Wind Turbine Gearbox Reliability

The Nature of the Problem

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Historical review

- 1993 began AGMA/AWEA 921 (1997)
- experience with WTG up to about 250 kW
- rotor diameters to 35 m,
- LSS speeds 50 to 60 rpm
- gearbox ratios from 25 to 40
- 750 kW turbines in early development stage
- Bearing failures and gear tooth failures due to breakage, macro-pitting and scuffing were serious problems in some turbines.

More History

- 1999, revised AGMA/ AWEA 921, which became ANSI/AGMA/AWEA 6006 (2004),
- operating experience WTG 50 m,
- speeds to 25 to 30 rpm
- gearbox ratios from 60 to 73.
- 2 MW turbines in early development stage
- Bearing failures continued to be serious problems in some units
- gear tooth failures due to the calculable failure modes had practically disappeared from the newer turbines.

Current Events

- extensive field experience with 1 to 2 MW
- rotor diameters to 80 m,
- speeds below 20 rpm
- gearbox ratios over 100.
- Turbines over 5 MW are in development
- Bearing failures are still a serious problem in some operating gearboxes.

Turbines < 500 kW

- thousands of WTG < 500 kW in operation in North America
- Most are more than 10 years old
- taught us that gearboxes are not forever,
- operator can still survive by repairing or replacing gearboxes as they fail in service.
- also learned that without clean oil no gearbox can survive

Turbines from 600 to 900 kW

- > 3000 this size operating in North America
- Rotor diameters from 40 to 50 meters
- Stall and pitch regulated
- All with pressure lube and filtration
- Most installed between 1998 and 2002, about 5 years old

More on 600 to 900 kW

- > 75% have hybrid planetary + helical gearbox
- All designs have undergone some redesign or retrofit
- Most are out of warranty
- Many are failing for the second time
  - Planet bearings – surface distress
  - Intermediate bearings – mounting failures
  - Accumulated debris damage

Gear design not the problem

- No fleet wide gear failure due to tooth breakage or pitting.

- Micropitting is still occurring, but is pretty much under control with better lubrication and better gear microgeometry.

Still seeing some gear failures

- Operating problems
  - Standstill damage
  - Debris damage and abrasive wear
- Manufacturing problems
  - Grinding temper
  - Non-metallic inclusions
  - Case crushing
  - Heat treatment and other quality mistakes

Bearings are a still a problem

- We still don’t understand why some wind turbine gearbox bearings fail and others survive

Defining “bearing failure”

- More than 15% of bearings in this location failed in the first five years – often much sooner.
- Random failures excluded:
  - Manufacturing defects in bearing or gearbox
  - Standstill damage
  - Lubricant starvation or overheating
  - Lubricant contamination

Hot spots for bearing failure

- High speed shaft bearings
  - Almost 100% of the 500 to 900 kW gearbox designs have had at least one retrofit/design change to the high speed bearing arrangement.
  - Some have had more than two.
- Planet bearings
  - More than half changed
- Intermediate shaft locating bearings
  - About half changed

