Development and Testing of a Very High Speed Oil Lubricated End Face Mechanical Seal

By

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Abstract

Six large radial inflow turbines were designed to expand isobutane for two electric power plants in Nevada which use heat from the earth (geothermal energy) as the energy source. Double end face mechanical seals lubricated by oil were selected to stop the isobutane from leaking out of the closed loop system and into the atmosphere. Two of the largest providers of mechanical seals in the world provided reference lists showing that this application was pushing the tip speed limits for existing liquid end face mechanical seals. A vendor was selected and the seals were purchased.

The first run of the seals on the test stand seemed successful, until the disassembly of the unit revealed the faces were severely overheated and heat checked. The face design was changed and the second test was successful. A major concern was to maintain a low seal leakage rate, so this was measured and was within the specified range. However, the

third test resulted in a catastrophic failure of the rotating faces and collateral damage to the entire seal cartridge.

Detailed investigation of the failure revealed several interesting problem areas. All of these were addressed in a new design which was implemented, built, and shipped in only one week! The fourth test was successful, but still showed a problem in which the very high velocity oil in the seal chamber was able to dislodge the stationary face retaining ring. A solution to this final problem was implemented and tested successfully.

At the time of this abstract, the seals appear to be successful. Both plants (all six machines) have been placed on line successfully. Two seals experienced damage in the field due to problems with the lube oil filter housings. These problems will be discussed during the presentation.

