High Definition Inertial Vibration Actuator Performance Specification

Haptics Industry Forum | hapticsif.org

Document History

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1.0	14 October 2020

1 Contributing Organizations

This document is maintained by the Haptics Industry Forum, which can be contacted at hello@hapticsif.org. This specification and associated compliance tests are a joint work product of the organizations listed below.

Organization	Contact	Email
Lofelt GmbH	Gwydion ap Dafydd	gwydion@lofelt.com
Immersion Corporation	Chris Ullrich	cullrich@immersion.com
TDK Electronics AG	Sonja Brown	sonja.brown@tdk-electronics.tdk.com
Nanoport Technology Inc	Tim Szeto	tim@nanoport.io

2 Overview

Consumer devices increasingly utilize haptics as part of the core user experience. This has increased awareness of the value of haptic feedback as well as increased understanding by consumers that not all haptic experiences are the same. Among device manufacturers and component suppliers, there is a lack of standardization of the key technical specifications that impact the haptic performance of a given actuator component.

The goal of this document is to define standard metrics and their corresponding tests to enable inertial haptic actuators to be evaluated consistently and objectively. Utilizing this specification, a product designer can readily compare actuators in terms of their ability to render high quality haptics. Actuator vendors may use this specification to precisely characterize the haptic quality of their offerings.

High quality inertial haptic actuators are often said to enable "HD haptics," but this term lacks a precise technical definition. Through the collaborative efforts of the Haptics Industry Forum, this document was created to serve as a common reference for what constitutes an "inertial HD actuator."

2.1 High Definition Haptic UX

The hallmark of an HD haptic experience is richness and precision that enables realistic, immersive tactile effects. For haptic effect designers, HD haptic systems offer significant design freedom, including reproduction of real-world textures and sensations as well as convincing feedback for virtual interaction.

The compliance and quality metrics proposed in this document are sufficient to enable OEM device designers to incorporate a number of rich haptic experiences into their devices and have confidence that these experiences will be faithfully rendered. HD haptic actuators are capable of three effect types, described below.

1. Rumble: Actuators with a wide range of distinct frequencies enables effects that have frequency domain contrast. In particular, lower frequencies, in the 50 to 100 Hz range, are able to produce rumble sensations similar to those found in legacy game controllers and are useful for immersive gaming and media experiences.
2. Mechanical clicks: Actuators that receive "A" grades in the HD quality metrics outlined in this document are well suited for the generation of sharp click effects, especially if they are paired with appropriate drive electronics.
3. Textures: Actuators that have the prescribed range of frequency and amplitude capabilities can render spatiotemporal effects at the speed of human finger movement and are well suited for tactile surface texture generation.

2.2 Dependence on Test Mass

Acceleration performance of any inertial actuator is affected by the rigidly attached moving mass. In all practical applications, this mass consists of the non-actuator portions of the system, such as a mobile phone case or game controller housing. Actuators are typically designed to move specific ranges of mass, and it is essential to capture this in an HD specification. For this reason, when an actuator is said to pass the HD tests outlined in this document, the mass used for testing must also be specified. The Haptics Industry Forum recommends that test mass ranges include 30 grams, 100 grams, and up to 1000 grams, which approximate typical moving masses found in wearable, handheld, and automotive use cases, respectively. It is recommended that actuators be repeatedly tested with increasing mass until they fail the HD fundamental requirement (see below). The highest mass that still passes this test should be reported on the actuator test report.

2.3 Dependence on Drive Signal

In order to enable a fair comparison, this specification requires that actuators under test are driven with uniform signals. This specification requires a pure sine wave drive signal to be reported with no braking, overdrive, or other signal modifications. Component vendors are welcome to generate additional test results with actuator-optimized drive signals, advanced controllers, and so on, but these results should always be presented in addition to the results obtained with a sine wave drive signal.

2.4 Dependence on Output Axis

For actuators that have multiple output axes, each axis should be tested separately and reported separately in a combined report.

