Rotating Machinery & Electrical Plant Reliability Workshop

Sponsored by the Doble Rotating Machinery Committee

Boston, Massachusetts USA
Westin Copley Place Hotel

Rotating Machinery Committee Technical Presentations
Wednesday, April 6th, 2016 | 7:30 AM to 12:00

Workshop
Wednesday, April 6th | 1:30 PM to 5:00 PM
Thursday, April 7th | 8:00 AM to 5:00 PM
Friday, April 8th | 8:30 AM to 12:30 PM

Note: Workshop attendees will also be able to participate in the Doble Rotating Machinery Committee Technical Presentations and by invitation, other Doble committee technical presentations and tutorials throughout the week.
Rotating Machinery & Electrical Plant Reliability Workshop
Sponsored by the Doble Rotating Machinery Committee

Advanced operations and maintenance training to maintain your generating and industrial plant at maximum performance and reliability.

Where
Boston, Massachusetts at the Westin Copley Place Hotel

When
Wednesday, April 6th | 1:30 PM to 5:00 PM  
Thursday, April 7th | 8:00 AM 5:00 PM  
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Earn Continuing Education Units

Continuing Education Units (CEUs) can be earned for the entire week's presentations.

Cost

The cost for this 2.5-day intensive learning seminar is

- $195 USD per person for attendees who are Doble Services Agreement (DSA) Clients
- $695 USD per person for attendees who do not have a DSA

Registration fee includes breakfast and lunch on Thursday, and breakfast on Friday.

For more information visit [http://events.doble.com/rm/](http://events.doble.com/rm/) or contact Doble Events at +1 617 926 4900.
Rotating Machinery & Electric Plant Reliability Workshop

Wednesday, April 6th | 1:30 PM to 5:00 PM

Generator Design & Construction

Clyde Maughan; Generator Consultants

This session covers the construction of the generator and its major individual components. In addition, issues that significantly influence the design of the various generator components are discussed. These machines are typically used in nuclear and fossil fueled power plants, cogeneration plants, and combustion turbine units. The power output of the generator generally follows the load demand from the system. Therefore, the voltages and currents in the generator are continually changing based on the load demand. The generator design must be able to cope with large and fast load changes, which show up inside the machine as changes in mechanical forces and temperatures. The design must therefore incorporate electrical current-carrying materials, magnetic flux-carrying materials, insulating materials, structural members, and cooling media, all working together.

Clyde Maughan has had a 66-year career in turbine-generators: 36 years with GE and 30 years as an independent engineering consultant on many hundreds of generator design and service issues. In the last 17 years he has authored 29 technical papers and a 240-page book on generator maintenance. His objective in this effort has been to pass along the knowledge of his generation of generator engineers to the next generations of generator engineers. These documents are all available for no-cost download on the IGTC web site www.generatortechnicalforum.org under the topic, Inner Water-cooled Stator Windings, of which he is moderator. At age 89, he is still working, focusing his efforts primarily on generator failure root cause analysis and on generator maintenance training. (And 6 months short of his 90th birthday, he become an IEEE Fellow.)

Generator Inspections

Nils Nilsson; Lanier Consulting

A large synchronous generator is a complex apparatus and should be viewed more like a system than a device. It is comprised of a low voltage DC rotor field (with a source of excitation) and a high power AC stator. Unlike most devices in electric utilities that can be viewed monolithically as an electrical apparatus with a simple function, it needs to be evaluated as an electrical system, a magnetic system and a mechanical system involving power transfer through a complex rotating element. The large synchronous generator is complicated to operate and maintain and can develop a number of problems over time. Accordingly, periodic maintenance inspections are required which provide an opportunity to uncover problems that need attention, some of them immediate attention. Sometimes, damage can occur that was not anticipated by operating and maintenance history and decisions must be made requiring some detailed understanding of design parameters and changes to these machine systems as they have evolved over time. A number of actual inspections, tests, evaluations and repairs will be discussed and suggestions for items for additional consideration will be presented.
Nils Nilsson has been active in the electric power engineering industry for over 40 years. He spent more than 30 years at FirstEnergy Corporation in electric plant engineering responsible for power plant electrical design projects, power plant electrical maintenance support and outage and diagnostic support. He currently serves as an independent consultant performing generator inspections, maintenance planning and root cause analysis. He served as an adjunct professor from 2003 – 2010 at Youngstown State University’s Technology College where he taught courses on Electrical Fundamentals, Electric and Magnetic Circuits and Electric Rotating Machinery. He also coauthored Monitoring and Diagnosis of Turbine-Generators, 1995.

