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PUMP NOISE AND VIBRATION MITIGATION IN HIGH-RISE RESIDENTIAL CONDOMINIUM

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Relatively small vibration or noise sources can create acoustical problems. In a residential condominium tower of more than 40 stories, five in-line pumps, ranging from 1.5 to 2 horsepower, are installed; one on every eighth floor, to equalize domestic hot water pressure at different building elevations. They caused continuous audible sound in adjacent residential units and in corridors. The developer was concerned that noise might affect sales. The pumps are housed in small mechanical closets with doors opening into circulation corridor and sharing two demising partitions with residential units. Room Criteria (RC) for full-octave permissible noise criteria were used in building design phases. Pump-generated sound conforms to acoustical criteria within adjacent residential units. Although not excessively loud, the pump noise is tonal and perceptible. Initial observations by pump installers and the building mechanical engineering designers concluded that the pumps were operating properly, but failed to find a consensus regarding sound paths or correction. The building architect requested review by the building acoustical consultant. The consultant listened to airborne sound in the pump room and in the residential unit for subjective evaluation. In addition, wall and cabinet surfaces were felt and listened to for evidence that confirmed structure borne transmission. Mitigation measures developed by the consultant and implemented by the building's general construction contractor will be enumerated with subjectively determined results. Spectrum charts with criteria for post-correction noise and vibration results will be shown along with photos of the pump installations before and after retrofit modifications.

1. Introduction

Small, low power sources of vibration and noise can cause audibly perceptible noise in nearby spaces. This is a case study about pumps that were not thought to be large enough to create sound or vibration issues. Audible small pump noise became a concern at five locations in a new residential condominium tower of more than forty stories. Single 1.5 to 2 horsepower in-line domestic hot water pumps were located on each eighth floor, i.e. levels 8, 16, 24, etc., to boost and equalize water pressure throughout the building. Room Criteria (RC)[1] for full-octave permissible noise criteria were used in building design phases, and residences were thought to be in conformance, but tonality of the sound made it potentially annoying.[2] With no consensus between installers and design engineers regarding noise transmission paths or corrective measures, the architect requested an acoustical consultant to observe and evaluate pump noise. The consultant visited the site during normal business hours of a weekday with the construction manager, who explained the history of this particular issue. Each of the five installations on various floors was shown to the consultant. The initial visit was intended to assess the conditions relative to potential residential disturbance, but not to validate pump noise with respect to manufacturer published noise data. No sound or vibration measurements were conducted, although visual observations were made. To also subjectively assess airborne versus structure borne transmission contributions the consultant felt wall and cabinet surfaces in the receiver room with finger tips and positioned his ear against surfaces to listen for reradiated sound. Transmission paths and noise remediation measures are presented below.

2. Existing Conditions

Each of the five installations is a vertically configured inline recirculation pump for hot water, driven by 1.5-2 hp TEFC electric motors. The motors and pumps produce vibration, which is transmitted to the structural floor via the pump mounting and secondarily, via inlet and discharge pipe hangers. The pipes have braided metal spool connections to pump, which can provide stress and misalignment relief, but only provide minimal pipe borne vibration transmission loss. The TEFC motor fans produce airborne noise, which is radiated from the air inlet at end of motor and air discharge along motor cooling ribs. The pump case radiated pump impeller noise.

