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VIBRATION CONTROL FOR A 25 MW STEAM-TURBINE GENERATOR INSTALLATION NEAR ACADEMIC TEACHING AND RESEARCH LABORATORIES

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Abstract

The electrical power generation plant on the campus of a large public university has several gas and steam turbine generators. Academic teaching and laboratory buildings, some of which have sensitive laboratory spaces that have experienced vibration disturbances in the past, surround the plant. A 25 MW turbine-generator installation was planned that would increase generation capacity and permit retirement of an older unit, but possibly also increase vibration disturbance. Reduction of vibration disturbance to surrounding science and engineering laboratory spaces was required. This paper discusses the vibration environment around the plant and in nearby buildings, based on pre-construction ground borne and floor vibration measurements. The new turbine-generator equipment is described in terms of electrical power and physical size. Design criteria and vibration isolation control strategies recommended by the acoustical consultant are presented with enumeration and discussion of recommended and implemented recommendations. Post-construction performance validation measurement results are presented for the successful installation.

INTRODUCTION

A very large public university campus in the United States has an electrical power generation plant with gas and steam turbine-generators ranging in size from 6 MW to

36 MW. All of the generators operate at either 1800 or 3600 rpm, (60 Hz power is standard in North America), but the turbine speeds vary from 3600 rpm (directly coupled) up to 5400 rpm (stepped down through gear reducers). Narrow band or discrete frequency disturbing vibrations at shaft rotation rates are transmitted to the power plant foundation, and via the ground to surrounding facilities. Narrow band vibration measurements, conducted on campus and within buildings in the general vicinity of the power plant, display peak amplitudes at the frequencies of turbine and generator shaft rotation rates.

Over time, complaints have been made about low-level vibration that interfered with vibration sensitive research equipment and instrumentation. Audible "hums" radiated from wall and ceiling surfaces resulting from structure borne vibration. Any proposed building renovations and new building construction near the plant had to consider vibration affects on foundation, structure and room designs.

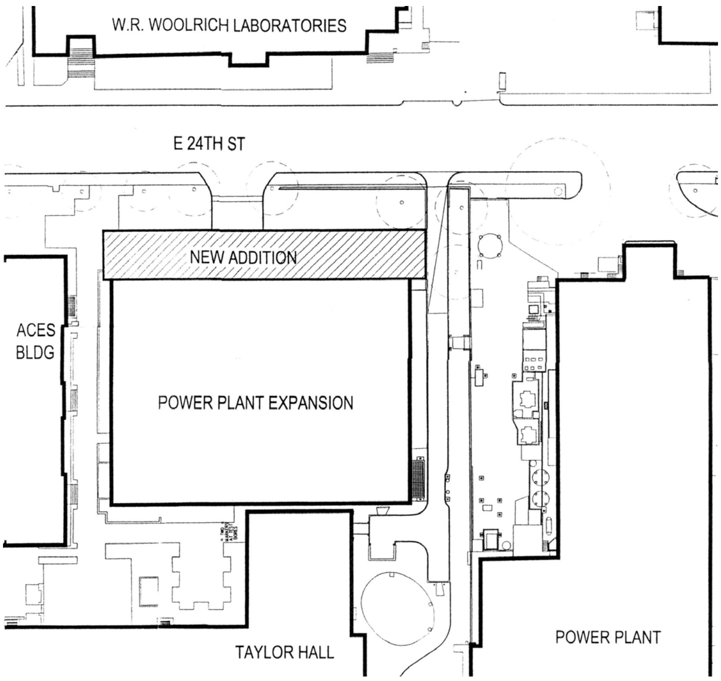


Figure 1 – Site Plan: Power Plant and Adjacent Buildings

A power plant expansion with a new 25 MW steam turbine-generator was proposed to increase capacity and permit retirement of older equipment. Because of the previous vibration issues surrounding the power plant, design parameters for the architects and engineers included vibration control for the new generator, to prevent vibration increases in nearby buildings, and as older generators retire in the future, ground borne vibration around the plant may decrease.