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16 MWe Expander-Generator

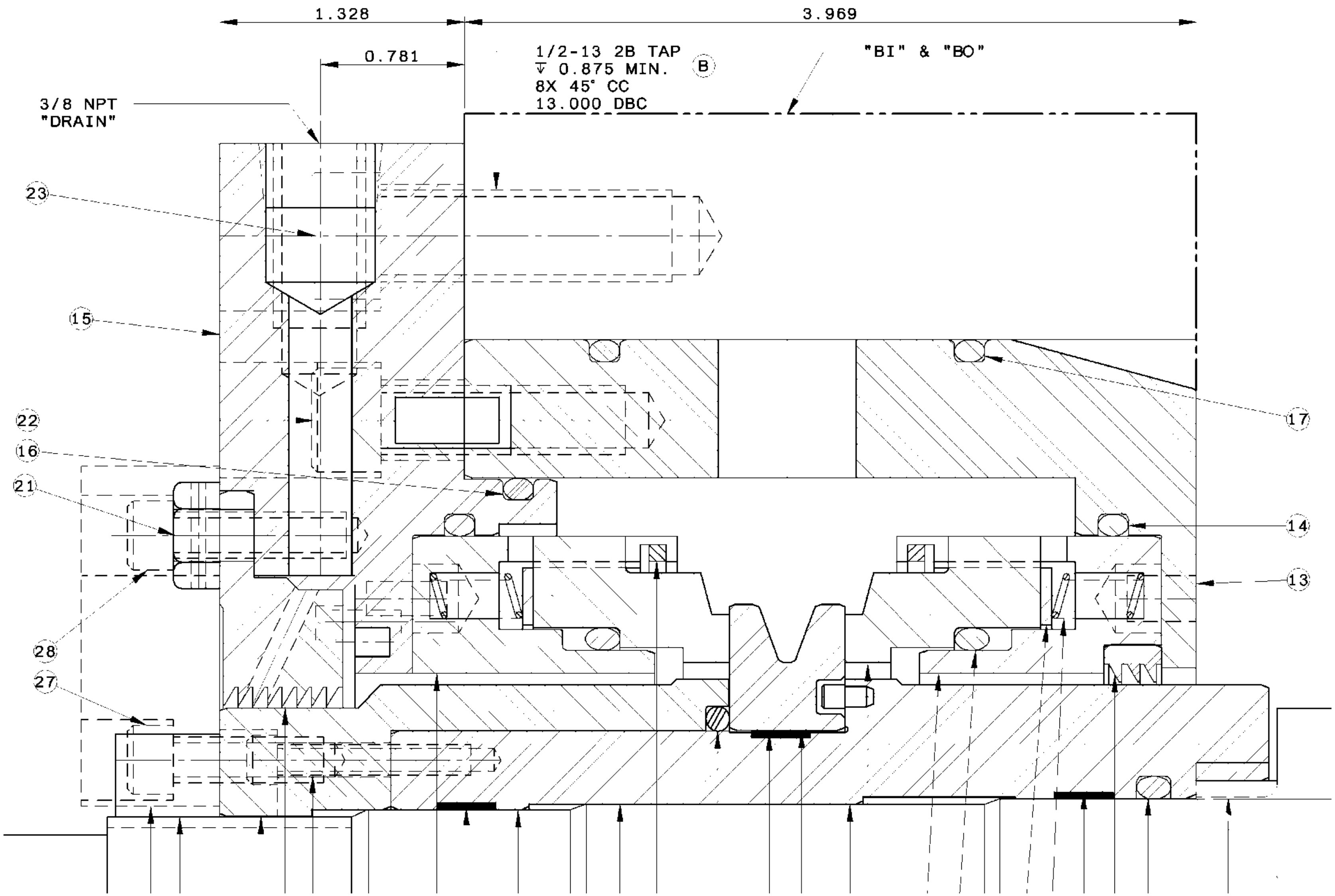
Very High Speed Wet Seal Application

- Two large geothermal plants in Nevada.
- Total of six expander generators.
- Each EC can produce about 16 MWe.
- Expander speed is 6,489 RPM.
- Generator speed is 3600 RPM.
- Synchronous generators, not induction generators, so speed is always the same.
- Seal tip speed tested at 280 ft/sec (85 m/s)!
- Design tip speed is 255 ft/sec (78 m/s).

Seal Conditions

- Process fluid is pure Isobutane.
- Barrier fluid is VG-46 lubricating oil.
- Double seal design with shared rotating face (one stationary face on each side).
- Inlet gas to expanders is in the range of 250 to 400 psia and 250 to 300 degrees F. (17-27 bar, 120-150 C).
- Outlet from the expanders in the range of 50 to 150 psia (3-10 bar).
- Ambient temperature, plant design, and geothermal resource determine process pressures and temperatures.

Double Seal Layout



The Geothermal Process

- Hot fluid is brought up from the geothermal resource via wells drilled into the resource.
- This fluid is used to vaporize Isobutane.
- The Isobutane is expanded in the turbine to produce electrical power.
- The Isobutane is then condensed, pumped back up in pressure, and re-vaporized.

First Seal Design

- The seal vendors had almost no experience at these tip speeds.
- Initial seal had “standard” seal faces (plain) and “standard” balance ratio.
- Initial testing looked good: Low leakage during test.
- Disassembly showed that seal faces had rubbed hard, and heat checking occurred.

