Development and Application of an ANSYS® based Thermo-Electro-Mechanical Anode Stub Hole Design Tool

Marc Dupuis

GENISIM

Plan of the Presentation

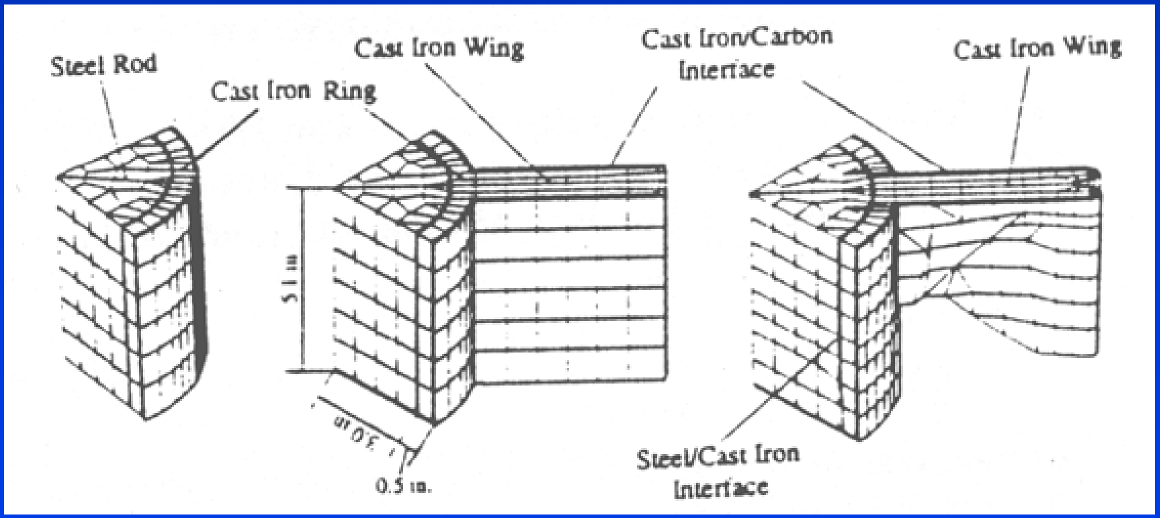
- Historical background
- ANSYS® version 12.0 based Thermo-Electro-Mechanical (TEM) anode stub hole model development
- First demonstration model, 8 flutes design
  - Constant contact resistance model results
  - Pressure and temperature dependent contact resistance model results
- Second demonstration model, 16 flutes design
  - Constant contact resistance model results
  - Pressure and temperature dependent contact resistance model results
- Using the developed ANSYS® based TEM stub hole anode model as a design tool
- Conclusions

Historical Background

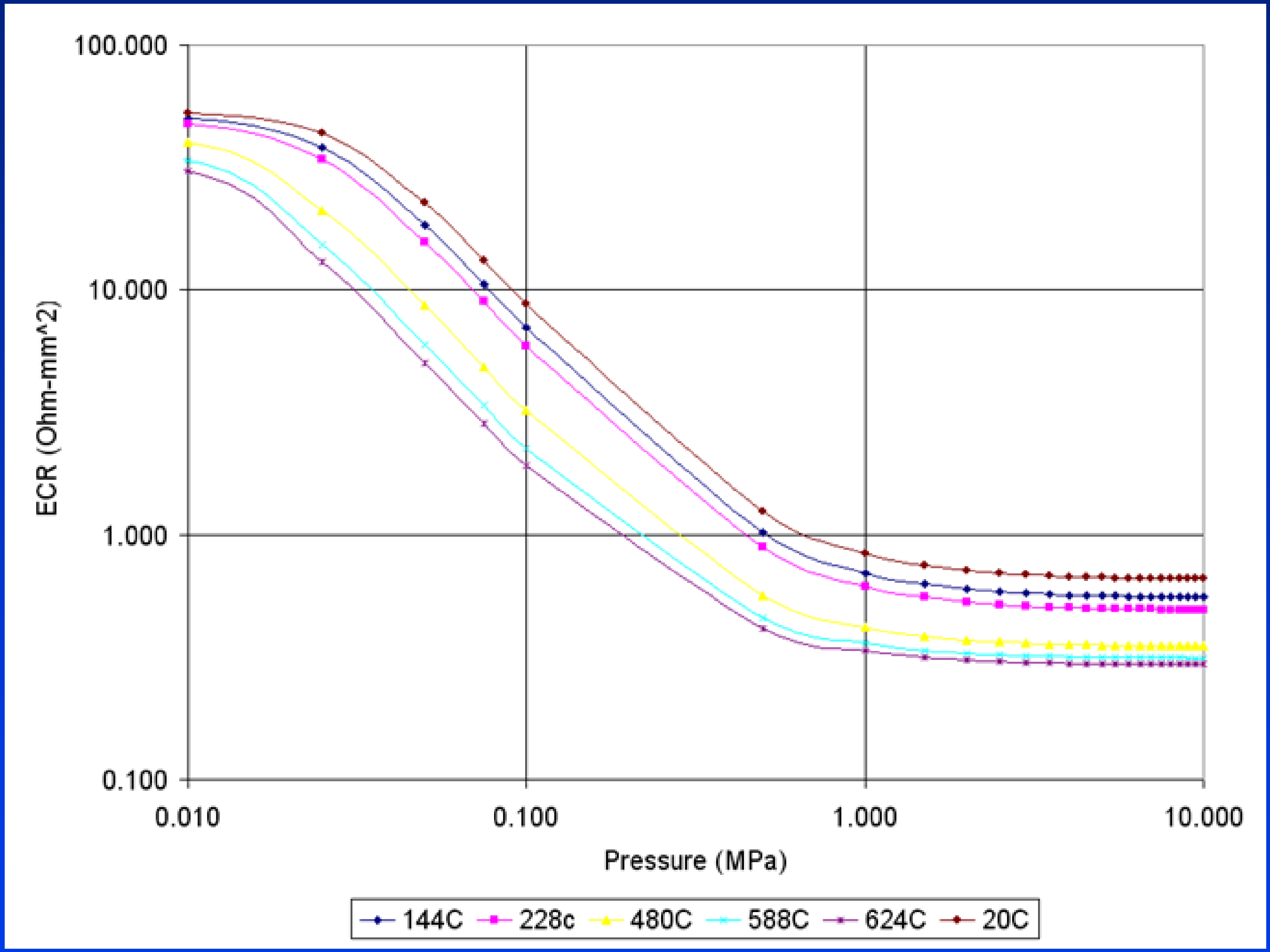
The typical approach for the last 20 years has been to optimize the stub hole using 3D Thermo-Electric (TE) mathematical modeling tools.

The weakness of this approach is that the contact resistance has to be considered as constant and the value of that constant has to be defined as a model input.

As a result, the model is only sensitive to the cast iron/anode carbon contact interface surface area leading designers to increase that interface surface area disregarding completely the mechanical impact of those stub hole design changes.



