MICHIGAN STATE
UNIVERSITY

Mar 29, 2012

To: Whom It Concerns

Attached is the Michigan State University, College of Engineering Dynamics and Vibrations Laboratory report on the effects of VIBEX (a damping product manufactured by Permawick Corporation) on a tennis racket.

The report contains results from tests that were conducted by Michigan State University. It was found that VIBEX has a positive effect on reducing vibrations in the handle of a tennis racket.

Sincerely,

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COLLEGE OF
ENGINEERING

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VIBEX Testing on a Tennis Racket

Test conducted at Vibrations Lab @ MSU, East Lansing
Mar. 29, 2012

Project Description:

Based on recent interest shown by tennis racket manufactures, it was decided to test a tennis racket with and without VIBEX. Results of the test are to be provided to Permawick.

Equipment:

- Regular VIBEX produced by Permawick
- A tennis racket
- 4 shear-type accelerometers (352B10/10AC) manufactured by PCB Piezotronics
- 16 channel signal conditioner (481A02) manufactured by PCB
- Eight 2-channel AR GXPA TEAC modules for data recording manufactured by Tritech
- Gateway Laptop w/ required software for post processing data (TEAC GX Navi and Matlab)

Procedure:

The tennis racket was suspended and struck vertically with an impact hammer on the center of the head. Four accelerometers were placed along the length of the handle, on two directions, as shown in Figure 1. Sensors 1 and 2 are in the vertical direction parallel to the impact direction (direction 1), while sensors 3 and 4 are in the horizontal direction perpendicular to the impact direction (direction 2).

The first test configuration is without VIBEX. And then different amounts of VIBEX were inserted at the center of the handle, as shown in Figure 1. The cases for 10 grams, 15 grams and 20 grams were tested.

5 sets of data were recorded for each test configuration to ensure accuracy of the results. Data were sampled at 5000 Hz with the low pass filter set to 2000 Hz.

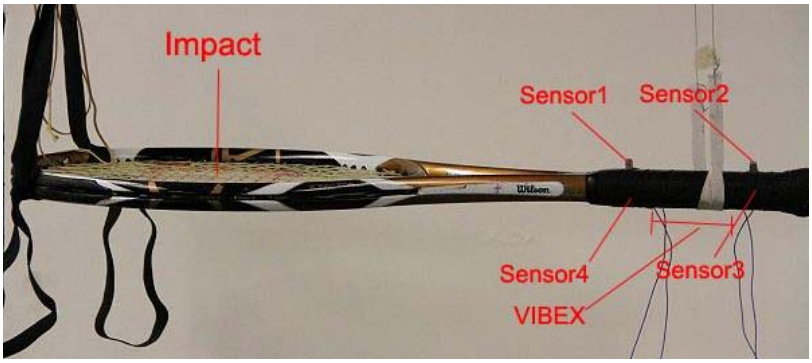

Figure 1: Experimental Setup

Results and Discussion:

The figures below display the fast Fourier transforms (FFTs) of the data collected. On the horizontal axis is the frequency, which is the rate of oscillation in cycles/second (Hz) units. The vertical axis displays the amplitude associated with a given frequency in the signal, normalized by the impact force, on a linear scale. The blue lines represent the test performed without VIBEX. The pink lines represent the test with 10 grams VIBEX. The green lines represent the test with 15 grams VIBEX. The red lines represent the test with 20 grams VIBEX. For the case of an impact excitation, a reduction in the peak of the FFT can mean that either the length of time that the vibration can be felt is reduced, or the amplitude of vibration is reduced, or both. In the figures below each line represents one sensor. In Table 1, however, we have taken the averages of all of the tests to give more comprehensive results.