Smiles Before Disassembly

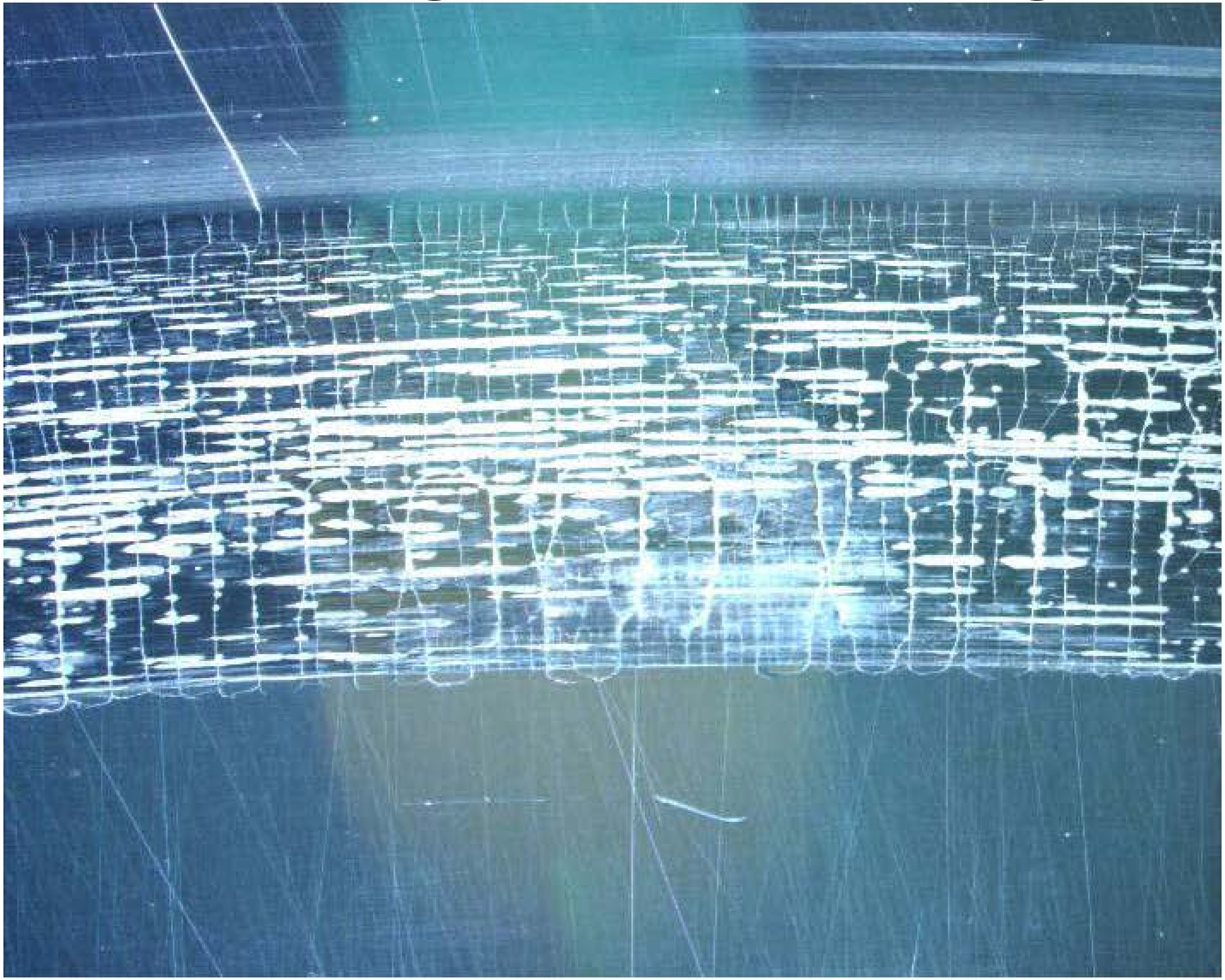
Disassembly

Wheel Removal

Seal Cartridge Removal

Seal Cartridge

Rotating Face Damage



Stationary Face Damage

Second Seal Design

- Reduced face loading.
- Added patented face pattern to stationary faces.
- Testing again went well.
- Disassembly showed no problems.
- First machine shipped to field with this seal.

Test of “Second” Seal Design in Second Machine

- Machine was run to “Trip Speed” at beginning of test.
- After 15 minutes at Trip Speed, machine speed was reduced to MCS.
- After a brief run at MCS speed, the seal self-destructed.
- Disassembly showed major damage to all seal parts and cartridge assembly.

