VIBRATION ANALYSIS FOR GAS TURBINE GENERATOR FOUNDATIONS

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This paper is documents vibration analysis study for Gas Turbine Generator Foundations. The continuous vibration that occurs might have cause the fatigue problem on the connections as well as human vibration discomfort and machinery components failure will lead damage no proportion to the cost. The main objective when designing a foundation for vibration-sensitive equipment is to limit the response amplitudes of the foundation to the specified tolerance in all vibration modes. The amplitude of the vibration should be controlled below the permissible limits set by the vendor. The procedure to evaluate this vibration study is by using SACS VIBRATION module. Stiffness of the vibration equipment accurately modelled to obtain the better results of the natural period and excitation of the vibrating equipment. The natural frequencies of the supporting structure shall be located away from equipment operating frequency to avoid any resonance. The velocity amplitude (peak to peak) also being checked to meet the vendor requirements. For the comfort level check the deflection of the support equipment with its associated structure need to ensure within the allowable limit.

Keywords: Vibration, Natural Period, Amplitude, Frequencies, Gas Turbine Generator.

1 Introduction

Gas Turbine Generator (GTG) is power generator for production of TEG platform. GTG is rotating masses machinery requires a support system that can resist dynamic forces and the resulting vibrations. When excessive, such vibrations may be detrimental to the machinery, its support system, and any operating personnel subjected to them. Hence, the vibration analysis is one of the important analysis on the offshore platform design.

Stiffness of this vibration equipment needs to model as much as accurate to obtain the better results of the natural period and excitation of the vibrating equipment. The dynamic analysis also needs to be performed to obtain correctness of the natural period. The final natural period considered in the analysis needs to be checked based on the mode shape performed with sufficient contribution of the mass participation factor. The natural frequencies of the supporting structure shall be away from range of the equipment's operating natural frequency to avoid any resonance.

The supporting structural can be built as stiff as possible to avoid the vibration. However, this will lead into time consuming and excessive cost to the project. The connections between this vibrating equipment and the topside structure will still have some effect on the package response that could make the robust design ineffective. Therefore, the vibration analysis sensitive study needs to be performed.

This vibration analysis has been successfully implemented on the actual project. Where three (3) nos. of Gas Turbine Generator with gross weight of 200MT has been evaluated located side by side. The support system on this equipment also being optimized to ensure enough

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stiffness to avoid any possible resonation that might occurs. In addition, velocity amplitude also being checked to meet the vendor requirements.