Thursday, April 7th | 8:00 AM 5:00 PM

**HV Materials & Testing**
*Dr. Nancy Frost; Gerome Technologies*

The focus of this session is the basic aspects of high voltage insulation materials for the novice. The fundamental aspects of insulation materials will be covered, including how to select materials, what properties are important and tests that are critical to performance. The session will cover the key electrical insulation materials, including their properties and applications of various types of insulation. The major test methods and standards used in selecting and qualifying insulation systems will be discussed. It is intended that this session help the generator operator and/or management team understand the critical working aspects of electrical insulation materials.

**Stator Bar & Coil Manufacturing**
*William G. Moore; National Electric Coil*

This session will focus on the manufacturing process to make new coils and bars for both turbogenerators and hydrogenerators. Design constraints that must be followed to manufacture high quality bars and coils are discussed in detail. Typical manufacturing process checks and all the key IEEE tests are described in detail. Both Vacuum Pressure Impregnation (VPI) and Resin Rich manufacturing are discussed. Methods for Corona Suppression and low Partial Discharge (PD) are also covered. Photos along with key videos will enlighten your knowledge of bar and coil manufacturing.

**Bill Moore, P. E., is Director of Technical Services for National Electric Coil.** Located in Columbus, Ohio, his department provides high level technical support in the areas of advanced engineering design, R&D, product development, technical proposals and sales and marketing technical support. Prior to joining NEC in 1997, Bill held utility power plant management positions with Florida Power & Light, working at three different power plants, over a ten year time span. A licensed professional engineer in Ohio and Florida, he started his 35 year power industry career as a generator design engineer with the Westinghouse. He has been awarded several design related generator patents and has published and presented over 75 papers and magazine articles in the power generation field. He is a frequent short course lecturer on generator industry issues at major conferences and insurance companies. Bill is a Fellow Member of the ASME and was past chairman of the ASME Power Division.
AC & DC Generator Testing

Bill Dollard, AGT Services

The purpose of stator testing is to assess & mitigate detrimental situations before serious/expensive damage occurs while also providing confidence that the winding will not fail in-service prior to the next outage. In this session, we will learn the purpose of conducting generator stator electrical tests, when they should (or should not) be conducted, and how to better analyze the collected data. Tutorial will cover stator DC test such as phase winding resistance, insulation resistance (Megger) & polarization index, DC leakage test, DC high potential over-voltage test, and RTD resistance & Megger test. Tutorial will also cover AC stator tests such power factor / tip up (Doble) test and AC high potential over-voltage test as well as Doble pole drop test and SFRA testing on hydro-generator rotors. Electro-magnetic core imperfection detector (EL CID) test on stator iron will also be discussed.

Bill Dollard is Services Manager at AGT Services. Bill has been active in the electric power engineering industry for over 25 years, primarily with General Electric. He began his career with GE in 1990; in 1997 he went through GE’s generator specialist program where he was responsible for performing test and inspections as well as managing major generator outages including rewinds. Bill joined generator manufacturing in 2000 where he was responsible for manufacturing of generator stators and later transitioned into a quality role supporting generator stator wind and core stack operations. Bill’s last role with GE was as a generator methods engineer for field services organization where he led the development of comprehensive, state-of-the-art technical reference materials and data evaluation tool.

Partial Discharge Testing & Monitoring

Hugh Zhu, Principal Engineer; Doble Engineering Company

On-line partial discharge (PD) testing has been applied to rotating machines successfully for over 30 years. With technological advancement and a greater understanding of PD in rotating machines, a more informed decision can be made about the condition of their associated insulation systems. Supported by updated IEC and IEEE standards, such as IEC 60034-27-2, these advances include better digital acquisition systems, noise rejection methods and sensors technology. This presentation will present several of these advancements and the reason they should be incorporated into an online PD test program for rotating machines. Examples of PD data interpretation are also presented.

