COMSOL CONFERENCE
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FEA Mechanical Modeling of Torque Transfer Components for Fully Superconducting Rotating Machines

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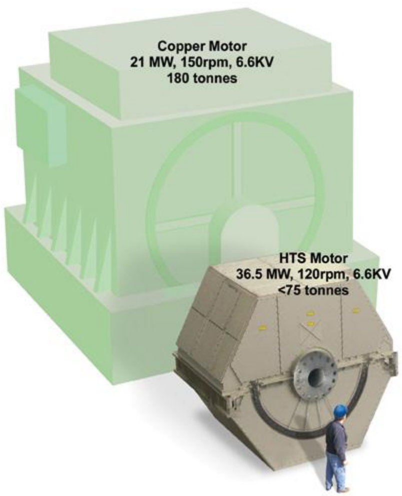
COMSOL MULTIPHYSICS

Outline

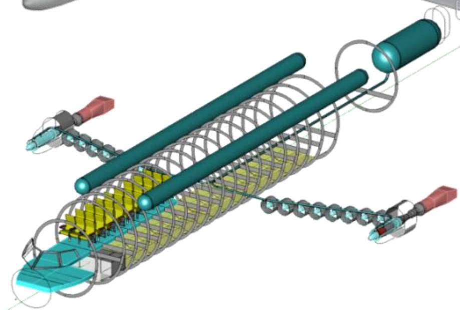
- Background
- Parametric Model
- Multiphysics Study
- Study Results
- Optimization Study
- Error Analysis

Background

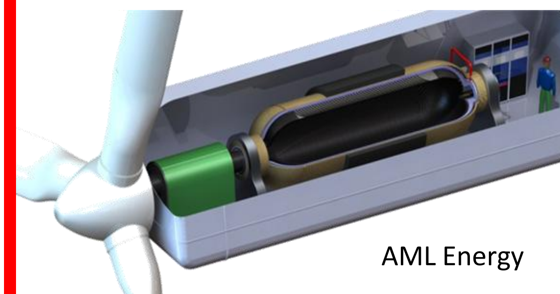
Applications with requirements in terms of specific power/torque and efficiency that cannot be matched by conventional machines



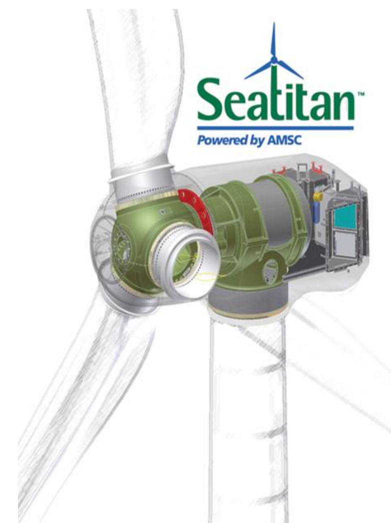
http://www.amsc.com/products/motorsgenerators/shipPropulsion.html



AML – ESAero – NASA GRC



AML Energy

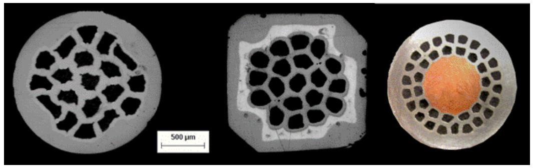


American Superconductor

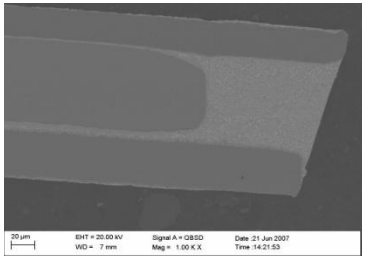
Background

Challenges

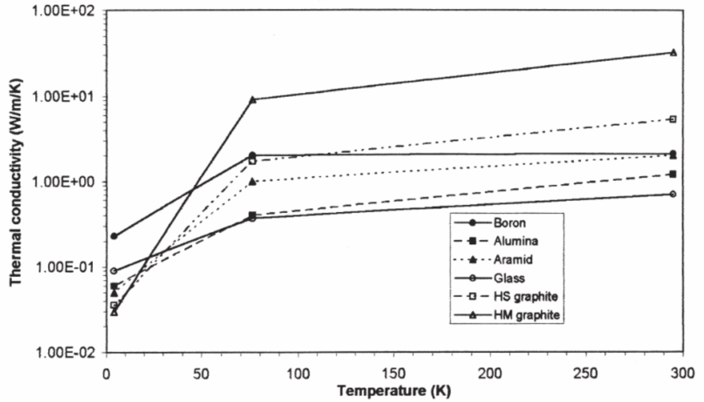
- Economic
  - Low cost conductors
  - Low cost cryocoolers
  - Superconductor availability
  - Cost effective manufacturing
- Mechanical
  - Torque transmission/torque tube
  - Large Lorentz forces on superconductors (peak field >4 T)
  - Torque and forces applied on conductors
- Thermal
  - Heat leaks need to be minimized
    - Conduction through shaft
    - Current leads
    - Splices
  - Multifilament conductors
- Stability
  - Quench detection/protection
  - Fault current/torque



MgB2 conductor



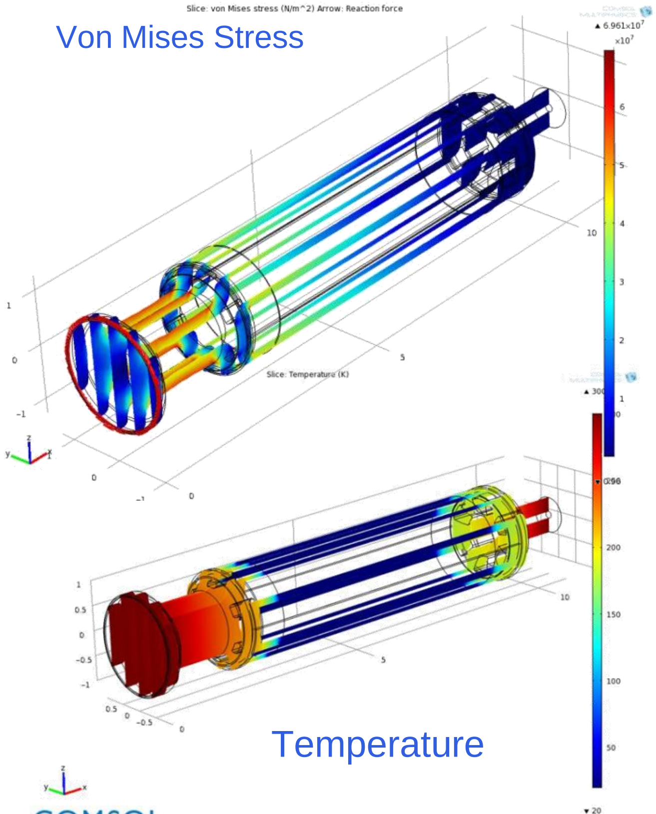
2G conductor



Carbon fiber composite thermal conductivity

Thermal Insulation and Torque Transmission

- Shaft sees a very large thermal gradient
- Torque tube needed to transfer torque to room temperature
  - Because of turbine rotor inertia, the full fault torque needs to be transferred
  - Design trade-off between structural and thermal



