November 1, 2013

To: Dan Chalfant

Attached is the VIBEX Laboratory report on the effects of VIBEX HP and VIBEX PLUS (dampening products manufactured by Permawick Corporation) in Liberty Skis.

The report contains results from tests that were conducted by the VIBEX lab. It was found that VIBEX HP and VIBEX PLUS has a positive effect on reducing vibrations in the skis. Notable reduction at key vibration points (averaging up to 40%) were obtained in the 0 - 500Hz range.
Overall reductions can be reviewed in **graph 2** and **graph 3 on page 7**. The executive summary on page 3 also summarizes preferred treat rates of VIBEX HP and VIBEX PLUS.

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VIBEX Vibration Test Lab

Sincerely,

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VIBEX HP is proud to be REACH and RoHS compliant

Rev Level: 1
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Liberty Ski Optimization Study
November 1, 2013
VIBEX Lab-Columbus, IN
Prepared by Andrew LaRouche: Director of Research & Development

Introduction

We received two sets of skis from Liberty for testing. In this Study we aimed to optimize the location and amount of VIBEX HP or VIBEX PLUS in the skis so as to obtain maximum vibration dampening.

Equipment used in Study

- Liberty ski sets (Variant 186)
- Impact hammer (Piezotronics Model #086C03)
- Accelerometers or sensors (Piezotronics Model #353B15)
- Computer using LabView to acquire data
- VIBEX dampening gels

Test Procedure

- The Skis was suspended by bungee cords. (See **picture #1 and #2 on page 4** below)
- Accelerometers were placed on the skis to record acceleration data to determine where the maximum deflections (vibration) were occurring. This allowed us to determine the effectiveness of VIBEX HP at the touch points before and after it was placed on the ski.
- In the first test VIBEX HP was injected from a caulking gun directly into the cavity routed out of each ski. (see example on **Picture #4 on page #5**)
- In the second round of tests additional mass (VIBEX PLUS) was added to each location. The added weight was 30 grams approx. at each location.
- Excitation of the system was introduced by impacting the front touch point of ski with an impact hammer that had a built in force sensor to measure the input force.
- A reduction in the peak of the amplitude meant that either the length of time that the vibration could be felt was reduced, and/or that the amplitude of vibration was reduced.

