



3D Simulation of an Automotive Wheel Hub and Induction Hardening Coil to Solve Coil Lifetime Issues

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Overview

- Summary of Previous Case Study
- Modern Advancements in Computing and the Virtual Prototyping Process
- 3D Modeling of the Redesigned Coil
- Conclusions

Summary of Previous Case Study



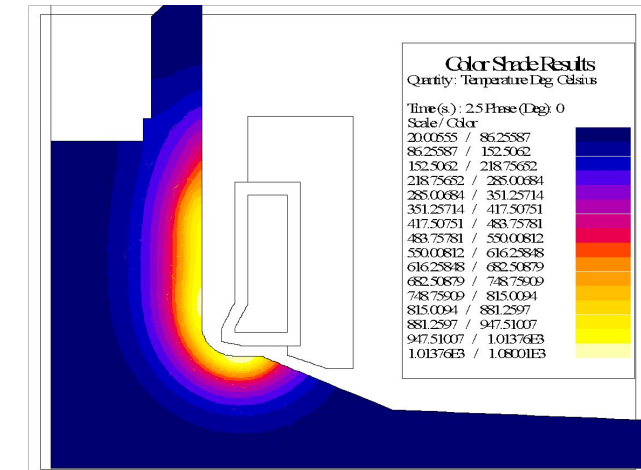
Original Wheel Hub Heat Treatment Coil

- A previous case study was done for HTS 2009 in which the goal was to solve a lifetime issue of an induction coil for heat treatment of an automotive wheel hub using virtual prototyping
- The original design can be seen to the right and the failure mode was known to be excessive coil temperatures leading to copper cracking due to thermal fatigue after only 8000-13,000 parts
- As faster computing becomes more widely available and finite element analysis (FEA) improves in scope and accuracy, virtual prototyping and detection of these failure modes are becoming faster and lower cost options compared to the traditional test and trial method



Induction Coil Redesign

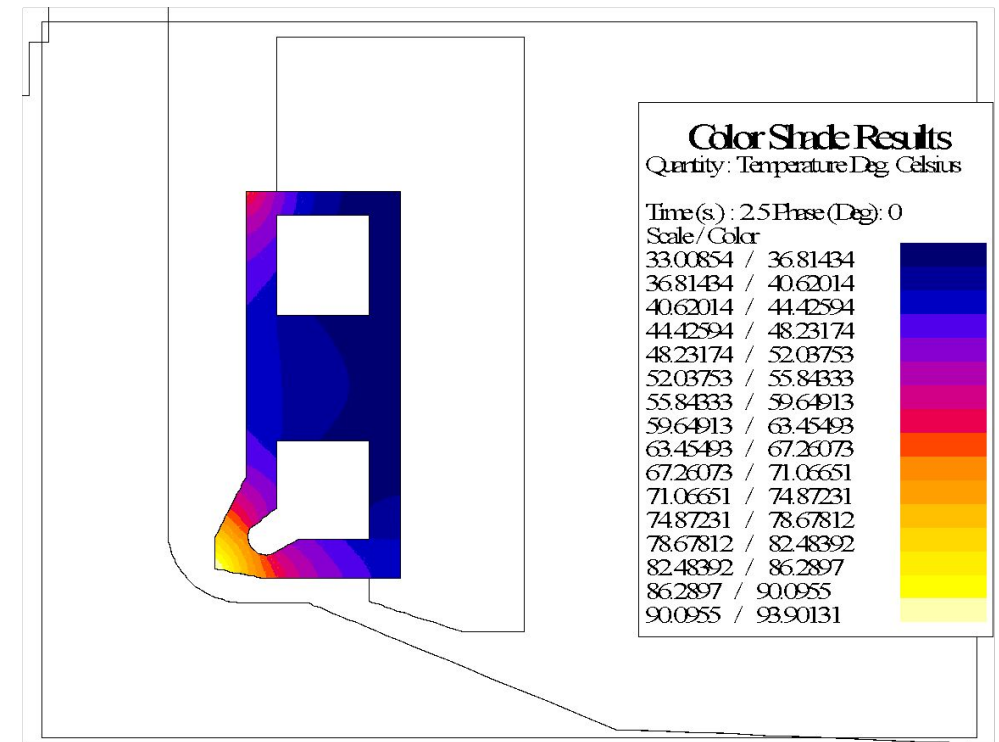
- Due to the relatively simple part design and heat treating pattern requirements, a fully-rotational encircling loop coil design was pursued as opposed the stepped partial loop design of the original coil
 - This means that the entire circumference of the coil is responsible for delivering power to a given region of the hub as opposed to only a small portion of the winding, resulting in significantly lower power densities
- A pattern that met the part specifications was achieved in 2D computer modeling