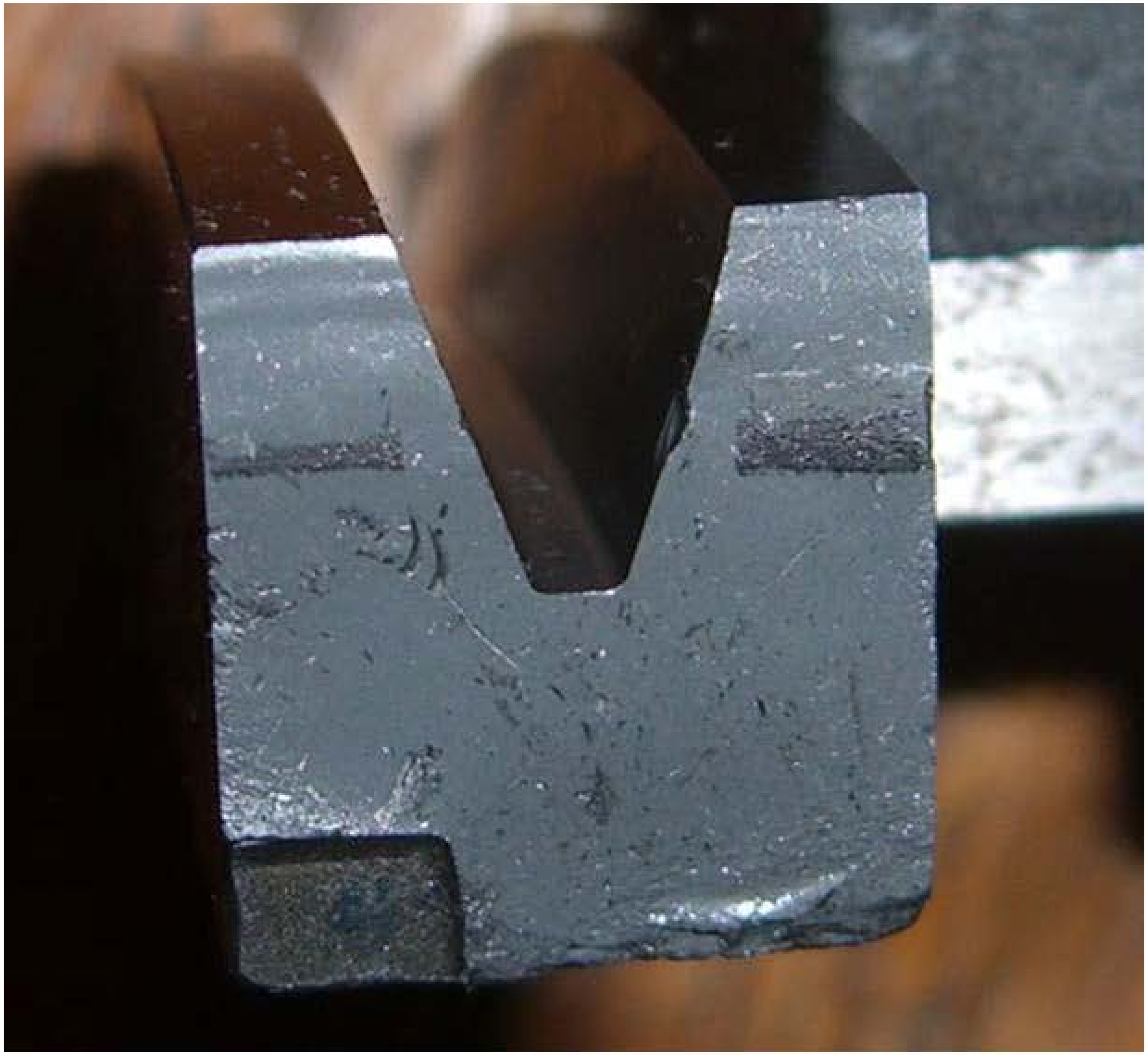
Seal Damage

Stationary Face Damage

Rotating Face Damage

Crack Initiation Site

Closeup of Initiation Site



Results of Investigation

- Failure caused by hoop stress overload.
- Hoop stress overload caused by thermal growth of sleeve into bore of rotating ring.
- Failure mode very much like overspeed (also from high hoop stress).
- Subsequent overspeed of identical rotating ring showed very similar surface.

Overspeed Failure of Identical Ring

Initiation Site

Other Side

Third Seal Design

- Stronger material for rotating ring.
- Axial pin drive for lower stress concentration factor.
- Drive slot drilled before sintering (no EDM).
- New, lower thermal growth sleeves with more clearance when operating.
- 10,000 rpm overspeed testing on rings (154% of design speed).

Results

- Seal worked well on test stand.
- Disassembly looked good (no face damage).
- Second machine was shipped with this design, and previously shipped machine with bad seal design was returned to factory for seal replacement and re-test.
- Five of the six machines were shipped and commissioned with this design.

Sixth Machine Had Problems

- On test stand, the sixth machine repeatedly had small streaks of contact on the process side seal (never on GB end).
- Investigation indicated that axial forces due to seal centering could be a contributing factor.
- Pinion shaft movement in field would be greater than on test stand due to thrust reversal, possibly making this type of damage more likely in the field.

