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Accelerometer Calibration -- A Comparison Between CESTA and NBS

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CONTENTS

TABLES

ILLUSTRATIONS

ACCELEROMETER CALIBRATION --
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ABSTRACT

This report describes a vibration measurement interchange between a French laboratory (CESTA) and the National Bureau of Standards (NBS). Methods of calibration at NBS and results of the calibration of two commercially available double ended or "piggy-back" type accelerometers are discussed. No difficulties were encountered in the calibration of System 1, however, above 4000 Hz difficulties were experienced in the calibration of System 2.

Key Words: Accelerometers; calibration; measurements; vibration; vibration exciters; vibration standards.

1. INTRODUCTION

The measurement techniques of individual laboratories charged with the calibration of physical standards for measurement of vibration differ considerably. This report describes a measurement interchange, involving vibration measuring instruments, between the National Bureau of Standards (NBS) and a French national laboratory within the Aquitaine Center for Scientific and Technical Studies (CESTA).

2. DESCRIPTION OF EQUIPMENT

Two commercially available, laboratory quality accelerometers and their associated charge amplifiers were used in these tests. These accelerometers are used as transfer standards and are of the double-ended or "piggy-back" type. One of the transfer accelerometers was manufactured in the United States and the other was manufactured in Europe. In this report these shall be referred to as System 1 and System 2, respectively.

A precision piezoelectric quartz accelerometer system was used as a reference standard. This system was periodically calibrated and maintained as a standard by the National Bureau of Standards. Although it had been calibrated in April 1976, it was recalibrated just prior to these tests, and the sensitivity factors used to reduce the data were adjusted to consider the slight drift shown by the history of the system.

One of the transfer standards (System 1) has a 1/4-28 UNF mounting hole at the upper end. A 1/4-28 to 10-32 adaptor stud which provided a definite thread depth for both accelerometers was used. The other transfer standard accelerometer (System 2) had a 10-32 UNF mounting hole at the upper end. A cable with a length of seven meters and a measured capacitance of 810.9 picofarads was furnished by CESTA and was used with the transfer systems throughout the tests.

The electrical connections for each accelerometer were cleaned and the connectors were securely attached. The cables were taped to the vibration generator as close to the accelerometer connections as possible without interfering with the motion. During the entire test period, line power was left applied to the charge amplifiers and all measuring equipment.

In all instances, the accelerometer outputs were applied to a charge sensing amplifier. For System 1 and System 2, two separate but identical model number charge amplifiers were used. These amplifiers were manufactured in France and their gain was nominally 1000 mV/pC. The NBS amplifier had a gain of nominally 10 mV/pC. The frequency-gain response of each of the test amplifiers was measured and used in the data analysis. Problems were encountered in the gain measurements and insufficient time was available to resolve the problems and to assess the amplifier gain measurement uncertainty.

The transfer standard accelerometers (System 1 and 2) had been calibrated by the French laboratory just prior to their arrival at NBS and more tests were to be made upon their return to CESTA.

3. COMPARISON TEST DESCRIPTION

The CESTA transfer standard accelerometers (System 1 and 2) were calibrated by a comparison method using an NBS accelerometer as a reference standard. The reference accelerometer was mounted on top of each of the test accelerometers throughout the comparison calibration. The accelerometers were attached with a stud which permitted the mating surfaces to be in direct contact with each other and were tightened with a torque of nominally 2 Nm. Two Dimoff Vibration Standards [1]* were used as vibration exciters.

An automated comparison calibration facility at NBS is used to calibrate accelerometers on a routine basis [2]. A software program in a mini-computer controls the entire test process. The program contains codes which are translated into frequencies and voltages by a programmable oscillator which in turn supplies a input to a power amplifier. This then drives the vibration exciter. At each test frequency there is a preset acceleration level which is program controlled through a closed-loop process to insure that this level remains constant.

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* Numbers in brackets correspond to references given at the end of this report.

Since the charge amplifiers used with the transfer standard accelerometers had high outputs, the automated system calculated the sensitivity factors using the relationship:

$$S_t = S_s R$$

where S_t = sensitivity of the transfer accelerometer,

S_s = sensitivity of the reference accelerometer, and

R = ratio of the transfer accelerometer voltage to the reference accelerometer voltage,

$$R = \frac{\text{Transfer accelerometer voltage}}{\text{Reference accelerometer voltage}} .$$

The system sensitivity factors are the open circuit output of the charge amplifier in millivolts per unit acceleration in g* (mV/g). The automated system is capable of measuring these ratios to within a few tenths of one percent.

