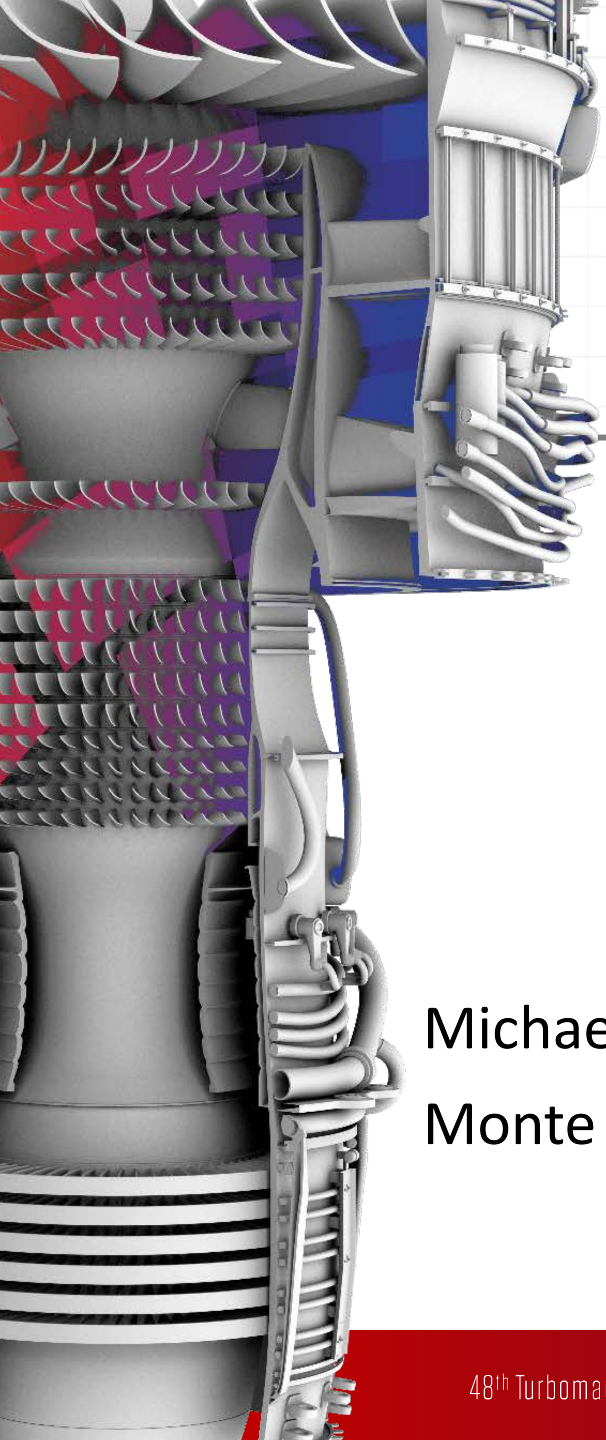


TURBOMACHINERY & PUMP SYMPOSIA

Influence of Bearing Selection on MTBF (Mean Time Between Failure) of a Screw Expander in Geothermal Power Generation Service

Michael Macek, P.E. - Macek Power & Turbomachinery Engineering

Monte Morrison, P.E. - Cyrq Energy

Presenter Biographical Information

Michael "Mike" Macek

is the Owner and Engineering Manager of the consulting and manufacturing firm, Macek Power & Turbomachinery Engineering. He has worked in the industrial turbomachinery industry his entire career, which began in 1993. Prior to founding his firm, Mike held engineering positions at various shops in the Houston area, including Sulzer Turbomachiery Services, Alfred Conhagen of Texas, and Revak Turbomachinery Services. His experience encompasses a wide range of turbomachines in both theoretical and "hands on" capacities. Mike holds B.S. (1991) and M.S. (1993) degrees in Mechanical Engineering, both from Texas A&M University (College Station).

