NDE 701: Enhanced Resonance Inspection for Light Metal Castings

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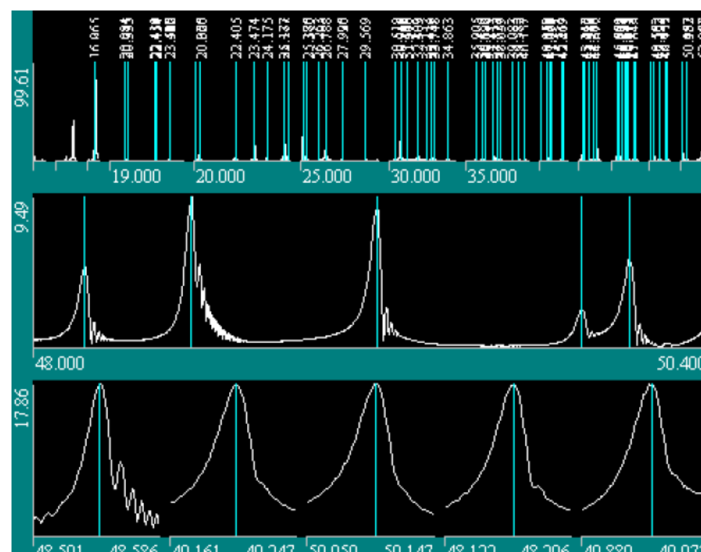
This presentation does not contain any proprietary or confidential information

Outline

- Purpose of work
- Barriers
- Approach
- Performance measures
- Accomplishments
- Technology Transfer
- Publications/Patents
- Plans for Next Fiscal Year
- Summary

Purpose of Work

- **To make the nondestructive inspection of light metal components using *<u>resonance inspection</u>* more reliable, robust, and quantitative.**
  - Resonance inspection uses shifts of the natural acoustic resonance frequencies to detect discrepancies.
  - Castings, forgings, and powdered metal
- **To use advanced modal analysis tools (both experimental and computational) to optimize the selection of inspection frequencies.**
  - Resonances are now picked empirically



Barriers

- **To improve the quality of delivered light-metal castings by improving the nondestructive testing of these components.**
  - Performance-critical castings need defect rates below 1 in 10 million
  - Currently, performance-critical castings are typically 100% radiographed and dye penetrant/visually inspected. These can not directly detect oxide features that can limit strength.
  - Resonance inspection is the most promising method for detecting these discrepancies, but it is difficult to implement, non-robust, and with unknown detectability.
- **To reduce the cost of light-metal castings by more effective feedback to the casting process and with faster, less expensive inspection**
- **To reduce the mass of castings which may be "over-engineered" to have an adequate safety margin with current manufacturing and inspection.**

Approach

- ❑ **Concept Feasibility Project**
- ❑ **Stretched to 2.25 years due to limited funding**
- ❑ **Manufacturing acceptance of Resonance Inspection (RI) is limited by its empirical methodology. Therefore augment current empirical methodology with predictive tools.**
  - Develop a set of tools to enable predictive capability.
    - Model to translate materials properties and geometry into predicted frequencies
    - Methods to identify mode shapes for each frequency
    - Sensitivity matrix to critical anomalies
  - Validate by comparing predicted and measured frequencies and mode shapes.

