USAMP/NDE 901 - Reliability Tools for Resonance Inspection of Light Metal Castings

PI: Martin H. Jones
Ford Motor Company

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Overview

Timeline

- Development project
- Start – Apr. 2009
- Finish – Dec. 2011
- 100% Complete

Budget

- Total project funding
  - DOE $273K
  - Contractor $273K
- Funding received in FY11
  - $113K
- Funding for FY12
  - $161K

FCVT Barriers Addressed

- Cost reduction of safety- and performance-critical light metal castings
- Performance – provide inspections required to assure high casting quality
- Modeling tools for quality assurance of castings

Partners

- OEMs – Chrysler, Ford, GM
- PM casting suppliers – CTC, DMI
- NDE suppliers – Magnaflux®, The Modal Shop
- CAE suppliers – LMS, Highwood Technology

Projective Objectives

- Resonance Inspection (RI) is a rapid, reproducible, and cost-effective technique to ascertain the structural integrity of light metal castings, especially safety and performance critical components
  - Primarily chassis components, some powertrain components

- Resonance Inspection is sensitive to structural anomalies that are currently difficult or impossible to detect non-destructively such as oxide inclusions.

- The widespread acceptance of RI has been hindered by the complexity of its regimen; by its failure to identify reasons for rejecting parts; and by unknown sensitivity to anomalies.

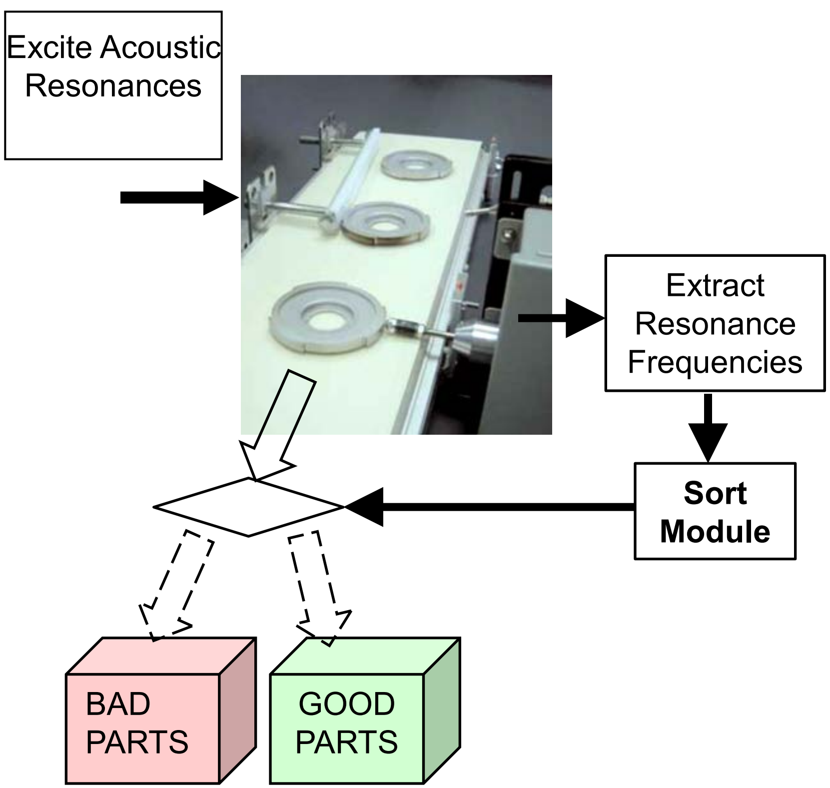
- **This project addresses these shortcomings using modeling including typical material variations and casting discrepancies measured for a production casting.**

Milestones

Month/Year	Milestone or Go/No-Go Decision
Jan 2011	Milestone: Produced finite element discrepancy models based on CT density measurements of production castings
May 2011	Milestones: FEM sort tool operational, FE database of good parts
Jun 2011	Milestone: Tool to map FE discrepancies into FE part models operational
Aug 2011	Milestone: Draft of Standard for Production RI completed
Sep 2011	Milestones: Tensile bar characterization complete
Oct 2011	Milestones: FEM sort tool software complete, FE discrepancies software complete
Dec 2011	Final report complete

