Design and Implementation of an Automated Intensity Scanning System at the Acoustical Testing Lab of the NASA Glenn Research Center

ABSTRACT

Intensity is a valuable tool in acoustic measurements for source identification and sound power levels, but most commercially available intensity probes on the market today consist of only one pair of phase-matched microphones to measure one axis at a time. A fully automated intensity measurement system was needed in the Acoustic Testing Lab at NASA Glenn to reduce the time of measurements and to increase the ability to identify noise problems at specific frequencies. A two-dimensional intensity probe was designed and machined at Brigham Young University and a gantry system was developed to guide the probe throughout the anechoic chamber. The system is capable of scanning planes as large as 10 feet in the vertical direction, and more in the horizontal directions. Multiple spacers were included with the probe to increase the frequency range available for each test. Labview based software was also written to handle the data acquisition and motion control of the system. The data was displayed using two methods. A color plot maps the magnitude over the measurement grid, while a modified quiver plot shows the direction and magnitude of the data. System parameters and capabilities will be presented as well as sample test data.

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INTRODUCTION

In September of 2000, the NASA John H. Glenn Research Center designed and constructed an Acoustical Testing Laboratory (ATL) to make possible frequent acoustical testing for a variety of test objects. The main purpose of the facility was to support an early integration of a low-noise design process for microgravity space flight hardware. Science experiment payloads that will reside on the International Space Station (ISS) are subject to acoustic noise emission requirements, which have been imposed by ISS to support hearing conservation, speech communication, and safety goals as well as to prevent noise-induced vibrations that could adversely impact microgravity research data[1]. The lab is a 23-ft wide by 27-ft long by 20-ft tall (all outer dimensions) anechoic test chamber that easily converts from anechoic to hemi-anechoic mode, depending on the needs of the measurement. This is done by way of modular wedges that can be removed through the main access doors. Thirty-six inch fiberglass-filled wedges, a spring-isolated floor system, and an isolated and silenced ventilation system feeding both the chamber and control room all allow for repeatable and accurate measurements to be made for a broad range of test configurations.

The majority of testing done in the chamber is on entire experimental racks and individual components of larger payloads in preparation for installation on the ISS. A picture of an experimental rack similar to that tested in this chamber is shown in Figure 1. As the number of tests and the complexity of each measurement increases, a simple, yet accurate system for acquiring qualitative and quantitative data is needed to improve efficiency of the laboratory for certain types of tests. Currently, the ATL can provide a variety of acoustical data, including noise criterion evaluation and sound power tests (per ANSI S12.34 and ANSI S12.35). It is a customized multichannel extension of an existing National Instruments sound power data acquisition software program and it allows simultaneous sampling of up to twenty channels for analysis. While this is a very capable system, it can only incorporate single pressure sensors and most measurements must be in the far field, which fails to give any localization information.

DESCRIPTION OF THE INTENSITY SCANNING SYSTEM

Intensity can be a valuable tool in evaluating an acoustic measurement over a test object. Sound power levels can be calculated and source identification can be done fairly easily in an accompanying software package if the intensity data has been acquired. Today's commercially available intensity probes are limited in the measurement they can take, though. Accurate positioning is not typically feasible due to the fact that the majority of probes are meant to be handheld instruments. If an averaged measurement over a rather large surface is preferred, then manually maneuvering the probe is acceptable. However, a test engineer interested in source identification would be in need of a more accurate system for positioning a probe in the test chamber to move throughout a set grid of points. This can give the user the ability to identify noise sources and their locations at any specified frequency and at any location through the measurable volume.

Additionally, common commercial intensity probes merely offer a single axis with which to acquire data. If two or three axes of data are desired for a sound intensity calculation, for example, multiple measurements at the same point must be made in order to acquire the needed data. This method, however, lends itself to positioning errors and alterations in operational conditions for each measurement at the same point. A probe with multiple axes for data acquisition would not only reduce the measurement time spent at each data point, but would ensure identical measurement conditions for each axis.