Historical Background

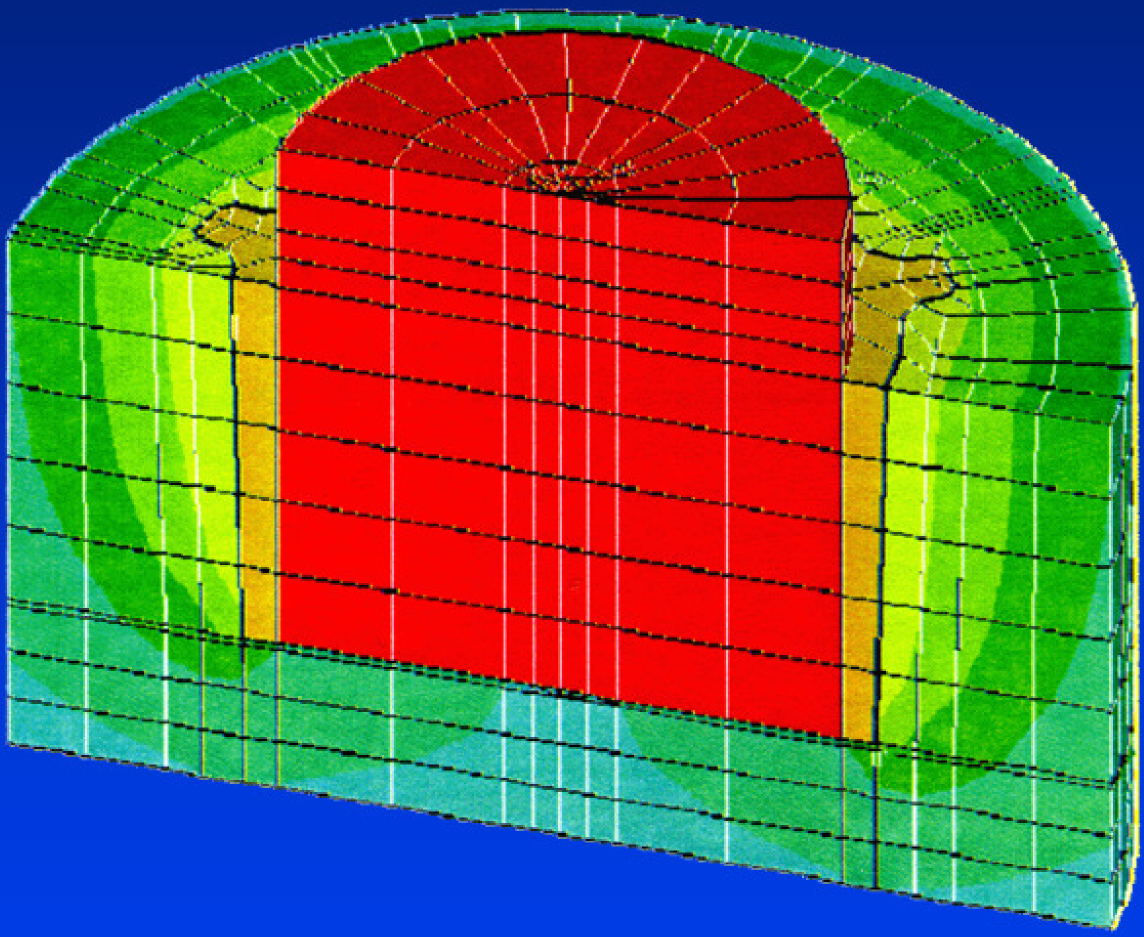


It was ratter measured that the contact resistance is strongly dependent on the applied pressure at the contact interface.

Richard, conveniently fitted the raw data into a 12 parameters equation that is function of both pressure and temperature.

GENISIM

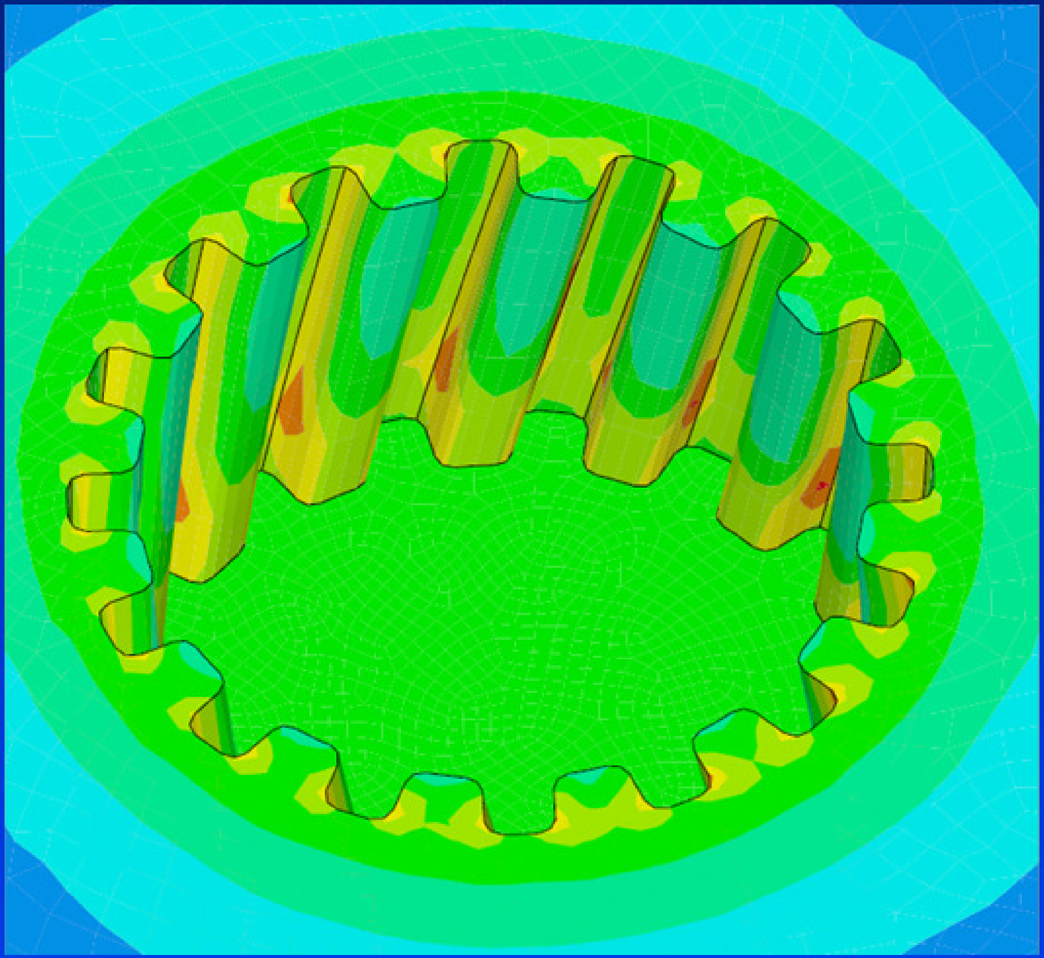
Historical Background



Richard was also the first to develop an ANSYS® based TEM anode stub hole model and to use such a model to do some stub hole design optimization work.

Unfortunately, the ANSYS® version available at the time was not supporting thermo-electro-mechanical contact elements preventing the development of a fully coupled model.

Historical Background

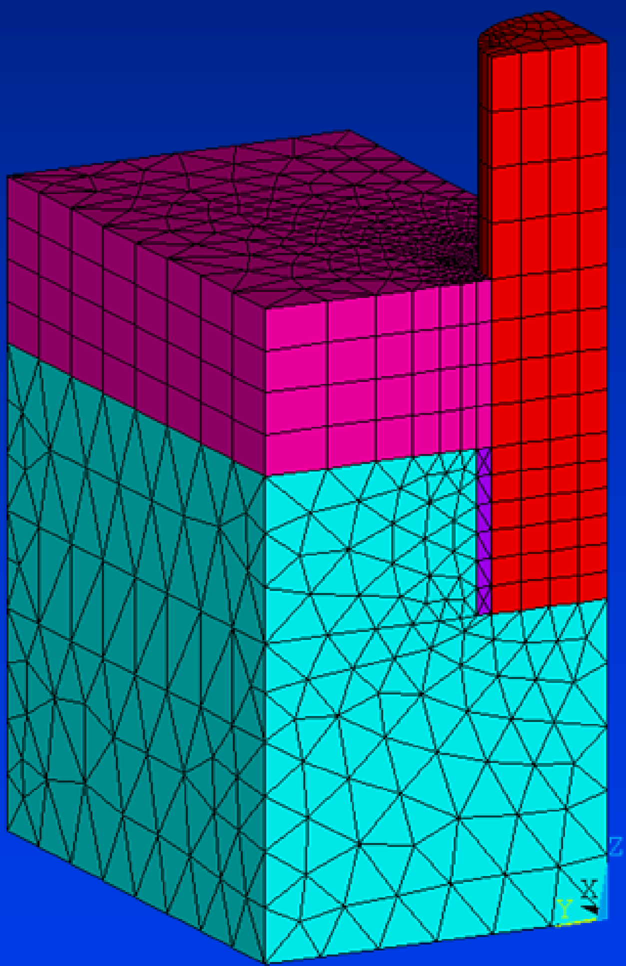


Following Richard's initial effort, Goulet developed a fully coupled TEM model based on Laval University's in-house Object-Oriented finite element code FESh++.

FESh++ supports the implementation of complex material behavior laws, for instance for carbon-based materials, so it is extremely useful to carry-up fundamental research work.

However, ANSYS® has been the code of choice of the industry for over 25 years now.

