Noise Trouble Shooting on a Variable Speed Planetary Gear Application for Off-Shore Process Gas Compressor

Hans Schirle
General Manager Engineering
Voith Turbo GmbH & Co.KG
Crailsheim, Germany

Daisuke Hirata
Mitsubishi Heavy Industries Compressor Corporation
Design & Engineering Center Division

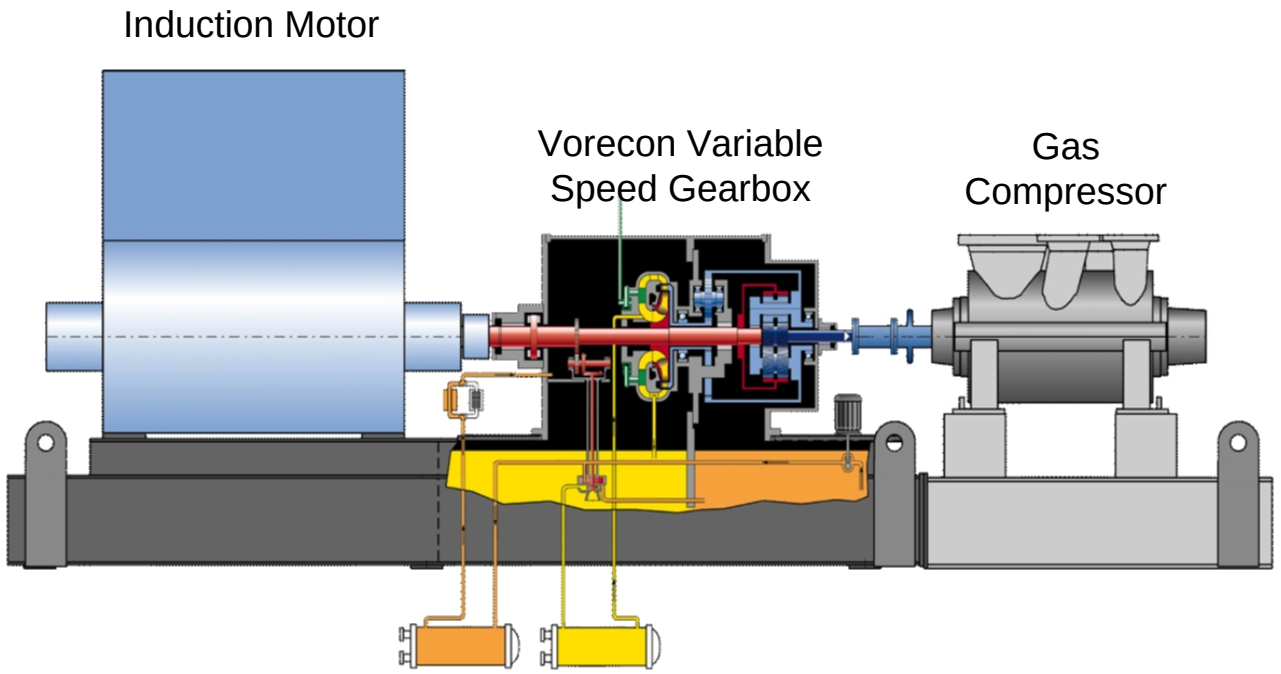
Nathan Pash
Machinery Engineer
ExxonMobil Development Company
Subsea Technology Project

George C. Hayles, Jr.
Sakhalin AD - Machinery Lead
ExxonMobil Development Company

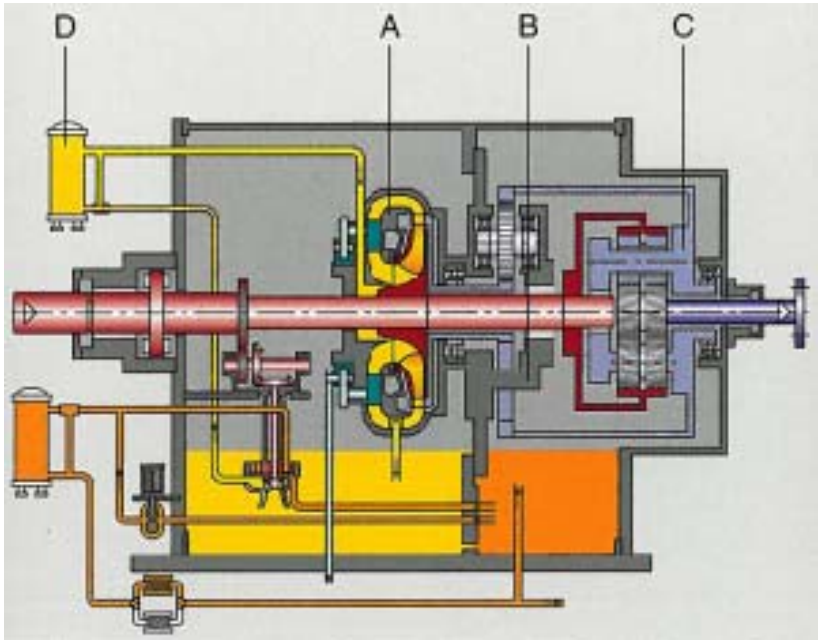
Contents

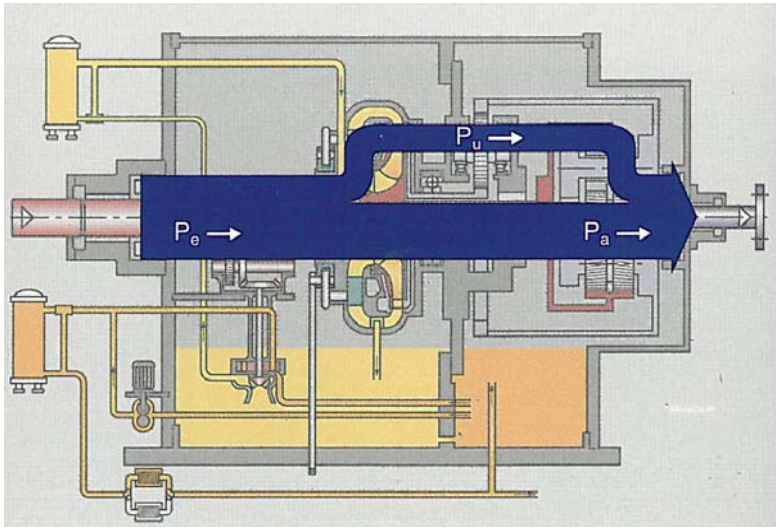
1. Application

Two Offshore Process Gas Compressors
Driven Equipment Power: 6900 kW
Rated Input Speed: 1493 rpm
Rated Output Speed: 12659 rpm
Speed Range 65-105%
Noise control was a key design issue
Noise attenuation measures included noise enclosure around the gearbox
Three gearbox units (Gearbox #3 is spare gearbox unit)