Layers of ceramics or Fiber glass composite to thermally insulate the shaft end

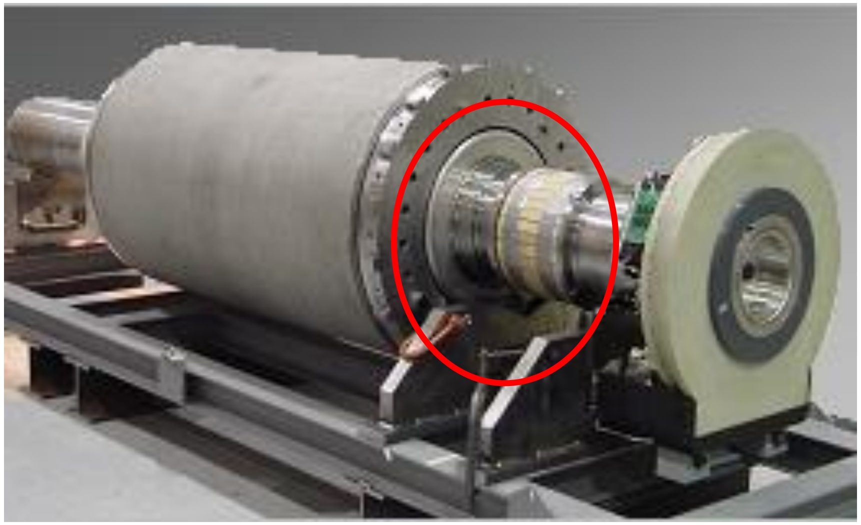


Photo courtesy of AMSC

Parametric Model

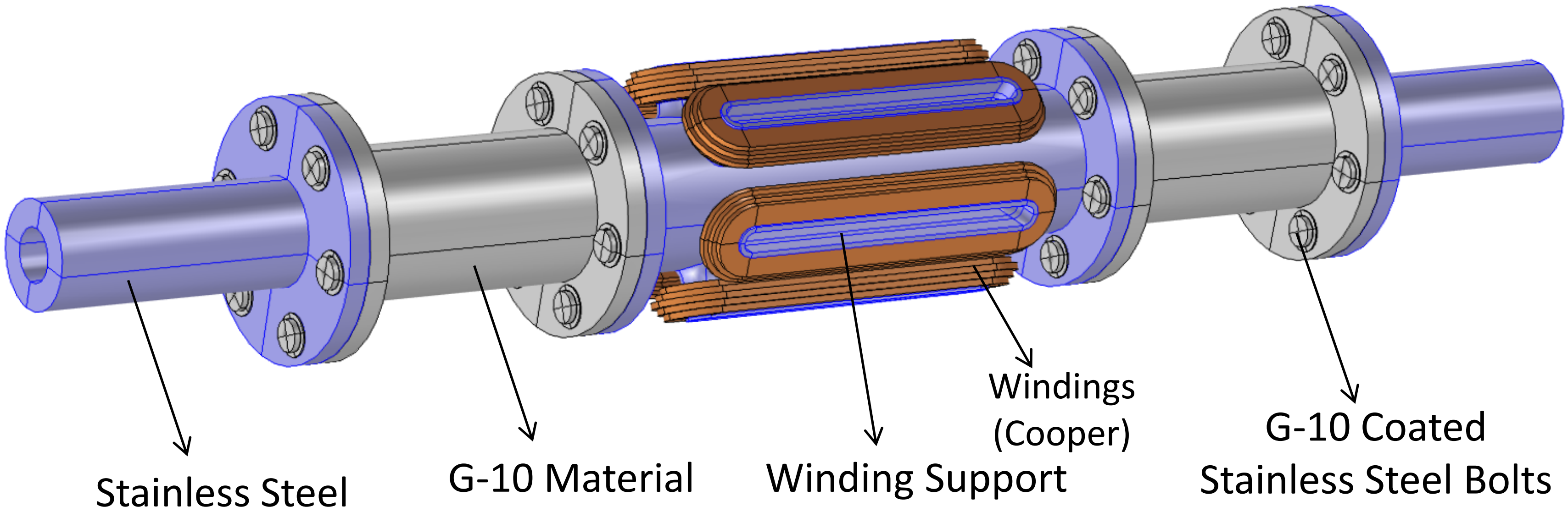


Figure 1. Parametric Designed Model

- ✓ *Fully Parametric Design Model*
- ✓ *Allows for Easy Parametric Sweep*
- ✓ *High-fidelity simulation of assembly*

Multiphysics Study

Thermal Stress (ts) → Heat Transfer in Solids + Structural Mechanics

Coupling: Thermal Expansion

- ❑ Requires large amount of computing memory
- ✓ Easy to calculate
- ✓ Easy to calculate

Multiphysics Study

Heat transfer (temperature distribution)

- Temperature conditions:

  The superconductor part keeps 20K

  Two ends keep room temperature (300K)

- Temperature Gradient

  G-10 fiber glass material

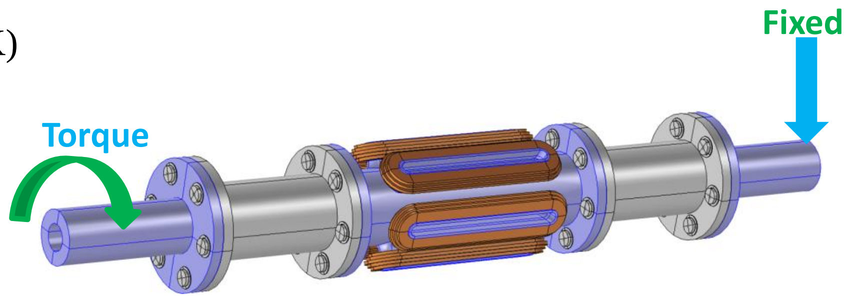


Figure 2. Parametric Designed Model

Solid Mechanics (stress analysis)

- Thermal Stress

  Induced by temperature gradient, coupled with Thermal Expansion

- Torque induced Stress

  Induced by the applied torque (shear stress)

Study Results

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Heat transfer (temperature distribution)

