Generalized Models for Rolling-Element Fatigue

Parts 2 & 3: Implementation for Ball & Roller Bearings

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Ball & Roller Bearing Implementation
Introduction

- Current LP life model benchmarked to pre-1940 bearing materials use fixed material properties in model constant
- Commonly used LP life equations underestimate life at light loads
- LP and GZ life models developed in Part 1 provide capability to model arbitrary material properties
- Newly introduced GZ life equation in Part 1 provides higher lives at light loads

Model Comparisons

Original LP Model	New LP Model	New GZ Model
Empirical model constant derived for Pre-1940 materials	**Empirical model constant derived for post-1960 materials**	**Empirical model constant derived for post-1960 materials**
Critical shear stress, Max τ_0	Critical shear stress, Max τ_0	**Critical shear stress, Max τ_{45}**
Elastic material properties, fixed, cannot be changed	**Material elastic properties, variable**	**Material elastic properties, variable**
Shear Stress-Life exponent function of Weibull modulus	Shear Stress-Life exponent function of Weibull modulus	**Shear Stress-Life exponent independent of Weibull modulus**
Life function of depth Z_0 to critical shear stress	Life function of depth Z_0 to critical shear stress	**Life is independent and of depth Z_{max} to critical shear stress**
Life function of stressed volume, V_0	Life function of stressed volume, V_0	**Life function of stressed volume, V where $V > V_0$**
Load-life exponent, 3 for ball bearings, 4 for roller bearings	Load-life exponent, 3 for ball bearings, 4 for roller bearings	**Load-life exponent, 4 for ball bearings, 5.6 for roller bearings**

Parametric Evaluation for Ball Bearing Life

- VIM-VAR AISI M-50, 133-mm bore turbine engine angular-contact ball bearing
- Thrust loads range from 10 to 50 kN
- Operating speed 5,000 to 22,500 rpm (0.6 to 3 million DN)
- Operating temperatures 20 to 200 ^{o}C

– Variation of elastic modulus with temperature

- Hybrid configuration

– AISI M-50 balls replaced with Silicon Nitride balls

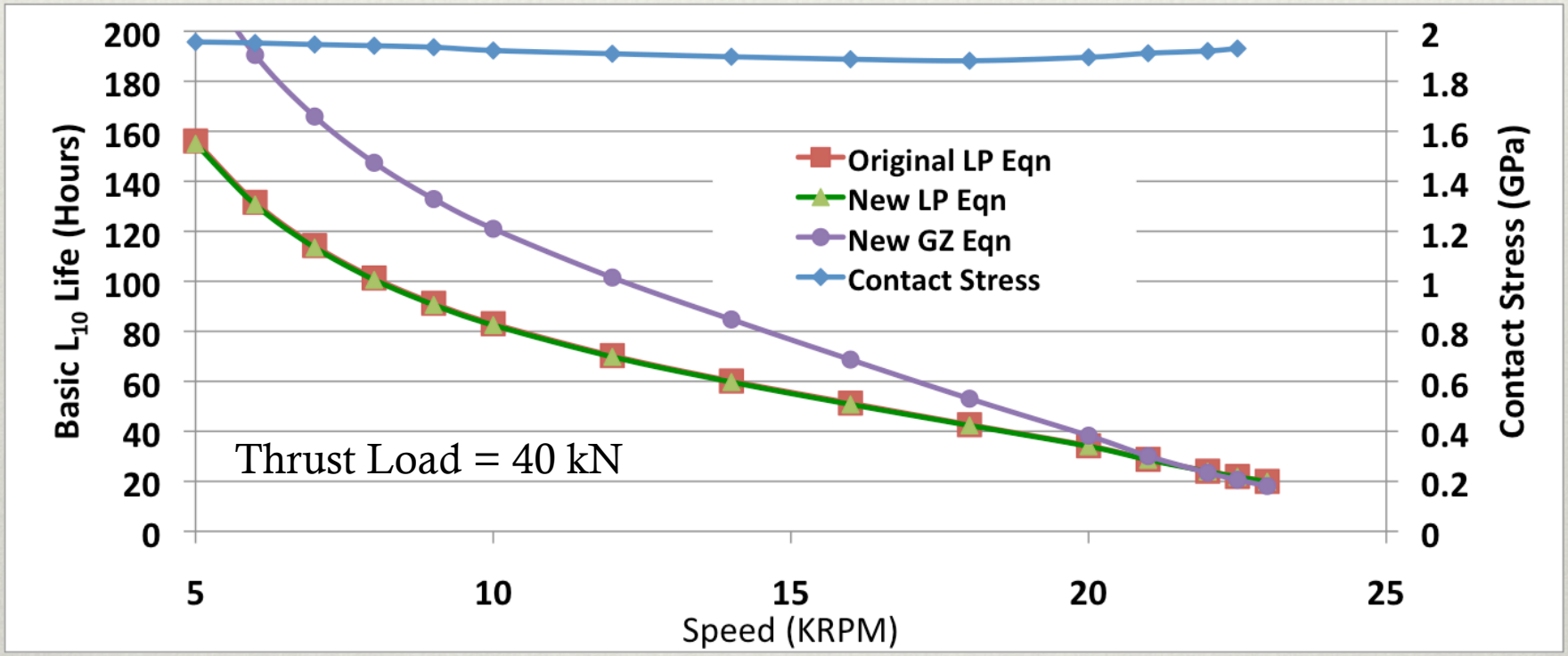
– Parametric runs over the above ranges repeated