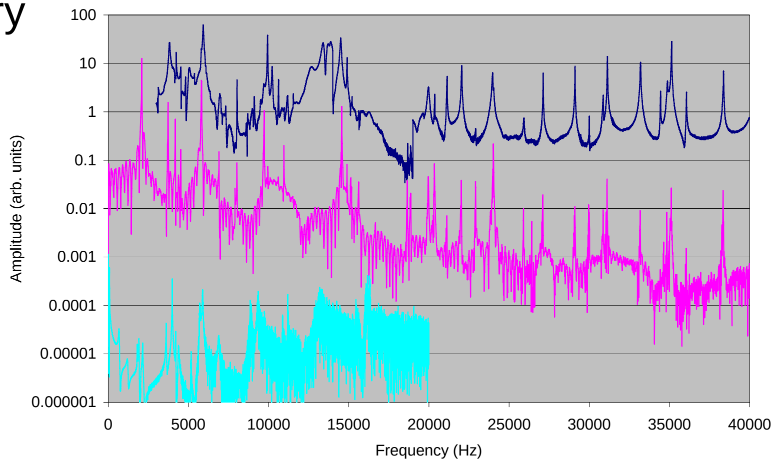
Methodology/targets

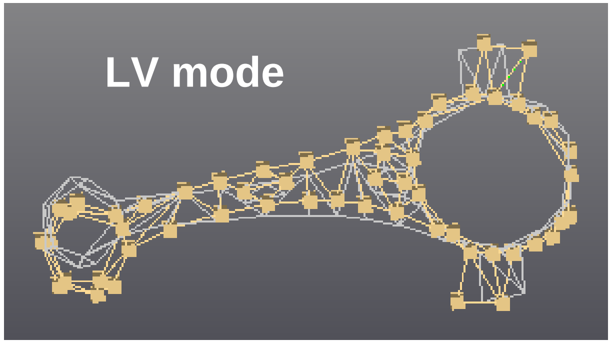
CAD Model	Simple geometry	Baseline casting
		
Make & select parts	✓	✓
Measure resonances	✓	✓
Measure mode shapes**	✓	
Measure material properties	✓	in process
Model resonances, mode shapes	✓	
Match observed and FEM modes**	✓	
Predict in-service high stress areas	✓	
Predict sensitivity to discrepancies**	✓	
Make discrepancies, measure effect	in process	
A priori method to select inspection frequencies**	Follow-on project	

** new technology

Accomplishments - Simple-Geometry Measurements

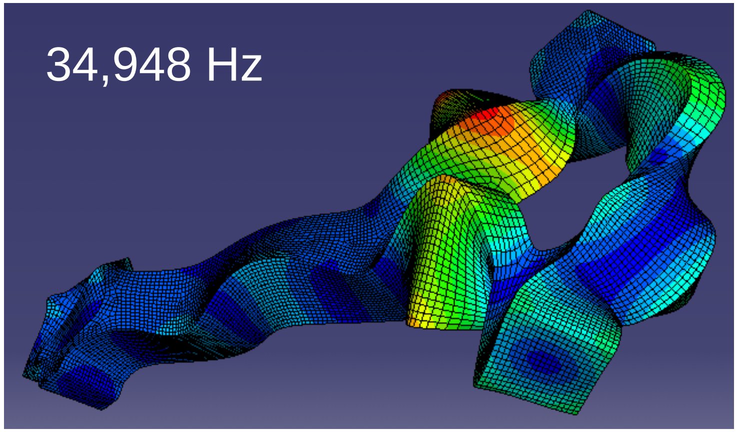
- **Simple-geometry: connecting rod-like, water jet cut from Al plate**
  - Material properties determined – isotropic, <0.2% (std. dev.) variation
  - CT scan to verify build - within 1% of CAD
  - RI inspection completed (10 parts, 3 methods, repeatability)
  - Mode measurement – 3d laser velocimetry