The waveform of each accelerometer's charge amplifier output was monitored on an oscilloscope. The waveform harmonic distortion generally did not exceed one-percent. The transverse motion ratio, although not monitored, is believed to be less than one percent over most of the frequency range under normal exciter load conditions. Lateral resonances at a few narrow frequency bands may cause the transverse motion ratio to be greater than one percent, but how much greater is not known.

4. INTERFEROMETER TEST DESCRIPTION

The normal method used to calibrate accelerometers on piezoelectric exciters is that of a modulated photoelectric measurement of amplitude utilizing a Fizeau interferometer and a fringe disappearance technique [3]. The light source is a HeNe laser. A small reflector is attached to the vibrating surface to be measured. The upper interferometer plate, a plano-convex lens, is mounted just above the plane reflector. In order to induce a low modulating frequency of vibration in the upper plate, a small piezoelectric mass-reaction exciter is mounted on the lens support and is driven at a frequency of about 100 Hz. A photodetector views the center fringe and produces a signal which is applied to a narrow-band filter which is phase locked to the 100 Hz modulating frequency.

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* In this study, units of acceleration are expressed in gravitational units of g. This was done to facilitate communication with the intended reader. Conversion to SI units may be accomplished by using the relationship 1 g = 9.80665 m/s^2.

In operation, the main exciter is first left at rest and the modulating frequency is induced in the upper plate. The amplitude of the modulating vibration is adjusted to bring the photodetector output to its first maximum. The mean mirror separation is then adjusted to further maximize the output. Control of the mirror separation is achieved by superimposing a dc bias on the ac driving signal to the modulating exciter. The main exciter on which the accelerometer is mounted is then driven to an amplitude which causes the photodetector signal to drop to a very distinct null (fringe disappearance). The output of the accelerometer is measured at this time to give one calibration point. Sensitivity factors are computed from values of displacement amplitude, frequency, and output voltage of the charge amplifier. For the system used, fringe disappearance occurs at a double displacement amplitude of 242.2 nm (9.536 μ in).

Measurements on the CESTA accelerometers were made by cementing a mirror onto the upper mating surfaces of each of the accelerometers. Data obtained from this test cannot be compared directly to the results from the comparison test described earlier. The "piggy-back" type accelerometers exhibit a mass-loading sensitivity, that is, their sensitivity changes as a function of the mass, and geometry of that mass, which is mounted on the upper surface. Normally, this "mass" is another accelerometer to be calibrated. However, in this test the "mass" is only a small glass mirror. The mass loading effect is generally larger at frequencies greater than 2 or 3 kHz. The values obtained from this test apply only under the conditions of this test. No methods have yet been developed which allow interferometric measurements to be made on double-ended, piggy-back type accelerometers with realistic mass loading conditions. However, it is possible to compare results obtained from two laboratories under the same mass loading conditions (i.e., with a mirror only as the mass). At the conclusion of the NBS testing the mirrors were left attached to the two CESTA accelerometers so they could be tested using a similar procedure at the French laboratory. Only then can any comparisons be made between the NBS and CESTA results using this type of measurement technique.

5. METHOD OF TEST

A comparison calibration on the NBS automated system, consisted of two runs from 10 to 10 000 Hz on one of the two NBS vibration generators. Data was taken at 10, 15, 30, 50, and 100 Hz at 100 Hz increments between 100 and 1000 Hz and at 500 Hz increments between 1000 and 10 000 Hz. After completion of a test, the entire assembly, consisting of the reference standard, stud and transfer standard was removed, mounted onto the second vibration generator and tested as above. The entire test was then repeated. This yielded four sets of data for the system. Both systems were subjected to the same cycle of testing. Both systems were once again tested in the same manner. At the conclusion of the comparison test program each system had been calibrated 8 times at 33 frequencies giving a total of 264 data points per system.

The interferometric test consisted of four data points at each of 20 frequencies between 1000 and 10 000 Hz in 500 Hz increments. Two different exciters were used with a repeat test on one of the exciters. This yielded a data set of 240 measurement points.

6. RESULTS OF TEST - SYSTEM 1

Table 1 presents the data and the average for each of the data points resulting from testing on each of the two NBS Dimoff Vibration generators. The four data points from each generator were averaged to yield the value of sensitivity for each of the test frequencies. The data presented are system sensitivity factors (mV/g). These factors were determined by comparing the voltage output of the charge amplifier used with the transfer standard accelerometer to the output of the reference standard.

Table 2 presents a summary of the comparison calibration data for System 1. The average data from the two Dimoff exciters are in column 2 and 3. Column 4 is the overall mean. Column 5 gives the factors used to adjust the reference system sensitivity factor to account for the calibration history of the system, and column 6 is the corrected transfer system sensitivity factor. Column 7 is the gain of the charge amplifier used with System 1. To present the results also in terms of the charge sensitivity of the accelerometer, the system sensitivity was divided by the amplifier gain. The results of this are in the last column. The accelerometer sensitivity factor is the output of the accelerometer in picocoulombs per unit acceleration in g (pC/g). Figure 1 is a graph of the system sensitivity. It is believed that whipping of the cable, which generates spurious signals due to triboelectric effect, and the poor signal-to-noise ratio of the test charge amplifier were responsible for the 10 and 15 hertz points showing an unexpected rise.