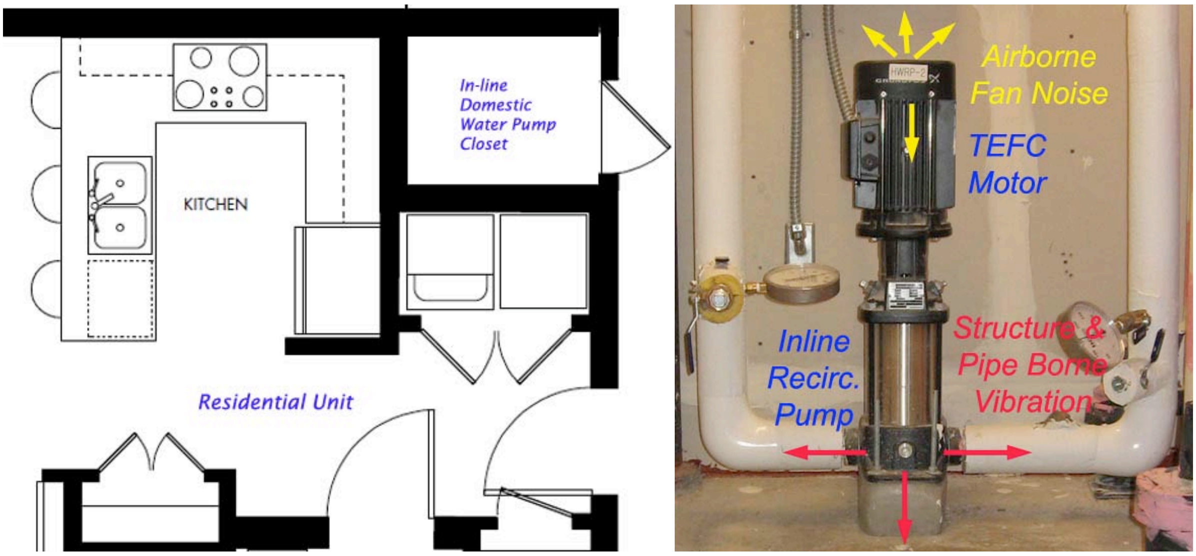


Figure 1. (a) Pump Closet Plan and (b) View of In-line Pump Installation.[3]

3. On-Site Evaluations

On-site observations and subjective evaluations were made to determine approach to pump noise mitigation. The construction manager agreed that corrective actions could be taken from consultant's recommendations without acoustical or vibration measurements to confirm observations.

3.1 Observations

On-site observations included listening to airborne sound in the pump room, in the adjacent traffic corridor and in the adjacent unfurnished and unoccupied residential unit to hear the difference in sound level with pump turned off and on. The sounds radiating from wall and cabinet surfaces around the kitchen area were listened to at close range to subjectively determine relative structure borne versus airborne sound transmission contributions. Vibrations on pump, pipes, pump room floor and walls, plus surfaces in the residential unit were subjectively judged by touch (tactile perceptions of vibration). No measurements were conducted during initial evaluation.

Observations within and around the pump room indicated generally good construction quality for containment of airborne noise. Pipe, conduit and other penetrations through the pump room walls and partition interfaces with structural floor and deck above are acoustically sealed with fire and other caulking. The pump room corridor door seals were marginally effective and there were no door threshold noise seals.

Figures 2 a, b. Pump Closet (a) door bottom, (b) door head & jamb seals.

Figures 3 a, b. Pump Closet (a) view through corridor door, (b) vibration transmission paths.

3.2 Judgements

Subjective judgments, based on observations were that the primary sound transmission path from: (a) pump room to traffic corridor is airborne via the door, due to inadequate head and jamb and threshold seals, and (b) pump room to adjacent residential unit transmission path is predominantly structure borne vibration, resulting in sound radiated from partition, and cabinetry surfaces.

It appeared that (a) motor noise needed to be attenuated within the pump room and (b) that the pump room doors needed better acoustical seals to contain sound. The pump-motor assembly and piping needed to be vibration isolated from the structure. Secondarily, reverberant build-up of sound could be reduced within the pump room.

Sensitivity of the residential unit was greater than the traffic corridor therefore, the structure borne transmission path should be first priority and airborne transmission to corridor secondary.

4. Recommendations

Following the site visit, the consultant referred to architectural and mechanical design plans and construction-phase pump submittal information to confirm (a) demising partition construction relative to sound transmission loss and (b) that manufacturers' noise data and operational parameters were consistent with field findings. Also, review of vibration isolation specifications for small pump installations indicated reliance on manufacturers instructions. This type of pump could be floor mounted or suspended in-line with piping. Recommendations were reported.[4]

