Polydopamine/PTFE Composite Coating for Large-Scale Journal Bearings in Next Generation Electric Machines

1467-1538

SurfTec, University of Arkansas, ABB

Period 2

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Washington, D.C.
June 11-12, 2019

Overview

Timeline

- Award performance period:
- 04/01/2017 to 08/31/2019
- Project 80% complete
- Budget period 2 approved

Budget

	FY2017	FY2018
DOE Funded	$ 562,376	$ 637,622
Project Cost Share	$ 140,594	$ 159,405
Total Cost	**$ 702,970**	**$ 797,027**
Cost Share %	20	20

Partners

- **University of Arkansas Nanomechanics and Tribology Laboratory**
- **The ABB Group**

Project Goal

Explore the use of a low-friction polydopamine (PDA) /Polytetrafluoroethylene (PTFE) nanoparticle composite coating to replace traditional Babbit liners in large-scale journal bearings enabling the DOE AMO's goal of reducing energy losses in high speed, megawatt class, MV electric motors and generator systems while simultaneously removing lead and bismuth.

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Project Objective

Enabling the Replacement of Lead and Tin Babbitt in Large-scale Journal Bearings

Optimization of low-friction PDA/PTFE nanoparticle composite coating to reduce wear rate of PTFE.

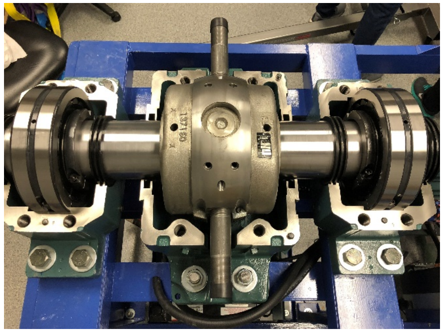
- Analysis of dopamine polymerization parameters and chemical composition allowing high strength bond to PTFE.
- Study of ceramic and metallic filler concentrations to improve mechanical properties of PTFE film.

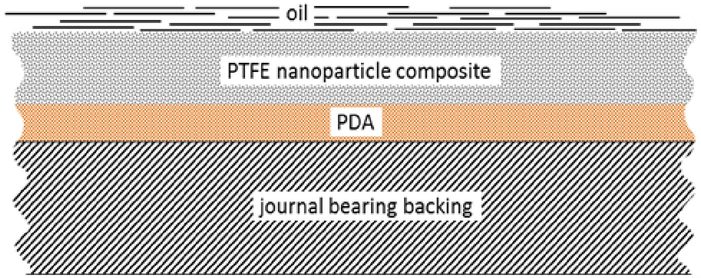
Develop coating deposition process compatible with high through-put industrial processing lines.

- Characterization of surface topography and chemistry of **spray coated** PDA/PTFE nanoparticle coating. Study the tribological performance of spray coated films.
- Characterization and tribological testing of **dip coated** PDA/PTFE nanoparticle coating.

Evaluation of coating performance on large-scale journal bearings benchmarked against tin Babbitt.

- Design and assembly of bearing tester. Validation of test results with industry partner.
- Analysis of wear life, vibration, temperature torque loss, and current discharge in coated bearings.
- Benchmark against commercially available Babbitt bearings in boundary, mixed and hydrodynamic lubrication regimes.
- Testing in full-scale prototype.