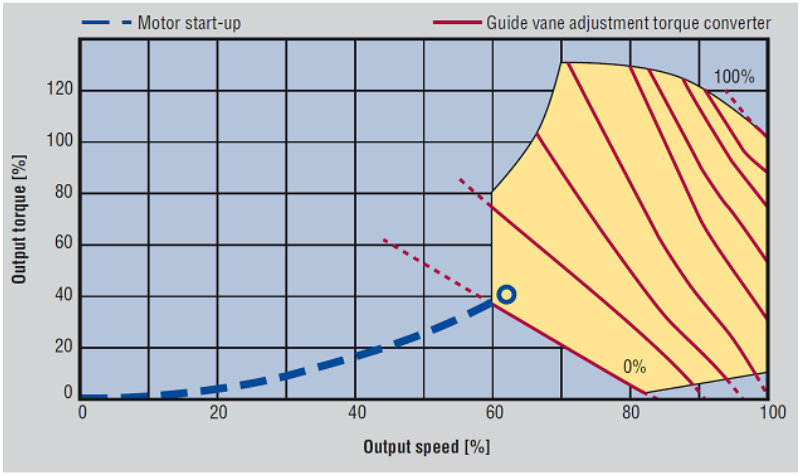


2. Introduction of Variable Speed Planetary Gear





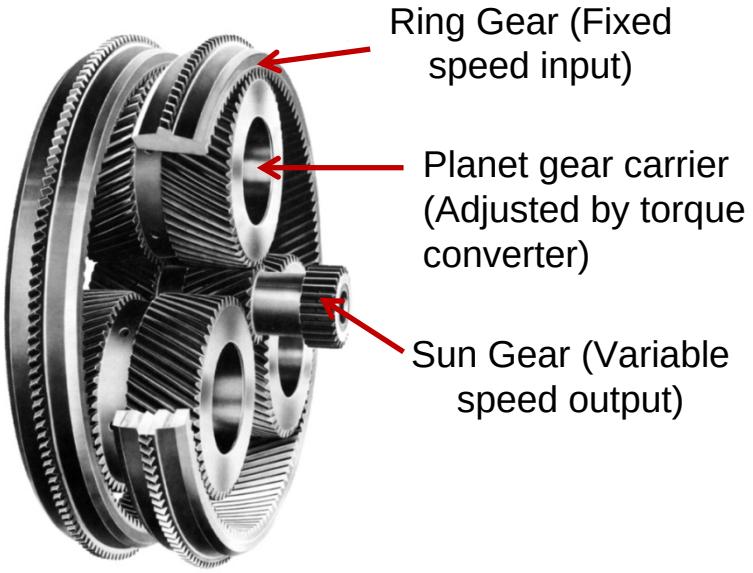
A: Torque Converter
B: Fixed Planetary Gear (spur gear)
C: Planetary Gear Superimposing (double helical)

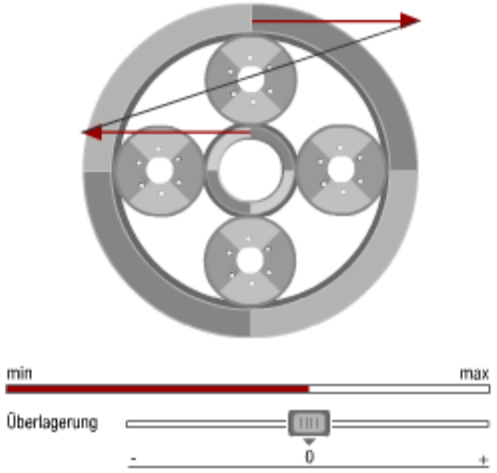


- *Power Splitting Principle*
- *Adjustable Output Speed for Compressor Drive*

3. Principle of Operation

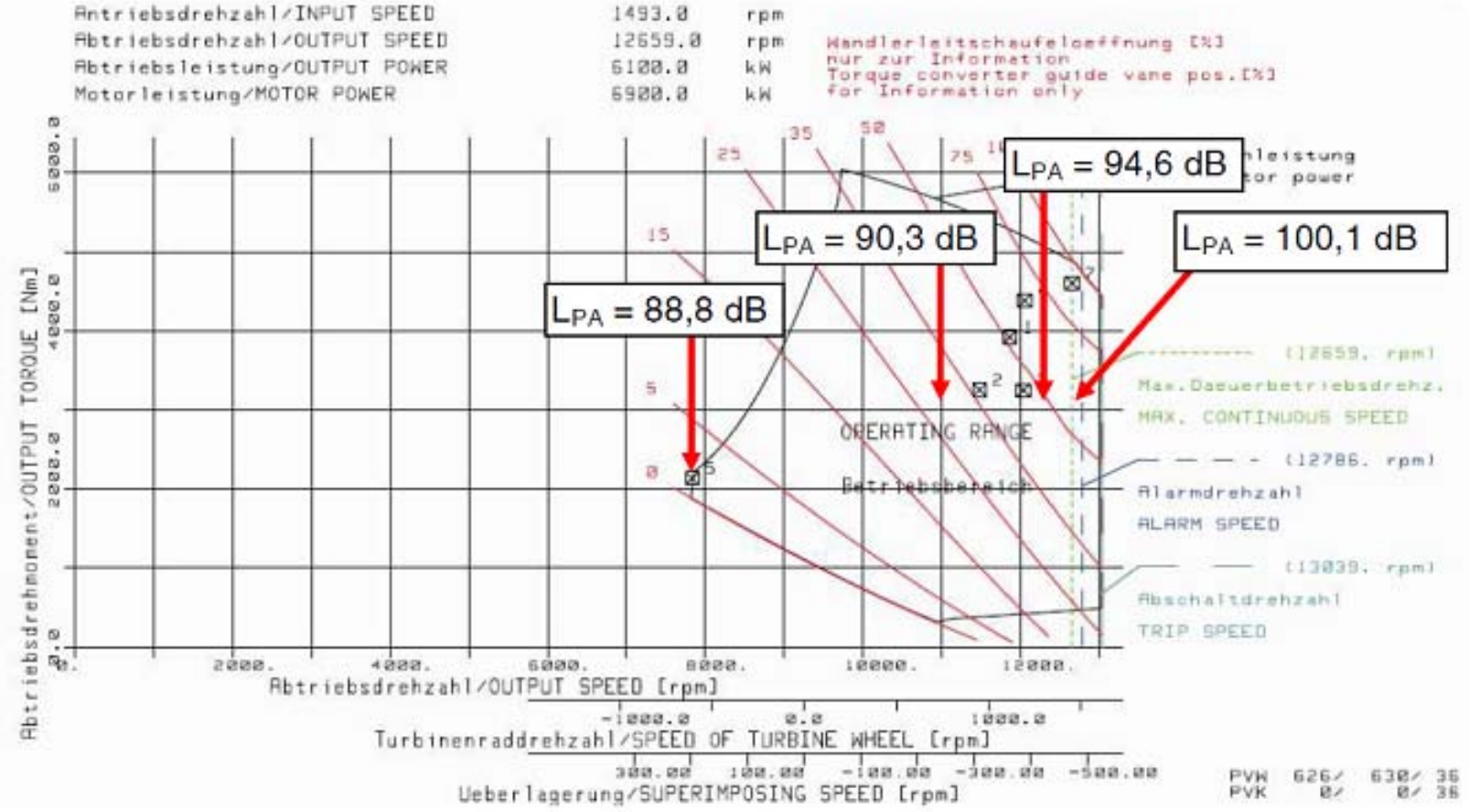
- The ring gear is at constant input speed (ni = motor speed)
- Planetary gear carrier rotational speed (ns) can be adjusted via the torque converter
- Rotation of the planet carrier in the same direction as ring gear results in a reduction in the sun gear output speed (na), as depicted below.
- Conversely, rotation of the carrier in the opposite direction will result in an increase in the speed of sun gear.