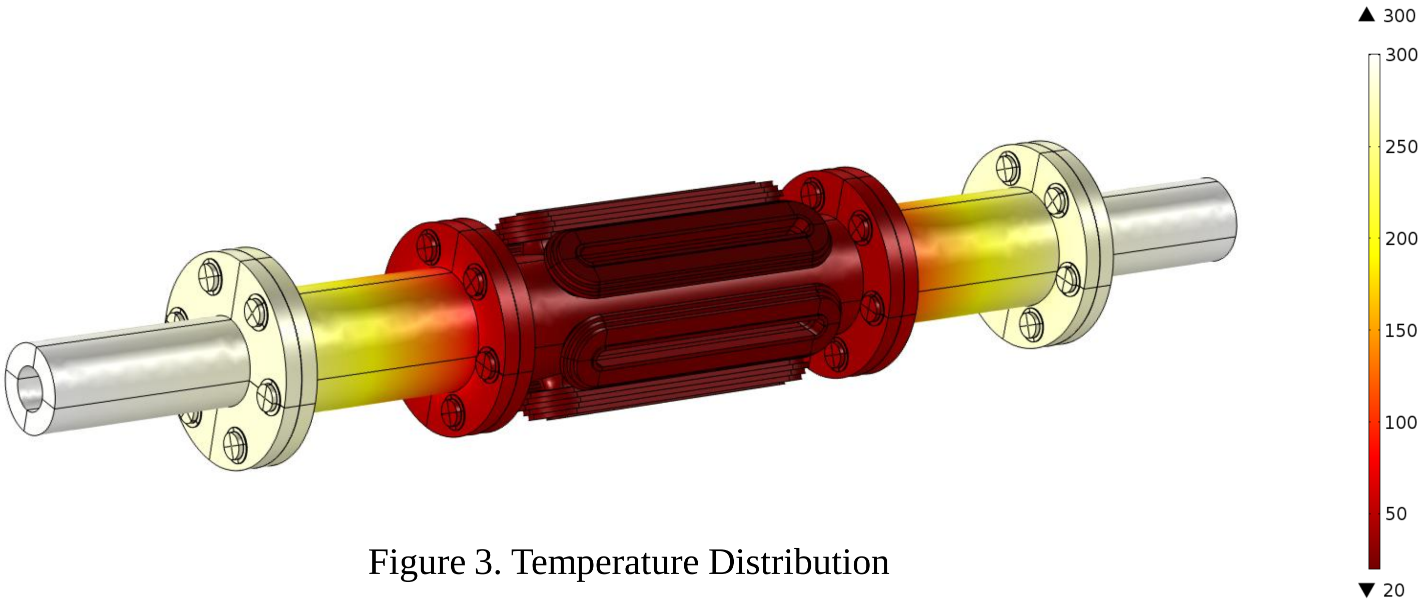


Figure 3. Temperature Distribution

- G10 components take most of the temperature gradient
- Bolts connect G10 and stainless steel parts

Heat transfer (temperature distribution)

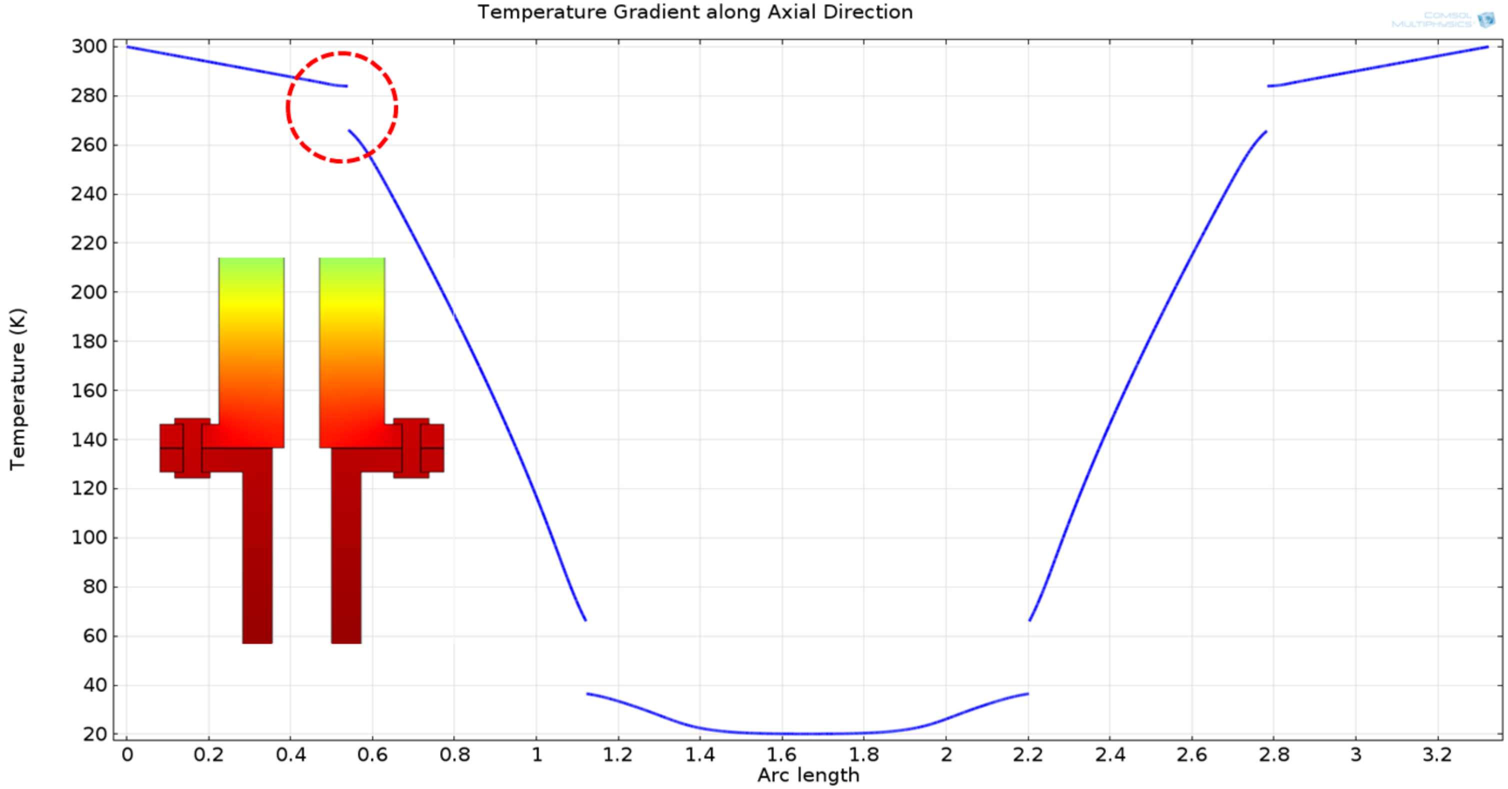


Figure 4. Temperature Distribution along Axial Direction

- Thermal contact resistance implemented to represent rough surfaces of connected parts.