Strategy for RI Reliability Tools

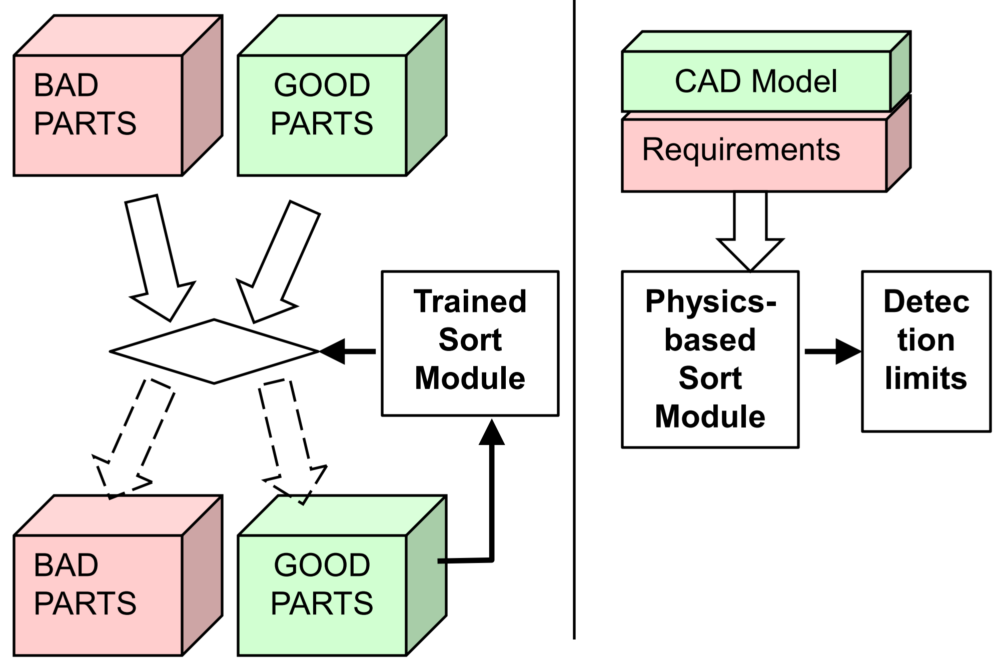
Components of RI



Sort Module Creation

Current Empirical Methods

USAMP Method



Deliverables

- Deliverables for the Concept Feasibility gate (completed)
  - Quantitative prediction of RI frequencies for con rod and knuckle
  - New technology to uniquely identify part resonances
  - Prediction of RI sensitivity to casting discrepancies and variability

- Deliverables for the Technical Feasibility gate

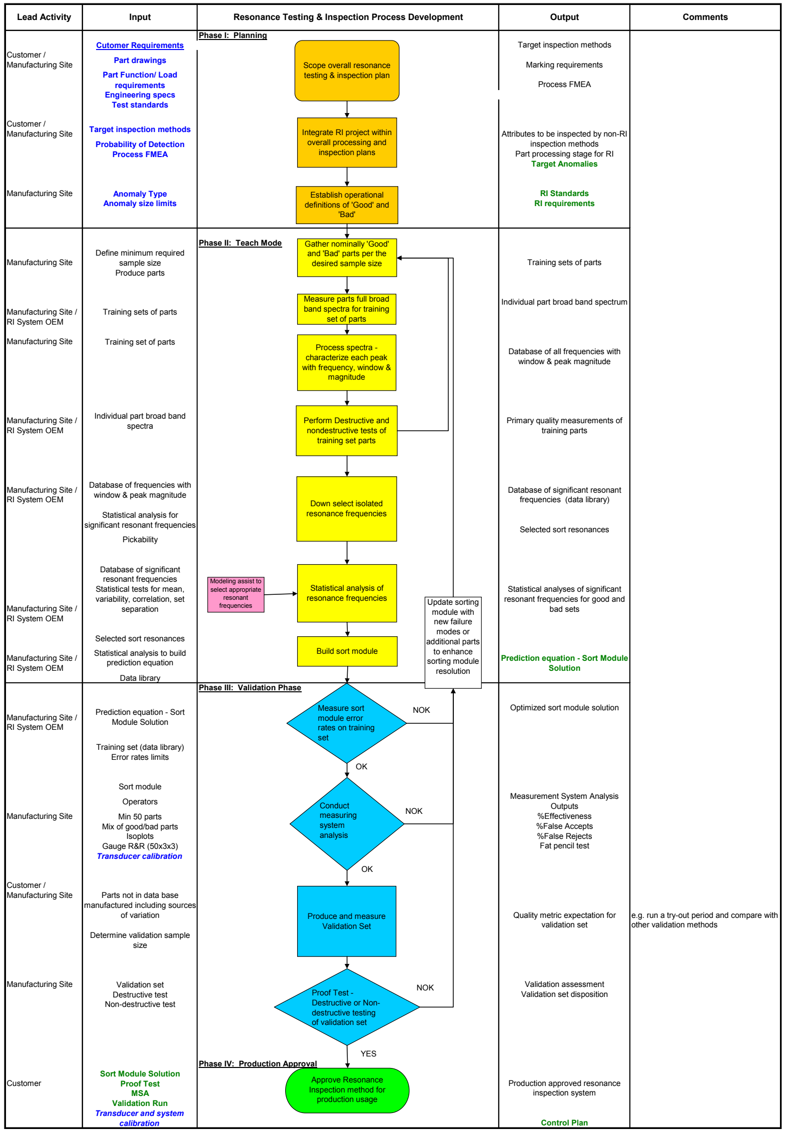
Deliverable	Metric
1. Standardized procedure for RI in production	**ASTM or SAE style standard**
2. Integrated tools to predict probability of detection (POD) to critical defects	**Software program: surface model in, POD out; <4 hrs on commodity computers**
3. Software tools to create sort modules	**Software to generate from CAD or CT model: 5x faster than now**

