39th Turbomachinery Symposium

PREVENTION OF SHAFT END DAMAGE DUE TO HIGH CONTACT PRESSURE

Raymond Vollmer
Goodrich Corporation

Satoru Yoshida
Mitsubishi Heavy Industries, Compressor Corporation

Monica Crowe
Goodrich Corporation

Hiroki Terado
Mitsubishi Heavy Industries, Compressor Corporation

Introduction

- Shaft end damage observed at small end of taper, occurred during hub removal
- Hub installation and removal procedure was reviewed, did not raise concerns
- Finite element analysis used to diagnose the conditions leading to the damage
- Hub modifications proposed to relieve conditions causing damage
- Mock up test performed to verify that modifications prevented damage
- Additional analysis, modification, and testing iteration performed with reconditioned shaft geometry

Abrasion in 8 inch Shaft/Hub Edge

Photo of Abrasion in 8 inch Shaft/Hub Edge

The hub had been successfully installed and removed three times, but after the fourth installation, the hub could not be removed from the shaft and had to be cut off.

Finite Element Analysis

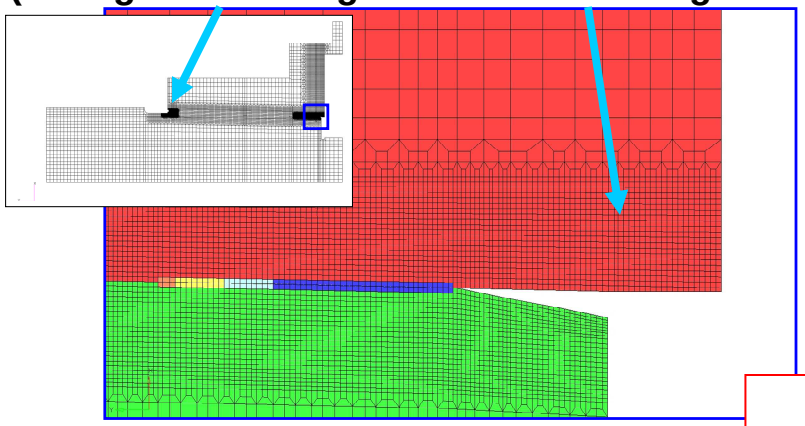
- FEA models created to simulate interference fit between the hub and shaft
  - Both the hub and shaft were modeled
  - Damage occurred during hub removal, therefore static analysis performed
  - Contact pressure between hub and shaft was primary concern
  - After design modifications, stresses in added features also examined to prevent material deformation during installation

Influence of Hub Overhung Mass

A comparison of two models was made, focusing on contact pressure at the bore.

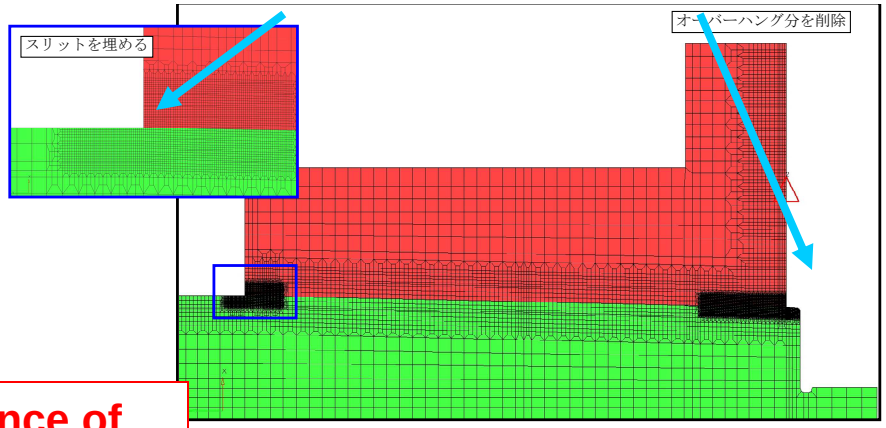
Current Configuration

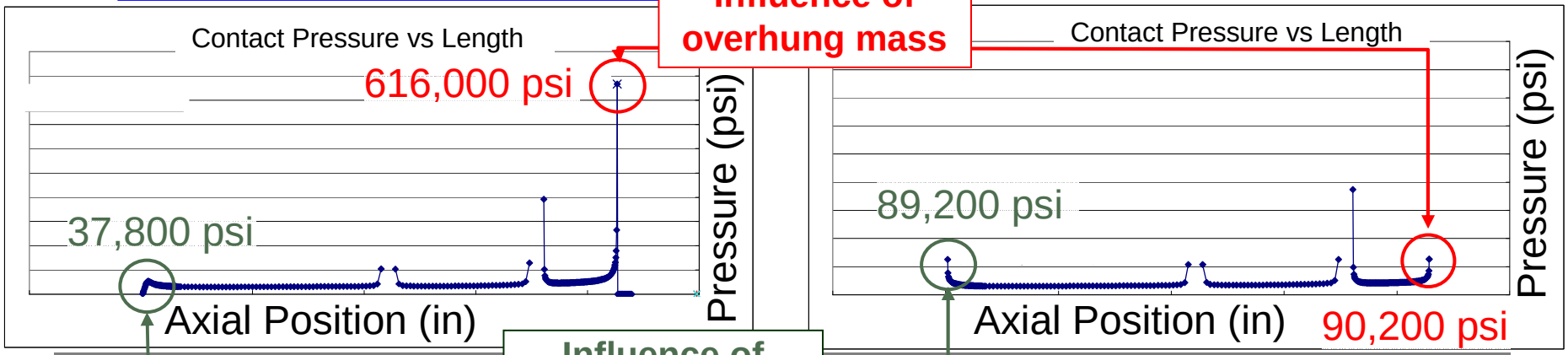
(With groove at large end and overhung mass)