VIM-VAR AISI M-50,

133-mm angular-contact ball bearing

Life Comparisons as a Function of Speed

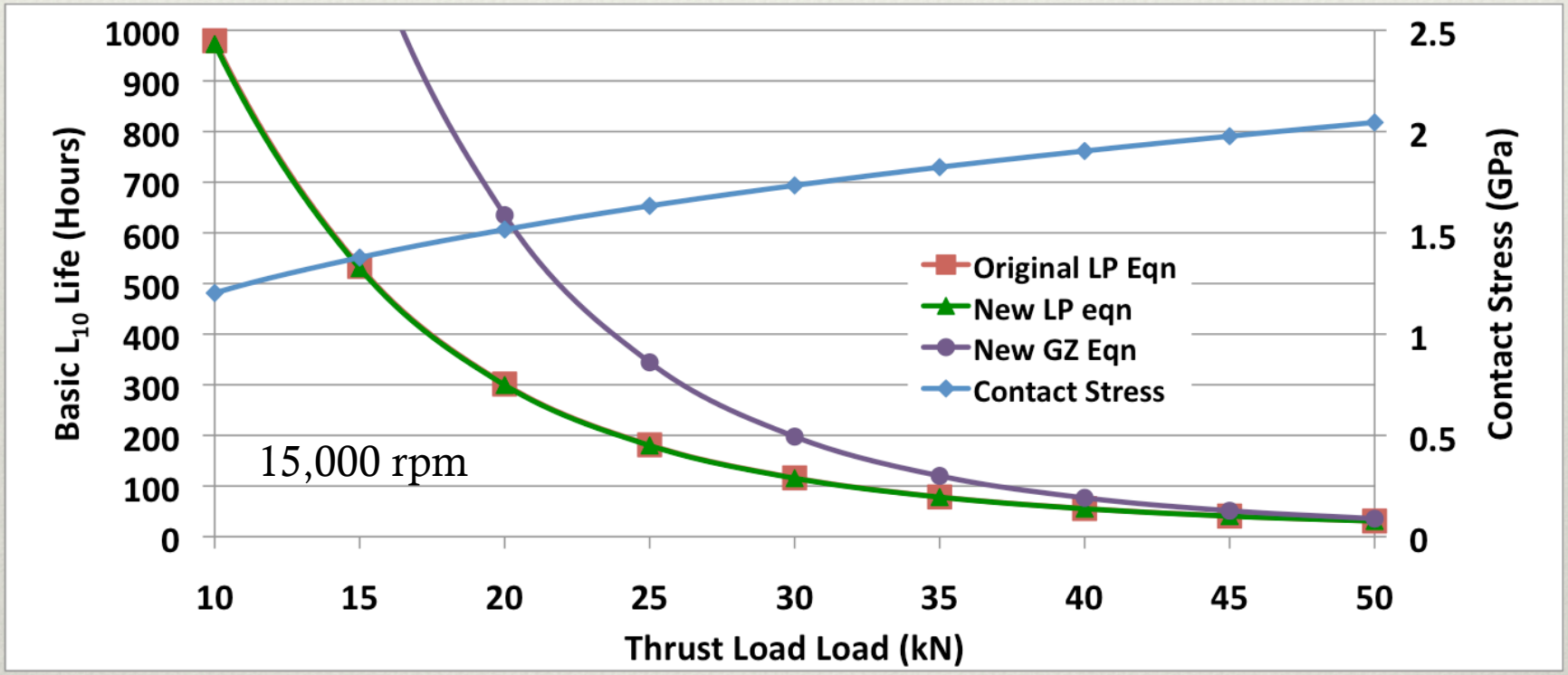
VIM-VAR AISI M-50 133-mm Angular-Contact Ball Bearing at Room Temperature



- Original and new LP predictions are identical
- GZ predictions at low speeds are significantly higher
- At high speeds all predictions seem to merge

Life Comparisons as a Function of Load

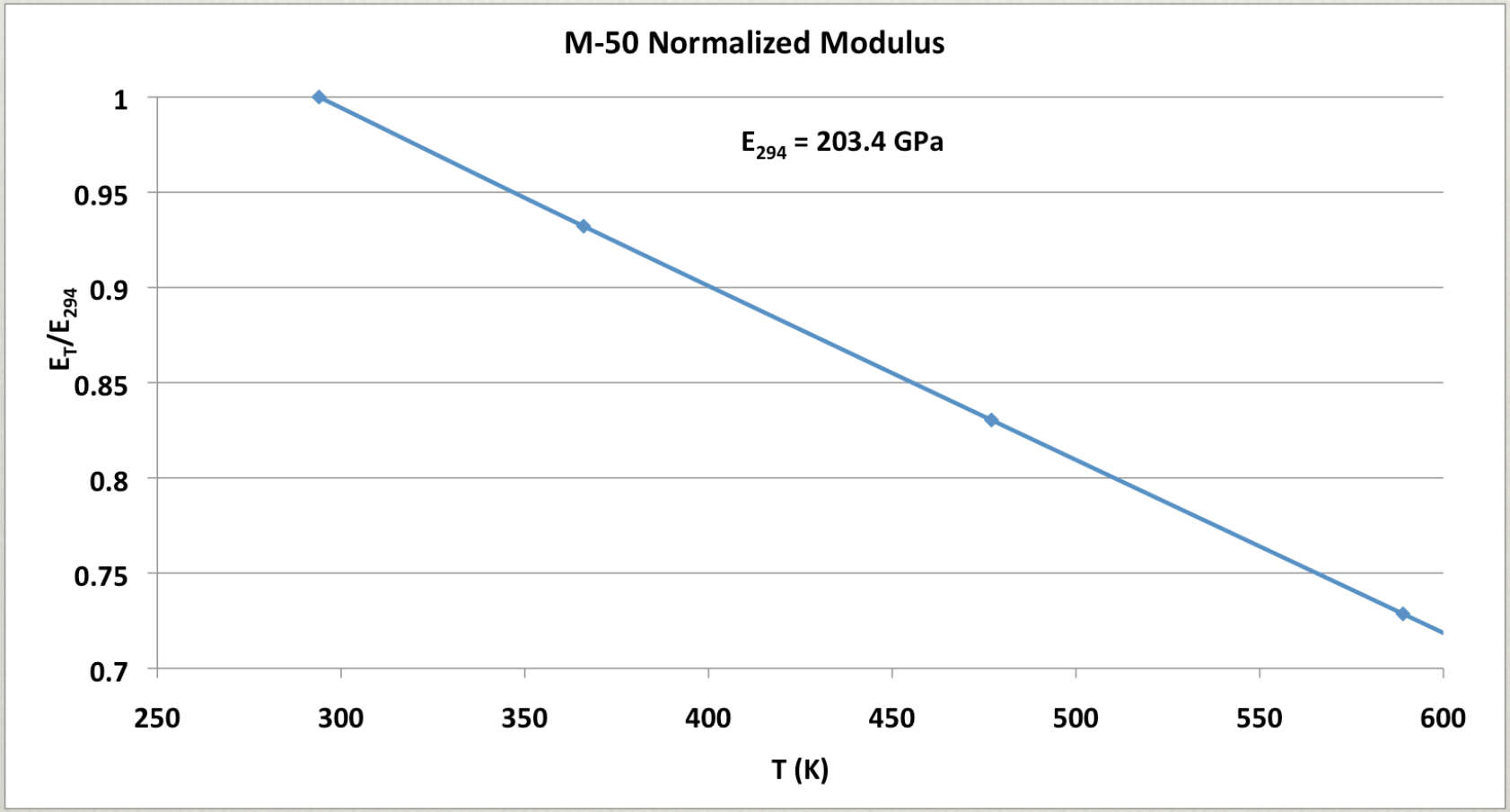
VIM-VAR AISI M-50 133-mm Bore Angular-Contact Ball Bearing at Room Temperature



