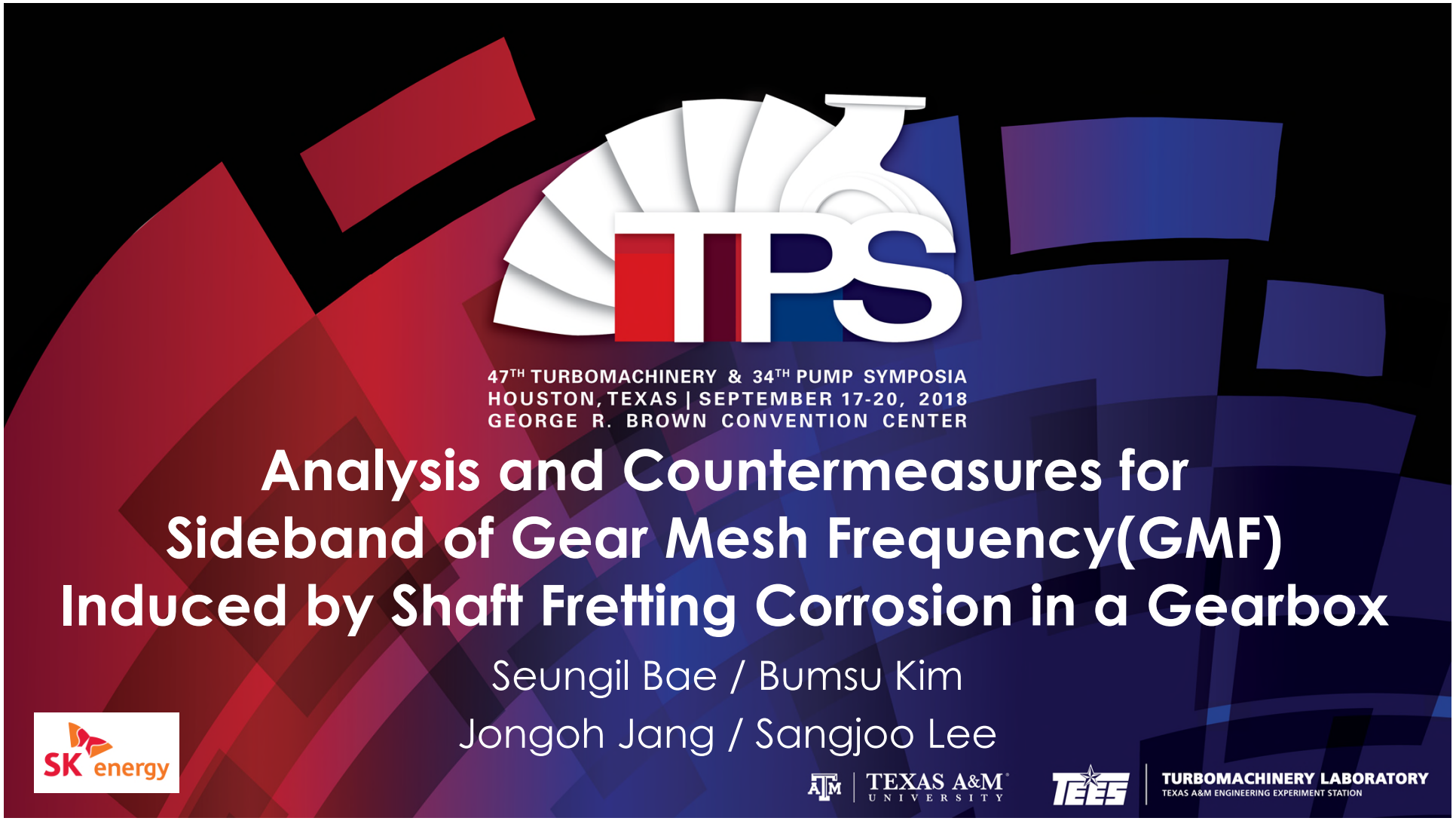

TPS
47TH TURBOMACHINERY & 34TH PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 17-20, 2018
GEORGE R. BROWN CONVENTION CENTER
Analysis and Countermeasures for Sideband of Gear Mesh Frequency(GMF) Induced by Shaft Fretting Corrosion in a Gearbox
Seungil Bae / Bumsu Kim
Jongoh Jang / Sangjoo Lee
SK energy
TEXAS A&M UNIVERSITY
TEES
TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Presenter/Author bios

Presenter, Mr. Seungil Bae

Engineer in Rotating machinery Reliability & Engineering Team of SK Energy Ulsan, Korea, since 2010.

Received a M.S.degree (Mechanical Engineering from Busan National University, Korea).

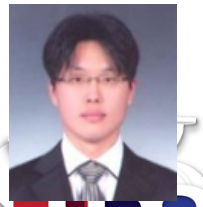
Co-author, Mr. Bumsu Kim.

Team Leader of Rotating machinery Reliability & Engineering Team for SK Energy Ulsan, Korea.

Received a B.S.degree (Mechanical Engineering from Busan National University, Korea) and a key member of KRMEA(Korea Rotating Machinery Engineers Association).

Co-author, Mr. Jongoh Jang Kim.

Senior Engineer in Rotating machinery Reliability & Engineering Team of SK Energy Ulsan, Korea, since 1988 a key member of KRMEA(Korea Rotating Machinery Engineers Association).



Co-author, Mr. Sangjoo Lee

Rotating machinery engineer in reliability for SK Energy Ulsan, Korea, since 2007.