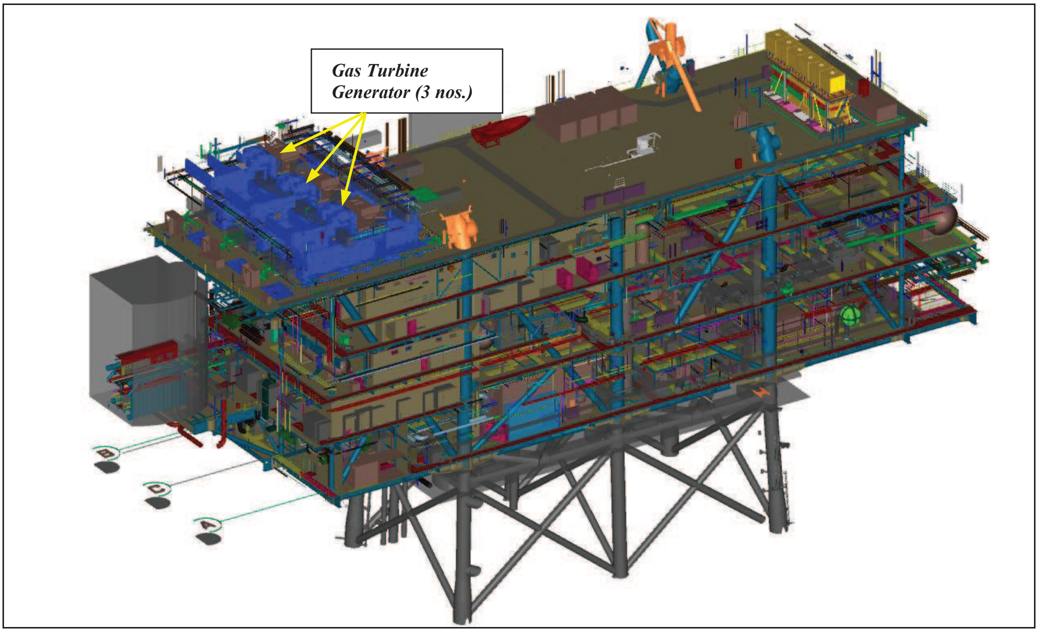

Figure 1. Gas Turbine Generator at TEG platform.

2 Overview of Gas Turbine Generator and Support Foundation

Gas Turbine Generator located at the top-level west of the platform at cantilever side. During installation condition, GTG will be supported at six points (T1 to T6) while during operation, GTG will be supported at three points (namely M1, M2 and M3). The supports location illustrated in vendor's foundation layout in Figure 2 below.

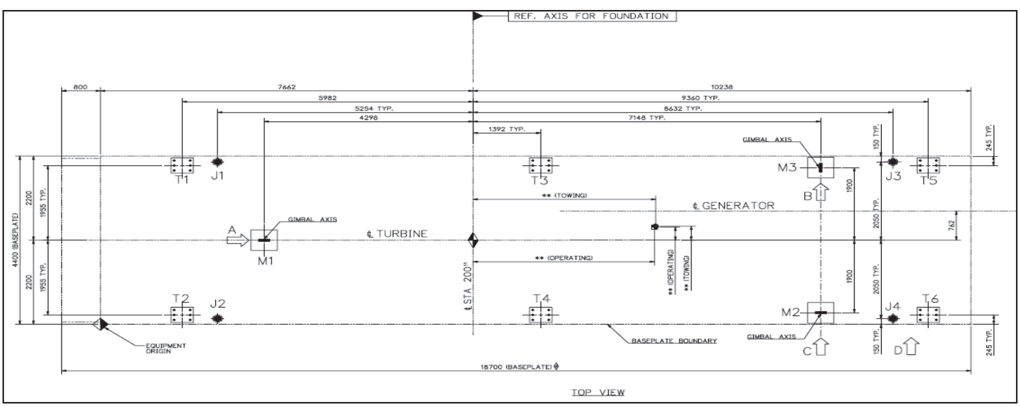

Figure 2. Gas Turbine Generator vendor's foundation layout.

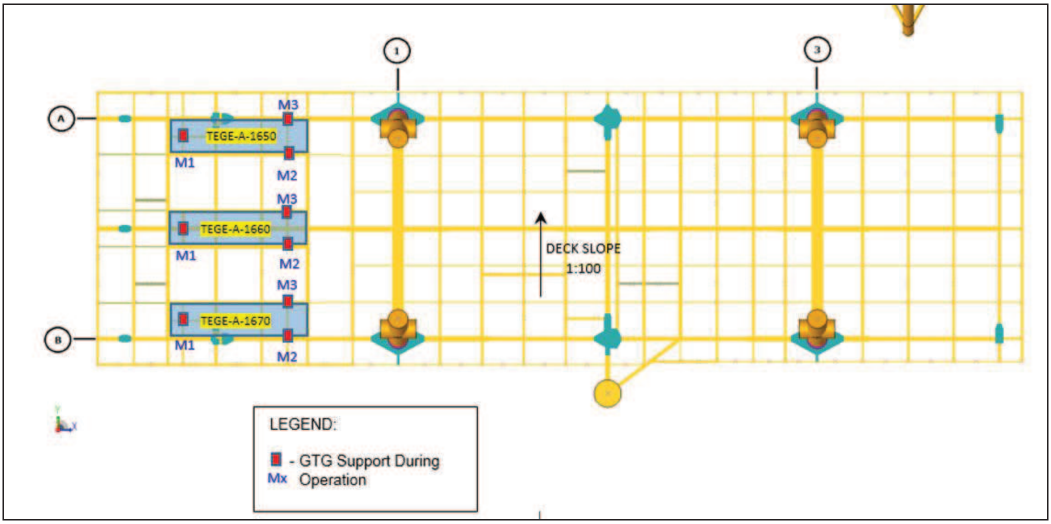

Figure 3. Gas Turbine Generator support foundation on the deck.

