Development of a Multi-Resonant Impact-Driven Energy Harvester (MRI-DEH) for Electrification of Rural Rail Crossings

Deliverables and Reporting Requirements for UTC Grants Awarded in 2023 (June 2023)

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Mohsen Amjadian (PI, UTRGV) and Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: Joseph Turner (Collaborator, University of Nebraska-Lincoln (UNL)) and Carl Nelson (Collaborator, UNL)

Research Project Funding: $48,634 (Federal), $32,534 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

Project Description: This research proposal aims to address the critical need for enhancing safety at rural rail crossings where reliable power sources are often lacking. Building upon previous work of the PIs, where low-power vibration sensors were explored for detecting trains upstream in rural areas using deep learning-based time series prediction algorithms, this project focuses on designing, analyzing, and testing a Multi-Resonant Impact-Driven Energy Harvester (MRI-DEH) by incorporating an impact-driven mechanism for electrification of rural rail crossings. This innovative approach seeks to enhance electromechanical coupling by integrating multiple resonators, each tuned to a specific local excitation frequency of rail-track vibration, and to broaden the device's resonance frequency band by leveraging impact effects. The proposed tasks include analytical modeling with closed-form solutions for a parametric study, numerical simulations, and both laboratory and field testing. The optimization of the energy harvester's design will involve conducting a parametric study on key parameters to maximize the generated electrical power. These parameters include the geometrical dimensions and pole orientations of permanent magnets, dimensions of copper coils, their distances from the outer surfaces of the permanent magnets, and the size of gap between the copper coils and the stopper. The anticipated outcome of this research is a scalable, cost-effective energy harvester optimized for rural grade crossings to enhance their safety by providing electric power for train detection sensors.

US DOT Priorities: The proposed work in this project is aligned with three of the six USDOT strategic goals: **(a) Safety:** This goal is addressed by designing, fabricating, and testing a multi-resonant impact-driven energy harvester. This device is intended to power sensors and other low-power electrical safety equipment at rural rail crossings, enhancing safety measures. **(b) Equity:** The project promotes equity by offering training opportunities to citizen graduate and undergraduate students from underrepresented populations and diverse communities in the United States. It aims to equip them with the necessary skills and knowledge for successful careers in transportation and railway engineering, thus contributing to a more inclusive workforce. **(c) Transformation:** This goal is achieved by adopting innovative developments from several engineering fields (e.g., civil, mechanical, and electrical engineering) to harvest electrical power from vibrations in railroad track systems. The project involves research to understand the needs and implications of smart sensing technologies in railroad engineering and aims for the eventual transfer of technology to stakeholders and industrial partners, thereby transforming the field.

Outputs: The expected products include:

1. Detailed design documents and assembly guides for the proof-of-concept energy harvester prototype,

provided in AutoCAD, SolidWorks, and Adobe formats. (File Formats: DWG, SLDPRT, PDF).
2. A comprehensive Finite Element (FE) model of the prototype and its critical components developed using COMSOL Multiphysics software. (File Format: MPH).
3. Extensive laboratory and field raw data capturing time history of acceleration, voltage, and electric power output of the energy harvester. (File Formats: TXT, CSV).
4. A fully operational proof-of-concept prototype based on an optimized design, which will undergo rigorous testing both in the laboratory and the field.
5. A detailed report (or publication) summarizing the findings from FE modeling, numerical simulations, and both lab and field tests, prepared to meet the specifications of the USDOT and UTCRS.
6. The dissemination of research findings through one or more conference presentations or journal publications. The PI will lead a session at the 2025 ASCE EMI Conference focusing on advancements in energy harvesting systems.

Outcomes/Impacts: The proposed research project has potential for addressing societal challenges by advancing scientific knowledge and fostering tangible educational improvements in safety of the U.S. rail network. **Research and Industry Impact:** The results of this project will be used to develop a cost-effective energy harvester to power train detection sensors and other basic safety electrical equipment at rural rail crossings. This will eventually help to improve the safety of railway operations and reduce the risk of accidents. **Educational Impact:** This project aims to foster diversity and inclusion in STEM education by supporting students from underrepresented racial and ethnic groups at UTRGV. This will be accomplished by creating hands-on educational activities and materials for K-12 students during summer camps in UTCRS and taking advantage of senior design courses in CIVE and MECE to involve STEM undergraduate students in different research tasks of the project. The objective is to train a diverse and skilled STEM workforce to contribute to the safety and sustainability of the U.S. rail network by understanding the concept of energy harvesting through vibration. Furthermore, this project promotes partnerships between academia and industry, and engagement with stakeholders and policy makers by organizing workshops, webinars, and publicly available publications (e.g., ASCE EMI Conference).

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.