Study Model

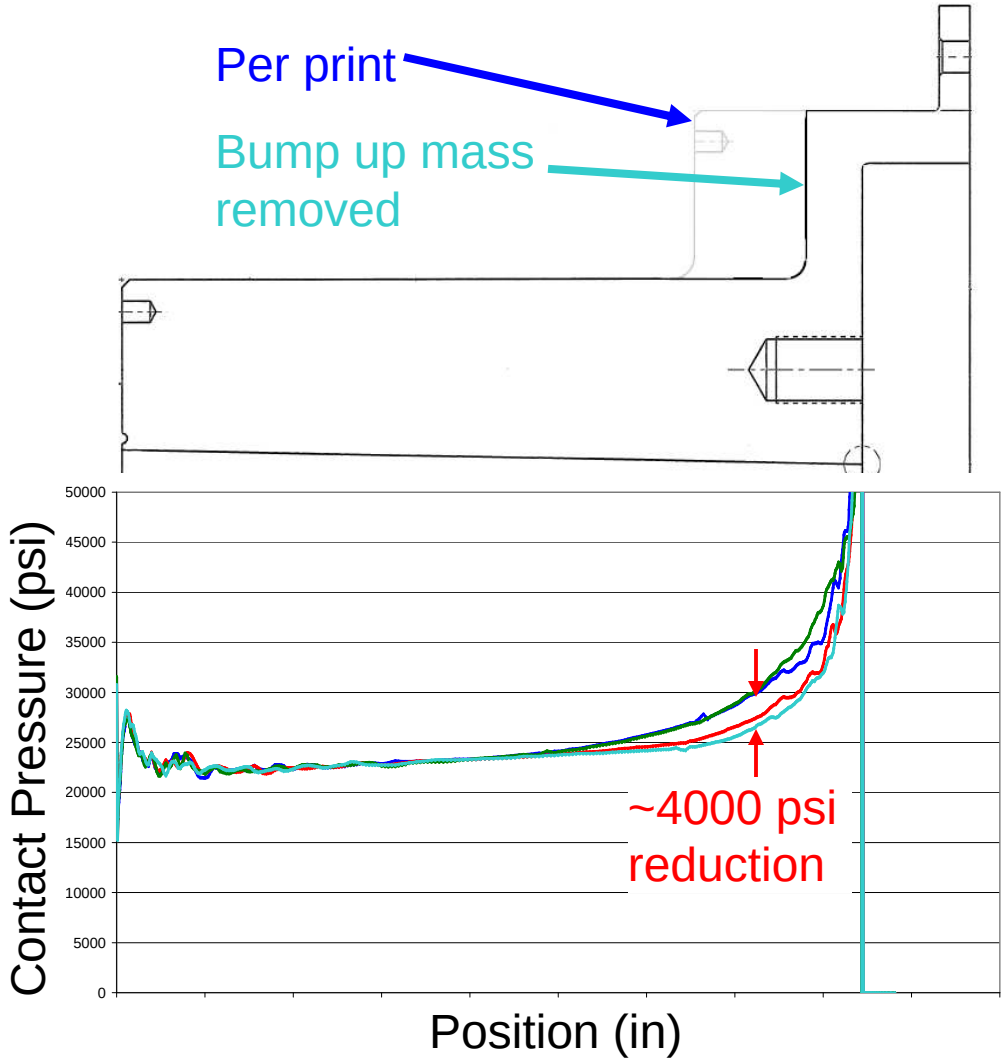
(No groove at large end and no overhung mass)