Presenter Biographical Information

Monte Morrison

is a third generation Nevadan, having grown up in Sparks, NV and currently residing in Fallon for the past 28 years. He attended the University of Nevada's Mackay School of Mines and gained a BS in Chemical Engineering in 1986. He earned a Professional Engineering License from the State of Nevada in Chemical Engineering. Monte has over 34 years of experience in the management of power plants and geothermal well fields within the power generation industry. He has managed geothermal power plants and well fields in Nevada, California, Hawaii, Utah and New Mexico for six different companies from assistant manager to an executive in operations and safety. Mr. Morrison is now Cyrq Energy's VP Operations and Safety for their operating fleet. His responsibilities include all aspects of managing the operations of Cyrq's power plants in the United States and safety responsibility for the entire organization.

In addition, Mr. Morrison has managed safety at the executive level for the former Alterra Power Corporation run of river hydroelectric and wind power plants in British Columbia, Canada and for two large geothermal power plants in Keflavik, Iceland. Monte has been a certified Emergency Medical Technician (EMT-1) in Nevada for the past 30 years.

Background

Lightning Dock Geothermal, one of several facilities owned by Cyrq Energy, is a power producer located near Animas, New Mexico, USA. Installed as part of Phase I are four (4) “power blocks”. The prime mover of each power block is a screw expander unit, rated at 1,000 kW. The driven machine is a synchronous AC generator. The working fluid is R245fa refrigerant, which is transformed to a slightly superheated state by means of a heat exchanger and hot geothermal water extracted from the well field.

The plant was commissioned in 2013 December and unfortunately, since that time, has suffered from numerous equipment failures related primarily to equipment design. Chronic, extremely short expander life manifested through catastrophic bearing failure has been the most notable and by far, the most costly of the equipment problems. This case study describes a change in bearing selection that significantly increased MTBF (mean time between failure).

Problematic Machine – Screw Expander

Application: Power generation

Rated Output: 4 x 1,000 kW (4 identical units installed)

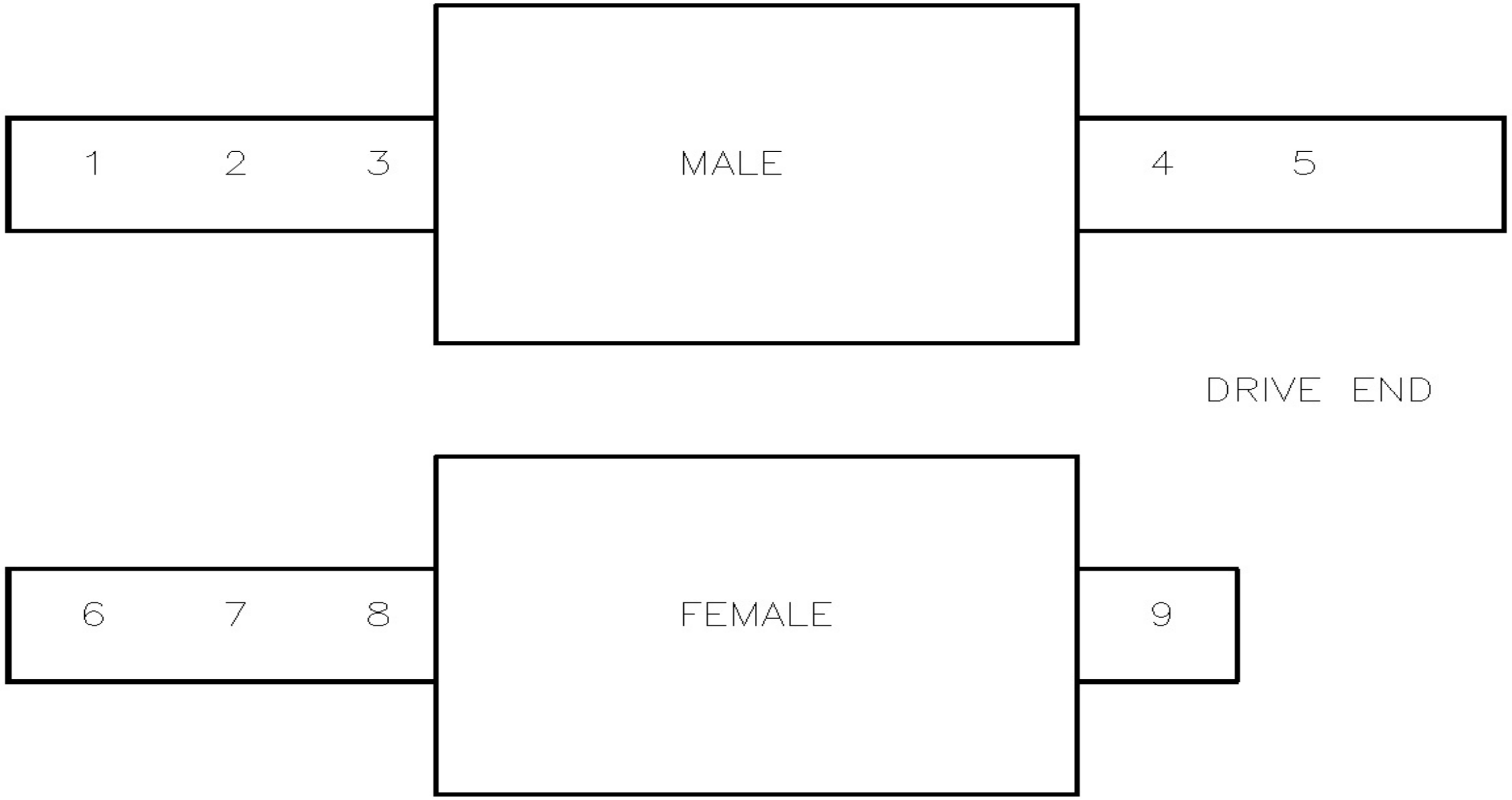
Working fluid: R245fa (refrigerant)