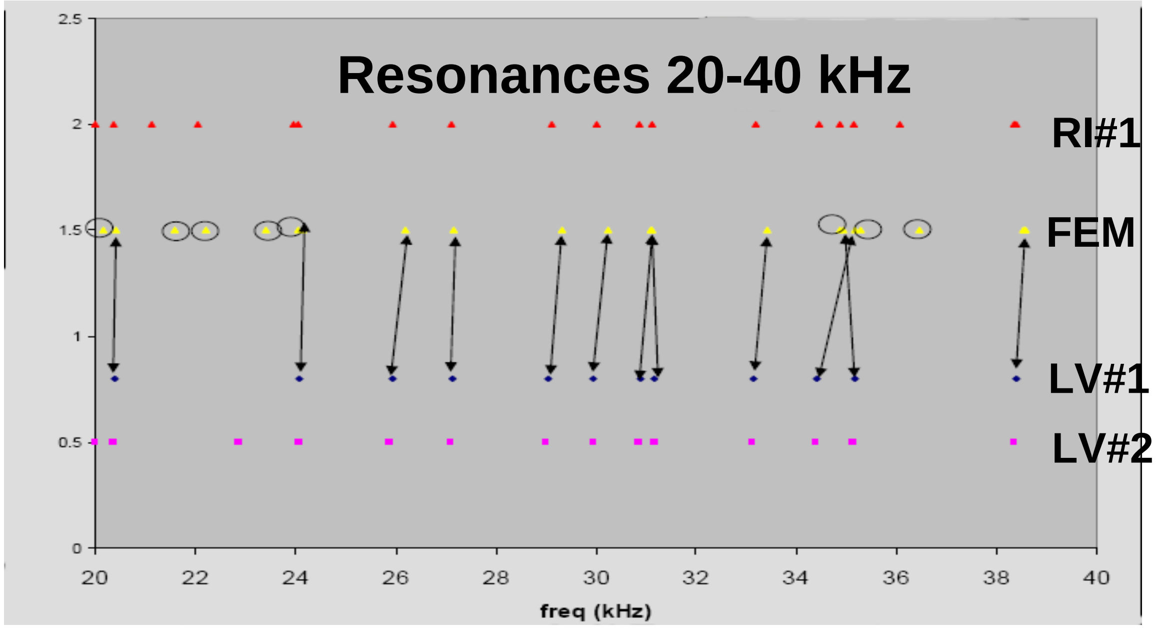




Accomplishments – Simple Geometry FE Analyses

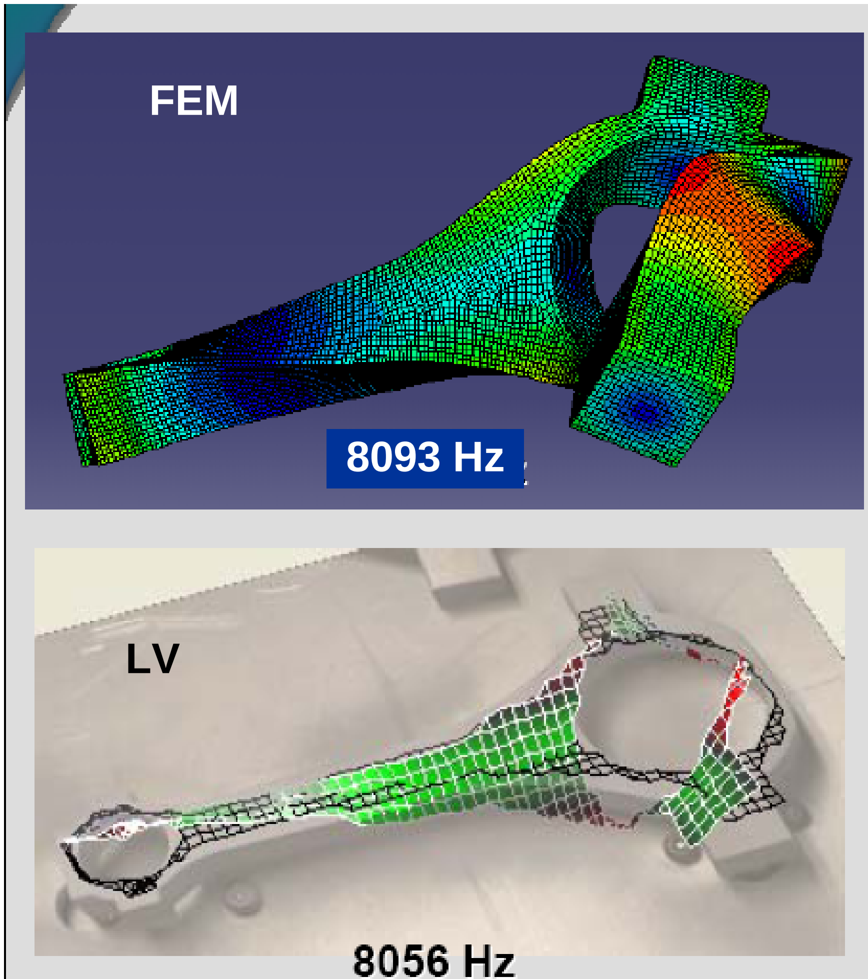
- **Use commercial FEM software on commodity computers**
  - Input
    - CAD or CT geometries
    - Actual material props
  - Output
    - Resonance frequencies
    - 3-d mode shapes
- **Match to experiments**
  - Automatic mode matching

