

25th IRIS Rotating Machinery Conference

Recent Generator Stator Coil Insulation System Developments

*W. Howard Moudy
Director of Operations
National Electric Coil*

hmoudy@national-electric-coil.com

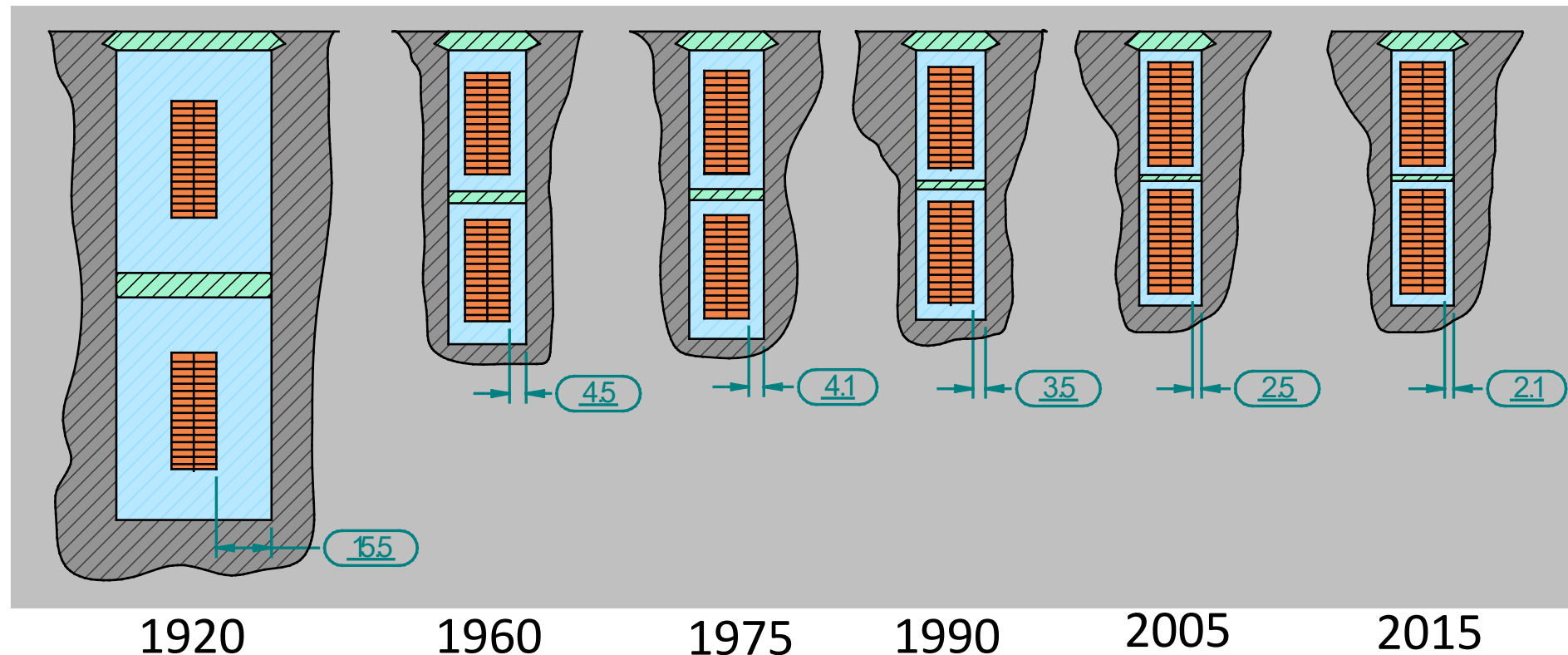
724-787-4967

[*www.National-Electric-Coil.com*](http://www.National-Electric-Coil.com)



Past Century of Ground Wall Insulation Evolution

- Material - Asphalt Mica \longrightarrow Polyester \longrightarrow Epoxy
- Process – Dipping, Wet Lay Up, Autoclave / VPI, Resin Rich
- Volts Per Mil (VPM) - 65 VPM is a good target for today's technology

