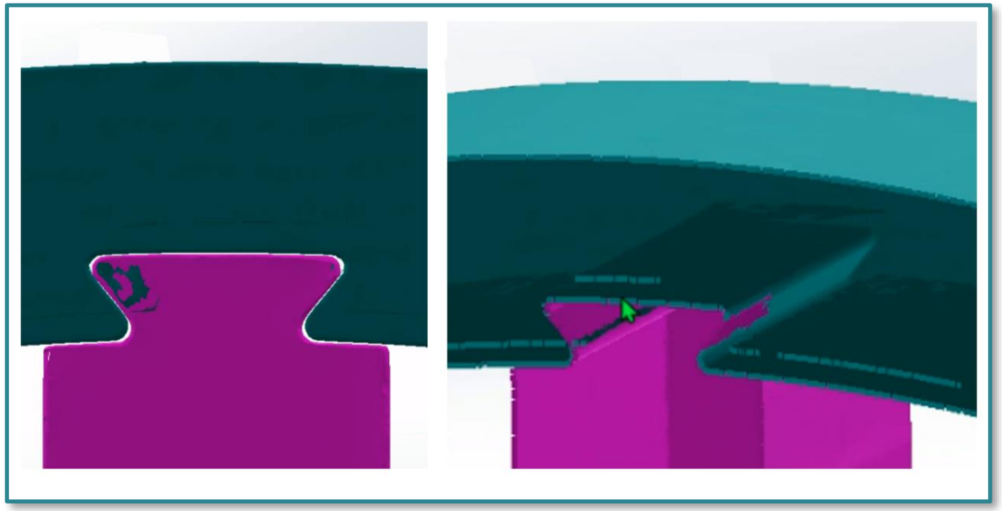
Screenshot of QIF file import into MBDVidia, showing sampling points planned using the Pundit uncertainty simulation tool..

Case Studies

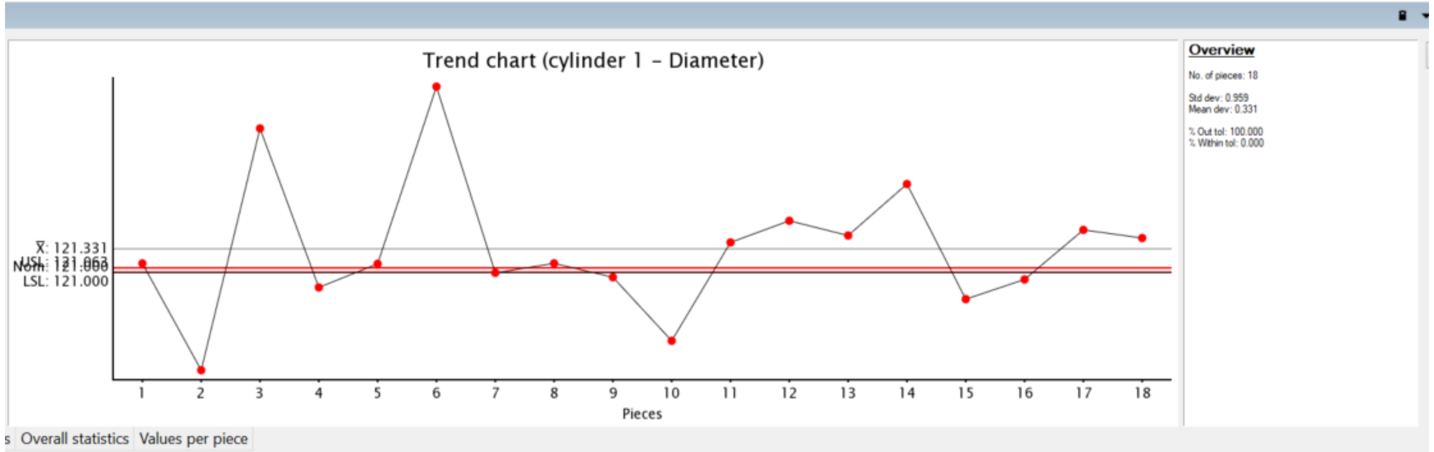
FEMS4 Example Stack – Stator Tooth, Inspection Results

➢ Summary

- ➢ Results of the inner cylinder diameter:
  - ➢ **Mean size deviation of 0.3 mm, with large variation;**
  - ➢ **100% out of specification;**
- ➢ Note: GOM ATOS 5 approx. accuracy – 0.025 mm;
  - ➢ Co-ordinate Measuring Machine – 0.003 mm.
- ➢ Using standard deviation at point level removes additional GD&T error at feature level:
  - ➢ **Single point standard deviation between 6 and 14 µm depending on position.**
- ➢ Illustrates the impact of design decisions downstream.



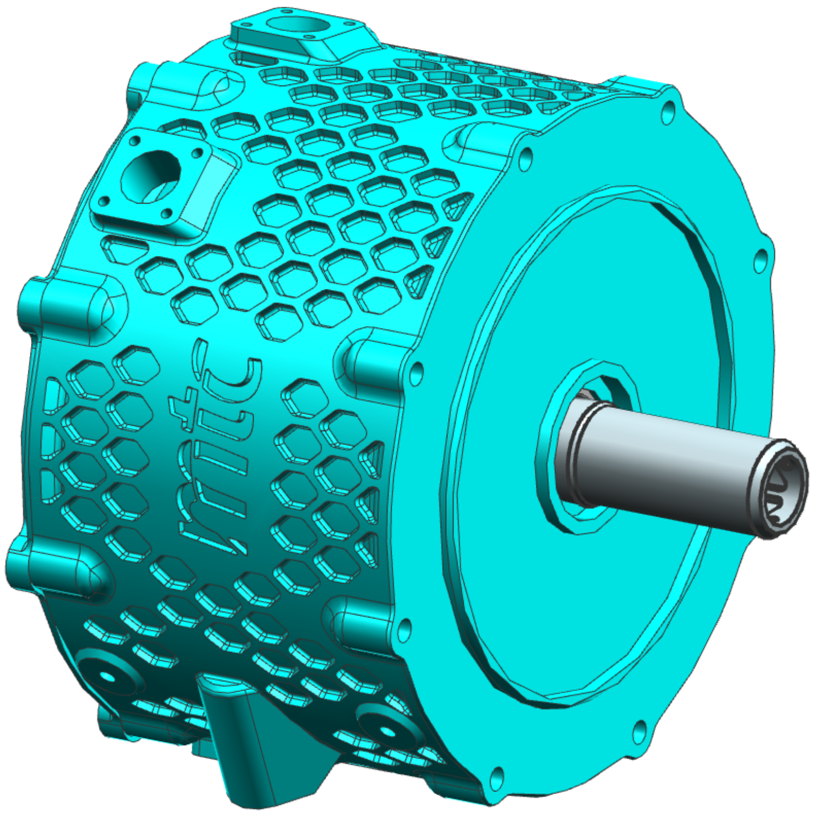
Origin assembly analyser captures that there are no interferences between the stator teeth and yoke.



Stator Tooth size variation extracted using Polyworks

Summary

- **Key Takeaways:**
  - Powerful current state capabilities;
  - Vital to understand how the software works and its assumptions;
  - Key enablers for understanding GD&T, design, and assembly;
  - Digital thread – connect the data for multiple tools to amplify impact;
  - Focusing on design optimisation opposed to tolerance optimization.



CAD of FEMS4 Motor.

Proud to be part of CATAPULT High Value Manufacturing

Thank you

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