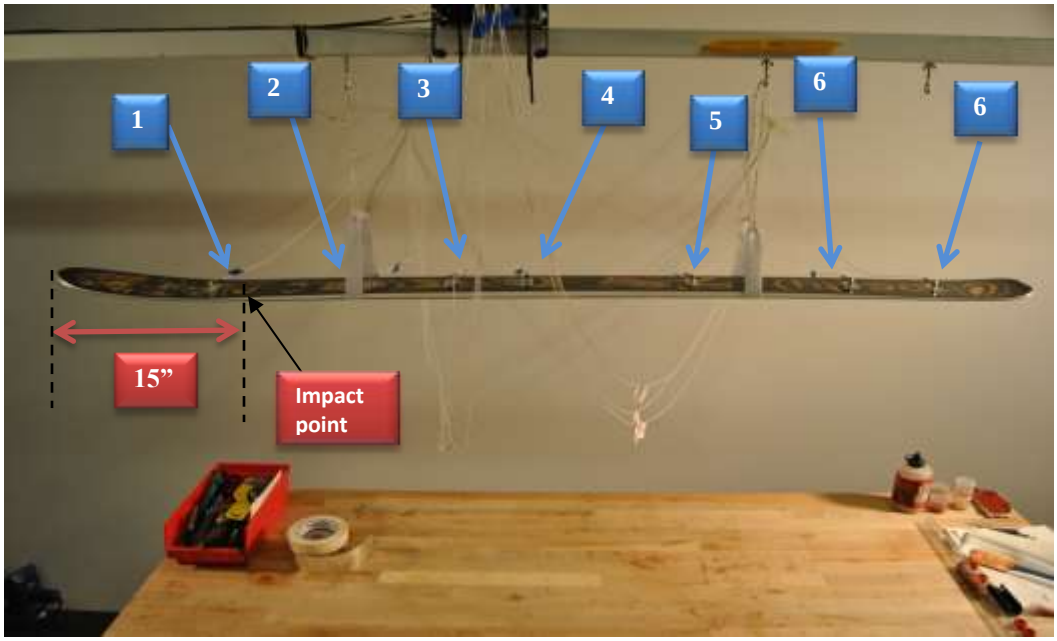
Executive Summary

With no natural available cavity to utilize, the Liberty Ski had sections routed out to create space to place VIBEX HP before testing. Results were favorable especially when we used a VIBEX PLUS (55 grams total) which produced about 40% reduction at the lowest and most important natural frequencies for the skis.