All these concerns were addressed, as well as many others, when Brigham Young University (BYU) and NASA Glenn Research Center agreed to design and install a fully automated intensity scanning system to increase the capabilities of the ATL. This system was also designed to allow the user to make handheld tests if the measurement is simple or if he merely requires a rough estimate of the sound field. The main goal of this system, however, was to provide data for noise source identification and radiation characterization, while eliminating much of the time constraints and user errors common to current intensity systems.

THE INTENSITY PROBE

In order for the newly designed system to not be limited in the same way as common commercial probes, a new type of probe had to be designed and fabricated. Figure 2 shows the probe, completely assembled. Four Larson Davis (type 1) precision microphones are used to measure intensity along a pair of axes. Half-inch microphones are used to maintain an optimal frequency bandwidth and dynamic range available to the user. Larson Davis 902 preamplifiers attach to these adaptors and Larson Davis 2200C power supplies are used to supply the required 200 volt bias voltage to the microphones. All microphone signals are carried through cables to the control room by way of the utility ports provided in the chamber.

Solid sets of spacer sets were fabricated at BYU to take advantage of the maximum available bandwidth. The probe allows for adjustable microphone spacing between 16mm, the smallest allowable size for a 2-dimensional system if half-inch microphones are being used, 25mm, and 50mm, the largest standard size spacer used in making intensity measurements. The 16 to 50mm spacer range allows the user to make intensity measurements from the 40 Hz out to, and including, the 8 kHz third-octave band. At the center of the probe, a series of arms and clamps were built to hold the preamplifiers in the correct position for each measurement. The arms are jointed to allow various sizes of spacers while holding the overall length of the probe constant. This was done to simplify the coding of the accompanying program.

POSITIONING SYSTEM

A few issues arose when designing the positioning system to control the movement of the intensity probe. We wanted to minimize the acoustic intrusion of the rail system which meant mounting it near the ceiling wedges of the test chamber. Small acoustic wedges were attached to the underside of the railing to further prevent acoustic reflections. The system needed to be able to measure test objects as small as a disc drive or cooling fan and as large as an experimental rack for the ISS, as shown in Figure 1. The system should also be out of the way, but still a permanent fixture in the chamber.

In order to maintain the ability to take measurements throughout the room volume, the vertical control needed to be able to travel approximately thirteen to fourteen feet. To satisfy both conditions, a telescoping control system was proposed. This was manufactured by Patterned Fiber Composites, Inc. and consists of five concentric tubes, each made from a wavy-composite material with embedded viscoelastic damping material. The damping layers applied to the tubes assists in preventing swaying of the telescoping system when fully extended. This high damping material in the tube walls has proven in recent measurements that it works extremely well when small amplitude swaying occurs. The damping material also decreases the settling time needed for the system to wait until motion stops before the next measurement can be made. The motion of this axis is controlled by a stepper motor and gearbox mounted to a plate at the top of the rail system. The motor shaft is attached to a pulley wheel on which is spooled a braided wire rated up to 150 pounds. The probe is attached by a standard connection at the end of the smallest tube. This allows the user to attach any length extension to the vertical axis to accommodate any particular measurement. A swivel head is also provided for the end of the telescoping system to attach the probe base. The test engineer can then be certain that the probe is pointing true along the axis intended.

The portion of the positioning system that controls the motion in the X-Y plane is comprised of Macron 14 Linear Actuators fabricated by Macron Dynamics, Inc. The X-axis has 11.2 feet of travel while the Y-axis has 15.9 feet of travel. Each rail is driven by a belt drive which was chosen to minimize the amount of noise produced by the system while in motion. This plane, like the vertical control, is controlled by stepper motors and accompanying gearboxes. The motors are all produced by Pacific Scientific and are 1.8° per step, two-phase motors. Each axis has a pair of rails connected by a shaft from the motor mount to the end of the corresponding rail on the opposite side of the system. All gearboxes are produced by Bayside and have a 10:1 ratio. They were installed to increase the precision of our motion control and decrease the risk of damage by running at velocities greater than recommended. Such velocity limits were later set in the accompanying code, as well.

