MICHIGAN STATE
UNIVERSITY

July 26th, 2013

Dear Ms. Vivian Wong

Attached is the Michigan State University, College of Engineering Dynamics and Vibrations Laboratory report on the effects of the VIBEX damping system on Easton Mako CXN skates.

The Easton skates provided by Tom Corden from Permawick Corporation were tested in laboratory and on-ice conditions.

The results show that VIBEX helps reduce vibration in the skate blade holder by an average of 40%. Addition of VIBEX to the holder cavity also makes the skates feel quieter and the skating experience on ice softer.

In lieu of this, we recommend addition of VIBEX to the skates as a viable solution for the vibration related issues with the skates.

Sincerely,

Venkat Ramakrishnan
Graduate Research Assistant
Michigan State University College of Engineering

COLLEGE OF
ENGINEERING

Department of
Mechanical Engineering

VIBEX testing in Easton Bell Sports manufactured skates

Test conducted at Vibrations Lab @ MSU, East Lansing

July 26th, 2013

Project Description:

Easton Bell Sports is a well-known manufacturer of sporting equipment for ice hockey. Preliminary testing of the new top of the line skates (Mako CXN) showed some vibration and/or chatter when the skier makes quick/hard turns to the left and right. Vibration is consistent but changes slightly based on product variability.

Permawick Corporation was approached to test the use of their popular vibration-damping product VIBEX to on these skates. Michigan State University has a working relationship with Permawick wherein the use of VIBEX for vibration reduction is tested for products across different markets. VIBEX has been shown to reduce vibration from about 30% for systems with continuous excitation (outdoor power equipment) to as high as 80% for impact excited vibration (baseball bats, ice hockey sticks, golf clubs, etc.). The goal of this work is to demonstrate if VIBEX has the same effect on hockey skates and to determine the optimal amount and location of VIBEX in the skates. The lighter version of VIBEX, marketed as VIBEX Sport was chosen for initial round of testing. For phase 2 of the lab test, VIBEX HP (water resistant dampener) was chosen.

As a part of this project, three sets skates (size 10) were provided. Testing was done in the lab as well as on-ice. The same of skates/holder was chosen while comparing vibrations in the lab due to inherent variability in products during manufacturing process. However, this was not feasible for the on-ice tests.

Equipment:

- 3 pairs of Easton Mako CXN skates
- 4 shear-type accelerometers (352B10/10AC) manufactured by PCB Piezotronics
- 16 channel signal conditioner (481A02) manufactured by PCB
- 2 channel AR GXPA TEAC module for data recording manufactured by Tritech
- Impact hammer w/ force transducer (086B04sn3116)
- Gateway Laptop w/ required software for post processing data (TEAC GX Navi and Matlab)

Procedure:

1. Lab Testing (Phase 1):

The Easton skates were suspended to simulate a free-free boundary condition and struck with an impact hammer at multiple locations. Accelerometers were places on the holder and the shoe to capture the level of vibration across different materials and substructures in the skates (see figure 1). Different amounts of VIBEX (30g and 50g) were tested on the left and right skates. Care was taken to maintain the weight balance of the skate i.e., equal amount of damping gel was added to the front and rear cavity of the blade holder. The VIBEX was added in specific amounts – 15g and 25g inserted in each bladder (balloon) and stuck to the front and rear cavity of the holder (see Figure 2). This was done to have flexibility in changing the amounts of VIBEX for additional testing.

Four different impact locations (two on blade, two on the boot) were chosen to gather the vibration response of the system. Data was sampled at 5000 Hz with the low pass filter set to 2000 Hz. Three sets of data were recorded for each set of test scenario.

2. <u>Lab Testing (Phase 2):</u>

Vibration experienced by the user of the skates originates from the contact of the blade with ice and travels through the holder into the boot. If the system were damped at the holder, lesser amounts of energy would propagate through the boot. Hence, we isolated the holder and tested the structure as a stand-alone system as seen in figure 3. This enabled us to have more precise information on the holder's natural frequency and test the efficiency of VIBEX in damping those critical frequencies. The rivets that hold the boot and the blade holder together are known to rust from the water released from the foot of the skates due to perspiration. Hence, we chose VIBEX HydroPhobic (VIBEX HP). This product is known to have worked well in applications where the gel comes in contact with water. The product is fractionally lighter than VIBEX, but slightly heavier than the sport version. VIBEX HP was injected into the holder directly using a caulking gun (see Figure 4). The damping gel has more contact area with the vibrating structure and hence dampens it more if this method is chosen over the bladder mechanism.