3 High Definition Haptics Specifications

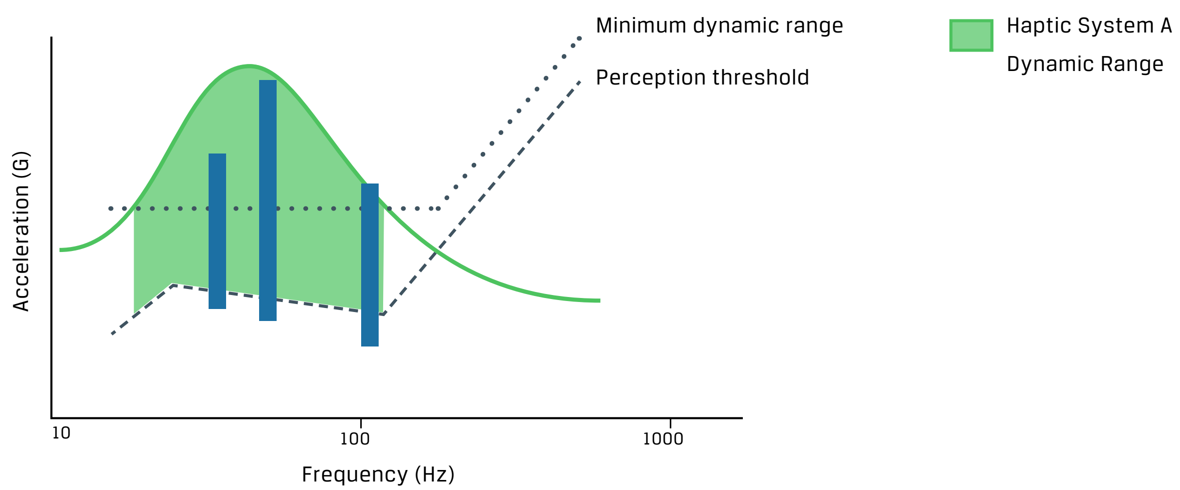
3.1 Fundamental Requirement

The term "HD haptics" is often used to refer to haptic systems with independent control of an actuator's frequency and amplitude. Legacy haptic actuators, such as those comprising a single eccentric rotating mass (ERM), are limited to rendering only amplitude-modulated signals, and are therefore not HD. Actuators that have two resonant frequencies also do not enable the full breadth of HD experiences. These considerations motivate the fundamental HD actuator requirement:

Fundamental HD Actuator Requirement:

An HD actuator must be able to generate acceleration at 3 perceptually-distinct frequencies at least 0.5 G above the threshold of perception at each frequency for handheld devices, and at least 2.0 G above threshold of perception for grounded touch surfaces, and at the threshold of perception for a reference mass.

The diagram below illustrates the definition in practice for a resonant actuator. The blue bars represent three perceptually-distinct frequencies, and the height of the bar is at least 0.5 G in each case, which provides dynamic headroom. An actuator that can render haptics along the vertical extent of all three of these blue bars will satisfy the fundamental requirement.



3.2 Test Procedure for Fundamental HD Actuator Requirement

The test procedure for verifying the fundamental HD requirement is as follows:

1. Perform a frequency sweep using three or more sine wave cycles at many test frequencies and extract the maximum peak-to-peak acceleration from the system response for each test frequency.
2. Select three frequencies that are perceptually distinct using the estimates in the section of this document entitled "Reference Tables for Thresholds of Perception."
3. Verify that the dominant frequency component of the output signal is equal to the selected drive frequency in each case.
4. For each frequency, measure the acceleration headroom above threshold of perception.
5. If the total dynamic range of acceleration range at all selected frequencies is 0.5 G or higher, the component is HD.

Analysis scripts for this test procedure are available. See Section 5 for a sample.

3.3 Quality Metrics

Beyond the fundamental HD test, there are additional metrics that can be used to further characterize the quality of an actuator. In general, actuators that score highly in all of these categories will provide the best possible haptic experience and enable the most design freedom to application developers. As noted above, it is likely that these metrics can be improved with custom (non-sinusoidal) drive signals. The Haptics Industry Forum recommends providing both a baseline (sinusoidal) report and a custom report, and an explanation of the differences between the two reports.

3.3.1 Rise Time

Rise time refers to the number of cycles required for an actuator at rest to reach 90% of its steady state value. For this test, actuator vendors may choose any of the frequencies previously used to test the fundamental HD requirement. The steady state acceleration is the acceleration achieved by the actuator during continuous drive, which is typically 10 cycles or more.