Incorporating limits at each end of the rails was also a concern when designing this scanning system. Optical limit switches are installed on each end of all three axes to limit the motion in each plane. A future improvement to be implemented includes an active feedback control in addition to the limit switches on all three axes. It will be a set of optical encoders giving continuous feedback to the motion controller as to where the carriages and the probe are currently located. Small pressure sensors on the probe may also be added to cut power to the motors if the probe were to come in contact with another object.

All cables are organized through cable tracks made by KabelSchlepp. These tracks run in small trays along side each rail and contain all power cables for the motors, limit switch cables, and microphone signal cables. To reduce the possibility of inducted noise, the microphone cables are in separate tracks and run on the opposite side of the rail system from the power cables. This entire rail system is suspended near the ceiling of the ATL test chamber by 3/8 inch threaded rod mounted to the ceiling, behind the wedges. Eckel Industries, the industrial acoustics firm who also designed and built the anechoic chamber, installed the system.

SOFTWARE OVERVIEW

As previously stated, this intensity scanning system was initially intended to provide the test engineer with data for source identification, evaluation, and report generation. In view of the fact that the existing sound power system at the ATL is LabVIEW based and uses the NI 4552 boards, it was felt that our system should also be LabVIEW based in order to tie in well with the existing equipment. The Intensity Measurement System (IMS) was written in National Instruments (NI) LabVIEW 6i with the 6.0.2 upgrade, NI-DAQ 6.9.3, NI Flex Motion 5.1.1, NI Value Motion 5.0, and the Sound and Vibration Toolset 2.0. IMS uses a NI-4552 four channel dynamic signal analyzer stored in a Magma PCI slot expansion chassis. Due to limited narrowband resolution for on-board-processing, we simply streamed our data directly to the PC's on-host processor for the data analysis. In addition to these boards, an NI PCI-7334 motion control board is also housed in the chassis. This motion control board passes the control signal to a NI NuDrive power drive which powers the motors and limit switches.

The IMS code is divided into two main programs. These programs manage the handheld intensity system and the automated intensity scanning system. Each program is comprised of the same four main sections which proceed sequentially: calibration, measurement, plotting, and the generation of a report cover page. When either program begins, the user is required to input the test documentation for the measurement, followed by a calibration. This can be performed at the time of the measurement or a previously saved calibration may be loaded. Once a calibration is completed, the measurement portions of the two programs begin, but differ significantly in the methods utilized.

In the handheld intensity system, the user is required to specify the measurement parameters such as frequency span, number of FFT lines, the lowest third-octave band of interest, number of averages taken at each measurement point, the measurement plane parameters, and the configuration of the NI-4552 data analysis board. Once set, the measurement may begin. The test engineer may measure the points in the order he desires, but an “auto-increment” function has been built in to increase the speed of a measurement by automatically incrementing to the next position. Input ranging is also an issue that had to be dealt with. As a result, the user is given the ability to choose the range desired, which may be changed between measurement points, if required. The ATL test chamber is also equipped with a system which reports the ambient pressure and temperature to the PC. These values may be updated at any time during the measurement to account for changes in ambient conditions resulting from a test object in the measurement volume. Once each measurement has run, the third-octave and narrowband data for each axis is displayed on the screen for inspection, printing of the plots, or saving of data.

The automated intensity measurement system takes a somewhat different approach to each measurement plane. The user must input all the parameters required in the handheld program with the addition of several others, as well. Units (meters or inches), chamber mode (anechoic or hemi-anechoic), probe velocity, vertical extension length (if applicable), and the test article’s placement in the chamber must be entered. Once entered, the program will draw the object and the measurement plane on a plot for inspection. The front panel of this configuration program is shown in Figure 3. This serves two purposes. First, the user can visually check whether or not the measurement plane and object placement are oriented correctly. Second, if the measurement plane and object volume intersect or either set of data is not completely contained in the test volume, an error will appear and the user must reenter the parameters until valid. This configuration portion of the automated program contains many other error checks to assure that the scanning system itself or the objects under test are not damaged in any way.