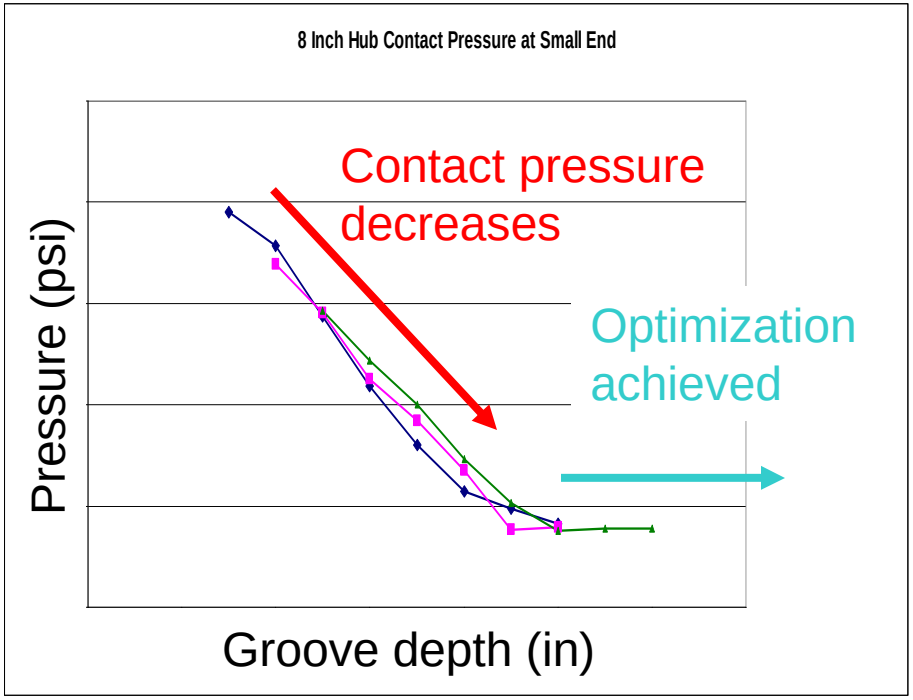
Influence of "Bump Up" Section

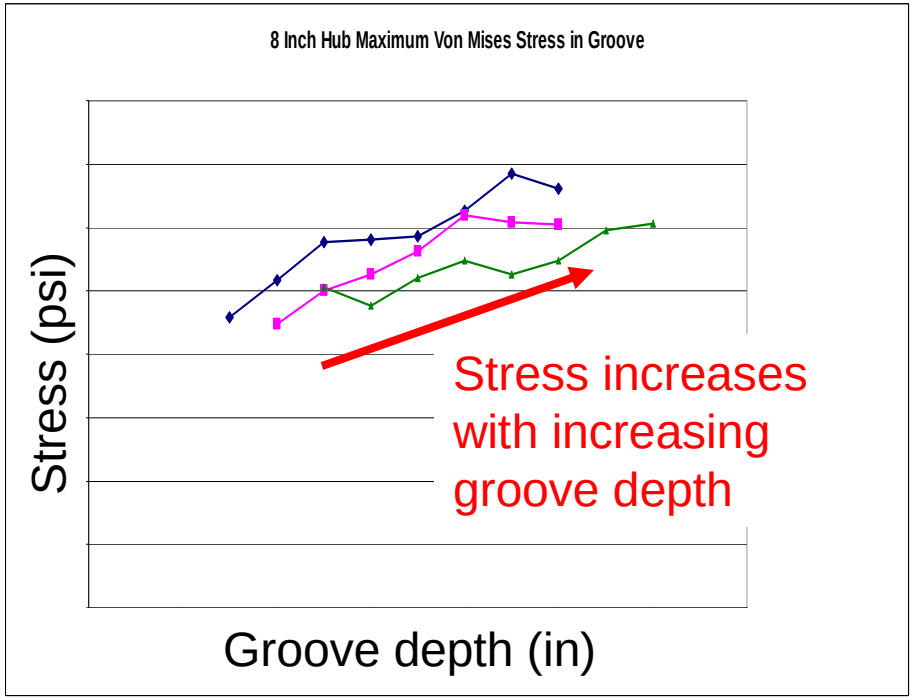
- Second investigation evaluated effect of material mass on contact pressure
- Contact pressure reduced ~4000 psi in area of shaft damage



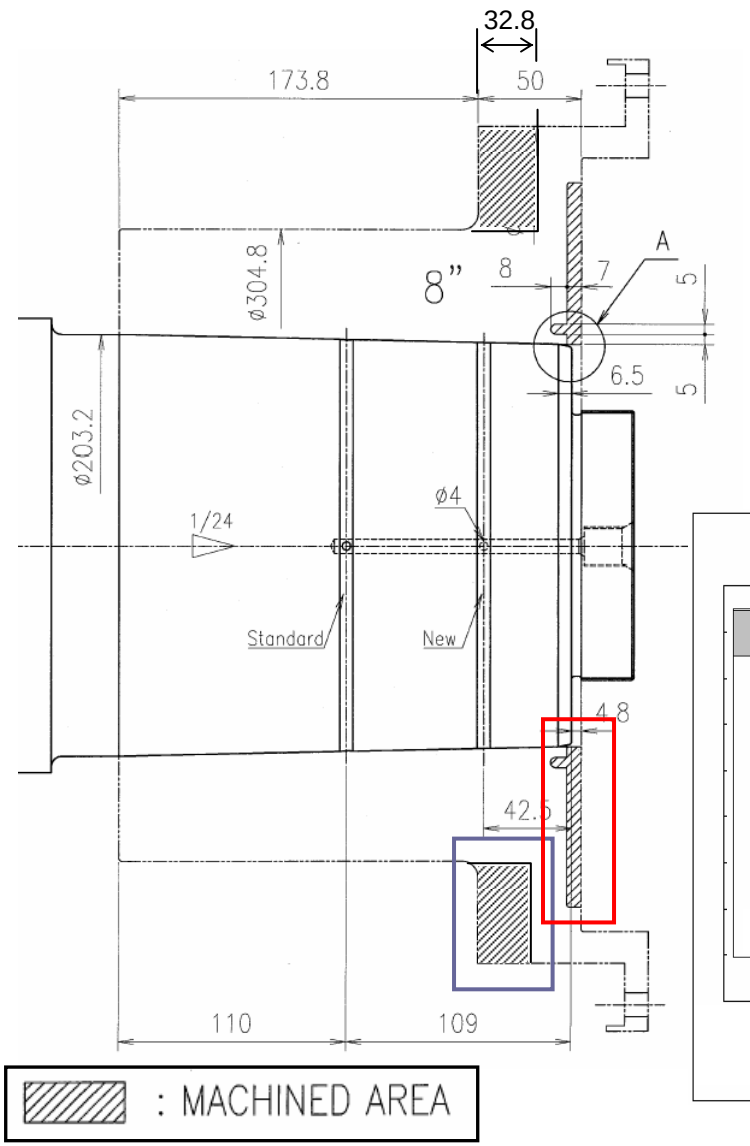
Groove Dimension Study

- Effects of various groove geometries investigated using finite element analysis
  - Groove depth increased to reduce pressure, until a minimum pressure was reached where increasing the groove depth had no effect
  - Groove depth optimized for stress consideration and manufacturability





