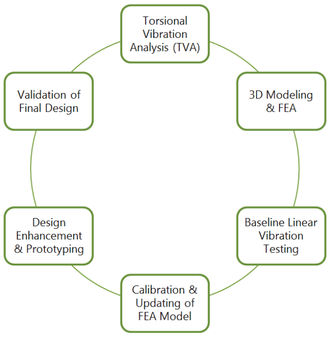
VIBRATION ENGINEERING

"The Six-Step Process"

ACS uses the Six-Step process to offer analytical and experimental vibration engineering services for enhanced structural design of complex test equipment and facilities.



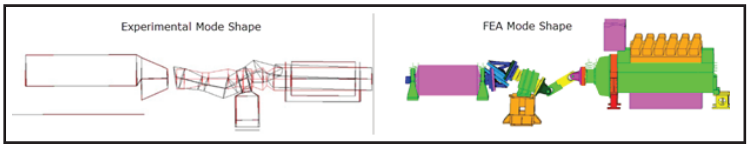
Step 1 **Torsional Vibration Analysis (TVA)**
The program begins with a review of the torsional vibration analysis (TVA) of rotating systems. The TVA is ideally carried out by the client or by the rotating equipment supplier. In cases where the manufacturer/supplier is unable to execute a TVA, ACS will take on the responsibility with support from the supplier.

Step 2 **3D Modeling & FEA**
ACS creates a 3D model of the test system and analyzes it using finite element analysis (FEA) techniques to determine natural frequencies of resonance of the entire coupled system. Design optimization is an eventual next step that follows the results of this analysis. The optimized design moves along the integrated project delivery model and is implemented at the client's test facility.

Step 3 **Baseline Linear Vibration Testing**
Once the installation is completed, as part of the commissioning activities, the Structural Vibration Analysis & Testing (SVAT) team schedules an onsite baseline measurement of the coupled system. This testing helps evaluate the design and also establishes the state of the system in the as-built condition. Two types of testing are usually carried out:

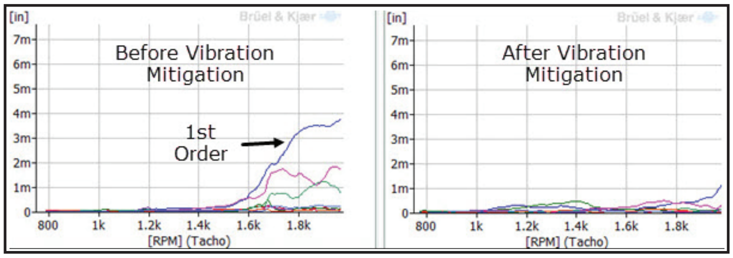
1. **Impact based Modal Test** - striking the system with an instrumented hammer and measuring the response to determine natural frequencies of the overall system.
2. **Operational Test** - running the test equipment through a series of loaded and unloaded speed sweeps while measuring vibration responses. The measured data is used to compute the **operation deflection shapes (ODS)** of the system. The data is also used for **order analysis** and **order tracking**.

Step 4 **Calibration & Updating of FEA Model**
The experimental results obtained through measurements are then used to calibrate the previously created FEA model. Once the model is calibrated, it can be manipulated for the purpose of improving the structural characteristics of the system. This typically involves several design iterations before a final concept design solution is reached. Design reviews are scheduled with the client to make sure the modified design is feasible and will achieve the desired results.



Step 5 **Design Enhancement & Prototyping**
To verify the proof-of-design concept, prototype components are fabricated and installed. Once the prototypes are installed, the modal and operational tests are repeated to evaluate the impact of the design revisions.

Step 6 **Validation of Final Design**
If the desired vibration levels are achieved, the design is adopted into further fabrication, installation and use. If modifications are still required, the calibrated FEA model is used to evaluate further design iterations. More than one pass of the design- test-modify process might be required before arriving at the final design. Sound engineering judgment is used to try to keep these steps to a minimum.