4. Noise Problem

Noise Measurement during Gearbox #2 FAT

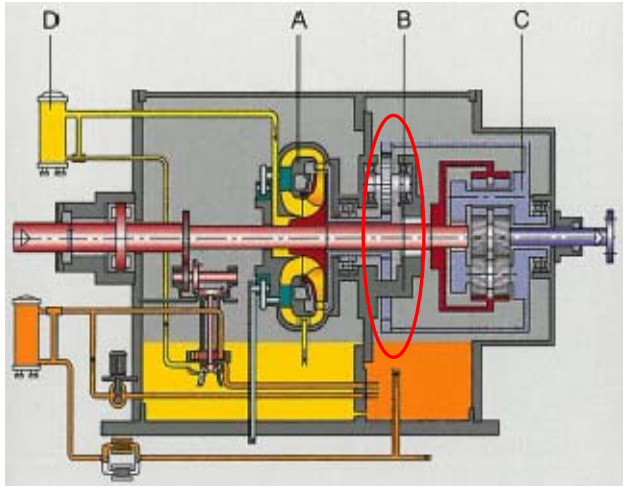


Abnormally high noise of 100 dBA at output torque of 3000 Nm was identified.
(normally 93.5 dBA)

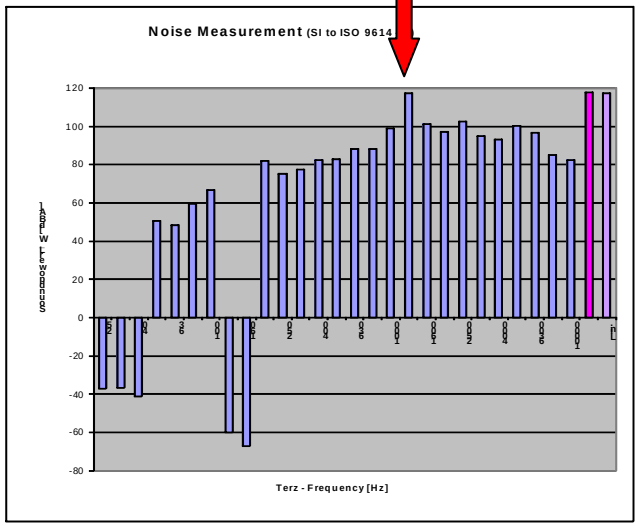
4. Noise Problem

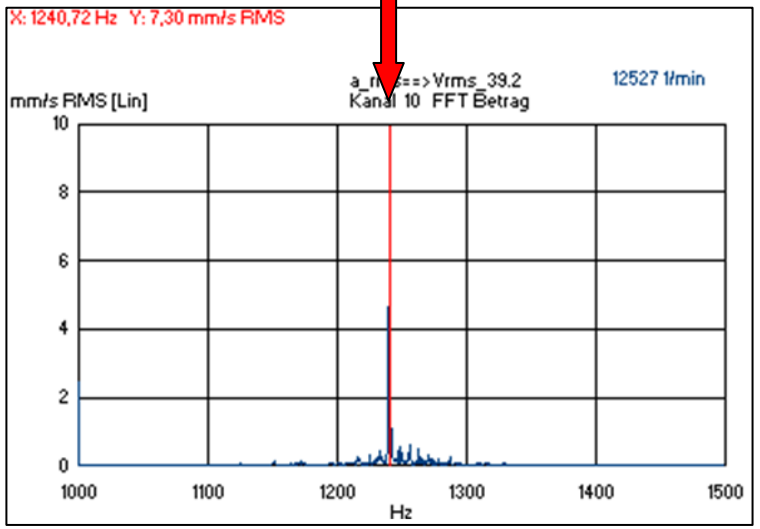
Spectrum of Gearbox #2 acoustic level and gear housing vibration

- *Peak at gear mesh frequency of Fixed Planetary Gear (FPG) at output speed of 12527 rpm.*



Terz - Frequency	Soundpower L_W
Hz	dBA
25	-37,2
31,5	-36,5
40	-41,4
50	50,7
63	48,3
80	59,5
100	66,8
125	-59,8
160	-67,0
200	82,0
250	75,4
315	77,5
400	82,5
500	82,9
630	88,0
800	88,3
1000	99,0
1250	117,3
1600	101,2
2000	97,0
2500	102,4
3150	94,8
4000	93,1
5000	100,1
6300	96,5
8000	85,1
10000	82,6
A - Filter	117,8
Lin.	117,2





