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M A R I N A B A Y S A N D S



# Emergency Damage Restoration Experience of 25MW Heavy-Duty Gas Turbine: Bearing Retrofit Design and Test Run

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- Currently, Principal Researcher / Rotordynamics Team, Dept. of System Dynamics Research, Mechanical Systems Safety Research Div., KIMM, South Korea
- Received Master in 1988 and Ph.D. in 1992 from Georgia Tech, USA
- Founded in 2005 Korea Rotating Machinery Engineers Association, KRMEA, and served as a president till 2011, and hosted the Annual Korea Rotating Machinery Symposium the past 13 times
- Serves as a Korean committee member of ISO/TC108
- A member of ASME, STLE, Korean Society of Mechanical Engineers, Korean Society for Noise and Vibration Engineering, Korean Society of Tribologists and Lubrication Engineers, and Korean Fluid Machinery Association
- An accomplished scientist and researcher with international recognition in the field of Rotordynamics, Lubrication, Design Audit, Failure Analysis, and High-Speed Balancing
- Author or co-author of over 150 publications, including over 60 journal papers with 5 ASME papers

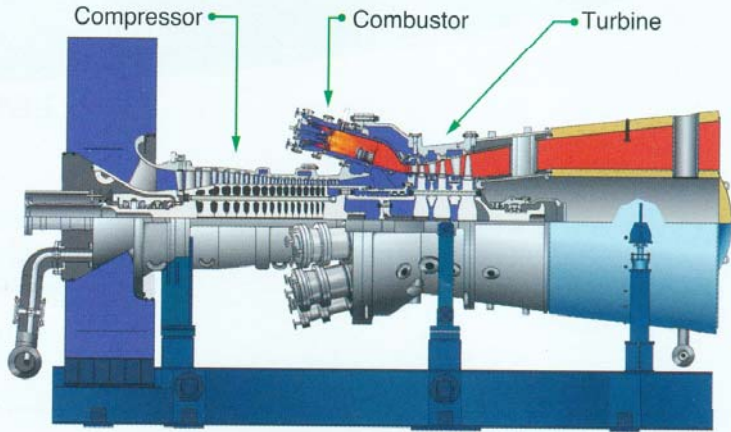
### **ACKNOWLEDGEMENTS**

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## Short Abstract

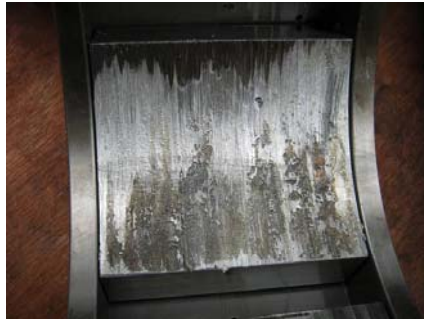
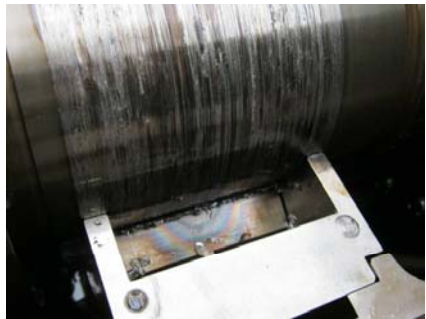
**Emergency Damage Restoration Experiences of 25MW Heavy-Duty Gas Turbine: Bearing Retrofit Design and Test Run** - A 25MW gas turbine had been damaged during operation. Particularly, its tilting pad journal bearings and shaft journals had suffered complete wiping-out and deep crack damages, respectively. For an emergency restoration, both cracked journals had been machined out as much as 2% per the specified design diameter, and a series of design, analysis and manufacturing of the retrofit journal bearings had been carried out to have practically identical overall design characteristics to the OEM bearings. To verify operational reliability, the restored GT rotor had been test-run at KIMM's high-speed balancing facility. Since the test results had been favorable, the rotor had been put into an onsite operation, immediately. The restored GT system has been continuously running a stable commercial operation for more than 41 months up until now. This presentation introduces design analysis of the retrofit bearings, test run result of the restored GT rotor-bearing system, and the lessons learned.

## Problem Statement



- H25 GT: 25 MW (1st unit ever exported overseas out-of Japan)
- Rated speed: 7,280 rpm

- Due to the loss of lubrication oil supply, the GT suffered extensive damages, particularly, at its bearings and journals.