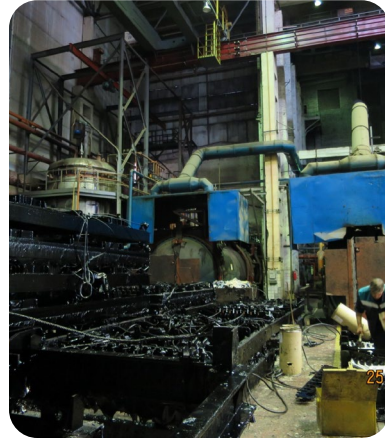


Today's Primary Insulation System Options



Autoclave / Single Coil VPI

- High Capital Set Up and Maintenance Cost
- Excellent results including highest terminal voltages
- Essentially Void Free
- Longest manufacturing process time



Autoclave Resin Rich

- High Set Up and Maintenance Cost
- Efficient for volume production of identical winding sets
- Dimensional variance challenges
- Asphalt bath process pictured



Hot Pressed Resin Rich

- Lowest Capital Setup and Maintenance Cost
- Limited capability at high terminal voltages
- Internal CTQ concerns with voids and other internal deficiencies
- Short Production Time



Global VPI (GVPI)

- Lowest Overall Cost
- Fastest rewind and processing
- Size / capacity concern – need for larger tanks
- Limited reparability after processing and during service



Surge in Resin Rich Hot Pressed Systems

- The market has recently seen considerable growth in the use of resin rich hot press systems
 - Low cost of Capitol Investment
 - Minimal advanced Process Development
- On the surface, hot pressed coils ***appear*** to have high quality technical characteristics.
- Commercially, hot pressed coils have a very attractive price.



Critical to Quality (CTQ) Processes & Equipment

OEM's and major independent manufacturers have and continue to invest millions of dollars to purchase, implement, maintain, and utilize key capital equipment and tooling for CTQ processes. The Autoclave / VPI is **not used** in resin rich hot pressed systems. Many manufacturers of resin rich hot pressed coils **do not** use robots for the CTQ process of taping either.



Autoclave / VPI



Robotic Taping



Appearance of Quality

On the surface, coils produced by most insulation systems may appear to be satisfactory.

Below the surface,

- Coils produced with inferior processes and insufficient capital equipment can be found lacking CTQ characteristics.
- Characteristics observed can include:
 - Delamination
 - Wrinkles
 - Voids
 - Inclusions

The challenge is to differentiate between processes that:

Deliver CTQ quality characteristics and long-term reliable performance

- and those that -

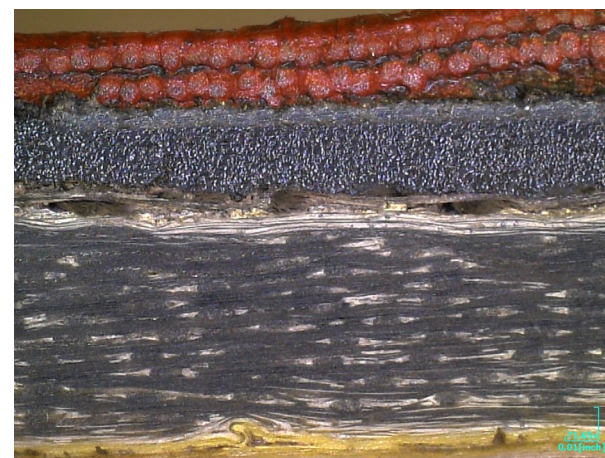
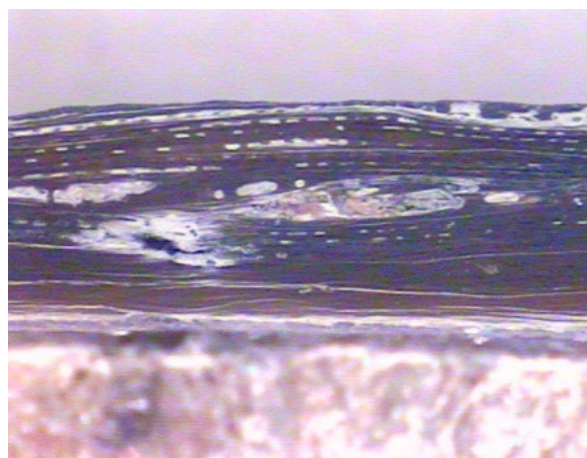
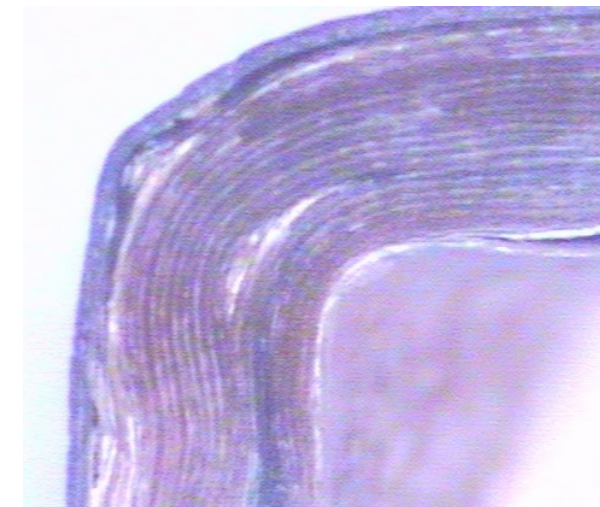
Do not delivery quality and long term reliable performance