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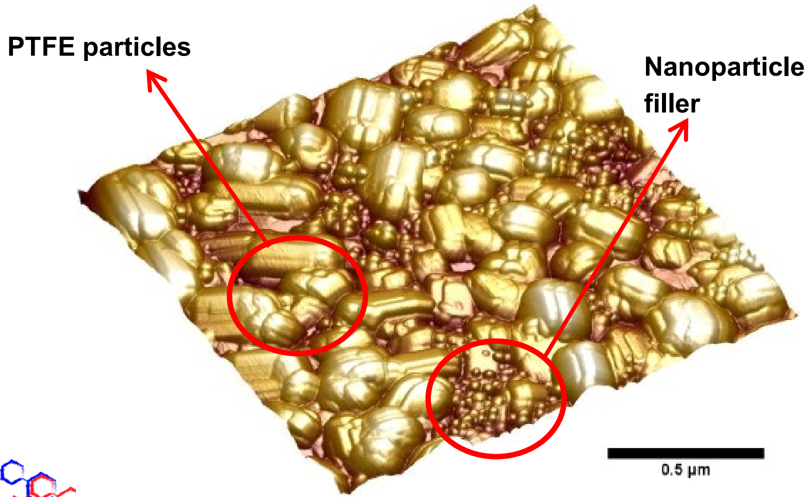
Technical Innovation

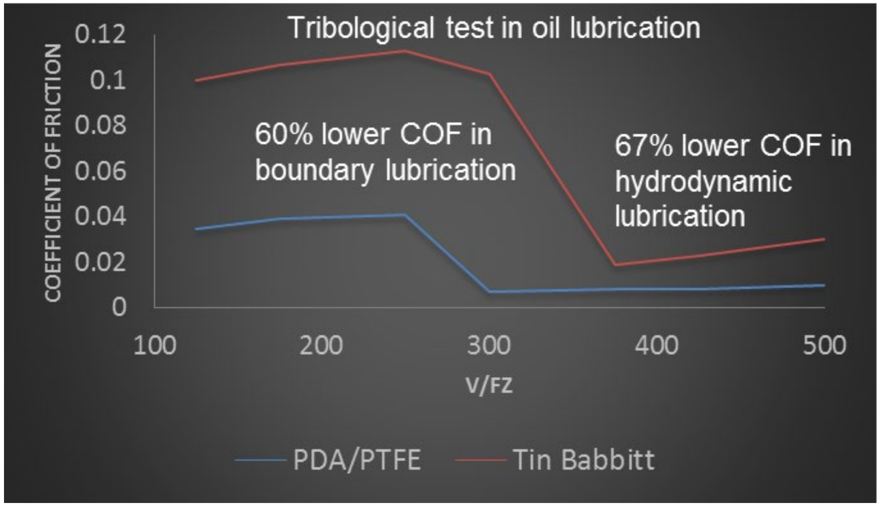
Traditional Tin/Lead Babbitt Journal Bearings Contain Appreciable Amounts of Lead

- Function well during hydrodynamic lubrication
- Are susceptible to high frictional losses during start/stop operation in electric motors.
- The price of tin is currently $7.36/lb, significantly higher than other bearing materials. Cassiterite (tin) is considered a conflict mineral .
- In the fabrication of lead containing babbitt alloys, the disposal of waste materials produced during machining as well as the disposal of contaminated lubricants used in the machining process presents an environmental issue

Low-friction PDA/PTFE Nanoparticle Composite Coating is an Attractive Alternative

- Can reduce frictional losses by 60% and increase wear-life by 40%.
- Low cost ~ $0.01/in2 , Low weight – 2 g/cm3