ANSYS® version 12.0 based Thermo-Electro-Mechanical (TEM) anode stub hole model development

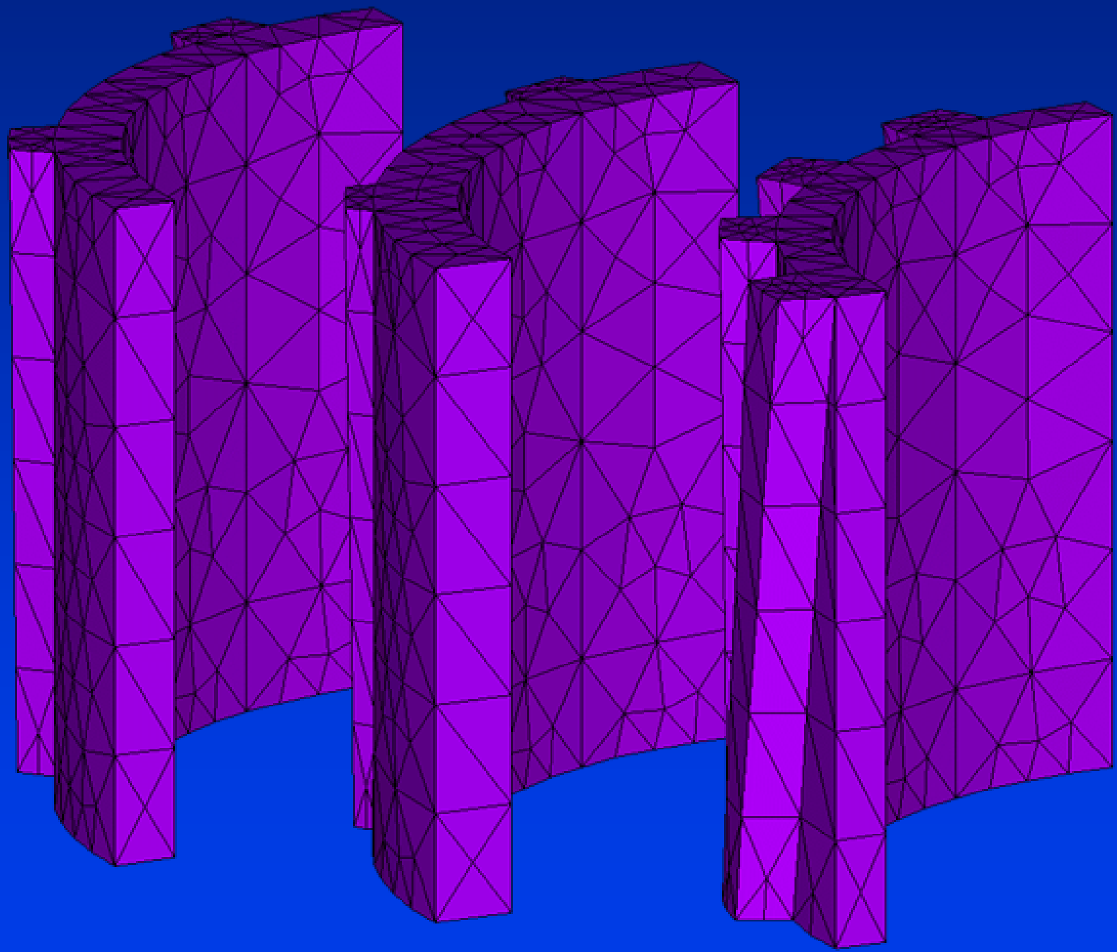


An ANSYS® version 12.0 based fully coupled TEM anode stub hole design tool based on the usage of SOLID226 3D thermo-electro-mechanical second order element together with CONTA174 and TARGE170 thermo-electro-mechanical contact pair elements have now been developed.

CONTA174 element supports the setup of a pressure and temperature TCC (thermal contact conductance) and ECC (electrical contact conductance) values through the %table% option.

GENISIM

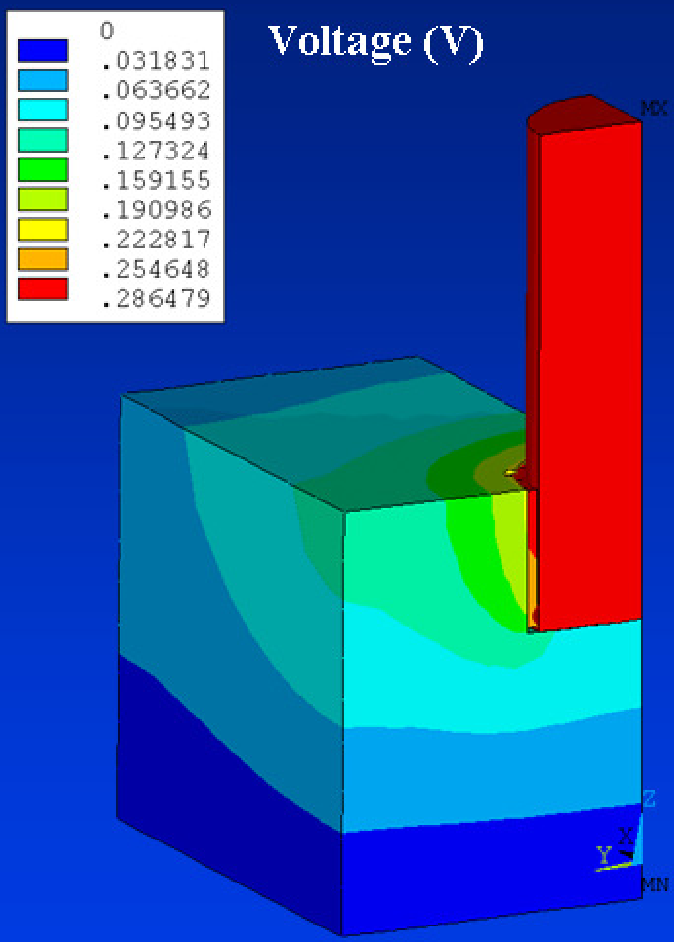
ANSYS® version 12.0 based Thermo-Electro-Mechanical (TEM) anode stub hole model development

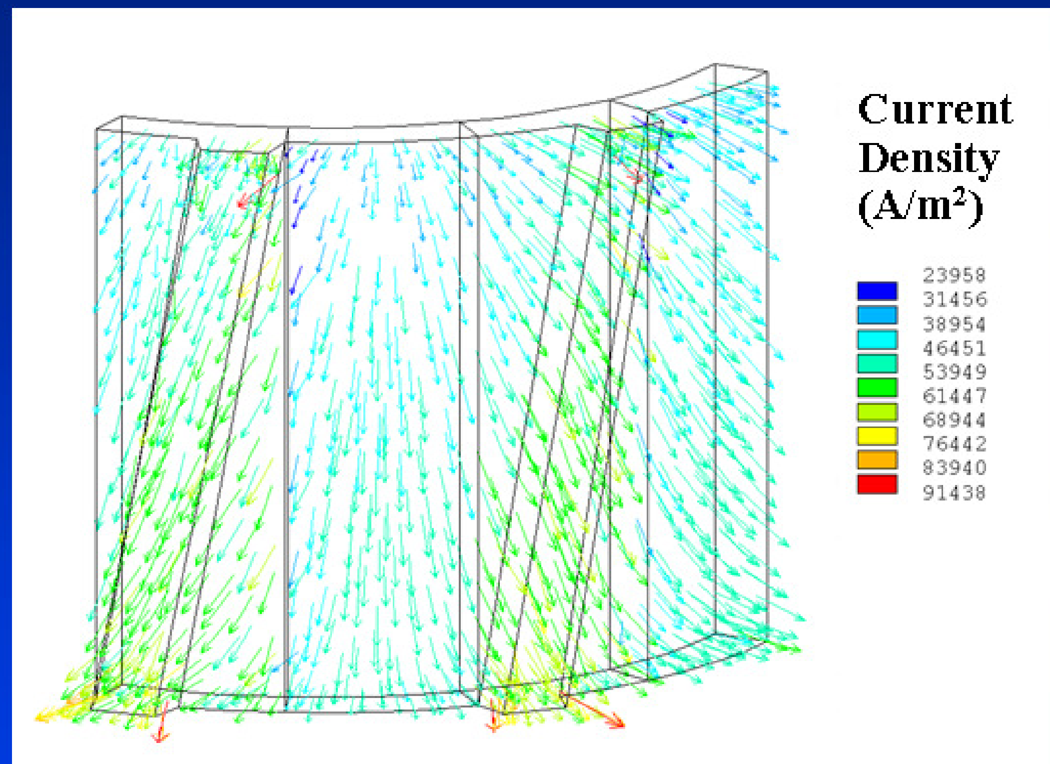


Having all the required components to model the complex stub hole cast iron/anode carbon contact resistance complex physic in ANSYS® version 12.0, it was quite straightforward to take advantage of the classic ANSYS® parametric design language (APDL) to develop demonstration anode stub hole models and to use them as efficient stub hole design tools.