The recommended vibration isolation designs which were successfully implemented in design and construction with small, but notable exceptions are discussed below with presentations of pre-design and post construction vibration measurement results to illustrate net changes in ground and structure borne vibration.

VIBRATION CONTROL ISSUES FOR DESIGN

The existing power plant has three adjacent buildings on the university campus with several steam and gas turbine-generators of different ages and sizes operating within. Over time, various complaints had been received in the Power Department from occupants of nearby buildings about structure borne vibration causing audible "hums", or vibration sensitive equipment and research apparata being disturbed by vibration. If any of the sources of vibration disturbances were power generators, the vibration would have to travel through the ground and through utility tunnels that connect the buildings' foundations. On-site measurement studies have shown direct correlation, based on vibration spectra at the receiver locations that contained narrowband "tonal" vibration peaks at turbine and generator operating speeds[1]. Some procedures were implemented to mitigate vibration at the power plant, but academic departments also had to provide vibration control for sensitive equipment, while the facility design and construction department had to consider ground borne vibration affects on building foundation and structure design. Vibration control design for a new building to be constructed adjacent to the power plant was discussed in another case study presented at Euronoise 2003.[2]

Identification of vibration sources is relatively easy, based on comparison of the frequencies of discrete peak amplitudes versus machine operating speeds at the source, at the receiver location or along the path(s) between them. Machines with rotating shafts produce unbalanced force vibration, and are dominant at the shaft speed in rotations per minute (rpm) or cycles per second (cps or Hertz).

$$\text{rpm} / 60 \text{ sec} = \text{cps (Hz)} \tag{1}$$

Existing power plant vibration disturbance spectra were known. It would be possible to project disturbance frequencies of the proposed generator installation, based on turbine and generator speeds, as shown in the table below:

Turbine-Generator ID No.	**Turbine Type**	**Capacity (size)**	**Turbine Speed (rpm)**	**Disturbing Tur. Freq (Fdtur)**	**Generator Speed (rpm)**	**Disturbing Gen. Freq (Fdgen)**
#4 (Exstg)	Steam	6 MW	3600	60 Hz	3600	60 Hz
#5 (Exstg)	Steam	6 MW	3600	60 Hz	3600	60 Hz
#6 (Exstg)	Gas	13 MW	4862	81 Hz	3600	60 Hz
#7 (Exstg)	Steam	25 MW	3600	60 Hz	3600	60 Hz
#8 (Exstg)	Gas	36 MW	5400	90 Hz	3600	60 Hz
New #9	*Steam*	*25 MW*	*5011*	*84 Hz*	*1800*	*30 Hz*

Table 1 – Existing (#'s 4—8) and Proposed (New # 9) Turbine-Generator Vibration Sources[3]
(Note: The standard electrical power frequency is 60 Hz (3600 rpm) in North America.)

Not only can sources be identified by spectrum characteristics, but also structural de-tuning can be implemented at the receiver, based on known disturbance frequencies. De-tuning is the procedure of building or modifying the structure to have a resonant frequency that is dissimilar or non-coincident with the disturbing frequency. For example, if disturbing frequencies exist at 30 Hz and 40 Hz (with harmonics at 60, 90 Hz and at 80, 120 Hz, etc.), floor structures can be designed to have resonant frequency at 8 or 11 Hz (with harmonics at 16, 32, 64 Hz and at 22, 44, 88 Hz, etc.). Building systems equipment, such as fans, pumps and compressors, can also be sized and selected to operate at speeds that are different from ground borne sources, so that the peak disturbing frequencies of internal sources will not add to the external sources at their peak amplitude levels.