Table 3 presents the results of the interferometric testing. Columns 2, 3, and 4 are the average of the four data points from the three runs. Column 5 is the overall average of all the data. Column 6 gives the charge amplifier gain in units of millivolts per picocoulomb (mV/pC). The last column is the result of dividing the system sensitivity (column 5) by the gain to give accelerometer sensitivity in units of picocoulombs per g (pC/g).

A comparison of the data generated during these tests with informal CESTA data showed that, in the frequency range of 30 to 7000 Hz (which is the upper limit of the CESTA measurements), the NBS data generally averaged a difference of less than one percent from the CESTA mean. The NBS data was lower at each of the test frequencies. Above 7000 Hz, the NBS data indicated a rise of about three percent at 10 000 Hz. The slight variations in response between 2500 and 7000 Hz are believed to be caused by interactions between the reference and transfer standard as an assembly.

Table 1. Results of comparison calibration of System 1.

Frequency	System sensitivity									
	Vibration generator 201					Vibration generator 203				
	Run 1	Run 2	Run 3	Run 4	Ave	Run 1	Run 2	Run 3	Run 4	Ave
Hz	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g
10	1906	1908	1904	1906	1906	1906	1909	1898	1898	1903
15	1893	1894	1893	1892	1893	1895	1895	1889	1889	1892
30	1888	1889	1886	1885	1887	1889	1888	1888	1888	1888
50	1889	1890	1887	1887	1888	1891	1891	1888	1889	1890
100	1889	1890	1888	1888	1889	1893	1893	1890	1890	1892
200	1890	1890	1890	1891	1890	1892	1892	1890	1890	1891
300	1891	1891	1890	1889	1890	1893	1891	1890	1890	1891
400	1891	1892	1889	1889	1890	1892	1892	1890	1890	1891
500	1891	1891	1890	1890	1890	1893	1893	1891	1891	1892
600	1892	1892	1890	1890	1891	1893	1893	1891	1891	1892
700	1891	1892	1890	1890	1891	1893	1893	1891	1891	1892
800	1892	1893	1891	1891	1892	1893	1893	1892	1892	1892
900	1892	1893	1891	1891	1892	1894	1894	1892	1892	1893
1000	1893	1893	1891	1891	1892	1894	1894	1892	1893	1893
1500	1894	1894	1892	1892	1893	1895	1895	1893	1894	1894
1700	1894	1894	1893	1892	1893	1895	1895	1894	1894	1894
2000	1895	1895	1893	1893	1894	1895	1896	1894	1894	1895
2500	1896	1896	1894	1895	1895	1897	1897	1895	1896	1896
3000	1895	1896	1894	1894	1895	1899	1899	1897	1898	1898
3500	1900	1900	1899	1898	1899	1900	1901	1900	1900	1900
4000	1901	1901	1900	1900	1900	1902	1902	1901	1900	1901
4500	1902	1902	1901	1901	1902	1904	1904	1902	1903	1903
5000	1904	1904	1903	1903	1904	1906	1906	1903	1904	1905
5500	1905	1906	1904	1904	1905	1907	1907	1904	1904	1906
6000	1904	1905	1907	1908	1906	1909	1909	1905	1906	1907
6500	1913	1913	1911	1912	1912	1914	1914	1912	1912	1913
7000	1913	1914	1914	1914	1914	1916	1916	1915	1917	1916
7500	1924	1924	1915	1914	1919	1923	1922	1925	1925	1924
8000	1934	1934	1929	1929	1932	1934	1934	1932	1933	1933
8500	1940	1940	1937	1937	1938	1945	1945	1939	1940	1942
9000	1948	1948	1946	1946	1947	1949	1950	1949	1950	1950
9500	1953	1953	1956	1956	1954	1956	1956	1955	1955	1956
10000	1971	1972	1975	1975	1973	1969	1970	1965	1966	1968

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

Table 2. Summary of comparative test results for System 1.