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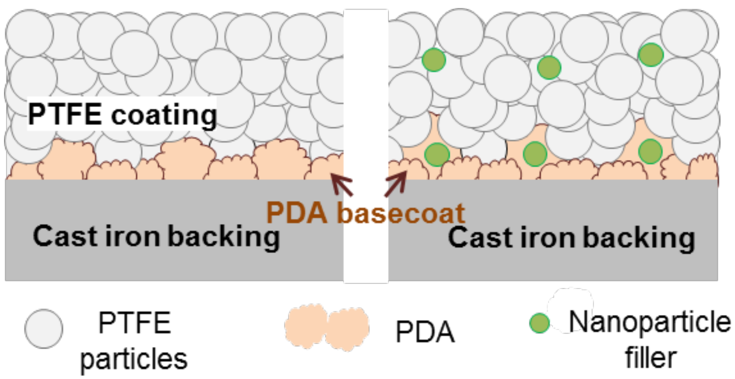
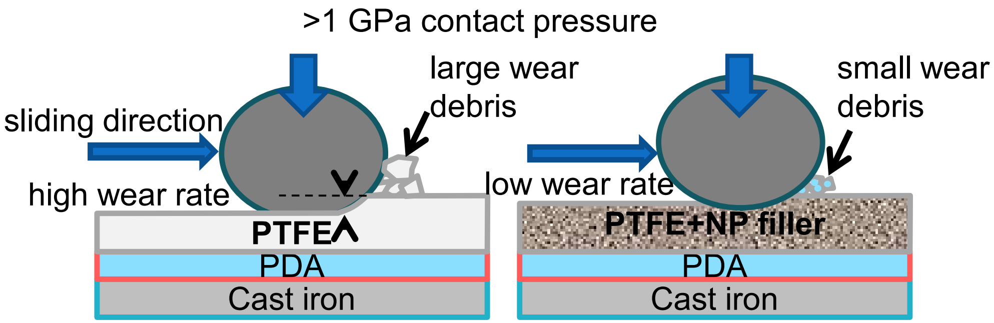
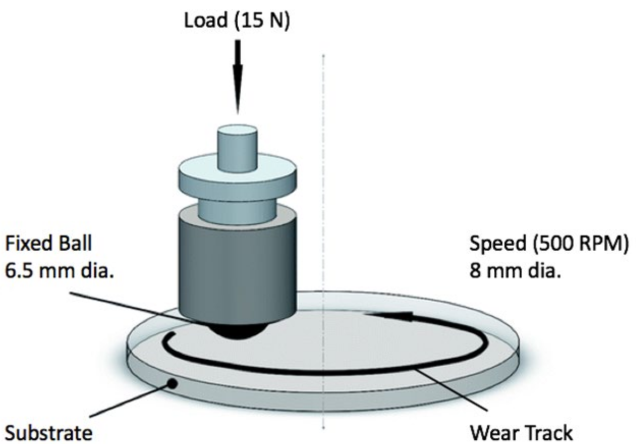
Mechanism for Wear Resistance

- Dopamine used to promote adhesion and prevent coating delamination
- Nanoparticle filler used to deflect crack propagation and reduce wear debris size
- Testing under high contact pressures reveals we are performing far outside PTFE's pressure-velocity limit, outperforming PTFE coatings by 3 orders of magnitude and commercial fluoropolymer coatings by 20x.







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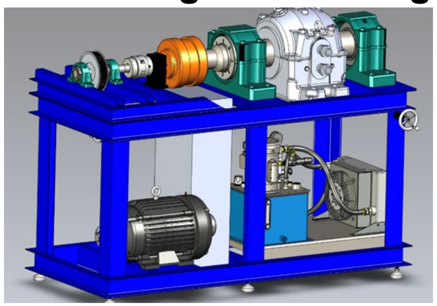
Technical Approach

Budget Period 1 - Coating Synthesis and Optimization / Benchtop Tribological Testing

Task performed by SurfTec and University of Arkansas Nanomechanics and Tribology Laboratory

