Exhibit F - UTCRS

UTC Project Information	
Project Title	Applications of Magnetostrictive Materials for Real-Time Monitoring of Vehicle Suspension Components
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Heinrich Foltz, Ph.D., P.E., Electrical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
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Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $44,820 Cost Share Funds (UTPA): $15,249
Total Project Cost	$60,069
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2014
Brief Description of Research Project	The purpose of this project is to investigate applications of magnetostrictive materials for real-time monitoring of railroad suspension components, in particular bearings. Monitoring of such components typically requires measurement of temperature, static load, and vibration, among other parameters. In addition, real-time, long-term monitoring can be greatly facilitated through the use of wireless, self-powered sensors. Magnetostrictive materials, such as Terfenol-D, have the potential to address both requirements. In this project, Terfenol-D was characterized in three applications: (a) as a static load sensor, (b) as a vibration sensor, and (c) as an energy harvesting device. Currently, piezoelectrics are used for many vibration and energy harvesting applications; however, they are fragile and are difficult to use for static load measurements. Magnetostrictive metals are tougher, and their property of variable

	permeability when stressed can be exploited to measure static loads. Deliverables for this project include: (a) characterization of Terfenol-D materials over a range of loads and frequencies appropriate for railroad bearing applications, (b) demonstration and performance measurements of Terfenol-D energy harvesting, (c) demonstration and performance measurements of a Terfenol-D load sensor, (d) demonstration and performance measurements of a Terfenol-D vibration sensor, and (e) support electronics allowing integration into a data collection system. In addition, the possibility of using a single Terfenol-D core to perform all three functions was explored, and the viability under conditions typically encountered in a railroad bearing adapter were tested.
Describe Implementation of Research Outcomes (or why not implemented) 	(a) Terfenol-D samples were acquired and tested on a universal test system for conventional mechanical properties as well as change in magnetic properties under load. One issue of importance that was investigated in this phase was hysteresis in both the stress/strain curves, and in the permeability versus stress curves. It was found that a significant component of the hysteresis can be eliminated through proper fixture design to eliminate "walking" of the material under cyclic load, and through elimination of soft materials such as epoxy during mounting. Additional hysteresis can be eliminated through application of appropriate bias magnetic field. (b) A pilot study of energy harvesting was completed, using cyclic loading comparable to that found in typical railroad bearing pads. Multiple steel fixtures to provide proper mounting combined with a closed, low reluctance magnetic circuit were examined (see photo at left), and a study of optimum static magnetic field bias was conducted. 75 mW of peak available power was obtained from a 13-mm diameter x 13-mm long sample, using a sinusoidally varying load with a maximum load rate of 120 kip/s and a 3300 Gauss bias field. (c) A pilot study of static load sensing using Terfenol-D was completed. The basic mechanism is change of inductance in a coil wound on a Terfenol-D core. A key finding of this work is that there is significant time delay in the inductance versus load relationship, giving the appearance of hysteresis when the load is cyclically varied. However, careful attention to timing shows that a repeatable curve can be obtained for nearly static loads. The relationship is nonlinear but monotonic, so a calibration curve can be produced. (d) Some testing of response to vibrations was conducted; however, the initial testing showed that the range of parameters (sample size,

	coil size and turns, and magnetic field bias) needed for vibration sensing would be significantly different from that needed for static load sensing and energy harvesting. Furthermore, it appeared that performance would not be competitive with conventional MEMS based accelerometers when cost is considered. Therefore, further study of vibration sensing applications was deferred. (e) For the work completed in this phase of the study, the support electronic systems were implemented using off-the-shelf laboratory instrumentation (inductance bridges and a data acquisition system). A follow up project, already funded, will have the goal of producing selfcontained, self-powered electronics using Terfenol-D for power production and load sensing, with enough surplus power to support temperature sensing, accelerometer-based vibration sensing, signal conditioning, and wireless data transmission.
Impacts/Benefits of Implementation (actual, not anticipated)	1. Estrada, R., “Applications of Magnetostrictive Materials in the Real Time Monitoring of Vehicle Suspension Components,” Master’s Thesis, The University of Texas Rio Grande Valley, December 2014. 2. Estrada, R., Foltz, H., Tarawneh, C., “Energy Harvesting Potential of Terfenol-D for On-Board Bearing Health Monitoring Applications,” *Proceedings of the ASME 2015 Joint Rail Conference*, San Jose, CA, March 23-26,2015. This work provided the basis for a newly funded University Transportation Center for Railway Safety project, and the expertise developed in magnetostriction was the basis for an NSF proposal currently under review.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2014/applications-of-magnetostrictive-materials/index.htm