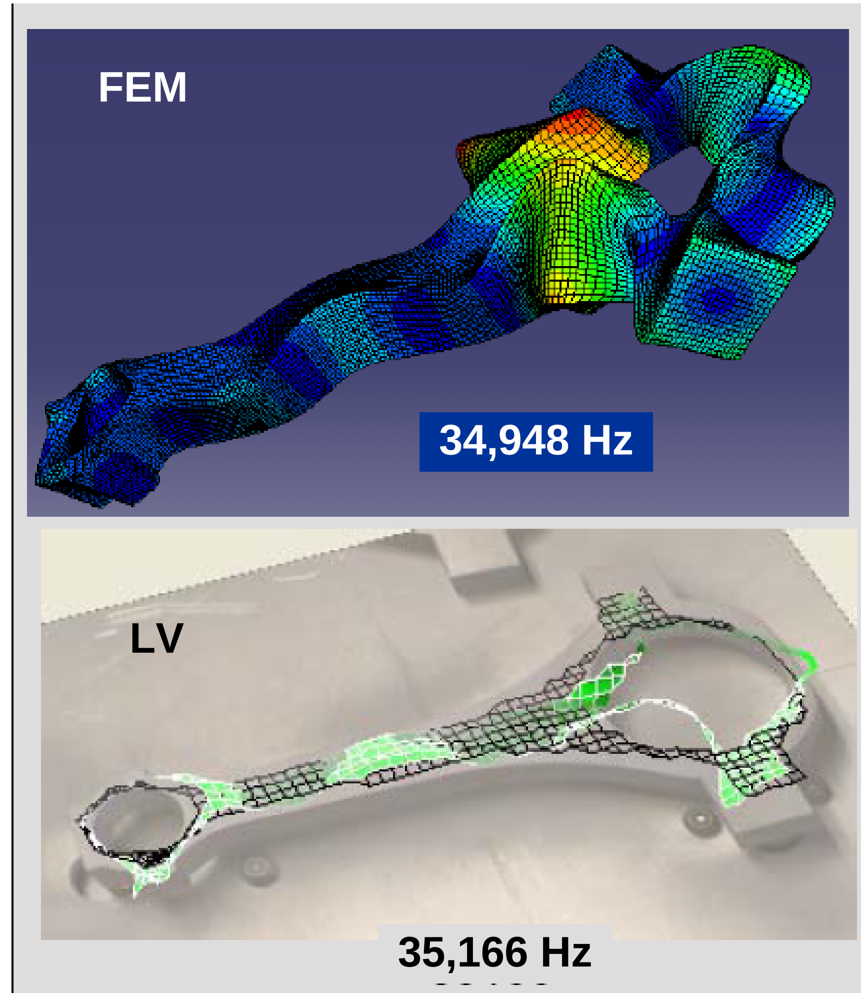




Accomplishments - Mode Shape Comparison

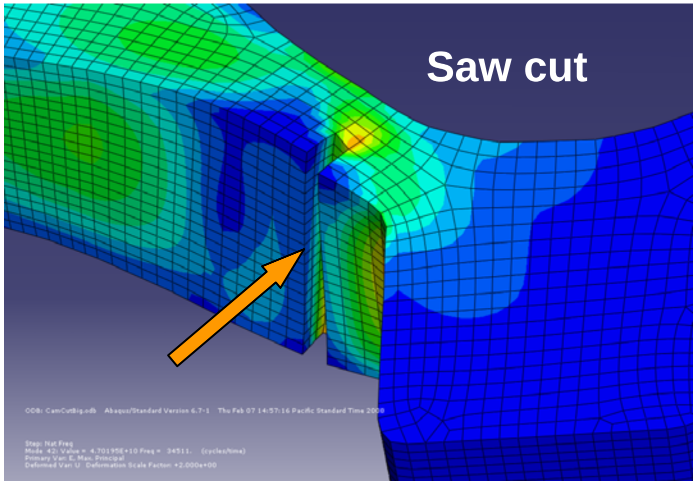
- Algorithm for automatic mode matching

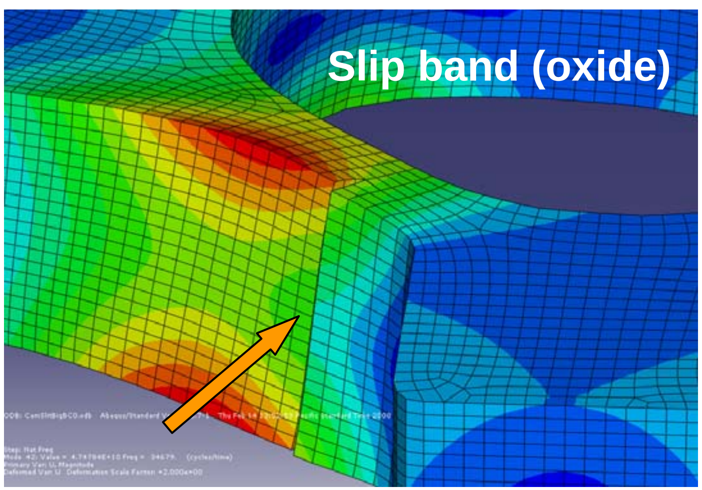




Accomplishments – local change sensitivity

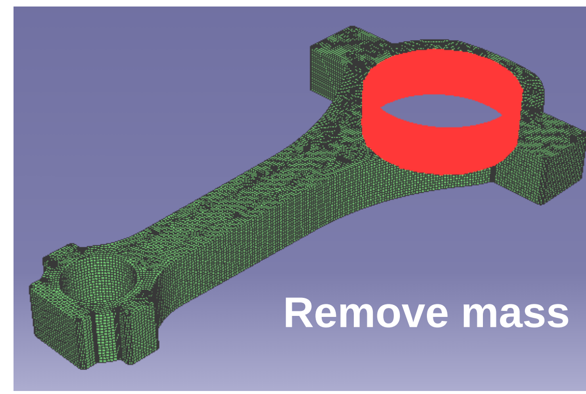
❑ Add model defects