Simulation of Wheel Hub Heating

Redesigned Coil Thermals

- While the pattern was achieved in simulation, the main goal was coil lifetime
- As the issue in the original design was thermal fatigue, modelling of the internal cooling pathway was done to simulate copper temperatures in the redesigned coil
- The results verified the theory as very moderate temperatures were observed in the model



Simulated copper temperatures at the end of heating

Original Results

- After engineering and fabrication, the redesigned coil was proven to achieve both the heat treatment specifications and coil lifetime objectives
- Using virtual prototyping and a 2D approach, the design was able to go through multiple iterations in a faster and more cost-effective manner than with the traditional test and trial method without taking up valuable production machine time



Original Coil (left) after 13,000 parts and
Redesigned coil (right) after successfully
heat treating over 180,000 parts



Actual Heat Pattern

Modern Advancements in Computing and the Virtual Prototyping Process



More Accessible 3D Simulation

- Over the last decade as 64-bit systems replaced 32-bit ones, the availability, speed and amount of computing power, RAM and storage space as well as the ability of the software to utilize it has increased dramatically
- Due to these factors, 3D simulation is becoming more accessible and cost effective for use in virtual prototyping
- While 3D simulation is not required or recommended for every application, for example the redesigned coil is approximated very well in 2D, there are certain cases in which it is necessary

Basics of Virtual Prototyping

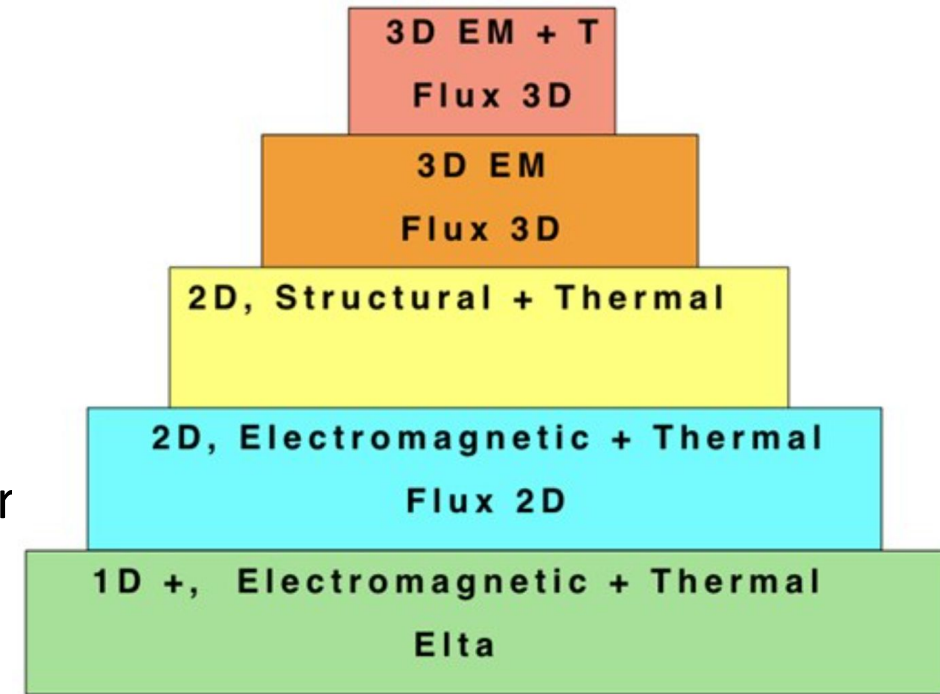
- Virtual prototyping is the use of computer models to develop and test a process or component without having to physically build or run it
- As technology advances and 3D models become faster and cheaper to use, the complexity and number of processes in the manufacturing and service life chain of a component that can be included in the virtual prototyping process continues to grow
- The goal of this paper is to show only the ability to model both the part heating and the induction coil temperatures in a 3D coupled rotational model
 - This is only a small portion of the full potential of virtual prototyping