Frequency	System sensitivity			Correction factor, k	System sensitivity	Amplifier gain	Accelerometer sensitivity
	Generator 201	Generator 203	Mean				
Hz	mV/g	mV/g	mV/g		mV/g	mV/pC	pC/g
10	1906	1903	1904	1.001	1906	1000.9	1.905
15	1893	1892	1892	1.001	1894	1001.7	1.891
30	1887	1888	1888	1.001	1890	1003.0	1.884
50	1888	1890	1889	1.001	1891	1003.9	1.884
100	1889	1892	1890	1.001	1892	1005.2	1.882
200	1890	1891	1891	1.001	1893	1006.5	1.880
300	1890	1891	1891	1.001	1893	1007.3	1.879
400	1890	1891	1891	1.001	1893	1007.8	1.878
500	1890	1892	1891	1.001	1893	1008.2	1.878
600	1891	1892	1892	1.001	1893	1008.6	1.877
700	1891	1892	1892	1.001	1893	1008.9	1.877
800	1892	1892	1892	1.001	1894	1009.1	1.877
900	1892	1893	1892	1.001	1894	1009.3	1.877
1000	1892	1893	1893	1.002	1896	1009.5	1.878
1500	1893	1894	1894	1.001	1896	1010.3	1.876
1700	1893	1894	1894	1.001	1896	1010.5	1.877
2000	1894	1895	1894	1.001	1896	1010.8	1.876
2500	1895	1896	1896	1.001	1898	1011.2	1.877
3000	1895	1898	1897	1.000	1897	1011.6	1.875
3500	1899	1900	1900	1.000	1900	1011.9	1.878
4000	1900	1901	1901	1.001	1903	1012.1	1.880
4500	1902	1903	1902	1.001	1904	1012.3	1.881
5000	1904	1905	1904	1.001	1906	1012.5	1.883
5500	1905	1906	1905	1.001	1907	1012.7	1.883
6000	1906	1907	1907	1.001	1909	1012.9	1.884
6500	1912	1913	1913	1.001	1915	1013.0	1.890
7000	1914	1916	1915	1.002	1919	1013.2	1.894
7500	1919	1924	1922	1.002	1925	1013.3	1.900
8000	1932	1933	1933	1.002	1937	1013.4	1.911
8500	1938	1942	1940	1.002	1944	1013.5	1.918
9000	1947	1950	1948	1.002	1952	1013.6	1.926
9500	1954	1956	1955	1.002	1959	1013.7	1.932
10000	1973	1968	1970	1.003	1976	1013.8	1.949