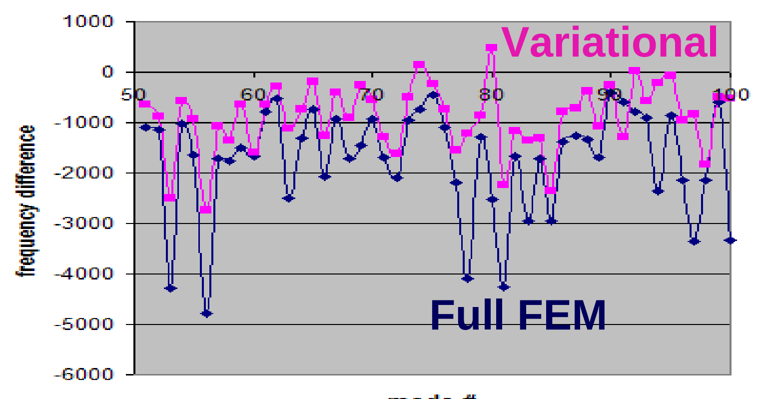




❑ New variational method

- Perform one FEM analysis
- Predict frequency shifts due to local material/geometry changes





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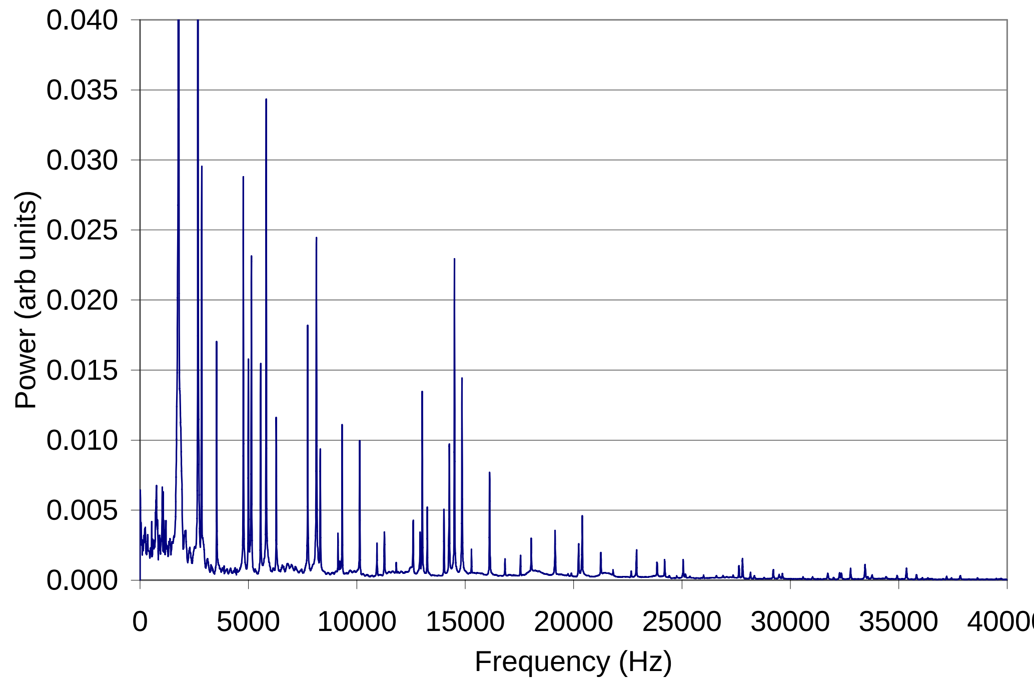
Accomplishments -Automotive Al Knuckle Casting