Advantages of Virtual Prototyping

- Virtual prototyping uses computer simulation to virtually explore the design space and provides more information related to the performance of the induction heat treated component than can be obtained from evaluating cut parts
- In this case, virtual prototyping may have the upper hand on the traditional method as catching excessive coil temperatures leading to shortened coil life is easier to compare between simulated iterations rather than physical testing of coils
- In production, this problem only became apparent after
 - › running thousands of parts, but with virtual prototyping
 - › it is possible to take things like coil thermals into consideration
 - › and preemptively design the coil for increased coil lifetime

Choosing the right program

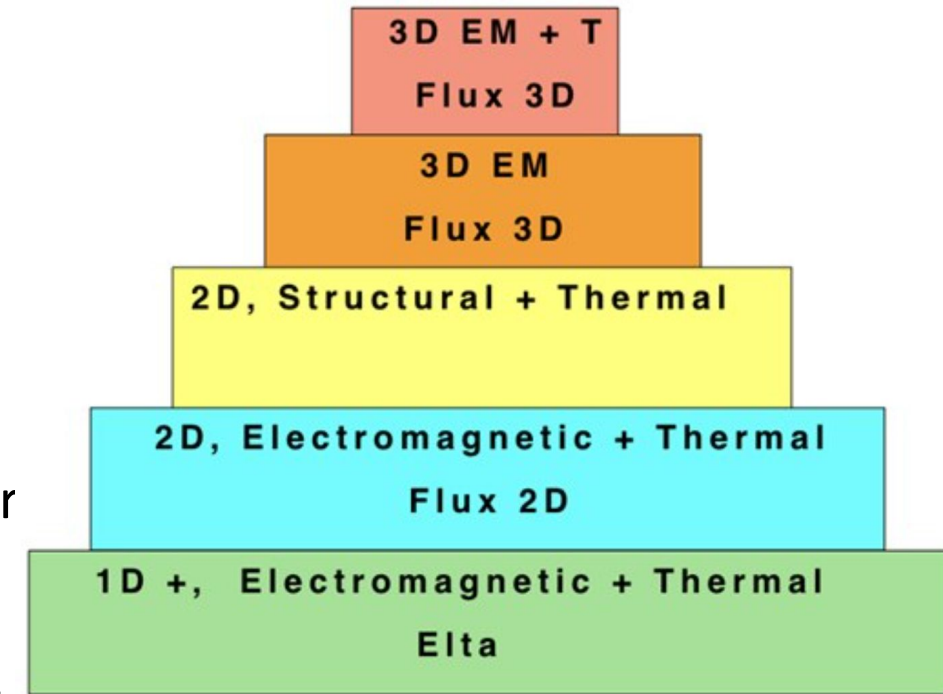
- While virtual prototyping can be a very powerful tool, it is still important to use best practices in setup and design of each model
- In general it is desired to use the least complex software when possible
 - This can help provide the final solution in simple cases or reduce the optimization area before using more complicated programs
- 3D multi-physics modeling remains time consuming and requires higher skill level modelers to achieve good results
- Even with the current advancements to simulation capabilities, there is no universal program that can solve all induction heating problems