GENISIM

First demonstration model, 8 flutes design

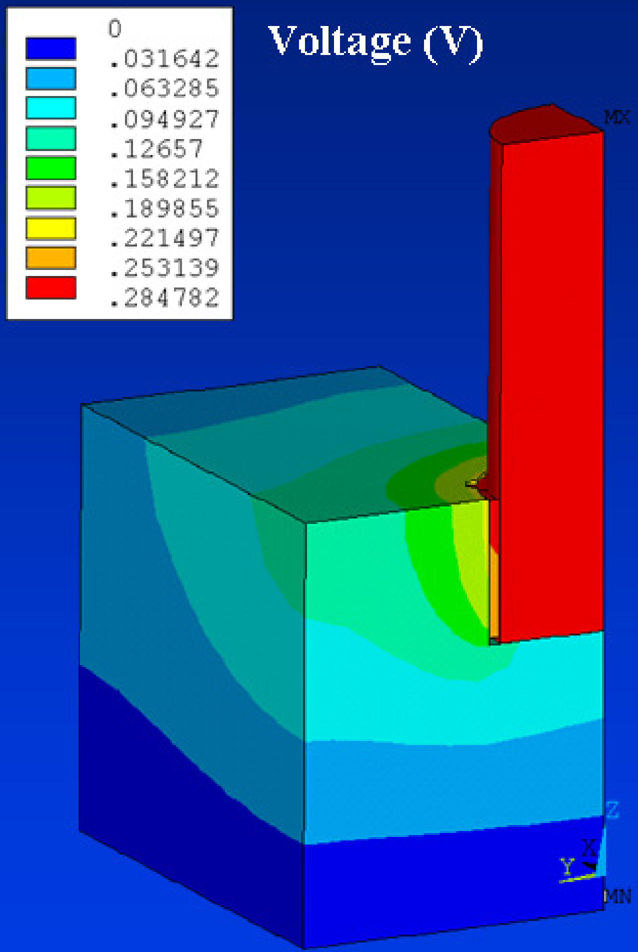


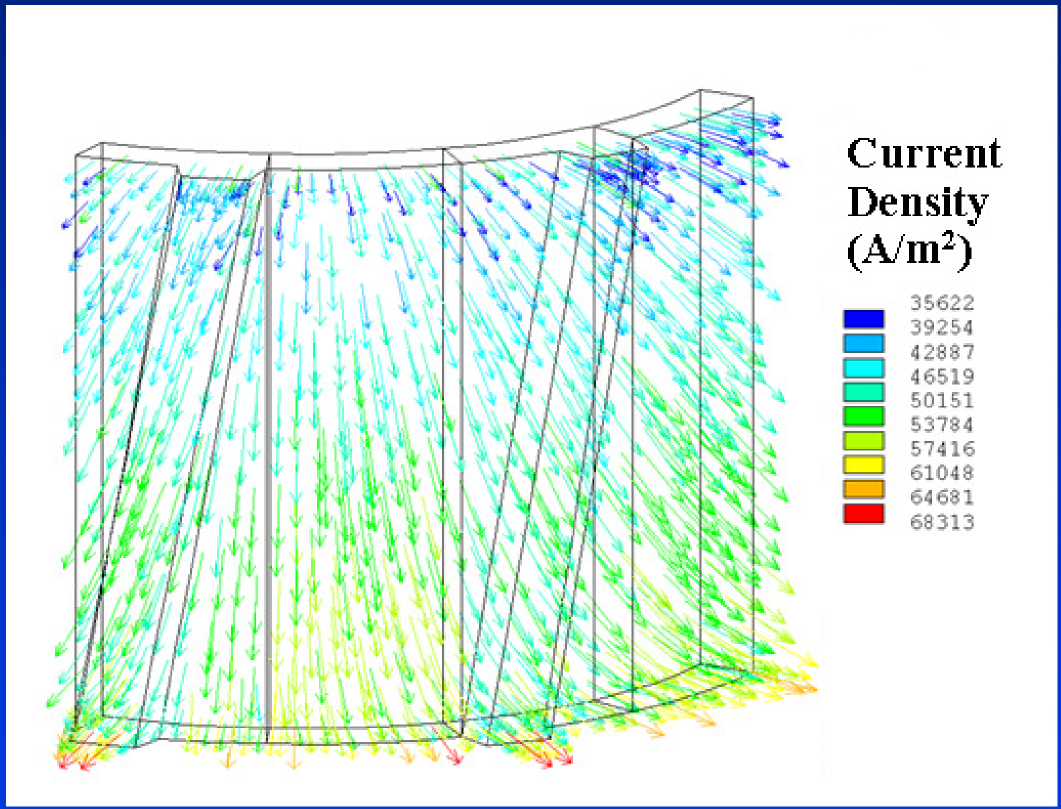


Constant contact resistance model results

GENISIM

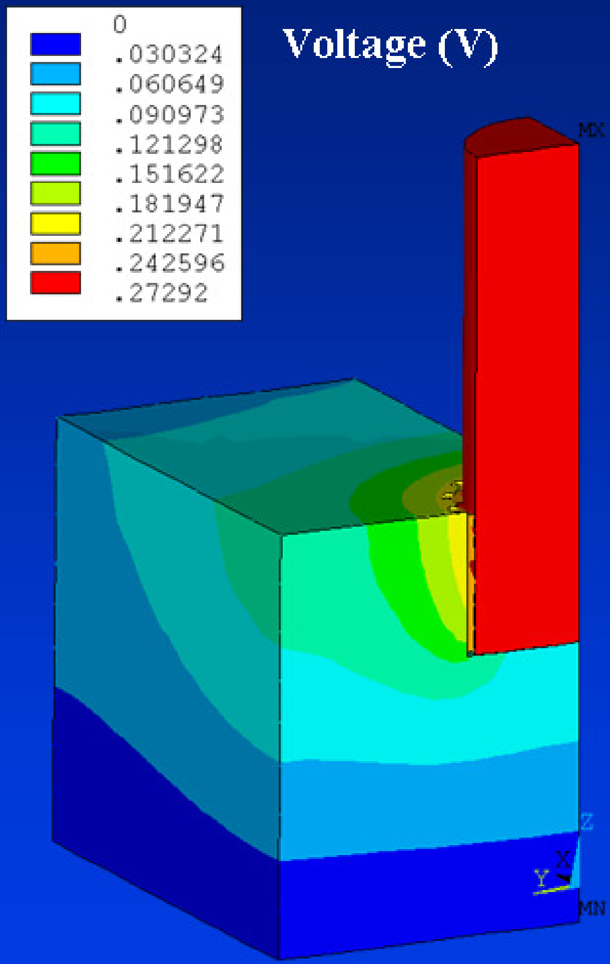
First demonstration model, 8 flutes design