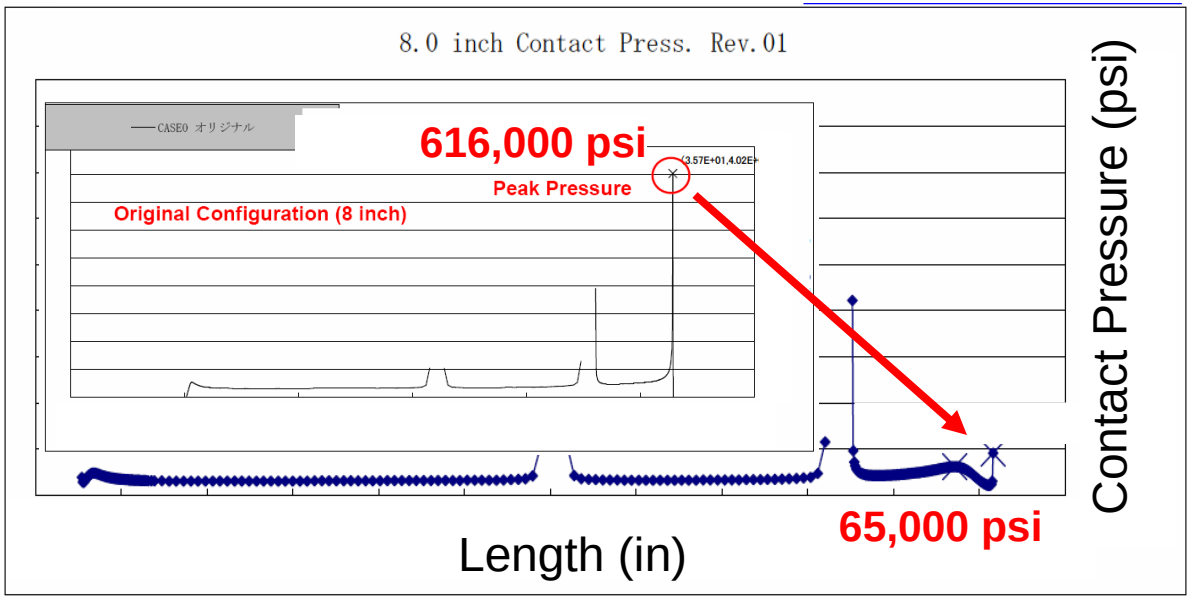
Hub Modification Plan



Solution: Reduce the shaft edge contact pressure (Area "A")

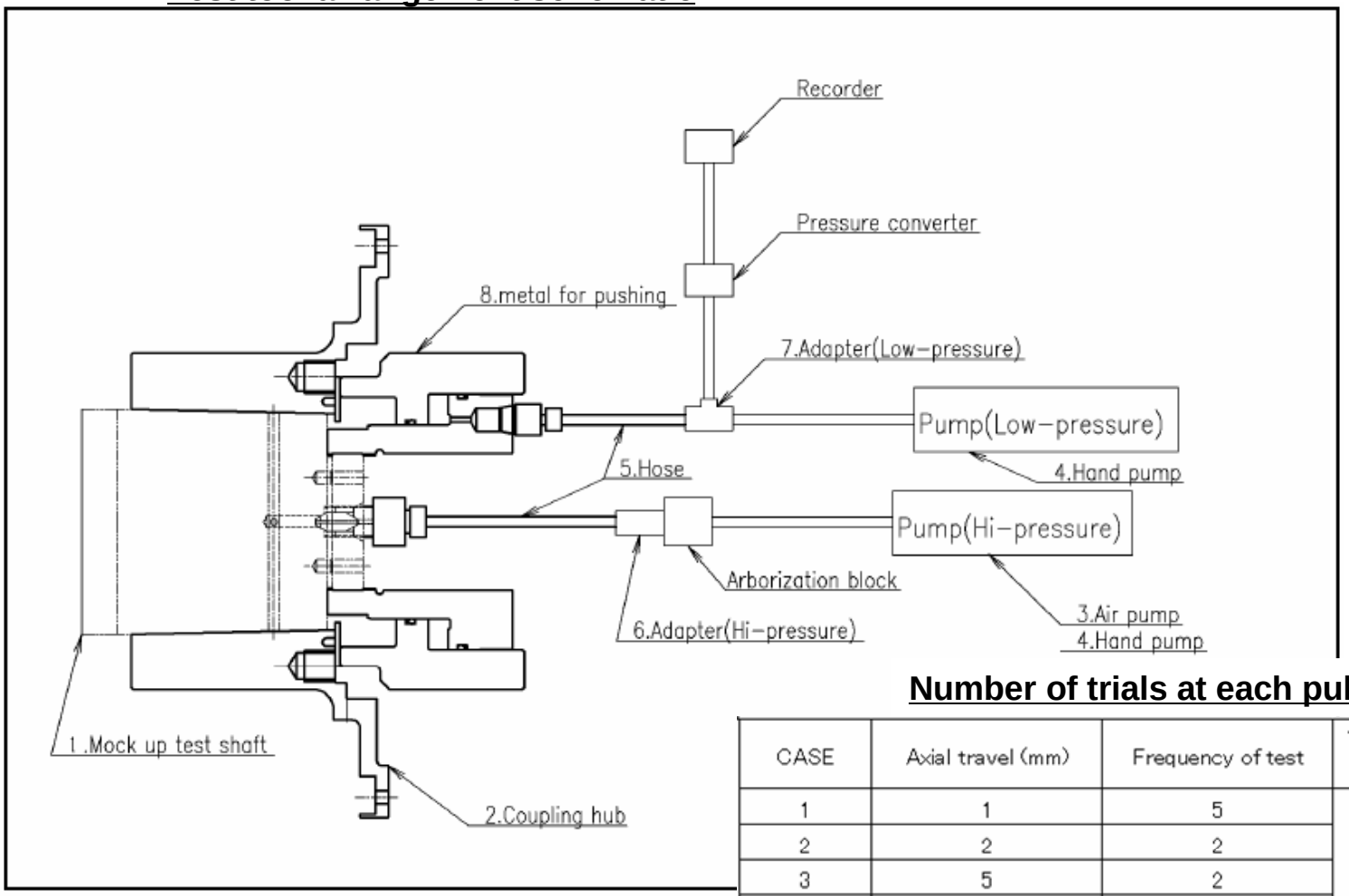
- **Reduce overhung mass and apply groove at small end of bore**
- **Reduce bump up mass**

