GE Transportation

- Global Headquarters
- Commercial Operations
- Engineering
  - Analysis and Diagnostics Laboratories
  - Test Development Laboratories
- Manufacturing
  - AC Inverters
  - Heavy & Light Fabrications
  - Generators
  - Traction Motors
  - Locomotive Assemblies
  - OHV Wheels
  - Wind Gearboxes

GE Transportation
Erie, PA
Founded 1907
5,500 employees

GE’s Major Manufacturing Groups

- Wire & Motor Manufacturing
- Gear & Gearbox Manufacturing
- Rotating Lab
- Fabrication & Machining

GE’s Major Manufacturing Groups

- Energy Infrastructure
- Technology Infrastructure
- Capital
- NBC Universal

- Energy
- Oil & Gas
- Water
- Aviation
- Enterprise Solutions
- Healthcare
- Transportation
- Aviation
- Financial Services
- Commercial Finance
- Energy Financial Services
- GE Money
- Treasury
- Cable
- Film
- International
- Network
- Sports & Olympics

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Challenges of Large MMW Gearboxes in Wind Turbine Applications

*Albuquerque New Mexico*  
*June 18, 2009*  
*Tony Giammarise / Mike Sirak*

- GE Transportation  
- DriveTrain Description  
- Challenges Moving Forward  
  - Design  
  - Manufacturing  
  - Validation  
- Real Life Examples
Transportation
2008 Revenue of $5.2 B

Locomotives

Financial Solutions

Parts & Service

Propulsion & Specialty Services

Signaling & Comm

Traffic Mgmt Systems
P&SS ... a derivatives business

15,000 Engines Operational in 20 countries

**Mining / OHV**
Drive Systems for Mining Trucks
18,000 drives shipped

**Drivetrain Technologies**
Wind Turbine Gearboxes
• Also part of NREL GRC consortium

**Transit**
Propulsion for Transit Cars

**Drill**
DC/AC Motors for Drill Rigs

**Marine & Stationary**
Engines for Boats & Power Generators
7GA87 Gearbox
7GA87E – 1.5MW 1:78 ratio Compound Planetary

- 3 stage CP design with helical gearing
- Straddle mounted planet bearings
- Flexible, splined ring gear
- No reversed bending loads on planet teeth
- One high speed stage
- Over 1300 produced
- Oldest fleet at 36 months
Gearbox Design is based on a design process where requirements are flowed to Drive Systems from:

• Turbine manufacturers
• public standards
• insuring bodies
• Internally imposed guidelines

**Typical Design deliverables include**

• Geometrical/Dimensional envelope, details in aux equipment placement
• Power capabilities, input rpm’s output rpm’s
• Weight limit
• Environmental operational conditions
  • Temperature extremes
  • Wind class
  • Emergency stops/overload conditions
• Noise limits
• Reliability guarantees
• Certification from insuring body
Current GET Gearboxes

Differential Planetary + Parallel Shaft
2.0 – 2.7 MW @ 14.4 – 18 RPM
1400 – 1900 KNm Input Torque
60:1 – 97:1 Ratio Possibilities
Approximate Weight: 39,000 Lbs
Horizontal and vertical output shaft locations @ 550mm CD
2350 / 2150mm Overall Length

2 Simple Planetaries + Parallel Shaft
2.3 – 2.9 MW @ 14 – 16 RPM Input Speed
1500 – 1920 KNm Input Torque
78:1 – 136:1
Approximate Weight: 46,500 Lbs
Horizontal Output Shaft @ 550mm CD
2550mm Overall Length

Compound Planetary + Parallel Shaft
1.4 – 1.8 MW @ 16 – 20 RPM
700 – 970 KNm Input Torque
59:1 – 86:1 Ratio Possibilities
Approx Weight: 33,000 Lbs
Horizontal Output Shaft @ 550mm CD
Working on Vertical Output Shaft for 2009.
2200mm Overall Length
Common Gearbox Components
2 Simple Planetary + Parallel Shaft Arrangement