Below The Surface

Resin Rich Hot Pressed Coils Retrieved From Rewinds

NOTE: Samples Shown Are Not NEC Manufactured Coils



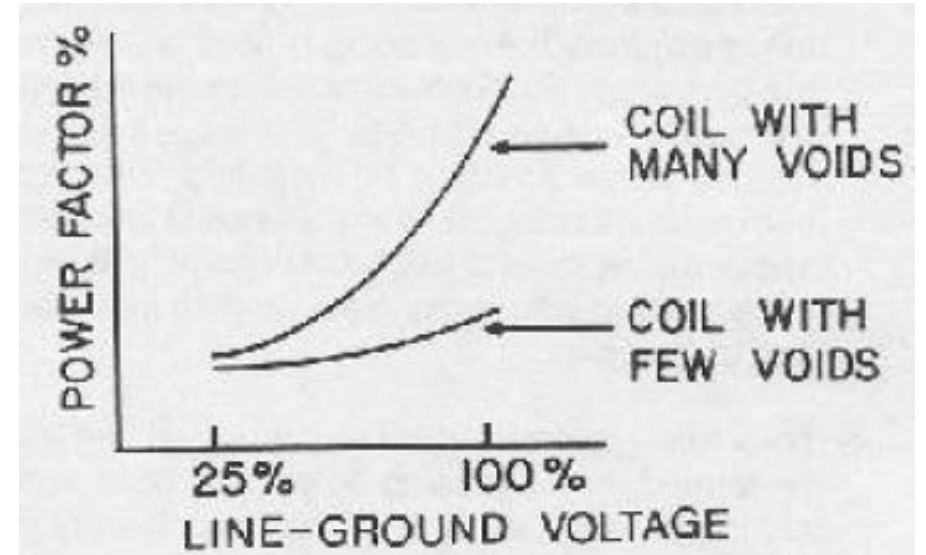
Insulation Quality Differentiation

- Coil dissection is a reliable way to determine if CTQ characteristics are present, and most helpful as a qualification method.
 - However, dissection is not practical for production
- Research, experience, and documented studies have found some forms of testing with tight tolerance requirements can help differentiate quality.
 - Tangent Delta & Power Factor Tip Up are tests that have proven to differentiate
 - However – testing and tight tolerance requirements have meet with a lot of resistance.
 - **Not Surprising!** - lower quality coils made without high capitol investment equipment and advanced process development, typically do not perform well in testing having tight tolerance requirements.



Power Factor Testing

- Performed per IEEE 286
- Higher readings indicate voids in the bar insulation
- Done at 25% and 100% of line to ground voltage
- Initial reading should be $< 2.25\%$
- Tip up - difference between the two readings
- Loose criteria considers $< 1.0\%$ acceptable but tighter criteria is becoming more common and certainly achievable



Tangent Delta Testing

- A document authored by Howard Sedding and published June 28, 2016 by Diagnostic News is a good resource to learn and understand more about Tan Delta Testing.
- Global study of the major insulation systems:
 - Paper conveyed by M.G. Krieg-Wezelenburg on behalf of CIGRE working group A1.39, and published in the IEEE Electrical Insulation Magazine – July/August 2021
 - *“Dielectric Dissipation Factor Measurements on New Stator Bars and Coils – Results from a Global Survey”*
 - IEEE Electrical Insulation Magazine; 0883-7554/21/©2021/IEEE; July/Aug – Vol.37, No.4 pp. 7-17
 - <https://www.cigre.org>