Four impact locations were chosen (two on blade, two on holder) and two accelerometers recorded vibration at different locations on the holder. Data was sampled at 5000 Hz with the low pass filter set to 2000 Hz. Three sets of data were recorded for each set of test scenario. Results are shown for 50g of VIBEX addition. Additional testing can be done for different weights of VIBEX HP or VIBEX Sport to optimize and achieve target performance – combination of maximum vibration reduction for least amount of weight addition due to gel.

3. <u>On-Ice Testing:</u>

After Phase 1 testing in the lab was completed, the skates were tested at the MSU Indoor Munn Ice Arena. Tom Campbell, Manager of Munn Ice Arena (varsity hockey player and equipment manager of the MSU Varsity Hockey Team for about 40 years) and Brian Feeny, Professor in Mechanical Engineering Department at MSU (avid hockey enthusiast) helped in testing the skates (see Figure 5,6). The blades were profiled and sharpened before use. Feedback about the performance of skates, specifically with regards to vibration was noted. The skaters made quick/sharp turns and hockey stops to duplicate the source of vibration mentioned by Vivian Wong of Easton Bell Sports.

Figure 1: Easton Mako CXN skates suspended with accelerometers

Figure 2: Easton Mako CXN blade holder with VIBEX Sport in the bladders (purple and yellow color balloons in figure have 15g of VIBEX Sport)

Figure 3: Easton Mako CXN blade holder suspended with accelerometers

Figure 4: Easton Mako CXN blade holder rear reservoir filled with VIBEX HP

Figure 5: Brian and Tom in the workshop with Easton Mako CXN skates (riveting the holder and grinding the blade profile)

Figure 6: Skating on ice with the Easton Mako CXN's (testing for performance with VIBEX)

Results from lab testing phase 1:

The frequency spectrum for the entire skates was very wide, i.e., the natural frequencies were not distinct (as seen in Figure 7). This is because of the numerous joints and the different materials in the skates. The inherent overall damping in the system also makes it difficult to distinguish between critical frequencies. For such a broad frequency spectrum, we would have to do more analysis to quantify the effects of VIBEX on reducing system vibration. One technique would involve sketch out the Power Spectral Density (PSD) of the response signal captured by the accelerometers to estimate the energy dissipated by the skates with and without VIBEX. However, given the time frame of tests and the amount of work required, we did not proceed in this direction. Instead, we chose to isolate the skate's blade holder and conduct tests on it to showcase the effects of adding VIBEX.

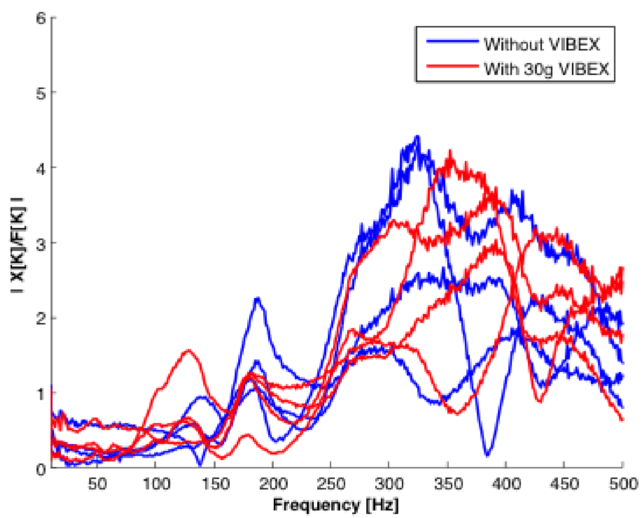

Figure 7: FFT of all Sensors from the entire skate (Impact at boot toe box)

Results from lab testing phase 2:

Figure 8-11 show the fast Fourier transform (FFT) of the data collected for different impact locations. On the x-axis is the frequency, which is the rate of oscillation in cycles/second (Hz) units. The y-axis displays the amplitude associated with a given frequency in the signal, normalized by the impact force, on a linear scale. The figures show that the Easton Mako CXN skate's blade holder response has three dominant components at frequencies around 150Hz, 200 Hz and 430Hz, which indicate frequencies of vibration modes for the freely suspended blade holder. Each line represents one sensor. The blue lines represent the baseline tests and the red lines represent tests performed with 50 grams of VIBEX HP. Depending on the excitation in an FFT, a reduction in the peak can mean that the magnitude of the vibration observed during a sustained excitation is reduced or that the length of time that the vibration can be felt after an impulse excitation is reduced. Additionally for the figures below one test was taken from each set of tests to allow the results to be clearly seen. In Table 1, however, we have taken the averages of all the tests to give more comprehensive results.