- Original and new LP predictions are identical
- GZ predictions at light loads are significantly higher
- Higher life-load exponent with GZ model

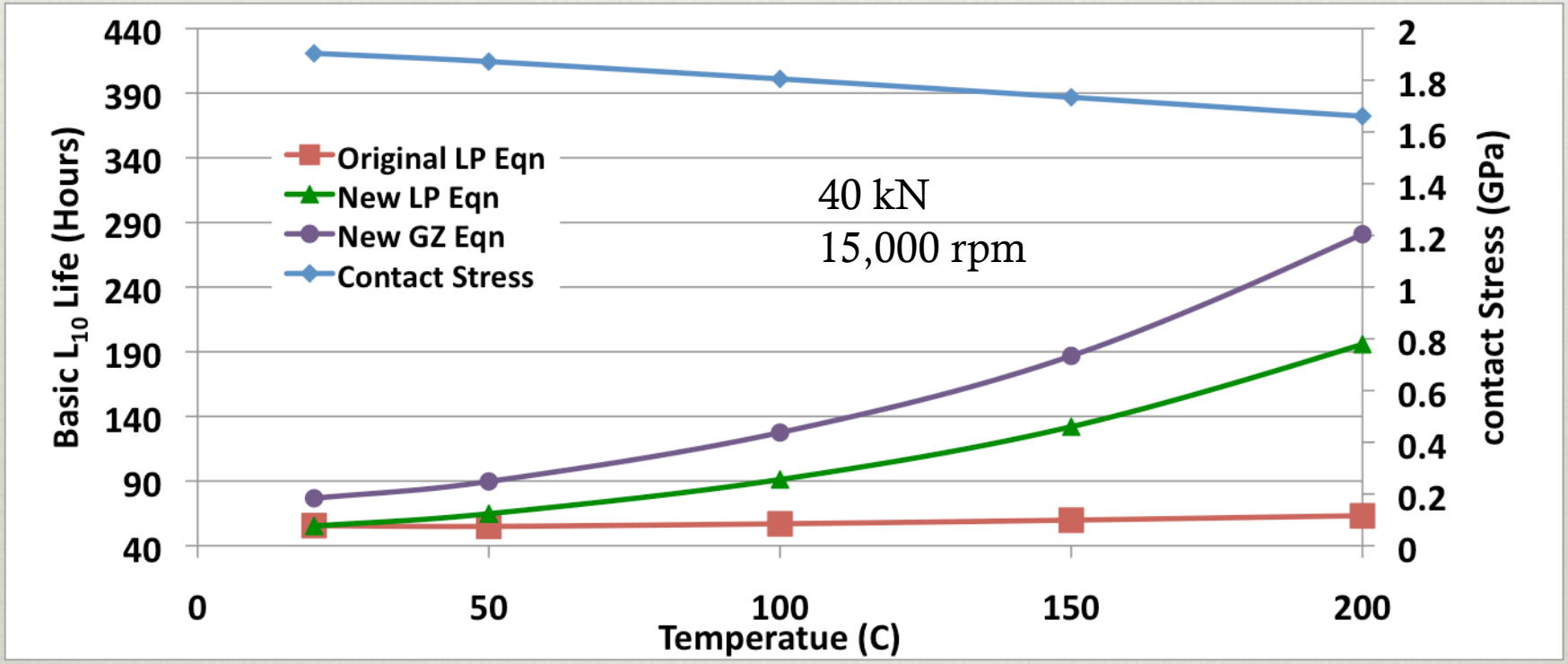
AISI M-50 Steel Elastic Modulus Variation

Material Data Sheet, Latrobe Lescalloy, VIM-VAR AISI M-50 Steel (www.matweb.com)