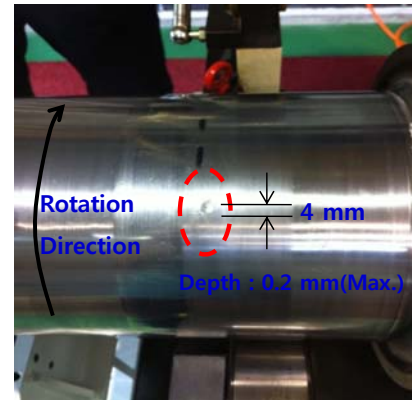


## Considerations and Objectives

- A tight restoration schedule of less than 2 weeks. So, buying a new rotor was not an option.
- A limited repair capability in Korea, i.e., no welding and heat treatment shop available.



Machining-out damaged journal

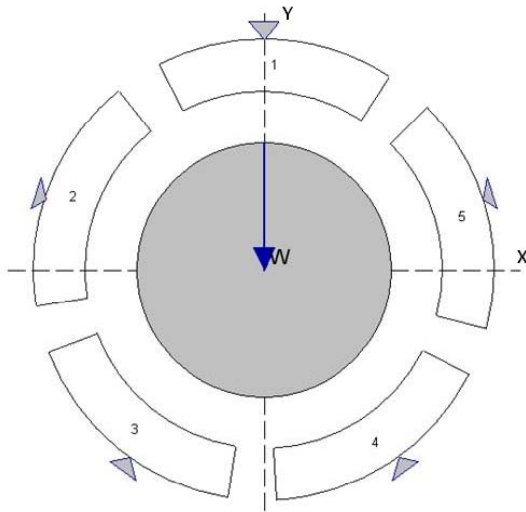


Remaining tear-drop in TBN side journal

- Because of repair machining-out, journal diameters decreased about 2%.
- But OEM gives a design assurance on any machining modification **only up to 1% of the shaft journal diameter.**
- **Need to secure a reliability on journal repair and bearing design retrofit by design analysis & review.**
- **Need to secure a vibrational/operational reliability of the whole rotor with rubbing damages of blades by test run, utilizing KIMM's high-speed balancing facility.**

## Bearing Design Analysis and Considerations

- Basic Approach Concept:** By thorough/comprehensive analysis and review on the interrelationships between the bearing performances and design variables, it is possible to come up with key design control variables of the bearings, which will best-minimize operational characteristic changes of retrofitted bearings and rotor system as well.



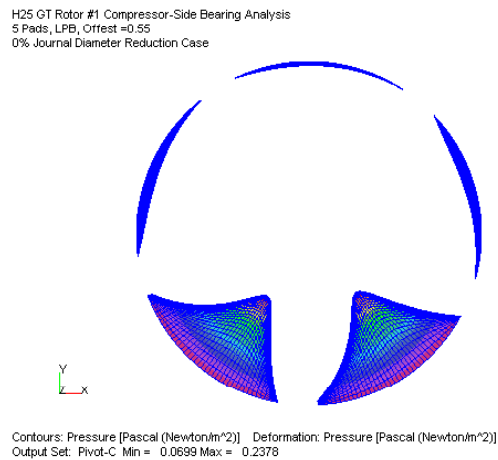
5-Pad LBP Geometry

	Compressor Side	Turbine Side
Bearing Type	Tilting pad, LBP	Tilting pad, LBP
Number of Pads	5	5
Journal Dia. (mm)	184	184
Bearing Length (mm)	90	110
Bearing Diametral Clearance (mm)	0.290	0.290
Bearing Load (N)	28545	32586
Rated Speed (rpm)	7280	
Lubricant	ISO VG32	
Supply Oil Temp. (°C)	52	52
Oil Flow Rate (l/m)	78	85

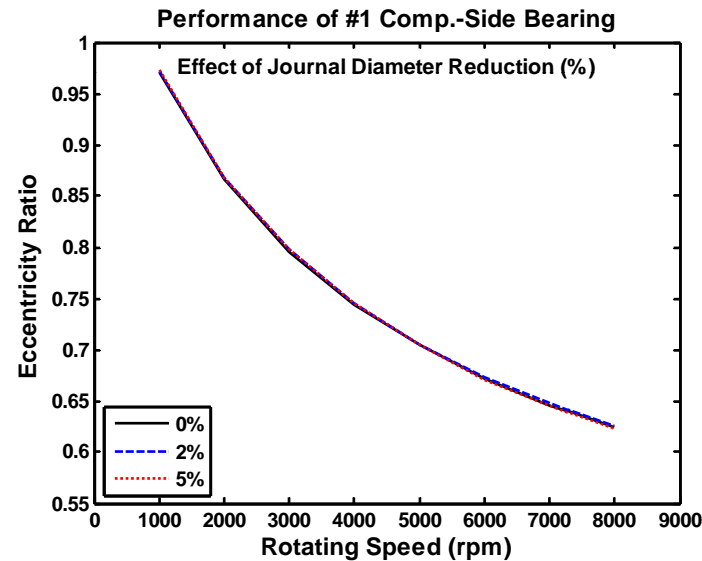
- Consider 3 bearings retrofit design analysis cases, depending on the journal diameter reductions (%):**
  - 0% less,
  - 2% less,
  - 5% less