Both ideas would be applied



Mock-up Test Arrangement (8 inch hub)

Test tool arrangement schematic



Number of trials at each pullup

CASE	Axial travel (mm)	Frequency of test	Tool for expansion oil pressure
1	1	5	Pump driven by air
2	2	2	
3	5	2	
4	8	2	
5	11	2	
6	12.67	5	
7	12.67	5	Hand pump

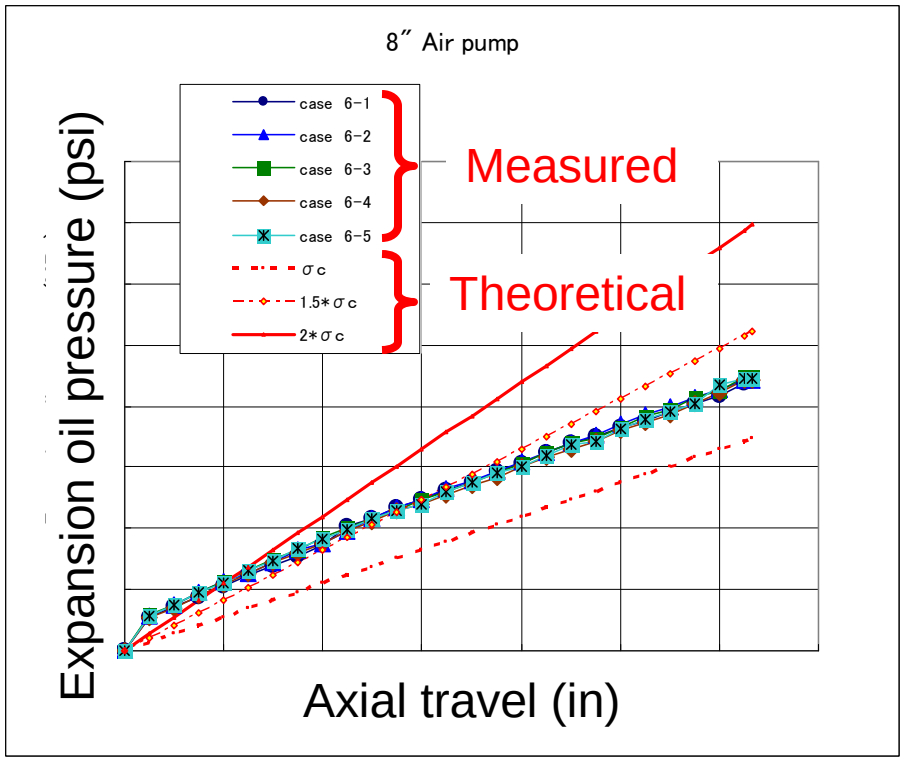
Mock-up Test Procedure (8 inch hub)

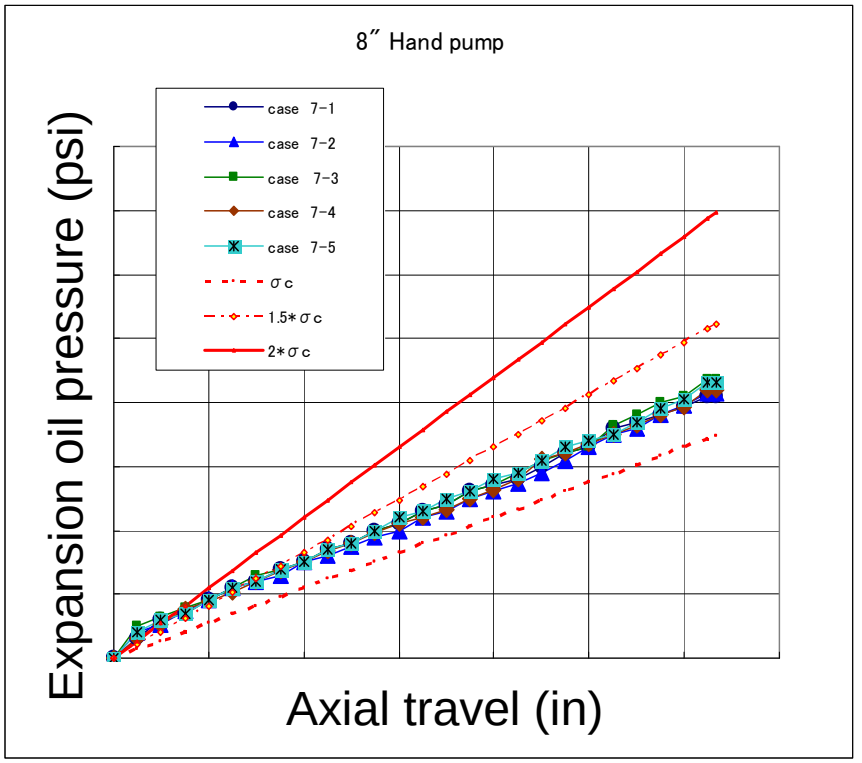
CASE1	Item	Target
1	Cleaning, smoothing up and dimension check of the groove	
2	Hub assembled on the shaft	
3	Setting axial travel meter (4 points)	
4	Tapping the end of hub with lead hammer	
5	Adjust the 0 point of axial travel meter	
6	Measuring the over hung distance	
7	Set the hydraulic fit tool	
8	Check the 0 point of axial travel meter	
9	Pressurize expansion oil pressure	Refer to the limitation
10	Pressurize axial oil pressure	Refer to the limitation
11	Pressurize expansion oil pressure	Oil leakage from large end
12	Record expansion oil pressure and axial oil pressure	
13	Pressurize axial oil pressure	0.5 mm (axial travel)
14	Record axial oil pressure	

