

Clipper's Design Approach to Improving Reliability and Integrated Condition Based Monitoring

Shaw Makaremi, PhD, PE
Sr. Electrical Engineer
Clipper Windpower, Inc.



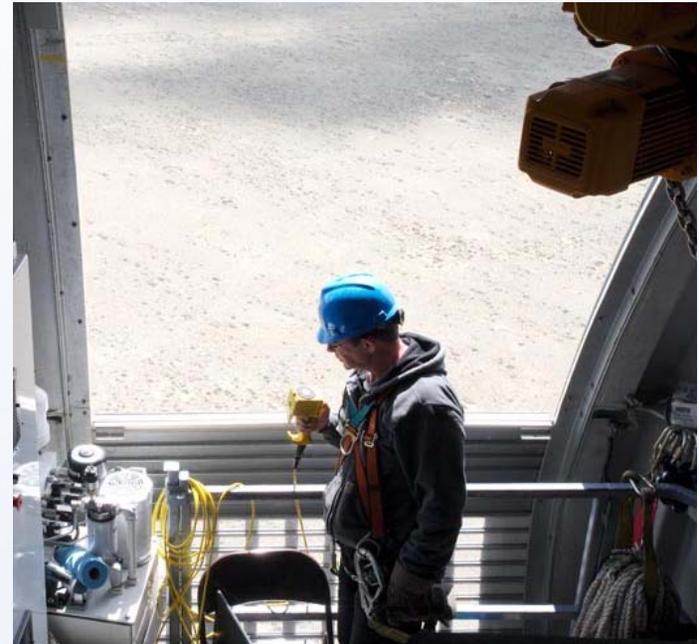
The Clipper approach to enhance reliability is comprised of three main activities:



- **Predictive Maintenance**
- **Scheduled Maintenance**
- **Integration of the two**

Predictive Maintenance:

- **Continuous remote monitoring** enables predictive maintenance.
- Predictive maintenance **minimizes downtime especially during optimal wind conditions.**
- On the Liberty Turbine continuous monitoring is used on the
 - **Gearbox**
 - **Generators**
 - **Blades**



Predictive Maintenance

- The monitoring measures and tracks in temperature, vibration, the number of particles in the gearbox lubricant and blade loads.
- Monitoring the trends will provide an indication of reduced efficiency or warning of future failure of components.
- The challenging task is to create a reliable algorithm for merging disparate information to accurately identify the condition of the turbine.

Predictive Maintenance: Measurements



The monitoring states are:

- Temperature of
 - Gearbox oil
 - Gearbox high speed bearings
 - Generator windings
- Vibration of
 - Main shaft and bearings
 - Intermediate pinion and bearings
 - Gear mesh frequencies
 - High speed pinion and bearing
 - Generators
 - Cooling Fans
 - Bearings

Predictive Maintenance: Measurements

- Oil particle counter
 - Counting ferrite and non-ferrite particles in the gearbox lubricant
- Blade loads
 - Using a Fiber Bragg Grating system incorporating optical sensors on the blades to measure micro- strain .
 - The strain measurements are both flap wise and edge wise.



Scheduled Maintenance

- Is performed regularly and is a complimentary practice to the predictive maintenance.
- Scheduled maintenance consists of many well defined and organized tasks with detailed procedures.
- Scheduled maintenance is performed on parts where the malfunction or replacement of component will not result to extensive cost and down time of the turbine.

Scheduled Maintenance:

Tasks and Documentation

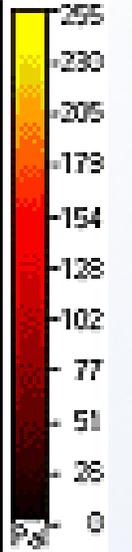
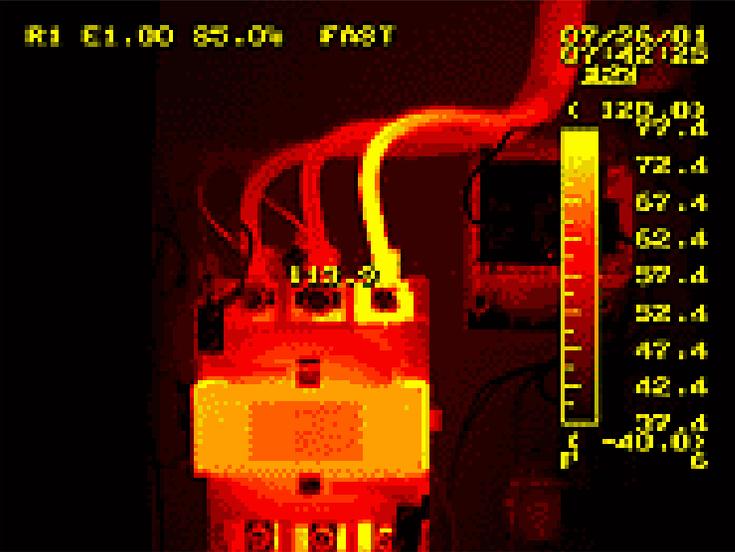
In general these tasks include:

- Taking an oil sample of the gearbox in compliance with ISO-4406 referenced to the oil cleanliness 16/14/11 with 100ppm moisture content.
- Visual inspection of listed components
 - Hydraulic oil leakage, cables, connectors general cleanliness.
- Part replacement suggested by manufacturer with reference to MTBF of components.
 - Pumps, motors, bushings etc
 - Greasing and lubricating bearings
- It is planned to use Infrared Thermography to detect mechanical and electrical hot spots on parts such as bearings, contactors, circuit breakers, fuses and brushes.

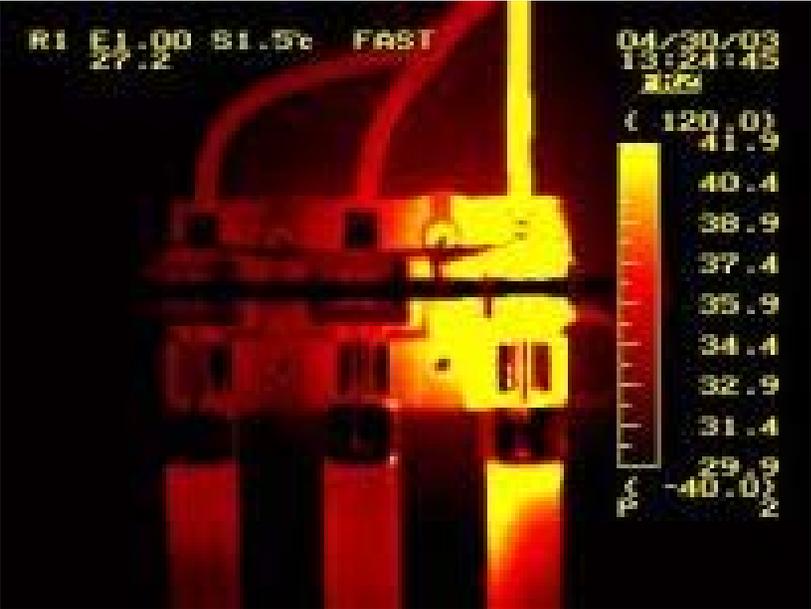
Infrared Thermography showing hot spot on the fuses



Infrared Thermography indicating hot spots on the contactor



Hot spot on the fuse holder



Maintenance & Repair

Should be Simple & Safe

The Liberty machine incorporates a number of features to enable this

Maintenance & Repair should be done with ease



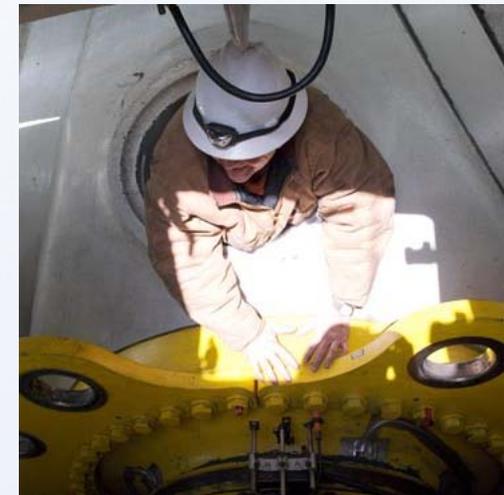
Ease of Assembly, Maintenance and service