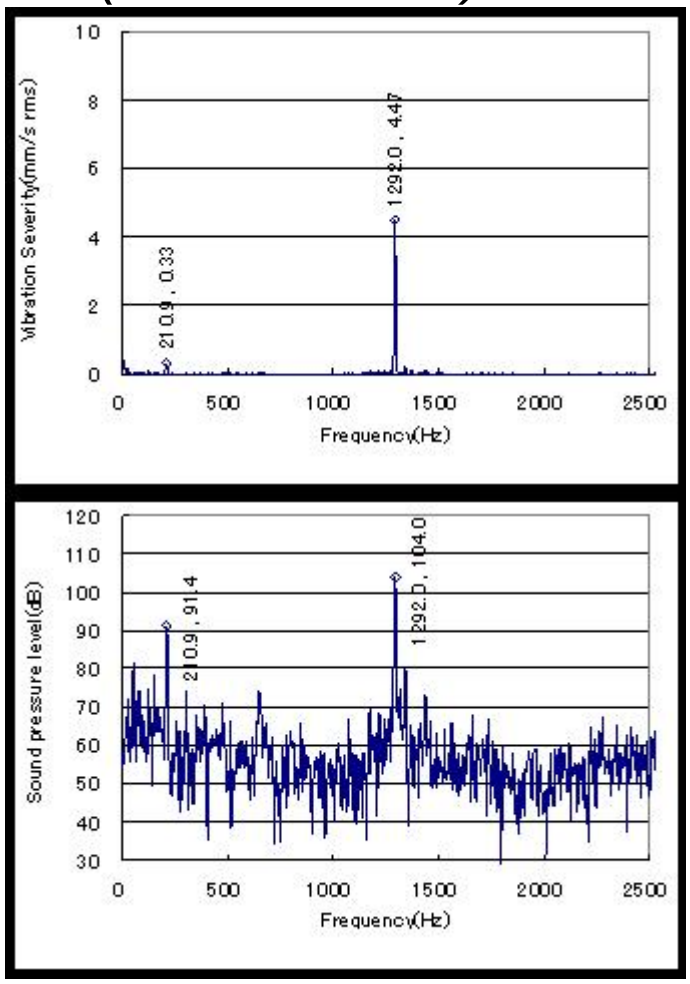
Acoustic Spectrum

Spectrum of gear housing vibration

4. Noise Problem

Noise Measurement during compressor string FAT (w/ Gearbox #1)

- Vibration level of 4.2 mm/s in gearbox housing
- Sound pressure level of 104dBA



Similar high noise and vibration levels, compared with Gearbox #2 testing.
Also found correlations with vibration frequency compared to Gearbox #2.

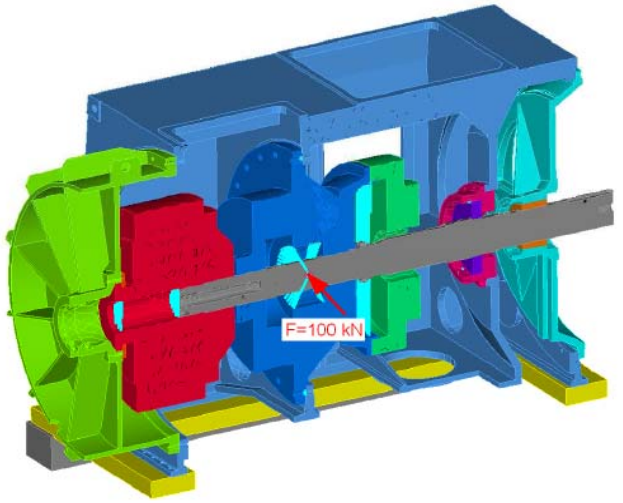
5. Root Cause Analysis

Root Cause Analysis Summary

Possible cause	Action	Result	Conclusion
Design Error	Counter check of gear design and gear calculations.	No design error was identified	Not root cause
Manufacturing error	Checked manufacturing records and performed additional measurements. Also checked alignment of sub-assemblies within gearbox.	No manufacturing error or assembly error was identified. Alignment was within manufacturer's tolerance.	Not root cause
Resonance problem	Check resonance of housing by hammering.	No significant natural frequency response was identified.	Not root cause
High excitability of housing in combination with unusually high tooth force excitation of spur gears.	Created FEA model for both housing materials. Applied same excitation force to both models.	Higher excitability of GGG-40 (special low temp) rather than standard material GG-20 was confirmed	Root cause

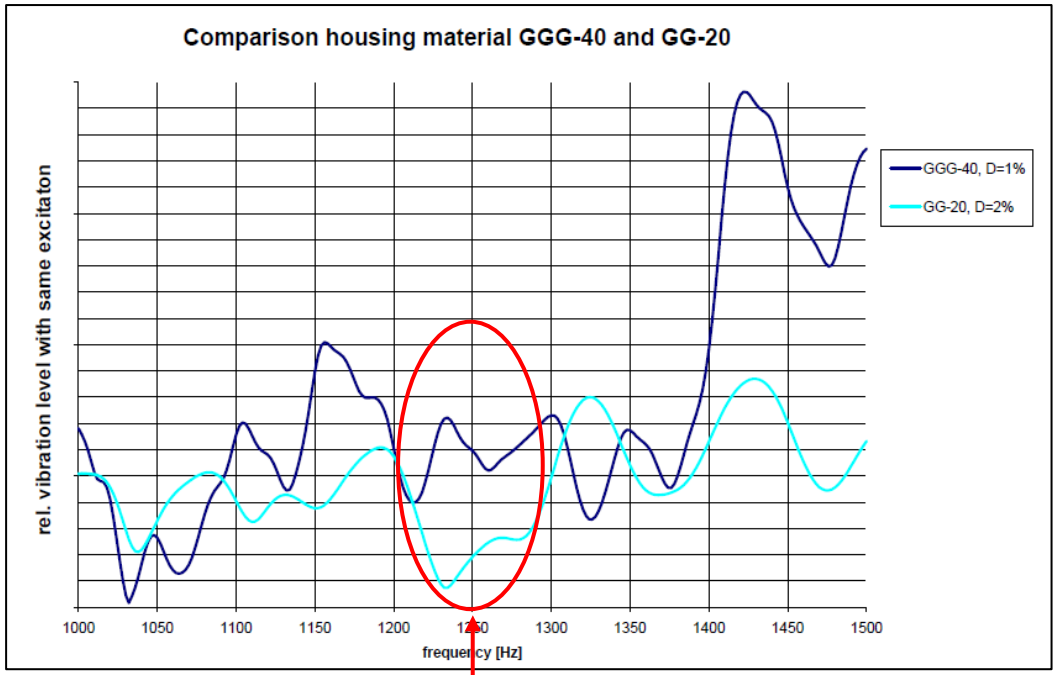
5. Root Cause Analysis

Excitability of Housing Material



- GGG-40 was applied due to low temperature environment.
  (GG-20 is standard material)

