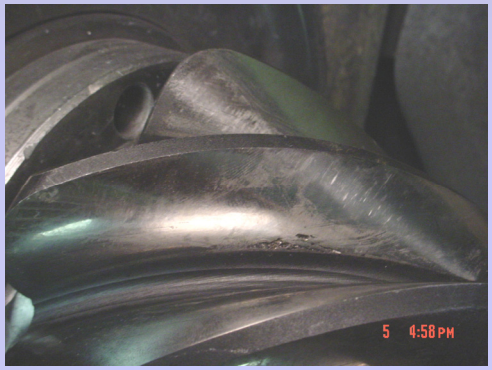
21D Ring & Pinion Life Investigation

- Metallurgical Analysis
- Geometry Investigation
  - Pattern Tester
  - Calculations - FEA
- Lab durability test
  - Determine performance of curved blade design
- Conclusion

Example of Pinion w/ Adhesive Wear Initiated Failure Mode

This series of pictures is indicative of the failure progression: 1) early adhesion 2)initial macropitting 3) advanced macropitting 4) early spalling 5) advanced spalling 6) final spalling

1.



2.

3.

4.

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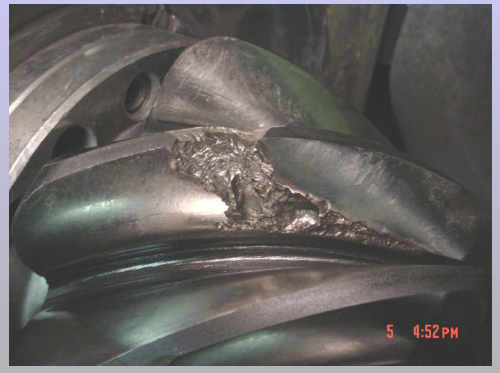


6.

Metallurgical Analysis

- Several pinions were analyzed (both field failures and new)
  - X-Ray Fast Stress, Microstructure (optical), Chemical composition (GDOES spectrograph)
- Early failure mode is adhesive wear which causes pitting, progressing into a spalling failure.
- Hardness, case depth, surface carbon, core hardness, and chemistry were within print specifications.
- Residual compressive stress profiles were not part of the current failure mode. However, flank peening will improve (increase) the residual compressive stress profile.

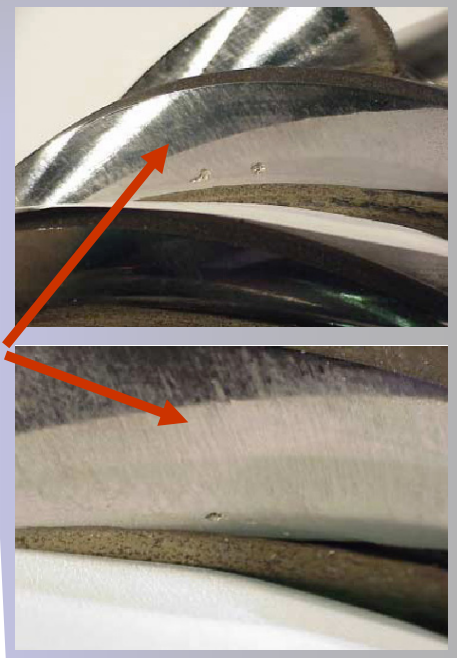
Pitting starting at SAP

Pitting turned into spalling failure

Adhesive Wear

Adhesive wear results from high attractive-forces of the atoms composing each of two contacting, sliding surfaces. Teeth contact at random asperities and a strong bond is formed. The junction area grows until a particle is transferred across the contact interface. In subsequent encounters, the transferred fragment fractures or fatigues away, forming a wear particle.

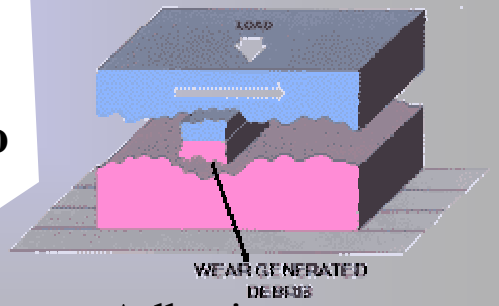
(Troubleshooting Gear Drives, The Falk Corporation)



Note vertical lines of wear / scuffing

Unlike surface fatigue that takes time to initiate, adhesive wear can occur immediately. Heavily loaded slow-moving components are the most prone to adhesive wear. Contact stress, surface finish, sliding velocity, surface hardness, lubricant viscosity and additives affect the onset of adhesive wear. Also known as scuffing and galling, adhesive wear may be the least controllable as compared to contact fatigue and abrasion. ... when loads are exceedingly high, there may be a need to deploy surface-active EP/AW additives or solid lubricants (borate, molybdenum disulfide, graphite, etc.).

(Machinery Lubrication Issue # 200209)



Adhesive wear

Geometry Investigation

- Acceptable development with regards to pattern position & length.