Mock-up Test Procedure (continued)

14	Record axial oil pressure	
15	Pressurize expansion oil pressure	Oil leakage from large end
16	Record expansion oil pressure	
17	Pressurize axial oil pressure	1.0 mm (axial travel)
18	Record axial oil pressure	
19	Completed hydraulic fitting	
20	Pressurize expansion oil pressure	Oil leakage from large end
21	Record expansion oil pressure and axial oil pressure	
22	Depressurize axial oil pressure	0.0 mm (axial travel)
23	Record expansion oil pressure and axial oil pressure	
24	Depressurize axial oil pressure	0 kgf/mm2G
25	Depressurize expansion oil pressure	0 kgf/mm2G
26	Remove the hydraulic fit tool	
27	Remove the coupling hub	
28	Visual check and photo of hub and shaft、dimension check of the groove	

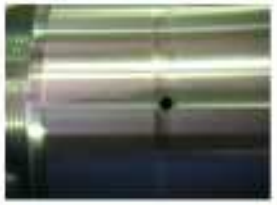
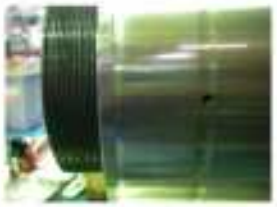
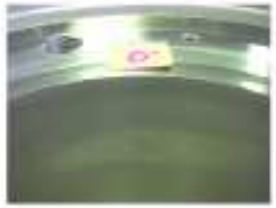
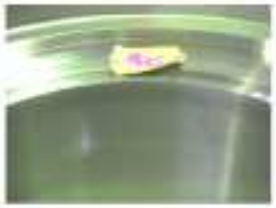
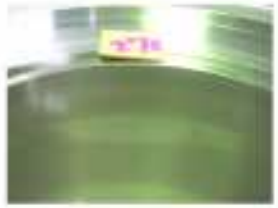
Results of Mock-up test (8 inch hub)



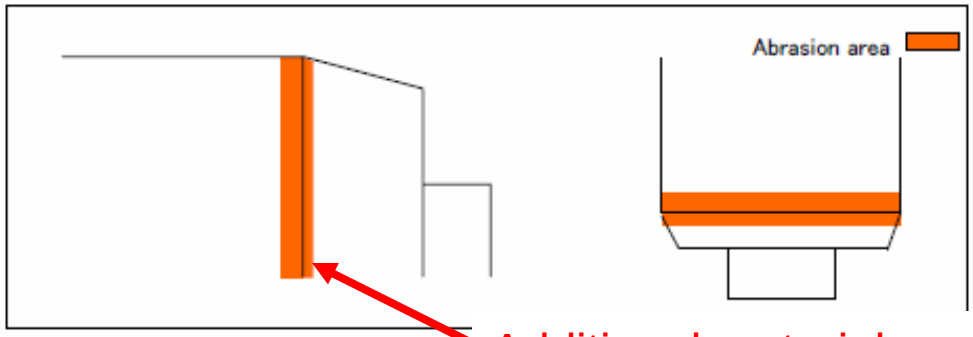


Measured expansion oil pressure with air pump and hand pump

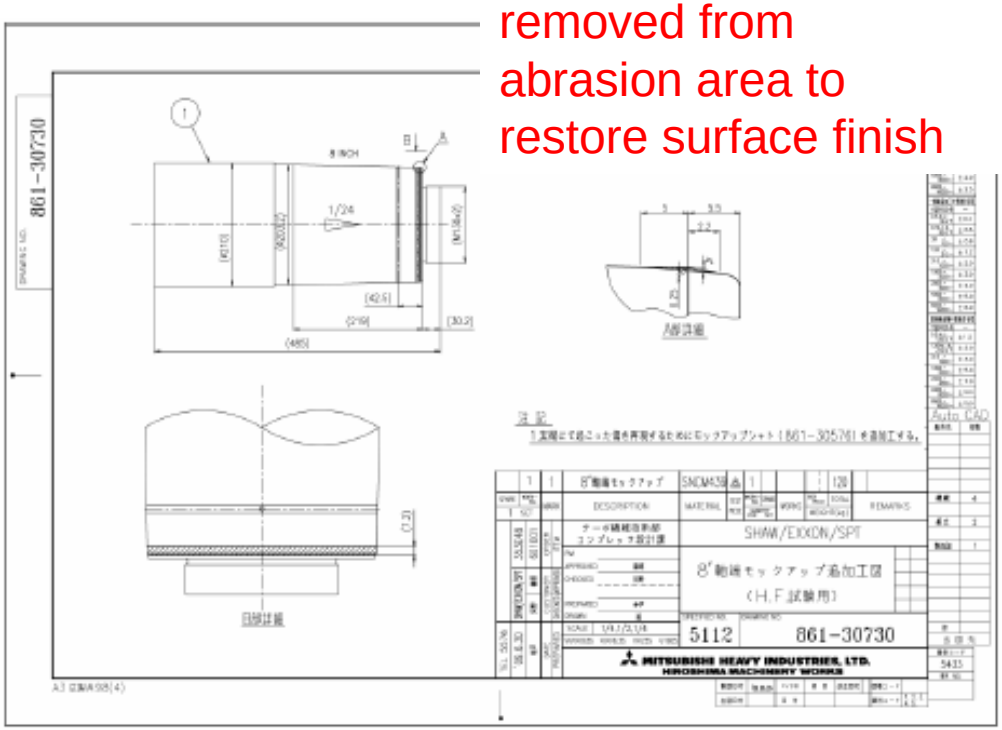
Result of Mock-up test (8 inch hub)

