Test-bed for Bose Speaker Impact Stress Analysis

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Abstract
Bose, an audio-technology developer and high-end audio-device manufacturer, relentlessly tries to improve the quality of their products. Joining forces with Bose engineers, the capstone group has developed an analytical model that estimates the level of impact stress necessary to break individual speakers and their subcomponents given the static shear stress data. In other words, the analytical model estimates impact stress from lab generated static shear stress data. This model enables to predict the breakdown behaviour of speakers and their subcomponents when they are subjected to impact stresses (due to drops, slams and handling) in the user environment. The capstone group built a test-bed to assess the performance of individual speakers and their subcomponents when subject to impact stress that imitate the impact stresses in the user environment. The data collected from the experiments are used to verify the analytical model that relates impact stresses to static shear stresses. A dual column free fall impact test-bed has been built and is used to generate the experimental data. Statistical analysis indicates that there is no significant difference between the impact stress estimated by the analytical model and the experimental measurements made on the test-bed. The model generated by the capstone group allows Bose to predict the quality behaviour of their speakers in the user environment from their lab data.

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The Need for Project

Currently no component level empirical testing exists to predict speaker robustness at an early design stage. The Transducer Technology Group (TTG) performs destructive impact tests during the development phase of their speakers. Currently the impact tests are conducted on the assembled products in an accelerated life environment. Due to the high cost of prototyping, the sample sizes used in testing are small, potentially yielding insignificant data. TTG aspires to investigate the structural integrity of newly designed speakers and their subcomponents at an earlier stage of the design process at a lower cost.

The Design Project Objectives and Requirements

Design Objectives

The goal of the project is to develop an analytical model that estimates the impact stress necessary to break speakers and their subcomponents. An impact test-bed will be designed to collect data to verify the model relating impact stress to static stress. The test-bed will simulate the impact conditions that speakers and their subcomponents will experience in a user environment. A standard operating procedure is to be created to allow easy use of the test-bed and analyzing data collected.

Design Requirements

The analytical model must estimate the level of impact stress required to break a speaker’s subcomponents. The data collected from the test-bed should be able to verify the model. The final test-bed design must comply with the following requirements. The tested part must not experience direct contact with the impact surface; the force must be translated through shock. The new test-bed must exert a g force range of 100-1000 gs, repeatedly and accurately on the object being tested. The test-bed should accommodate multiple subcomponent and speaker designs. The testing protocol should include step-by-step instructions to guide the user in performing tests and analyzing data.
Design Concepts Considered

Three design concepts were considered from which one was chosen. Multiple test-bed designs were considered with the objective of fulfilling the design requirements addressed above. There are three main designs the team has considered: three rail fixture, wire based fixture, and dual column test-bed.

The three-rail solution consists of three rails guiding a plate while free falling from a certain height onto an aluminum or plywood impact surface. A clamp attached to the plate grips the test subject preventing direct impact. The clamp also enables testing in different orientations. The wire based test-bed consists of a small lightweight aluminum or plastic plate holding the test subject. The plate is guided by two wires and dropped from a certain height onto an impact surface.

Finally, the dual column design concept consists of two 1500mm metal columns guiding an aluminum plate during free fall. The test subject is held by a clamping mechanism attached to the plate. An array of different impact surfaces was chosen as damping mechanisms. These include urethane sheets, springs, sponge washers, metal blocks, and dashpots controlling impact stress received by the plate and test subject.

Recommended Design Concept

The test-bed aids in accurately validating the analytical model, linking static stress to impact deceleration rates. The test-bed aids in accurately validating the analytical model, linking static stress to impact deceleration rates.

Design Description

Analytical Model

The following model describes the relationship between static stress and impact deceleration rates.

\[ ma = \sigma A \]

Where \( m \) is the mass of test subject, \( a \) is deceleration rate, \( \sigma \) is the static stress derived from previous data, and \( A \) is the contact area of the joint.

The model above was used to determine the required deceleration rate to break the subcomponent joints at full scale. The full-scale contact area was reduced by a ratio of 0.3:1, reducing the required impact breaking force to an achievable range.

Figure 1. Dual column test-bed
Test Fixture

The prime goal of the test-bed is to obtain a high level of repeatability and consistency in deceleration rates between trials with same setup. A maximum 5% coefficient of variation was set to determine a successful design. The recommended design shown in Figure 1 was able to achieve this tight tolerance of variation and recreate nearly identical impact conditions between trials.

Dual steel columns serve as guides during the drop are independently mounted to a strut frame. A steel circular clamp attached to an aluminum plate grips the test subject rigidly throughout the test. The clamp and its attachments are insulated using urethane sponges. A collar is used in conjunction with measurement markings to consistently re-set the drop height for each trial. This setup annihilates friction issues preventing the plate from free falling at gravitational acceleration. Aluminum blocks were mounted to the strut frame between the poles serving as the impact surface.

Experimental Investigations

An analysis was conducted to evaluate the reliability and test condition repeatability of the test-bed. The fixture was set up according to the test specifications of the proposed speaker subcomponent experiment, excluding any actual specimen. Five height and damping mechanism combinations were chosen and tested with a sample size of 10 components. The data was evaluated to revel very repetitive and accurate replications. Figure 2 displays the average g-forces for each height tested, each yeilding a coefficiant of variation below the target maximum identified.

Key Advantages of Recommended Concept

The recommended test-bed is capable of accurately replicating impact conditions experienced by the speaker in the user environment. The guided drop design where one bushing supports the plate only prevents binding during free fall allowing the plate to experience full gravitational acceleration without rolling. Moreover, the clamp’s isolation prevents shock resonance, reducing the noise levels in output.
data. Bose can simply change the detachable isolated clamping mechanism to accommodate a different speaker, while keeping the experimental conditions constant.

**Financial Issues**

The estimated cost of building the testing apparatus was $2,315. No financial issues were encountered during the length of the project. The initial cost to build the test-bed was $2,315. The project evolved, modifications to the test-bed resulted in an updated total cost of $1,141. Due to the nature of this project, there were no financial issues related to developing the analytical model or building the fixture. Yet the availability of test samples and lead-time to assemble them, acted as a time constraint. This limited the amount of data collected.

**Recommended Improvements**

A larger sample size and improvements to the testing apparatus would yield a more precise analytical tool. The study of this capstone project has been limited to testing the behavior of speaker subcomponent joints under impact stress. The test-bed is capable of performing several other tests investigating structural robustness of different parts of the speaker. In addition, a larger sample size would allow for a stronger correlation between impact stress to static forces.

Improvements to the test-bed can be made to widen the range of g forces exerted on the test subject to study different failure modes. Change the damping mechanism type to a flat-to-flat surface between the metal plate and the chosen dampers, potentially inducing higher deceleration rates.

Figure 4. Speaker subcomponents