Once the parameters have successfully passed all error filters, the motion control system verifies that the probe is indeed in the home position before beginning. The probe then moves to the first measurement point and acquires the 2-dimensional intensity data. During each intensity measurement, the narrowband cross-spectrum is collected. This data is then converted to third-octave data and normalized. Most available analyzers offer up to 800 or 1600 lines of resolution, but the NI-4552 boards also allow us to increase our FFT line resolution up to 25600. As it continues throughout the grid, the user may at any time pause the progression to examine or print the third-octave or narrowband data.

After all the data has been acquired in either the handheld or automated system, the user may choose from third-octave, narrowband, or sound power (if applicable) data to plot. In the case of third-octave and narrowband plots, there are two types of plots displayed. The first is a field or vector plot, showing linear magnitude and direction of the two intensity components. Opposite this plot is a color magnitude plot in units of dB. An example of this plotting application is shown in Figure 4. In this example, one can clearly see the presence of three sources near the bottom of the measurement plane. A further look at the directionality of the near-field acoustic flow will also reveal that the outer two sources are wired in phase, while the center source is wired out of phase and is acting as an “acoustic sink”. Sound power measurements are also displayed in third-octave bands and can be summed together if multiple faces of an object are measured in the same test. The user can also save the intensity data for the selected third-octave band, narrowband frequency, or sound power measurement to an ASCII format file that can be opened in a spreadsheet program for further analysis.

SUMMARY

The new IMS system offers many advantages over conventional intensity measurement systems. As previously stated, up to 25600 FFT lines are available, as compared to the standard 800 or 1600 lines. It offers the user simultaneous displays of third-octave and narrowband data for each measurement point. The different sets of spacers allow the user to take advantage of a wide frequency bandwidth, as well. The greatest benefit of the IMS system, however, is the fact that two axes can be measured simultaneously and that it is all automated. This eliminates the majority of time and resolution constraints for any measurement. A high resolution measurement of an object as large as an experimental rack can be set up and run while the test engineer is free to focus his attention on other details of the test. In the long run, this saves the testing lab and their customers a great deal of time and money.