		0°	90°	180°	270°	
Shaft	【Before mock up test】					
	【After mock up test】 +1mm × 5(Air pump) +2mm × 2(Air pump) +5mm × 2(Air pump) +8mm × 2(Air pump) +11.06mm × 5(Air pump) +11.06mm × 5(Hand pump)					
Hub	【Before mock up test】					
	【After mock up test】 +1mm × 5(Air pump) +2mm × 2(Air pump) +5mm × 2(Air pump) +8mm × 2(Air pump) +11.06mm × 5(Air pump) +11.06mm × 5(Hand pump)					

Reconditioned dummy shaft geometry



Additional material removed from abrasion area to restore surface finish

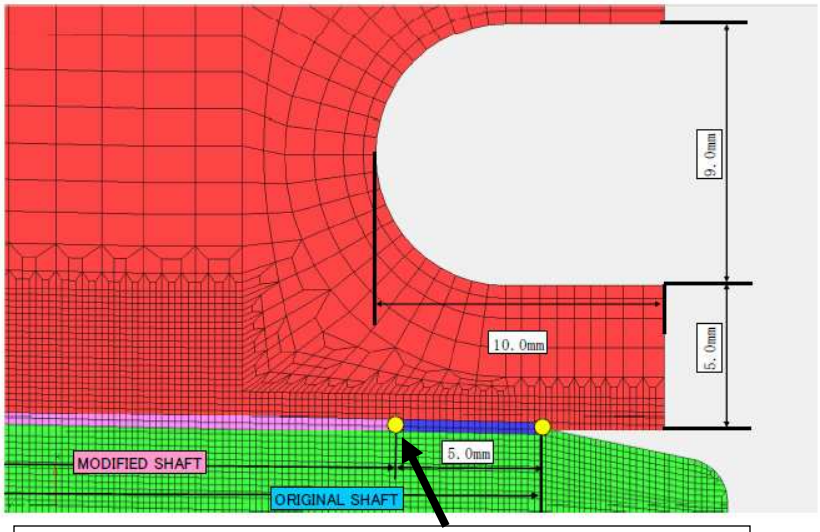


Contract shaft

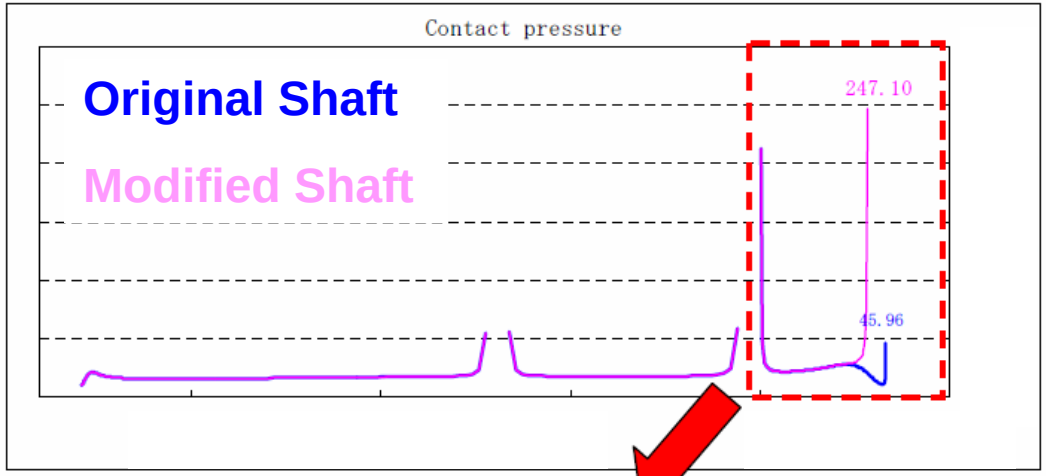
Dummy shaft

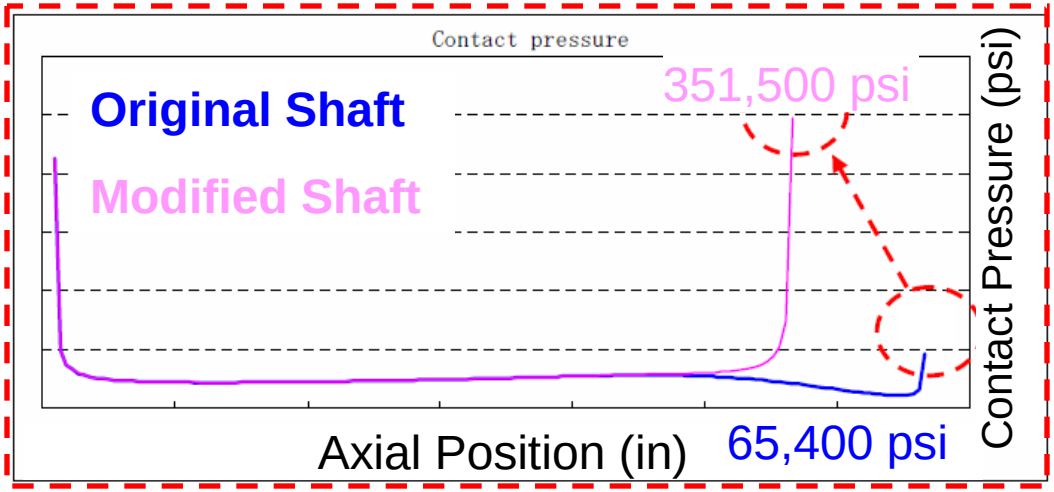
Study for Effect of Shaft Geometry

High contact pressure was noticed during installation of the hydraulic hub due to the reconditioned shaft geometry