Received a M.S. degree(Mechanical Engineering from Ulsan University) and a key member of KRMEA(Korea Rotating Machinery Engineers Association)

Presentation Overview

Analysis and Countermeasures for Sideband of Gear Mesh Frequency(GMF) Induced by Shaft Fretting Corrosion in a Gearbox

1. Abstract
2. Introduction
3. System gear ratios and GMFs
4. Chronology of events
5. Trouble shooting
6. Root Cause
7. Solution
8. Lessons Learned

Abstract

CS deals with trouble shooting and solving a chronic fretting corrosion damage between a gear and shaft (shrink fit). The damage on the geared shaft always accompanied by an increase in the amplitude and frequency side bands at the gear mesh frequency (GMF).

The troubleshooting process and analysis revealed that the distance between the two gears is a critical design parameter for preventing fretting corrosion.

Introduction

Located in a polypropylene plant, an extruder pushes molten polymer through a die plate to make the final product (pellets)

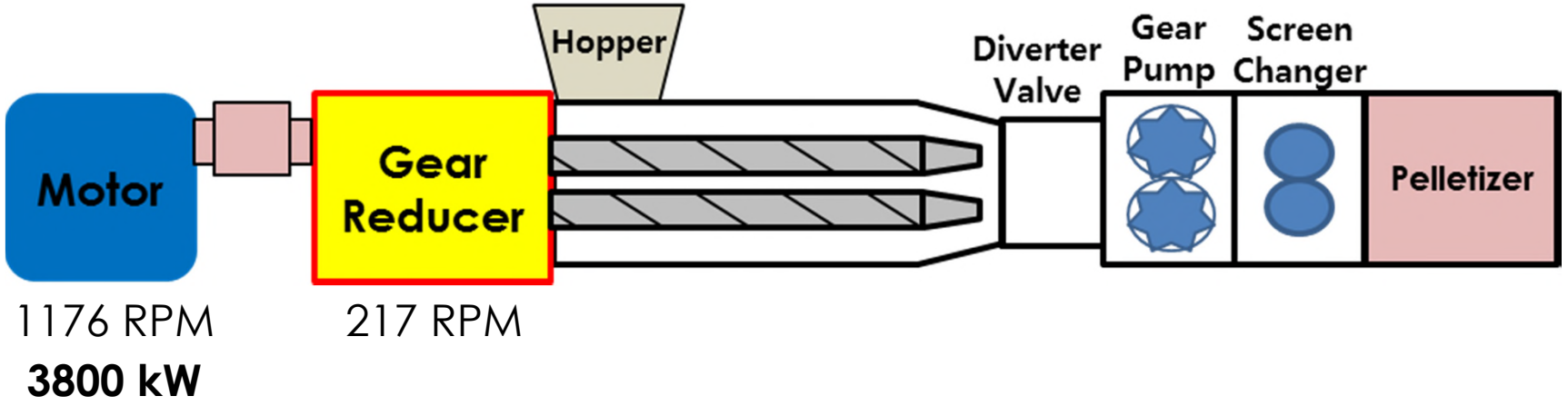
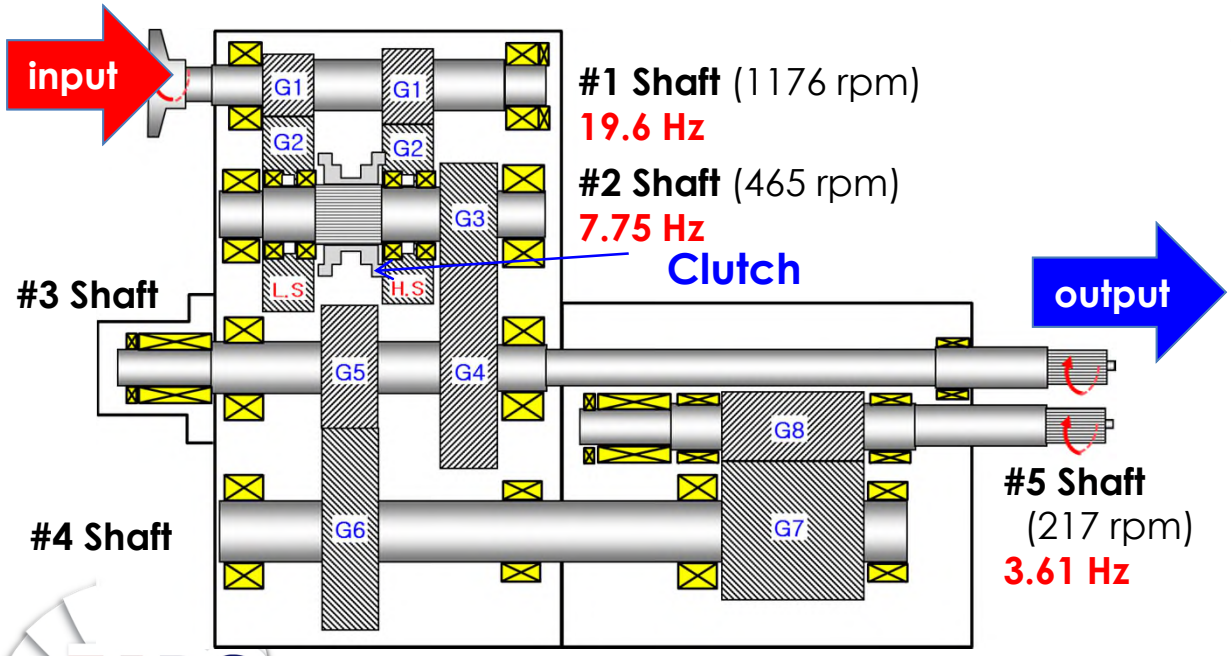


Fig. 1 Schematic drawing of extruder train

System gear ratios and GMFs

Overall gear reduction(ratio) is **5.4**, as determined by 5 shafts & 8 gears(without low speed)

LS: Low Speed
HS: High Speed
G1~8 : Gear No.