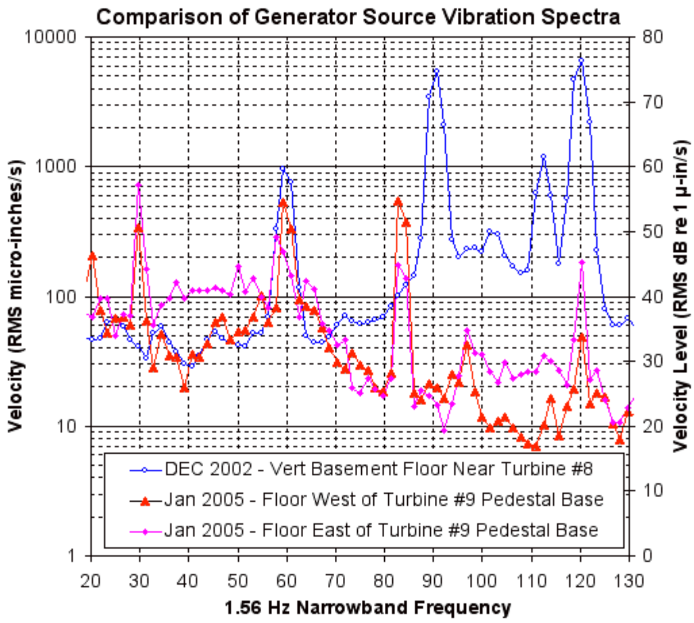


Chart 1 –Peak Frequencies at Shaft Speeds[4 5]

The amplitude of future vibration from the new turbine-generator could also be estimated, based on known vibration propagation through the soil from existing turbines and generators, i.e., differences between source and receiving levels at existing disturbance frequencies, when also taking account of unbalanced force magnitudes of existing and proposed future turbine-generators. The future vibration amplitudes at sensitive receiver buildings were not projected, however, because existing vibration levels were already considered somewhat excessive (the effort would only be an academic exercise to confirm what was already known). .

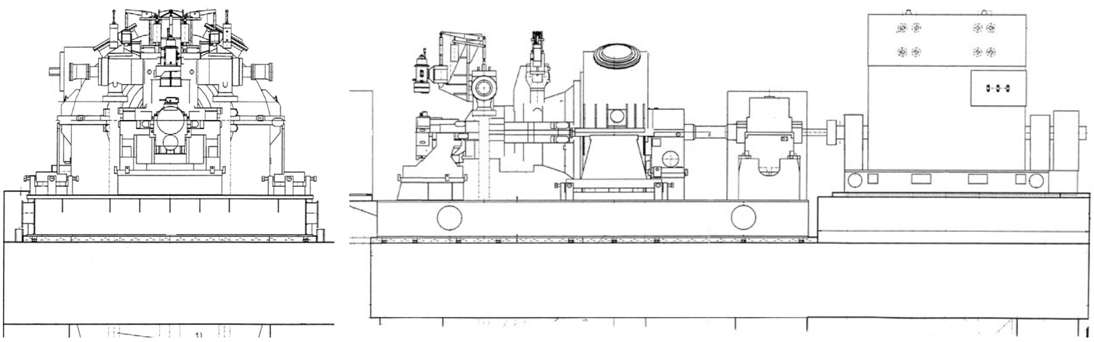
The campus facilities and power plant departments agreed that any new turbine-generator installation should not increase existing ground borne vibration amplitudes, and should permit reduction in ground borne vibration in the future, when older turbine-generators would be retired. The architects and engineers designing the power plant expansion building and turbine-generator installation were charged with incorporating vibration control in the design. This author was retained as a consultant to the structural engineers for that purpose. The design process would include:

- Review previous vibration measurement surveys in the area and types of sensitive occupancies to establish vibration criteria. Known disturbances existed at 60, 81 and 90 Hz (Table 1 and Chart 1, above).

- Conduct a new “baseline” vibration measurement of existing conditions in the power plant and on immediately adjacent building basement floors to confirm or update previous studies (re: Table 1 and Chart 1).
- Review the operating characteristics and technical specifications for the proposed turbine-generator equipment, which had been pre-purchased to assure delivery and construction schedules matched. It is a 4-pole type 1800 rpm generator: 30 Hz, driven by a 5011 rpm steam turbine: 84 Hz.
- Review proposed structural concept for turbine-generator foundation and architectural and engineering schemes for power plant building expansion.
- Develop a vibration control strategy for the turbine-generator that could be implemented in structural design, and be compatible with the building.
- Recommend vibration control methods and materials, to be incorporated in structural, architectural and engineering drawings and specifications.