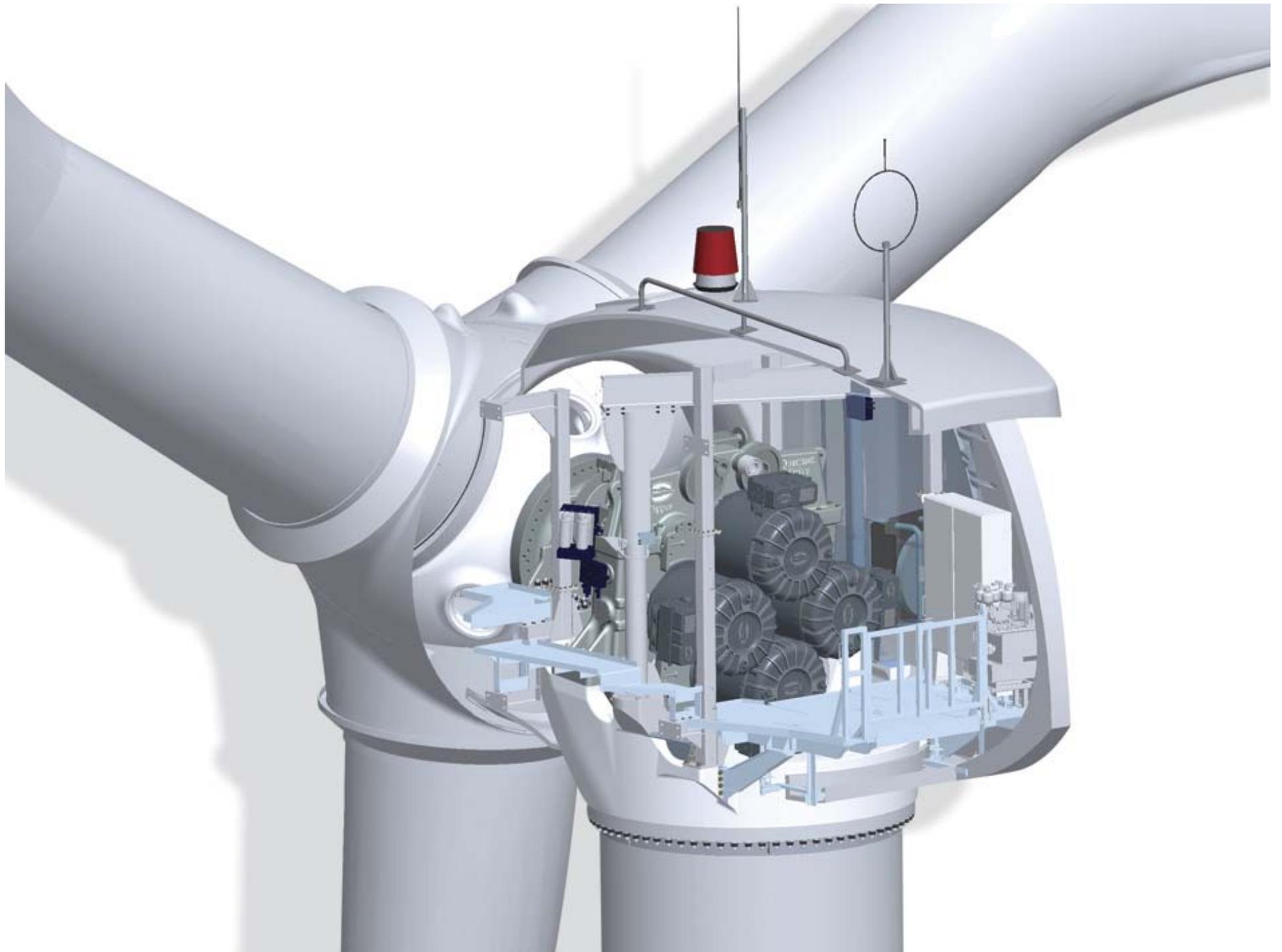
- Hub accessed through nacelle ports
- Full head-room and walk-around
- 2 ton jib crane services
 - Brakes
 - Generators
 - Pinion cartridges
 - Yaw motors
 - Hydraulics and cooling systems