※ Gears assembled on the shafts by shrink fit

Table. 1 RPM & GMF

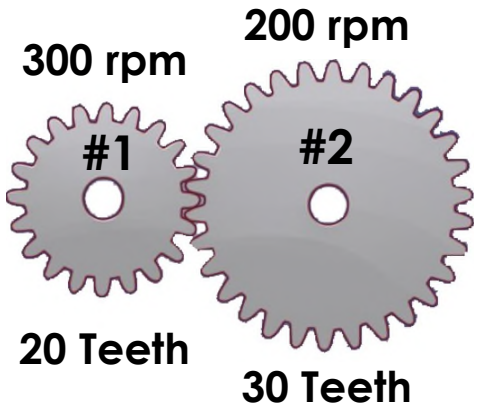
Shaft No.	RPM	Gear No.	GMF (Hz)
#1 (Input)	1176	G1	667
#2	465	G2	667
		G3	217
#3 (Output)	217	G4	217
		G5	109
#4	114	G6	109
		G7	109
#5 (Output)	217	G8	109

System gear ratios and GMFs

GMF: Gear Mesh Frequency, also called Tooth Mesh Frequency

= Number of teeth X **Shaft speed**

For example,



GMF of Gear #1 & #2

$= 20 \underset{\text{Teeth}}{} \times 300 \underset{\text{rpm}}{} / 60 = 30 \underset{\text{Teeth}}{} \times 200 \underset{\text{rpm}}{} / 60$

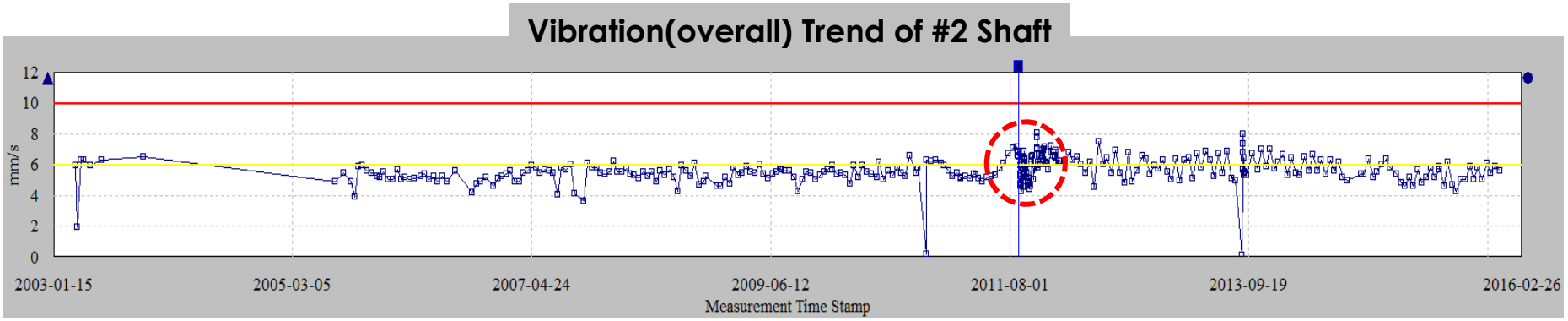
= 100 Hz

Chronology of events

1. **Aug. 2011** : Increased vibration of #2 shaft due to occurrence of **GMF side band**.
2. **Oct. 2011** : After gearbox overhauling, fretting corrosion was found on #2 Shaft
   → Replaced #2 Shaft with gear and bearing
3. **2013, 2015** : Again, GMF side band & fretting corrosion on #2 Shaft
   → Temporary repair by means of low temperature welding on shaft and Cr plating inside of gears.

Chronology 1. August 2011

Increased vibration of #2 shaft (5.8 mm/s → 6.9mm/s)