Tangent Delta Study Findings

- With over 19,000 records considered, the study concluded Single Coil VPI (VPI- blue) Insulation Systems had the best performance
- Autoclave Resin Rich (RH - green) was a close second in performance
- The performance results of Hot Pressed Resin Rich (RR - brown) were **considerably worse** than Autoclave/Single Coil VPI and Autoclave Resin Rich systems

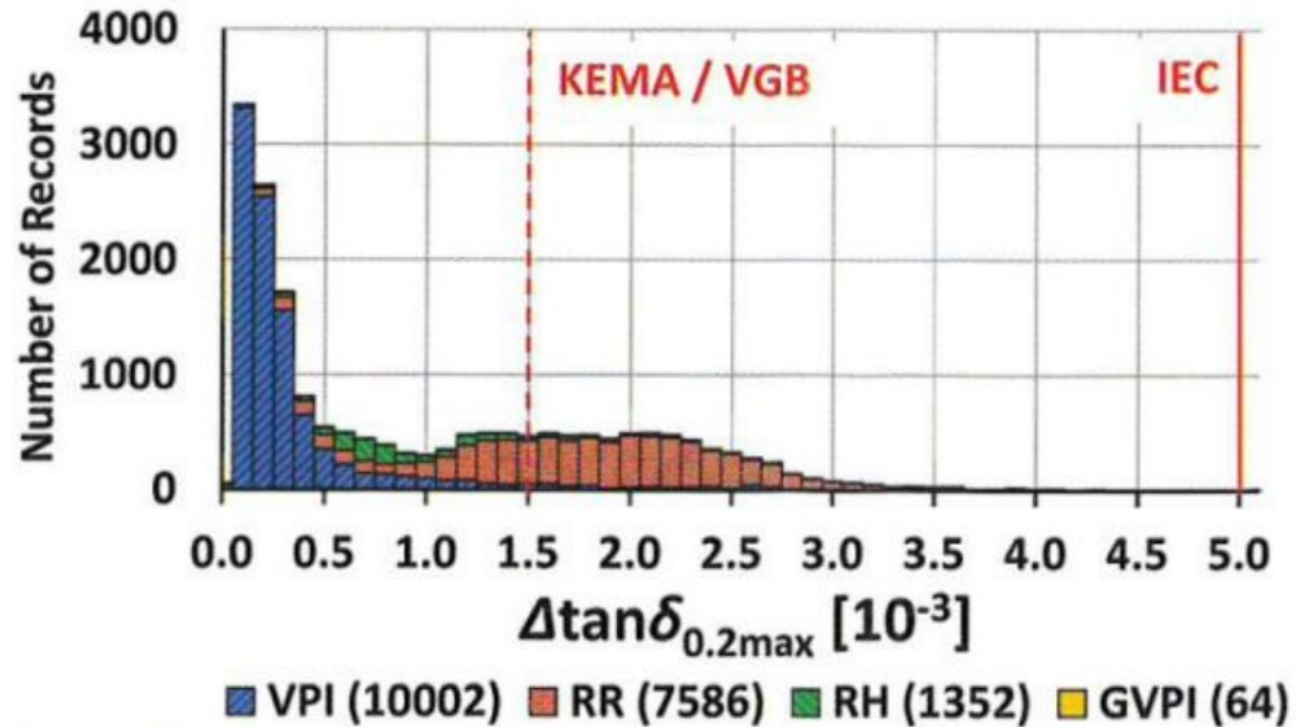


Figure 7. The $\Delta \tan \delta_{0.2 \max}$ of 19,004 records. Electrical insulation systems: VPI = vacuum pressure impregnation; RR = resin rich pressed and cured in heated plate molds; RH = resin rich with vacuum treatment and cured under hydrostatic pressure in high viscosity hot fluid; GVPI = global vacuum pressure impregnation.