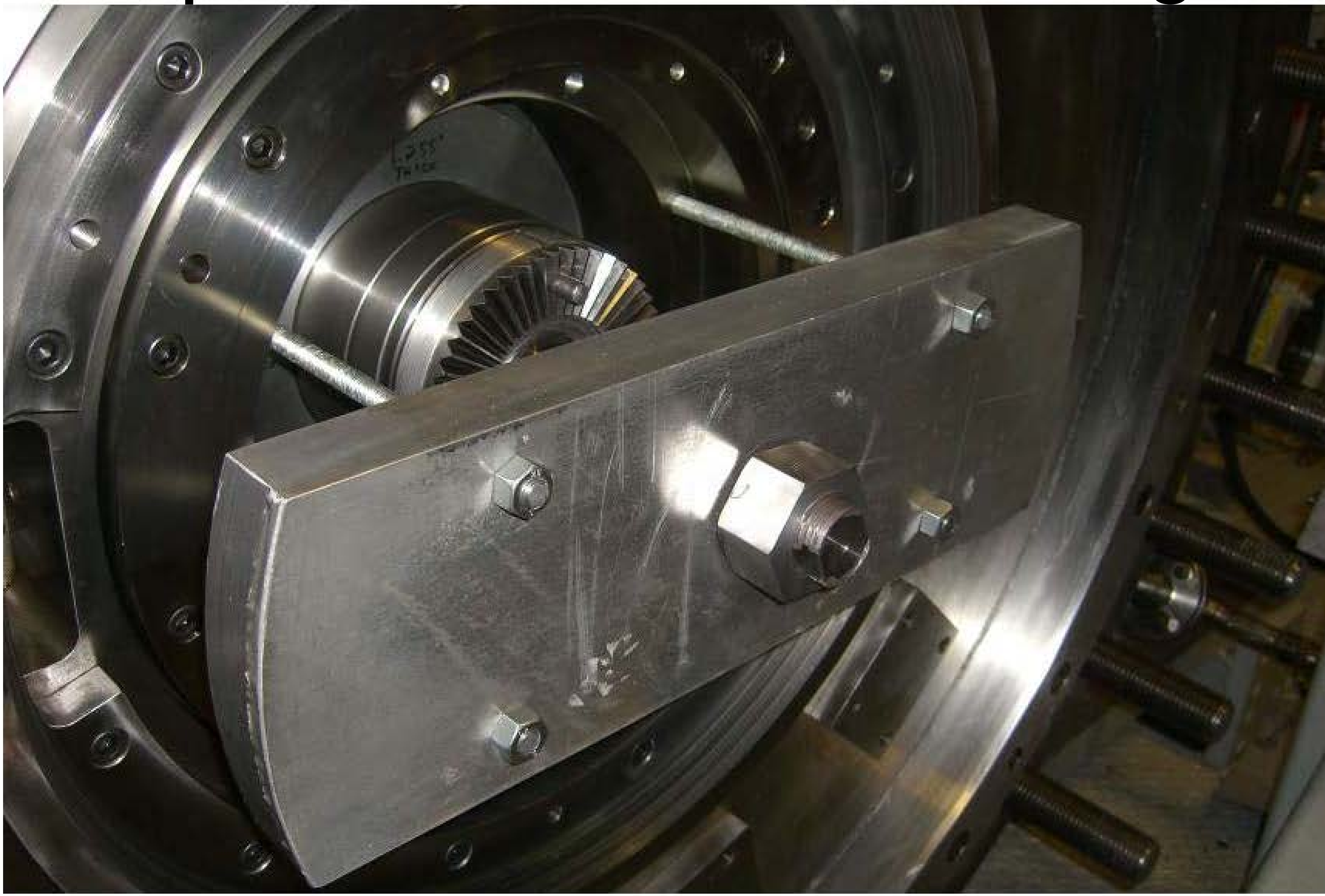
Seal Face Damage

Close-up Of Damage

Fourth Design

- Every third spring removed to lower both spring force and spring rate.
- Lower spring rate allowed less change in force as axial position changed.
- Special tooling designed to locate seal in proper position for operation in the field.
- Sixth (last) machine shipped and commissioned with every third spring removed.