Off-line PD testing is another tool for insulation diagnosis and condition assessment. The presentation of off-line PD testing includes the requirement of a high voltage source to energize the windings of rotating machines, requirement of the PD sensor and instrument, and how to perform PD testing.

Hugh Zhu is a Principal Engineer with Doble Engineering Company. He received his Ph.D. studying partial discharge (PD) measurement of rotating machines and his post-doctor fellowship studying PD measurement of transformers in the UK. Hugh has 25-year experience on testing rotating machine insulation through working in the UK, Canada, and USA. He has been involved in PD testing, condition assessment, and field and lab testing of hundreds of rotating machines.
worldwide. His expertise includes PD testing, insulation condition assessment, quality assurance testing on stator coils, and failure investigation of generator and motor insulation. His experience also extends to PD testing on transformers, cables, and other HV apparatus. He has published over 50 technical papers. Hugh chairs the Aging Factors Technical Committee of IEEE Dielectrics and Electrical Insulation Society. He is a member of the Technical Committees of IEEE, IEC and CIGRE to develop the standards of rotating machine insulation testing.

Electromagnetic Signature Analysis Testing - Generators, Iso-Phase Bus, Generator Step-up Transformers and Emergency Diesel Back-up Generators

Paul Spracklen, Sr. Test Engineer; Doble Engineering Company
James Timperley, Principal Engineer; Doble Engineering Company

Electromagnetic interference (EMI) Diagnostics has been utilized to provide information for the condition based maintenance of large machines at power plants and industrial sites since 1980. The advantages of totally non-intrusive data collection, in real time, while a motor or generator remains in service has a great economic and safety benefit all facilities. Design modifications are not necessary to collect data and there are no connections made to energized circuits. This half day session on EMI testing will include:

- Overview of EMI, PD and RFI detection applications
  - Generators
  - Iso-phase and non-seg bus
  - Motors
  - Transformers
- EMI fundamentals
- Int’l standards
- Work with the PDS200e
  - PDS200e
  - EMI Sniffer
- EMI testing work method statement
- Taking reliable measurements
- Analyzing data for proper data acquisition
- Managing PDS200 data and firmware
- PDViewer Software

Expert Panel: Question & Answer
Friday, April 8th | 8:30 AM to 12:30 PM

**On-line Generator Rotor Winding Shorted Turn Detection Technology – Theory and Case Studies**  
*David Albright, President; Generatortech, Inc*

Generator rotor winding turn shorts are a common problem that can sometimes limit unit output due to excessive rotor vibration or excitation current limitations. On-line detection of these turn shorts is possible using a magnetic flux probe to measure the magnetic field strength variations close to the surface of the rotor. The proper analysis of flux probe waveforms will identify the location of turn shorts in the rotor winding (which pole and coil) and the number of turn shorts in each affected coil. By testing operating generators, speed- and temperature-dependent shorts will also be detected. These types of turn shorts are not detectable after the generator is stopped and are therefore very difficult to find and repair. Theory behind flux probe testing, causes of turn shorts & various case studies will be presented.

*David Albright* is the president of Generatortech, Inc. Mr. Albright received a BS from Cornell University and an MS in electrical engineering from the University of Wisconsin-Madison. He helped start Generatortech in 1989 and developed the instrumentation and software that are used to record and analyze flux probe waveforms for shorted turn detection.

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**Iso-Phase Bus Circulating Current and Overheating Issues**  
*Gary Whitehead, Power Project Specialist; Electrical Builders Inc.*

This presentation will highlight the evolution of isolated phase bus designs and how circulating currents affect those different designs. Circulating currents can cause havoc with an isolated phase bus system, and the basic design of the bus will dictate the best practices that have been identified for analysis, inspection, cleaning and maintenance of those bus systems. Isolated phase bus systems have largely been ignored, forgetting it is the only system critical component in the power plant that does not have redundancy. With a renewed focus on the systems, many plants do not realize how different designs can cause different problems.