	GG-20	GGG-40
E-modulus (N/mm^2)	100 000	169 000
Damping coefficient	2%	1%



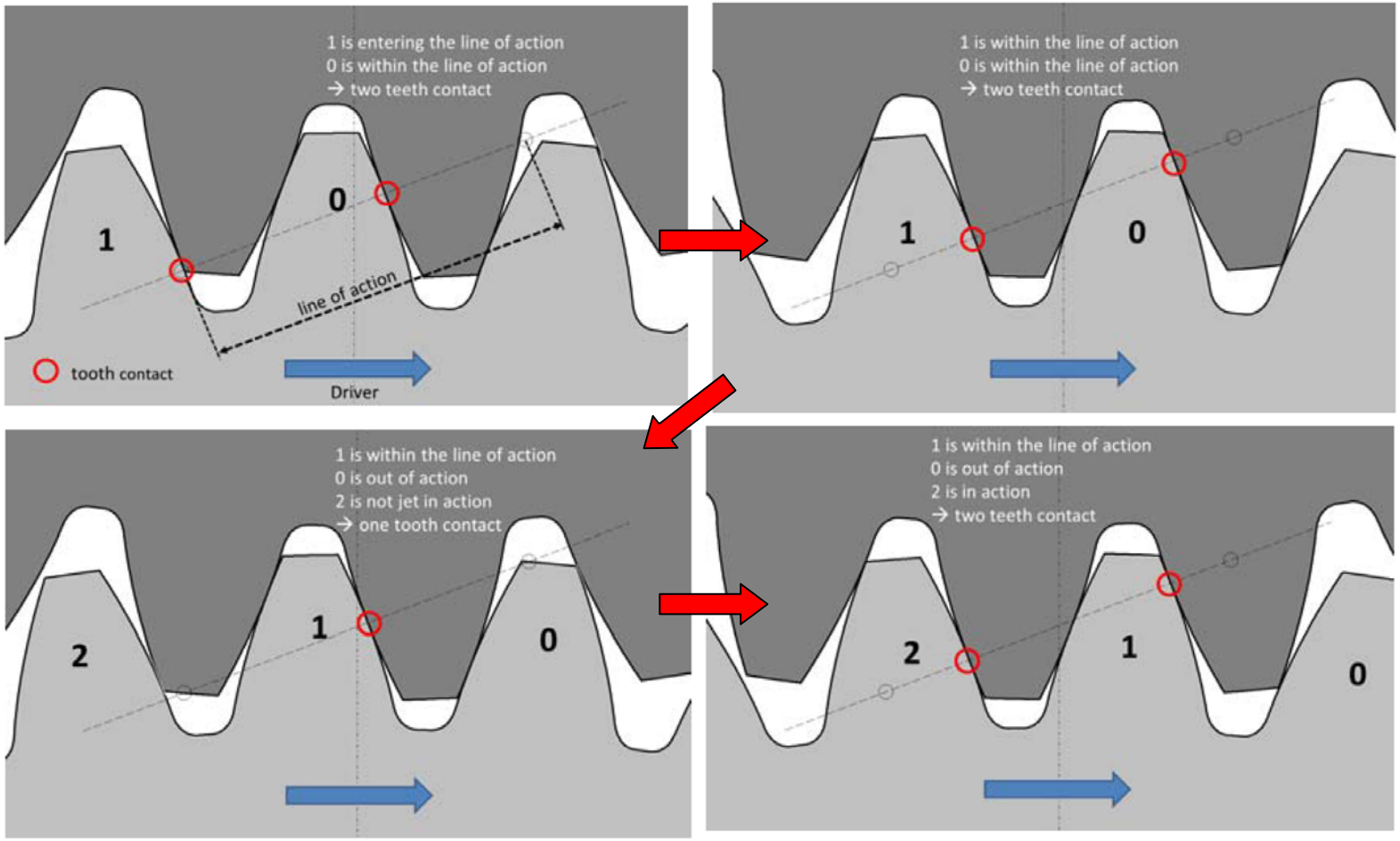
- Higher excitability around 1250 Hz of GGG-40 was confirmed compared with GG-20 by FEA.

- Gear tooth force is exciting the housing vibration and the acoustic level.

Gear mesh frequency of FPG.

6. Gear Optimization

Tooth Contact

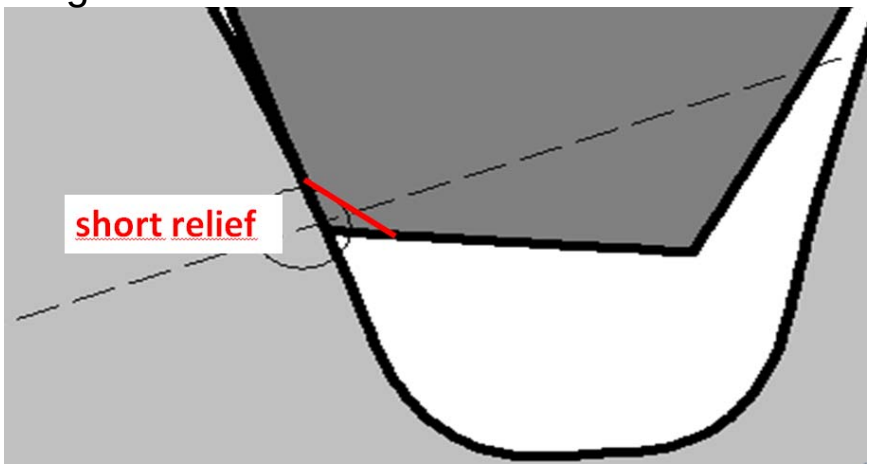


- *Cycle between 2 teeth and 1 tooth contacting produces the dynamic force change.*
- *Dynamic force change in the tooth contact is source of excitation force.*
- *High alteration of dynamic force due to suboptimal gear profile occurred.*