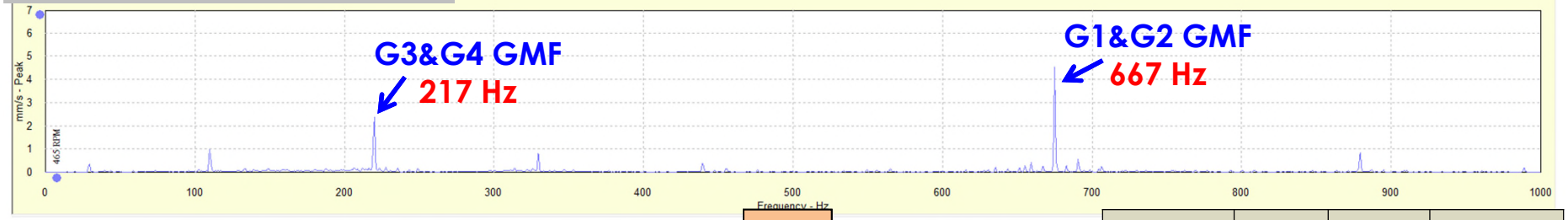


※ Vibration measured bi-weekly with portable sensor

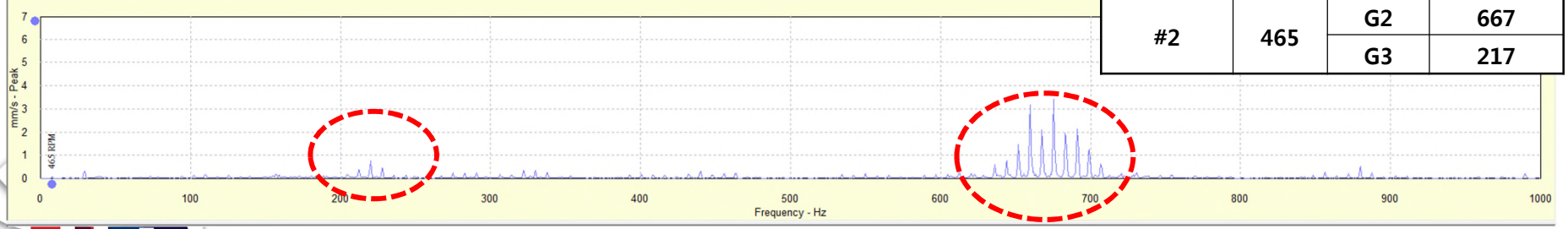
Chronology 1. Aug 2011

GMF side band frequency appeared, and affected vibration increase

Before increasing vibration



After increasing vibration

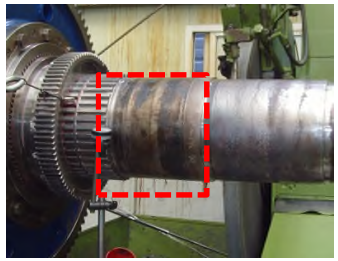


Shaft No.	RPM	Gear No.	GMF (Hz)
#2	465	G2	667
		G3	217

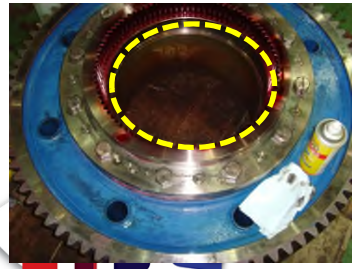
Chronology 2. October 2011

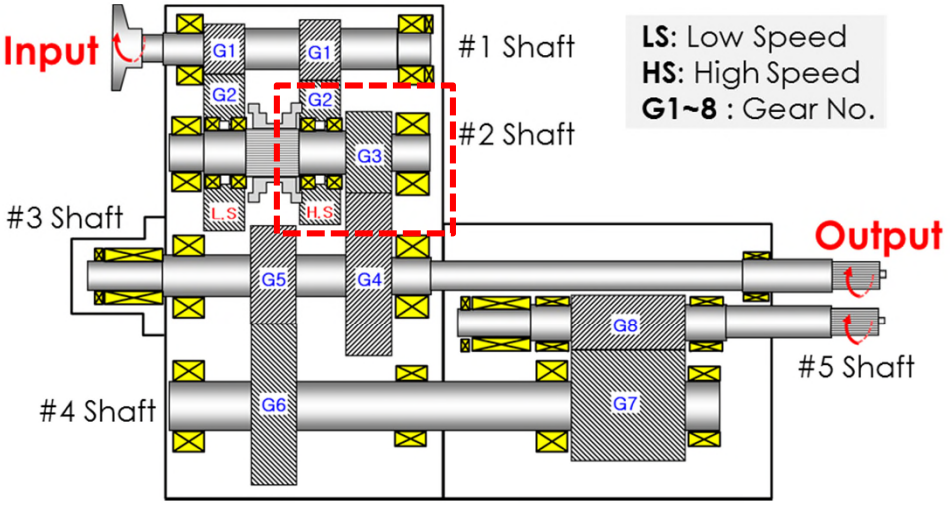
Severe damage: Fretting corrosion damage on #2 shaft.

No.2 Shaft
(HS G2 Gear Inner Bearing Mating)



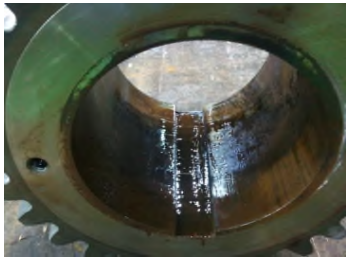
G2 Gear
(Inner Bearing Mating)





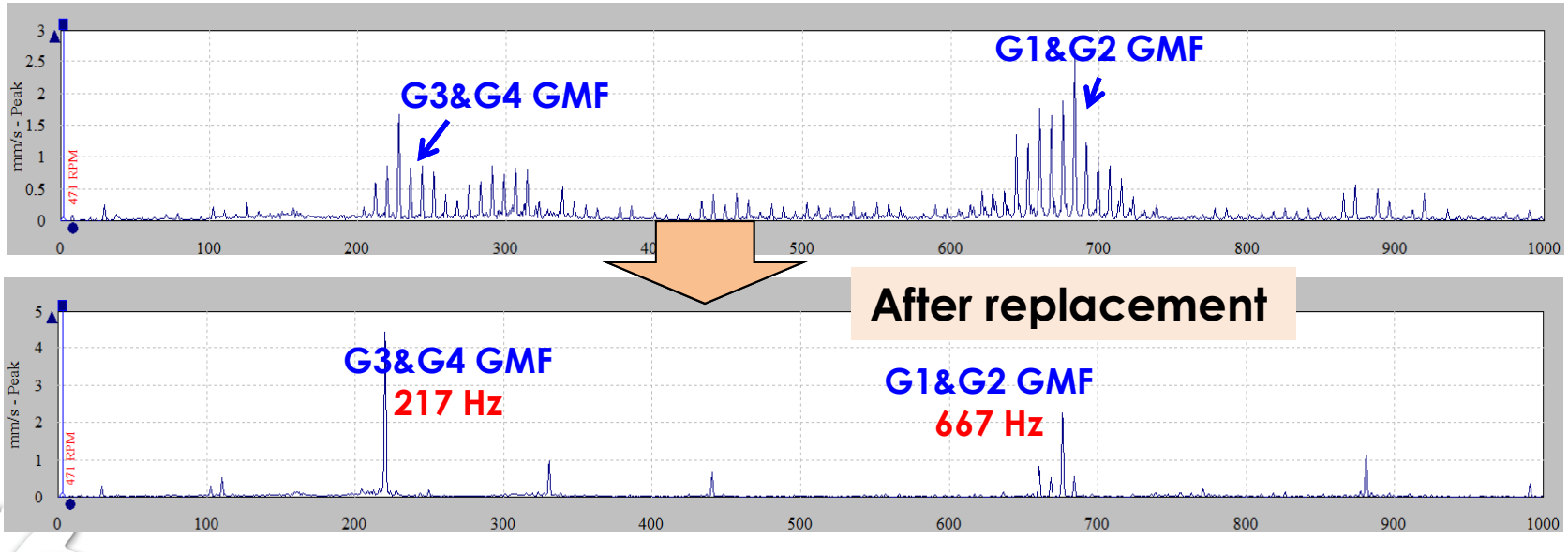
No.2 Shaft
(G3 Gear Mating)

G3 Gear



Chronology 2. October 2011

After replacing shaft and bearings,
Vibration side bands disappeared.