4.1 Structure borne transmission to residential unit

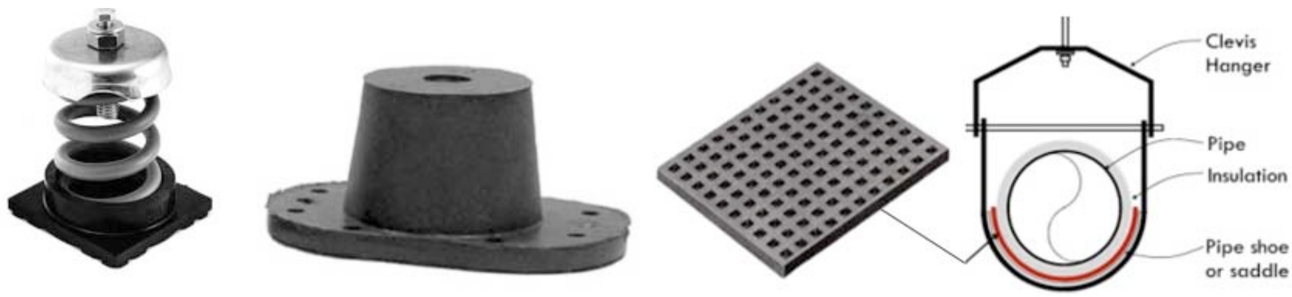
It was determined that the pump should be decoupled from the floor, but that vibration isolation at pipe supports would be sufficient to reduce transmission from pipes to structure without modifying pipe connections at pump inlet and discharge. Interruption of hot water service was highly undesirable. No recommendation was developed, therefore, to open up the piping for substitution of flexible spool pieces in lieu of the braided metal pipe connections, because that would require draining pipe risers and later bleeding of air from pipes.

4.1.1 Install vibration isolation for pump

Decouple the fan installation from floor by disconnecting the cement mortar base and replace with vibration isolation support. North American electrical line frequency is 60 Hz, so with friction loss, the motor operates just under 3600 rpm, resulting in disturbing frequency (f_d) $\simeq$ 59 Hz, i.e., rotations per minute (rpm) divided by 60 seconds gives cycles per second or Hertz (Hz). A vibration isolator with at least 4 mm (0.15 inch) static deflection should be used; such as double deflection machine mount to assure isolator natural frequency (f_n) is much lower than disturbing frequency (f_d).[5] Higher-deflection springs are acceptable, but not necessary. To avoid pipe elevation adjustment, provide adjustable-height mounting to maintain existing pump elevation above floor.

4.1.2 Install vibration isolation for connected pipes and conduit

Insert thin ribbed or waffled elastomer pads, static deflection 3 mm (0.10 inch), under pipes at hanger points to vibration isolate pipes without cutting or modifying hangers. Since pipes were small diameter and limited mass, the extra labor and expense of inserting vibration isolators into pipe hanger rods could be avoided without significant loss of effectiveness.



Figures 4 a, b, c. Pump (a) spring, (b) elastomer mount and (c) pad vibration isolator insert for pipe hanger.

4.1.3 Alternate: Install flexible pipe connections

Not recommended due to operational issues, as noted above.

4.2 Airborne transmissions to corridor and to residential unit

It was determined that the pump room demising partition was sufficient to contain airborne sound from the pump and motor so that transmitted sound to the adjacent residential unit should not be audible (relative to ambient). The tonal whine of pump noise was audible in the corridor and could potentially "cue" or subjectively alert residents to listen for that sound in their units. Therefore, improvement of pump room door containment became the primary airborne sound objective.

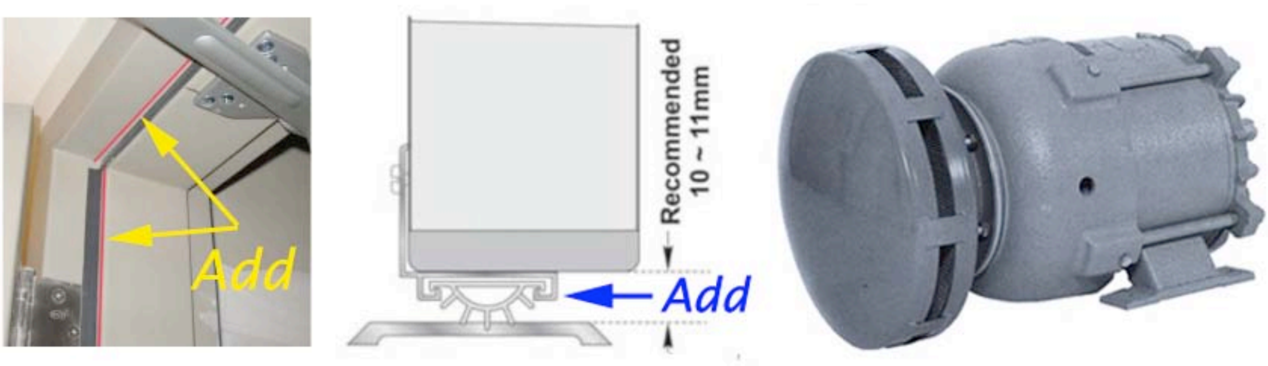
4.2.1 Install Pump Room door seals

Obtain acoustical seals equivalent to or better than the existing head and jamb seals, and install parallel to existing to create a double seal. Client was advised to assure that seals were labelled by manufacturer for acoustical service, as opposed to dust, smoke or infiltration service only.