# Bearing Design Analysis Results and Review

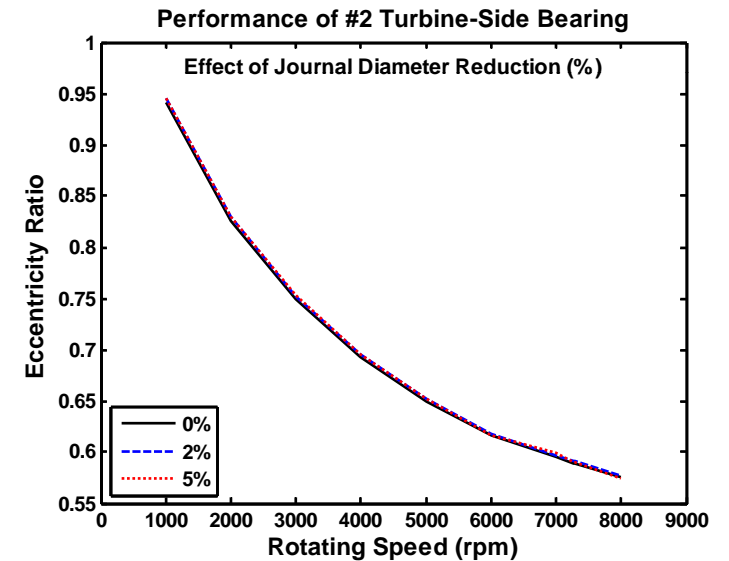
- Complex bearing performance analyses at rated and over full operating speed range, including a lift-off speed



Pressure Generation



Eccentricity Ratio Analysis

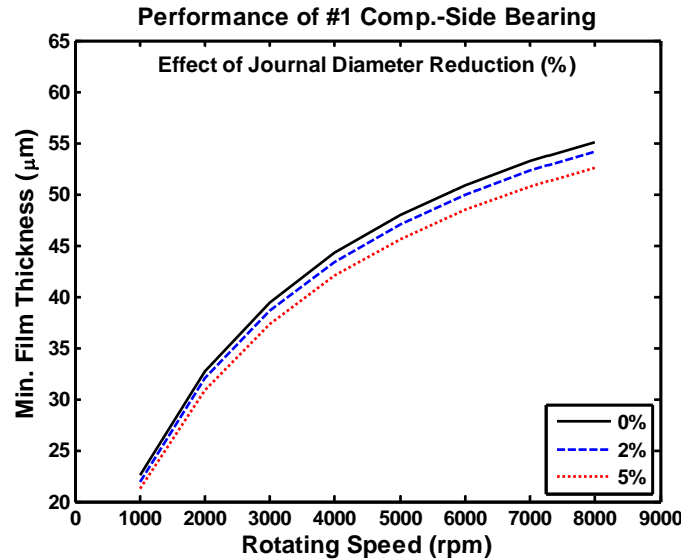


- Regardless of the journal diameter reduction rates (%), the eccentricity ratios are analyzed as almost identical to the original ones for the compressor and turbine-side bearings, respectively.
- Therefore, it is confirmed that the bearing design control variables have been selected satisfactorily.

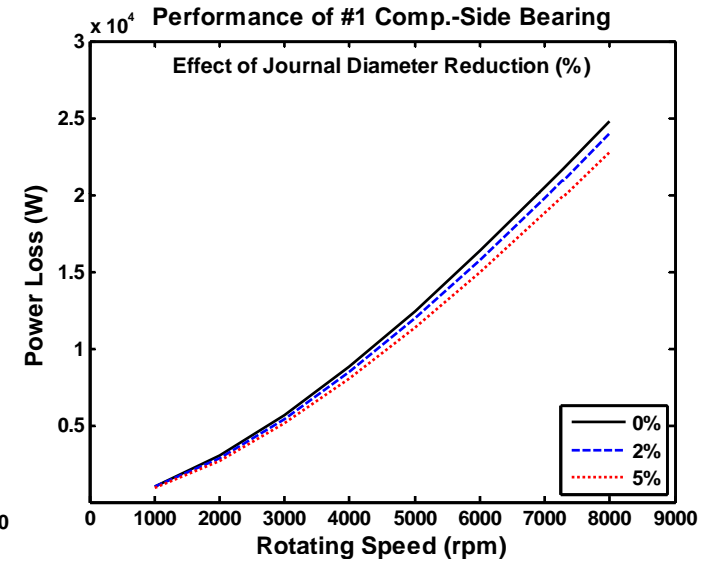
# Bearing Design Analysis Results and Review