There are three (3) nos of GTG located side by side and operates simultaneously. The major component of GTG rotary equipment namely Turbines, Gear box and Generator running in the same skid. Each component operates in different operating speeds; 100% operating speed at 1500 RPM, 3600 RPM and 9800 RPM operated in same skid.

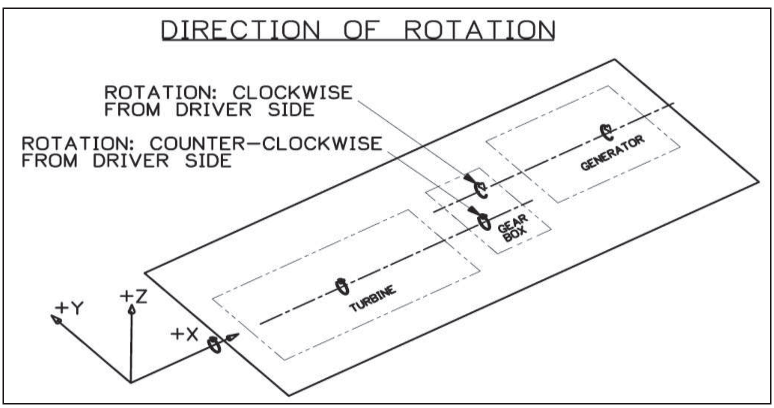

Figure 4. Rotating machinery component in GTG skid.

The vibration analysis checks are performed in accordance with DS/EN 1993-1-1 for both Ultimate Limit State and Service Limit State and corresponds to vendor's specified requirement to ensure satisfactory performance of the equipment. The permissible limit set by vendor will be the acceptance criteria for this vibration analysis.

3 Engine Vibration Analysis, Software and Acceptance Criteria

The vibration effect due to the rotating equipment torque and unbalanced forces on the topside structure is investigated using SACS program version 11.2 including program modules named DYNPAC and DYNAMIC RESPONSE. DYNPAC module is used to calculate the dynamic characteristic of the structure i.e. the natural frequencies and mode shapes (eigenvalues). The dynamic characteristics of the structure are then used by DYNAMIC RESPONSE module to perform the engine vibration analysis due to the engine torque load and unbalanced forces. The vibration analysis assesses the structural joint displacement due to the torque load and unbalanced forces and the calculated displacement is compared with allowable deflection from vendor data. Additional static analysis was performed for the structural integrity check during inplace operating condition using DS/EN 1993-1-1 code.

The global topside ultimate limit state check model is utilized. The boundary condition used during structural integrity check is assumed to be pinned at deck leg/jacket leg interface joint. When calculating the maximum displacement of all the support points, the maximum peak to peak speed allowed amplitude for foundation vibration corresponding to frequencies at +/- 20% has been considered. During engine vibration analysis, the maximum operating speed including +/-20% operating speed are included for displacement check. This displacement shall not exceed permissible displacement of 9 microns. The flowchart of vibration analysis for Gas Turbine Generator outline in Figure 5.