Technical Accomplishments and Progress

Task 1 Accomplishments

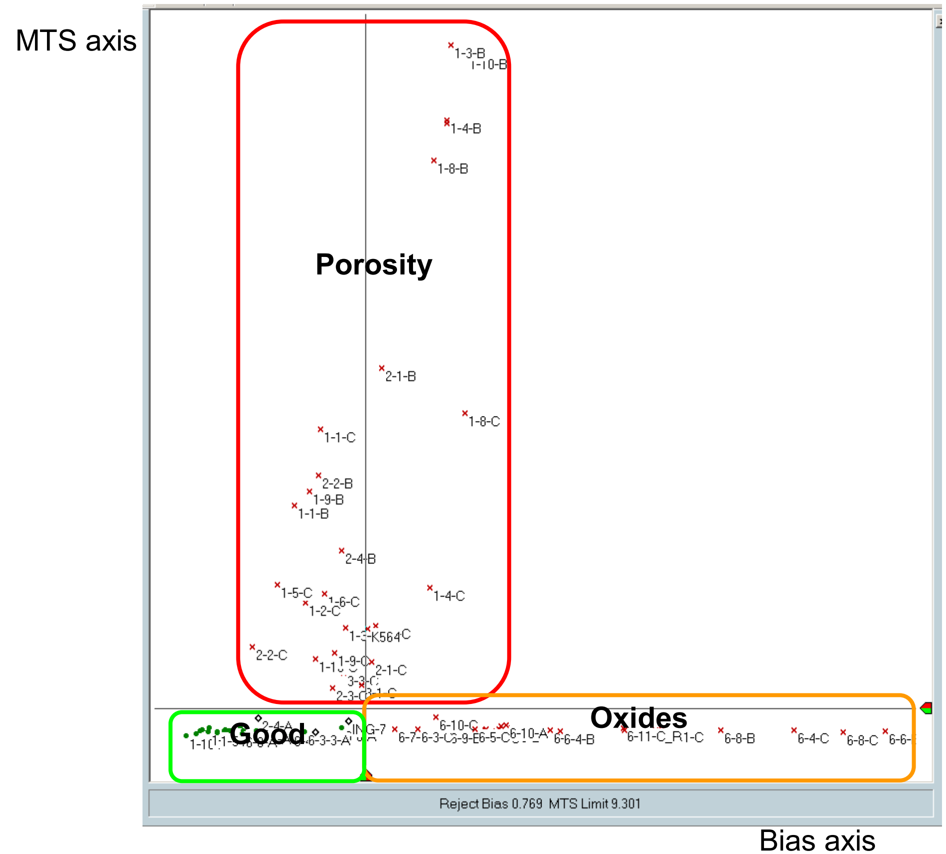
Created two protocols that aid in the production implementation of resonance inspection:

- The first protocol is a **guideline** that provides an overview and a detailed step-step methodology **for implementation**.
- The second protocol is a proposed **standard for resonance inspection** that is deployed as a production process and helps to ensure that the inspection is a reliable, traceable, and reproducible procedure.
- The implementation guidelines end and the inspection standard begins at the validation and approval stage.