VIBRATION CONTROL CONCEPTS AND IMPLEMENTATION

The turbine and generator, which operate at different speeds, are coupled with a gear reducer. The 5011 rpm (84 Hz) turbine drives the 4-pole, 1800 rpm generator (to create 60 Hz power). The equipment is nearly 17 m (51’) long and 5 m (15’) wide. The structural design concept employed a large turbine-generator pedestal base composed of six large concrete foundation columns supporting a massive concrete slab, greater than 1.5 m (5’) deep, 6.5 m (21’) wide and 17 m (51’) long. A large condensate vessel is located between pedestals in the space below the turbine base.



Figures 2 & 3 – Turbine-Generator: End and Side Views
(Courtesy Siemens AG Power Generation PG)

No physical connections between the turbine-generator and the building were anticipated, except for power and control cable conduits and steam pipes. The pedestal-base mounting arrangement is typical for this kind of installation. It permits convenient insertion of spring isolators on the columns to support the equipment base. Although this vibration isolation configuration has been successful in many applications around the world, especially Europe, it is not common in North America.

JEAcoustics recommended vibration isolation springs for the turbine-generator base. Several aspects of the design needed to be specified, either by the designer, or proposed by the isolation vendor for approval by the design engineer. Fundamentals of isolator selection are thoroughly discussed in numerous texts, so they will not be repeated here. Recommendations included:

- Spring isolators, sized for 1" static deflection, were selected based on disturbing frequencies equal to 30 Hz or higher, and nearby building structural resonances typically in 6 Hz to 10 Hz range, except for a very small number of special, stiff structures for vibration sensitive research installations in the 12-14 Hz range.

- Incorporate rubber or neoprene elements with small static deflection in spring isolator assemblies to isolate higher frequency "noise" vibration.

- Vibration damping was recommended for either slow start or stop, which would cause the equipment shafts to go from 0 rpm to operating speed or vice versa, inevitably passing through the isolator spring resonances (and harmonics). In the event of a catastrophic halt, there would be a torque shock. Viscous dampers were recommended to prevent excessive spring resonance displacement or fast stop torque.

- Flexible connections and/or vibration isolated supports for all connected pipes and conduits were recommended to prevent or reduce vibration flanking or bypassing the primary base isolators via connections. If large displacements or torques occurred, the flexible connections or resilient supports would also protect the steam pipes and conduits from damage.

- Determine acceptable construction phase load transfer method(s). During construction, the base needs rigid, non-deflecting support. When the concrete reaches high early strength, the load needs to be shifted from temporary supports onto spring assemblies. Isolator manufacturers were permitted to propose load transfer method and either hydraulic or bolt leveling for the springs. Compressive and shear strengths of hydraulic jacks or leveling bolts need to be confirmed prior to installation, based on total weight of installation, plus potential dynamic loads.



Figures 4, 5 & 6 – Pedestal Base (left), Gear Reducer (center) and Turbine Generator (right)

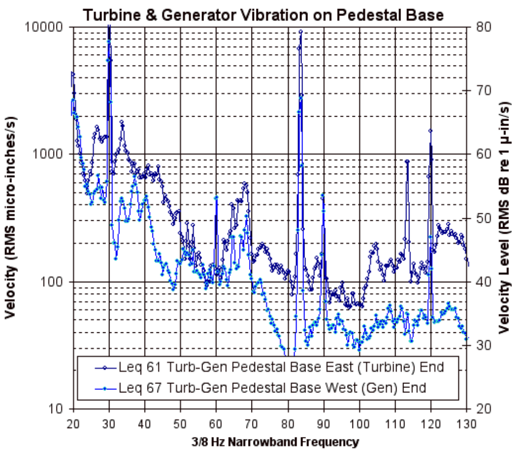
The structural engineer conducted load and dynamic analyses of the base to confirm anticipated structural loads and reactions at the column-base connections. Vibration isolator recommendations were accepted and implemented. Column heads were designed for spring assemblies, based on two manufacturers' spring assemblies.