Solid Mechanics (stress analysis)

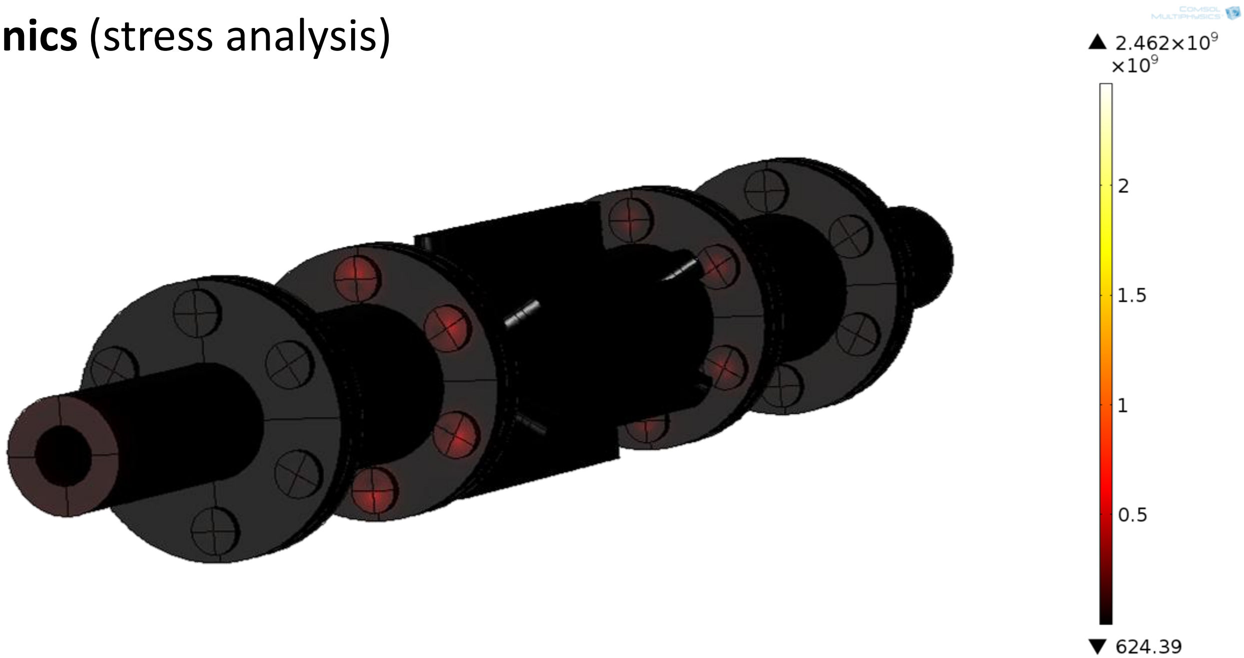


Figure 5. Stress Distribution

✓ Peak stress is in the connection bolts

Solid Mechanics (stress analysis)

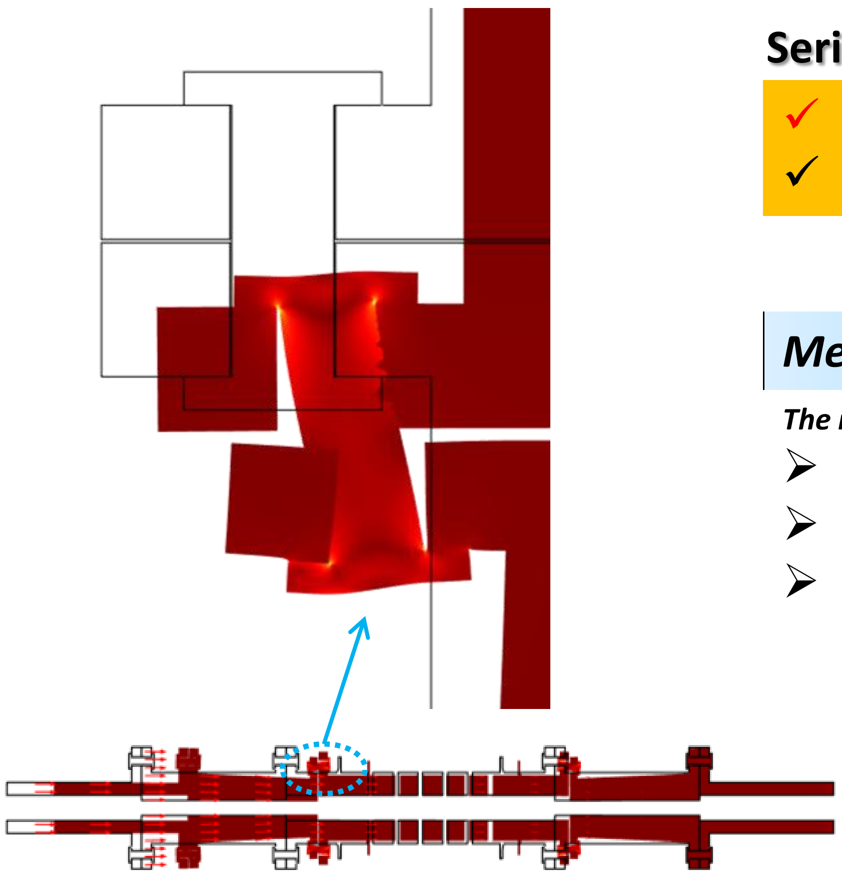


Figure 6. Stress Distribution of Bolts

Series of simulations show :

- ✓ Thermal stress is dominating
- ✓ Peak stress is in the connection bolts

Methods to decrease the Thermal Stress

The influence of following factors on peak stress was investigated

- Number of bolts
- Bolt cross-section area
- G10 coated bolts

Number of bolts

- Define the value of whole cross section area of bolts is A, and the number of the bolts is n ,
  Then, the radius of each bolt is:

$$R\_bolts = \sqrt{\frac{A}{n \cdot \pi}}$$

- The radius of the holes is R_nutshole = R_bolts + d (*d* is defined as the gap between the bolts and the holes)
- The locations of the bolts are defined by the following method:
  - Rotation angle $\frac{360}{n}$,
  - stop angle $\frac{360}{n} * (n-1)$