- **Input Housing** – Supports gearbox torque and blade loads.
- **Input Carrier** – Connects Gearbox to Blades.
- **Low Speed Annulus Gear** – Non-Rotating, fixed to Input Housing.
- **Low Speed Sun Gear** – Output of first speed increasing Stage. Inputs power to High Speed Planetary Stage.
- **Low Speed Planet Gears** – Typically 3, 4, or 5 gears. Meshes with Annulus and Sun Gear.
- **Input Carrier Bearings** – Supports blade loads.
- **High Speed Annulus Gear** – Non-Rotating, fixed to Input Housing.
- **High Speed Gear Bearings** – Supports Sun Gear & High Speed Gear loads.
- **Pitch Tube** – Conduit for electric or hydraulic supply to blade control system – rotates at rotor speed.
- **High Speed Pinion** – driven by high speed gear. Drives the generator.
- **High Speed Pinion Bearings** – supports gear and braking loads.
- **High Speed Sun Gear** – Output of second speed increasing Stage. Inputs power to High Speed Parallel Shaft Stage.
- **High Speed Carrier Bearings** – Supports Gear loads.
- **High Speed Planet Gears** – Typically 3.
- **Torque Arms** – Transfers torque and wind load to turbine structure.
- **High Speed Gear** – fixed to sun gear, drives high speed pinion.
- **High Speed Gear Bearings** – Supports Sun Gear & High Speed Gear loads.
- **ABQ June 18, 2009**
A Gearbox is part of a larger system

Known loads
Known Dynamic loads

Gear Box design Margins
- Bending fatigue
- Size/life bearings
- Lots of others

Known loads
Known Dynamic loads

Rotor/shaft
Coupled Mass

Gear Box

Generator
Coupled Mass

Energy is stored during speed changes
Parasitic Loads
Unknown Dynamic Responses
Extreme distributions

The overall stiffness of the system response during E-stops can generate oscillations and large additional loads
Constraints – Design Perspective

Design Complexity & challenges

- Dynamic Loads – Extreme coherent gust winds, Turbulent shear winds
- Low “Lamda” – Design challenge to maintain Lamda ratios >1
- High Torque Density
- Loads prediction & understanding
- Torque Arm Design – Currently used for a 1.5-2.0MW turbine Gearbox, but as the MW rating increases, this design becomes complex
- Adequate Cooling & heating – Challenge due to extreme environmental conditions
- Noise control – Huge factor due to noise regulations
- Vibrations
- Seal designs – Current Gearbox industry is challenged is oil leaks either on input side / output side
- Reliability – Design life 20 years
- Weight – Shipping and uptower

Various Terrains w/ unique challenges
Relative Sizes & Conversion of mils & microns: The scale of things

- Diameter of human hair, thickness of copy paper
  - ~ 0.1mm = 100 microns = 0.004 inch

1 mil = 0.001 inch = 25.4 microns

1 micron = 1 mm = 1e-6 meters = 0.001 mm

Film thickness on low speed wind bearings ~ 0.15 microns!
Growing wind turbine scale necessitates development of new drive train technology

3.6 MW HS Pinion Bearing
Roller Speed: 92 ft/s
Rotation 1,500 RPM

1.5 MW HS Pinion Bearing
Roller Speed: 65 ft/s
Rotation 1,500 RPM

Problem
- Conventional 3-stage gearbox-based drive trains are sub-optimal as wind turbine rated power grows from 1 MW to 5 MW
- Cause is increasing size of problematic HS Pinion Bearings which require decreasing oil viscosities
- Forces a dangerous compromise ... select low viscosity oil to support higher speed bearings OR higher viscosity oil to protect the low speed gear stages

Solution
- Develop generator technology that eliminates the need for the 3rd (high speed) stage of the gearbox