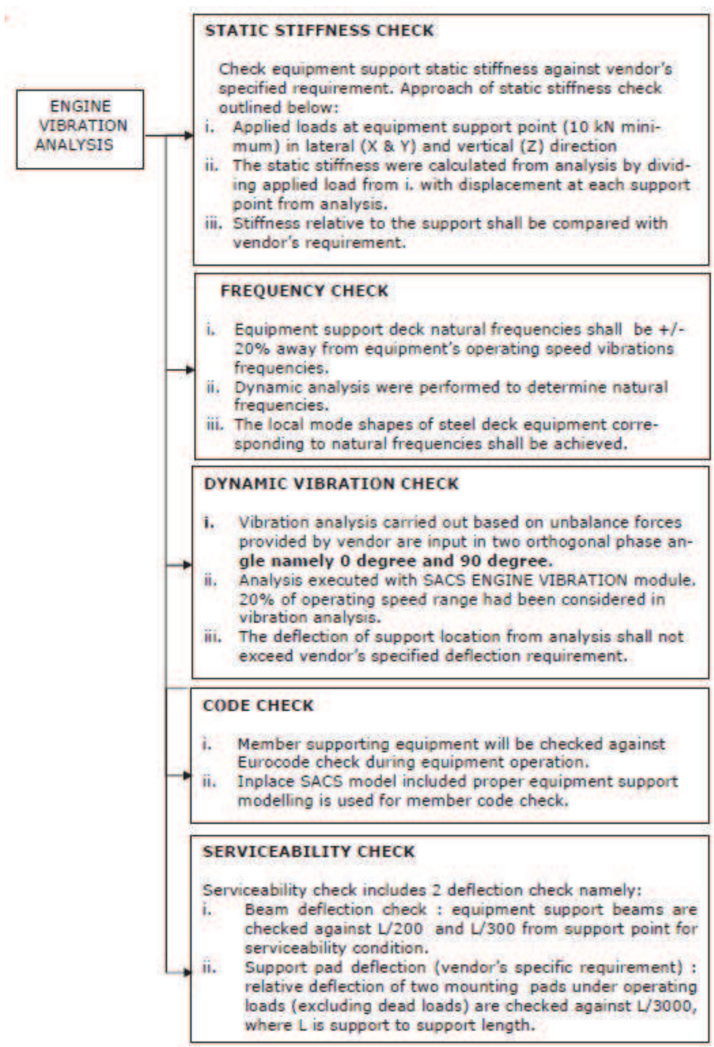

Figure 5. Flowchart Engine Vibration Analysis Procedure.

The following are the acceptance criteria applied for all equipment support check listed in Section 1. These requirements are specifying by equipment's vendor outlined below:

- For integrity check, the beam is code checked in accordance to DS/EN 1993-1-1.
- The total deflection shall not exceed L/200 while deflection due to variable action shall not exceed L/300.
- The platform shall be designed with the natural frequency of vibration to be 20% away from the equipment's operating range.
- The maximum amplitude for foundation vibration, at frequencies corresponding to the equipment's operating range ±20% is to be less than 9 microns under the effect of dynamic loads
- Minimum static stiffness at equipment supports shall be 5×10^8 N/m in the X and Y direction (horizontal plane) and 2×10^8 N/m in Z direction (vertical).
- Under the effect of operating loads provided by vendor (excluding the dead loads) and other loads acting on equipment support structure, the deflection in between two mounting pads of the base plate shall not exceed L/3000. L defined as length in between two mounting pads.

4 Vibration Analysis Check and Result

4.1 *Deflection Check Against Static Loads*

This section summarizes the deflection check performed for equipment support under serviceability condition. The deflection check is performed for the normal gravity load conditions including operating crane considering the partial action factor as 1.0.
The maximum deflection is as follows:

$$\Delta max = \Delta 1 + \Delta 2 - \Delta 0$$

where
$\Delta 0$ = pre-camber in the beam (if any)
$\Delta 1$ = deflection from permanent actions after applying the actions
$\Delta 2$ = deflection from the variable actions and any time-dependent deformations from permanent actions.

4.2 *Vibration Deflection During Operation*

The deflection between two mounting pads of the base plate due to operating loads provided by vendor (excluding the dead loads) and other loads acting on equipment support, shall not exceed L/3000. The same ULS model used to check the displacement with live loads.