Task 2 Accomplishments

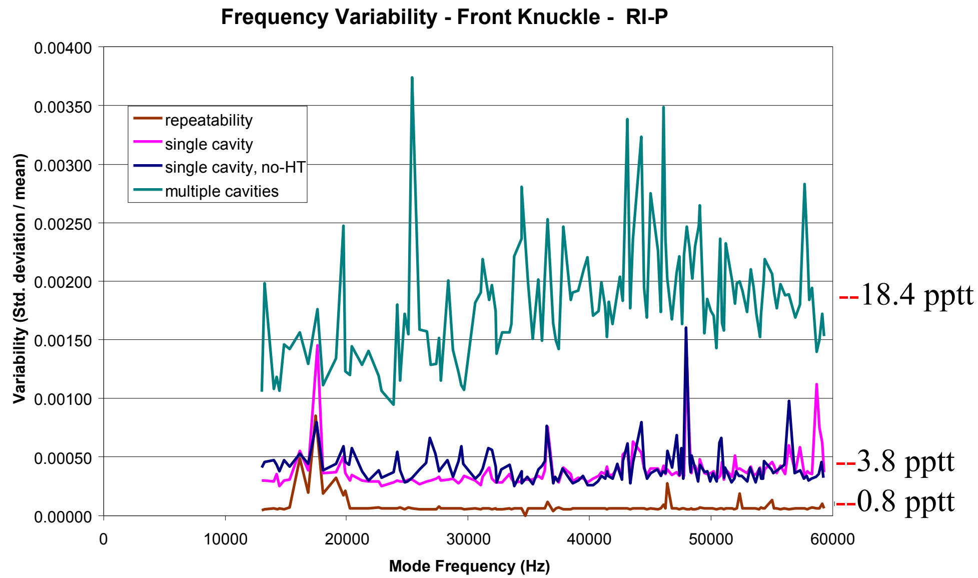
- The experimental castings, machined as tensile bars, were an essential component of this project. They have provided the most detailed information on the sensitivity of resonance shifts to shrink porosity.
- The data relating resonance shifts to mass loss were essential for developing the elastic model of the shrink porosity discrepancy FE models.
- The predicted FE shifts are very close to the measured values.
- The oxide film samples that were prepared offered a new avenue to put oxides at different locations



Graphical representation of the RI-P two-way sort. The porosity samples are displaced along the vertical MTS-axis, while the oxide film samples lie along the horizontal bias-axis.

Task 2 Accomplishments

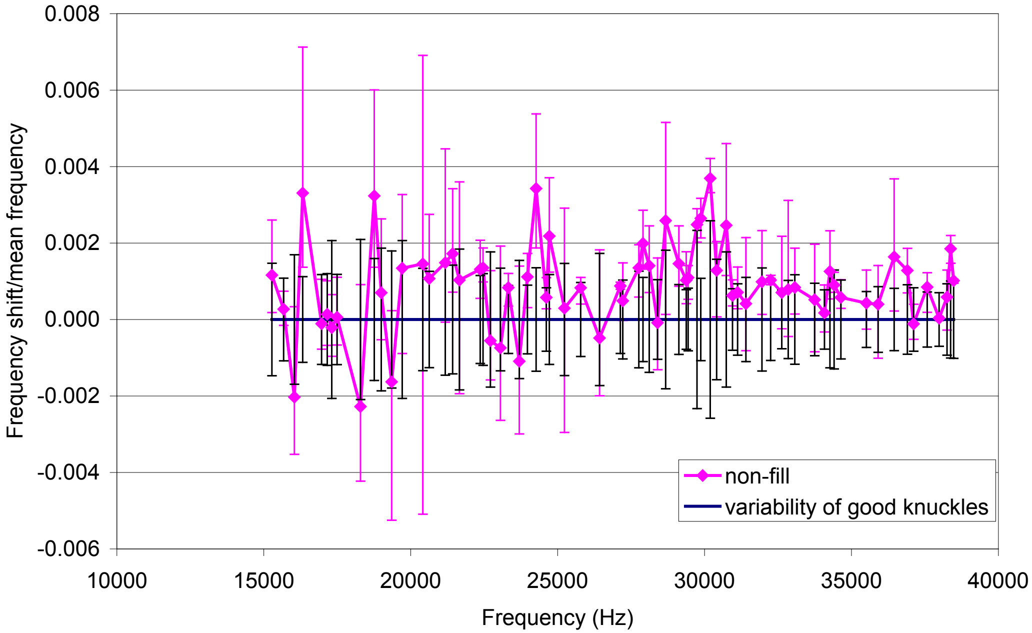
- The resonance frequencies of a high-quality automotive casting have been measured and analyzed in depth.
- The sources of resonance variability in good castings have been quantified and compared to the density and stiffness variations in the casting alloy and to variations in the degate height.