Life Comparisons as a Function of Temperature

VIM-VAR AISI M-50 133-mm Bore Angular-Contact Ball Bearings



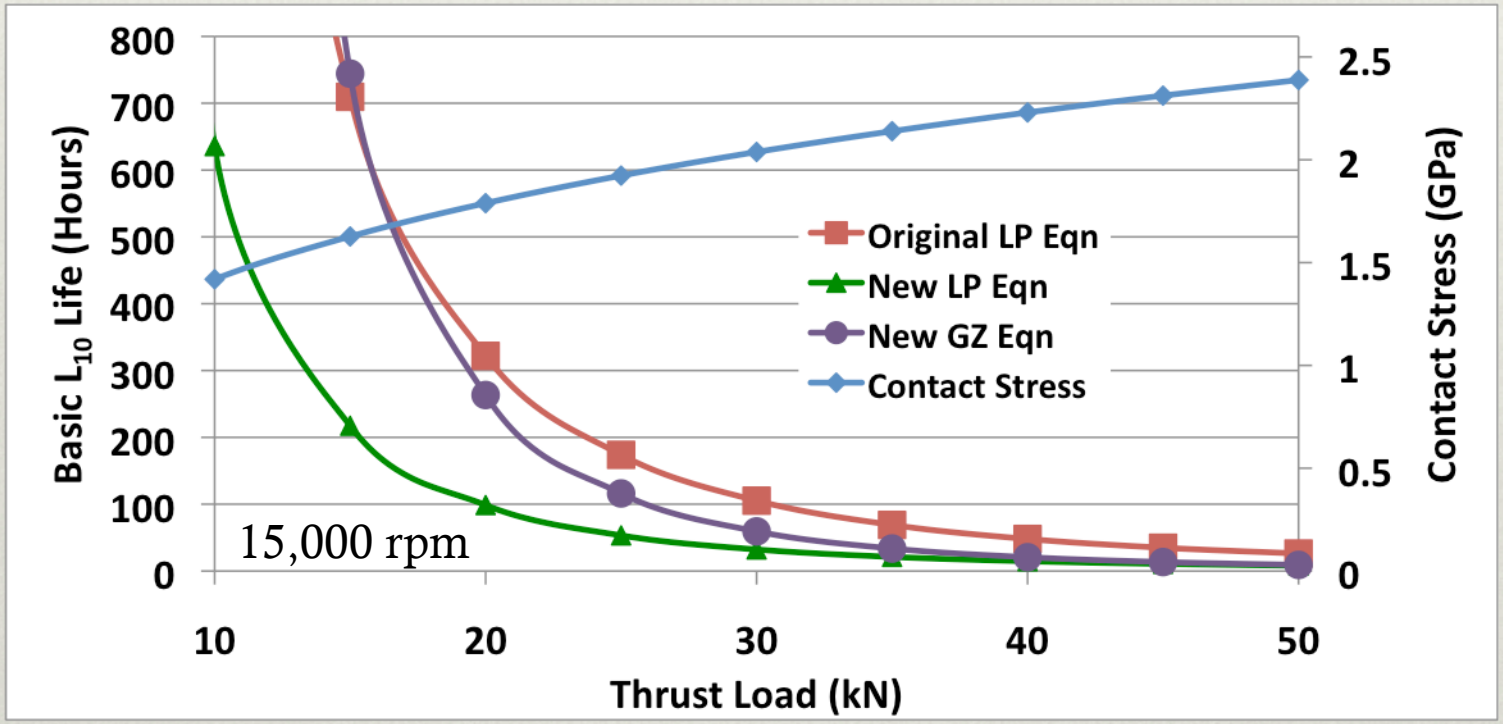
- Original LP predictions are insensitive to modulus change
- New updated LP equation provides better simulation of life
- GZ predict longer lives and higher load-life exponent

Hybrid Ball Bearing

AISI M-50 Rings and Si_3N_4 Balls

Life Comparisons as a Function of Load

Hybrid 133-mm Bore Angular-Contact Ball Bearing at Room Temperature

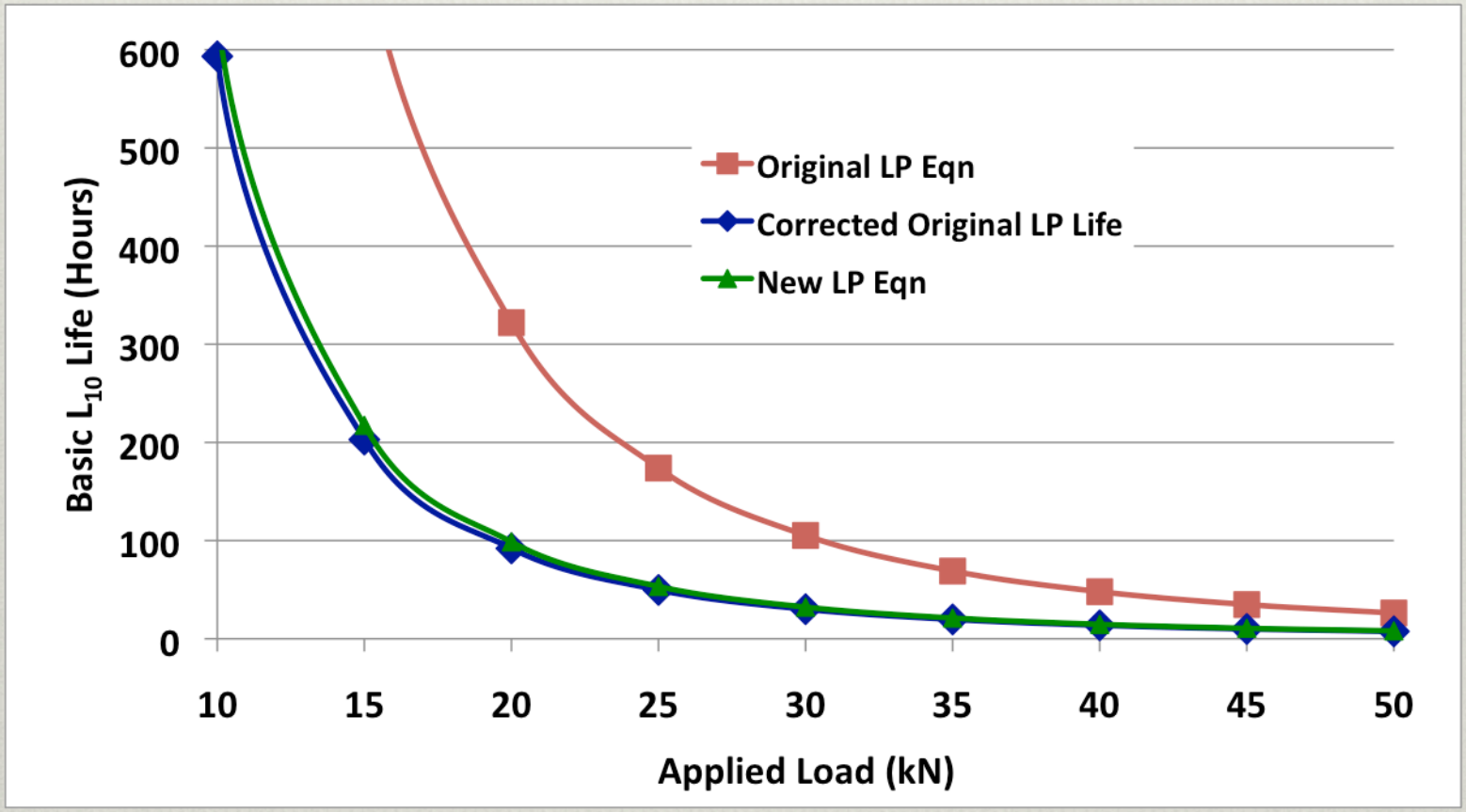


- Original LP predictions are high/does not account for higher Si_3N_4 modulus of elasticity
- GZ Model-higher load-life exponent