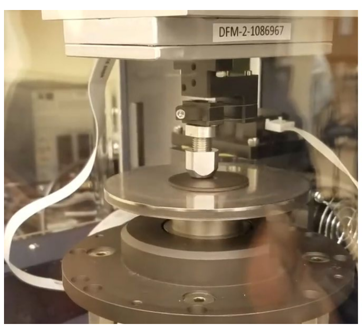
Bearing Tester Design/Assembly

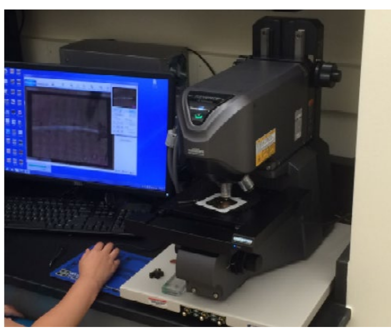


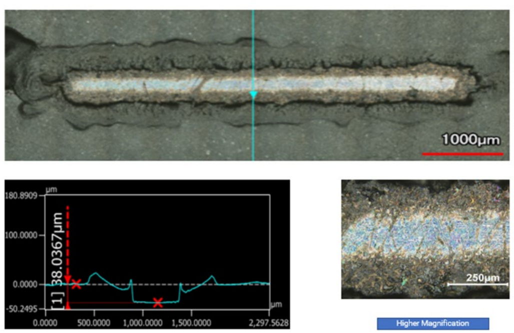
- RTD sensors to monitor bearing liner temperature
- Rotary torque sensor to measure frictional losses
- RTD sensors to monitor oil temperature
- Vibration sensor to determine metal on metal contact / wear life of coating or babbitt alloy.
- Oil recirculation system and oil analysis

Facile Coating Deposition

Benchtop friction and wear testing







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Technical Approach

Budget Period 2 - Verification of coating performance in journal bearings and demonstration with a full scale prototype

Task led by SurfTec and ABB

1. Key Technical Risks
   a. PTFE's non-wetting property may cause slip at the oil/PTFE interface and pose potential challenges in establishing fluid film lubrication.
   b. We have structured the proposed plan so that early tribological testing provides a go/no-go decision point based on overcoming these key risks.
2. Execution Attributes
   a. University of Arkansas Nanomechanics and Tribology lab has extensive experience in surface engineering and developing low-friction coatings, and is a key partner during the synthesis and optimization of the proposed coating.
   b. ABB is a world leader in power distribution, generation and transmission products and is a key partner to validate our technology in a full-scale prototype system. ABB also manufactures large-scale journal bearings and will serve as an entry point into the market.
   c. SurfTec founders have been developing the proposed technology for the past 7 years and have made significant progress in its performance.

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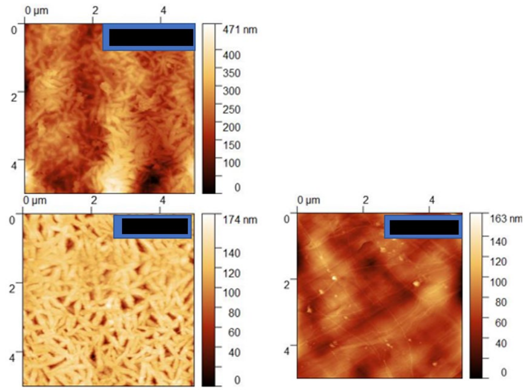
Results and Accomplishments

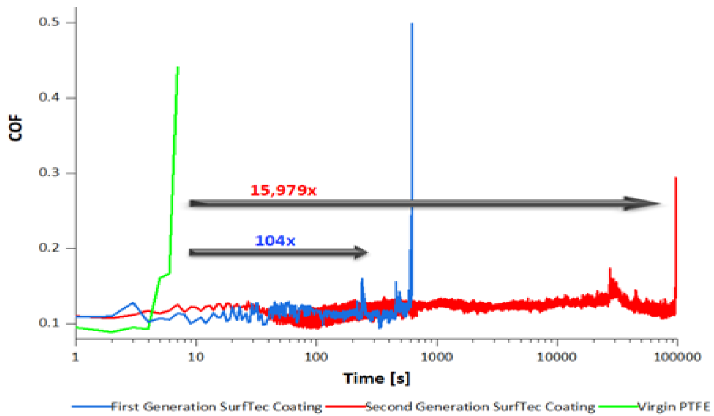
Tasks completed in Budget Period 1

Milestone 1.1	Design and BOM generation for journal bearing tester
Milestone 1.2	Assembly and validation of journal bearing tester
Milestone 2.1	Deposition 1-50um PDA/PTFE coating on cast iron and stainless steel
Milestone 2.2	Reduce porosity in coating below 250 nm length voids
Milestone 2.3	Produce coating with a dynamic COF <0.20 and wear life 100x greater than PTFE.
Milestone 3.1	Oil wetting and wear surface morphology characterization of coated cast iron. Coated cast iron exhibiting full hydrodynamic lubrication.
Milestone 4.1	Analysis and selection of optimal deposition method for large scale journal bearing geometries exhibiting controlled thickness up to 500µm, 100% surface coverage, >4N scratch adhesion critical load, and spray coating deposition duration under 5 min