Grade	Rise time (cycles)
A	2.25
B	4.5
C	6.75

3.3.2 Fall Time

Fall time refers to the average amount of time it takes an actuator's motion to decay from steady state acceleration to the threshold of perception (see table in Section 6). One of the three drive frequencies previously used to test the fundamental requirement must be used for this test.

Grade	Fall time (ms)
A	50
B	90
C	130

3.3.3 Overdrive

Overdrive refers to the amount of power (in Watts) or voltage (in Volts) that an actuator can be driven at relative to its rated nominal specification for two consecutive cycles. Typically used for producing transient haptic effects for button clicks, overdrive signals should have a frequency either at resonance or at the highest acceleration used in the fundamental HD requirement test. Overdrive capability can be expressed as a percentage of the nominal power or voltage rating.

Grade	Overdrive capability
A	200%
B	150%
C	130%

3.3.4 Distortion

Distortion refers to the amount that the actuator alters the input signal at each of the three frequencies used in the fundamental HD requirement test. Distortion is a measurement of the fraction of energy in the output acceleration that is not within the perceptual range of the input frequency. It is measured by taking the ratio of the output energy in the perceptual range of the input frequency to the sum of all output frequencies. It can be computed from the power spectrum.

Grade	Maximum distortion value
A	< 25%
B	< 50%
C	< 75%

3.3.5 Variance

Actuator variance is a measurement of the distribution of quality metrics among manufactured parts. Distribution variances should be estimated from a statistically meaningful sampling of parts for each of the specifications and reported on the test report.

3.3.6 Additional Recommended Specifications

The following additional specifications are recommended to be included when marketing actuators as capable of HD haptics. This document provides no specific guidance for these, but it is known that OEMs find them to be useful.

1. Maximum test mass to pass the fundamental HD requirement
2. Audible noise, measured as peak SPL at a distance of 10 cm
3. Nominal drive voltage
4. Resistance/impedance
5. Resonant frequency (f0)

4 Specification Summary Report Template

Part number:
Test date:
Number of samples:

Test Frequency	Peak-to-Peak Dynamic Range (G) (mean, variance)
[Frequency 1]	
[Frequency 2]	
[Frequency 3]	

Quality Metrics

Metric	Measured Value (mean, variance)	Grade
Rise time (cycles)		
Fall time (ms)		
Overdrive (%)		
Distortion (%)		

Additional Specifications

Specification	Value
Maximum HD test mass (g)	
Audible noise (peak SPL at 10 cm)	
Nominal drive voltage (V)	
Resistance/impedance (Ω)	
Resonant frequency (Hz)	

5 Resources

5.1 Analysis Scripts

Reference Python scripts for testing the fundamental HD requirement and for measuring distortion are available on GitHub here:

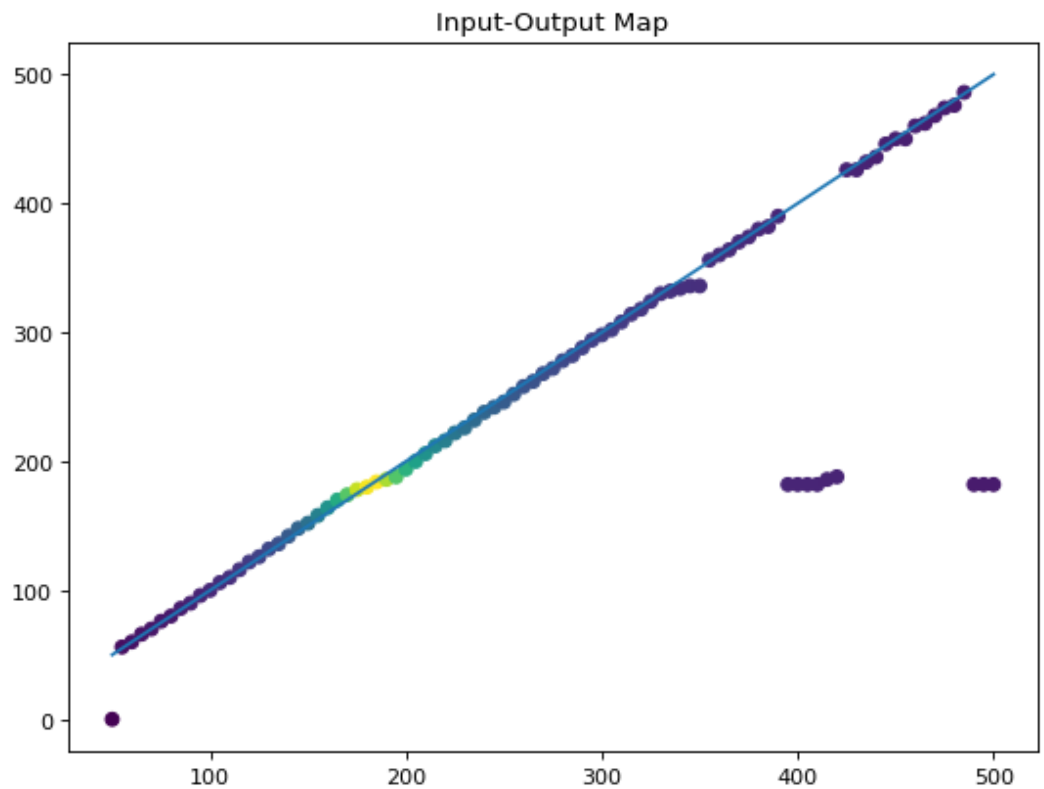
https://github.com/HapticsIF/HDActuatorSpec