Corrected versus New Generalized LP Life

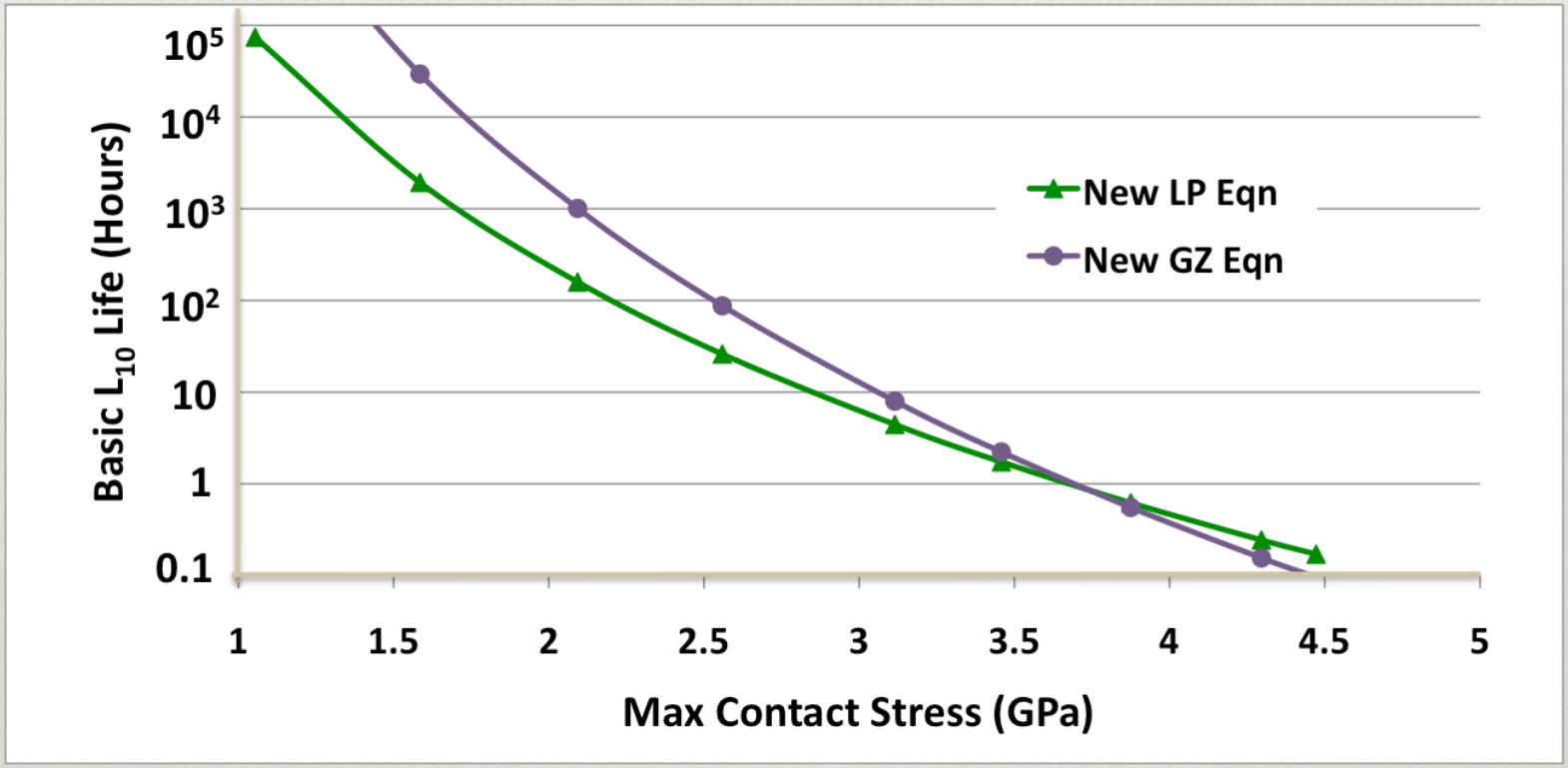
Hybrid 133-mm Bore Angular-Contact Ball Bearing at Room Temperature

- Original LP life may be corrected for modulus effects, $\lambda_E^{-6.30}$



Stress-Life Comparisons Between the LP and GZ Models

Hybrid 208-Size M-50 NiL Angular-Contact Ball Bearing



- At low stresses the GZ life is significantly higher than the LP Life – Approaches essentially infinite life at very low stresses
- At very high stresses the GZ life is lower than the LP life