Special Installation Tooling



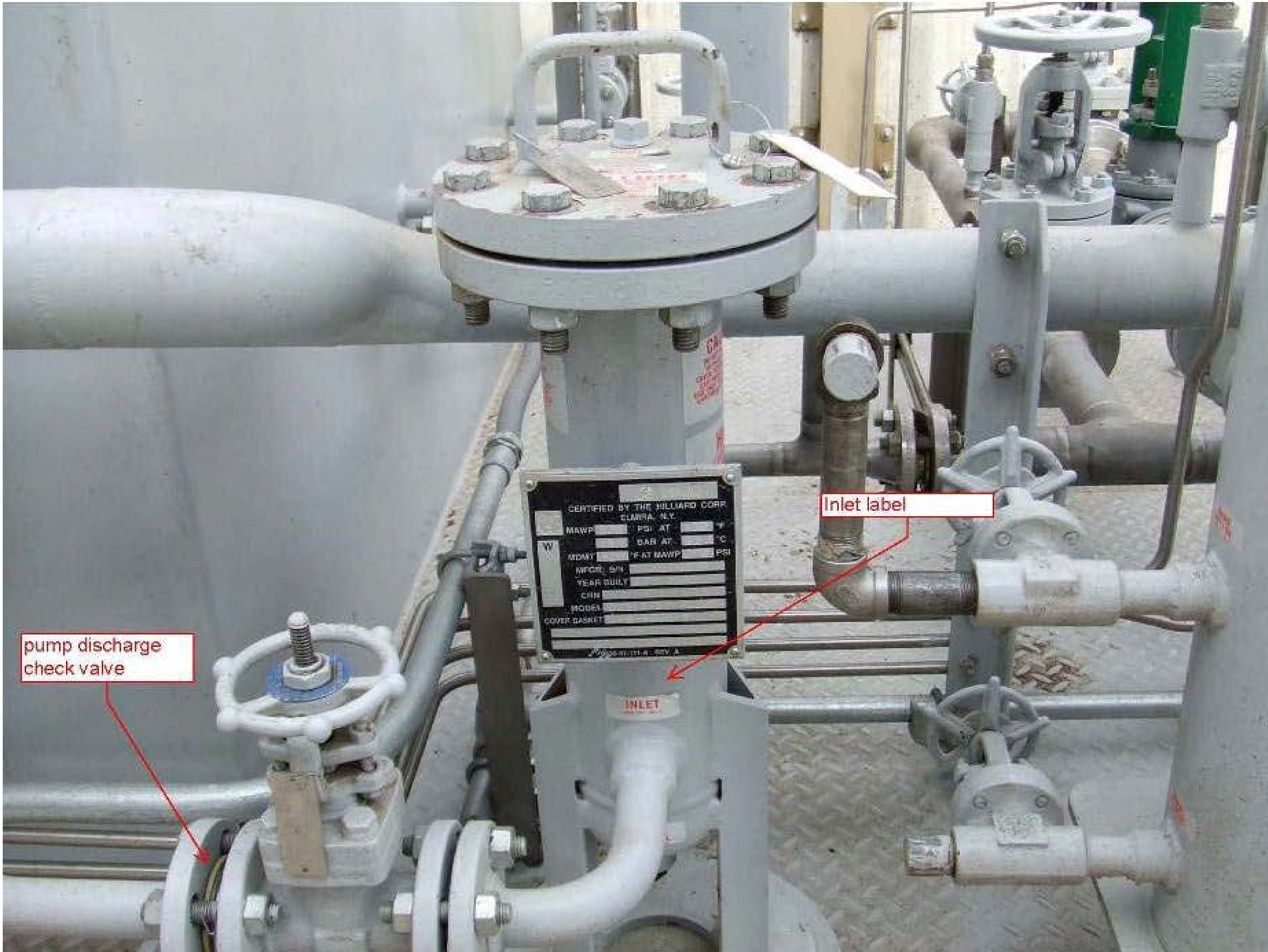
Logic For Shipping ONE Machine With Fewer Springs

(Three Outcomes Possible)