4.3 *Natural Frequency Check*

An eigenvalue analysis of the deck supporting equipment is undertaken to determine its natural periods and associated mode shapes. Analysis is performed for the maximum gravity load condition. The first fifth major natural frequencies and mode shapes is calculated using SACS DYNPAC to ensure that the primary modes of longitudinal, transverse and torsional translation are determined. These natural periods and associated mode shapes are obtained using pinned boundary located on major joints on deck leg location. The boundary condition varies between SACS models for each level to ensure local modes of the deck is captured. The natural frequency of vibration will be 20% away from the equipment's operating range.

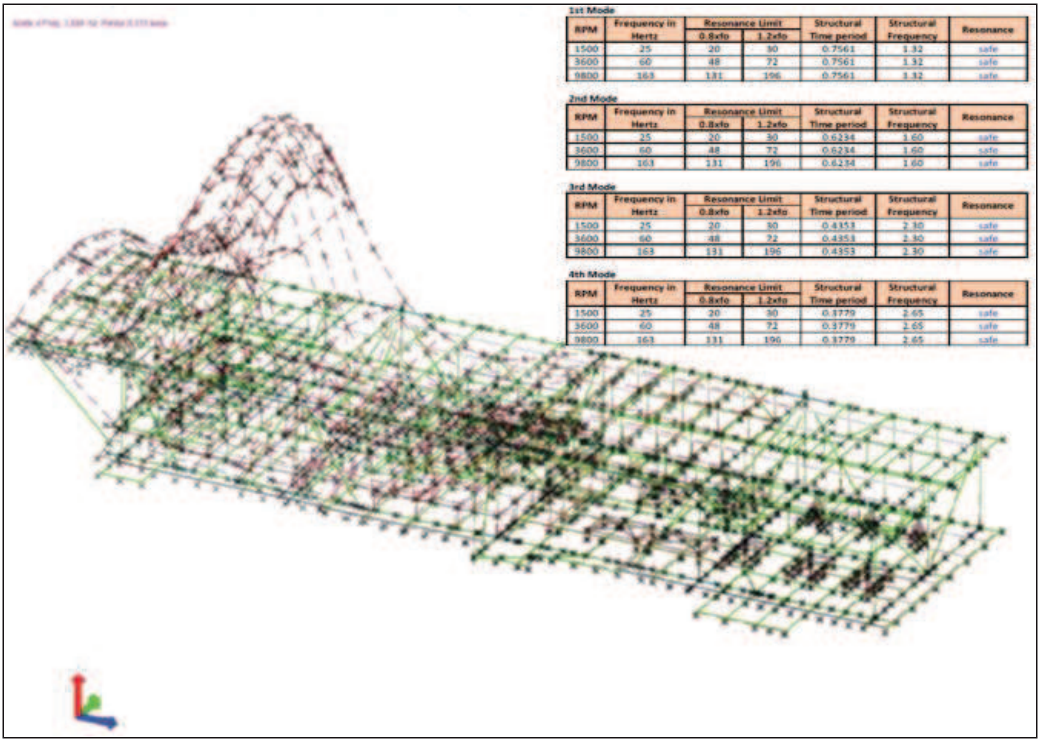

Figure 6. Mode Shape Plots in Natural Frequency Check

4.4 *Dynamic Foundation Stiffness (Amplitude Checks)*

The dynamic stiffness is different compared to the static stiffness as inertia and the deformation behavior of the foundation under harmonic dynamic loads is considered. The vendor makes certain assumptions regarding the bearing locations for the design of the shaft where stiffness and damping of the bearing itself and the foundations are considered. This leads to certain requirements for the foundation.