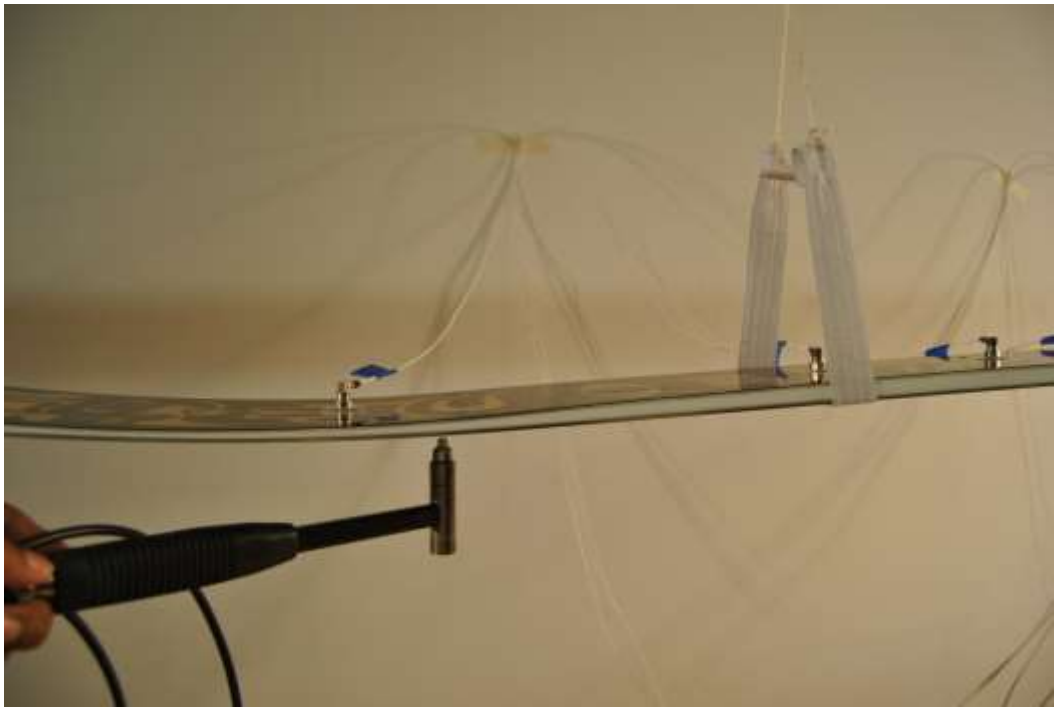
Summary

1. On the skis (as received) we observed four natural or resonant frequencies which occur approximately at 61.3Hz, 143.7Hz, 260.8Hz and 412.5Hz (See **Graph #1 on pg. 5**). There were some slight variations in natural frequency from ski to ski. The natural frequencies (sometime called resonant frequencies) always produce the greatest deflections in the equipment after impact or excitation.
2. VIBEX HP was trialed at several different locations when conducting optimization tests.
3. In our first tests we planned to place VIBEX at four locations that had been routed out of the skis. This was done by milling out a space in the designated location and filling it with dampening material. Only one cavity was routed per ski.
4. The cavities were a rectangular shape and centered at 285, 385, 500, and 685mm respectively from the tip of the ski. **See figure 1 on page 9**
5. Filling the first two cavities did not produce noticeable vibration reductions. We then omitted running the third cavity (at 500mm) as we deemed it too close to the second cavity and proceeded to run the fourth cavity. This also showed minimal improvements.
6. In the second round of tests we added addition mass to the VIBEX material which we refer to as VIBEX PLUS.
7. To obtain the most efficient dampening at all four natural frequencies we found that placing VIBEX HP or VIBEX PLUS at <u>two different locations</u> instead of one place produced the best result.
8. **Graph #1** shows a summary of the mode shapes of a ski (as received) at its natural frequencies. The mode shape shows the shape of the ski when it is excited (struck) with the impact hammer. This type of graph is useful in selecting locations on the ski where VIBEX HP should be placed. This would be where acceleration is greatest.
9. **Graph #2** shows a bar graph of acceleration vs. key resonant frequencies after VIBEX HP and/or VIBEX PLUS was added. The greater the accelerations indicate larger displacement (movement of the ski upon impact)
10. **Graph #3** shows further analysis of where the percentage reduction in vibration is shown for the original ski and the ones containing the VIBEX materials. In this case we look at the vibration measured specifically at the sensor #5. (View **picture #1** to see the location of **sensor #5**) This is where the operator's foot would be when skiing. We observe an average of drop of 10% when using VIBEHP but more notable drops at the first three major peaks of about **40%** when using VIBEX PLUS.
11. **Graph #4 and #5** show an overall view of all peaks at 0 - 500 Hz. In Graph #4 we see the result using VIBEX HP and in graph #5 the results using VIBEX PLUS are shown.

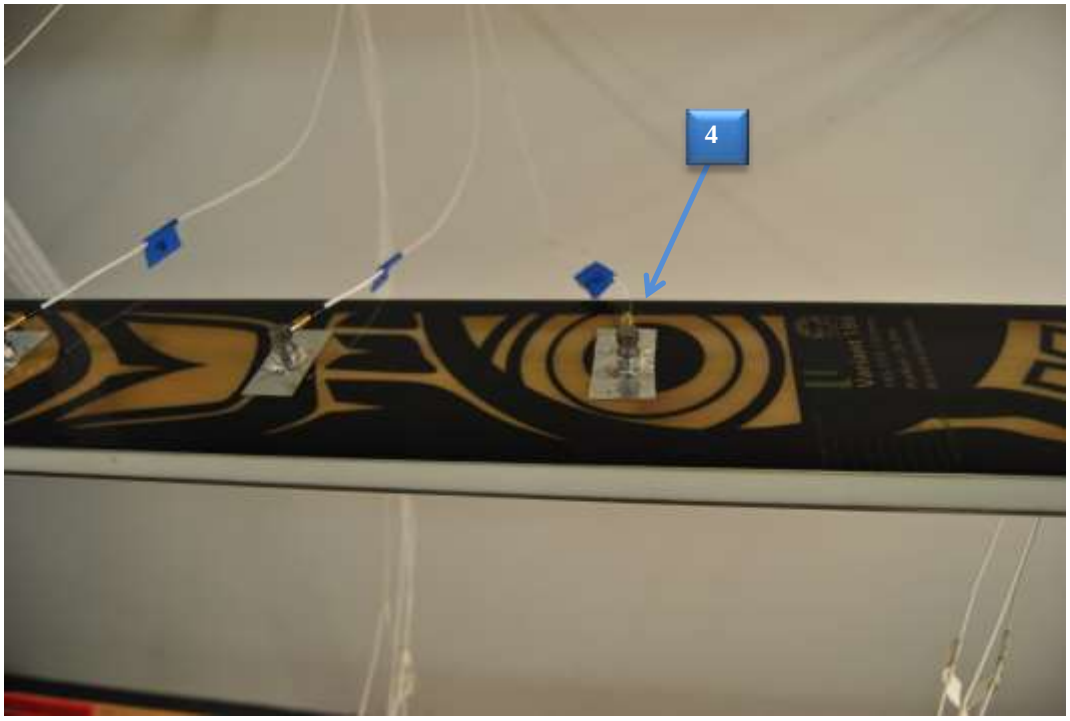
Picture 1: Sensor Locations with blank ski suspended on Bungee cords