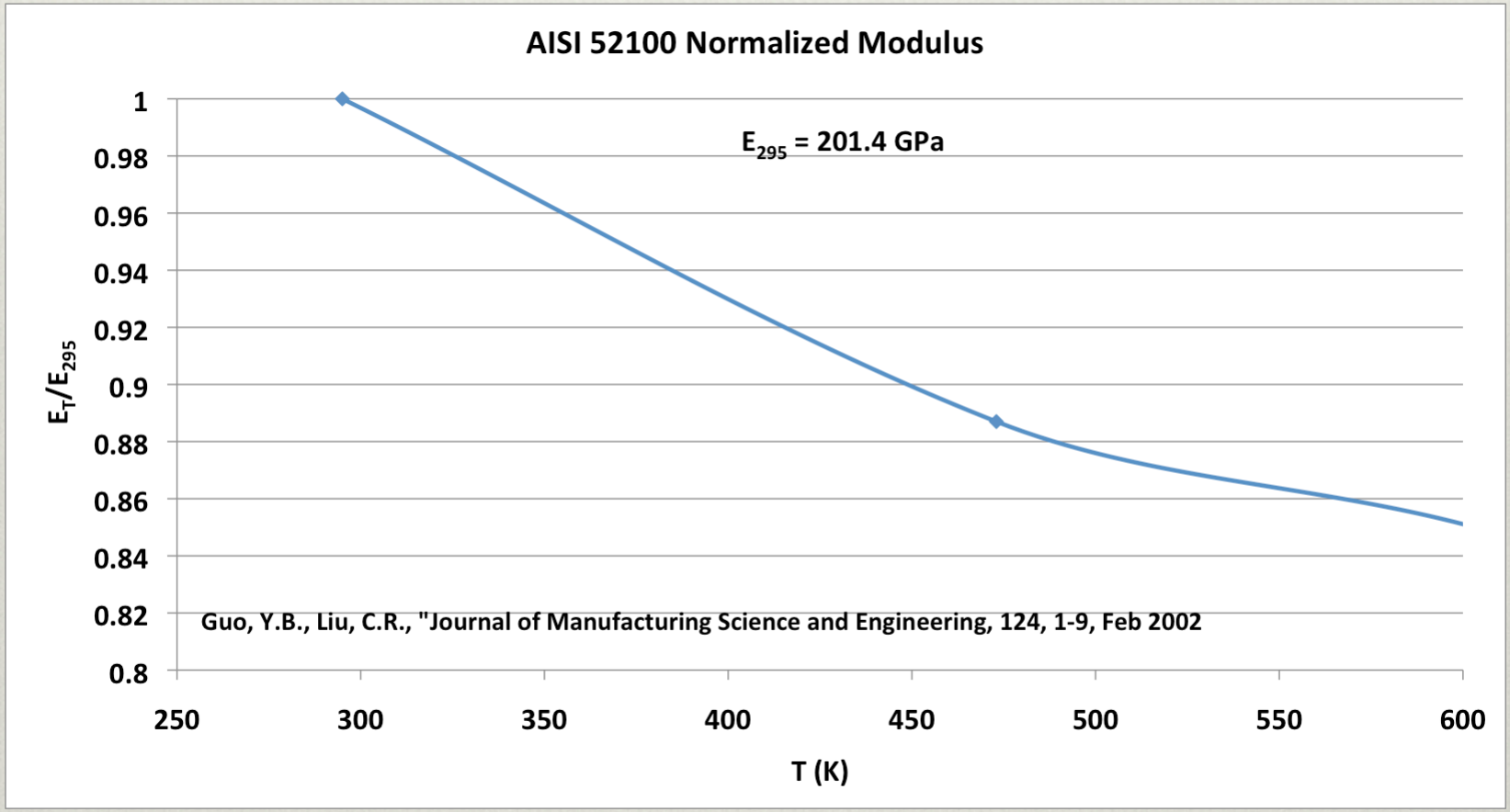
Roller Bearing Life Modeling

- Model constants in the New LP and GZ equations were derived from experimentally validated point contact constants
- A dynamic load capacity adjustment factor of 0.90 was essential to calibrate the new LP model with the original LP model for AISI 52100 steel
- No adjustment factor was necessary for point contact load (ball bearing) capacity equations

Parametric Evaluation of Roller Bearing Life

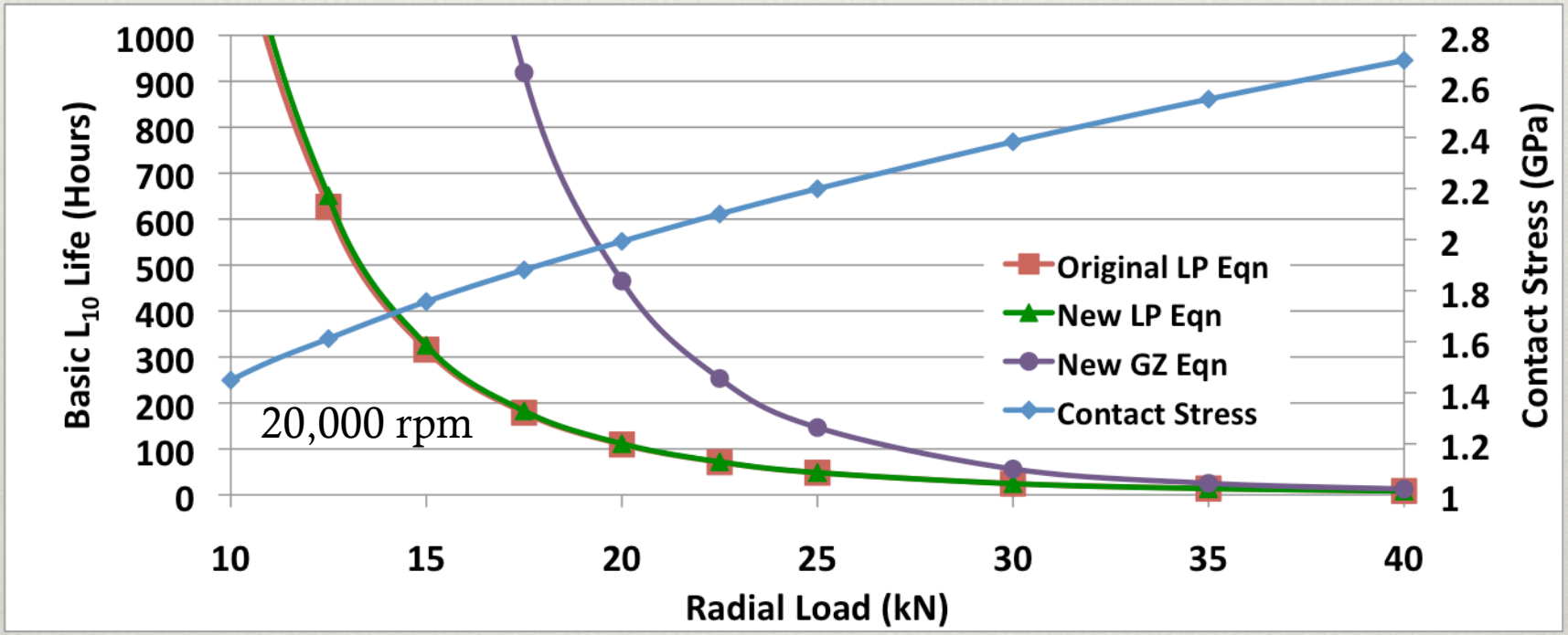
- AISI 52100 210-Size Cylindrical Roller Bearing (50-mm bore)
- Speed range: 5 to 40,000 rpm
- Load range: 10 to 40 kN
- Temperature range: 20 to 250 ^{o}C
- Variation of elastic modulus of AISI 52100 with temperature
- Hybrid bearing: Steel rollers replaced by Silicon Nitride Rollers

