1 INTRODUCTION

Automobile manufacturers produce vehicle body parts using large metal forming mechanical presses. Presses fitted with a forming die will stamp sheet metal blanks with up to 2000 to 3000 metric tons of downward force to form fenders and other body parts. Heavy stamping impacts generate significant structureborne vibration that disturbs the surrounding building frame and foundation. Noise and vibration disturbances from stamping operations can affect ancillary factory spaces and uses, including areas used by employees and product inspection labs, including coordinate measuring machines and scanning probes that require low-vibration environments for micron level accuracy. When a major U.S. automobile manufacturer built two new press lines, large elastomeric vibration isolation mounts were installed under new presses to investigate whether press vibration disturbances could be reduced significantly within the facility. For a comparative analysis, press disturbances were analyzed in the new facility with isolating mounts and equally in a similar facility that did not have isolating mounts.

New 2250-ton presses were installed on Vibro-Dynamics model MXLP Microlevel equipment vibration isolation mounts, pictured below, on top of reinforced concrete combined footings, or piers, inside the press pit. Equal presses at another plant were previously installed on rigid steel plates without vibration isolation on the press piers. The purpose of vibration and noise measurements in this study was to characterize at various locations the vibration and noise reduction provided by the isolated mountings.

![MXLP Model](image1)

Figure 1 – Press isolation mounts used. Manufacturer’s catalog images (left & center). Photo of installed isolator at facility (right).

This paper presents a comparison of analyzed results, with discussion on the potential effects of isolation mounts on press performance, maintenance, building vibration, building structural damage or soil settlement, and vibration and noise disturbances for nearby quality inspection instruments and employee stations.
2 CRITERIA

Generic floor vibration criteria (VC) shown in Figure 2 below are often used in building structural design and for comparisons of building performance and vibration perceptibility, which are in 1/3-octave bands and velocity terms.\(^1\) Vibration tolerance limits for Coordinate Measuring Machines (CMM) are approximately equal to VC-A or VC-B (25-50 \(\mu\)m/s velocity) highlighted red in Figure 2.\(^2\)

![Figure 2 – Generic floor vibration criteria (VC) curves](image)

Criteria for vibration-induced building damage, commonly used for evaluating construction impacts, indicate a maximum peak particle ground vibration velocity (PPV) of 100 mm/s for industrial buildings or for buildings of substantial construction.\(^3,4\) Peak particle velocity is the maximum 0-peak amplitude in the time domain along a given vector or direction. This study evaluates the vertical vector (z-axis). Additionally, much lower ground vibration limits of 2.0 mm/s to 2.5 mm/s could be considered as the threshold of possible significant settlements at vulnerable sites.\(^5,6\)

Airborne noise criteria are based on OSHA Standard 1910.95 Noise and Hearing Conservation regulations.\(^7\) The noise levels for personnel cannot equal or exceed 90 dBA for an 8-hour work period without engineering controls being implemented. In addition, and more relevant to the goals in this evaluation, the noise levels for personnel cannot equal or exceed 85 dBA for an 8-hour work period (82 dBA for a 12-hour work period) without an effective hearing conservation program being implemented, with personal protective equipment (ear plugs) made available.

3 TEST PROCEDURES AND MEASUREMENT LOCATIONS

3.1 Instrumentation

- Accelerometer Transducers: Wilcoxon Research Model WR 731A Seismic Acceleration Transducers (10 V/g), S/N 1230 and 2140, each sensitive to motion along one axis.
- Microphone: Larson Davis Model 2560, 1/2" random incidence (45.2 mV/Pa) ANSI Type I precision microphone, S/N 2104, with Larson Davis Model 900 preamp, S/N 1505171
- Microphone: Ivie Model 1134, 1/2" random incidence (6.5 mV/Pa) ANSI Type I precision microphone, S/N 1107B749, with Larson Davis Model 900 preamp, S/N 1418085

Setup

Stamping or pressing operations were repeated, using a load cell test stand in place of a metal forming die, in order to achieve relatively consistent vibration impacts or "hits" at various press tonnage settings. Following the first day of tests, the same load cell test stand was packed up and shipped to the second facility to maintain consistency between setups.
Each press was fitted with the same load cell test stand shown in the photo below and set to press at equal tonnage targets, listed in Table 1, below. Vibration measurements were conducted while each press made at least four consecutive hits at 18 stamps per minute, with nominal target press tonnages of 750, 1250, 1750 and 2000 metric tons-force.