Journal Dia. Reduction Rate	Starting Lift-Off Speed of Journals (rpm)	
	Compressor-Side Bearing	Turbine-Side Bearing
0% Less	58	52
2% Less	60	53
5% Less	61	54

Starting Lift-Off Speed Analysis



Minimum Film Thickness Analysis

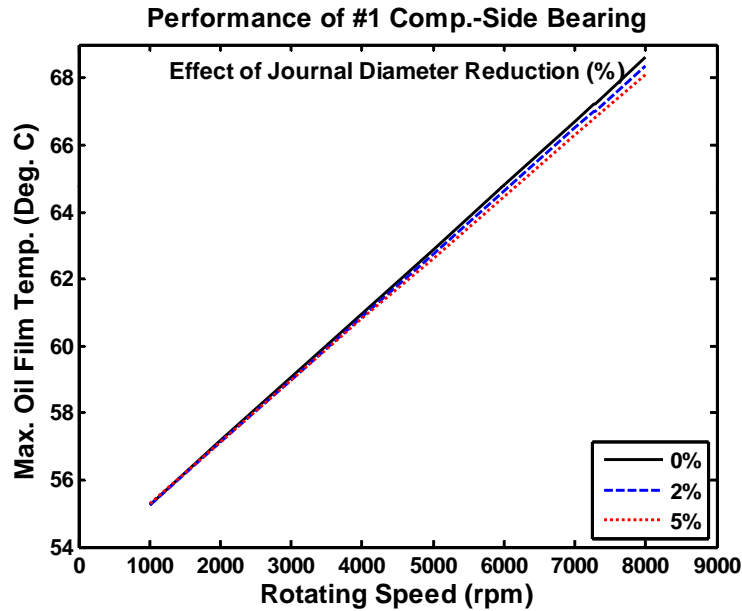


Power Loss Analysis

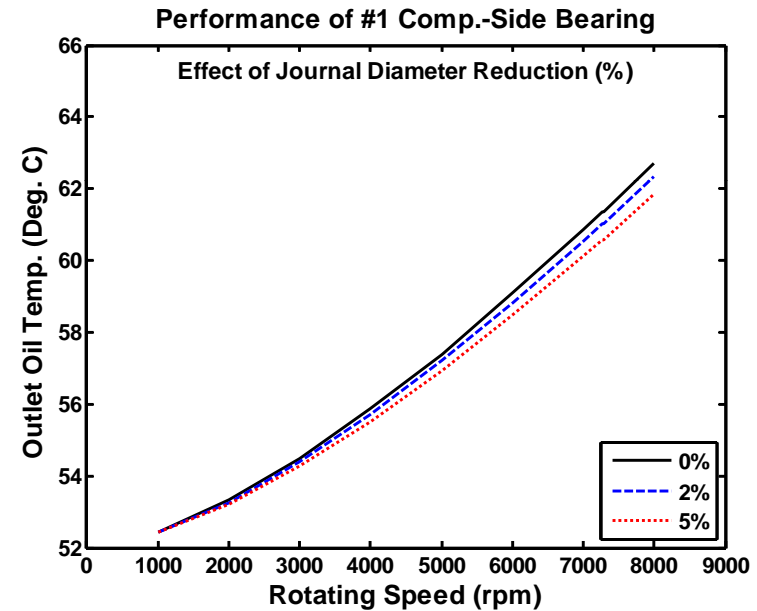
- As the journal diameters decrease 2%, the starting lift-off speeds increase 1 ~ 2 rpm. **No detrimental effect on pad babbitt wear at starting is expected.**
- At the rated speed the minimum film thickness of compressor-side bearing decreases about 1 µm from 53.75 to 52.80 µm.
- The power loss of compressor-side bearing improves about 3.5% from 21,659 to 20,910 W.