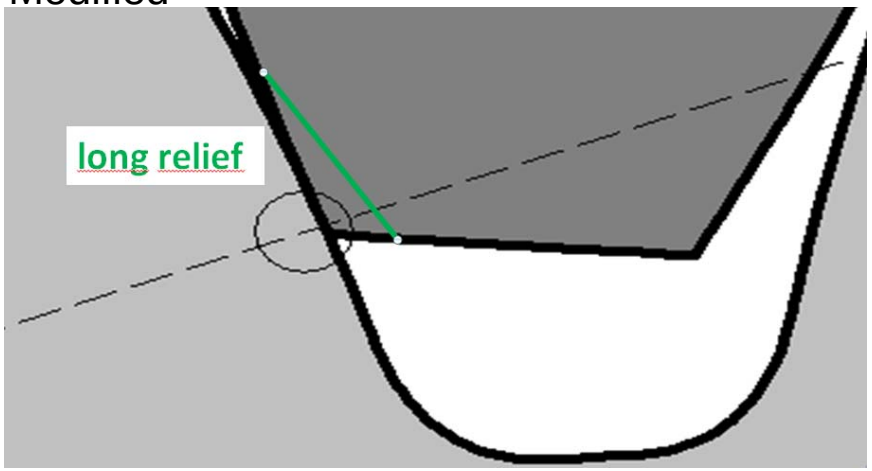
6. Gear Optimization

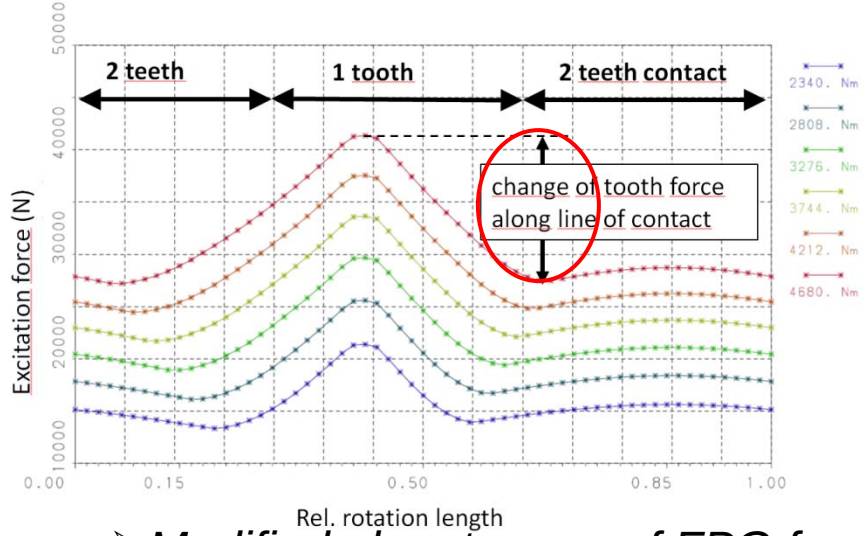
Tooth Modification

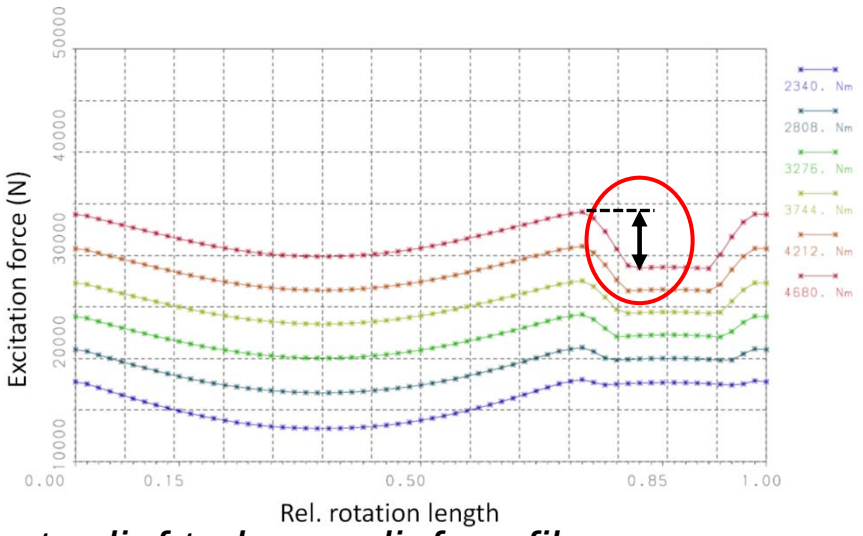
Original



Modified





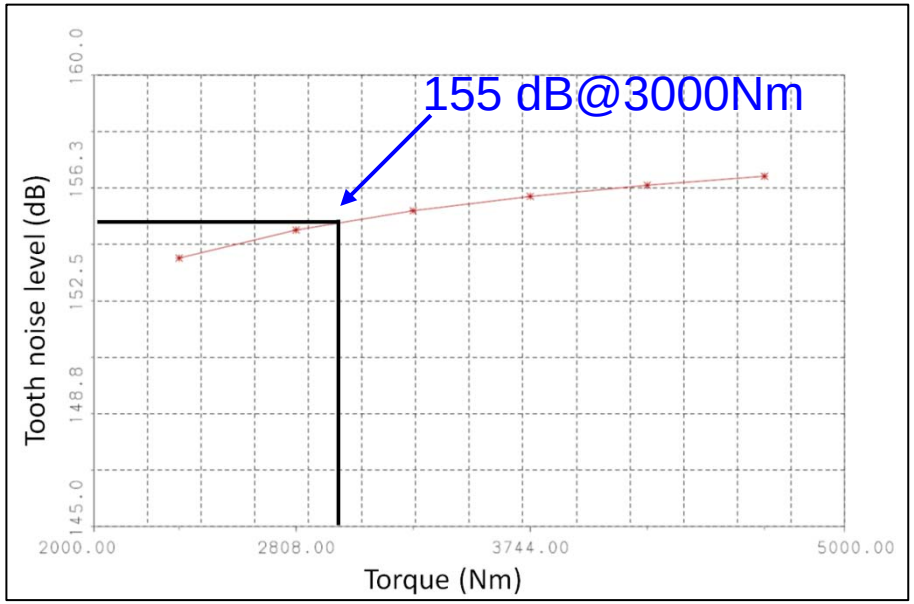


- *Modified planet gears of FPG from short relief to long relief profile.*
- *Amount of alteration of the dynamic force is significantly reduced with the modified profile.*