Picture 2: Impact Test location

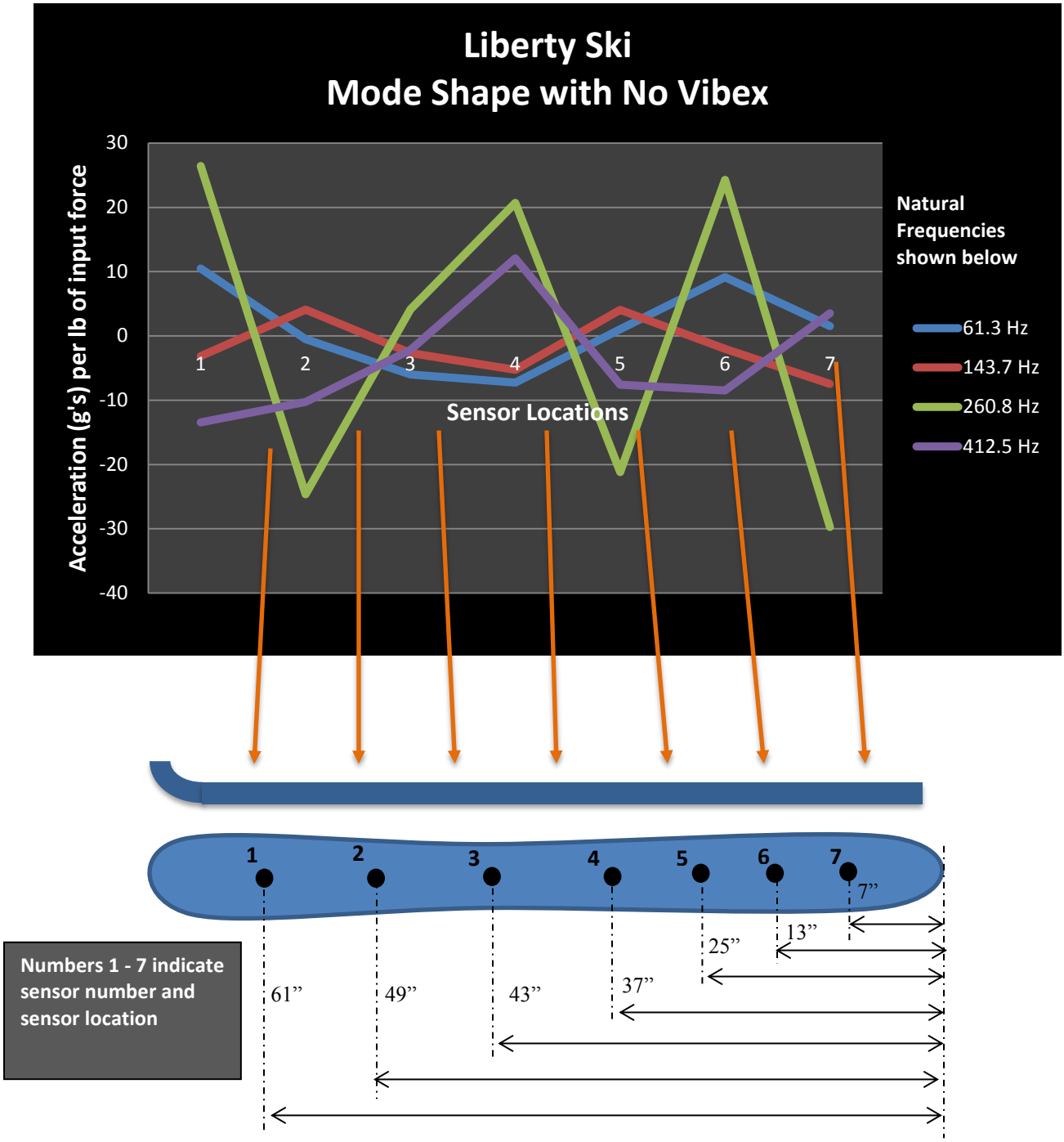


Picture 3: Close up of Sensor #4 (Data from this sensor was evaluated)