# Bearing Design Analysis Results and Review



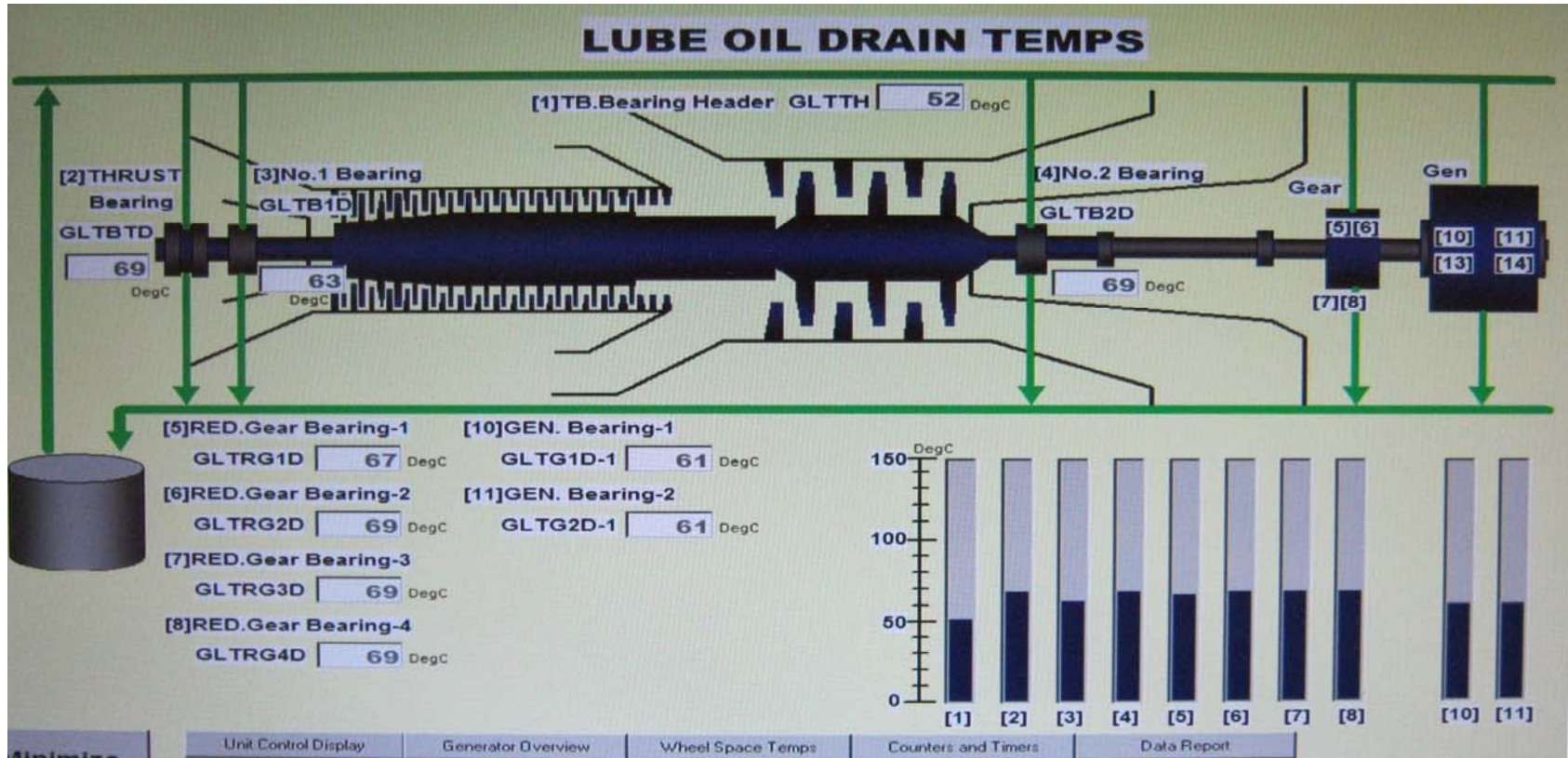
Maximum Oil Film Temperature Analysis



Outlet Oil Temperature Analysis

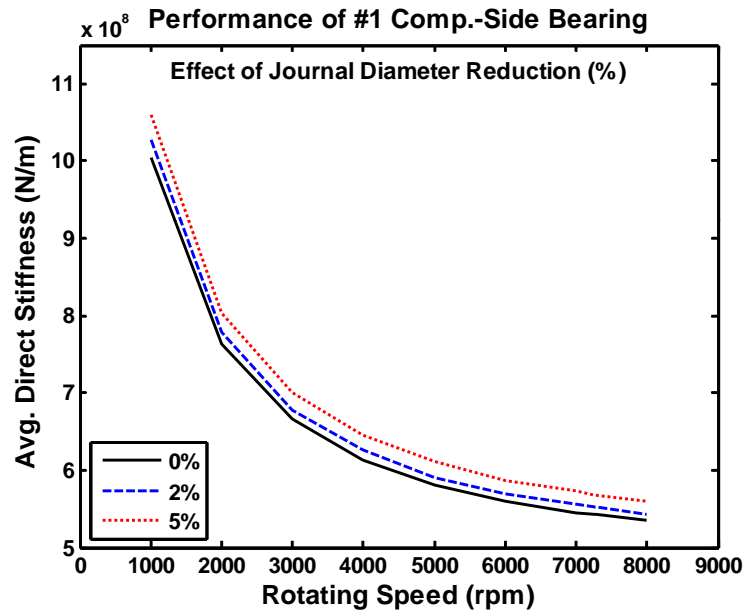
- As the journal diameter decreases 2%, at the rated speed the max. oil film temperature of compressor-side bearing decreases 0.2°C from 67.2 to 67.0°C.
- The outlet oil temperature of compressor-side bearing decreases 0.4°C from 61.4 to 61.0°C.