- **The frequency shifts due to discrepancies have been measured systematically and are reported for the first time. These provide the most quantitative measurements and correlations to date of the resonance behavior of a production casting.**
- These measurements provide a test bed for the ability to finite element model not only the mean resonance frequencies of good castings, but also the frequency variation of good castings and the shifts of discrepant castings.

Task 2 Accomplishments

- The rear knuckle has confirmed the results from the front knuckle and the tensile bars leading to a consistent pattern to the frequency shifts trends with discrepancy class and the frequency variations in non-discrepant samples.
- Resonance inspection has been qualified to replace FPI in this component after an extensive process of revising the inspection (part orientation and machining state) and of quantifying the performance.



Mean frequency shift for rear knuckles with non-fill discrepancies. The large colored error bars indicate the minimum and maximum values. The small black error bars indicate the frequency variability of good parts.

- This inspection stands as a benchmark for the process needed to implement this inspection and for the benefits that can be attained.

Task 2 Accomplishments

- Experimentally derived finite-element models for shrink cavity discrepancies range in size from ASTM E155 Grade 3 to Grade 6 were developed.
- These have realistic maps of the density variations and an experimentally determined relationship between the local density and the stiffness.
- These models were used in the finite element simulations and in the sort module testing.

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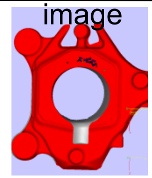
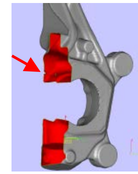
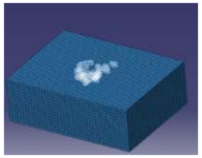
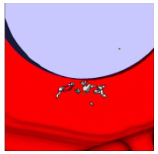
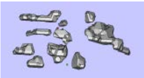
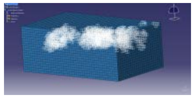
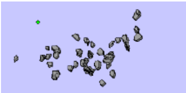
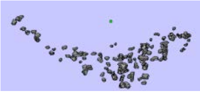
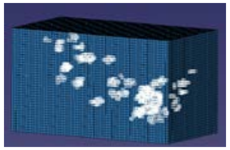
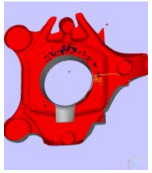
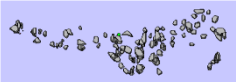
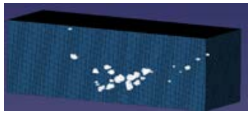
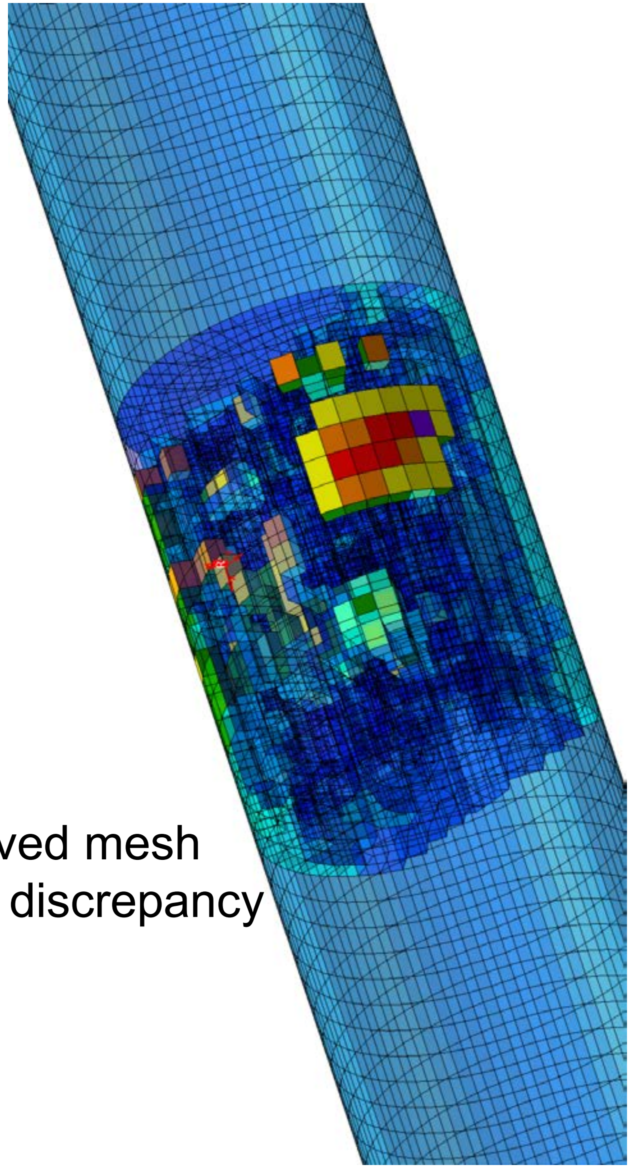
G3-#503			
G3-#535			
G4-#547			
G4-#521			
G5-#544			
G6-#549			