Persistence of issue and steps to solution

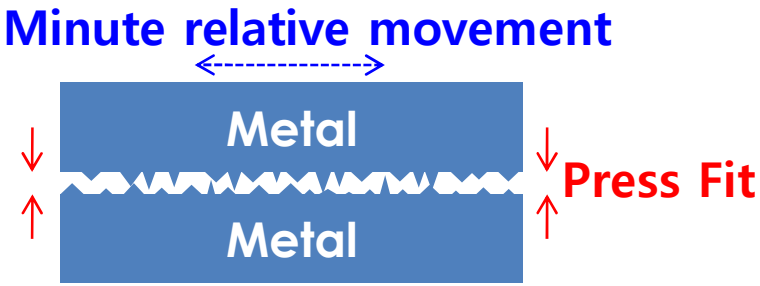
However, fretting corrosion with **GMF side band** repeatedly happened every 1.5 ~2 years (in 2013 & 2015)

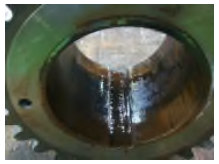
To prevent fretting corrosion damage, we had to reduce charge rate of extruder.

To find the root cause for the persistency of fretting corrosion damage occurs on #2 shaft only, all aspects were analyzed from operating condition to shaft design, as well as installation condition.

Troubleshooting

Fretting corrosion obviously occurs due to minute relative movement (of parts) operating under high pressure.





Since the gear and shaft are assembled by shrink fit (=high pressure), **one must find out why relative movement happens.**

Troubleshooting

Three likely causes produce the relative motion:

Probable Causes	Possibility
① Insufficient force while shrink fitting	X
② **Excessive torsional load**	O
③ **Excessive shear force (shaft bending)**	O

Most likely are **excessive torsional load & shear force that continuously produced the relative movement.**

Troubleshooting

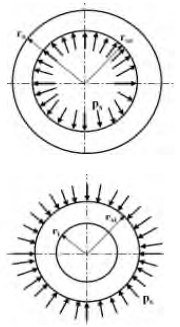
① Insufficient force for shrink fit (shaft-gear)

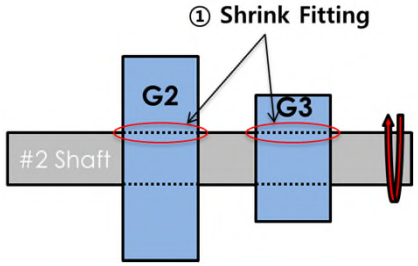
Allowable transmission torque by shrink fit is approx. 3.4 times actual transmitted torque.

→ **Low probability for relative movement btw gear & shaft**

❖ **Lame's Equation for Thick Cylinder Shrink Fit**

Transmitted Power (kW)	RPM	Transmitted Torque (kN-m)	Interference Pressure (MPa)	Friction Force (kN)	Allowable Transmission Torque (kN-m)	Remark
2700	465	55.4	36.6	1138	188	**Safety margin** = 188 / 55.4 = 3.4