These scripts are illustrative and may be used and modified as needed.

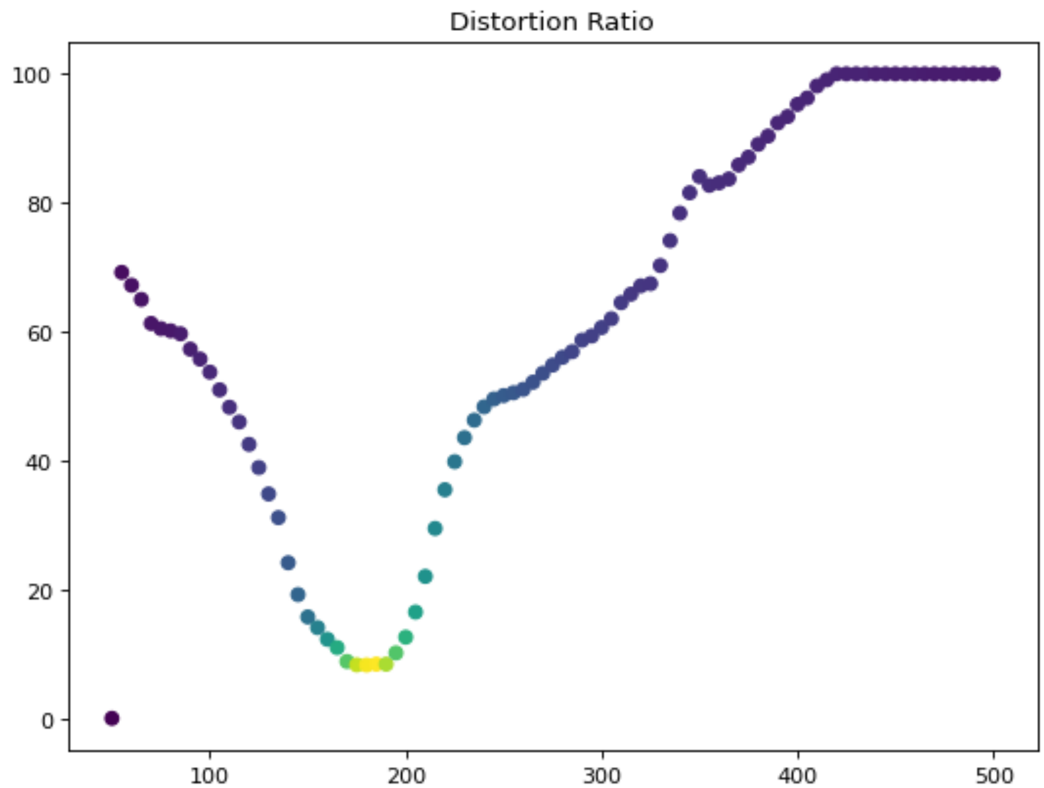
Note that these scripts expect test data sampled at 10 kHz.