* In this case we take A= $5*\pi * 0.016^2\ m^2$

Optimization Study

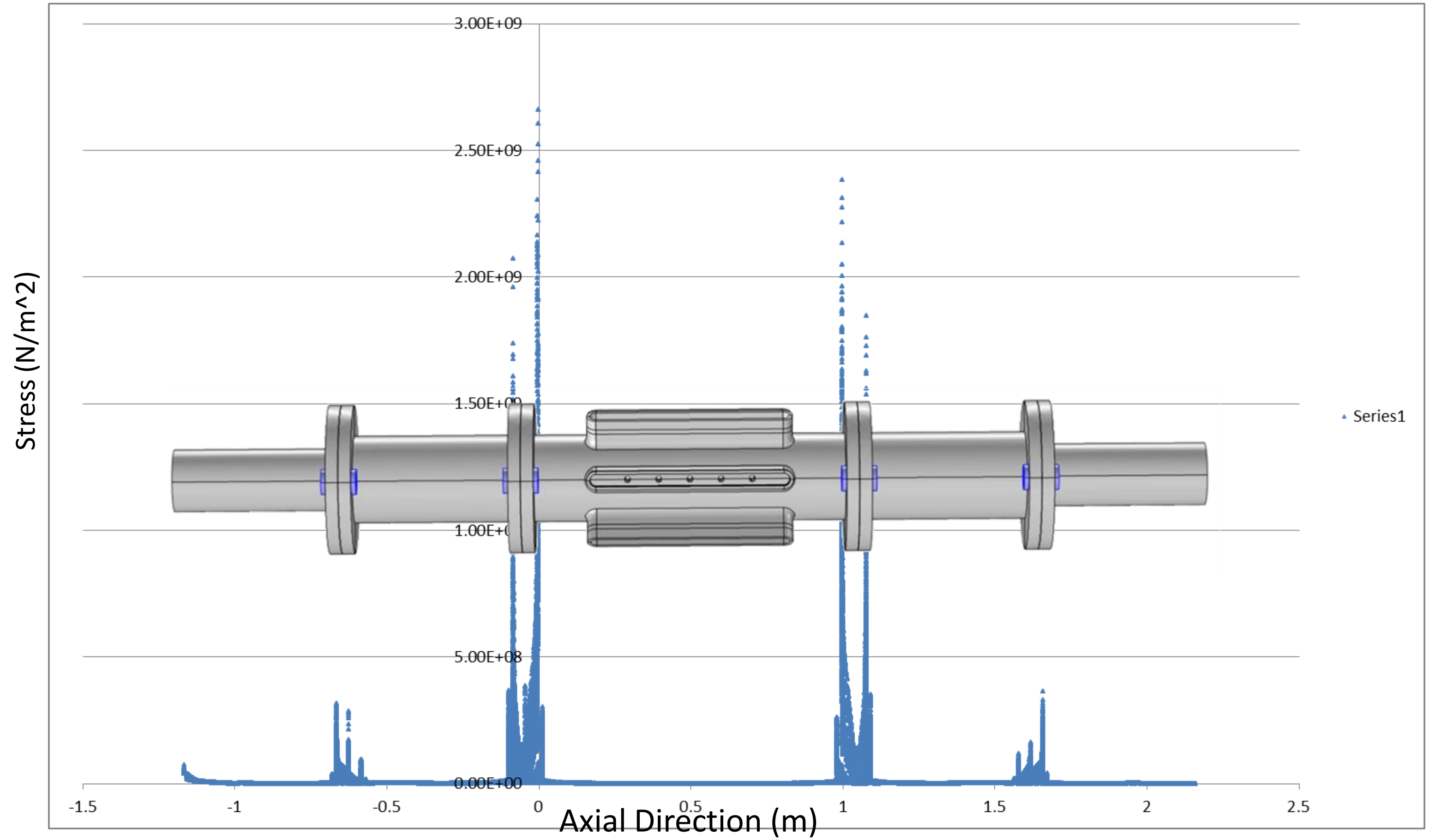


Figure 7. Stress Distribution plot along axial direction *

* Plot in Excel® Microsoft®, data exported from COMSOL Multiphysics®.