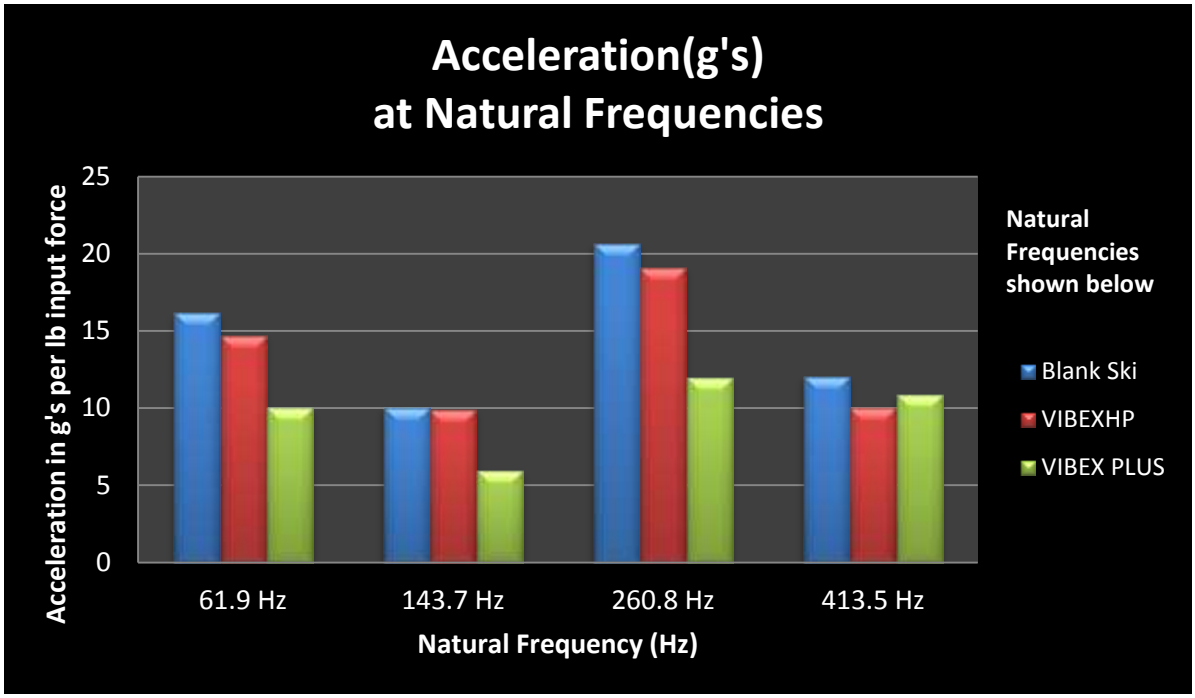


Picture 4: A cavity filled with VIBEX HP (Location #1 at 285mm)