*Gary Whitehead* is the Power Projects Specialist at Electrical Builders Inc. (EBI). Since coming to EBI his main focus has been working on projects such as new installation, retrofits as well as design improvements and value engineering on existing systems. Mr. Whitehead has attended numerous colleges studying industrial and architectural drafting and design. He has over seven years of experience in this industry working for AZZ/Calvert, a designer and manufacturer of Iso-Phase systems as an Engineering Technical Coordinator and also in their Installation Services as a Designer/Quotation Specialist and Project Manager.

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**Introduction to Generator Protection**  
*Ed Khan, Director of Protection R&D and Training; Doble Engineering Company*

The role of the generator in a power system is to produce electrical energy at the correct voltage and frequency that meets the electrical transmission system’s load demands. The generator connects to the transmission system along with other generators and must automatically react to conditions that affect its ability to meet the requirements for voltage and
reactive power support. In case problems on the transmission system or within the generating plant arise, the generator has protection systems designed to ensure safety for operations personnel and prevent, or at least minimize; equipment damage.

**Ed Khan** is the Director of Protection Training and R&D at Doble Engineering Company. He has been with Doble for seven years. At Doble, he had also worked as the Product Manager for the protection testing product line. Prior to joining Doble, Mr. Khan had worked for several companies such as GE, Westinghouse, ABB, KEMA, SEL, and others. He has a very broad background in power systems and has performed system studies, relay application, coordination studies, and equipment sizing for power plants. He has presented various courses and seminars on protection and harmonics both in US and overseas.
Doble Rotating Machinery Committee Presentations

Wednesday, April 6th | 7:30 AM – 12:00 PM

1. Condition Assessment for Emergency Diesel Generators  
   *James E. Timperley; Doble Engineering Company*

   There is a need in the Nuclear Industry for condition assessment of the standby emergency generators. Most in the USA are over 30 years old but often have 2000 hours or less of full load operation. There have been exciter, voltage regulator, breaker and power cable problems. Very few generator stator failures have occurred. Most machines operate at 4 kV and all are rated less than 10 MW. Very limited generator condition monitoring is installed. Since these are safety related systems there is reluctance to add new sensors because of the design change expense involved.

   Electro-Magnetic Interference, EMI, diagnostic testing is an on-line, in-service evaluation that can detect numerous mechanical and electrical problems of a generator system from the first test. Trending helps to identify a variety of problems early in their evolution. There is no interference with normal operation to collect data during a monthly scheduled generator test run. Case studies are presented.

   Examples of problems found with alignment, generator exciter, voltage regulator, stator and power cables are presented from several non-nuclear emergency generators tested and over one hundred larger engine driven generators tested over the past five years.

2. Experience in SFRA Testing of Generator Field Windings  
   *Eric Eastment; U.S. Bureau of Reclamation  
   Don Prien; Doble Engineering Company*

   There have been a few cases where people have used the sweep frequency response analysis (SFRA) test technique to monitor or determine the condition of rotating machine field poles. These cases show that the SFRA is effective at identifying problems with the field poles and field windings. This paper reviews the findings and presents some new examples of tests performed on hydro generator and synchronous condenser poles. The testing on the field poles of the hydro generator were performed with the rotor in place and the tests were performed from the brush holders, across the entire field winding, pole pairs and individual poles. The tests included simulating a shorted winding on one of the poles and looking for differences in the responses from the different test points. The tests on the synchronous condenser poles were done in the factory after removal from the rotor and on the individual poles. They are compared with the poles after the field windings were replaced.

   This paper finds that there is value and possible time savings in using the SFRA test to monitor the condition of the filed poles, either on or off the rotor. This simple test method has been proven effective in identifying shorted, open, and grounded field windings.
3. Water-Cooled Stator Windings
   *Clyde V. Maughan; Maughan Generator Consultants*
   *Mathias Svoboda; SvoBaTech*

Direct water cooling of stator windings has been common since the early 1960s. In general these windings have performed well, although as would be expected in any liquid system involving many varied components, there has been problems with both large and small leaks. Equipment manufacturers working with users have developed procedure to effect necessary repairs.