All this should result in enhanced turbine availability and easy maintenance

Maintenance & Repair Should be done with ease

Liberty: Designed for enhanced availability and easy maintenance



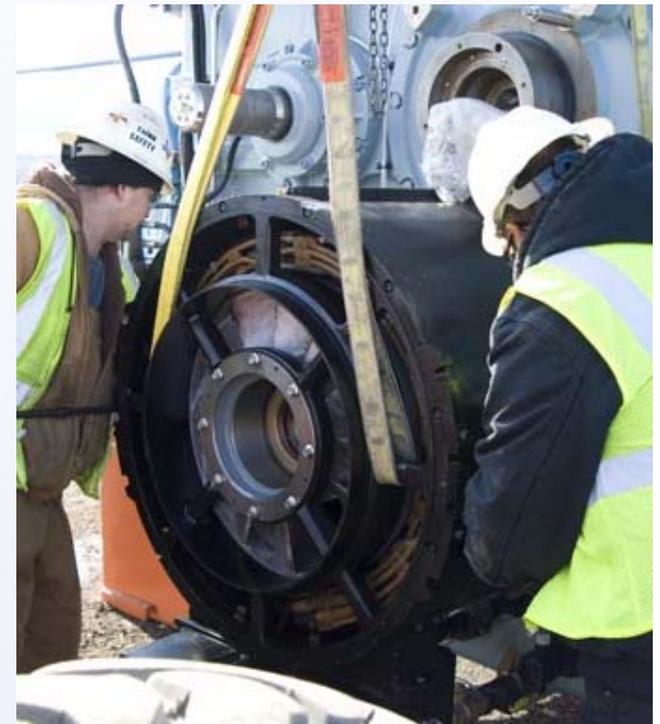


Maintenance & Repair should be done with ease

Generator

Enhanced Reliability & Serviceability

- Rugged design
- Fewer parts and higher reliability
- One up-tower-serviceable bearing per generator
- Replaceable with on-board crane
- Turbine can continue to operate with 2 or 3 generators
- Generators completely isolated from grid, which allows for easier voltage ride-through capability and complete isolation from grid disturbance
- Low weight < 4000 Lbs. per generator



Maintenance & Repair should be done with ease

Gearbox

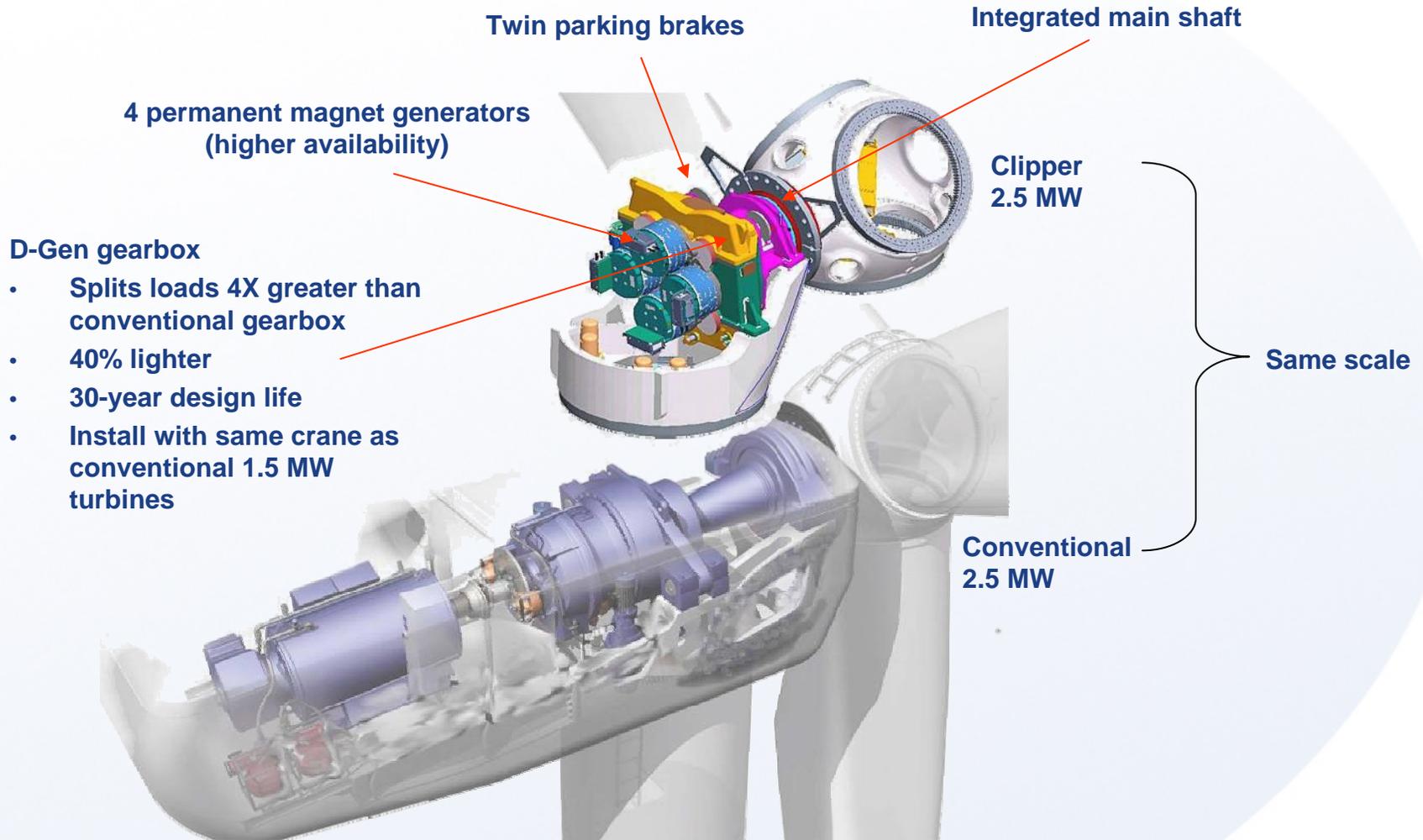
The Quantum Drive™ distributed powertrain