- ❑ **Automotive knuckle casting selected as baseline part**
  - Partnered with major supplier to produce parts (HT and non-HT)
  - RI testing completed in January 2008



Technology Transfer

- **Among project participants, good mix of links in the tech transfer chain**
  - OEM NDE experts who qualify methods
  - OEM castings experts who specify inspection requirements
  - Two major casting suppliers who are currently using or planning to use RI
  - Three major RI/modal analysis suppliers actively participating – new business relationships formed
- **Target – RI supplier to implement as paid service**

Publications/patents

- **ROI in process**
- **In preparation for Review of Progress in Quantitative Nondestructive Evaluations, July 2008**

  "Towards Quantitative Resonance Inspection: Resonance Modeling and Mode Identification"

Activities for Next Fiscal Year

- **Test ability to predict and detect shifts due to anomalies on simple geometry**
  - Produce anomalies and measure effects
  - Analyze/quantify ability to predict
- **Test methodology on base casting (knuckle)**
  - Any road blocks with more complex part?
  - Any technology to facilitate methodology (e.g. mode measurements)?
- **Modeling work to rationalize differences between predicted and observed frequencies is in progress**
- **Propose follow-on project?**
  - Develop *a priori* selection of inspection frequencies

Summary

- **This is an important technology to verify light metal castings/forgings/PM parts**
    - Improved reliability for critical components
    - Reduced inspection costs
    - Potential for reduced mass
- **Technical achievements during first year**
    - Demonstrated that experimental resonances can be uniquely identified and automatically assigned to a FE modeled mode.
    - Demonstrated that shifts due to discrepancies can be efficiently predicted based on a single FEM modal analysis.
- **Critical links for production implementation are in place**
- **Coming Year**
    - Demonstrate that discrepancy shifts are accurately predicted
    - Demonstration on production part

Questions?