Optimization Study

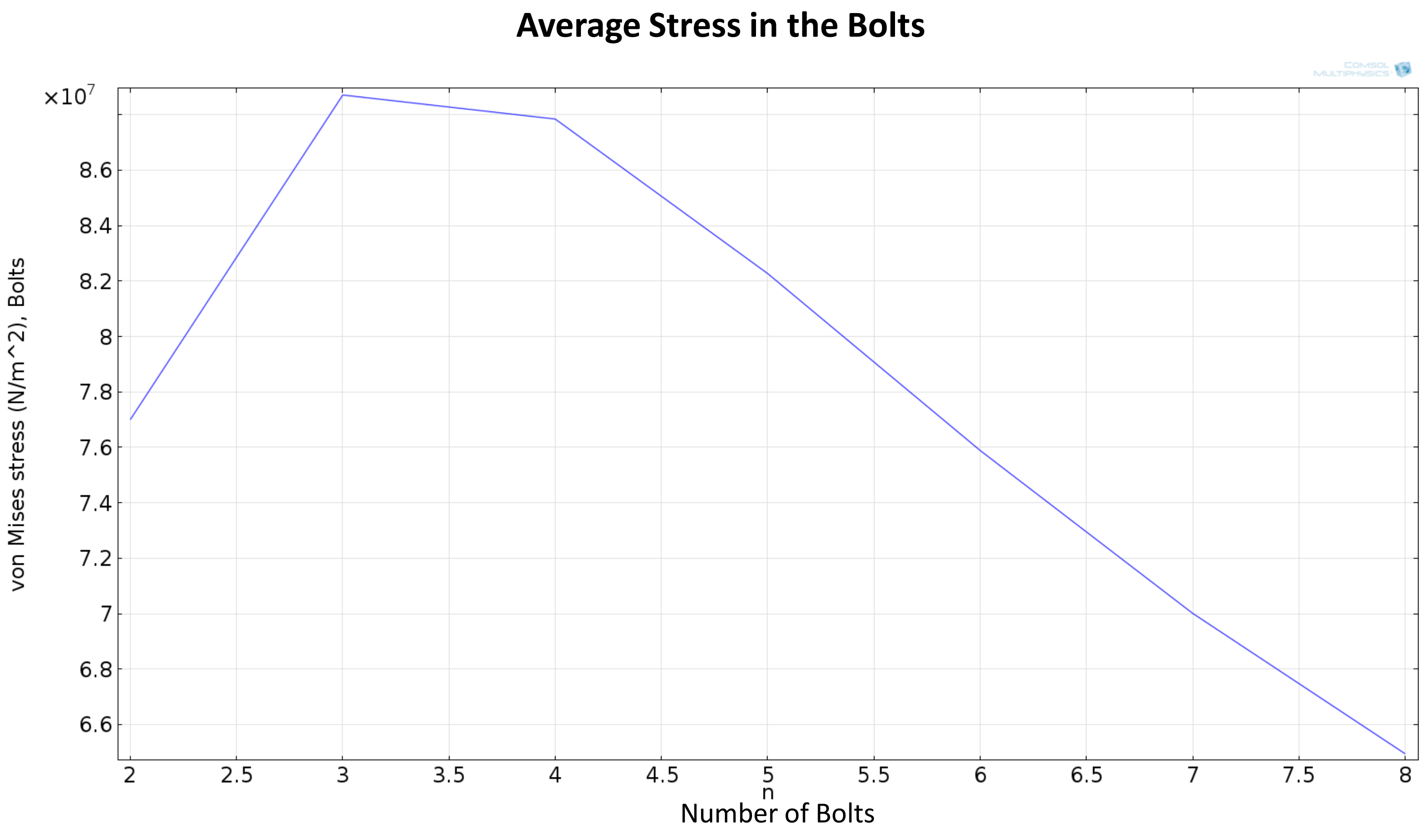


Figure 8. Stress Change with number of bolts

✓ The general trend of stress is decreasing when *n>3*

Cross-section Area

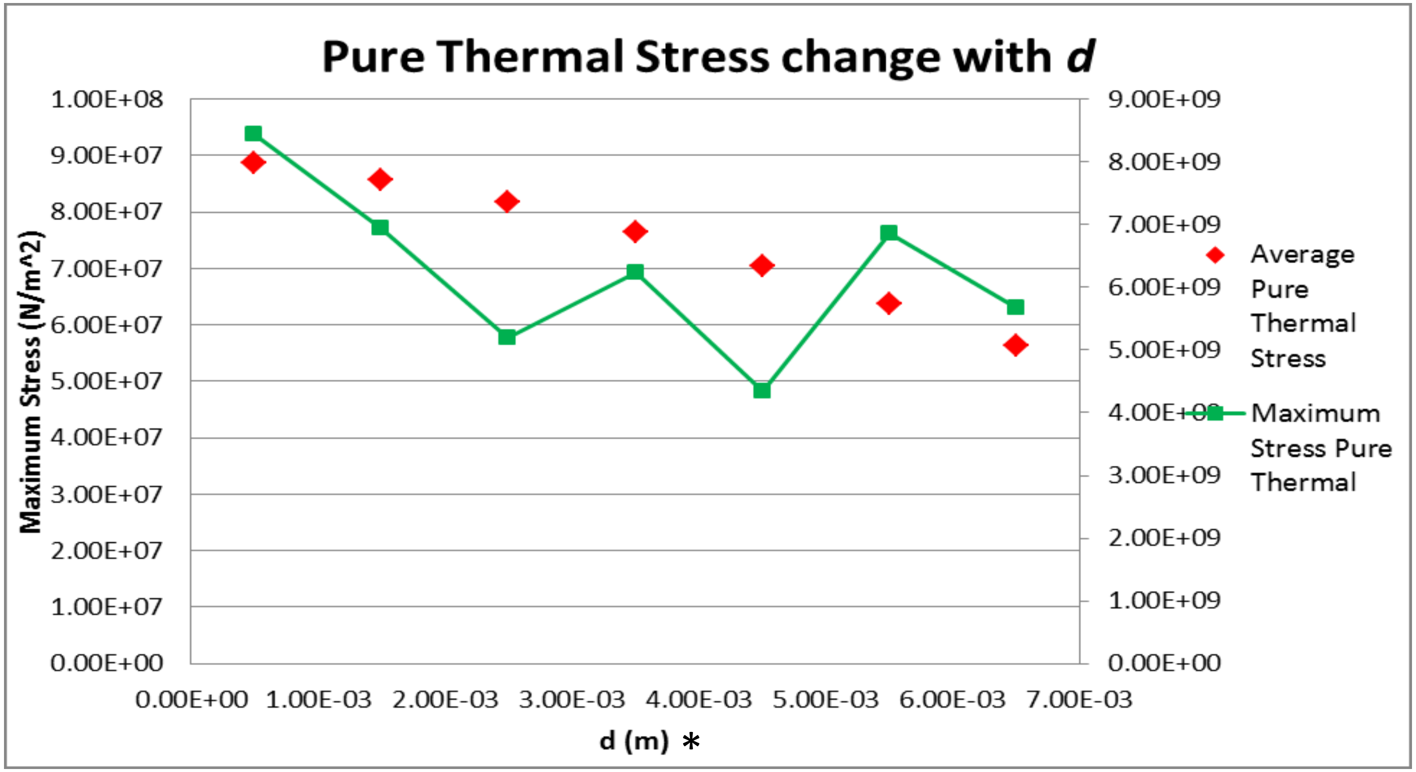


Figure 9. Stress Change with cross section of bolts

✓ The figure shows that with the decrease of radius of bolts, the thermal stress will also decrease.

* **d** is defined as the gap between the bolts and the holes.

Optimization Study

G10 Coated Bolts

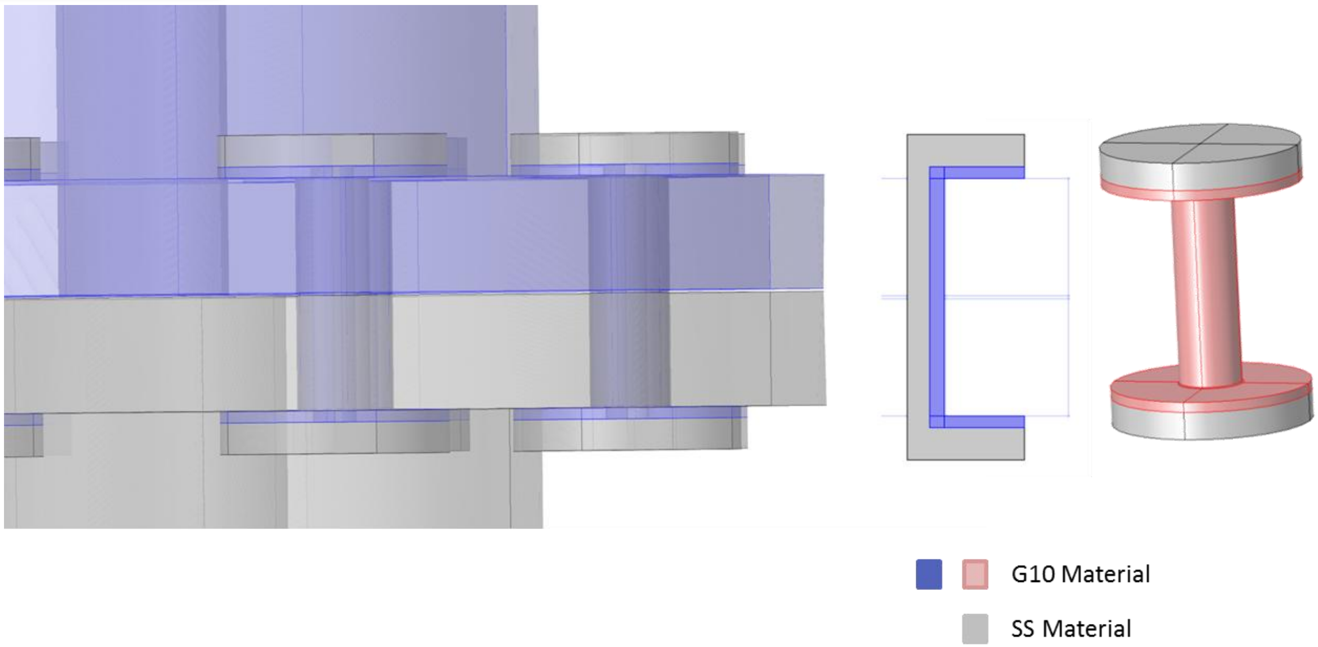


Figure 10. G10 Coated Bolts

- ✓ *Lower Thermal Conductivity compared with Stainless Steel*
- ✓ *Easy to manufacture and assemble*