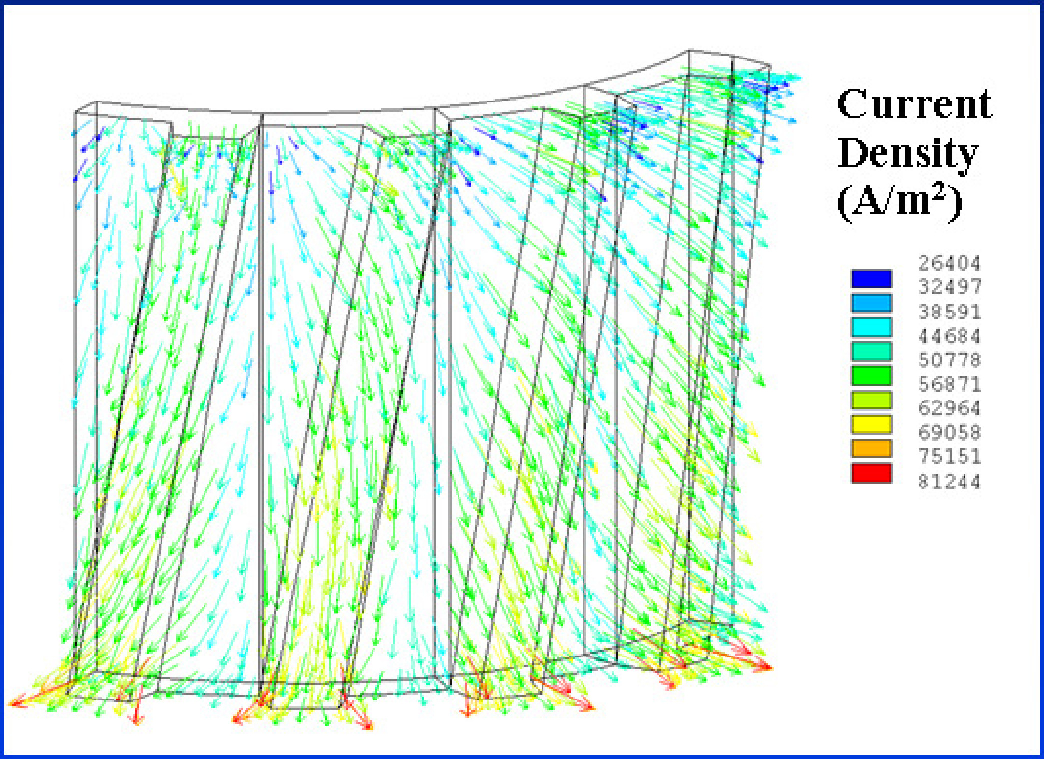




Pressure and temperature dependent contact resistance model results

Second demonstration model, 16 flutes design

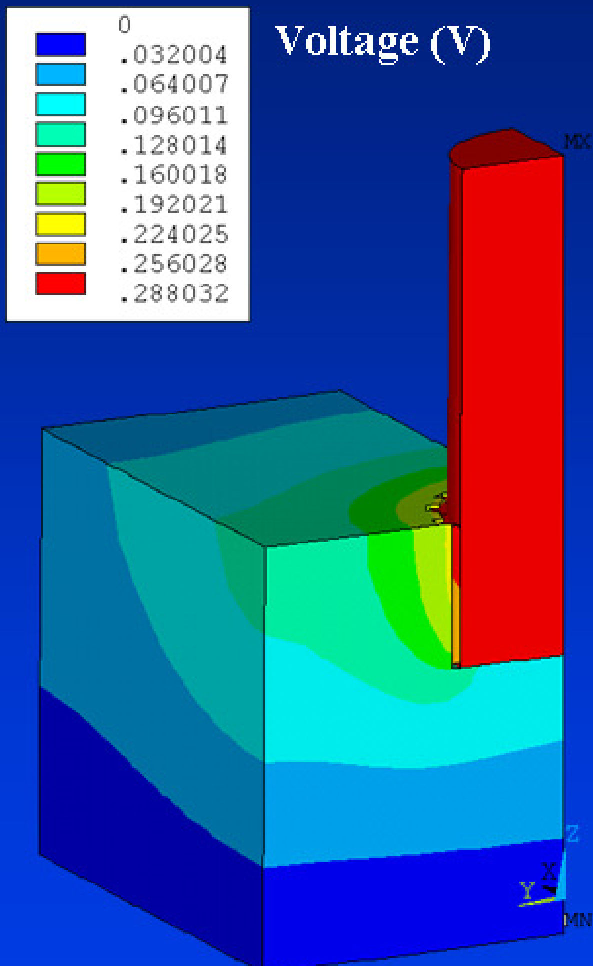


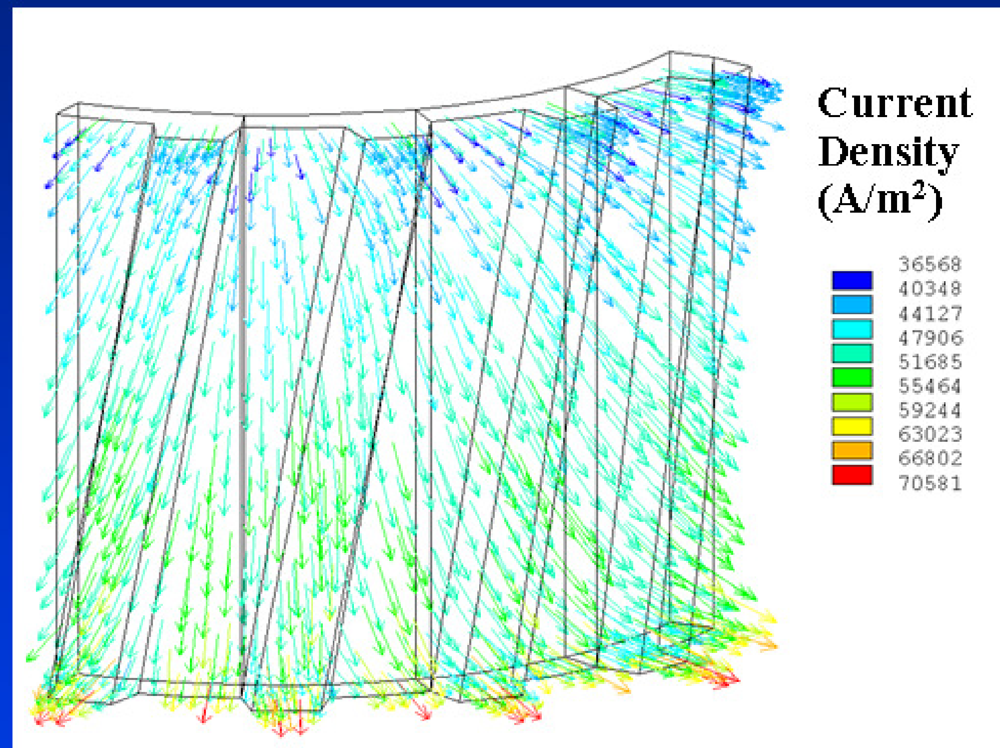


Constant contact resistance model results

GENISIM

Second demonstration model, 16 flutes design



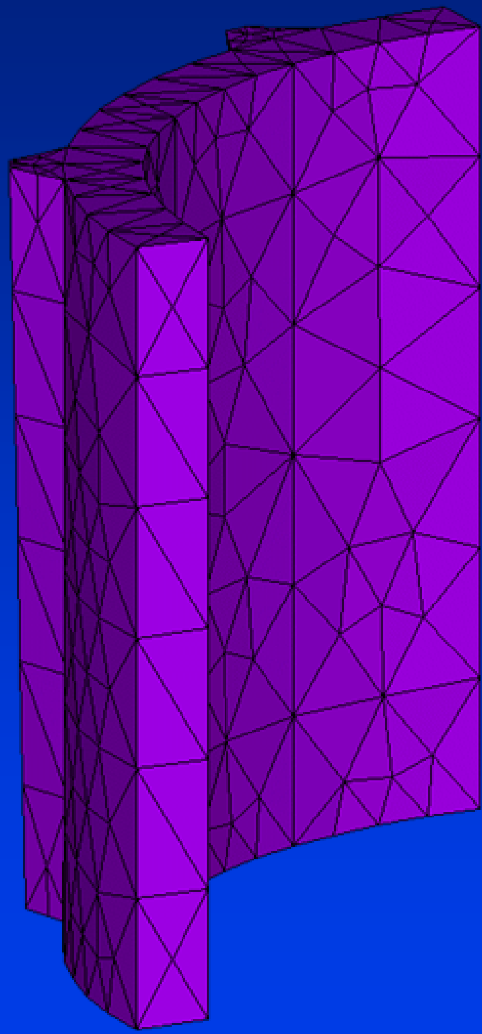


Pressure and temperature dependent contact resistance model results

Second demonstration model, 16 flutes design

- The first run with the constant 2 micro-ohm m2 contact resistance predicts 273 mV for the anode voltage drop, a reduction of 13 mV or 4.5% compared with the 8 flutes design constant resistance case reflecting the increased of the interface contact surface.
- This is very misleading because the run with the pressure and temperature dependant contact resistance setup rather predicts 288 mV for the anode voltage drop which is 3 mV more than the 8 flutes variable contact resistance case.
- Hence according to the TEM model with the pressure and temperature contact resistance setup, adding more flutes, of that design at least, is not reducing the anode voltage drop, on the contrary, it is increasing it slightly.
- This slight increase of anode voltage drop prediction is quite consistent with what was reported at last year TMS conference for a very similar stub hole design change study by Richard.