6 Example Analysis: Haptic Reactor

Moving a mass of 20 grams for 10 cycles at 3 Volts, the ALPS Haptic Reactor is able to track the drive signal frequency well:



However, there is significant distortion in the output signal. Remember that distortion is calculated as the ratio of energy not within the equivalent perceptual frequency range of the input signal to the total output energy for all frequencies. Lower distortion values indicate that most of the output energy is at the drive frequency.



This data suggests that frequencies of 100 Hz, 160 Hz and 200 Hz would be good choices to test. The analysis scripts produce the following output:

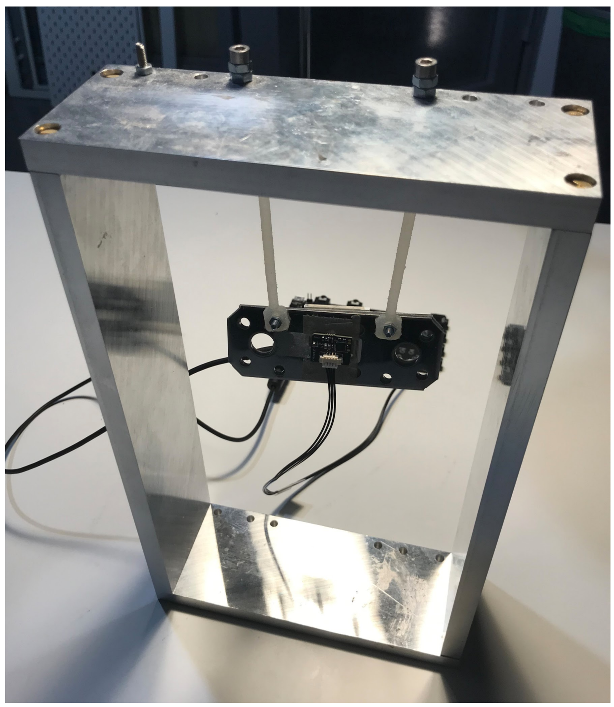
```
Test Frequencies: 100.0Hz 160.0Hz 200.0Hz
Test frequencies are perceptually distinct. Proceeding with
signal analysis.

Input Frequency: 100.00 (64.50,135.50) Peak Frequency:
100.00Hz Acceleration Peak: 1.46G Dynamic Headroom: 1.40G
Distortion: 53.71%
Input Frequency: 160.00 (121.30,198.70) Peak Frequency:
164.00Hz Acceleration Peak: 6.47G Dynamic Headroom: 6.41G
Distortion: 12.26%
Input Frequency: 200.00 (167.40,232.60) Peak Frequency:
194.00Hz Acceleration Peak: 8.08G Dynamic Headroom: 7.99G
Distortion: 12.59%
============ Part PASSED ===========
```

7 Measurement Setup

7.1 Test jig

A test jig must be designed to hold an actuator and sensors in such a way that the energy created by the actuator, and only this energy, is collected by the sensors. It is designed to reduce any external influences on the system so that the data it produces reflects the performance of the actuator being tested. A well-designed test jig should enable consistent and repeatable measurements.

An example of a test jig is shown below. The mounting plate is suspended from a heavy frame such that the actuator is not coupled to any materials other than the moving mass.

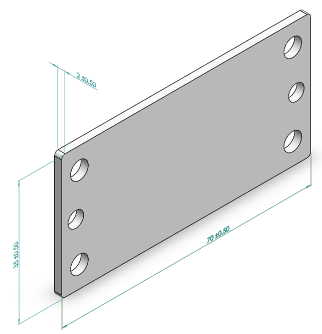
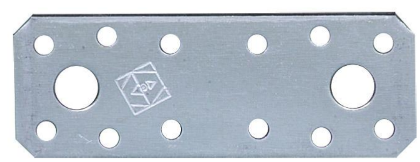


In this example, the frame of the test jig is made from four pieces of aluminum arranged in a rectangle. Its total weight is 1300 grams.

Viscoelastic bands connect the suspended metal plate to the top of the frame. These bands are made of silicon rubber and have an A22 Shore hardness. It is important to use bands with as little stiffness as possible so that they allow free side-to-side (left-right) movement of the metal plate to which the actuator and sensors are attached.