Good bearing survival locations

- Planet carrier bearings
- Hollow shaft bearings
- Non-locating bearings

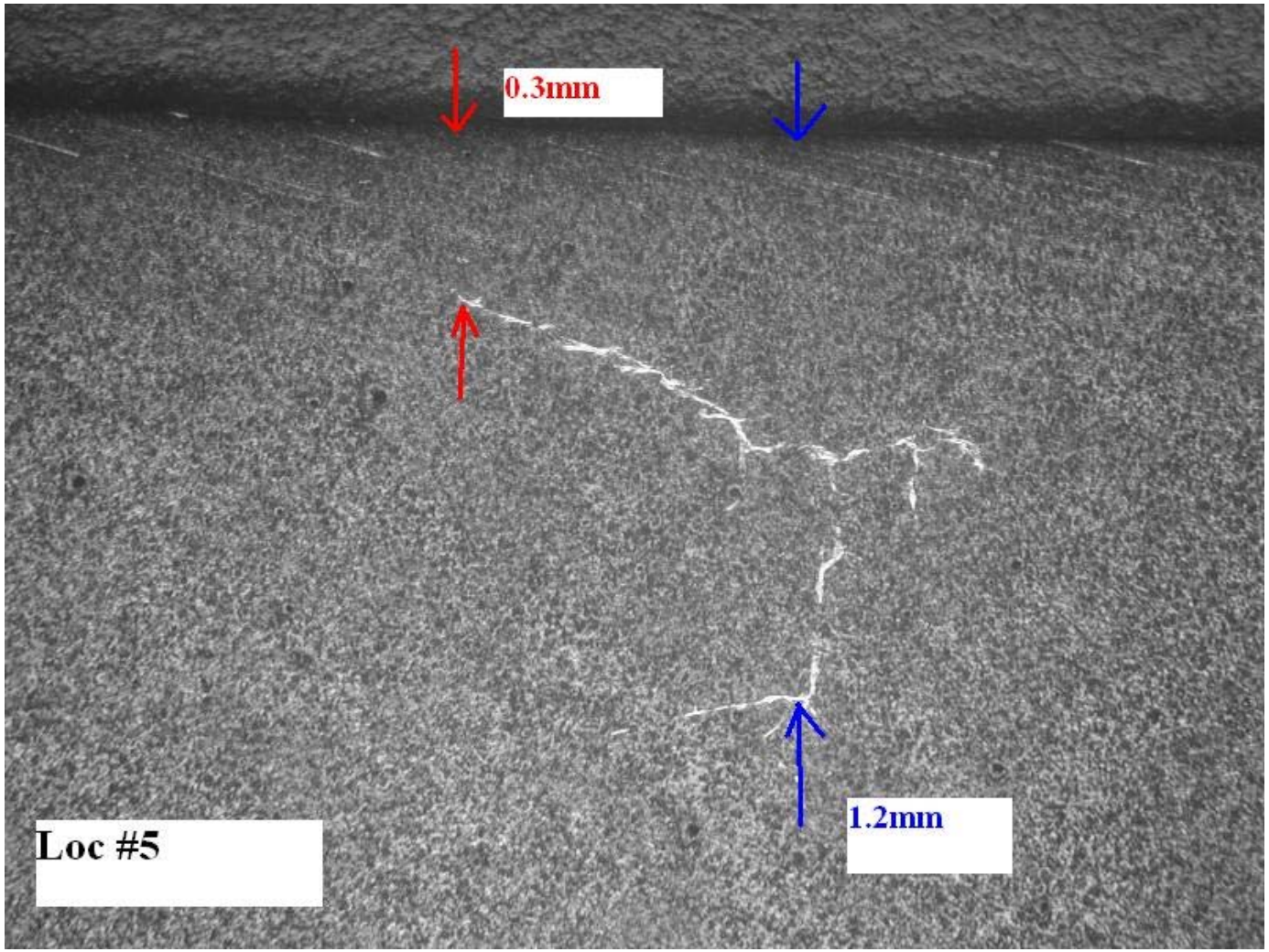
What is the difference?

- Some hypotheses to check
  - Lower stress?
  - Less cycles?
    - Doesn’t compute, since planet bearings are low speed
  - Cooler operation?
  - Mystery factors?
    - Locating bearings? Torque reversals?
    - Case deflection and misalignment?

Failure modes – early failures

- No manufacturing defects
- Signs of overstress
  - Deep white etching areas, “butterflies” below the expected depth of maximum stress
  - Changes in surface compressive stress due to heavy rolling contact
- Debris denting
- Surface distress and lubrication effects

Butterfly micrograph – wind turbine bearing



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What is happening now?

- Bearings are failing due to surface distress
  - Not a calculable failure mode
- Bearings are failing due to debris damage
  - Debris generated near the bearing is not filtered out of the oil
  - Housing bore wear up to 0.20 mm
  - Snap ring wear

Planet bearing after 40,000 hours

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