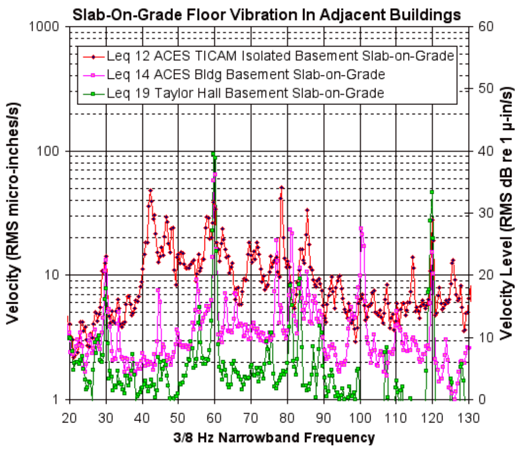
Architectural and other engineering disciplines partially implemented the design recommendation to integrate flexible connections or vibration isolation for pipes and conduits that attach to turbine or generator. When the building and generator installation drawings and specifications were completed and approved by the owner, they were released for bidding, as a public-sector construction project.

POST-CONSTRUCTION PERFORMANCE VALIDATION

As consultants to the structural engineers, JEAcoustics reviewed vibration isolation vendor submittals to assure conformance with design intent as expressed in construction drawings and specifications. We did not review final architectural and other engineering drawings or contractor submittals, nor did we conduct on-site observations of construction progress, because that was left up to the field engineer.

The neoprene and spring vibration isolator assemblies were correctly installed. After installation of the turbine-generator equipment on the concrete base, the load was transferred from temporary supports to spring isolators and leveled with bolts. There is some vibration flanking via conduits that are attached to the pedestal columns below the springs and to equipment on the base above the springs. The steam piping was not permitted to have flexible connections for fear of potential "blow-out" failure. Because of very limited clearances, there may be some steam pipe supports that are not vibration isolated, which can transmit vibration from the turbine to other building structural elements, and ultimately into the plant foundation.





Charts 2 & 3 – Validation Measurements – Note that 30 Hz and 84 Hz Tones are Controlled[6]

In spite of some flanking, the vibration isolators significantly reduce the amount of unbalanced force from the turbine and generator shafts to the foundation. Post-construction performance validation vibration isolation measurements were made in the first week of January, a period between academic semesters, when there is minimal activity on the campus, and therefore, fewer vibration sources to mask the vibration from the power plant generators. Vibration measurements in the power plant and on basement floors of immediately adjacent buildings show lower amplitudes at the new 30 Hz and 84 Hz disturbing frequencies, than the existing 60, 81 and 90 Hz disturbing frequencies from non-isolated existing turbine generators.

Figures 7, 8 & 9 – Spring Isolators, Viscous Damper (center) and Conduit Flanking Isolators

SUMMARY

The new 25 MW turbine-generator installation is complete and considered successful. No vibration complaints have been received from adjacent building occupants. Measurements show that vibration at the disturbing frequencies of the new installation have substantially lower amplitudes than the peak frequencies of power plant equipment that existed prior to this project.

REFERENCES

[1] J.B. Evans, "Ground & Structure Borne Vibration Impact Analysis and Design Guidelines – Applied Computational Engineering Sciences Building", JEAcoustics, Austin, TX, Rpt. No. 814-01, (1998).

[2] J.B. Evans & C.N. Himmel, Vibration Mitigation Design for an Academic Building Adjacent to a Turbine-Generator Power Plant. In *Proceedings of EuroNoise 2003 - the 5th European Conference on Noise Control, Naples* (pdf 282-1). European Acoustics Association and Acoustical Society of Italy (2003).

[3] J.B. Evans, "Baseline Measurements Ground Borne and Floor Vibration Measurement Analysis – Weaver Power Plant", JEAcoustics, Austin, TX, Rpt. No. 2218-01 (2002).

[4] *Ibid.*

[5] J.B. Evans, "Post-Construction Vibration Validation Measurement Analysis – Weaver Power Plant 25 MW Expansion", JEAcoustics, Austin, TX, Rpt. No. 2218-03 (2005).

[6] *Ibid.*