Coating performance		
Metric	**Projection**	**Achieved**
Dry COF	0.20	0.12
Wear life increase over pure PTFE	100x	15900x
Dielectric strength	20 MV/m	70 MV/m
Void length of pores	250 nm	<10nm



AFM images showing reduction of porosity



Tasks to be completed in Bidget Period 2

*Testing of coating on journal bearings, build full scale prototype, study effect of filler

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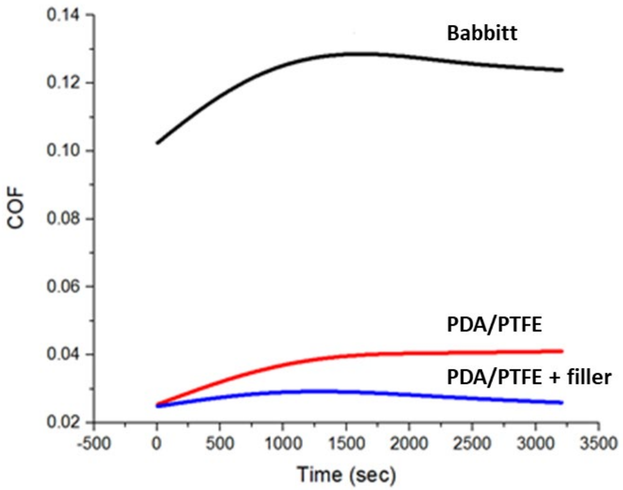
Results and Accomplishments

Tasks completed in Budget Period 2

Milestone 5.2	Demonstrated 30% reduction in frictional losses during dry operation, 10% reduction in boundary and mixed lubrication conditions, and >10% increase in wear-life in pristine oil and water contaminated oil tests.
Milestone 5.4	Determination of chemical changes through shifts in and deconvolution of C1s and F1s spectra. Determination of resulting failure mode in wear-life and friction loss testing performed using in-house testing apparatus.
Milestone 6.1	Selection of composite composition for dynamic COF <0.15 in boundary and mixed lubrication and wear life >120% higher than virgin PDA/PTFE.
Milestone 7.2	SurfTec coated large scale journal bearing exhibiting torque values 10% below traditional babbitt bearings in boundary and mixed lubrication conditions, equal or lower values in hydrodynamic lubrication, >10% increase in wear life over traditional babbitt bearings using pristine oil lubrication and water contaminated oil lubrication, and resistance to current discharge in normal megawatt class MV electric motor operating conditions.
Milestone 7.3	Determination of bearing failure modes and correlation to wear-life, operating and performance parameters, and current discharge.
Milestone 8.1	PDA/PTFE coatings on low-cost liner materials exhibiting equal or lower values of friction in boundary, mixed, and hydrodynamic lubrication compared to PDA/PTFE coated cast iron lubricated using pristine oil and water contaminated oil.
Milestone 9.1	Relationship between nanomechanical (hardness, modulus, adhesion) and chemical structure of coating and the friction and wear performance is determined statistically.
Milestone 10.1	Full scale prototype with electrical efficiency >95%, >10% reduction in frictional losses during hard start and hard stop conditions, 10% increase in wear-life, and no significant increase in vibration or friction in hydrodynamic lubrication compared to traditional babbit

Coating Performance		
Metric	**Projection**	**Achieved**
COF in Oil	0.120	0.025
COF reduction in Oil	30% reduction	80% reduction
Wear	.0028 mm^3/m	.000005 mm^3/m