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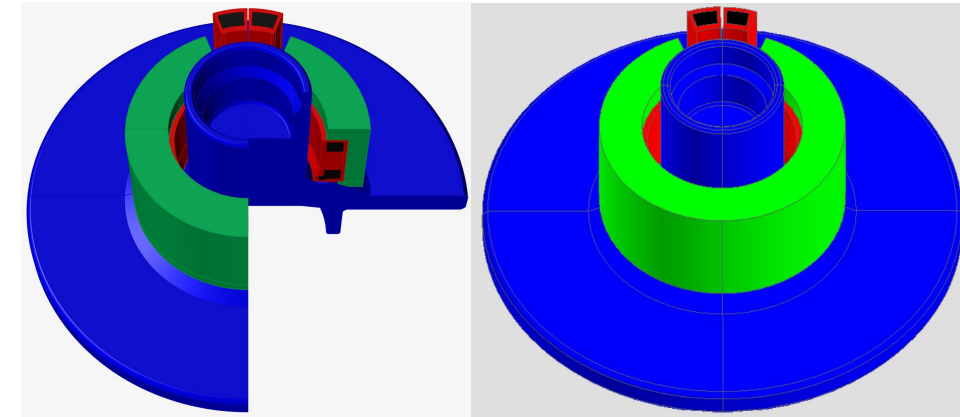
Rule of Pyramid

3D Modeling of the Redesigned Coil



Redesigned Coil recreated in CAD

- While this geometry was well estimated using 2D simulation, it was modeled in 3D to demonstrate 3D effects not seen in 2D as well as to try and highlight the advancements in simulation capabilities since the previous study
- The programs used for computer simulation of this induction heating process were Inspire™ and Flux 3D™
- Inspire™ is a 3D CAD program that was used to create a 3D drawing of the system, which was subsequently imported into Flux 3D™
- Flux 3D™ is an effective tool for analyzing electromagnetic and thermal fields for the part and coil. Aside from electromagnetic and thermal physics coupling, it is also able to accommodate rotational movement of the part to describe the mechanics of the process more accurately