Male rotor: 5 lobes (1800 RPM)

Female Rotor: 6 lobes (1500 RPM)

Bearings: Rolling element (cylindrical and tapered)

Bearing Arrangement



Bearing	Type
1	Tapered Roller
2	Tapered Roller
3	Cylindrical Roller
4	Cylindrical Roller
5	Cylindrical Roller
6	Tapered Roller
7	Tapered Roller
8	Cylindrical Roller
9	Cylindrical Roller

Rotors

Male

Female

Objective:

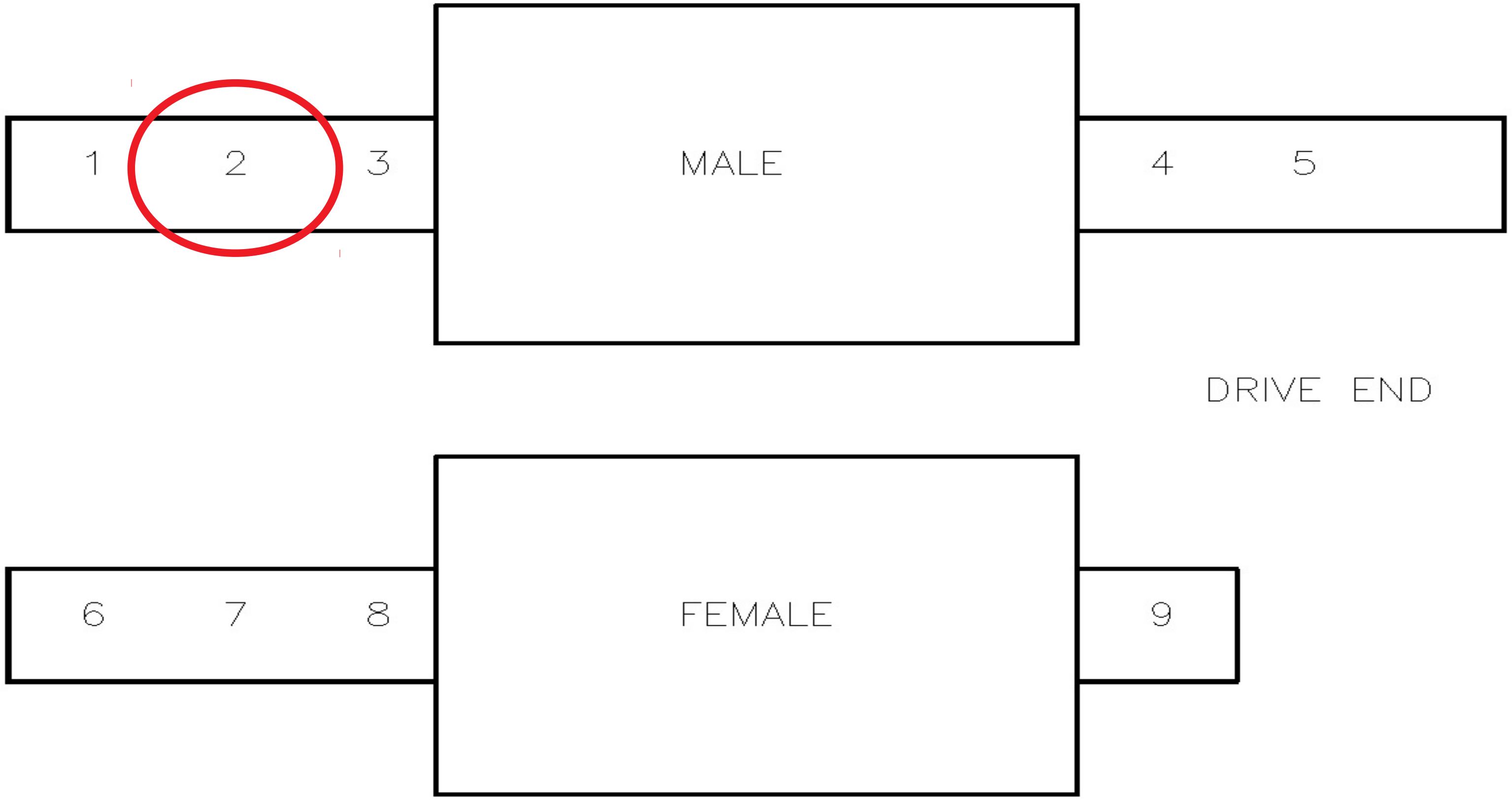
Determine cause or causes of highly premature bearing failure

Failure	Unit	Run time at Failure [hrs]
1	3	2,769
2	4	2,065
3	2	3,891
4	1	3,460
5	4	1,338
6	3	2,808

Pending failure indicated by casing vibration (velocity) sensors.

Failed Component

Bearing '2' (Male rotor active thrust bearing) – All six (6) failures



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Possible Causes of Failure

1. Axial shock load
2. Excessive steady load
3. Misalignment
4. Improper installation
5. Manufacturing defect
6. Insufficient lubrication
7. Contaminated lubricant
8. High oil supply temperature
9. Change in expander operation

Possible Causes of Failure

1. ~~Axial shock load~~
2. **Excessive steady load**
3. ~~Misalignment~~
4. ~~Improper installation~~
5. ~~Manufacturing defect~~
6. ~~Insufficient lubrication~~
7. **Contaminated lubricant**
8. ~~High oil supply temperature~~
9. ~~Change in expander operation~~

Analysis of Steady Radial Load

Assumptions:

1. Adequate lube oil flow and supply temperature
2. ISO 4402 lube oil cleanliness 16/14/12 or better
3. Radial bearings carry 100% of radial load

Bearings:

- NU326 ECML (Male rotor, non-drive end)
- NU228 ECML x2 (Male rotor, drive end)
- NU2226 ECP (Female rotor, both ends)

Method:

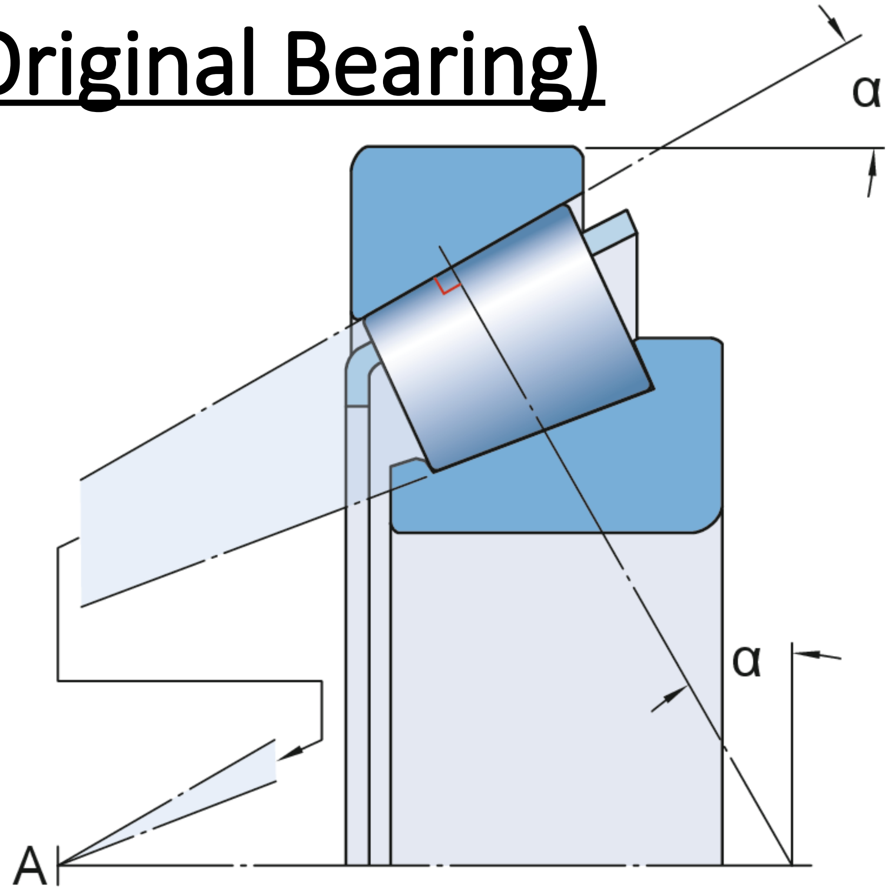
- Publicly available life rating calculation methods

Result:

- All radial bearings expected to provide >1,000,000 hours (114 years) bearing life

Conclusion:
Radial Load is NOT excessive.

Analysis of Male Rotor Steady Axial Load (Original Bearing)



Load:

Independently estimated axial load as 73 kN (16,425 lb_f)

OEM reported axial load as 71 kN (15,975 lb_f)

Bearings:

- **30326 J2 (Active thrust, Tapered roller, 12° Contact angle)**

Method:

- **Publicly available life rating calculation methods**

Result:

14,400 hours predicted life for extremely clean oil at 75°C inside bearing

Comment:

- **Calculation result supported by operation history (premature failure)**

Conclusion:
Axial Load is excessive.

Analysis of Male Rotor Steady Axial Load (Changed Bearing)

Bearings:

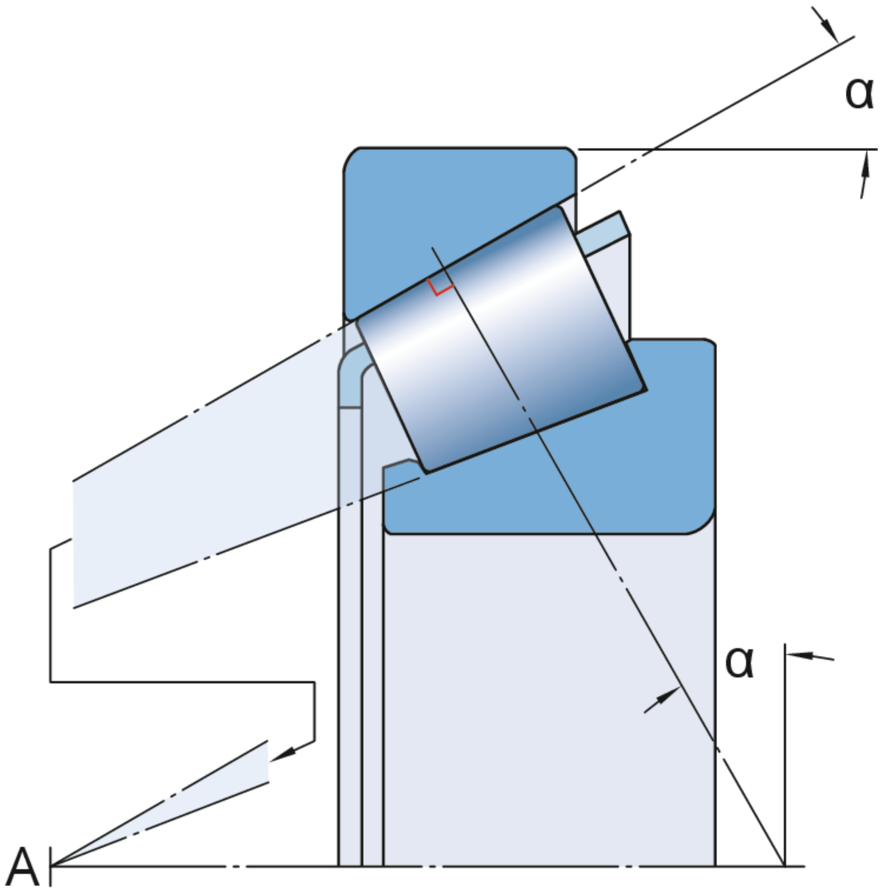
- **30326 J2 (Original, Active thrust, Tapered roller, 12° Contact angle)**
- **31326 XJ2 (Changed, 30° Contact angle, Same fit and form as original)**

Result:

34,900 hours predicted life calculation for extremely clean oil at 75°C inside bearing

Comments:

- **True tapered roller thrust bearings provide contact angle >45°**
- **2.4x improvement in new male rotor active thrust bearing life expected**
- **Dramatically improved theoretical life calculation result still falls short of typically acceptable design criteria (50,000 hrs minimum life), but bearing replacement is limited by existing bearing fit geometry.**



Q: What was done?

A: Replace 30326 J2 bearing with 31326 XJ2 bearing

(The #2 bearing, which is the male rotor thrust bearing)

What were the results?

Actual Results

1. **MTBF (Mean Time Between Failure) approximately doubled.**
2. **Premature bearing failure continued to be significant due to lube oil dilution (by the working fluid) and contamination (particle size).**

Unit	MTBF [hrs] (Previous)	MTBF [hrs] (Next)
1	3,460	7,035
2	3,891	5,967
3	2,808	5,269
4	1,338	6,756

Previous = MTBF Prior to #2 bearing change from J2 to XJ2 model

Next = MTBF subsequent to #2 bearing change

Conclusions

1. **A true thrust bearing was not provided by the expander manufacturer. The tapered roller bearing initially provided as the male rotor active thrust bearing was not appropriate for the application.**
2. **The change in bearing selection approximately doubled MTBF, but was still not a true thrust bearing. Thus, although MTBF improved, it was not considered acceptable. A bearing retrofit suitable for the application would have required major redesign of the expander.**
3. **Publicly available bearing life calculation methods, in this instance, were a good indicator of expected bearing life for the thrust bearing application.**
4. **Oil lubrication characteristics can be significantly affected through dilution by the working fluid in "wet" screw applications such as the one considered by this case study.**
5. **Bearing life is significantly affected by load, lube oil type and condition, and temperature. Each application should be carefully reviewed prior to bearing selection, especially where critical equipment is concerned.**

Thank you