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

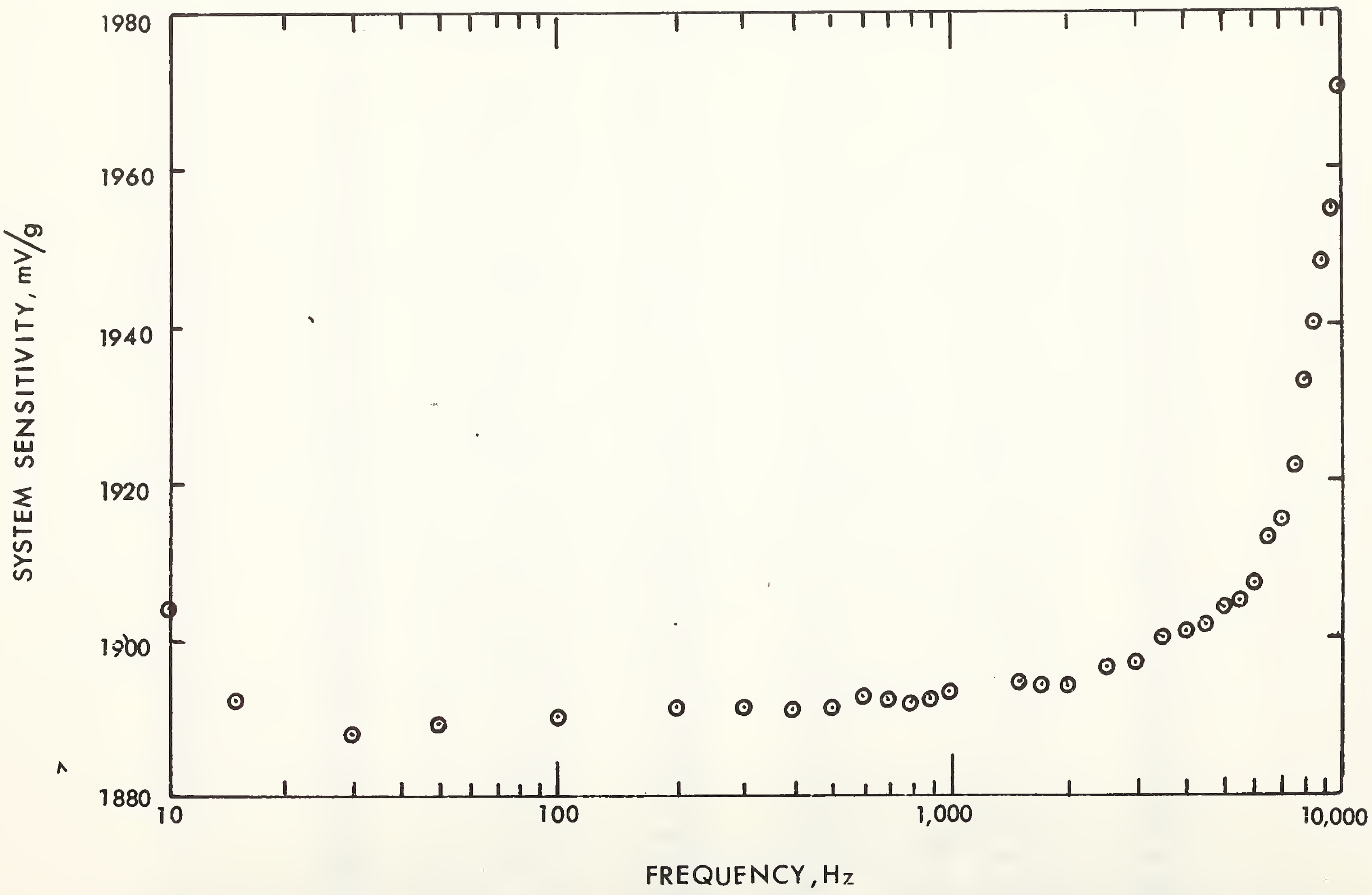

Figure 1. Sensitivity of System 1.

Table 3. Results of interferometric measurements of System 1.

Frequency	System sensitivity				Amplifier gain	Accelerometer sensitivity
	Run 1	Run 2	Run 3	Ave		
Hz	mV/g	mV/g	mV/g	mV/g	mV/pC	pC/g
1000	1897	1896	1900	1898	1009.5	1.880
1500	1900	1897	1898	1898	1010.3	1.879
1700	1899	1898	1900	1899	1010.5	1.879
2000	1901	1900	1902	1901	1010.8	1.881
2500	1900	1905	1904	1903	1011.2	1.882
3000	1905	1911	1914	1910	1011.6	1.888
3500	1917	1924	1928	1923	1011.9	1.900
4000	1915	1914	1918	1916	1012.1	1.893
4500	1896	1899	1898	1898	1012.3	1.875
5000	1904	1901	1909	1905	1012.5	1.881
5500	1908	1904	1912	1908	1012.7	1.884
6000	1883	1902	1884	1890	1012.9	1.866
6500	1857	1863	1856	1859	1013.0	1.835
7000	1867	1841	1852	1853	1013.2	1.829
7500	1884	1863	1856	1868	1013.3	1.843
8000	1892	1881	1865	1879	1013.4	1.854
8500	1897	1898	1897	1897	1013.5	1.872
9000	1903	1909	1892	1901	1013.6	1.876
9500	1908	1917	1897	1907	1013.7	1.882
10000	1912	1922	1910	1915	1013.8	1.889

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

7. RESULTS OF TEST - SYSTEM 2

Table 4 presents the data and the average for each data point resulting from testing System 2 on each of the two NBS Dimoff Vibration generators. The four data points from each generator were averaged to yield the value of sensitivity for each of the test frequencies. The data presented are the system sensitivity factors (mV/g). These factors were determined by comparing the voltage output of the charge amplifier used with the transfer standard accelerometer with the output of the reference standard.

Table 5 presents a summary of the comparison calibration data for System 2. The average data from the two Dimoff exciters is in column 2 and 3. Column 4 is the overall mean. Column 5 is the correction factor used to account for the calibration history of the reference system, and column 6 is the corrected system sensitivity factor. Column 7 is the gain of the charge amplifier used with System 2. Again, to present the results also in terms of the charge sensitivity of the accelerometer, the system sensitivity was divided by the amplifier gain. The results of this are in column 8. The accelerometer sensitivity factor is the output of the accelerometer in picocoulombs per unit acceleration in g (pC/g). Figure 2 is a graph of the system sensitivity. The unexpected rise at 10 and 15 hertz is again believed to be caused by cable motion and the poor signal-to-noise ratio of the charge amplifier.

Table 6 presents the results of the interferometric testing. As with System 1, column 2, 3, and 4 are the average of four data points from the three runs. Column 5 is the overall average of all of the data. Column 6 gives the charge amplifier gain, and the last column is the accelerometer sensitivity.

The results of the calibration of this transfer standard at NBS compare closely with informal CESTA data in the range of 30 to 3000 Hz. The results from the two laboratories tend to overlap very well.