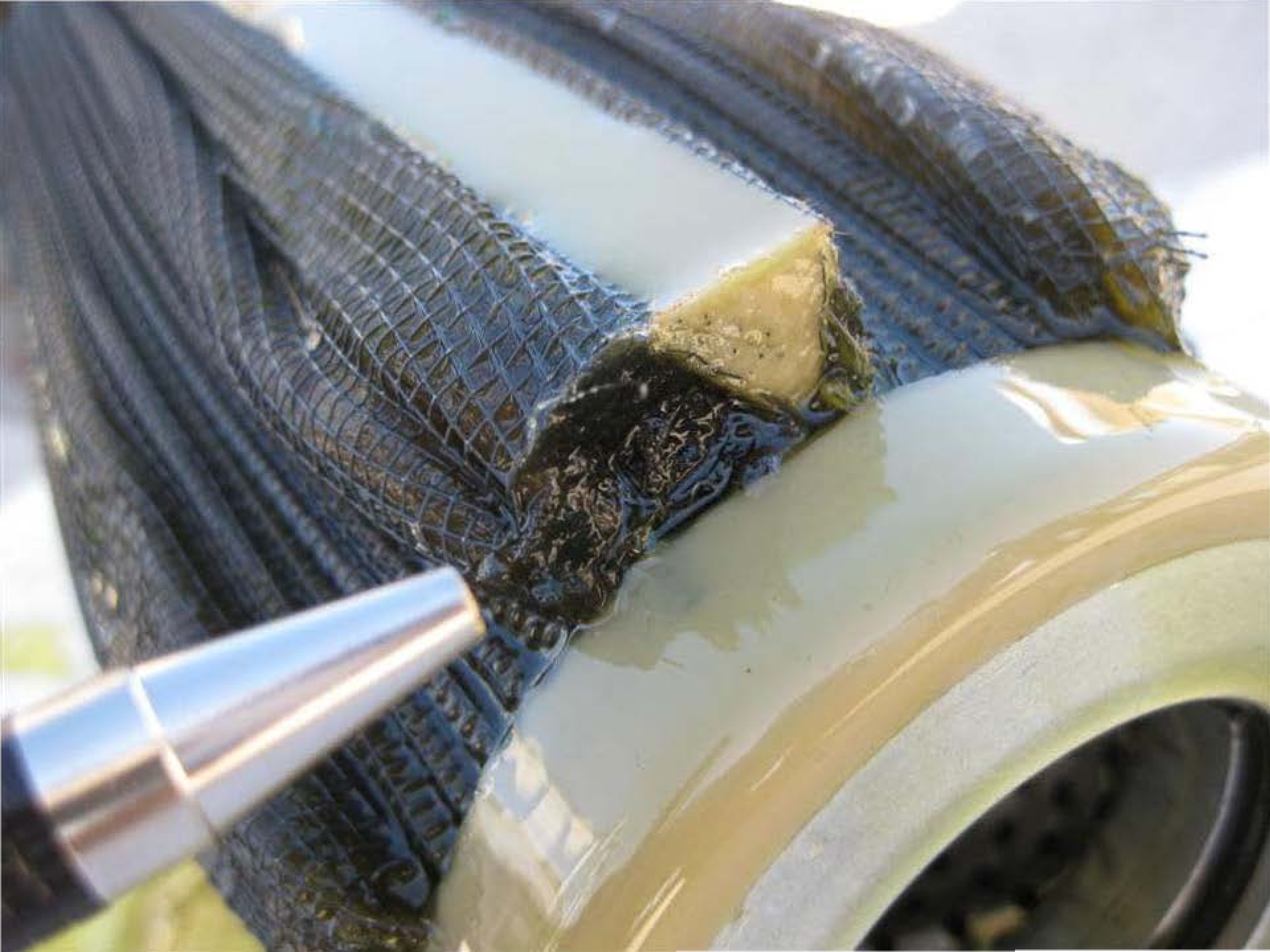
- **BOTH** designs were factory tested and should work in field (full complement of springs AND 2/3 of springs). Pick “best” after field overhauls.
- If **ONE** design had problems in the field, we will already have a “solution” installed and running in the field. This should save time.
- If **NEITHER** one worked in field, then it wouldn’t matter which one we would have chosen.
- Therefore there was no benefit to going with a single design for all six machines at that point.

Field Results

- All six machines have been commissioned in the field (Q1 of 2009).
- All six seals seem to be working properly.
- Two of the seals have been replaced due to damage caused by bad filter housings.
- The oil leakage rates cannot be measured precisely, but they appear to be better than guaranteed.



pump discharge check valve
Inlet label
CERTIFIED BY THE HILLIARD CORP.
ELMIRA, N.Y.
MAWP
PSI AT
BAR AT
MDMT
°F AT MAWP
PSI
MFGR. S/N
YEAR BUILT
CRN
MODEL
COVER GASKET
INLET



Current Status

- All six machines continue to run well.
- All six filter housings were found to be marked (and thus installed) backwards!
- Four of the six machines continue to work with seals that experienced filter failures, but did not cause high seal leakage.
- Two seals that began leaking after filter failure were replaced and running fine.

Questions?