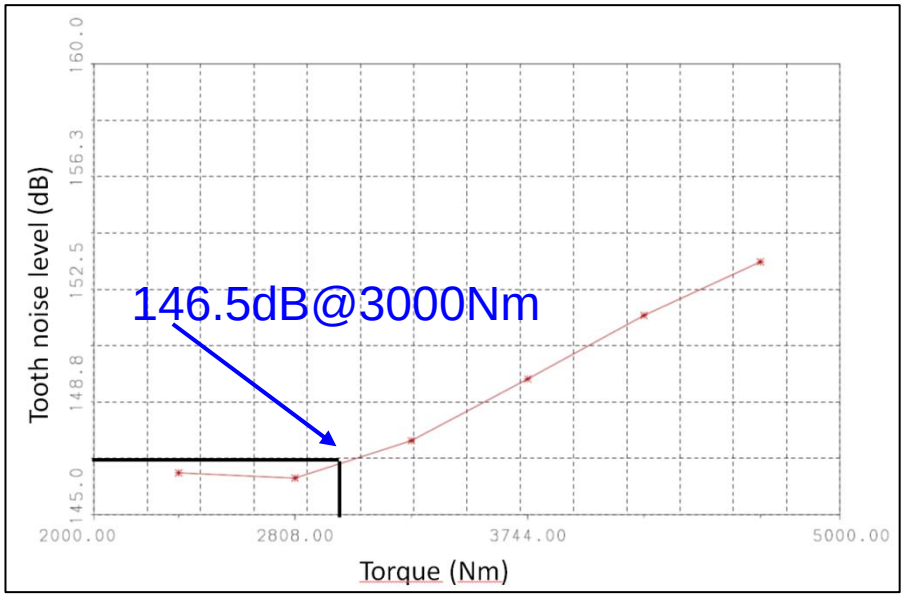
6. Gear Optimization

Tooth Noise Level

Calculation with short relief profile



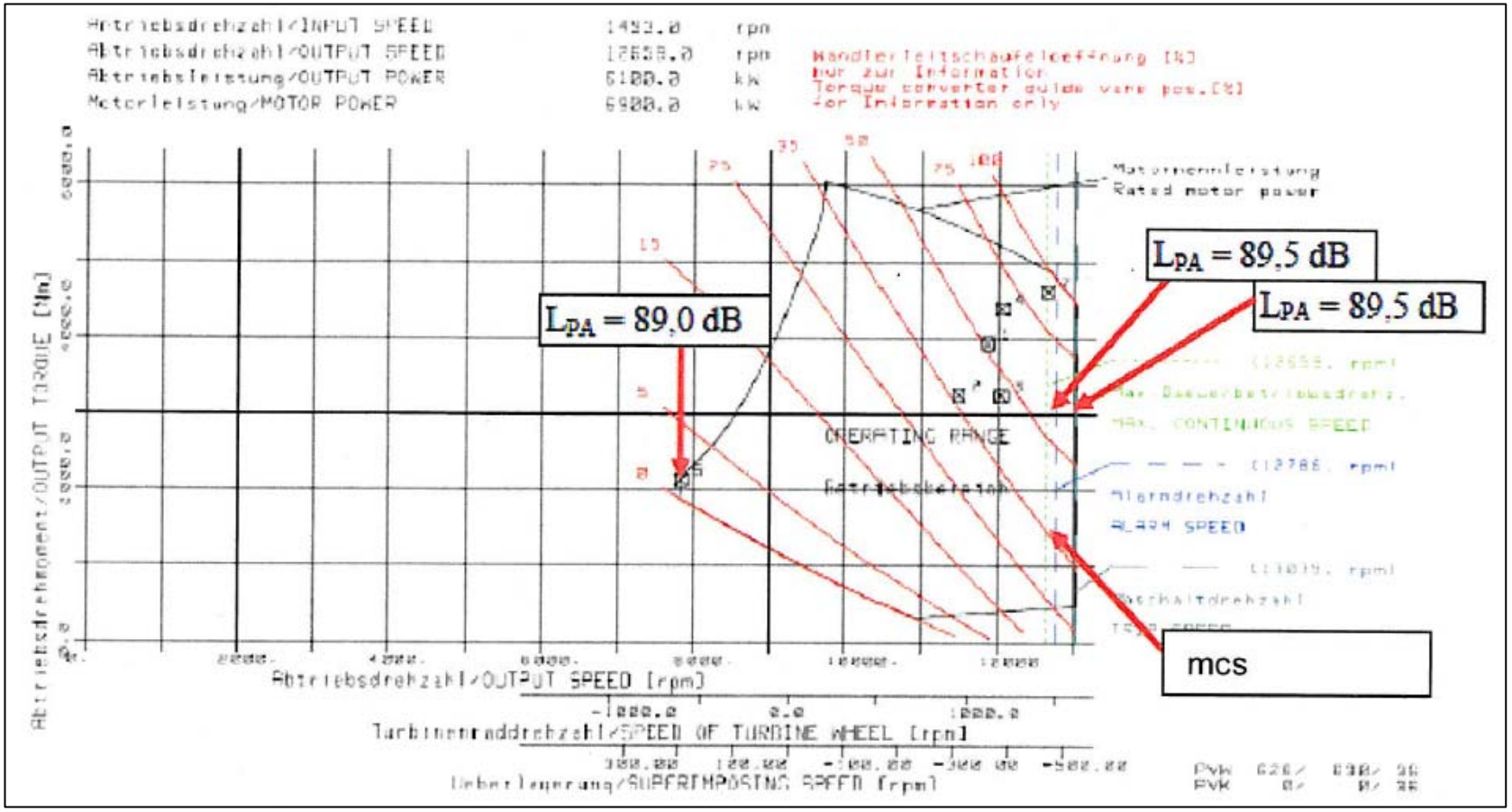
Calculation with long relief profile



➢*Tooth noise level can be reduced significantly by tooth modification.*

7. Noise Level After Gear Optimization

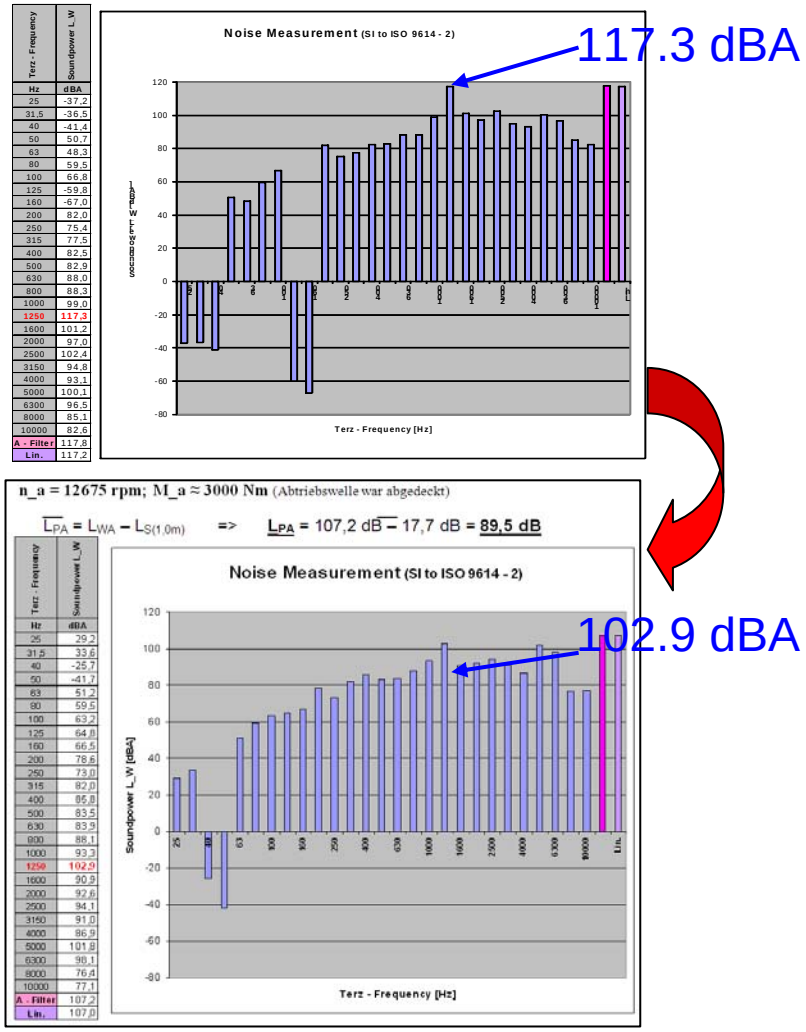
Gearbox #2 FAT result for noise measurement