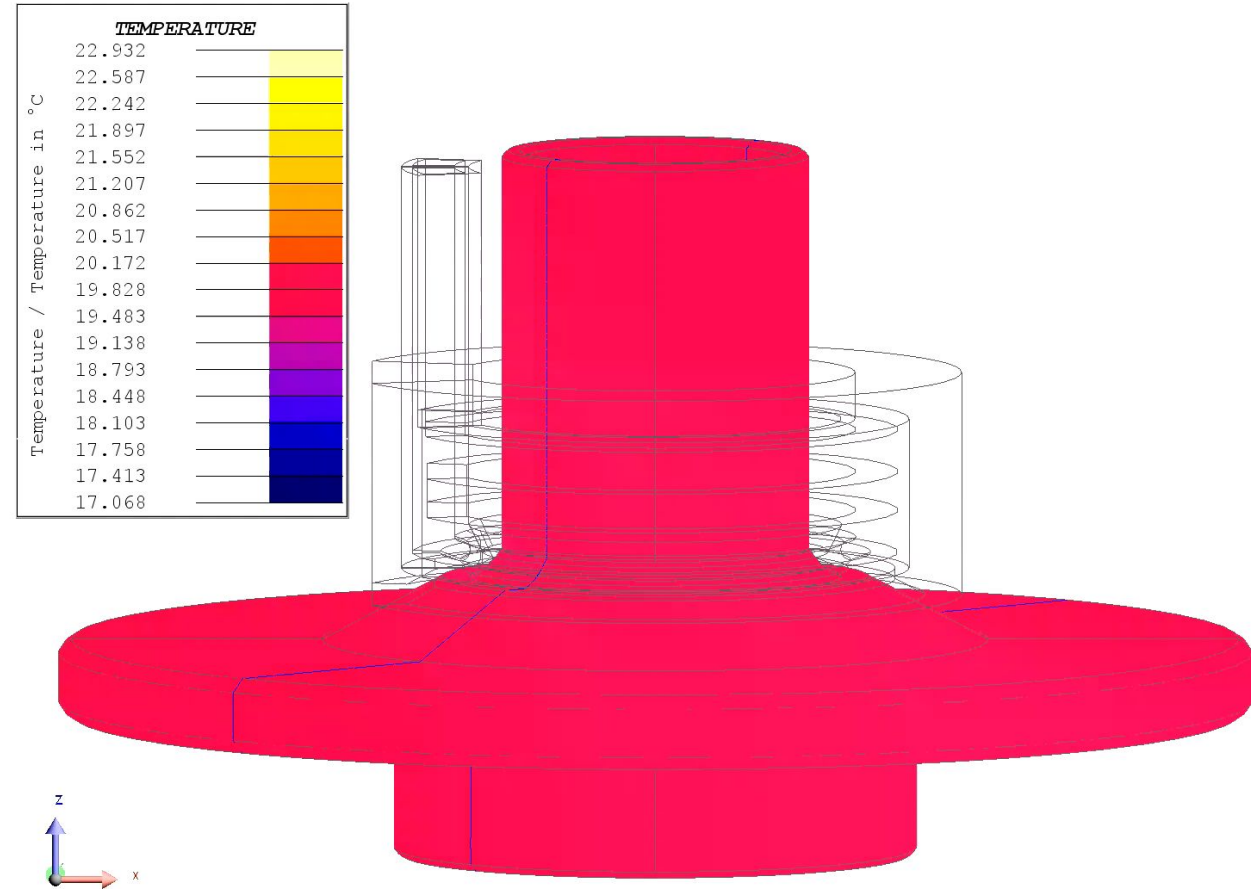
Model of the redesigned coil and wheel hub in Inspire (left) and imported into Flux 3D (right)

Simulation of Redesigned Coil

- After reproducing the geometry, the mechanical, electromagnetic and thermal parameters of the system were defined in Flux 3D
- To ensure accurate simulation of the coil thermals, heat transfer boundaries were assigned to allow for radiation and natural convection on the outer faces of the wheel hub and coil, as well as for forced convection within the water circuit of the coil
- The current was adjusted until the proper temperature distribution in the wheel hub was achieved to obtain the desired hardening pattern and temperatures evolved in the coil and part were compared to the previous case study

Video of Simulation

- Shown here is a video of the completed simulation
- The time scale is slowed down so that each second only shows 2 steps, or 0.2 seconds of the heating process
- The pattern is not axisymmetric initially, but fills in near the end of the heating process
- It must be noted, that in the end the part in this model was underheated by about 10-15%