Task 2 Accomplishments

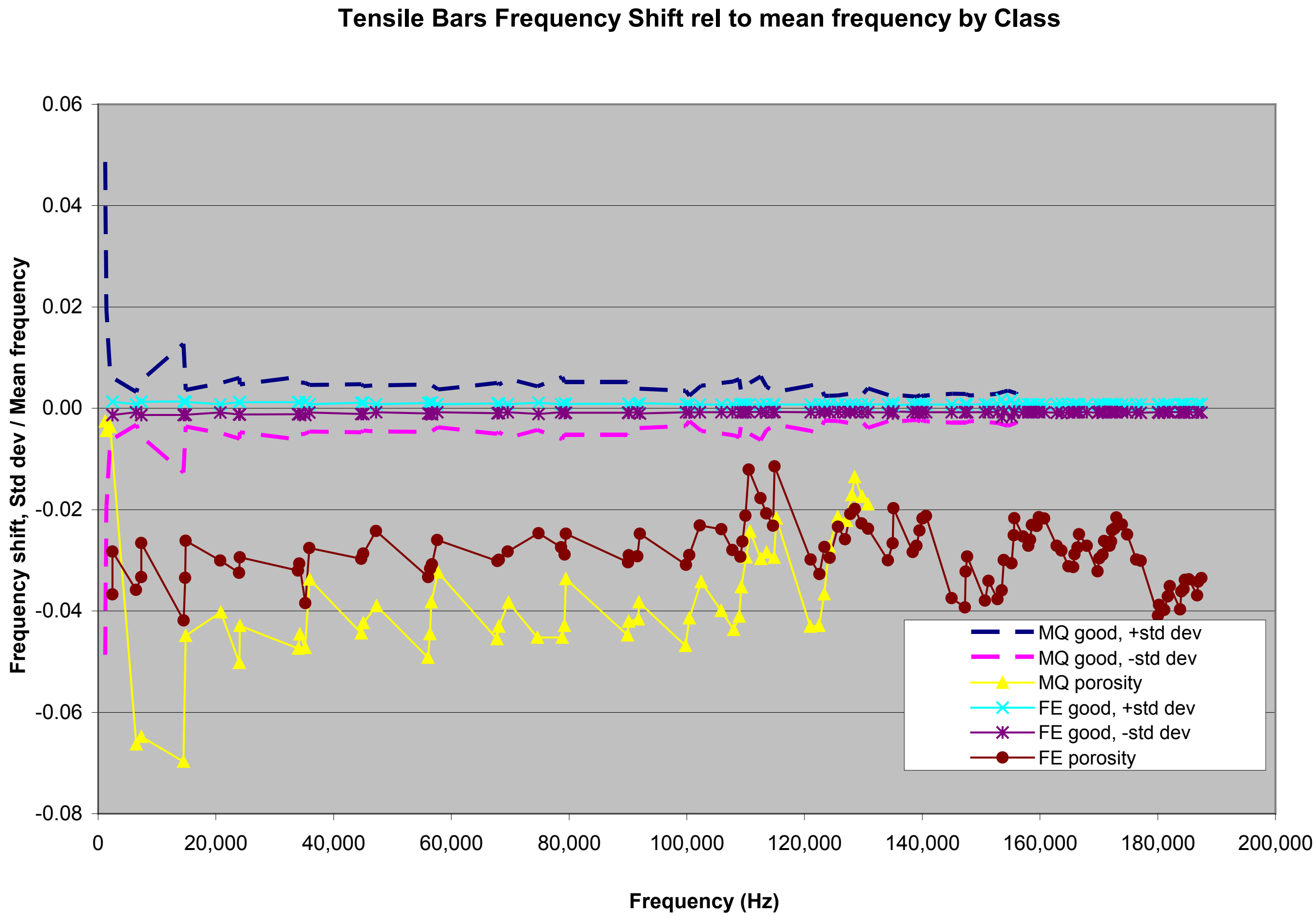
- The first simulations for resonance inspections including an ensemble of both good parts and discrepant parts was achieved.
- These were calculated with the first comprehensive set of tools that can start with the CAD model of a component and generate a database of frequency shifts that can be used to create a priori sort modules.