Implementation of the solution can vary widely depending on the number of system components that need to be changed. Several changes might be implemented to achieve the final performance levels in the coupled system.

ACS recently implemented the six-step program successfully at several of its client facilities.

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Project Examples

Vibration Testing and Analysis 5MW Wind Turbine Spin Test Facility

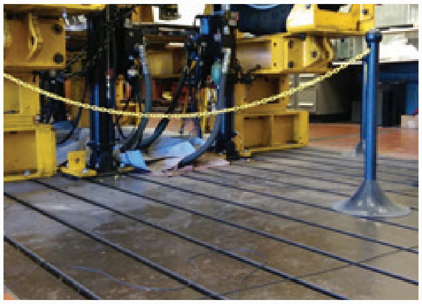
ACS performed vibration testing on a 5MW Dynamometer test facility operated by the National Renewable Energy Laboratory (NREL). The objective of testing was to evaluate the vibration levels in the dyno spin test system. The system was tested under several configurations:

- The initial test was in the decoupled configuration, with the dyno physically disconnected from the gearbox, Non-Torque Loading system (NTL) and load. In this decoupled state, the dyno was tested in both normal and reverse directions of operation.

- In the subsequent tests, the dyno was coupled to the rest of the system and data was collected in both unloaded and loaded conditions.
- The testing activity consisted of taking 300 channels of operational vibration data for measuring vibration levels in the machine foundation and other major sub-systems in running conditions.
- Recommendations were provided for safe operation of the test facility, based on the findings of the testing and analysis effort.

Shaker Lab Floor Vibration Measurement

ACS is involved in the front-end planning for development of a new 4 post hydraulic shaker lab for an agricultural equipment manufacturer. The new lab will significantly increase the capability of the client to test larger tractors and combines, than an existing shaker lab in the same facility.

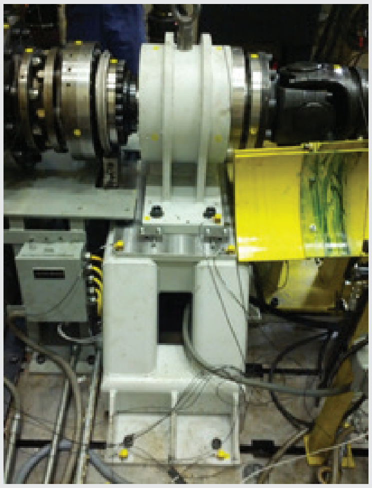


As part of the initial feasibility study for choosing the site location for the new shaker lab, a floor vibration study was conducted by ACS at the existing lab to evaluate vibration levels at the parking lot and outside perimeter of the client property. This data was used to evaluate the feasibility of extending the existing building into the parking lot, in order to house the new shaker lab.

Evaluating Vibrational Behavior of Coupled Dynamic Systems in Engine Test Cells

ACS uses system level experimental vibration testing and finite element analysis methods to mitigate high vibration levels in complicated dynamic systems such as engine test cells.

ACS performed modal and operational vibration tests to establish baseline vibration levels at a diesel engine test cell during commissioning. Measurements were taken on all major sub-systems such as the engine assembly, dynamometer assembly, intermediate driveshaft bearing pedestal and driveshaft components. Correlation of modal data with order tracked data (derived from operational testing) revealed an axial mode of the driveshaft bearing pedestal that was getting excited by a higher order vibration of the dynamometer trunnion bearings. Continued operation in this condition would have led to structural failure of the dynamometer bearings and significant wear of the intermediate driveshaft bearings. Finite Element Analysis (FEA) methods were used to develop a design solution to achieve vibration mitigation. This led to a revised support structure for mounting the driveshaft bearing on its base pedestal. The final design was installed in the test cell and its performance was validated by repeating the modal and operational tests.



This case aims to emphasize the need for more system level testing in coupled dynamic systems that will eventually avoid damage to test equipment and reduce downtime in engine test facilities.