Perhaps less expected have been problems with copper oxide formation within the hollow copper strands which carry the water (as well as electrical current). Two types of oxide can be produced, cupric (a black compound CuO) and cuprous (a red compound Cu2O). The latter tends to be more common and more troublesome.

This paper will briefly summarize some basic stator winding design, operation and monitoring considerations relating to water cooling, and will then discuss parameters relating to oxide buildup and removal.

4. Field Pole Attachment Cracking on Hydrogenerators
   *William G. Moore; National Electric Coil*

This paper will discuss a serious issue right now in the hydro industry involving cracking of field pole attachments. Field poles are attached to the rotor rim on hydrogenerators typically by a tee tail or dove tail configuration.

The tail, or in some cases, two tails, are wedged tightly into the keyway space in the rotor rim. The tails can have sharp fillet radii that have high stress concentration factors. This high stressed area can be the source of crack initiation, when the generator is cycled frequently. Pump storage units that cycle at least once daily may be the most prone to this cracking. At least one catastrophic failure has occurred in the industry in 2009. Also discussed will be the details involving one of the first units inspected by the author’s company and found with these cracks.

To date, there have been only a handful of these units inspected and found to have these cracks, but more owners are scheduling inspections. The paper will also present comparisons to tooth top cracking found on turbogenerator rotors.
5. **Wind Turbine Generator Failures – Subtitle: Experiences since 2005 and the Apparent Effect of Various Insulation System Designs**  
   **Kevin Alewine; Shermco Industries**  
Failure data has been collected on more than 4GW of wind turbine generators repaired or remanufactured by Shermco Industries since 2005. There are a wide range of sizes, designs, and specific application details. This paper will provide an update of the study as well as observations regarding various OEM insulation systems. Also discussed will be some of the North American aftermarket options that are available to improve reliability and longevity of the generators. Special attention will be paid to the failure modes involving the loss of magnetic wedges utilized in many designs to improve efficiency.

6. **End-Windings Vibration Monitoring for Hydro-Generators**  
   **Marc R. Bissonnette; VibroSystM**  
End-winding vibration issues have been an ever increasing subject of interest in the industry, specifically in the turbo generator side of power generation. An increasing number of major failures, due mostly to insulation breakdown, have been directly attributed to end-winding vibration. Although the usefulness of this monitoring technology has been proven many times over in turbo generators, a definite interest in the use of fiber optic technology has been observed in hydro-generation, as well as in the mining industry, for SAG and ball mills. The case study included in this paper will show quite clearly how this technology can be very effective in monitoring, detection and identification of problems emanating from electromagnetic stresses exerted on the end-winding structure of hydro generators. It will show how proper trending and analysis capabilities and early detection of end winding vibration issues on hydro-generators can be achieved. This leads to the prevention of major and costly failures and allows for the lifetime of a stator core and winding to be extended. The intervention to improve the stiffness of a specific end-winding, covered in this paper, was deemed a success and demonstrated that such action could delay or stop a major failure mechanism. It also showed that end-winding vibration data doesn’t always paint the entire picture as the vibration observed may not be the highest vibration level recorded on a unit. The importance of installing the correct number of sensors, along with the proper location of said sensors, is critical in order to provide accurate and pertinent data and therefore provide a better assessment of the end-winding structure integrity.

7. **Study of Insulation Resistance Profiling Use on Random and Form Wound Machines**  
   **Howard W. Penrose; MotorDoc**  
The insulation resistance profile polarization index curve can be a powerful tool in understanding the condition of a ground wall insulation system when properly applied. Finally included as an Addendum in IEEE Std. 43-2013, the methodology has been in existence for over a Century. The purpose of this paper is to review the success of several approaches including: all phases to ground; each phase to ground with other phases grounded; and, time applied. The pattern related to different types of insulation to ground conditions will be discussed as will a series of observations as to the effectiveness of this prognostic