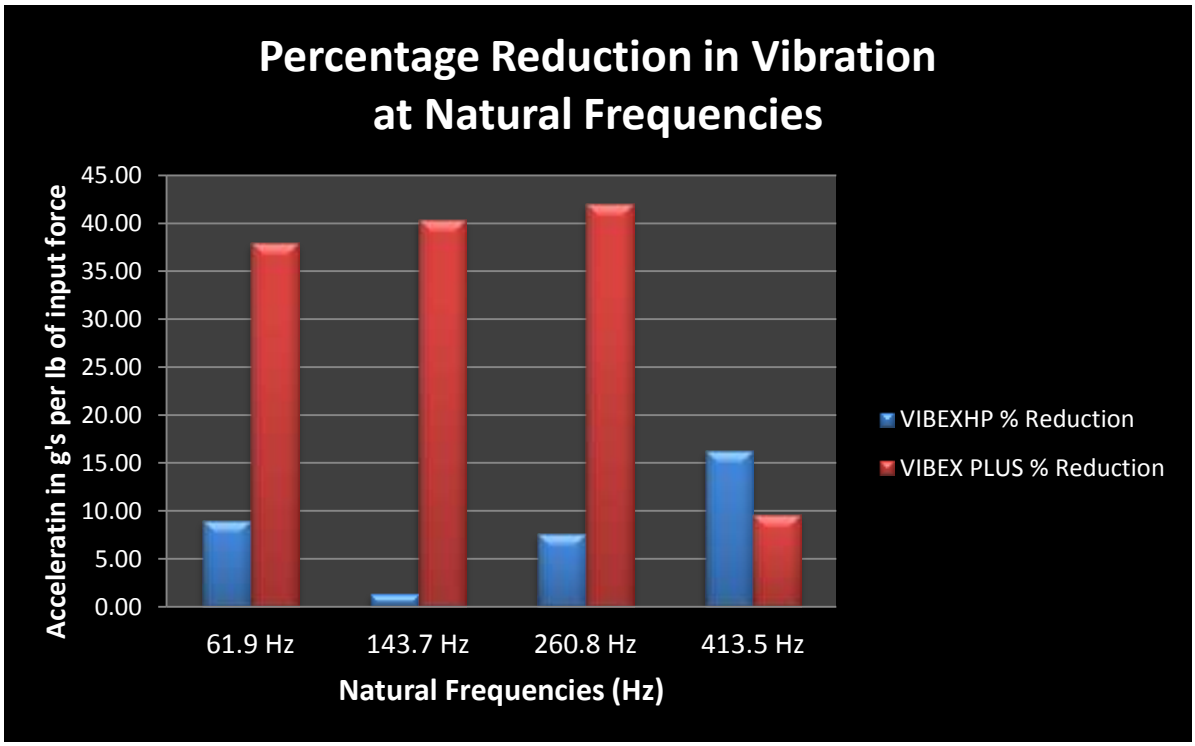
Graph 1: Mode Shape in Ski with no VIBEX HP



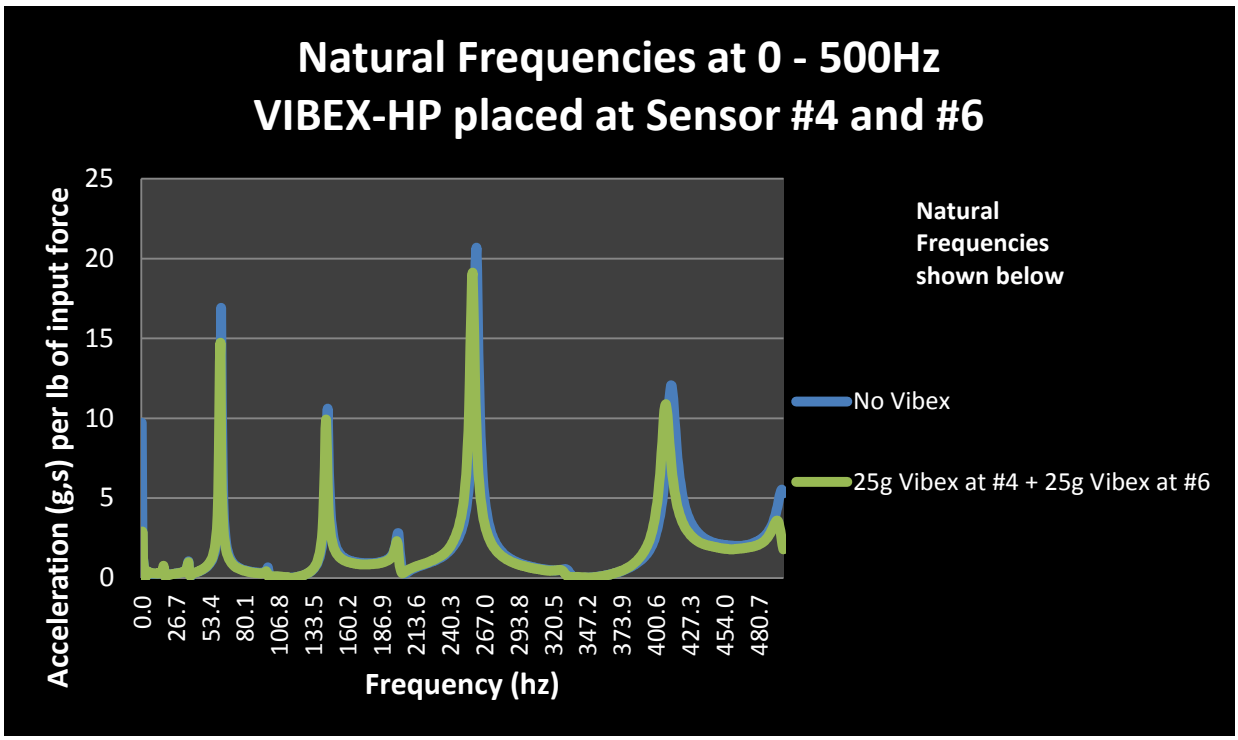
Graph 2: Sensor acceleration data at key natural frequencies (VIBEX at Sensor 4 and 6)