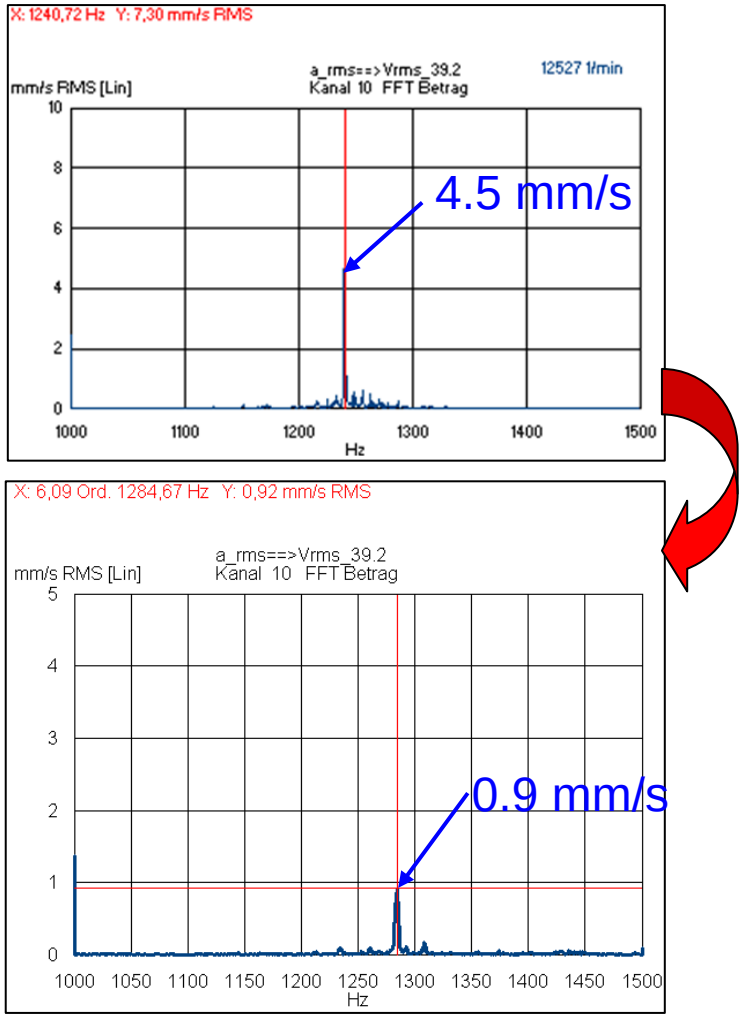
- *Overall noise level was reduced, from 100dBA to 89.5 dBA at output torque of 3000 Nm.*

7. Noise Level After Gear Optimization

Spectrum of Gearbox #2 acoustic level and housing vibration at 1250Hz



Acoustic level



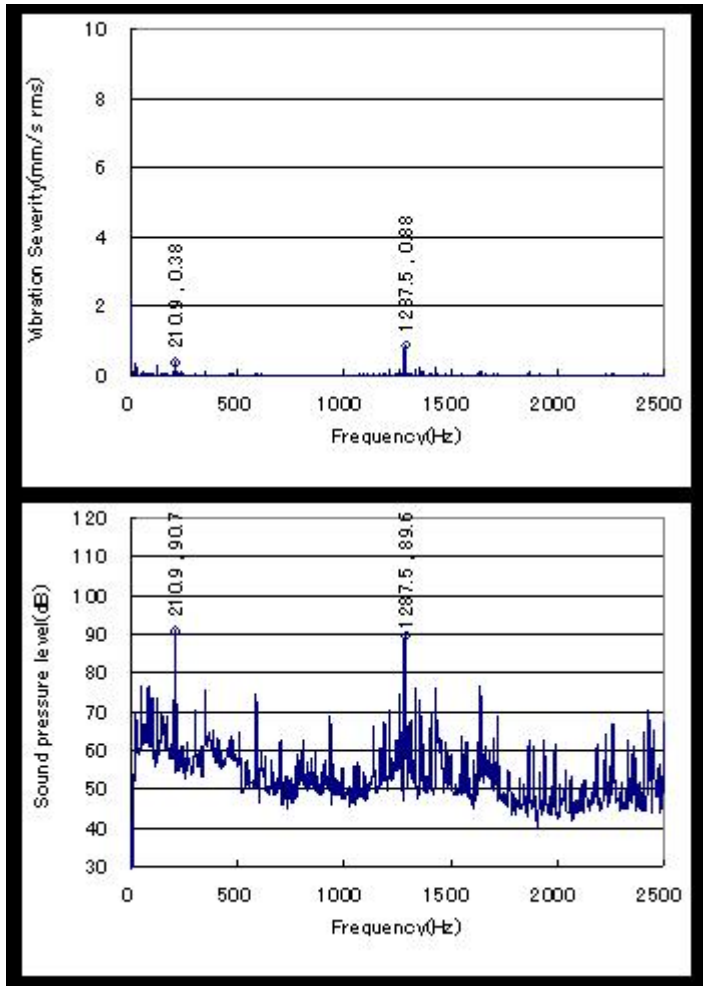
Gear Housing Vibration

7. Noise Level After Gear Optimization

Noise Measurement during compressor string FAT (w/ Gearbox #1)

•Vibration level of <1 mm/s in gearbox housing

• Sound pressure level of 90dBA



➢*With vibration and sound reduction achieved for two units, the gear profile change was also applied to Gearbox #3.*

8. Conclusion

- Variable speed planetary gear is based on power splitting principle.
- Abnormally high noise level and housing vibration were observed during gearbox FAT, as well as during compressor string FAT with a different gearbox.
- The possible causes were chosen and investigated using RCA-method.
- Planet gears of FPG were modified with long relief profile.
- The noise level and housing vibration improved significantly with gear tooth profile modification.
- The noise behavior of a system is dependent on various influences. (Load, mechanical properties of the housing, frequency range and gear parameters including gear tooth profile).
- With increasing focus on noise from a regulatory and occupational health perspective, gear tooth profile optimization, offers great potential for noise reduction.
- The knowledge and the calculation program for gear noise optimization has been implemented in the OEM design department for variable speed planetary gears.
- The profile modification of all upcoming units will be optimized for each particular application instead of using a generic profile for all units.