## Past Measured Outlet Oil Temp. For #2 GTG During Normal Operation (Verification Reference)

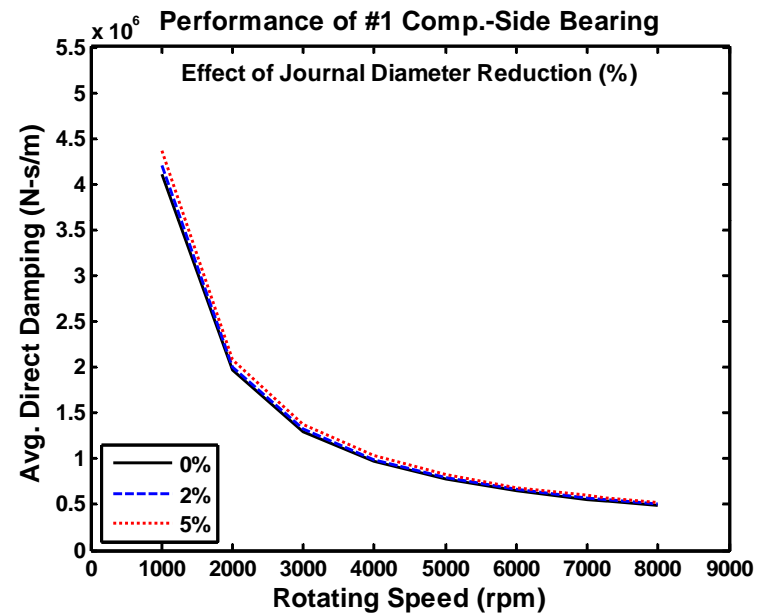


- With a supply oil temp. of 52.0°C, the outlet oil temps. of compressor and turbine-side bearings were 63°C and 69°C, respectively.
- Considering a heat transfer effect from the rotor shaft, the 63°C measured at the compressor-side bearing agrees very well with the 61.4°C predicted by the analysis.

# Bearing Design Analysis Results and Review



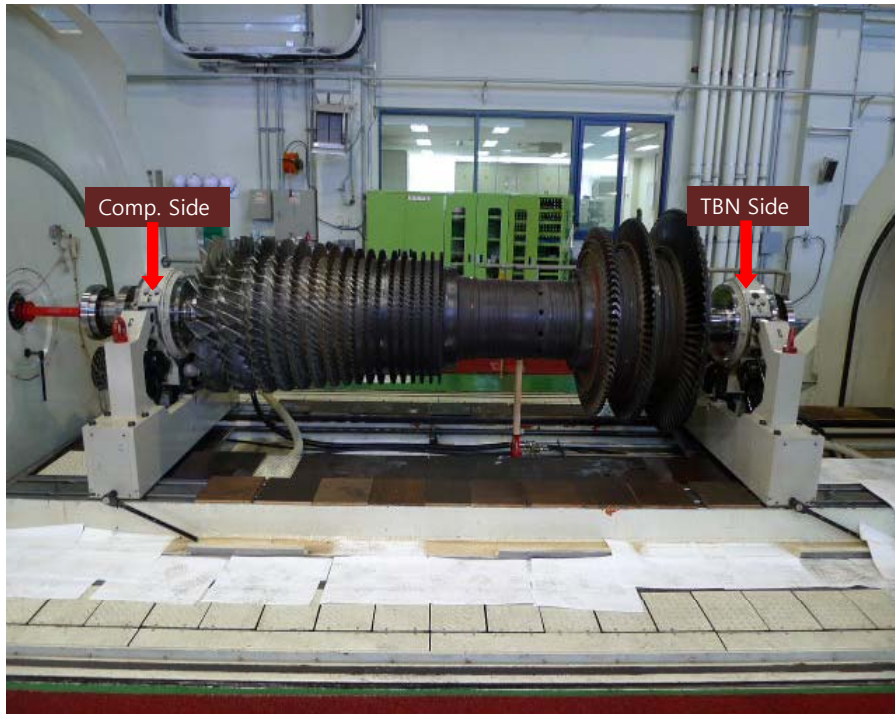
**Bearing Stiffness Analysis**



**Bearing Damping Analysis**

- As the journal diameter decreases 2%, at the rated speed the average direct stiffness of compressor-side bearing increases about 1.84% from  $5.421 \times 10^8$  N/m to  $5.521 \times 10^8$  N/m.
- The average direct damping of compressor-side bearing increases about 2.03% from  $5.415 \times 10^5$  N-s/m to  $5.525 \times 10^5$  N-s/m.
- Therefore, not much differences are expected, concerning the bearing stiffness and damping.