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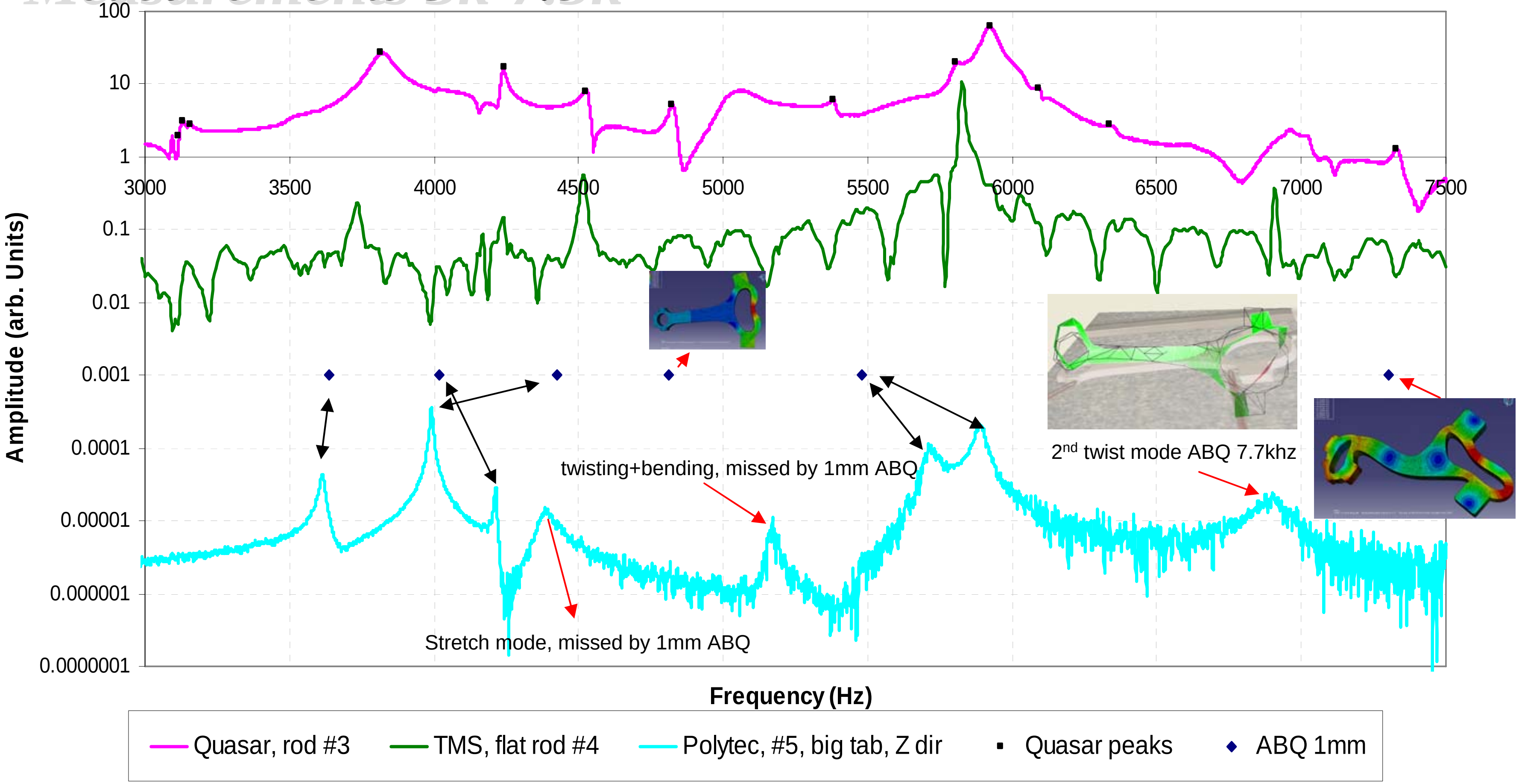
Project Overview