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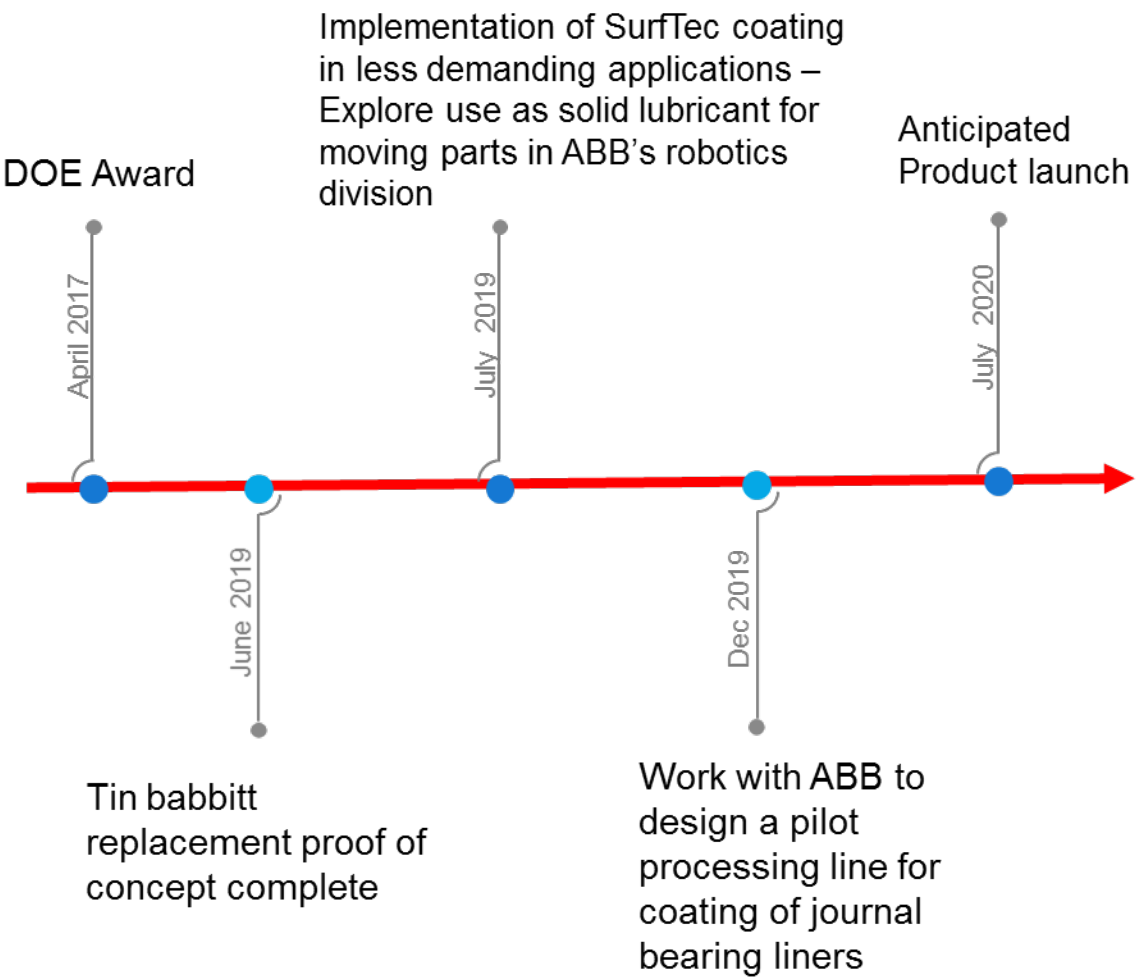
Transition (beyond DOE assistance)



Measure of success:

1. Reduce oil consumption in bearings
2. Extend service life in bearings and as a result in motors
3. Reduce maintenance costs related to bearing failures
4. Reduce energy consumption in electric motors
5. Eliminate environmental issues related to lead content in babbitt bearings

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