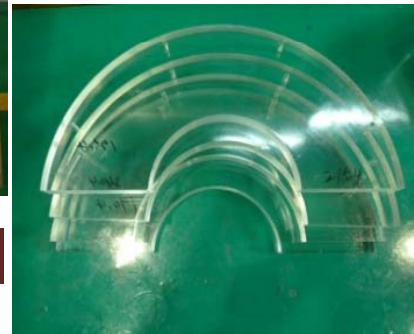
# Test Run: Preparation & Installation at KIMM's High-Speed Balancing Facility



## ○ Manufacturing of necessary parts



Coupling flange

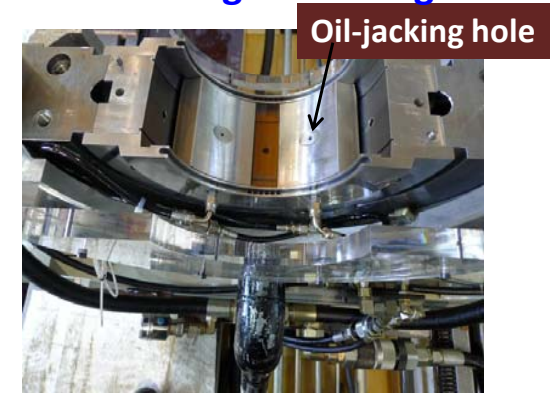


Oil cover



Test-run bearings

## ○ Mounting of Bearings

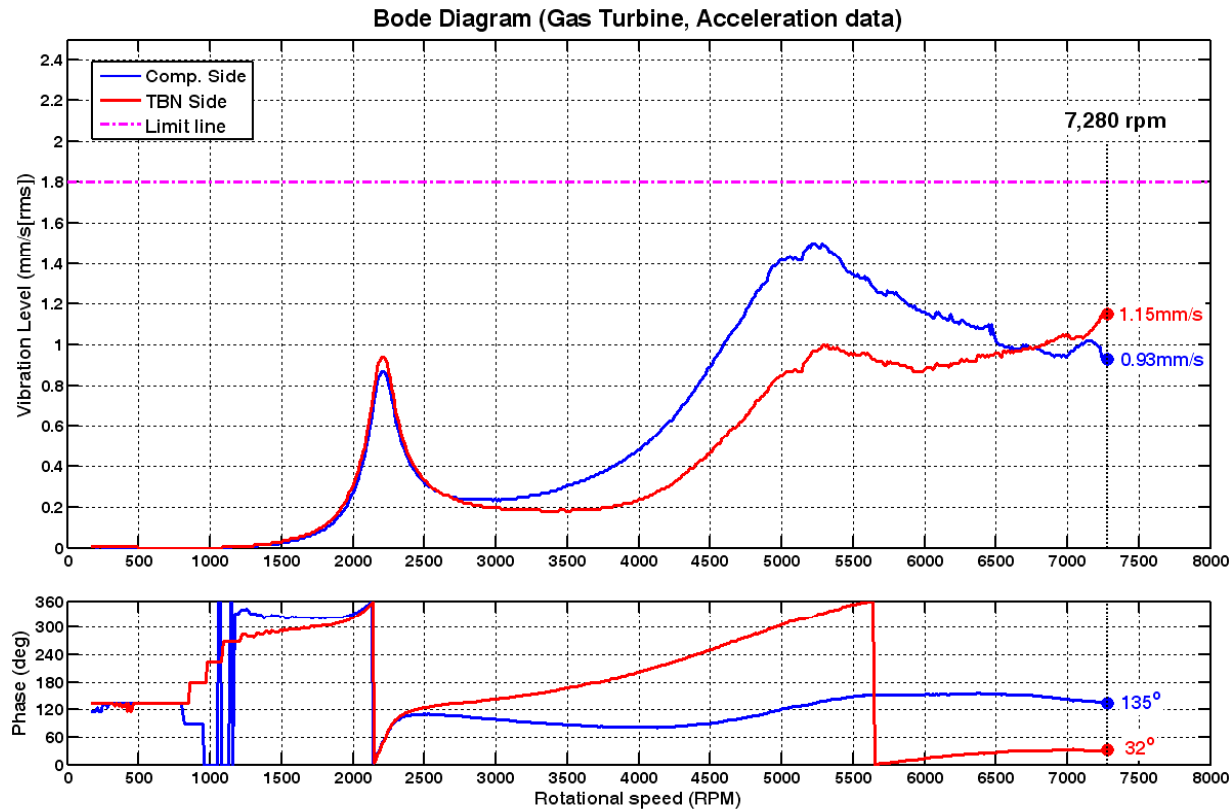


## ○ Laser Alignment



- Total mass: 6234 kg
- Test speed: 7,280 rpm
- 1<sup>st</sup> Critical speed: ? rpm
- 2<sup>nd</sup> Critical speed: ? rpm
- Balancing/Vibration criteria:  
1.8 mm/s at Brg Pedestals