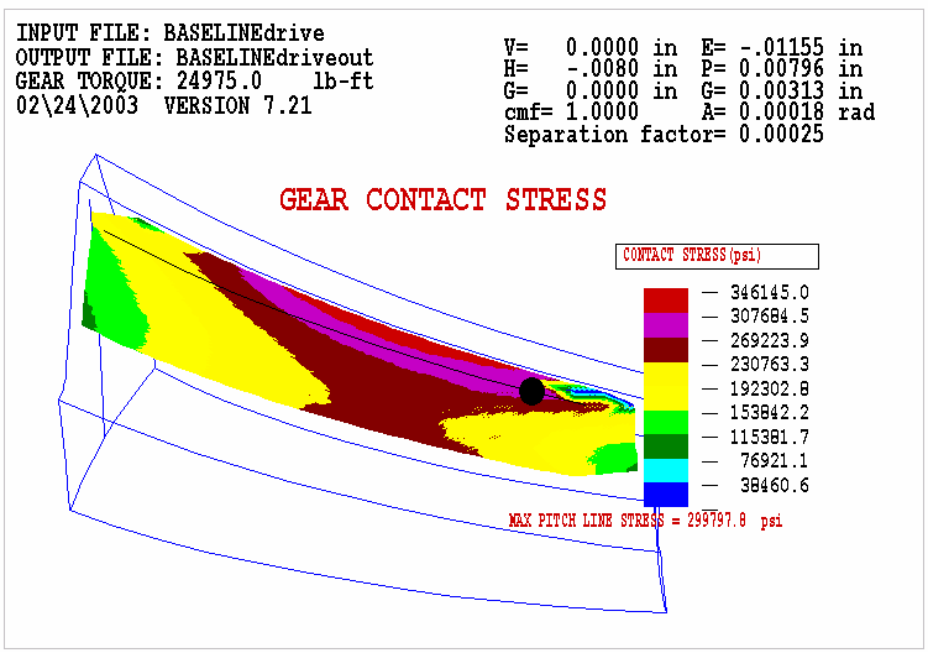
Gear Design / FEA

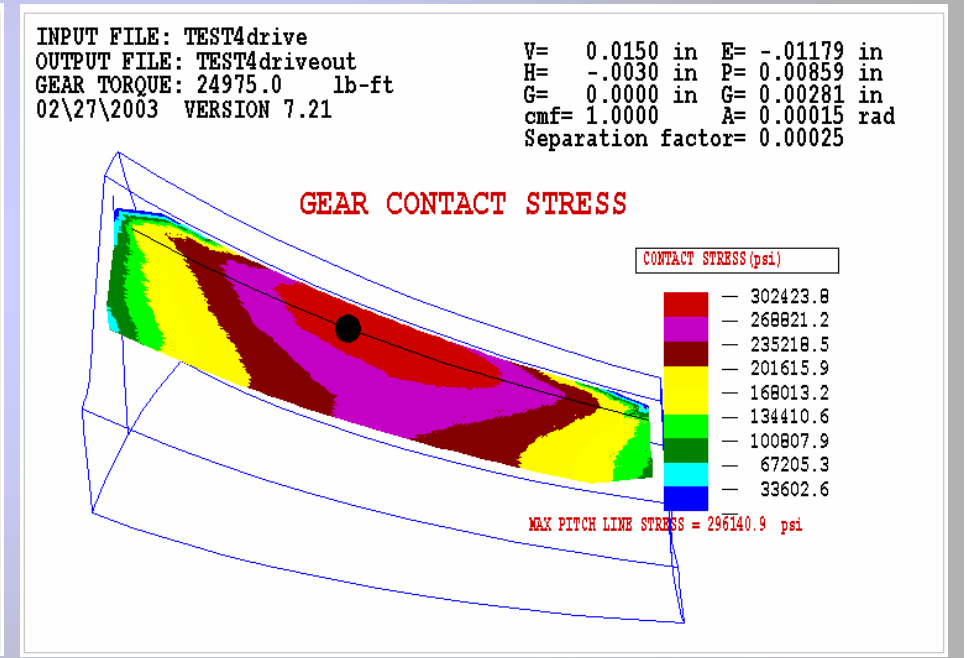
FEA model of straight blade gear design.

C_S = 346.1 ksi

FEA model of curved-blade gear design.

C_S = 302.4 ksi





Gear Design / FEA

21D R&P ***Summary of T900 FEA data:***

	T900 FEA S_C (psi)	Percent stress	Life factor
BASELINE (pre-Phoenix, 35° PA)	341,145	100%	1.00
TEST 2 (Stsvl curved-blade)	302,424	89%	4.01

Life calculations are for pitting initiated failure.

Dynamometer Testing

Curved blade design, 5.429:1 ratio

- First sample suspended at 232 hrs (B_{10} life = 71 hrs – accelerated test)
  - Indications of adhesive wear
- Second sample failed at 114 hrs (Exceeded minimum test criteria)
  - Failure mode is to be analyzed
- First sample will be put back on test & run until failure

Conclusion

- **Parts met metallurgical specifications.**
- **Failure mode appears to be from adhesive wear which could be caused by;**
  - **Contact stress,**
  - **Surface finish,**
  - **Sliding velocity,**
  - **Surface hardness,**
  - **Lubricant viscosity and additives**
- **Gear geometry and pattern was found to be acceptable.**
- **Curved blade design results in lower contact stress and up to 4 times pitting fatigue life increase.**
- **Dynamometer tests confirm the curved blade design.**
- **Lubrication is a major contributor to this failure mode.**