Optimization Study

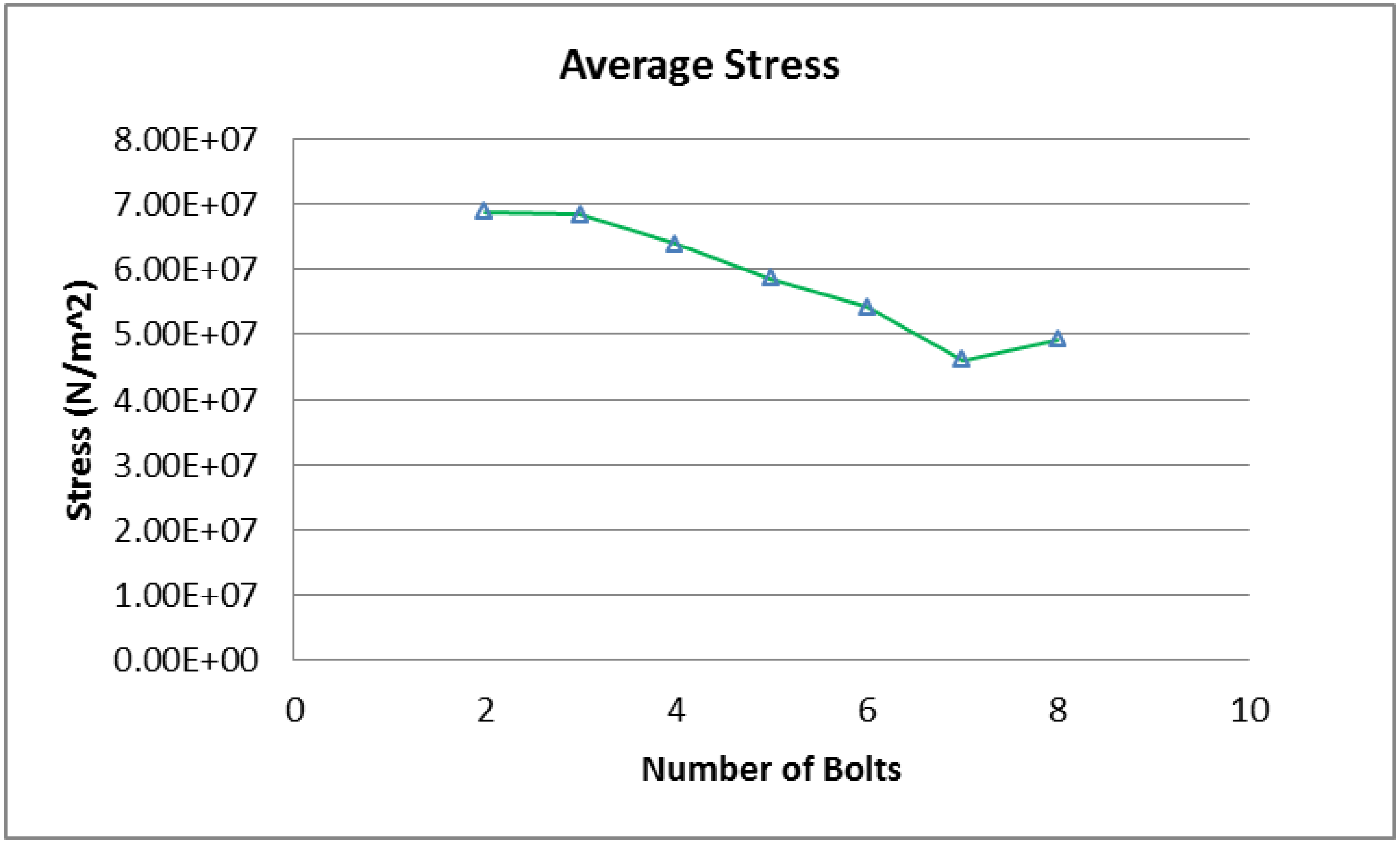
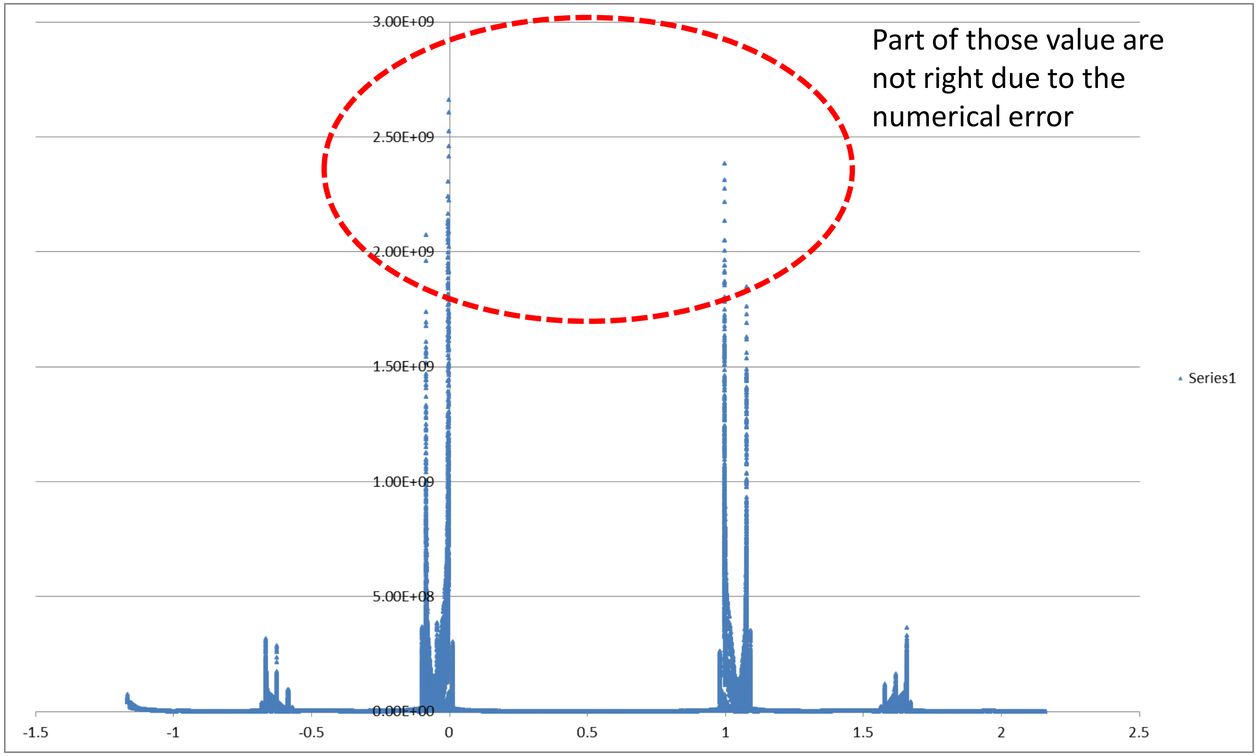