Using the developed ANSYS® based TEM stub hole anode model as a design tool

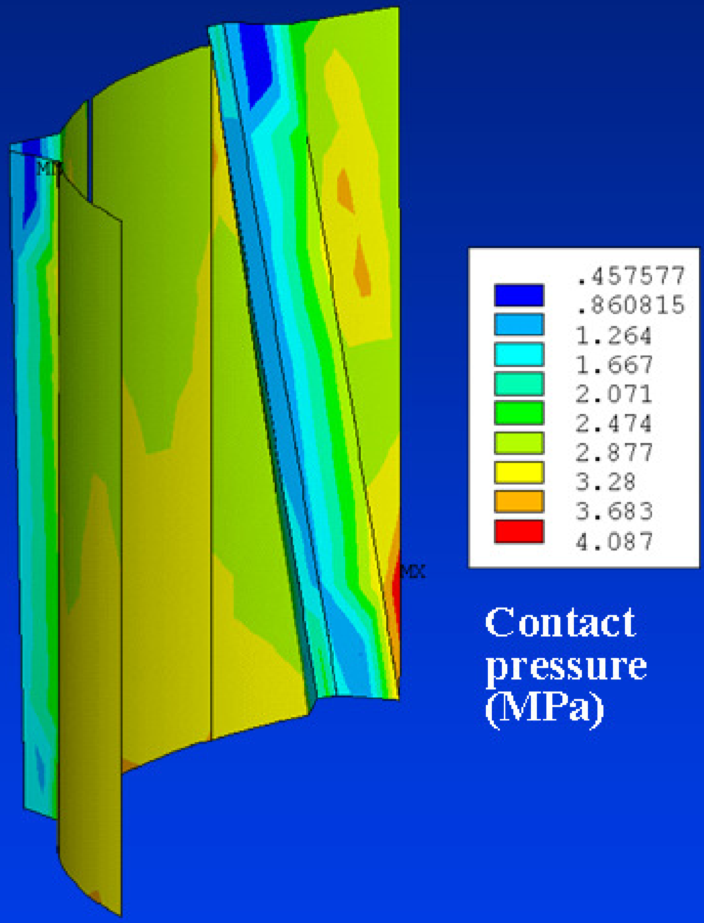


Testing of a few flute design alternative quickly revealed that the most sensitive parameter in the flute design is the angle departure from the radial axe of the two side faces of the flute.

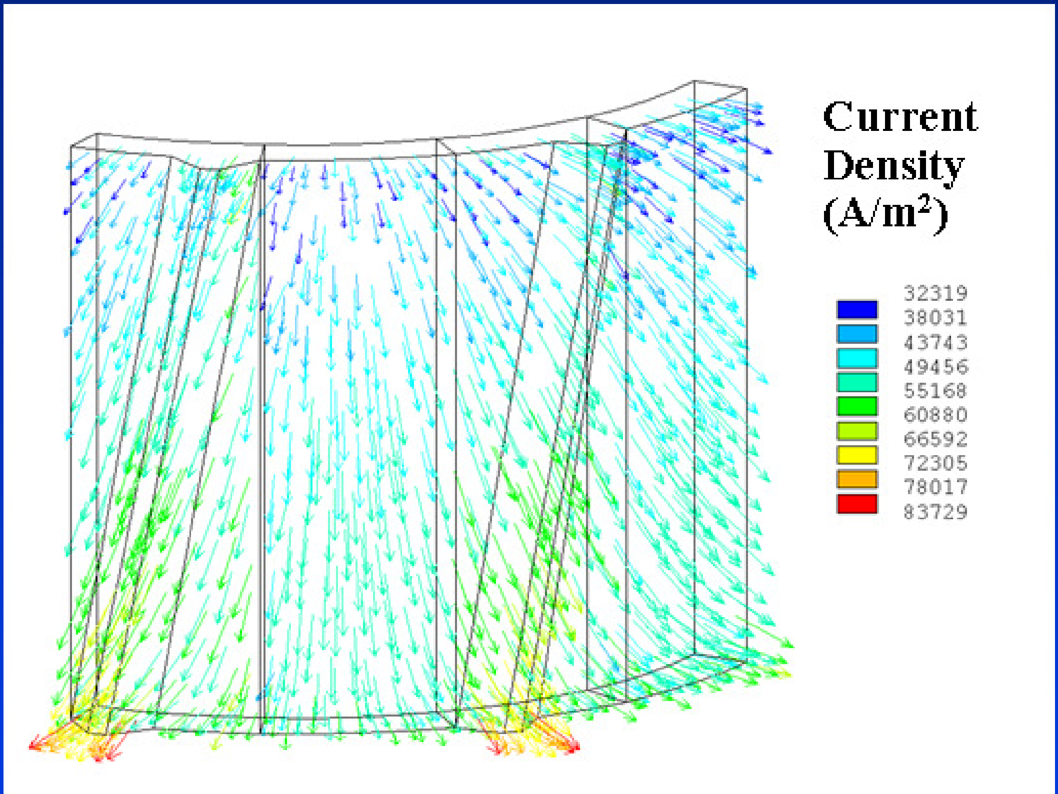
Detailed model results analysis revealed that those angles are too shallow to permit any significant pressure buildup on these two flutes side faces and that without a good pressure, essentially no current is passing through those contact interface surfaces because that without significant pressure, the interface contact resistance is much too high.