3 Patents Issued

- Four high-speed output shafts
- Lighter and more efficient than other commercial GBs
- Split load by a factor of 16, 400% more than the commercially available GBs
- Two stages, versus the three used in commercially available gearboxes
- Increased efficiency
- Ability to replace all high-speed stage components using on-board gantry crane (in less than four hours by two people)



Liberty Turbine – Breakthrough Technology



Integration of Predictive and Scheduled Maintenance

- This integration will give us a comprehensive understanding of the behavior of the turbine.
- Feedback to engineering and manufacturing for modification and product improvement.
- Timely information to O&M people for scheduled maintenance such as
 - Preparation of parts and tools for repair.
 - Collection of knowledge and documentation.
 - Special equipments and crane.
 - Safety consideration.
- In general this integration enhances and prolongs the productive life of the turbine.
- The integration is done at the Remote Monitoring & Diagnostic Center

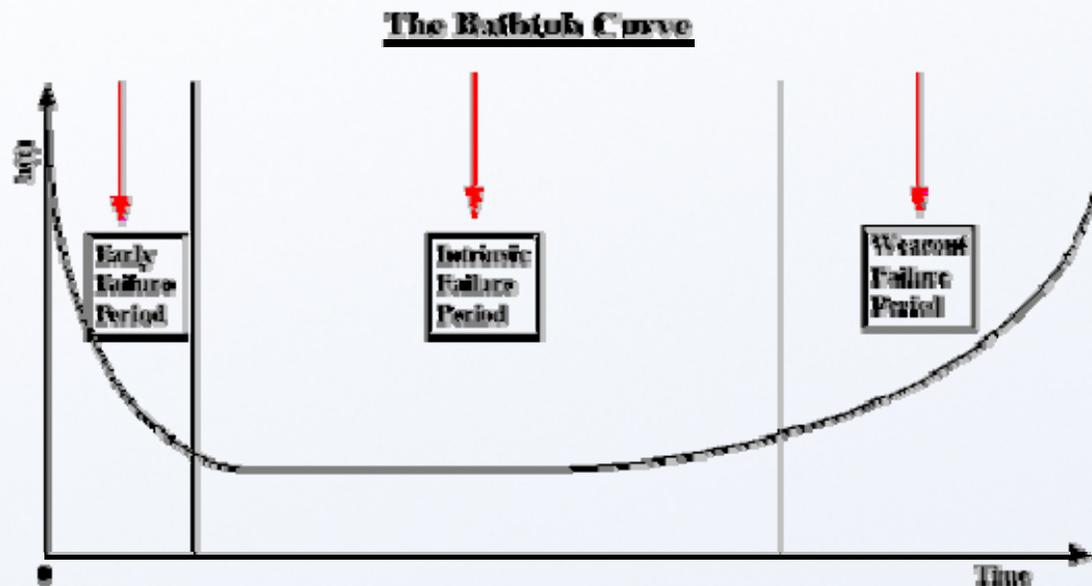
Tools of predictive maintenance are also used for quality control and to reduce infant mortality rate

- Quality Control
 - Mechanical assembly of gearbox and generator involve bearings (rolling elements) and gears.
 - Improper assembly of these elements introduce:
 - Misalignment
 - Resonance
 - Imbalance
 - Gear-tooth wear
 - Looseness

They all can be detected using accelerometers and vibration measurements.

Condition Based Monitoring (CBM)

- Infant mortality reduced by design and QC – reduced in prototype
- Late stage fatigue failure reduced by CBM – allows replacement prior to failure extending the component and machine life.