Install a fixed compressible elastomer sweep seal on door bottom that can seal to existing metal threshold. Client was advised that an automatic bottom or drop-bar seal may be used, but for this application the fixed sweep seal is adequate, durable without needing adjustment maintenance.

4.2.2 Reduce motor fan noise

A TEFC motor inlet attenuator was recommended to reduce motor cooling fan noise. This is an acoustically lined cover for the air inlet opening and motor cooling ribs below the fan cowl. Motor "mutes" or attenuators are capable of providing 7-10 dBA reduction of cooling fan noise.



Figures 5 a, b, c. (a) Door jamb seals, (b) threshold seal and (c) TEFC motor inlet attenuator illustrations.

4.2.3 Reduce reverberant build-up in Pump Room

A secondary recommendation was made to install acoustically absorptive surface finish, such as glass fiber insulation on two wall surfaces. The small room volume can only cause a minor reverberant build-up, but absorption in the room could reduce higher frequency sound 3-5 dBA.[6]

5. Implementation

5.1 Remedial Installations

The construction manager, in coordination with condominium management considered the recommendations with regard to cost, ease of installation and ability to install with minimal or no interruption in domestic hot water service.

- Adjustable stop acoustical gaskets were applied to pump closet door head and jambs.
- The cement mortar pump base was removed and replaced with compressed fibreglass cube (in-shear) isolators in a structural rail base to reduce pump vibration into the floor structure.
- The isolator and base was selected and adjusted to the same height as original base, so that pump and piping would not require disconnection or elevation change.
- 6 mm (1/4") elastomer-in-shear pads were inserted into pipe clevis hangers with metal saddles (to distribute loading) to reduce transmission of pump vibration via pipes into structure above.
- Semi-rigid fibreglass insulation board was installed on the rear wall of the pump closet to reduce reverberant build-up of sound in the closet.

5.2 Not Installed

With the steps above completed, the construction manager and condominium manager determined subjectively that corridor and residential unit noise was reduced enough to meet perceived occupant expectations. The pump motor inlet attenuator, therefore, was not installed.

Figure 6. As-installed modification illustrations: Pump closet view with acoustical absorption (left), pump and pipe vibration isolators (center) and door head, jamb and threshold seals (right).

6. Post-Installation Results

The consultant returned to the site after completion of remedial vibration and noise control installations. Residential units adjacent to pump rooms have been sold and occupied. Observations and measurements could not be conducted within a residential unit, but vibration measurements were conducted on the pump room wall and sound measurements were made in the pump room for evaluation of post-installation spectra and levels of vibration and sound.

6.1 Observations (subjective)

With the pump room door closed, pump noise was only barely audible in the corridor, and unlikely to be distinguished by a casual listener passing by as coming from that particular location or due to a pump. The building management indicated to the consultant that, to their knowledge, pump noise was not audible in residential units and has not been a cause of complaint.

As indicated above, all recommendations were implemented with the exception of the motor inlet attenuator. While neoprene-in-shear double deflection machine mounts were recommended for the pump, compressed fibreglass isolators of similar static deflection capacity were substituted. By touch, very little pump vibration was transmitting to structural floor. Vibration pads consistent with recommendations had been inserted into pump hangers, and seemed (by touch) to be effective. Better door seals than recommended had been applied with great effect. Adjustable gasket seals, which can be conformed to the door surface, had been applied in lieu of a second set of parallel fixed elastomer gaskets. The fixed sweep seal recommended was applied to door bottom. Insulation was installed on the rear wall surface behind the pump to provide acoustical absorption. All remedial installations appeared to be of good quality and workmanship. Sound levels seemed moderated and feelable vibration on the wall surface seemed to be much less than the consultant's memory of the initial evaluation visit.