Complications with this Model

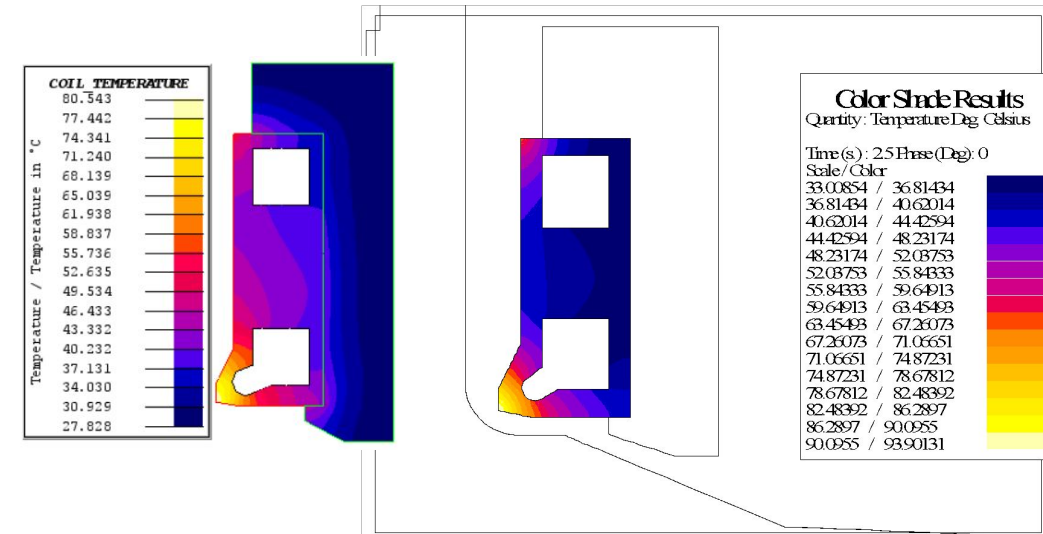
- 3D modelling comes with a variety of challenges ranging from issues with model geometry, setup of the simulation parameters, and lengthy solve times
 - This is very common in processes for selective induction hardening of steel components as the process of going from an initial magnetic structure to a non-magnetic austenitic structure changes the distribution of heat sources induced during the induction heating process dramatically, which is challenging for the models to resolve
- In this case longer solve times (weeks) combined with insufficient time allocated, the proper results in the 3D models were not achieved prior to the deadline
 - Additional efforts are ongoing to improve the models to achieve better results with improved solution times

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Redesigned Coil Temperature Comparison

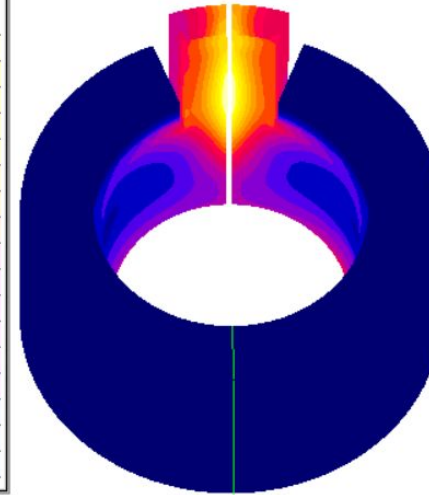
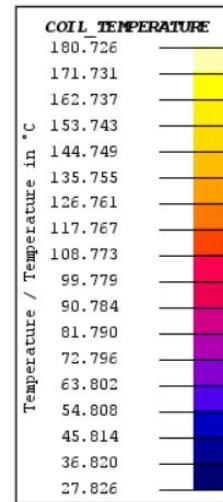
- In the 2D case, maximum temperatures on the heating face of the redesigned coil were 94°, while the underheated 3D model was predicting a somewhat lower temperature at 81°C
- If a 10% higher power setting was used, the ΔT for the 3D model would be ~20% higher leading to a temperature matching much more closely to the originally predicted 2D value
- In both cases, these temperatures along the heat face would not lead to the same stress induced cracking as seen in the original coil, which would lead to the extended coil lifetime seen in practice



Temperatures in the redesigned coil when modelled in 3D (left) and previously modelled in 2D (right)