Elastic Modulus of AISI 52100 Steel as a Function of Temperature



Life Comparisons as a Function of Speed

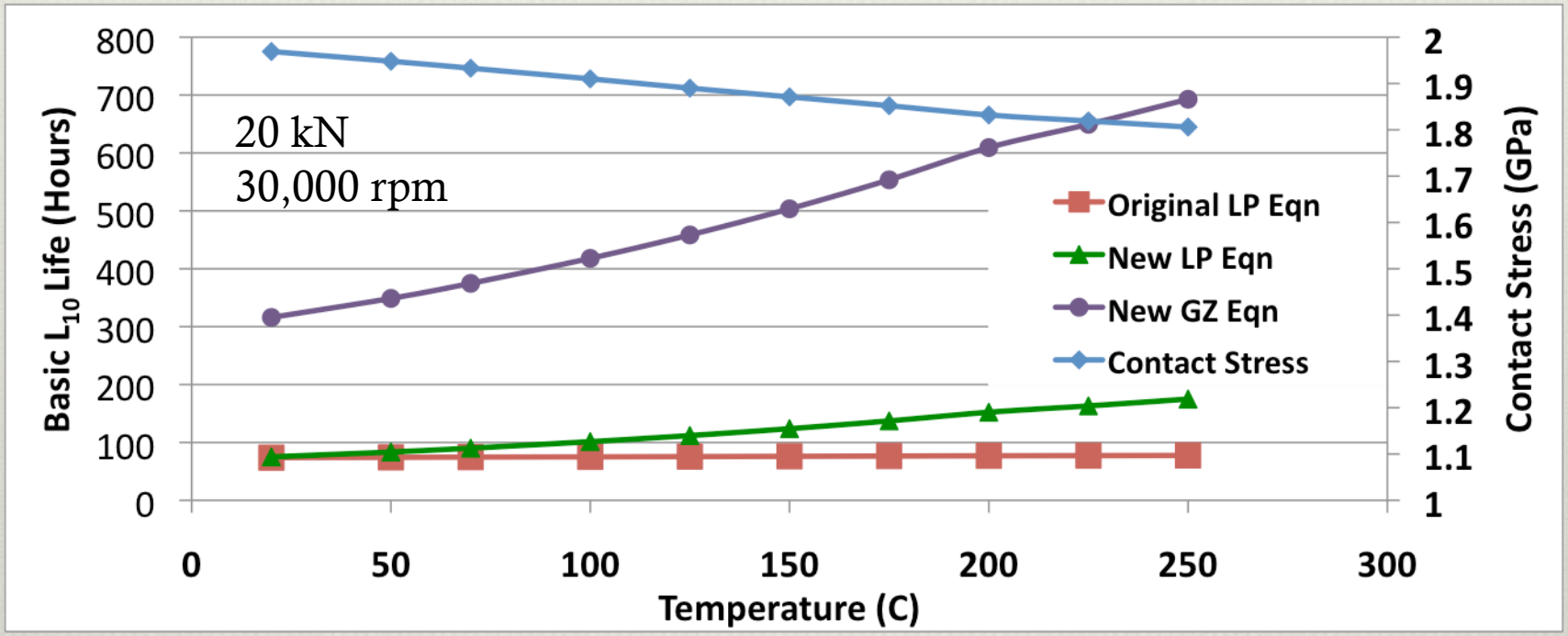
AISI 52100 210-Size Cylindrical Roller Bearing at Room Temperature



- Original and new LP predictions are identical
- Calibration factor of 0.90 used in the new LP equation
- At high loads LP and GZ models merge
- Significantly higher GZ life at light loads

Life Comparisons as a Function of Temperature

AISI 52100 210-Size Cylindrical Roller Bearing



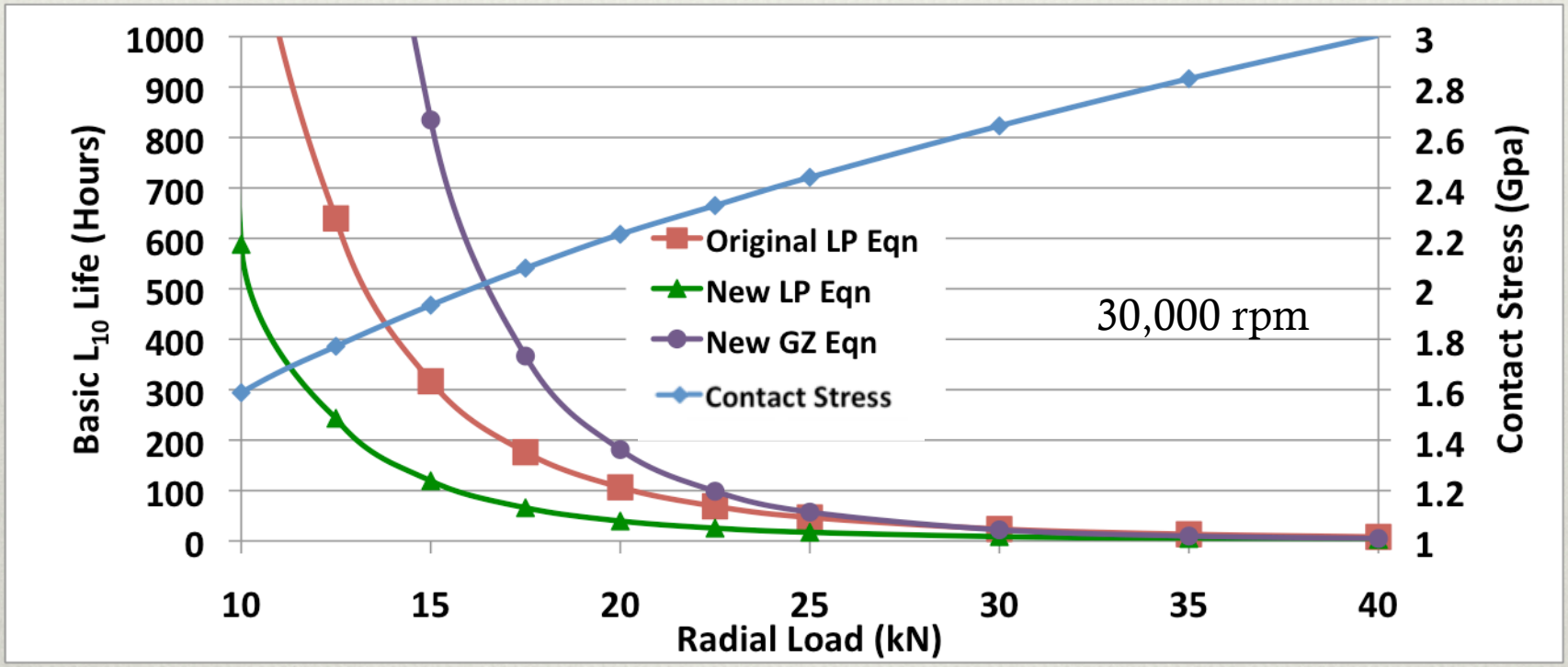
- Original LP predictions are insensitive to modulus change
- Significantly higher GZ life
- GZ Model higher load-life exponent