It can be seen in from figures 8-11 that, when VIBEX is added in the blade holder, the magnitude of vibration is reduced. Table 1 compares the amplitudes of the sensors at each natural frequency, and indicates the percent reduction when VIBEX is added. It should be noted that the units for the y-axis label X[k]/F[k] are not explicitly stated but for the reduction calculated we take a ratio which produces a non-dimensional result. Also Table 1 contains a more comprehensive result that includes all the data that was collected.

As we can see from Table 1, VIBEX HP achieves reduction at critical frequencies for all sensors and impact locations. We see an average reduction of 40% in the peak amplitude.

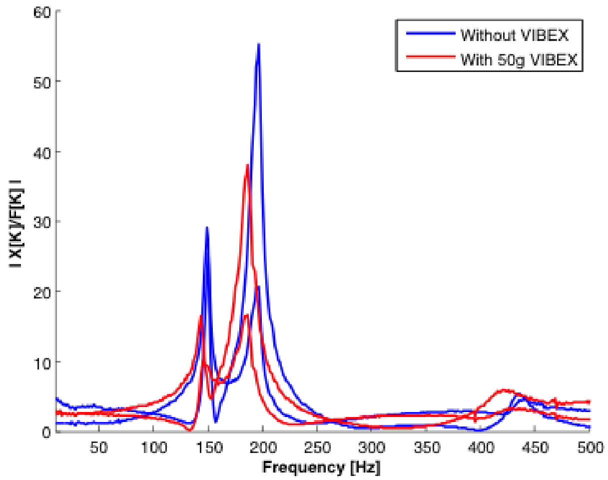

Figure 8: FFT of all Sensors (Impact location – 1, at the front end of the blade)

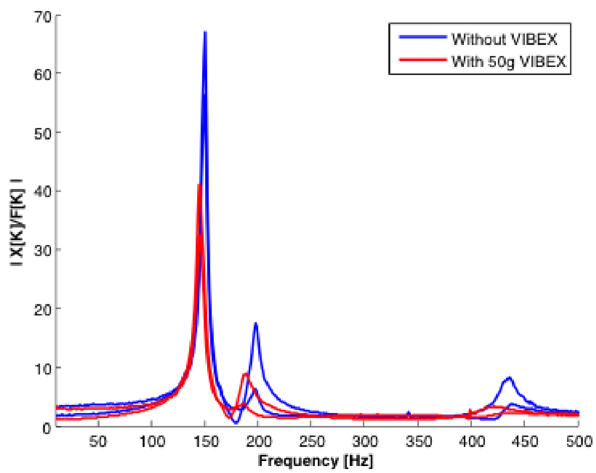

Figure 9: FFT of all Sensors (Impact location – 2, at the front end of the holder)

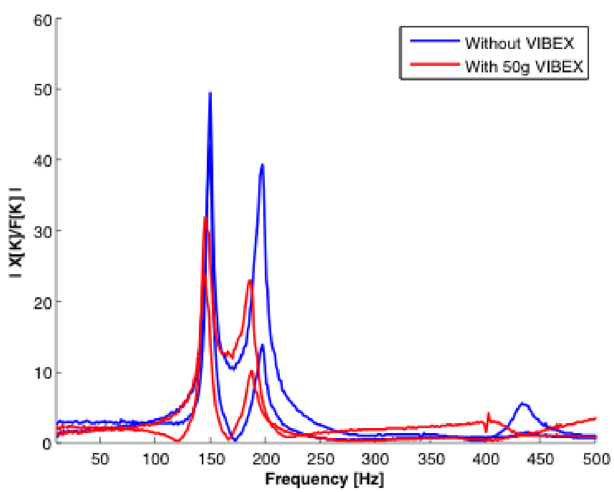

Figure 10: FFT of all Sensors (Impact location –3, at the rear end of the blade)