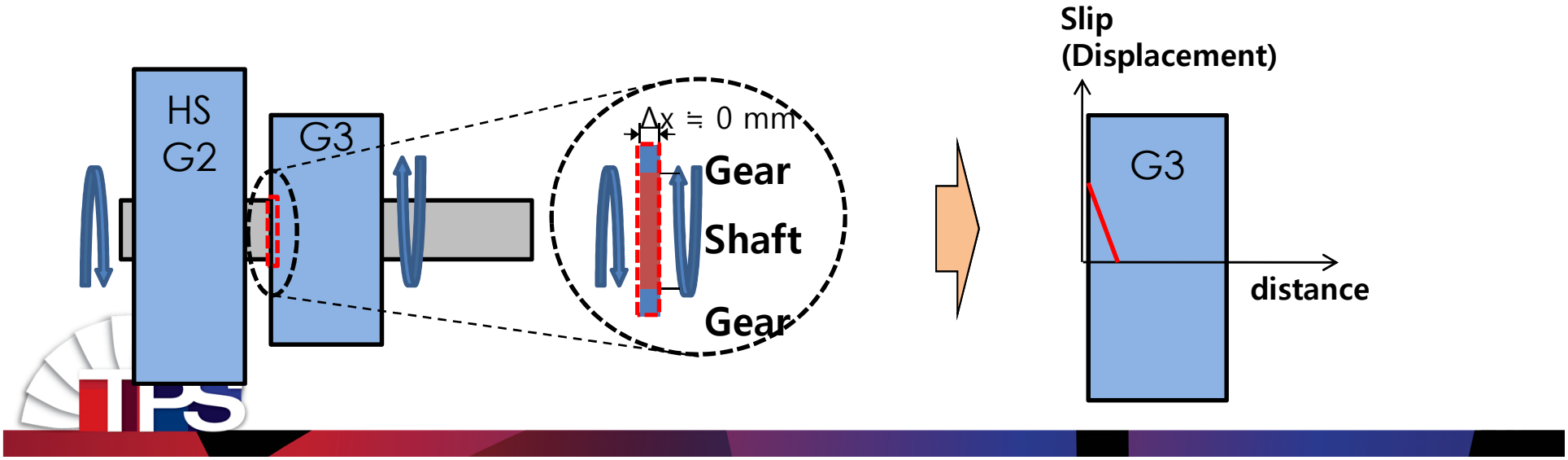




Troubleshooting

② Excessive torsional load

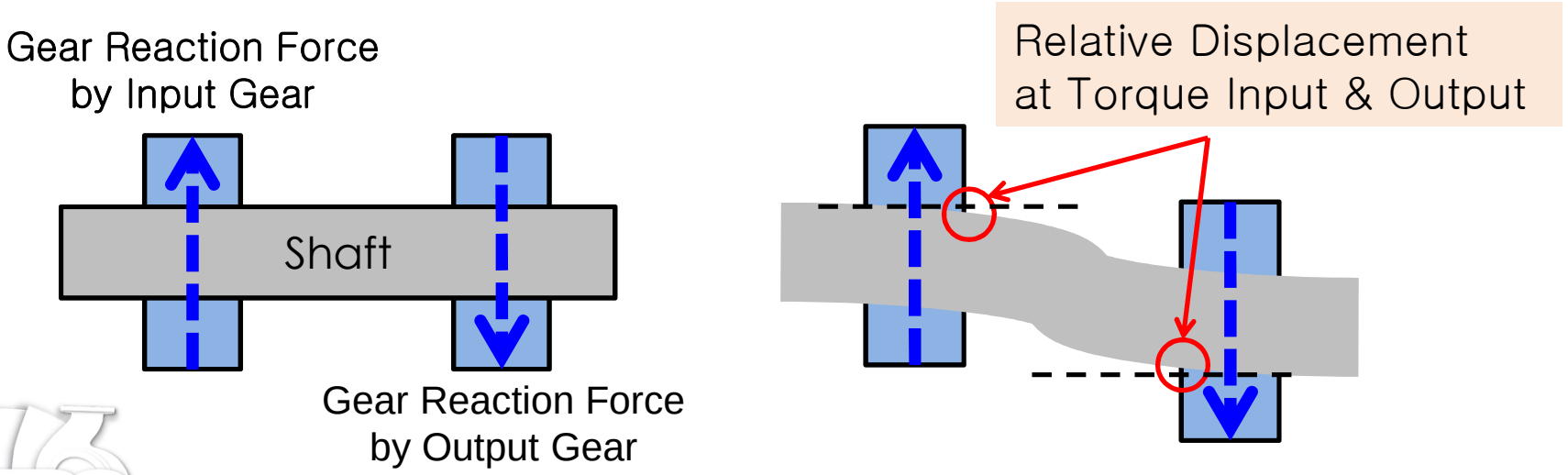
Relative movement can occur at the gear edge zone
(red dotted box)
As transmitted torque increases, the relative movement at the edge zone accordingly increases.



Troubleshooting

③ Excessive shear force (shaft bending)

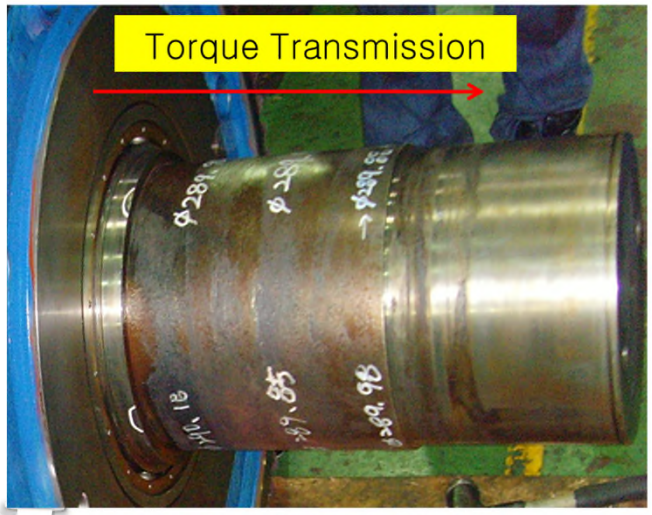
Shear from gear reaction force can cause shaft bending, thus resulting in relative displacement.



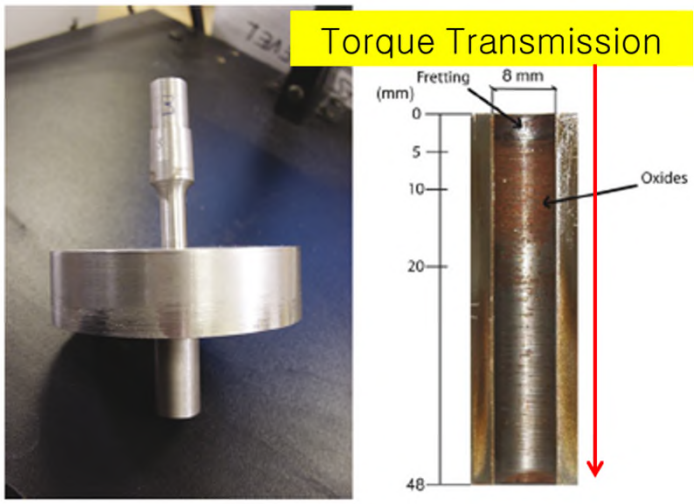
Troubleshooting

③ Excessive shear force (shaft bending)

Fretting corrosion starts from torque input & output by torsion and bending, then propagates to opposite side