Hybrid Cylindrical Roller Bearing

AISI 52100 Races, Si_3N_4 Rollers

Life Comparisons as a Function of Load

Hybrid AISI 52100 210-Size Cylindrical Roller Bearing at Room Temperature

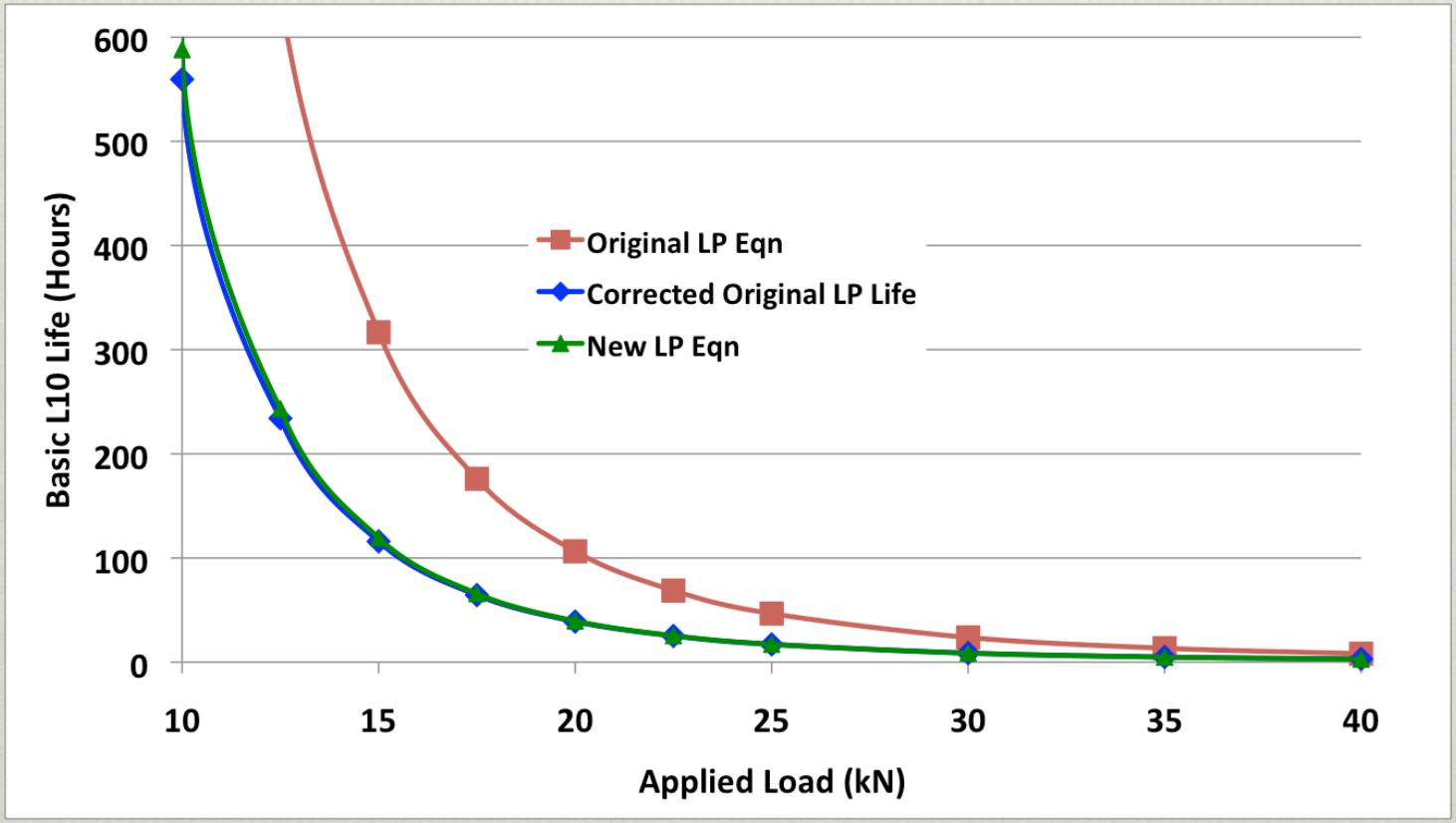


- Original LP predictions are high, no account for higher modulus
- New generalized LP predictions are more realistic
- GZ predictions are significantly higher at light loads

Corrected versus New Generalized LP Life

Hybrid AISI 52100 210-Size Cylindrical Roller Bearing at Room Temperature

- Similar to ball bearings original LP life may be corrected for modulus effects for roller bearings
- Applicable factor = $\lambda_E^{-5.25}$



Summary

- Gupta-Zaretsky and New Lundberg-Palmgren Bearing Life Models were implemented in Bearing Computer Code ADORE.
- New LP Model with variable elastic material properties predicted longer fatigue life than original LP Model.
- Fatigue life prediction with original LP Model can be corrected by elastic property factor, $\lambda_E^{-6.30}$ for ball bearings and $\lambda_E^{-5.25}$ for roller bearings.
- At max Hertz stresses < 2 GPa, the G-Z Model predicts higher lives than new LP Model. At contact stresses > 2 GPa life results are similar.
- Gupta-Zaretsky Model implemented in the bearing code ADORE better reflects results obtained with post-1960 bearing materials.

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Acknowledgements

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