![Press with load cell stand installed and almost ready for testing](image)

Table 1 – Vibration Testing Press Tonnage Values

<table>
<thead>
<tr>
<th>Nominal Tonnage Target</th>
<th>Non-Isolated Press (Tonnage Actual*)</th>
<th>Isolated Press (Tonnage Actual*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 tf</td>
<td>~ 784 tf</td>
<td>~ 766 tf</td>
</tr>
<tr>
<td>1250 tf</td>
<td>~ 1270 tf</td>
<td>~ 1272 tf</td>
</tr>
<tr>
<td>1750 tf</td>
<td>~ 1780 tf</td>
<td>~ 1786 tf</td>
</tr>
<tr>
<td>2000 tf</td>
<td>~ 2033 tf</td>
<td>~ 2029 tf</td>
</tr>
</tbody>
</table>

* Actual tonnage with each test was variable, typically +/- 5% to 15% of values listed.

### 3.2 Measurement Locations

Measurements were taken at equivalent locations underneath and around press lines at both facilities. Soil and subsoil differences between the two sites could potentially affect ground borne vibration propagation, and building and structural design differences between the facilities above the foundations could affect structure borne propagation through the buildings over distance. In an attempt to reduce the effects of soil and structural differences on our comparison of vibration surveys, we measured vibration at locations very close to the press: in the pit directly below the press center line and on two opposing corners of the press crown, within 3 to 5 meters of the press center within the press pit, as well as a few additional locations at pit level and ground level slabs on grade, up to 37 meters away from the press center.

![Press Line Floor Plan with Measurement Locations](image)

Measurement locations in the diagram above are red dots. The footprint of the tested press is highlighted green. Press piers, located in the pit below press floor, are shaded grey.
Measurements were taken at the following locations 1-9 at both facilities and location 10, only at the isolated press facility, all described in the table below and shown in Figure 4.

**Table 2 – Measurement Locations**

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vertical vibration at pit slab surface below press center.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Vertical vibration at top of press concrete pier (combined footing) at left side of press (operator’s side). View looking up at the pier from pit floor.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Vertical vibration at pit slab at the base of press pier, about 3 meters away from press centerline.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pit slab along press centerline, about 8 meters up production flow direction from press center.</td>
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</tr>
<tr>
<td>5</td>
<td>Ground floor slab along press centerline at press line in-feed door, 24 meters up production flow direction from press center.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ground floor slab along press centerline at materials staging area, about 37 meters up flow direction from press center.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Crown (top) of press near right side, down-flow corner opposite from the press operator station.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Crown (top) of press near left side, up-flow corner on the same side as the press operator station.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sound levels at press operator station, near ear level.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>(Isolated press facility only) Vertical and horizontal floor slab vibration at a 3D coordinate measurement (CMM) station, about 23 meters left of press line centerline.</td>
<td></td>
</tr>
</tbody>
</table>
4 MEASUREMENT RESULTS AND OBSERVATIONS

Typically, vibration in the vertical direction was significantly greater than in the horizontal vibration levels. Therefore, this study focuses on vertical vibration results. Vertical peak particle velocity (PPV) results on press piers were lower in the isolated press facility, at less than 3 mm/s, compared to the non-isolated press results around 4.7 and 5.6 mm/s. Results at both facilities were well below referenced 100 mm/s criterion for industrial building damage concerns\textsuperscript{3,4} but exceed 2 mm/s, which may be considered the threshold for possible dynamic soil settlements at vulnerable building sites.\textsuperscript{5,6} The isolated press bounced noticeably on its isolation mounts with the strongest press hits. As a result, the maximum PPV results on the press crown were somewhat higher in the isolated press facility, typically at 162-412 mm/s, compared to 160-363 mm/s on the non-isolated press.

One-third octave band measurement results for press slab, pier and crown vibration were compared with VC curves in rms velocity (microns per second) versus frequency charts, Figures 6 and 7. Ambient conditions indicated apparent building/slab 1/3-octave resonances at 12.5 Hz at the non-isolated facility, and 20 Hz at the isolated facility. In Figure 6, charts show the equivalent average levels (Leq) compared with statistical percentile (Ln) levels measured during stamping hits at both facilities, where the transient, short-term levels only occurring 1%, 5% or 10% of the measurement period are L1, L5, and L10 respectively for each test run duration, which typically was around 30 to 40 seconds. The L1, L5 and L10 results characterize vibration with actual stamping hits.
Figure 7 – Prominent slab vibration around 12.5 Hz in the isolated facility exceeds CMM tolerance at CMM inspection location 10 during normal press line operations, stamping side panels.