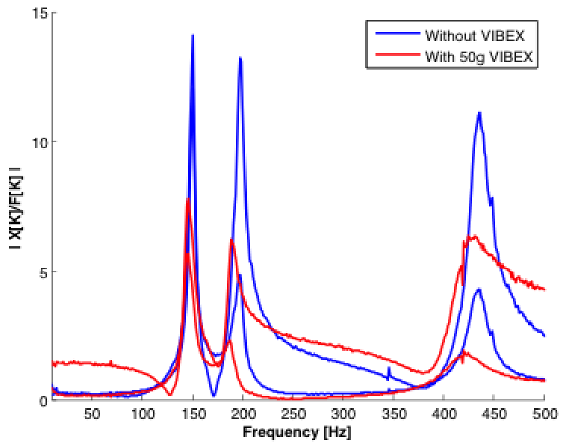

Figure 11: FFT of all Sensors (Impact location –4,at the rear end of the holder)

Table 1: Maximum Amplitudes at Main Frequencies (average of 3 tests for each impact location)

Sensor #1						
Impact Location 1	≈ 150 Hz	% Reduction	≈ 200 Hz	% Reduction	≈ 430 Hz	% Reduction
Baseline	29.09		55.16		5.44	
With 50g Vibex	16.37	43.73	37.96	31.18	5.92	-8.82
Sensor #2						
Baseline	25.40		20.54		4.45	
With 50g Vibex	10.06	60.39	16.51	19.62	3.29	26.07
Sensor #1						
Impact Location 2	≈ 150 Hz	% Reduction	≈ 200 Hz	% Reduction	≈ 430 Hz	% Reduction
Baseline	67.02		17.44		8.35	
With 50g Vibex	41.12	38.65	8.82	49.42	3.25	61.08
Sensor #2						
Baseline	56.35		6.30		3.72	
With 50g Vibex	32.39	42.52	3.78	40.00	1.96	47.31
Sensor #1						
Impact Location 3	≈ 150 Hz	% Reduction	≈ 200 Hz	% Reduction	≈ 430 Hz	% Reduction
Baseline	49.37		39.16		5.42	
With 50g Vibex	31.80	35.59	22.90	41.52	1.40	74.44
Sensor #2						
Baseline	42.07		13.72		1.38	
With 50g Vibex	23.84	43.33	10.00	27.11	1.30	5.79
Sensor #1						
Impact Location 4	≈ 150 Hz	% Reduction	≈ 200 Hz	% Reduction	≈ 430 Hz	% Reduction
Baseline	14.09		13.23		11.12	
With 50g Vibex	7.79	44.71	6.19	53.21	6.36	42.81
Sensor #2						
Baseline	12.05		4.86		4.26	
With 50g Vibex	5.66	53.01	2.23	54.12	1.90	55.40

Results from on-ice tests:

Comments** from Tom Campbell with regards to vibration:

- Adding VIBEX seems to make them quieter (has a softer feel on ice) and there is some damping effects that can be felt
- No noticeable weight difference by adding up to 50g of VIBEX on each skate.

**There are additional comments from Tom Campbell about the overall design improvements that could be done to improve the skates feel and performance. The comments were related to recommended modifications with regards to blade profile, tendon guards, holder flexibility, etc. These comments can be made available upon request.

Things to Note

- The location of accelerometers and the string supports for the free-free boundary conditions, along with the location of impact for exciting the structure, have a crucial influence on the responses read by the accelerometers. Care was taken to ensure similar sensor locations on tests with and without VIBEX, and the error is assumed to be negligible.
- The accelerometers used have a reduced accuracy at frequencies below about 10 Hz. This in conjunction with slight bouncing that sometimes occurs during testing accounts for peaks at lower frequencies that can be ignored.
- When the blade holder was struck some bouncing occurred with the support strings, which contributes to the peaks at low frequencies.
- The tests were plotted for frequencies less than 500 Hz. Higher frequencies can be examined if applicable.
- The vibration characteristics with a full skates will be different than those of the free-free hanging blade holder. The free-free hanging holder provides repeatable test conditions. We expect the general trend of vibration reduction to carry over.
- The peak frequency is left-shifted for the holder response with VIBEX. This occurs because of the additional weight added by VIBEX, which reduces the critical frequency. Previous tests have shown that VIBEX is not only a mass affect as addition of similar weight just shifts frequency and doesn't contribute to reduction in peak amplitude.

Acknowledgement:

Input from Tom Campbell was critical to understand the inherent dynamics and properties of skates.

Research, Testing and Results conducted by:

Venkat Ramakrishnan:
Email: venkat@egr.msu.edu Phone: 517-432-1085
Graduate Research Assistant, Dynamic Systems Lab, Vibration Research, Michigan State University

Dr. Brian Feeny:
Email: feeny@egr.msu.edu Phone: 517-432-1085
PhD, Mechanical Engineering, Dynamic Systems Lab, Vibration Research, Michigan State University