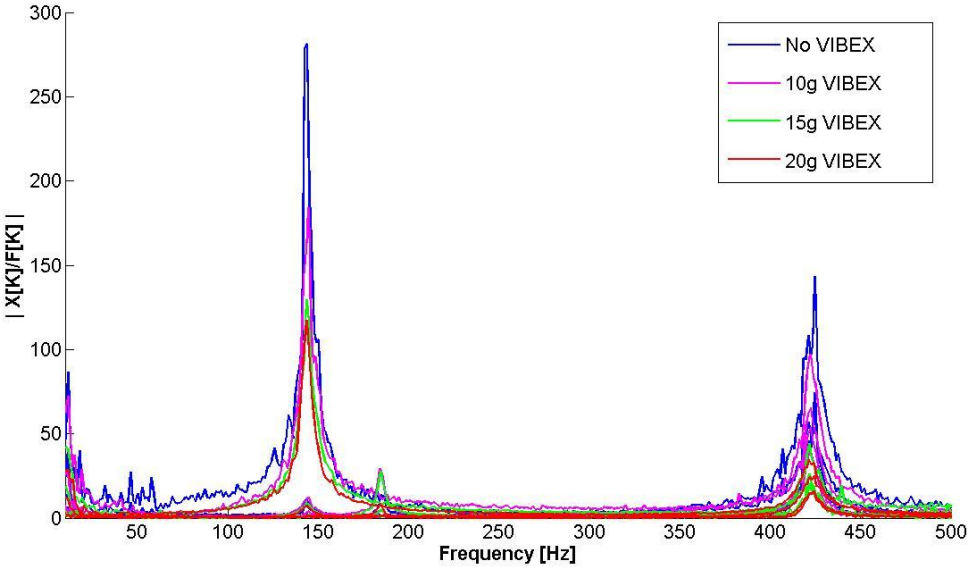

Figure 2. FFT of all sensors

Table 1: Maximum Amplitudes at Main Frequencies

		Amplitudes at 148Hz	Reduction	Amplitudes at 425Hz	Reduction
Sensor1	NoVIBEX	7.8467	×	143.62	×
	10gVIBEX	3.8216	-51.30%	97.503	-32.11%
	15gVIBEX	1.7787	-77.33%	44.268	-54.60%
	20gVIBEX	1.3194	-83.19%	34.63	-21.77%
Sensor2	NoVIBEX	281.27	×	71.134	×
	10gVIBEX	184.36	-34.45%	65.424	-8.03%
	15gVIBEX	129.51	-53.96%	26.309	-63.01%
	20gVIBEX	117.61	-58.19%	25.118	-64.69%
Sensor3	NoVIBEX	10.816	×	64.014	×
	10gVIBEX	12.257	13.32%	40.213	-37.18%
	15gVIBEX	8.7693	-18.92%	18.245	-71.50%
	20gVIBEX	7.1034	-34.33%	16.133	-74.80%
Sensor4	NoVIBEX	2.34	×	74.539	×
	10gVIBEX	1.2389	-47.06%	53.833	-27.78%
	15gVIBEX	1.108	-52.65%	20.396	-72.64%
	20gVIBEX	1.199	-48.76%	15.037	-79.83%

Table 2: Average reduction

	Average Reduction	Vertical Direction	Horizontal Direction
10gVIBEX	-28.07%	-31.47%	-24.67%
15gVIBEX	-58.08%	-62.23%	-53.93%
20gVIBEX	-58.19%	-56.96%	-59.43%

Table 3: Average reduction based on the average amplitudes

	Average Amplitudes at 148Hz	Reduction	Average Amplitudes at 425Hz	Reduction	Average Amplitudes	Reduction
NoVIBEX	75.568	×	88.327	×	81.947	×
10gVIBEX	50.419	-33.28%	64.243	-27.27%	57.331	-30.04%
15gVIBEX	35.292	-53.30%	27.305	-69.09%	31.298	-61.81%
20gVIBEX	31.808	-57.91%	22.730	-74.27%	27.269	-66.72%

Table 4: Average reduction in both directions based on the average amplitudes

	Vertical Direction	Reduction	Horizontal Direction	Reduction
NoVIBEX	125.968	×	37.927	×
10gVIBEX	87.777	-30.32%	26.885	-29.11%
15gVIBEX	50.466	-59.94%	12.130	-68.02%
20gVIBEX	44.669	-64.54%	9.868	-73.98%

Table 1 compares the amplitudes of the sensors at each natural frequency, and indicates the percent reduction when VIBEX is applied. Table 2 shows the mean of the percentage reduction in Table1 for each VIBEX amount, while the percentage reduction in Table 3 and Table 4 is the reduction of the mean of the amplitudes of the sensors. It should be noted that the units for the vertical axis label X[k]/F[k] are not explicitly stated but for the reduction calculation we take a ratio which produces a nondimensional result.

Figure 2 shows that the main frequencies are around 148Hz and 425Hz. It can be seen both in Figures 2 and table 1 that when VIBEX is applied to the tennis racket, the maximum amplitudes for almost all of the sensors are reduced. And with an increase of the amount of VIBEX, the reduction increases. Table 1 and Table 4 also show that the vibration amplitude in direction 1 is larger than the one in direction 2, as the relative amplitude values of sensors 1 and 2 are larger than those of sensors 4 and 3 at 148Hz and 425Hz. The percentage reduction in direction 1 is also larger than that in direction 2.

Summary:

- VIBEX significantly reduced the vibration in the handle of the tennis racket.
- The percent reduction increased when more VIBEX was inserted, up to 20 grams.
- A maximum average reduction of 66.72% is obtained when 20 grams was inserted.
- Further testing on optimization studies may be possible at the customer's request.

Things to Note

- The location of accelerometers has an influence on the responses read by the accelerometers. Care was taken to ensure very similar sensor locations on tests in each case, and the location error is assumed to be negligible.
- The tests were plotted for frequencies less than 500 Hz. Higher frequencies can be examined if desired.

Research, Testing and Results conducted by:

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