REFERENCES

[1] http://facilities.grc.nasa.gov/atl/atl_design.html

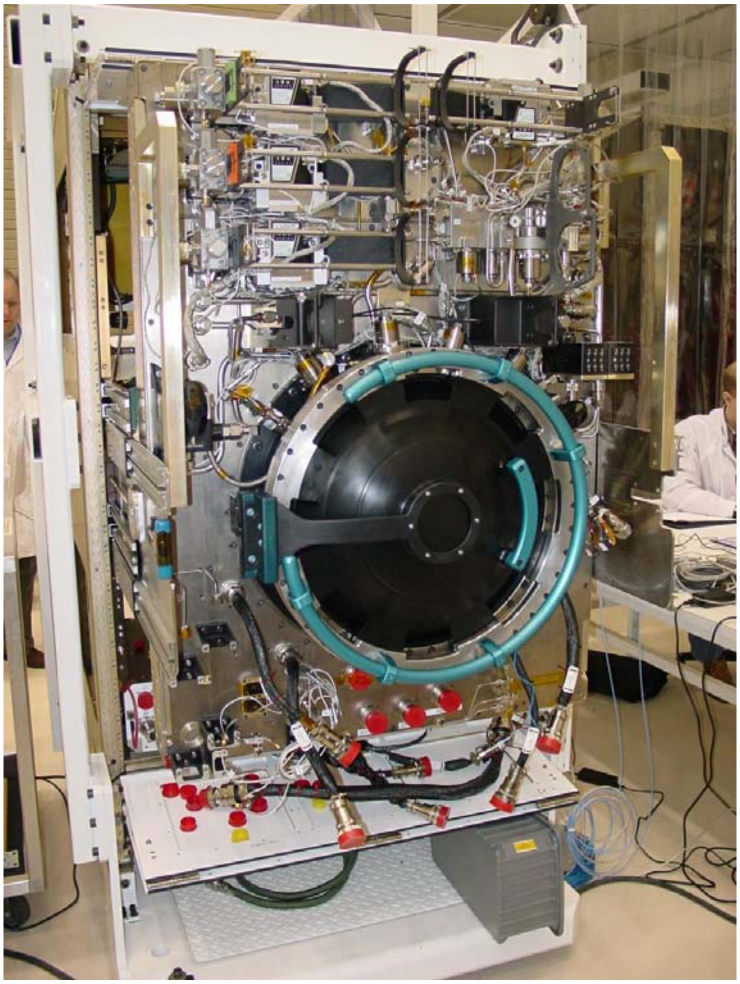
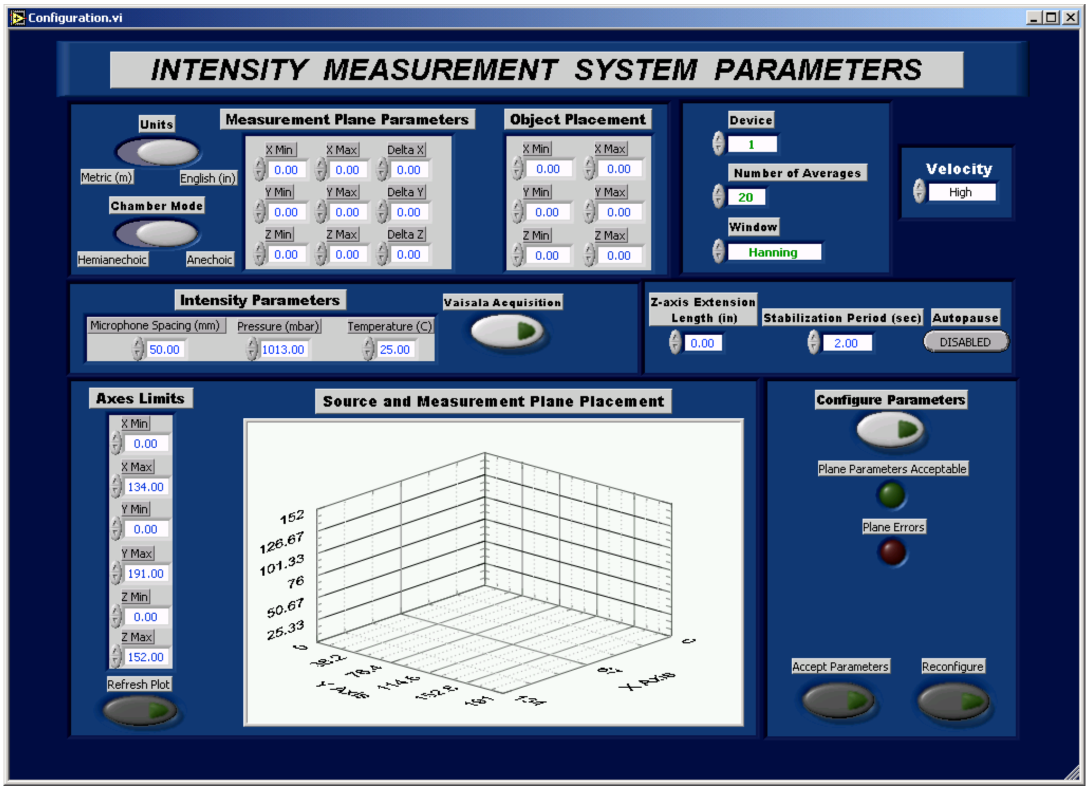


Figure 1: Experimental rack for the ISS.

Figure 2: 2-dimensional intensity probe.