Table 1. GTG Maximum Amplitude

Equipment	Maximum Amplitude due to Vibration (micron)		
	X-direction	Y-direction	Z-direction
Level 4			
Gas Turbine Driven Generator (A-1650)	0.238	1.016	3.977
Allowable Displacement	9	9	9
Gas Turbine Driven Generator (A-1660)	0.117	0.978	4.050
Allowable Displacement	9	9	9
Gas Turbine Driven Generator (A-1670)	0.136	0.940	2.517
Allowable Displacement	9	9	9

Vibration analysis carried out based on unbalance forces provided by vendor are input in two orthogonal phase angles namely 0 degree and 90 degree. Analysis executed with SACS ENGINE VIBRATION module. 20% of operating speed range had been considered in vibration analysis. The deflection of support location from analysis shall not exceed vendor's specified deflection requirement.

The permissible limit of amplitude of foundation vibration specified in vendor drawing is 9 microns.

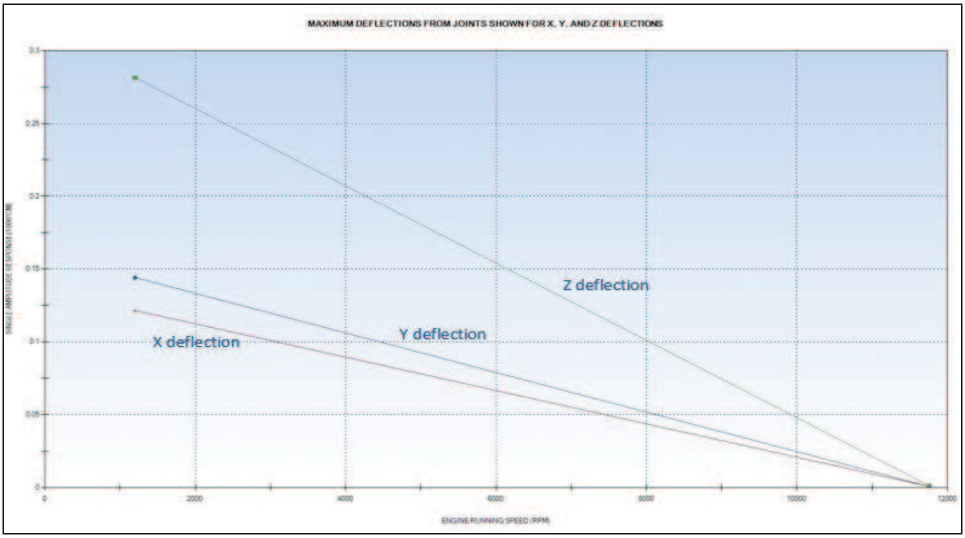

Figure 7. GTG Maximum Vibration Amplitude Check

4.5 *Static Foundation Stiffness*

Static foundation stiffness to compare the actual foundation deformation with the maximum permissible deformation but also the relative deformation at the different bearing locations, as the GTG foundation provides the stiffness for the different machine parts. Typically, the machine manufacture will provide deformation limits permissible after the alignment of the shaft. This leads to a specific deformation analysis for the foundation of major interest, the difference between the deformation during operation and when the machine is shut down.

The preferred stiffness specified in vendor drawing is $5x10^8$ N/m (X and Y directions) and $2x10^8$ N/m (Z direction).

Table 2. GTG Maximum Support Stiffness

Equipment	Minimum Support Stiffness (N/m)		
	X-direction	Y-direction	Z-direction
Gas Turbine Driven Generator (A-1650, A-1660 & A-1670)	5.35E+08	1.23E+09	2.39E+08

5 Conclusion

The dynamic analysis is to check for the resonance condition and to ensure that amplitude of vibration is restricted within acceptable limit by vendor. This is achieved through a free vibration analysis to accurately determine the natural frequencies for various modes of vibration and the harmonic forced vibration analysis to determine the foundation response to loads due to machine unbalance.

From the analysis result, the foundation checks are compliance with the natural frequency avoidance, maximum vibration amplitude minimum static stiffness and deflection limits specify by vendor. The stiffness of the foundation can be access by conducting vibration analysis and ensure the operation of GTG safe. It is also can avoid excessive strengthening in later stage due to vibration.

It can be concluded that by conducting vibration analysis for support foundations can be a cost-effective and economic alternative.

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