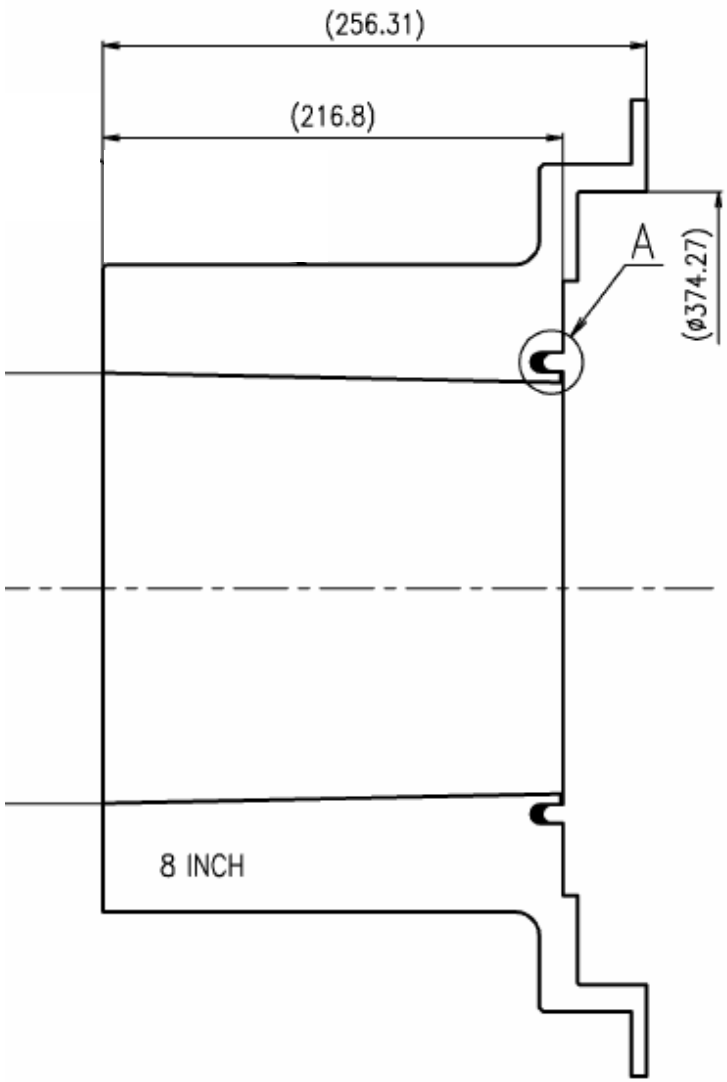


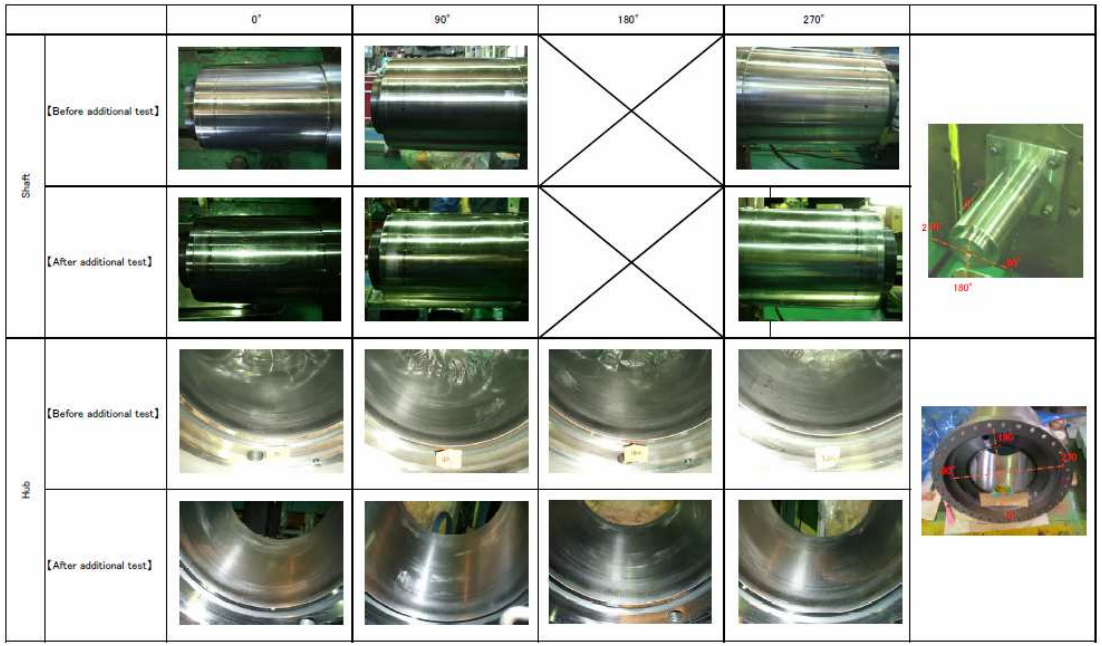
Relief groove has minimal effect on modified shaft due to relative position of groove to high pressure area.





Result of additional mock-up test





Relief groove depth was increased to prevent damage.

Additional mock-up test was successfully completed.

Conclusions

To optimize hydraulic hub design to prevent shaft end damage during installation and removal:

a) Finite element analysis verified that high contact pressure existed between hydraulic hub and shaft and was therefore a probable explanation

b) Mock up test verified that removing material from hub bump up mass and machining deep relief groove into face at small end of bore eliminated shaft end damage

c) Additional mock-up test performed on reconditioned working shaft resulted in need for further design modification

d) Hydraulic hub design change eliminated shaft end damage