Difficulties were encountered in the calibration of System 2. Results indicated a difference, when mounted on the two NBS exciters, of 1 to 2.5 percent in the response above 4000 Hz. It had been noted during check-in of this equipment that the upper and lower surfaces of this accelerometer were badly scarred. Time was expended in refinishing these surfaces. An additional run on both exciters indicated an improvement in the response but the differences were still considerably greater than usually expected. This can be seen by comparing these results with the corresponding results from System 1. The data included in this report is the data obtained after refinishing.

Table 4. Results of comparison calibration of System 2.

	System sensitivity									
	Vibration generator 201					Vibration generator 203				
Frequency	Run 1	Run 2	Run 3	Run 4	Ave	Run 1	Run 2	Run 3	Run 4	Ave
Hz	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g	mV/g
10	1229	1226	1223	1223	1225	1228	1228	1230	1230	1229
15	1205	1206	1204	1204	1205	1207	1207	1206	1206	1206
30	1198	1197	1198	1198	1198	1197	1197	1196	1196	1196
50	1197	1197	1196	1197	1197	1197	1197	1199	1199	1198
100	1198	1198	1198	1199	1198	1195	1196	1197	1197	1196
200	1198	1198	1199	1199	1198	1196	1196	1196	1196	1196
300	1199	1199	1200	1200	1200	1198	1197	1196	1196	1197
400	1199	1199	1199	1200	1199	1199	1199	1200	1200	1200
500	1200	1200	1200	1200	1200	1200	1200	1200	1201	1200
600	1200	1200	1200	1200	1200	1201	1201	1200	1200	1200
700	1200	1200	1200	1200	1200	1202	1202	1203	1203	1202
800	1201	1200	1200	1200	1200	1203	1203	1203	1203	1203
900	1200	1200	1200	1200	1200	1203	1203	1204	1204	1204
1000	1201	1201	1201	1201	1201	1204	1204	1204	1204	1204
1500	1202	1201	1202	1202	1202	1207	1207	1208	1208	1208
1700	1200	1201	1201	1201	1201	1208	1208	1209	1209	1208
2000	1201	1201	1202	1202	1202	1209	1210	1211	1211	1210
2500	1204	1205	1204	1204	1204	1214	1214	1215	1214	1214
3000	1210	1211	1210	1210	1210	1210	1209	1213	1212	1211
3500	1209	1209	1212	1210	1210	1210	1210	1215	1215	1212
4000	1210	1210	1210	1210	1210	1215	1214	1217	1217	1216
4500	1206	1206	1206	1205	1206	1220	1220	1214	1214	1217
5000	1208	1208	1208	1208	1208	1217	1217	1216	1216	1216
5500	1206	1207	1208	1207	1207	1215	1215	1217	1217	1216
6000	1213	1213	1212	1212	1212	1221	1221	1223	1223	1222
6500	1217	1218	1216	1216	1217	1225	1225	1231	1225	1226
7000	1221	1222	1218	1218	1220	1234	1234	1227	1227	1230
7500	1226	1227	1222	1222	1224	1243	1242	1236	1237	1240
8000	1229	1230	1225	1226	1228	1251	1251	1255	1255	1253
8500	1253	1254	1258	1257	1256	1245	1245	1258	1258	1252
9000	1252	1252	1250	1250	1251	1254	1255	1258	1259	1256
9500	1259	1259	1257	1258	1258	1263	1264	1266	1266	1265
10000	1269	1270	1268	1269	1269	1274	1275	1278	1278	1276

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

Table 5. Summary of comparative test results for System 2.

Frequency	System sensitivity Generator 201	System sensitivity Generator 203	System sensitivity Mean	Correction factor, k	System sensitivity	Amplifier gain	Accelerometer sensitivity
Hz	mV/g	mV/g	mV/g		mV/g	mV/pC	pC/g
10	1225	1229	1227	1.001	1228	984.4	1.248
15	1205	1206	1206	1.001	1207	986.9	1.223
30	1198	1196	1197	1.001	1198	989.4	1.211
50	1197	1198	1197	1.001	1199	991.3	1.209
100	1198	1196	1197	1.001	1198	993.8	1.206
200	1198	1196	1197	1.001	1198	996.4	1.203
300	1200	1197	1198	1.001	1199	997.8	1.202
400	1199	1200	1199	1.001	1201	998.9	1.202
500	1200	1200	1200	1.001	1201	999.7	1.202
600	1200	1200	1200	1.001	1202	1000.4	1.201
700	1200	1202	1201	1.001	1202	1000.9	1.201
800	1200	1203	1202	1.001	1203	1001.4	1.201
900	1200	1204	1202	1.001	1203	1001.8	1.201
1000	1201	1204	1202	1.002	1205	1002.2	1.202
1500	1202	1208	1205	1.001	1206	1003.7	1.202
1700	1201	1208	1205	1.001	1206	1004.1	1.201
2000	1202	1210	1206	1.001	1207	1004.7	1.202
2500	1204	1214	1209	1.001	1210	1005.5	1.204
3000	1210	1211	1211	1.000	1211	1006.2	1.203
3500	1210	1212	1211	1.000	1211	1006.8	1.203
4000	1210	1216	1213	1.001	1214	1007.3	1.205
4500	1206	1217	1211	1.001	1213	1007.7	1.203
5000	1208	1216	1212	1.001	1214	1008.1	1.204
5500	1207	1216	1212	1.001	1213	1008.4	1.203
6000	1212	1222	1217	1.001	1218	1008.7	1.208
6500	1217	1226	1222	1.001	1223	1009.0	1.212
7000	1220	1230	1225	1.002	1228	1009.3	1.216
7500	1224	1240	1232	1.002	1234	1009.6	1.223
8000	1228	1253	1240	1.002	1243	1009.8	1.231
8500	1256	1252	1254	1.002	1256	1010.0	1.244
9000	1251	1256	1254	1.002	1256	1010.2	1.244
9500	1258	1265	1262	1.002	1264	1010.4	1.251
10000	1269	1276	1273	1.003	1276	1010.6	1.263