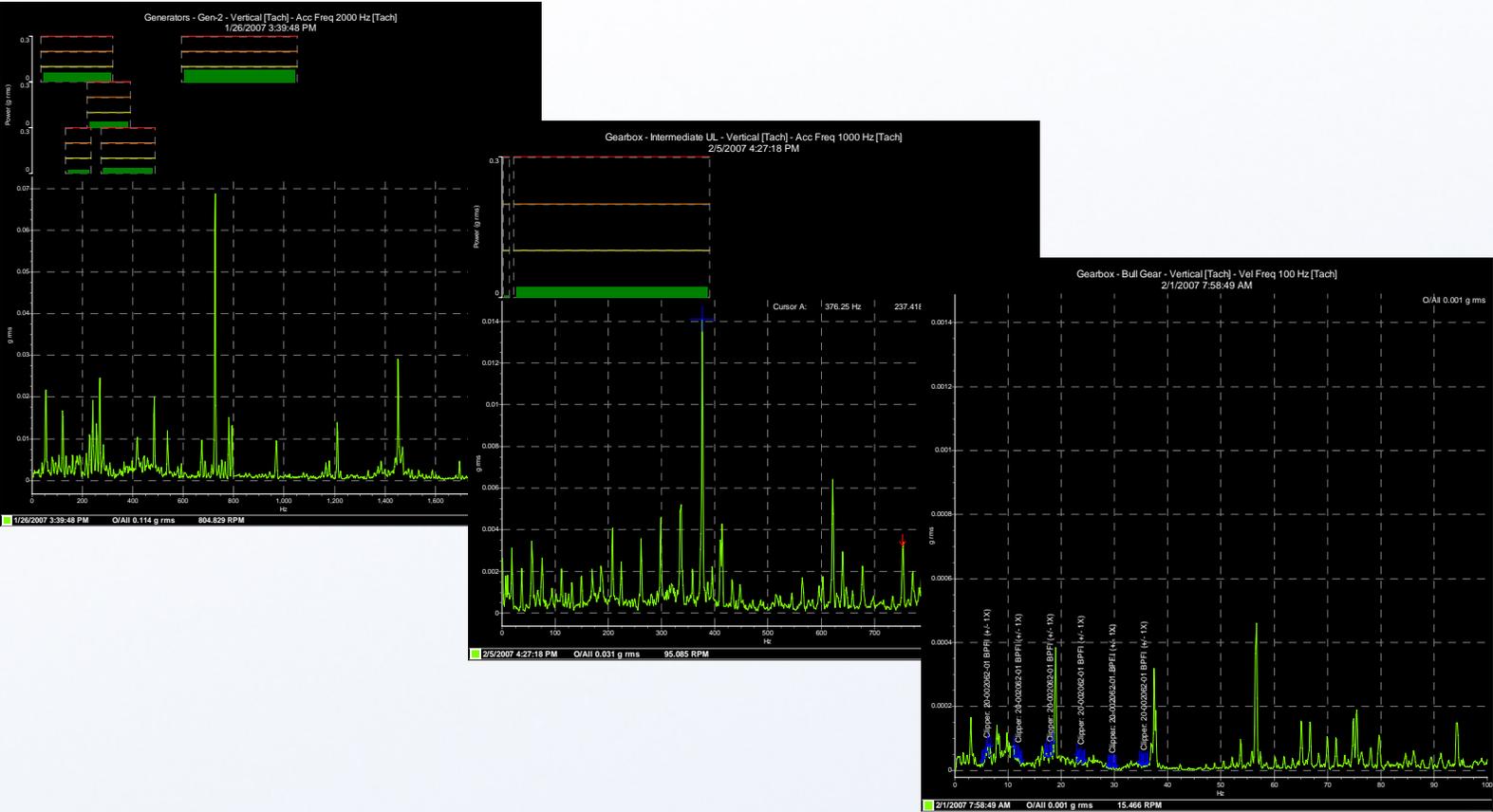


Infant Mortality Rate



- Transportation and installation of heavy equipments such as gearboxes, generators and blades are difficult and damage to these parts should be avoided.
- As part of commissioning, vibration measurements and comparison with some known baseline will clearly verify the proper installation of the equipment.
- Continuous measurements and monitoring of the gearbox and the generators during the first 1000 hours of operation will drastically reduce the infant mortality rate of the turbine.

Following are some scattered spectrums and plots depicting the operating condition of the turbine



Thank You

Shaw Makaremi, PhD, PE
Sr. Electrical Engineer
Clipper Windpower, Inc.