Impact of change from ISO VG 320 to ISO VG 460 oil on Low Speed Planetary gear film thickness


**Gear Design Process**

- **Identify Design Inputs**
  - Loads
  - Speed
  - Size, etc

- **Preliminary Gear Sizing**
  - Ratios
  - Face width
  - Diameter, etc

- **Optimize Gear Macro Geometry**
  - Utilize RMC program
  - Kissoft program

- **Bearing Selection**
  - Life
  - Stiffness
  - Size
  - Clearance

- **Shaft Design**
  - Diameter
  - Stiffness

- **Housing Design**
  - Preliminary sizing
  - Detailed design

- **Detailed FEA**
  - Housing deflection
  - Carrier deflection
  - Shaft deflections
  - Bearing deflections

- **3-D Mesh - Micro Geometry**
  - LVR/LDP
  - Gear stresses
  - Load Distribution

- **AGMA/DIN Ratings**
  - Predictor for Gear Life

- **Validation Testing**
  - Strain gaging
  - Load Distribution Profiles
  - HALT testing

- **Design Complete**

---

- **Process requires both advanced methods and several iterations to optimize**
- **Integrated with bearing design iterations and structural models**
- **Structural modeling, Bearing life calculations/sizing, lubrication system sizing, validating, testing each follow iteration to finalize**
Advanced analysis tools

Load Distribution Program (LDP)
- 3rd mesh analysis
- Root/contact stress
- Transmission error

Run Many Cases (RMC)
- Optimization
- DOE

Romax
- Analysis of housing influence on gear mesh
- Concept study
- Centralized analysis
  - Shaft deflection
  - Bearing reaction
  - Gear forces
Constraints – Manufacturing Perspective

• Size of Gearing

Size of gears used causes a challenge in manufacturing a quality gear, current industry supported by few suppliers in market

• Heat Treatment Process

Several heat treatment process available but process is generally difficult to monitor and maintain long term process capability

• Steel Quality

• Casting & Machining

• Cleanliness

Plays a major role in the overall reliability of the gear box from performance & life stand point

• Grinding

• Quality

Very critical to this business as cost of producing a non-quality part accumulates into a higher maintenance costs
Typical Carburized Gear Process

**Steel Supplier**
- Steel Run (Heat)
  - 240k lbs
- Ingots
  - 29" square
  - 30 ingots/run
- Billets
  - 14.5" round corner
  - 1 billet/ingot

**Forging Supplier (Q =13)**
- Rough Machining
  - 1 gear/forging
- Forgings
  - 1 forging/mult
- Mults
  - 6-8 mults/billet

**Gear Supplier**
- Heat Treat Carb/Quench
  - 2 gears/heat treat
- Hard turn/Grinding
  - 1 gear/grind
- Assembly into Gearbox
  - 1 gear/gearbox

**GE Transportation**
Clean Steel Technology a Definition

Steel making methods utilized for Clean Steel

• Bottom taping EAF
• Ladle refined
• Deoxidized
• Vacuum degassed
• Bottom poured ingot or con-cast
• Protected from re-oxidation during teeming/casting
• Careful limits on Hydrogen and Oxygen

All of the above need to be done to assure high quality steel

Steel cleanliness by various melting methods

<table>
<thead>
<tr>
<th>Steel cleaning by various melting methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro cleanliness</td>
</tr>
<tr>
<td>Comparison of micro cleanliness in different melting or remelting methods in acc. to DIN 50602 method K1.</td>
</tr>
</tbody>
</table>

Decreasing steel quality

Gear & Bearing quality

Increasing cost 2x

Single melted standard air

Double melting
Manufacturing sequence for typical precision Wind gears

Steel making/ ingot production
- Grades 18CrNiMo7-6, 43B17, 4820 and similar
- Clean steel technology required/ No naughty bits in the steel/ inspect it

Forging operations to rough shape ingot into forged blank
- heat it/ beat it / heat treat it and then inspect it