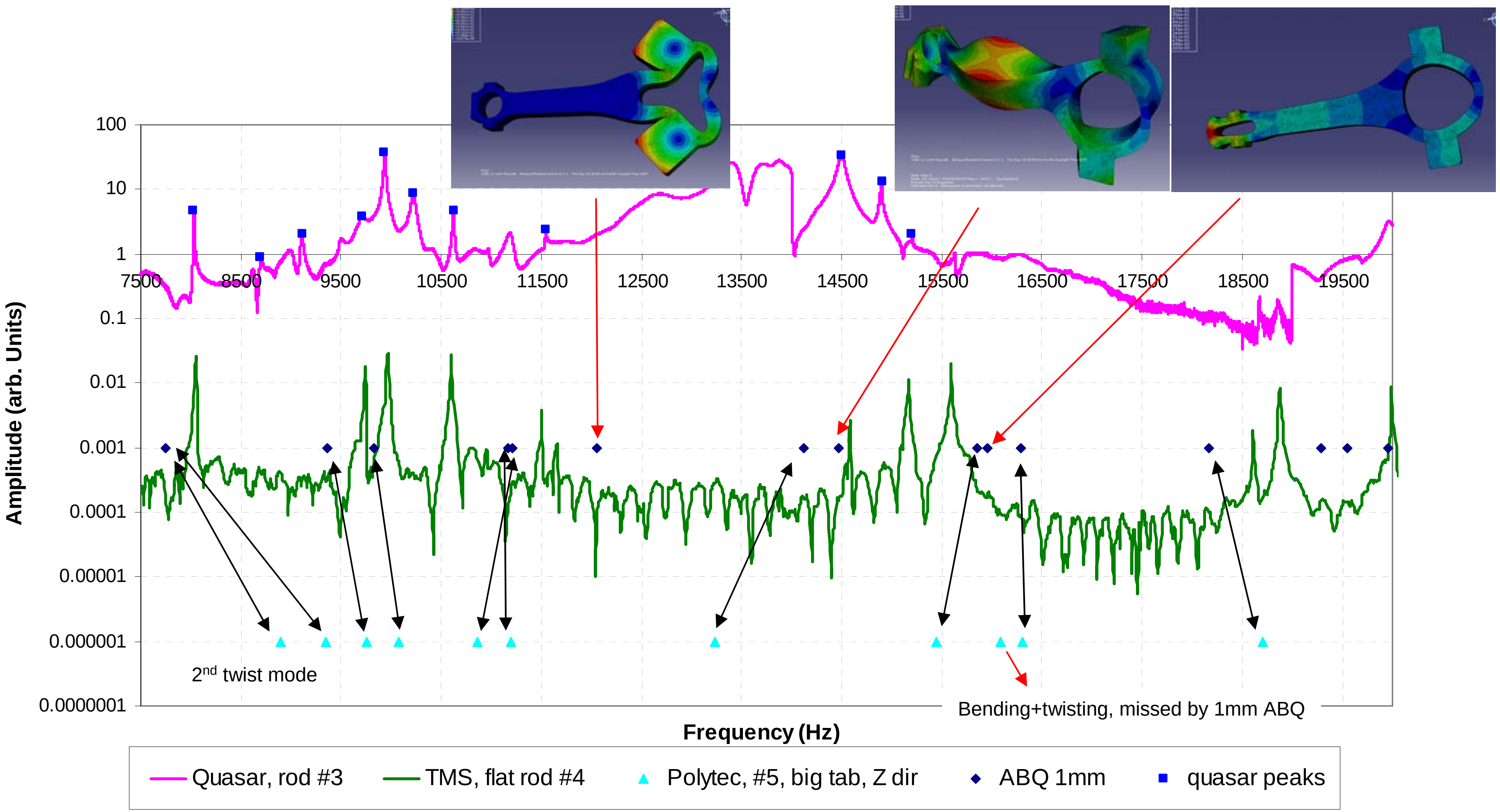
❑ Task 1: Part selection and protocols establishment	Complete
❑ Task 2: Production of baseline parts	Complete
❑ Task 3: Inspection of baseline parts	Complete
❑ Task 4: Correlation of finite element modal analysis prediction to simple-geometry part	Complete
❑ Task 5: Computational modal analysis of baseline parts	In Process
❑ Task 6: Modeling and analysis of imperfect parts to determine sensitivity to selected anomaly types	In Process
❑ Task 7: Selection/fabrication and characterization of discrepant parts	In Process
❑ Task 8: Perform RI on parts with anomalies	In Process
❑ Task 9: Development and evaluation of modeling to enhance RI	In Process
❑ Task 10: Project management, information dissemination, reports, final report, future directions	

Accomplishments (Finite Element Modeling)

Comparisons between Predictions and Various Measurements 3k-7.5k



Accomplishments (Mode Shape Comparison)



Gaps

Risk/challenge	Plan to overcome challenge	Explanation
Prediction accuracy for mode frequencies may be limited by computational state-of-the-art	Document, then transfer emphasis to prediction of frequency shifts	Frequency shifts are the most important component in present sorting algorithms
Prediction accuracy for mode frequencies may be limited by materials inhomogeniety	Determine variations in denisty and moduli from experiments or casting codes	Property variations can be mapped by computed tomography or other techniques
High mode density may confound identification of mode shapes	Supplement computations with laser vibrometry or other experimental approach	Direct measurement of mode shapes is possible and can be used to identify exact shapes

Approach

- ❑ **Concept Feasibility Project lasting 2.2 years**
- ❑ **Develop methodology on simple geometry test**
  - Design and make parts
  - Measure acoustic characteristics
    - – Resonance frequencies (3 methods)
    - – Mode shapes (1 method)
    - – Material properties using cuboids/
  - Develop a set of tools to enable predictive capability.
    - – Model to translate materials properties and geometry into predicted frequencies
    - – Methods to identify mode shapes for each frequency
    - – Sensitivity matrix to critical anomalies
  - Validate by comparing predicted and measured frequencies and mode shapes.
- ❑ **Validate methodology on a baseline part**

Conclusions

- **Project is proceeding on planned path. Progress to date is encouraging even in early stage**
- **Physical part selection and testing ahead of schedule**
- **Major hurdle of uniquely identifying specific mode shapes has been solved using laser vibrometry**
- **Modeling work shows promise**
- **Technical hurdles may still exist, but two of the most serious have been solved – Mode shape determination and frequency correlation**