Graph 3: Percentage reduction in Vibration (VIBEX Placed at Sensor 4 and 6)



Graph 4: Natural Frequencies at 0 -500Hz using VIBEX HP



Graph 5: Natural Frequencies at 0 – 500Hz using VIBEX PLUS (Weighted VIBEX HP)

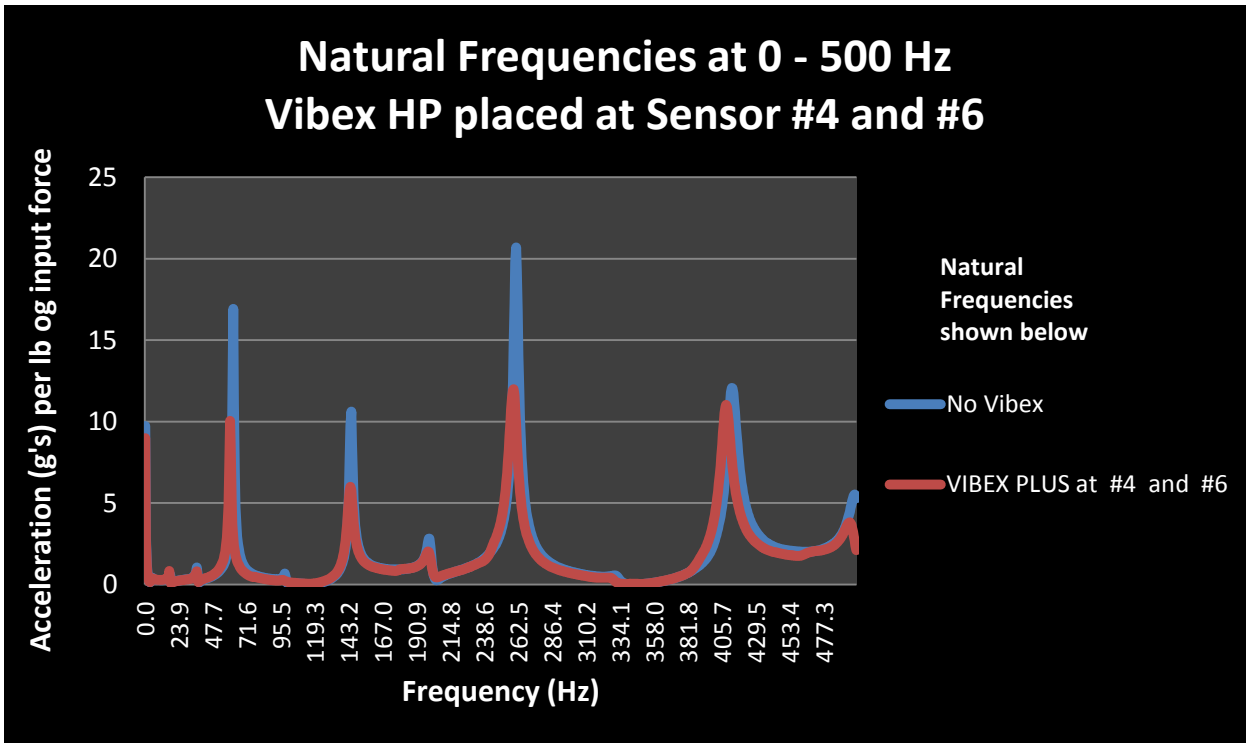
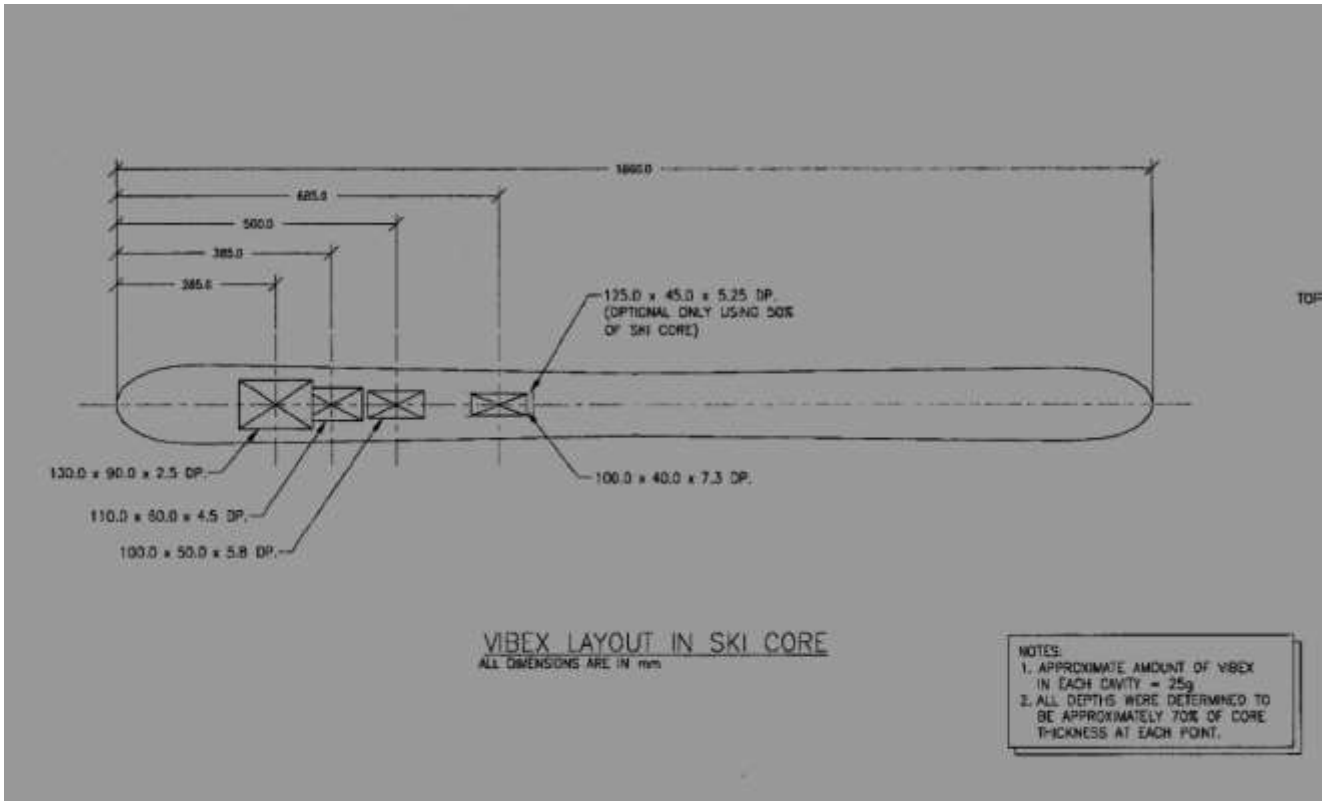


Figure 1: Locations routed out for VIBEX HP Placement



Our Recommendation:
For the most economical benefit place 25 - 30 grams VIBEX HP by sensor #4 and #6.
For an improved benefit, place an additional VIBEX PLUS by Sensor #4 and #6.

Things to Note

i. The values obtained from the sensors are in units of m/s/s or acceleration per pound of force that is measured by the sensors.
ii. 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.
iii. The tests were plotted for frequencies less than 500 Hz. Higher frequencies can be examined if desired. Frequencies below 10Hz are basically produced by movement of the ski up and down on the floor and not a direct consequence of ski vibration, therefore they are ignored.