GENISIM

Testing a new flute design, 8 flutes option

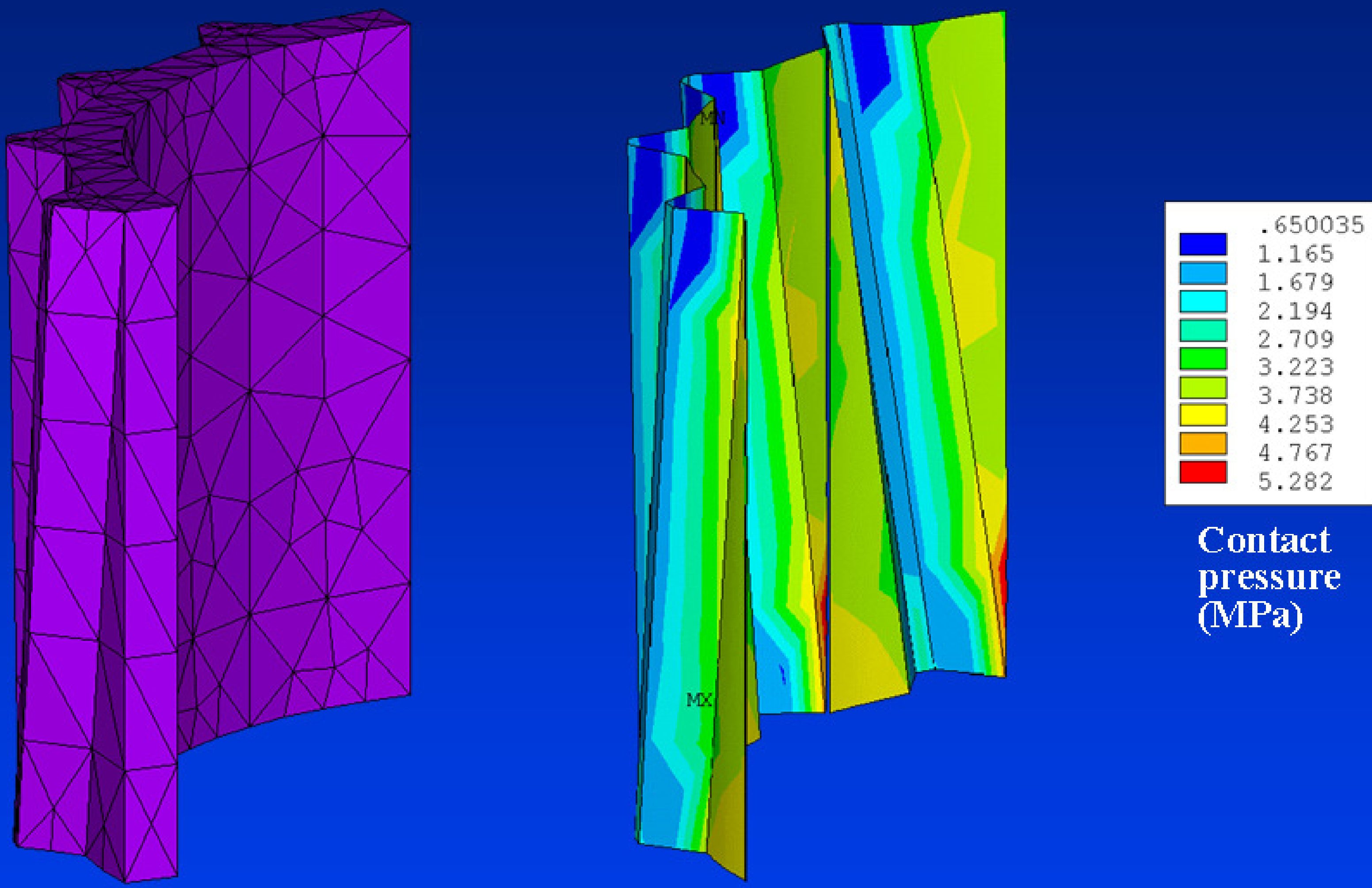


Contact pressure (MPa)



Pressure and temperature dependent contact resistance model results

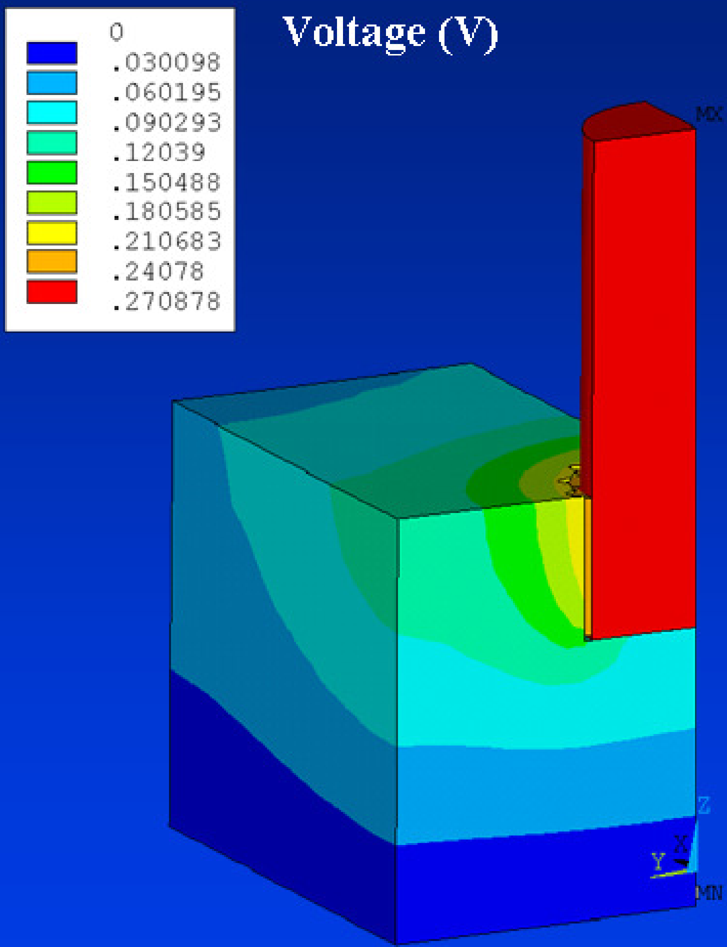
Testing a new flute design, 16 flutes option

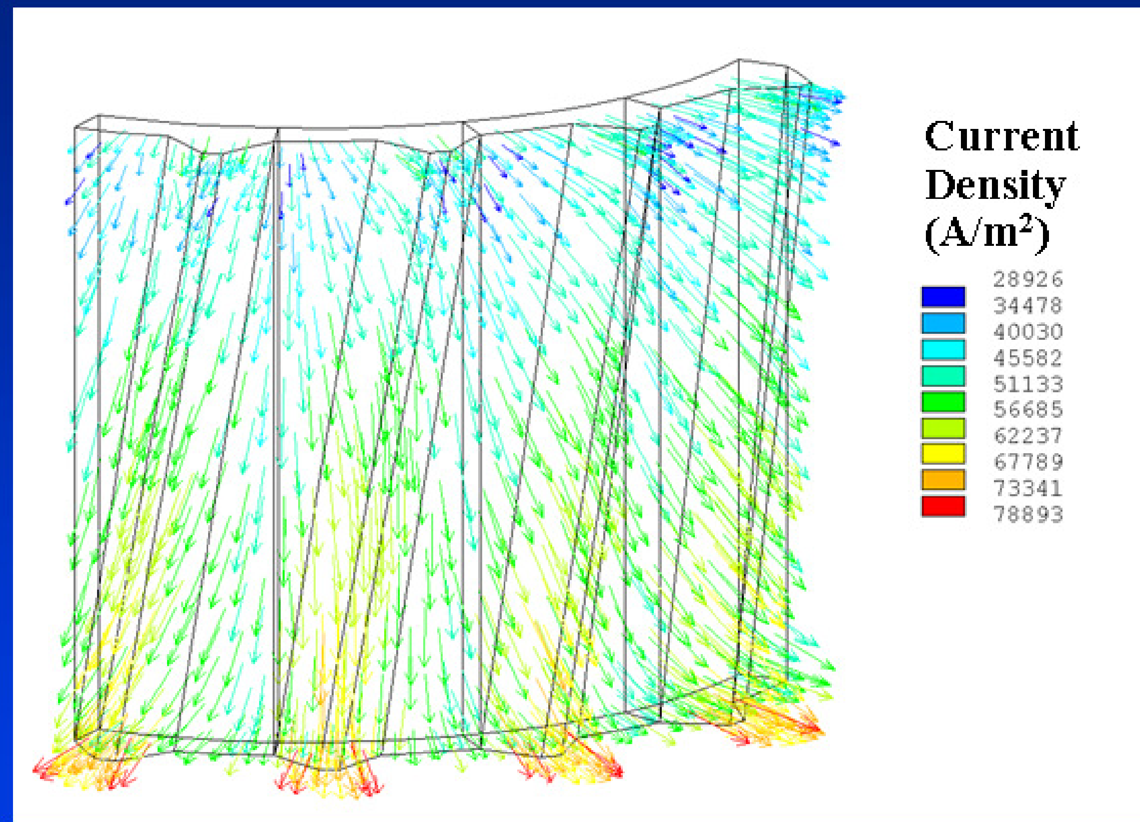


Pressure and temperature dependent contact resistance model results

GENISIM

Testing a new flute design, 16 flutes option





Pressure and temperature dependent contact resistance model results

Testing a new flute design

- For the 8 flutes option, the pressure and temperature dependent contact resistance model setup run predicts 278 mV which is a 7 mV or 2.5% decreased over the original design obtained by that very simple flute geometry change.
- For the 16 flutes option, the model predicts 271 mV for the pressure and temperature dependent contact resistance run, which is a 17 mV or 5.9% decreased over the original design.
- This represents a reduction of about 0.3 MM $ per year of operating cost for a typical modern smelter simply by changing the shape of the stub hole former!
- Of course, a much more detailed optimization study should be able to identify designs offering even more voltage drop reductions!

Conclusions

- An ANSYS® version 12.0 based fully coupled TEM anode stub hole design tool has been successfully developed and is now available to the whole aluminium industry through GeniSim Inc.
- The ANSYS® based APDL model is parametric, which means that for a given model topology, it is possible almost instantaneously to edit the APDL model input file to change the model geometry and submit another run.
- The quarter stub hole model presented here solves in only around 4000 CPU seconds on a 64 bits dual core Intel Centrino T 9300 Cell Precision M6300 portable computer running ANSYS® 12.0 version. So this parametric ANSYS® based TEM anode stub hole model is a very efficient tool to study alternative flutes design per example.
- A very quick flutes design optimization study revealed that a very slight change in the flutes design aiming at increasing the contact pressure of the flutes side faces should decrease the anode voltage drop by 17 mV or 5.9% which represents a reduction of about 0.3 MM $ per year of operating cost for a typical modern smelter simply by changing the shape of the stub hole former!