6.2 Measurements (objective)

Vibration measurements were conducted on the surface if the pump room-to-residence demising partition within the pump room. Since validation measurements could not be obtained in the occupied residence, measurement spectra on the pump room side would give a clear indication of prominent peaks and approximate levels that transmit through the wall to the residence. Using a nomograph[7] to estimate radiated sound levels based on surface acceleration, it is possible to evaluate significance of the wall vibration as a contribution to audible ambient sound hear the wall.

Sound spectra were measured within the pump room. Narrow-band spectra were compared to wall surface acceleration to confirm correlations between building vibration in the wall (including from the in-line recirculation pump) and sound in the pump room. In addition, the estimated full-octave radiated sound, based on surface acceleration was compared to measured airborne sound. Common prominent octave peaks occur in 63 Hz and 1000 Hz bands, confirming correlations seen in narrow-band vibration and sound measurement.

Review of the relative differences in spectrum shapes within the pump room between actual measured airborne sound and estimated radiated sound contribution from acceleration measurement shows that in the 1000 Hz octave, the radiated sound peak due to vibration is much quieter than airborne sound. Of course the ambient sound level within the adjacent residence is typically quieter than the pump room, but assuming the surface radiation on the residential side of the wall is reduced several dB due to damping and transmission loss (re: flexing of partition framing channels), radiated sound in the residence would not be expected to exceed ambient or be noticeably audible.

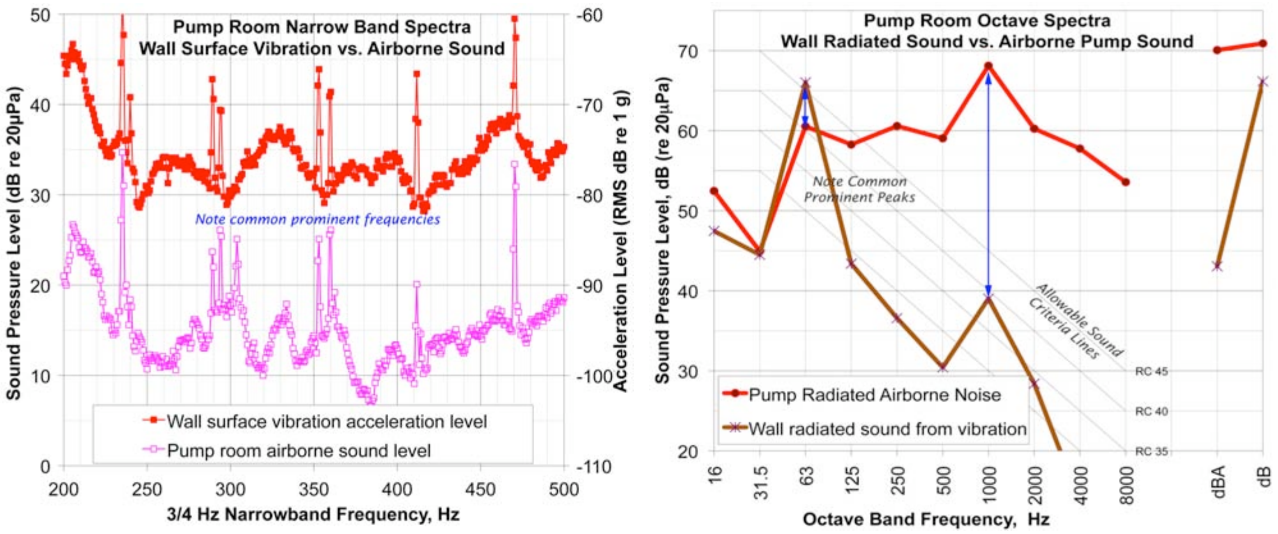


Figure 7. Vibration and sound measurements within pump closet.

7. Conclusion / Summary

Very small mass or low power mechanical elements within a building can generate enough vibration energy that when transmitted to lightweight wall or ceiling surfaces, resultant surface vibration can cause audible sound.

The building designers for a proposed building of more than forty stories were dealing with many significant central plant, elevator, HVAC and other systems. By comparison, 1-2 Hp in-line recirculation pumps did not seem significant, so they were simply specified to be installed according to manufacturer's instructions, with little thought to vibration isolation due to their small size. Unfortunately, due to the immediate adjacency between the pump rooms and residences, wall surface vibration due to transmitted pump vibration did cause audible sound and potential annoyance.

Application of normal "good practice" vibration isolation measures reduced vibration transmission and resultant radiated noise in the residence. The remediation was successful.

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