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

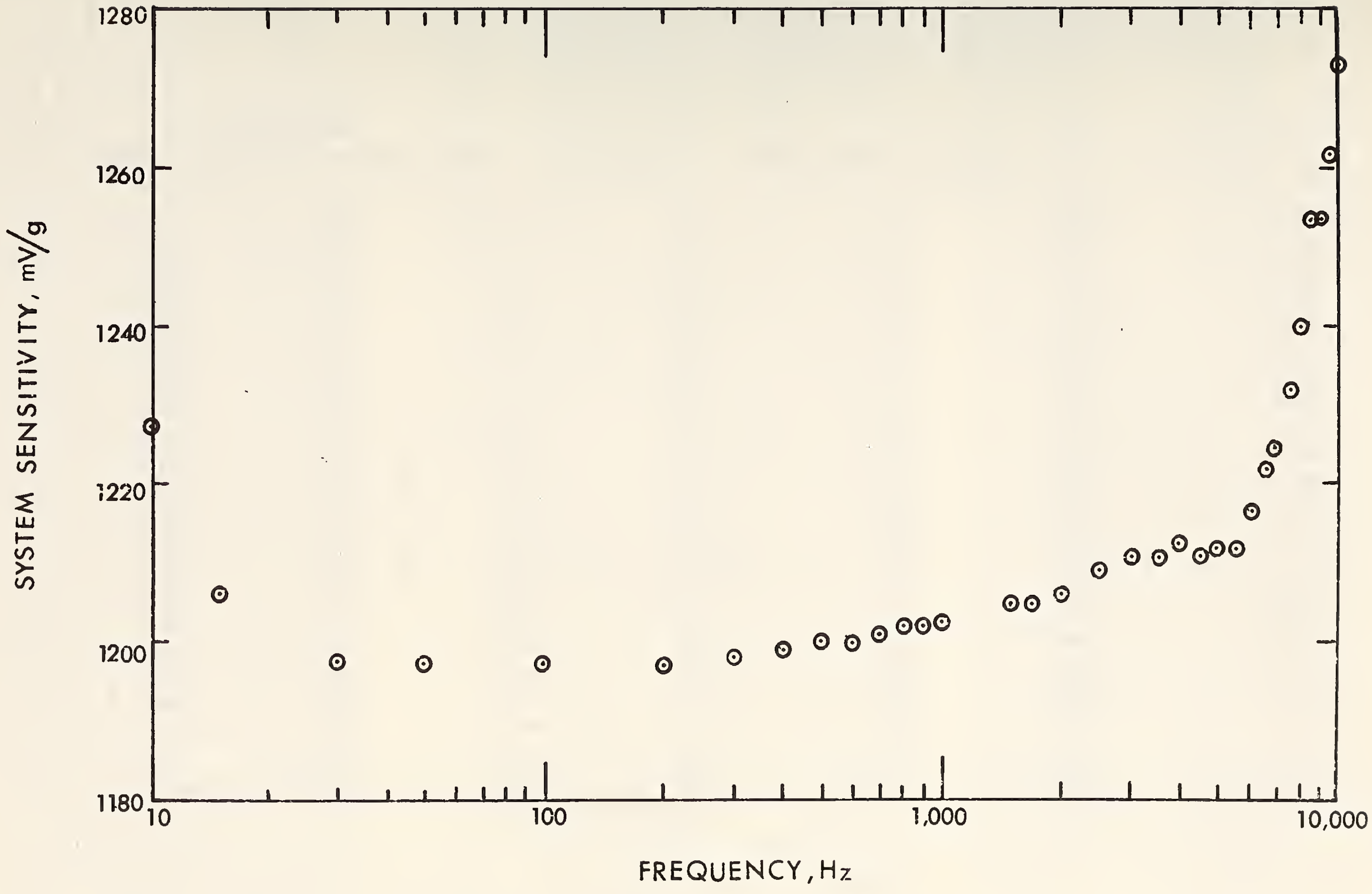

Figure 2. Sensitivity of System 2.