Figure 11. Stress change with number of G10 Coated Bolts

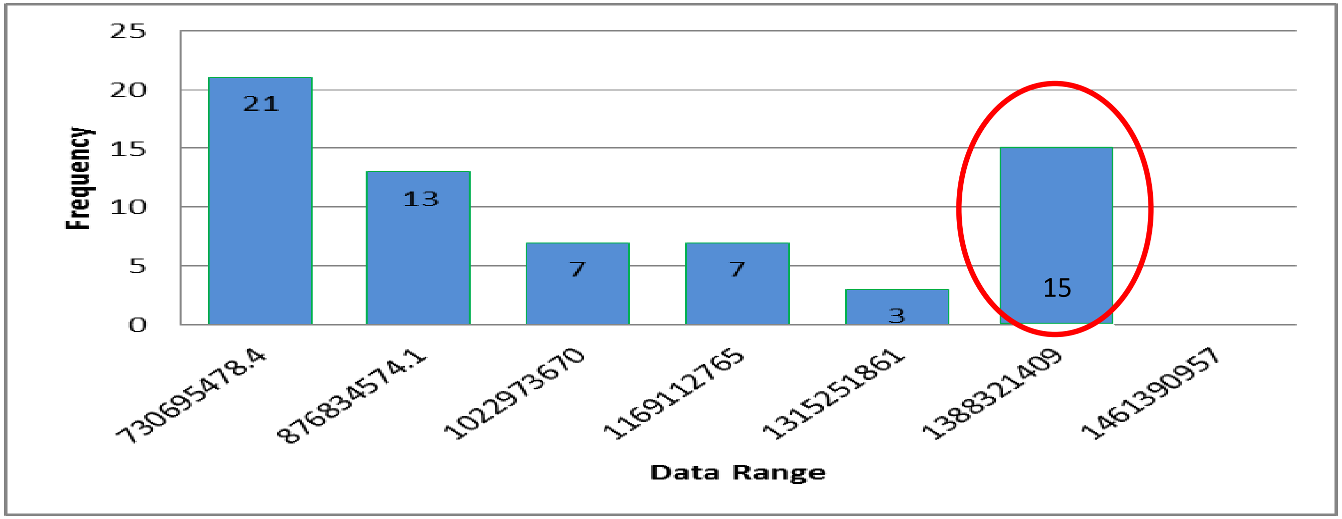
*Total Cross Section Keep the Same, *Increase **n**, each cross section decreases.*

Error Analysis



To find out the real maximum stress, we need to pick out those fake values due to the numerical error.

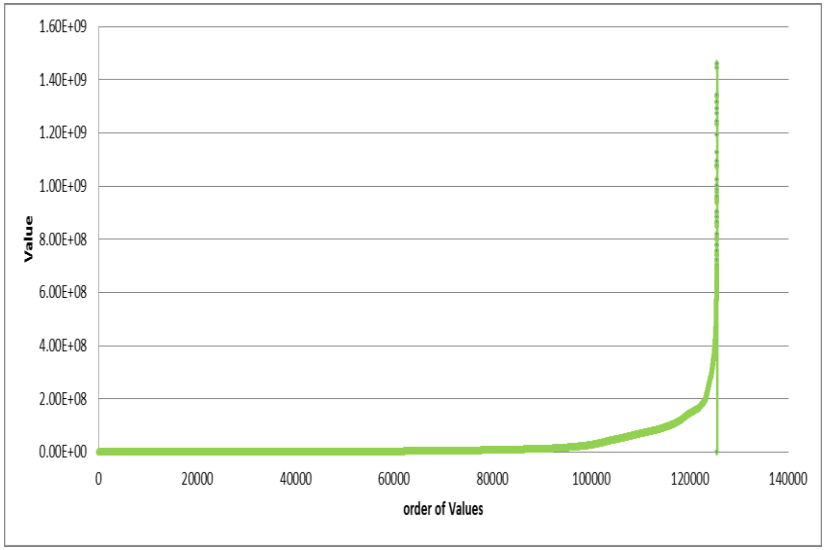
Error Analysis

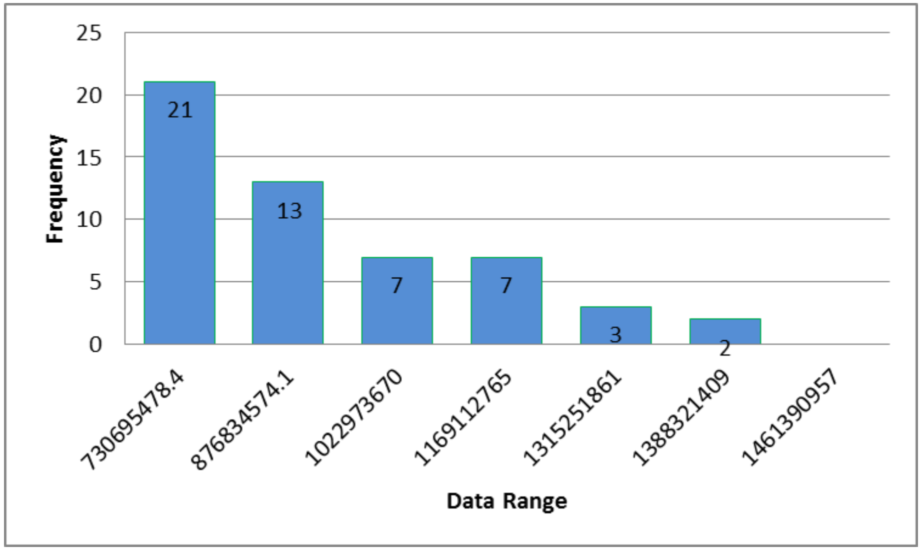


Take the largest part of the data, which includes the fake values, and get the frequency of each value range.

The frequency distribution should decrease with the increase of stress. According to the frequency distribution, deleted those data that has very low frequency but very high value or those have very high value with high frequency.

Error Analysis





In this case, we can take the maximum stress value as $8.7 \times 10^8 - 1.0 \times 10^9 N/m^2$.

Thank you