Gearbox Shaft



Lab Experiment

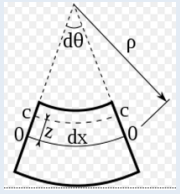
Troubleshooting

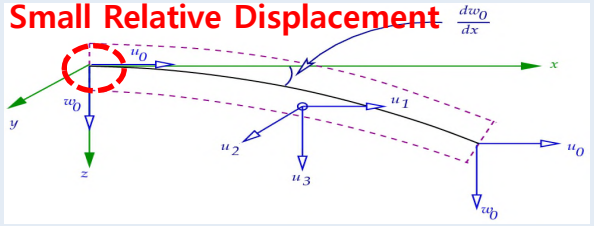
③ Excessive shear force (shaft bending)

ⓐ Long distance between two gears
: **Small Relative Displacement**

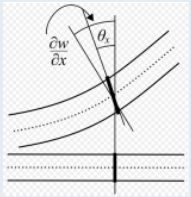
ⓑ Short distance between two gears
: Large Relative Displacement

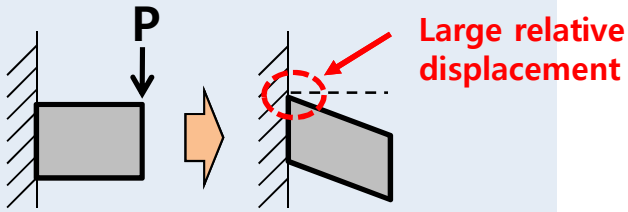
ⓐ Apply **Euler Beam Theory** to long shaft





ⓑ Apply **Timoshenko Beam Theory** to short shaft



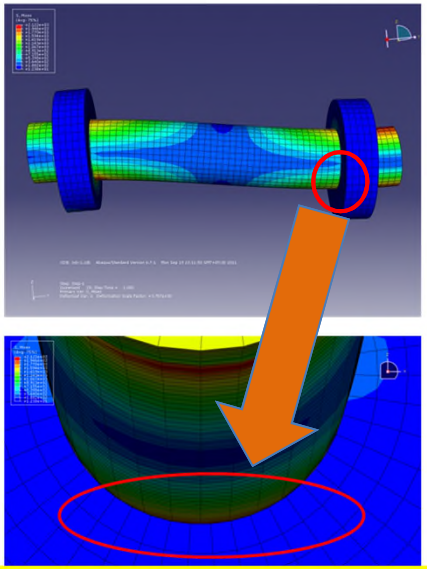


Troubleshooting

③ Excessive shear force (shaft bending)

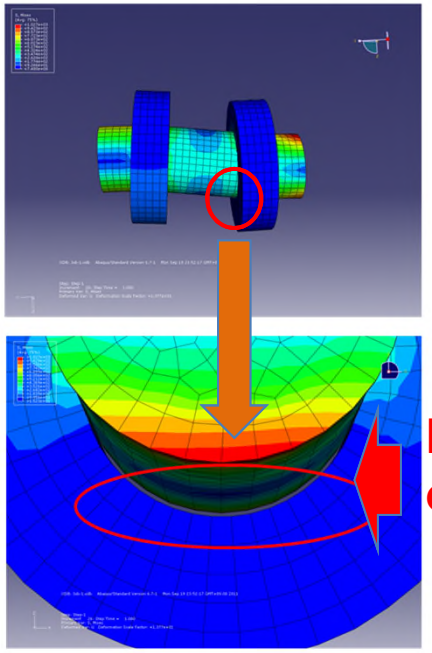
FEM results also reveal a short shaft undergoes a large relative displacement.

Long Shaft(Euler Beam Model)



Long Shaft has smaller relative displacement

Short Shaft(Timoshenko Beam Model)



Large relative displacement

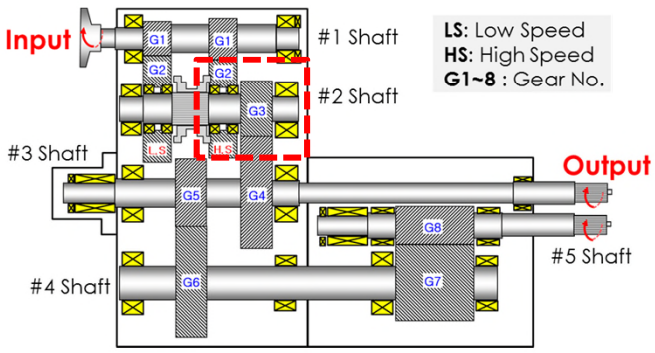
The root cause:

Thus, the distance between two gears is a critical parameter for causing fretting corrosion b/w a gear and shaft

Since G2 & G3 are too close together (25mm),

#2 shaft has the highest potential risk for fretting corrosion.

Category		G3	G4	G5	G6	G7
ⓐ	**Distance (mm)** (Gear - Gear)	**25**	210	210	1500	1500
ⓑ	**Torque (kNxm)**	**55.4**	189	59	113	113
	Fretting Index (= ⓑ / ⓐ)	**2.22**	0.90	0.28	0.08	0.08
	Fretting Severity	**1**	2	3	4	4



Solution

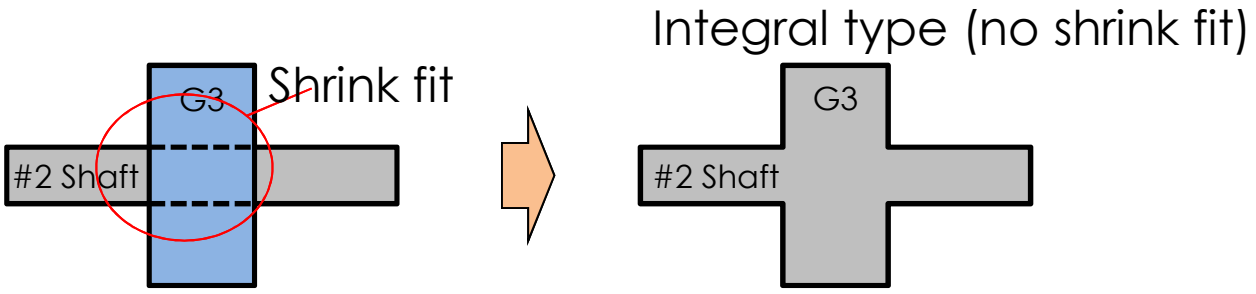
To prevent reoccurrence of fretting corrosion on #2 shaft,

The distance between G2 and G3 must be increased.