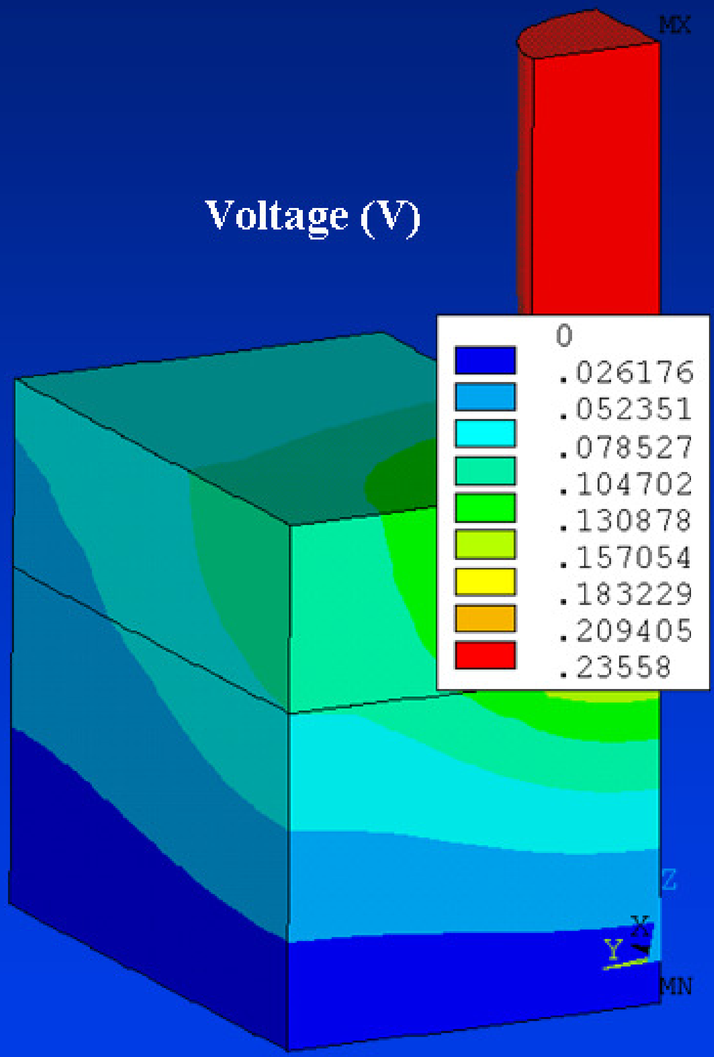
GENISIM

Acknowledgements

The author wishes to thanks Mr Lalit Mishra of Dubal and Mr. Dave Looman of ANSYS Inc. for their much needed assistance in using ANSYS® 12.0 advanced thermo-electro-mechanical contact elements features.

GENISIM

Follow-up Work

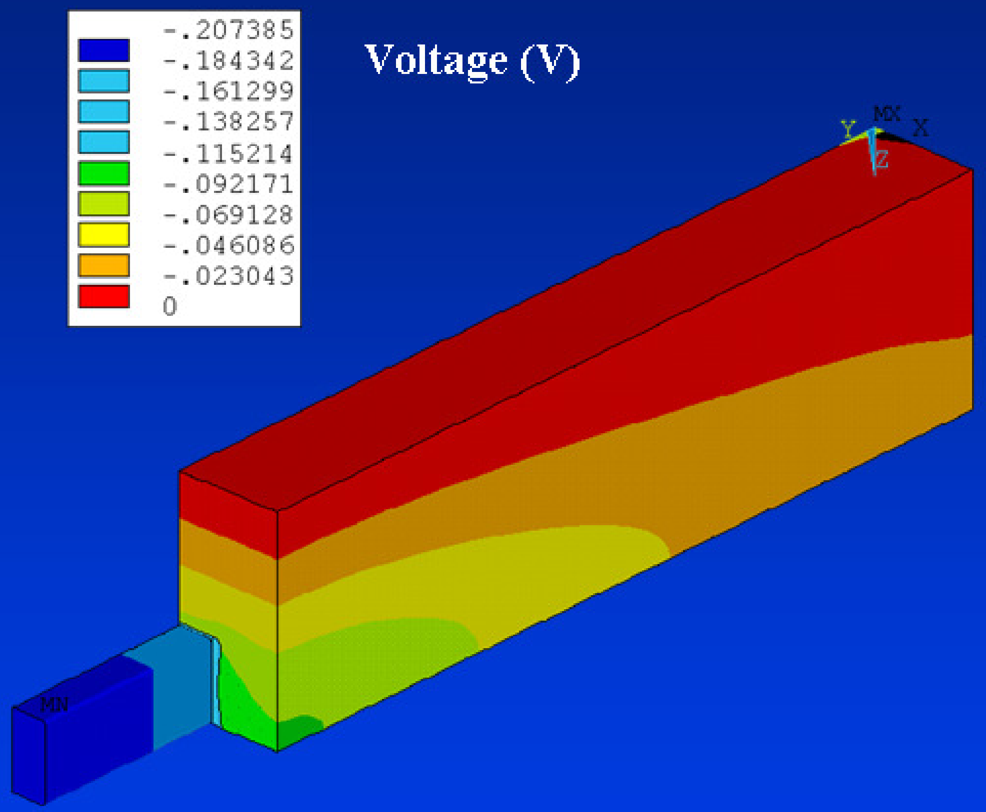


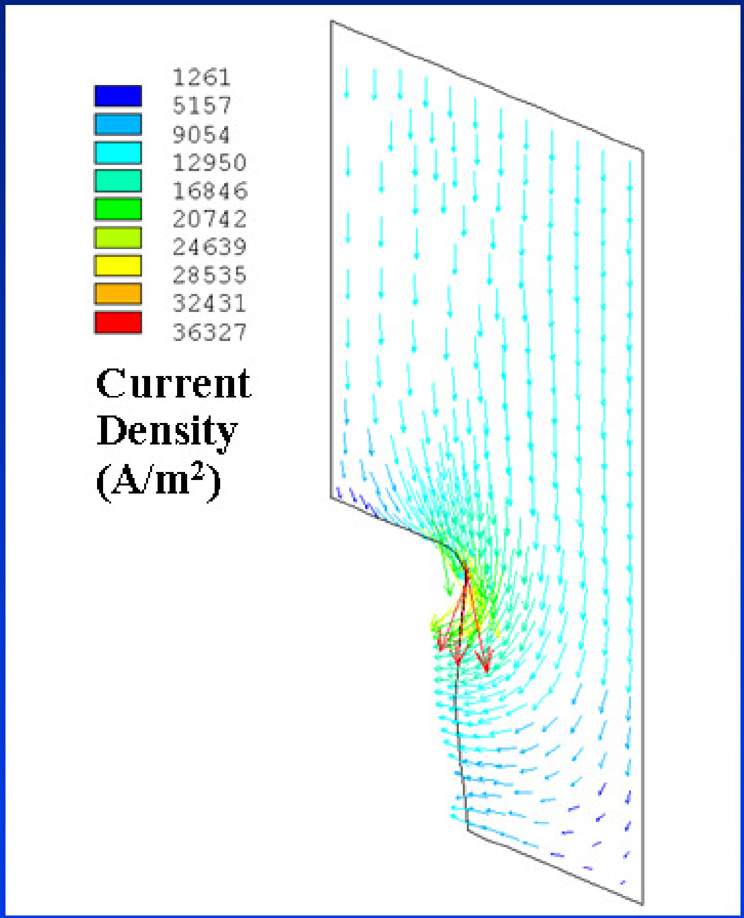
Since the paper was written, a new "patentable" stub/stub hole configuration was tested on the model.

The model predicts an additional 35 mV of anode voltage drop reduction as compared with the best solution presented in this paper.

GENISIM

Follow-up Work





A TEM cathode model has also been developed.