Gear making operations
- rough it, hob it ( First outline of the tooth form )
- prep it for carburizing
- pump carbon into the surface (Extensive diffusion based high temperature controlled cycles changing the near surface to a different alloy!)
- quench it to make it hard
- temper it to make is a little less hard but improve it’s toughness
- grind it to very accurate finish dimensions
- inspect it, measure it, making sure it meets print and is free from manufacturing defects
- protect it during storage/shipment
Typical Case Carburized tooth form and the scale of things

### Why Case harden gears
- Resist bending Fatigue loads
- Resist Surface contact Fatigue
- Add compressive residual stress to aid in the fatigue loading capabilities
- Core structure remains ductile
- Highest allowable design loads per all international standards
- Large capacity worldwide for this type of hardening process

### Case hardening Terms
- Surface Hardness
- Effective Case depth to HRC 50
- Pitch line Case depth
- Root hardness
- Core hardness

![A tooth form showing the surface hardening; scale is in mm](image-url)
Modern Gear Grinders required to meet the tolerance needs for wind gearing. High quality tolerances needed to reduce noise.
The requirements of Wind Gearing also require large capital investments.

Current grinding technology both measures, distributes stock and self corrects dimensions, before and during grinding.
Gear Tolerances and the scale of things

Typical AGMA Class 12 gearing found on a 40 inch diameter high speed gear

<table>
<thead>
<tr>
<th>INSPECTION</th>
<th>NOMINAL</th>
<th>MINIMUM</th>
<th>MAXIMUM</th>
<th>CTQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGMA 2000 - ABB QUALITY</td>
<td>0.12</td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>RADIAL RUNOUT TOLERANCE Vr-T</td>
<td>XX</td>
<td>0.0024</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>PITCH VARIATION Vpa</td>
<td>XX</td>
<td>0.0004</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>PROFILE TOLERANCE VphiT</td>
<td>XX</td>
<td>0.0006</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>TOOTH ALIGNMENT TOLERANCE VpsiT</td>
<td>XX</td>
<td>0.0007</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>TOOTH-TO-TOOTH COMPOSITE TOL VqT</td>
<td>XX</td>
<td>0.0005</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>TOTAL COMPOSITE TOL VcT</td>
<td>XX</td>
<td>0.0026</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>TOOTH FLANK SURFACE FINISH</td>
<td>XX</td>
<td>0.0051</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>ROOT SURFACE FINISH (BEFORE S.P.)</td>
<td>1.25 UIN</td>
<td>1.50 UIN</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>PIN DIAMETER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEASUREMENT OVER PINS (MEASURED IN CENTER OF FACE WIDTH WITH SPECIFIED PIN)</td>
<td>41.1433</td>
<td>41.1048</td>
<td>41.1817</td>
<td>Y</td>
</tr>
</tbody>
</table>

These magnitudes require

• temperature controlled grinding processes,
• temperature controlled measurement processes to produce accurate gears.