However, it's impossible to modify the gear arrangement of #2 shaft.

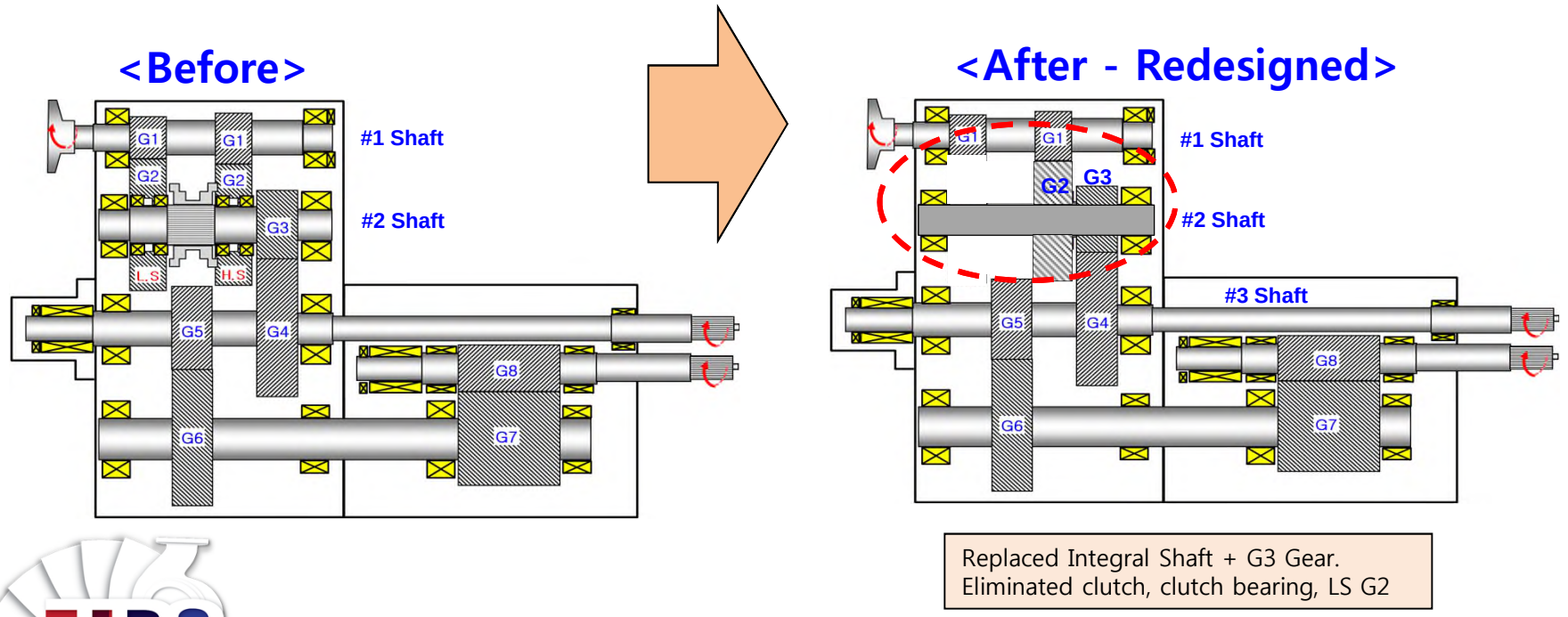
Thus, the following improvements performed in 2016

1. To eliminate relative movement, a new integral shaft + gear #2 manufactured.



Solution

2. Eliminated clutch, clutch bearings, and LS G2 gear:

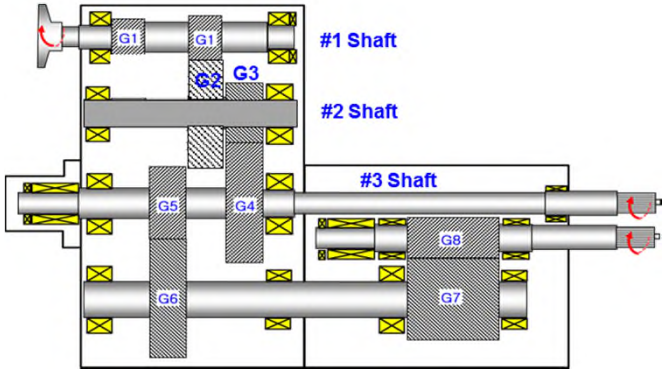


Replaced Integral Shaft + G3 Gear.
Eliminated clutch, clutch bearing, LS G2

Solution successful

Fretting corrosion fully eliminated, and vibration significantly reduced (max. 7.9 mm/s → 2.9mm/s).

The improvement allowed to increase 10% in extruder capacity.



Lessons Learned

- If side-band frequency at GMF increases, a probable cause is fretting corrosion damage between shaft and gear.
- Through FEM modeling and other, analysis found that the distance between two gears is a critical design parameter for preventing fretting corrosion. Removed chronic trouble by shaft/gear design modification.
- In case of chronic fretting corrosion damage of a gear shaft, applying an integral gear shaft is a proven solution.

End of Presentation

Questions?