Configuration.vi

INTENSITY MEASUREMENT SYSTEM PARAMETERS

Units: Metric (m) / English (in)

Chamber Mode: Hemianechoic / Anechoic

Measurement Plane Parameters: X Min 0.00, X Max 0.00, Delta X 0.00; Y Min 0.00, Y Max 0.00, Delta Y 0.00; Z Min 0.00, Z Max 0.00, Delta Z 0.00

Object Placement: X Min 0.00, X Max 0.00; Y Min 0.00, Y Max 0.00; Z Min 0.00, Z Max 0.00

Device: 1

Number of Averages: 20

Window: Hanning

Velocity: High

Intensity Parameters: Microphone Spacing (mm) 50.00; Pressure (mbar) 1013.00; Temperature (C) 25.00

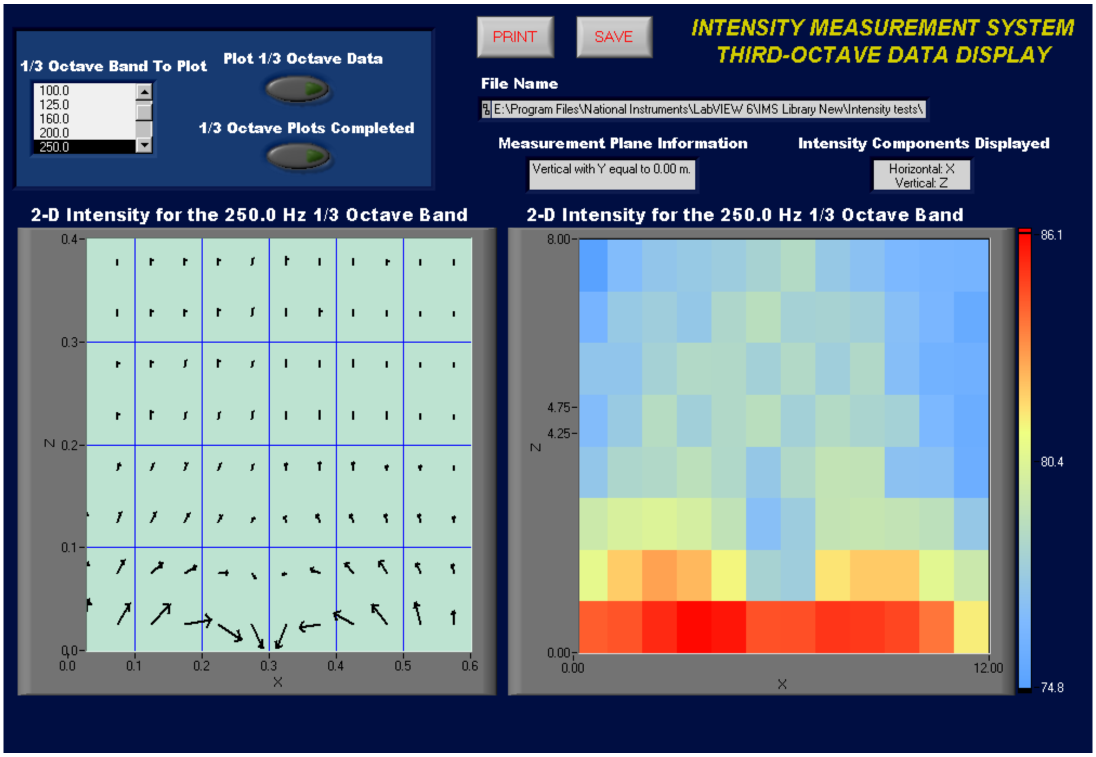
Z-axis Extension Length (in): 0.00

Stabilization Period (sec): 2.00

Autopause: DISABLED

Axes Limits: X Min 0.00; X Max 134.00; Y Min 0.00; Y Max 191.00; Z Min 0.00; Z Max 152.00

Figure 3: Configuration front panel.



INTENSITY MEASUREMENT SYSTEM THIRD-OCTAVE DATA DISPLAY

1/3 Octave Band To Plot: 100.0, 125.0, 160.0, 200.0, 250.0

File Name: E:\Program Files\National Instruments\LabVIEW 6\IMS Library New\Intensity tests\

Measurement Plane Information: Vertical with Y equal to 0.00 m.

Intensity Components Displayed: Horizontal: X Vertical: Z

Figure 4: Third-octave data display showing both a vector field and color magnitude plot.