Accurate tooth form assures uniform loading
## Typical Gear Quality Checks

<table>
<thead>
<tr>
<th>Process</th>
<th>Spec</th>
<th>Check points</th>
<th>Check Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>9310H grade 2 per C50E76</td>
<td>Must from TIMKEN</td>
<td>Every Heat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cleanliness per ASTM A534</td>
<td>Every Heat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrogen content besides chemistry</td>
<td>Every Heat</td>
</tr>
<tr>
<td>Forging</td>
<td>From Canton Drop Forging</td>
<td>Reduction ratio</td>
<td></td>
</tr>
<tr>
<td>Normalize and temper</td>
<td>B50E215</td>
<td>Visual check green painting</td>
<td>Every piece</td>
</tr>
<tr>
<td>Rough Turning</td>
<td>Process sheet</td>
<td>Dimension check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Drilling / tapping</td>
<td>Process sheet</td>
<td>Dimension check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Forging soundness</td>
<td>AGMA 923 grade 2</td>
<td>UT</td>
<td>Every piece</td>
</tr>
<tr>
<td>Hobbing</td>
<td>Process sheet</td>
<td>M.O.P check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Tooth shaping</td>
<td>Process sheet</td>
<td>M.O.P check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Chamfer</td>
<td>Process sheet</td>
<td>Dimension check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Carb / Quench</td>
<td></td>
<td>Hardness, metallurgical test</td>
<td>Every heat lot</td>
</tr>
<tr>
<td>Shot peen</td>
<td>AMS-S-13165</td>
<td>Coverage/saturation</td>
<td>Every piece</td>
</tr>
<tr>
<td>Hard turning</td>
<td>Process sheet</td>
<td>Dimension check</td>
<td>Every piece</td>
</tr>
<tr>
<td>Enternal tooth grinding</td>
<td>Process sheet</td>
<td>Gear charts / M.O.P</td>
<td>Every piece</td>
</tr>
<tr>
<td>Internal spline grinding</td>
<td>Process sheet</td>
<td>Gear charts / M.O.P</td>
<td>Every piece</td>
</tr>
<tr>
<td>Dynamic balance</td>
<td>Process sheet</td>
<td></td>
<td>Every piece</td>
</tr>
<tr>
<td>MPI</td>
<td>AGMA 923</td>
<td></td>
<td>Every piece</td>
</tr>
<tr>
<td>Nital etch</td>
<td>AGMA 2007</td>
<td></td>
<td>Every piece</td>
</tr>
<tr>
<td>Final inspection</td>
<td>blue prints</td>
<td>Dimension check, visual check</td>
<td>Every piece</td>
</tr>
</tbody>
</table>
Issues in gear manufacture for wind gear systems

• Special problems of large forgings
• Distortion during heat treatment
• Distortion during quenching
• Achieving adequate case and or core properties in large parts
• Achieving the final gear tolerance accuracy required
• Damaging hard surfaces during final grind operations
• Capacity worldwide for large high tolerance gear manufacture
GearBox Assembly Requirements

• Process Capability
  – Supplier ... component characteristic data
  – Assembly ... validated measurement systems
  – Test ... temp, vibration, particulate count, wear

• Documentation & Systems
  – Manufacturing instructions
  – e-Traveler
  – Quality system audits
  – Test documentation

• Cleanliness
  – Pre and post-test gearbox oil flush to ISO 4406
  – Component cleaning
  – Lean supermarket
Constraints – Validation Perspective

- Comprehensive commercial testing
- Component testing
- Sub-system testing
- HALT - Every new production or significant change
- Field testing - ~ typically 6 months field test
- Cost – testing costs are expensive but critical
- Larger gearboxes = larger test stands
Component testing ... demonstrated high reliability at high confidence

Input Housing  Carrier  High Speed Gear Bearing

Two synchronous hydraulic jacks used to simulate 1137.6 kNm Force reacted by ring gear attached to stationary base plate Two synchronous hydraulic jacks used to simulate 1137.6 kNm Reaction at simulated planet pinions
Systems level testing

Cold Chamber

Lube System Flow Rate

Strain Gauge Testing
HALT “graduation” test

Simulates 20 yr life on gearing
- Loads increased to decrease total test time
- 3x and 2x overloads
- Run on dedicated engineering test stand

Monitoring
- Bearing and oil temperatures
- Oil pressures
- Stresses in critical components
- Power, torque, and speed
- Gear wear patterns
- Particle count

Capability
- 2.5 MW @ 1440 rpm continuous
Gear Mesh Pattern

- All gear contact patterns were good and passed typical acceptance criteria.
- Gear contact patterns & condition are best indicators of system validation.
- Validates deflection calculations in structures, shafts and bearings
- Validates adequate lube flow
Verification/Validation Strategy
1st Stage Gearing