# Test Run: Run-Up Test Result After Sag Stabilization

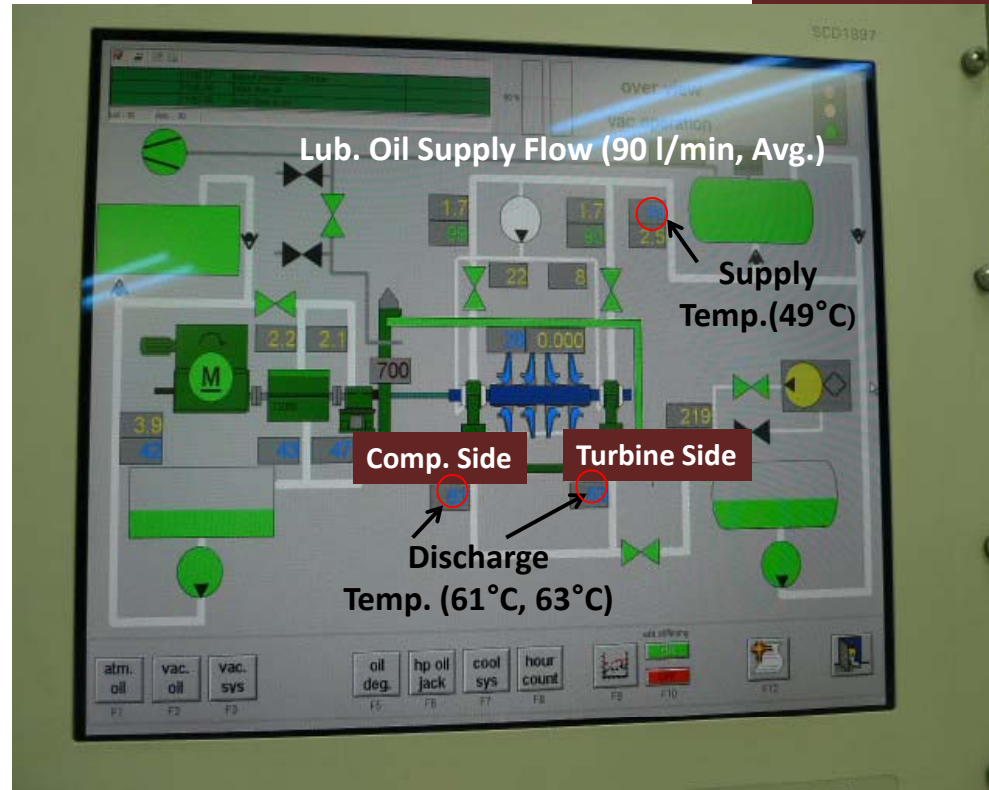


<b>7,280 RPM</b>	
<b>Comp. Side</b>	<b>0.93 mm/s <math>\angle</math> 135°</b>
<b>TBN Side</b>	<b>1.15 mm/s <math>\angle</math> 32°</b>

- After several run-ups, the sag effect was eliminated.
- After sag removal, the vibration responses were stable at the 2nd critical (about 5,300 rpm) and rated speeds.
- The vibrations at the rated were even and favorable as the max. 1.15 mm/s. (Therefore, a ship-out was determined without any high-speed balancing effort.)

## Test Run: Operation Result of Test-Run Purpose Bearings

At rated speed



At rated speed with supply oil temp. of 49C, discharge oil temps. were measured as the comp.-side bearing: 61°C and turbine-side bearing: 63.5°C.

## Ship-Out of H25 GT Rotor



## Conclusions and Lessons Learned

- During an emergency restoration process of damaged 25MW industrial gas turbine, we had tried best to secure some verified-reliabilities on the proposed bearing design retrofit, inevitable, after repair machining-out of damaged rotor journals and also on the vibrational soundness of the GT rotor, suffered with wide rubbing damages:
  - By comprehensive analytical design analysis and review on the retrofitted bearings
  - By test run, utilizing the High-Speed Balancing Facility
- The restored GT rotor system has been continuously running a stable commercial operation for more than 41 months up to now, without a single problem.
- At a time of emergency accident, an end-user's initial evaluation and decision are very important, based on a given situation:
  - Make a comprehensive/rational judgement and reasonably challenging decision
  - Within given limitations, prepare best possible complementary measures not to let your decision be foolhardy or reckless
  - Best mobilize available cooperation partners, especially, domestically if possible
  - After a decision, execute fast