Redesigned Coil Temperature 3D Effects

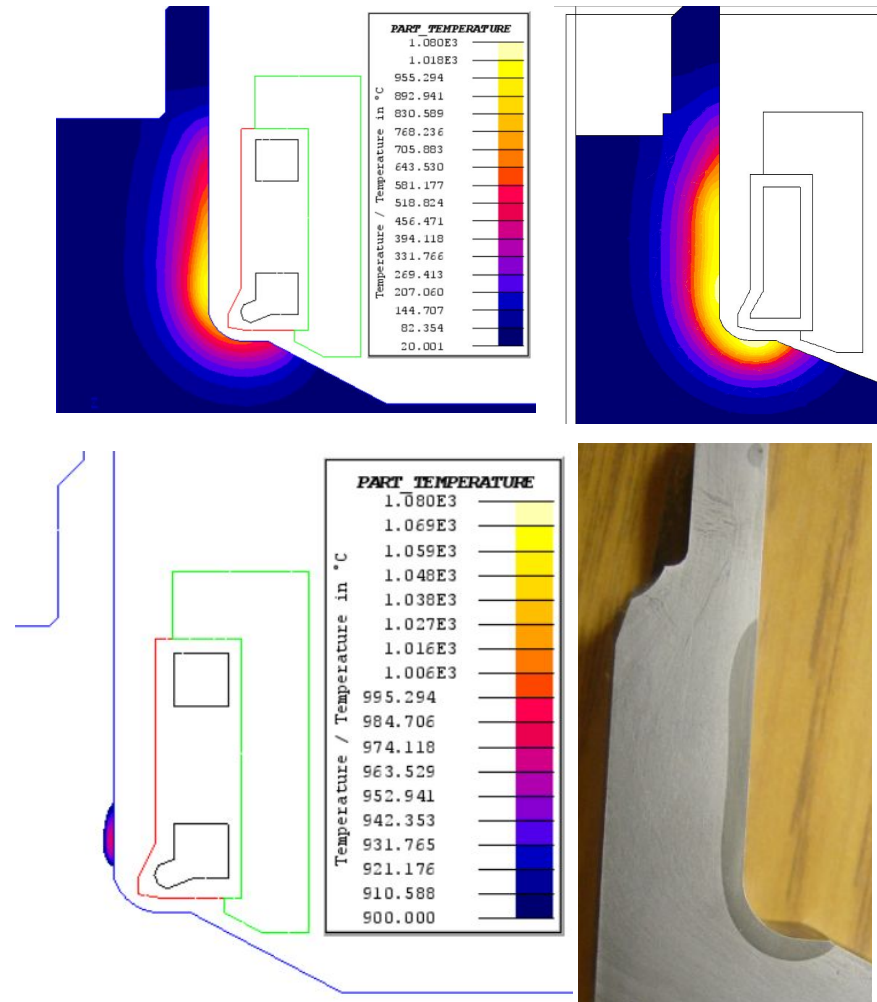
- An interesting effect that was not seen in 2D simulation, which was a hotspot positioned in between the leads of the inductor which reached a maximum temperature of $\sim 181^{\circ}\text{C}$
- While the redesigned coil did not fail in production, inspection of the leads show heavy discoloration in the section adjacent to the concentrator



Full redesigned coil thermals depicting highest temperature in between the leads

Redesigned Coil Wheel Hub Heating and Hardening Pattern

- Shown here is a comparison of redesigned coil temperatures in the wheel hub when modelled in 3D (left) and previously modelled in 2D (right) as well as the associated hardening pattern
- Due to the underheating it is difficult to make a good comparison, but running at a higher power would lead to a closer result



Conclusions

- As faster computing becomes more widely available and finite element analysis (FEA) improves in scope and accuracy, virtual prototyping and detection of these failure modes are becoming faster and lower cost options compared to the traditional test and trial method
- While 3D simulation may not be strictly necessary in this case, it can allow for a more accurate depiction of the process provided sufficient time for setup and solving of the scenario
- Moving forward, models of the original coil will be run to pinpoint the cause of failure leading to shortened coil lifetime
- In addition to electromagnetic and thermal models, it is desired to add additional physics packages to study this process further; in particular, to look at the dimensional movement of the coil face and analyzing the sources of stress that lead to the observed cracking

Conclusions Cont.

- To reiterate, while virtual prototyping using 3D modelling is a powerful tool, it is important to use best practices and simplify problems into easier models when possible
- This redesigned coil is estimated very well in 2D due to its near axisymmetric geometry and 2D models run at a fraction of the time 3D models with rotation take
- This allowed for the previous study to investigate multiple iterations within the time it took to run a single 3D model and come to a result that lasted 10X longer than the original coil



THANK YOU!

Please direct any questions to
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