Winding Specification Considerations

- **Specification Purpose**
 - The primary purpose of the specification is to clearly define technical expectations and requirements.
 - Identify CTQ characteristics, the tools to measure, and acceptance criteria.
- **Specification Philosophy?**
 - Performance Requirement -OR- Instructions to Follow
 - Strongly recommended performance requirements!
- **The best time to develop the specification is before you need it!**



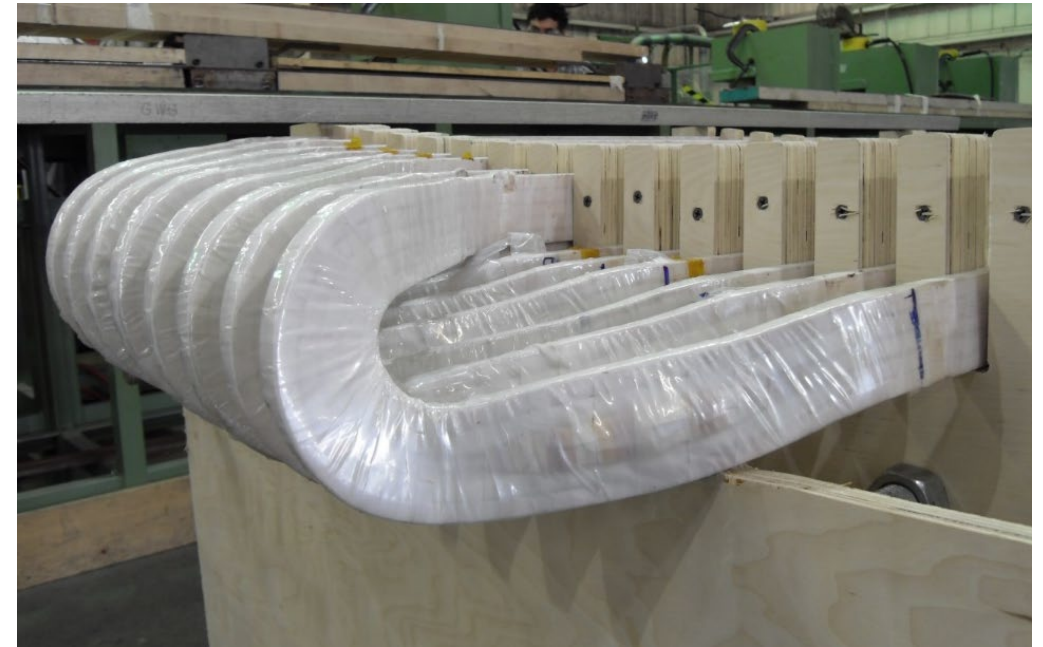
Winding Specification Considerations

- The technical specification should clearly state CTQ requirements & criteria.
 - Require Autoclave / VPI Processing
- The RFQ is a good tool to request / require from vendors, specific performance data for CTQ items. (See examples below)
 - **Outer Corona Protection (OCP) System**
 - Slot, end turns & paint, tape
 - **Losses**
 - I^2R , Circulating Current, Eddie Current
 - **Recent coil & insulation qualification test results**
 - Voltage Endurance – IEEE 1043 & 1553
 - Thermal Cycling - IEEE 1310
 - **Ground Insulation**
 - Type, resin system, temperature class, manufacturing process
 - **Overall Slot Buildup**
 - Maximum allowable operating stress, volts per mil (VPM)
 - **Strand Copper**
 - Arrangement/size of strands, losses, material
 - **Strand Insulation**
 - Type, number of layers
 - **Turn Insulation**
 - Description
 - Build



Autoclave / VPI Example

- Autoclave / VPI Process
 - Thermosetting Epoxy Resin
 - Pre-heat coils
 - Load into process pans
 - Vacuum cycle
 - removes trapped air pockets
 - Resin introduced and coils submerged
 - Pressurize with Nitrogen



Autoclave / VPI Example

- CTQ performance checks of each process – Production Approval
 - Verification of Tooling & Winding Manufacturing
 - Dissection & evaluation for geometric alignment and void free characteristic



Key Take Away Points

- Winding manufacturing processes can vary considerably between manufacturers. However, CTQ winding characteristics should be applicable to processes.
- Modern insulation systems are not all created equal!
- Many different machine models, ratings, sizes, and applications. Choose the best systems to serve the specific machine characteristics and reliability expectations.
- Specifications are:
 - Best if performance based, not instructions
 - Important tools to communicate expectations and requirements
 - A way to convey detail but the detail should be specific and hopefully be tied to CTQ value and characteristics



25th IRIS Rotating Machinery Conference

Recent Generator Stator Coil Insulation System Developments

Questions

*W. Howard Moudy
Director of Operations
National Electric Coil*

hmoudy@national-electric-coil.com

724-787-4967

www.National-Electric-Coil.com