Elements of a CAD derived mesh replaced with a porosity discrepancy model.

Task 2 Accomplishments

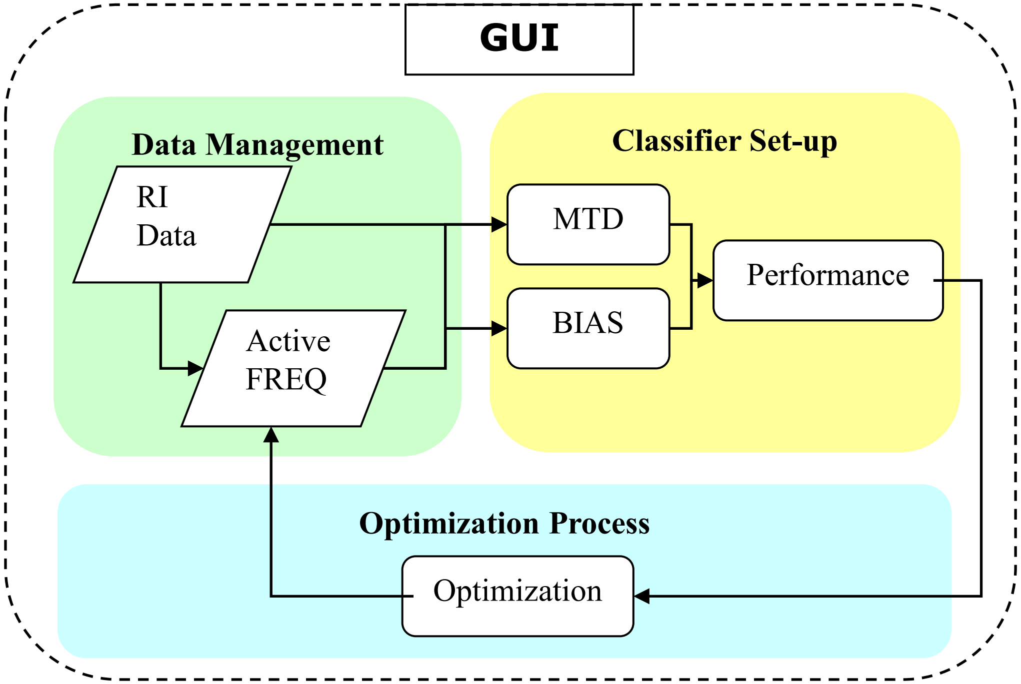
- The experimental and predicted results match well.
- Both experimental and predicted responses are well outside the 1 standard deviation shifts for good parts at nearly all frequencies.
- Experimental (MQ) results are from RI testing.



- Predicted results are from FEA analysis using the part model with discrepancies inserted.