<table>
<thead>
<tr>
<th>Primary tolerance/displacement variables</th>
<th>units</th>
<th>values</th>
<th>tolerance</th>
<th>Center Distance Shift</th>
<th>Axial Offset</th>
<th>Pressure Angle Error</th>
<th>Lead Misalignment</th>
<th>random error</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring Gear Axial Coning</td>
<td>mils</td>
<td>1.2</td>
<td>1.2</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00120</td>
<td>0</td>
<td>0.0012</td>
</tr>
<tr>
<td>Planet Bearing Bore Alignment Horz.</td>
<td>mils</td>
<td>0</td>
<td>0.75</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Carrier Bearing Bore Alignment Horz.</td>
<td>mils</td>
<td>0</td>
<td>0</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mounted Planet Bearing Clearance</td>
<td>mils</td>
<td>2.8</td>
<td>2.1</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00117</td>
<td>0</td>
<td>0.0028</td>
</tr>
<tr>
<td>Ring Gear Wrap Up</td>
<td>mils</td>
<td>-1.5</td>
<td>0.15</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>-0.00150</td>
<td>0</td>
<td>-0.0015</td>
</tr>
<tr>
<td>Carrier Deflection</td>
<td>mils</td>
<td>7.2</td>
<td>0.72</td>
<td>0.00246</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00207</td>
<td>0</td>
<td>0.0072</td>
</tr>
<tr>
<td>Bending of Planet (face)</td>
<td>mils</td>
<td>3</td>
<td>0.3</td>
<td>0.00103</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00300</td>
<td>0</td>
<td>0.003</td>
</tr>
<tr>
<td>Planet Shaft Twist</td>
<td>deg°</td>
<td>-16</td>
<td>1.6</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>-0.0014</td>
<td>0</td>
<td>0.018</td>
</tr>
<tr>
<td>Planet pinion lead correction</td>
<td>mils</td>
<td>-3</td>
<td>0.5</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00030</td>
<td>0</td>
<td>0.003</td>
</tr>
<tr>
<td>Ring gear lead correction</td>
<td>mils</td>
<td>0</td>
<td>0.5</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00030</td>
<td>0</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Excel sheet used to calculate mesh misalignment and required gear lead corrections (mean and range)

5 Strain gages mounted in the ring gear tooth root for 6 teeth (2 adjacent and equally spaced at 120 deg). This validates mesh load distribution along the mesh effective face width in addition to HALT test validation.
Constraints – Maintenance Perspective

- Filtration – Lube oil used needs regular filtration & maintenance
- Contamination of Oil w/metal particles
- Load Management
- Monitor noise
- Periodic oil sampling
- Shipping & Logistics – Weight & shape of the Gearboxes causing a challenge for shipping & logistics
- Condition based monitoring system – Proactively monitors, detects impending drive train issues, enabling increased availability & decreased maintenance costs
- Can only climb two or three towers per day!
IntegraDrive geared generator

3.5 MW IntegraDrive in the space of a 3-stage 2.3 MW gearbox

Turbine Efficiency Comparison

Generates 6% higher AEP versus conventional DFIG drive train

<table>
<thead>
<tr>
<th></th>
<th>Conventional Gbx &amp; Generator</th>
<th>IntegraDrive</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Bearings</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>No. of Gear Meshes</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Efficiency Range</td>
<td>96.5% - 97.0%</td>
<td>99.3%</td>
</tr>
<tr>
<td>System Efficiency</td>
<td>90%</td>
<td>93%</td>
</tr>
</tbody>
</table>
Design success means:

- Understand the requirements
- Know and measure loads
- Utilize knowledge in Public Standards
- Understand the operating environment
- Detail and define requirements and flow them from System, to sub-System, to each component
- Inspect Components using the right methods and technologies
- Manufacture carefully Utilizing the right advanced and traditional tools
- Test to failure

The outcome is, the ability to achieve the level of reliability desired

Thank you