Table 6. Results of interferometric measurements of System 2.

Frequency	System sensitivity				Amplifier gain	Accelerometer sensitivity
	Run 1	Run 2	Run 3	Ave		
Hz	mV/g	mV/g	mV/g	mV/g	mV/pC	pC/g
1000	1198	1208	1204	1203	1002.2	1.201
1500	1205	1209	1206	1207	1003.7	1.202
1700	1207	1211	1207	1208	1004.1	1.203
2000	1208	1217	1208	1211	1004.7	1.205
2500	1215	1206	1215	1212	1005.5	1.205
3000	1217	1214	1218	1216	1006.2	1.209
3500	1222	1219	1223	1221	1006.8	1.213
4000	1228	1224	1230	1227	1007.3	1.218
4500	1236	1226	1236	1233	1007.7	1.223
5000	1240	1235	1240	1238	1008.1	1.228
5500	1248	1248	1249	1248	1008.4	1.238
6000	1259	1260	1261	1260	1008.7	1.249
6500	1269	1273	1269	1270	1009.0	1.259
7000	1256	1276	1267	1266	1009.3	1.255
7500	1237	1274	1262	1258	1009.6	1.246
8000	1230	1270	1255	1252	1009.8	1.240
8500	1220	1235	1238	1231	1010.0	1.219
9000	1182	1161	1169	1171	1010.2	1.159
9500	1077	1077	1060	1071	1010.4	1.060
10000	1228	1161	1187	1192	1010.6	1.180

Note: Apparent inconsistencies in rounding may occur since additional digits were used in calculations.

The NBS laboratory had available another accerlerometer of this same type. This was substituted for the CESTA System 2 accelerometer and data taken. This second accelerometer did not exhibit any such deviation in the response above 4000 Hz. The reason for the problem in the CESTA accelerometer was not determined. Additional testing should be performed at the French laboratory to determine the cause of this anomalous behavior.

8. UNCERTAINTY OF RESULTS

The calibration procedures followed at NBS will generally give system sensitivities (mV/g) with uncertainties of not more than one percent over the frequency range of 10 to 1000 Hz and two percent from 1000 to 10 000 Hz. An additional uncertainty of about 0.25 percent would be expected in measuring amplifier gain and converting to accelerometer sensitivity (pC/g).

In the tests covered here, the amplifier noise level and possible triboelectric effects due to cable whipping have introduced a significant, but unevaluated, additional uncertainty at 10 and 15 Hz. The problem encountered with System 2 (Section 7) also added to the uncertainty of the results for this system above 4000 Hz. Since the effects of these problems were not determined, an estimate of uncertainty at 10 and 15 Hz and, for System 2, at the higher frequencies cannot be given.

Examination of the results of the amplifier gain measurements has shown them to be less consistent than expected. It is not known whether this problem was a result of the amplifier behavior or of the gain measurement process. Unfortunately, the systems were not available at NBS long enough for these factors to be resolved. As a result, the accelerometer sensitivities also contain an additional, unevaluated uncertainty, and no value of this uncertainty can be given.

With the exceptions noted above, the usual uncertainties can be assigned to the results of these tests.

9. CONCLUSIONS

The results should be considered valid only for the methods and hardware tested. Although there was general agreement with the limited, informal CESTA data that was available, several things do remain unexplained. For example, the almost constant difference between the NBS measurements and the CESTA measurements of System 1, and the problem of System 2 above 4000 Hz. In the first case, the results agree within the claims of both laboratories and the difference may be in the measurement techniques employed and the random and systematic errors expected. Certain interactions between the particular units tested are difficult to ascertain and might have had an effect. Some of these might have been column resonances of the reference and transfer standards as a column assembly, relative motion between the upper and lower surfaces of the transfer standard, strain sensitivity of the transfer standard, noise, etc. The problem with System 2 above 4000 Hz remains unexplained.

10. ACKNOWLEDGEMENTS

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes a vibration measurement interchange between a French laboratory (CESTA) and the National Bureau of Standards (NBS). Methods of calibration at NBS and results of the calibration of two commercially available double ended or "piggy-back" type accelerometers are discussed. No difficulties were encountered in the calibration of System 1, however, above 4000 Hz difficulties were experienced in the calibration of System 2.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Accelerometers; calibration; measurements; vibration; vibration exciters; vibration standards.

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