Figures 8 and 9 show the difference in vibration level in decibels at the two facilities, or apparent transmissibility or insertion loss performance of the isolation mounts. Note, apparent resonance at 12.5 Hz indicates vibration amplification (vibration increase compared to non-isolated press), while effective isolation (vibration reduction) is achieved at other frequencies above and below 12.5 Hz.

Figure 8 – Insertion loss or apparent transmissibility of press isolators measured at pit slab location 3 (left) and location 5 (right) with all 750-ton through 2000-ton press hits.

Figure 9 – Insertion loss or apparent transmissibility of press isolators measured at all floor slab locations 1-6 (left) and at press crown location 8 (right).
Connections that may bridge the intended press isolation of Vibro-Dynamics mounts were observed at the bottom portions of isolated press, shown in photos below. Catwalk welds connecting to the press structure appeared to transmit some press impact vibration directly or indirectly to the building structure. Also, conduit and oil line connections to the press and pier bridge across the isolators.

Figure 10 – Comparison of very similar sound levels measured in both facilities at press operator station location 9 with the strongest 2000-ton press hits, and with ambient conditions.

Figure 11 – Bridging Elements; (left) welded support at pit catwalk; (right) oil lines attached to pier.

5 COMMENTS AND CONCLUSIONS

Results indicate the press isolators are effective in reducing building vibration at frequencies other than 10-20 Hz. Vertical peak particle velocities were effectively reduced in the isolated facility, which may prove beneficial regarding long term potential for dynamic settlement in soils below the press foundation. However, at 10-20 Hz, with prominent vibration peaks at the apparent isolator resonance around 12.5 Hz, the isolated press often generated greater building vibration disturbance with stamping than the non-isolated press showed. Amplification at 12-13 Hz clearly indicates isolator resonance around 12-13 Hz. It is possible that isolator resonant amplification of press impacts could trigger building resonances observed in the 10-20 Hz range, which could actually increase the potential for settlement in sub-slab soils. Years of operation may reveal whether the isolated press and its foundation fare better or worse in comparison with non-isolated presses.

Although we measured better vibration isolation performance at frequencies above and below 12.5 Hz, the overall impact on sensitive imaging uses on the same production floor is not effectively reduced, since metrology scanning, 3D coordinate measurement systems and similar instruments
are likely to be sensitive to vibration at 10-20 Hz. Moving farther away from the press, for example at location 5, about 24 meters away from the press, the amplification effect around 10-20 Hz was not as apparent, illustrated in Figure 8, but again, very little press vibration isolation was achieved at those same frequencies. Various other vibration disturbances such as forklifts, carts, and overhead cranes also affect the CMM area. Thus, isolation using active or passive isolation bases or isolated slabs at the CMM location may be more practical and effective than press isolation for those instruments to achieve their environmental vibration tolerances.

Sound measurement results showed low frequency 16-Hz to 100-Hz press impact noise at the isolated press was several decibels quieter outside the press at the press operator station compared to the non-isolated press. However, mid and high frequency noise at the operator's station was not effectively reduced, even though vibration isolation was mostly effective from 200 Hz up to 10 kHz. Thus, the overall A-weighted sound level (dBA) difference would not be significant to employees' ears with respect to hearing protection and OSHA noise exposure limits. Similar to the vibration results, while relative spectral noise reductions between 16-100 Hz were -2 to -8 dB, very little relative noise reduction was achieved at the 12.5 Hz one-third octave band.

The bridging connections identified between the isolated press and building structure could transmit vibration, flanking the isolators. Bridging connections may or may not exacerbate the transmission of 12-13 Hz resonant amplification, but can undermine the intended isolation at frequencies above and below 12 Hz that do not match the isolators' resonance. In addition, isolated presses are allowed to bounce freely on isolation mounts, with apparent amplification measured on the crown as shown in Figure 9, and the resulting stresses on bridging oil lines could affect leaks and necessary repairs or recurring adjustments. Bridging concerns could easily be addressed by adding flexible connections to those lines (flexible hoses, braided steel tubing) or flexible mounts (springs mounts or double deflection neoprene mounts), which is likely to be done in the future.

Isolators with a lower resonant frequency, 8 Hz or less, would be less likely to excite dominant building resonances at 10-20 Hz, and could provide better overall isolation and performance for the presses. Isolation of bridging elements could also improve isolation. However, it seems very unlikely that effective airborne noise reduction for employee hearing protection on the press line would be possible with press base isolation at this particular facility. Also, any base isolator with undamped or partially damped resonance would still produce resonant amplification at its natural frequency. Depending on isolators' transmissibility performance, isolation mounting could still produce similar results and concerns regarding press bounce, foundation settlement, and CMM disturbance.

6 REFERENCES