7.2 Moving Mass

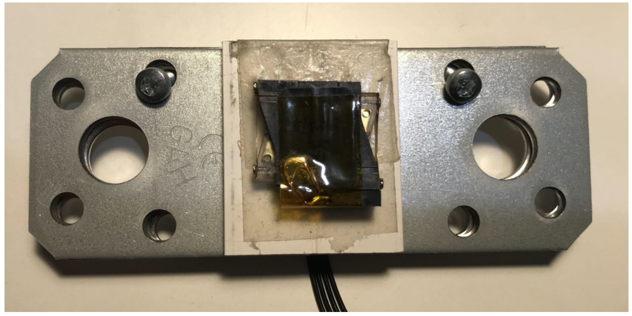
A metal plate is used both as a defined moving mass and as a mounting platform for the actuator and sensors. Note that we ignore the mass of the actuator and of the accelerometer for the purposes of this test.

Moving Mass	Description	Example construction
30 grams	▪ One rectangular plate with holes for mounting the silicon suspension bands ▪ Dimensions: 70 x 35 x 2 mm ▪ Material: Aluminum	
100 grams	▪ One rectangular plate with holes for mounting the silicon suspension bands ▪ Dimensions: 96 x 35 x 4 mm ▪ Material: Steel, stainless steel, or galvanized steel ▪ Alternatively, two 2 mm plates may be attached together with double-sided adhesive tape.	

To increase the quantity of mass, plates may be stacked. For masses larger than about 200 grams, the plate dimensions may need to be altered.

The actuator should be attached to the center of the plate in such a way that the vibration direction of the actuator corresponds with the two axes parallel to the ground in which the metal plate can move. In other words, the actuator should not be mounted such that it vibrates along the up-down axis, as this would cause the elastic bands to absorb some of the actuator's output energy.

In the example below, an actuator is attached to a 100-gram moving mass using double-sided adhesive tape:



7.3 Measurement Sensor

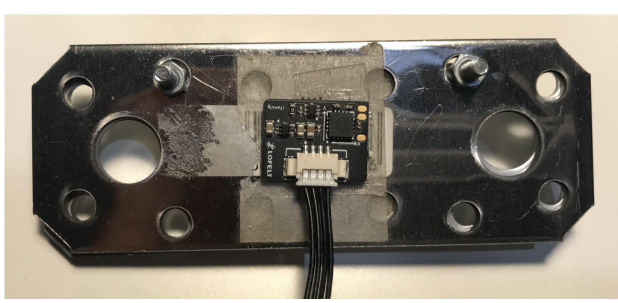
An accelerometer is used for testing the fundamental HD requirement and the quality metrics. The accelerometer should be chosen to give accurate and consistent results within the operating force and frequency range of the actuator under test. The accelerometer must also have a very small mass itself, especially when testing a 30-gram moving mass. Wires connected to the sensor must also be lightweight and must be flexible enough to not interfere with the vibration of the moving mass.

An example accelerometer that meets these requirements is the ADXL325 by Analog Devices. This accelerometer has these characteristics:

- Upper limit of measurement range: 6 G
  ✓ Within the range the actuator under test
- Sensitivity: 174 mV/G
  ✓ Allows small, subtle changes in G to be captured
- Frequency response: 0.5 Hz to 1600 Hz
  ✓ Covers the entire frequency range of haptic perception

The accelerometer is mounted to the opposite side of the metal plates from the actuator. The accelerometer's measurement axis must align with the vibration direction of the actuator.

An example is shown below. An ADXL325 is fixed to the 100-gram moving mass using double-sided adhesive tape:



The accelerometer output is then connected to an oscilloscope for real-time observation, or to an analog-digital converter for data logging and subsequent analysis.

8 Reference Tables for Thresholds of Perception

Frequency (Hz)	Median frequency discrimination threshold (Hz)
25	3
31.5	6
63	23
125	44
250	25

Median value of vibrotactile frequency discrimination thresholds as measured on the wrist [5].

Frequency (Hz)	Magnitude of perception threshold (G RMS)
8	0.095
10	0.1
12.5	0.095
16	0.108
20	0.15
25	0.16
31.5	0.109
40	0.065
50	0.072
63	0.049
80	0.028
100	0.023
125	0.022
160	0.021
200	0.029
250	0.032
315	0.061

Magnitude threshold of perception as a function of frequency. Adapted from [6].

References

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