Task 3 Accomplishments

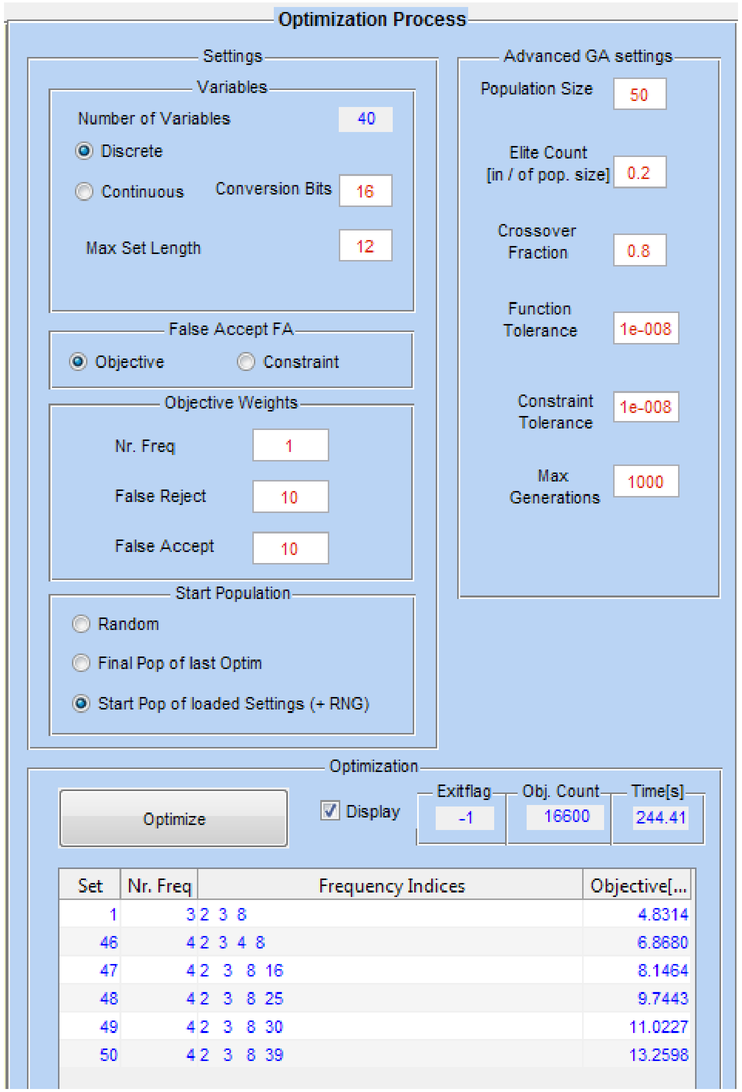
- A versatile sort module (named RISOR) with a graphical user interface has been developed that offers high flexibility in terms of:
  - classification, which has two multidimensional distance options and two classifier options (distance to class and distance from good)



Task 3 Accomplishments

- active frequency optimization, which is based on a genetic algorithm and allows balancing between different objectives data management of training and testing data together with sort results (frequency sets)
- written in MATLAB© for rapid prototyping and sophisticated toolbox.

- The optimization and evaluation runs very quickly (essentially in real time) even using non-compiled code. This sort tool has the unique capability of sorting parts by discrepancy class and could potentially be adapted to determine discrepancy location.



Collaboration, Summary, Future

Project Collaborators

Chrysler LLC (CLLC)
George Harmon
Dean Martin
Phillip Seaton
Lin Zhang

Ford Motor Company (Ford)
Martin Jones, Chairman
James Loeffler

General Motors Company (GM)
Daniel Simon
Leonid Lev
Kasi Goudan

CTC Casting Technologies (CTC)
Martin Brady
James Waters

Diversified Machines, Inc. (DMI)
Chuck Leonard

LMS International
Laszlo Farkas
Tom Van Langenhove
Mike Pyrkocz
Prasad Vesikar

Magnaflux Quasar (MQ)
Jay Saxton
David Geis
Robert Nath

The Modal Shop (TMS)
Gail Stulz
Scott Sorenson

Highwood Technology LLC
Cameron Dasch
Project Manager

Ajilon Services
Meg Bowman
Chris Sippl

Future Work

- Project work completed Sep 2011.

Summary

- This project has created a suite of protocols, experimental databases, and software tools that can improve the implementation, reliability, and traceability of resonance inspections for safety- and performance-critical automotive castings.
- Two sets of protocols were developed. These include a “Guidelines for Implementation of Production RI” that provides a step-by-step process for defining the inspection requirements and implementation. The second protocol is an ASTM-style “Standard for Production RI” that defines the instrumentation requirements and performance documentation.
- To broaden the available experimental information on the sensitivity of RI to discrepancies, data from three types of castings were collected. A wide range of both acceptable and discrepant knuckles were collected, documented, resonance inspected, and had sort algorithms created. Typically the correct call rates are >95% for all the available discrepancy locations, types, and sizes.

Summary

- An industry-first software tool bench was created that can generate a library (database) of frequency shifts for both acceptable and discrepant samples. The library can be used to develop and test sort algorithms. The tool bench uses standard finite-element methods to predict the resonances of the target samples. These methods are widely available and accurate to the needed level of better than 1 part in a thousand. The first realistic finite-element models for shrink porosity discrepancies were created starting with computed tomography scans of the density in the production knuckles and combining this with an empirical correlation of stiffness loss to density loss measured in the cylindrical castings.
- The last component of the tool bench is a new sort optimization tool. This tool uses several classical multivariate measures of spectral shift to identify discrepancies by type. The selection of the resonances is optimized using a customized genetic algorithm. The optimization converges within minutes and avoids local minimums. The identification of discrepancy type is an additional new capability.