DEVELOPMENT OF DIESEL GENERATOR ISOLATION SYSTEMS FOR LOW NOISE AND VIBRATION

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Overview

This paper presents an outline of the engineering design process applied to the development of noise and vibration isolation systems for a 60 kW diesel generator. Two of these DGs are fitted in each of four 35 metre research vessels, currently being procured by the Department of National Defence. The main role for these vessels is sound range support, and thus the greatest emphasis is on low underwater noise levels. Specific issues which are discussed include the specification requirements and process, design requirements, and obstacles to the design process which needed to be overcome. Particular emphasis is placed on the responsibilities and required contributions of the various participants. An outline is provided of the final design details including a discussion of the concept designs which were explored and discounted, finite element assessment, design of all fluid and other flexible connections, design of the acoustic enclosure, and requirements for shipboard interfaces including structure. In conclusion, a discussion of the trials and evaluation process is presented.

Design Objectives

As the primary role for the vessels for which these modules have been designed is underwater noise research and measurements, low underwater noise levels from ship's machinery are critical. The vessel will normally be moored during measurement intervals, and therefore it is only necessary that the auxiliary machinery be isolated to the highest degree. The major items are two 60 kW diesel generators, which provide power for auxiliary systems, and a plethora of scientific instrumentation fitted to the vessels. The DND specified underwater noise levels as a curve of octave band levels not to be exceeded. Further guidance was provided to the builder by the specification of vibration levels at the foundation top, which the DND believed that if met would ensure compliance with the underwater noise level requirements.

The DND had identified that double mounting of the DG would be required using a suitable intermediate raft, with the entire unit enclosed by an acoustic enclosure.

Contractual Considerations

This section will present an overview of the complex contractual arrangements under which this project proceeded. Prime contractor responsibility was awarded to West Coast Manly Shipyard (WCM), of Vancouver, British Columbia, the builder for the vessels. The prime contract specified that WCM must direct the subcontract for design of the DG isolation systems to one of the two agencies which the DND considered to be qualified and experienced for the task, namely BBN or YARD. This requirement was cascaded to the supplier of the diesel generators, Cullen Detroit Diesel/Allison Ltd. of Surrey, B.C., which in turn contracted with YARD Inc. of Ottawa to do the design work. WCM engaged the services of Barron Kennedy Lyzun and Associates Ltd. of Vancouver to monitor and direct all noise and vibration aspects of the vessel design, construction and trials.

It is important to reflect upon these arrangements for a moment and appreciate how important it is that all appropriate contractual requirements are suitably shared by the players. The requirements for underwater noise levels and foundation top vibration levels were passed to YARD, which retained the right to inspect the build, however there were no weight restrictions placed upon YARD's design.

It was agreed between YARD and Cullen that provision of a suitable DG with free vibration levels within specified limits remained the responsibility of Cullen. It was also agreed that Cullen would furnish mounting points for the upper stage mounts at the required locations. WCM supplied compartment arrangement, ship's structure, and ship's services drawings.

The Design

The engine selected by Cullen was the GM 4-60. This is a four cylinder engine, displacing 60 cubic inches per cylinder. The engine is available in both naturally aspirated and turbo charged configurations. For this application only the lowest power rating was required, specifically naturally aspirated with the smallest injector size available. As is typical for many units of this type, the engine was designed for hard mounting to a substantial baseplate, in turn further hard mounted to a concrete slab. Cullen's first attempt at a baseplate utilized an existing design which had given good results previously, but only for hard mount applications. This design was provided to YARD for review. When this baseplate was supported on springs for test, vibration levels were extreme however. Subsequent analysis indicated considerable resonance, and this design had to be discarded.

It then became necessary to explore alternative methods to provide the required mounting point structure from the engine to the upper stage mounts. The preferred design was based on six upper stage mounts, which necessitated that attachment points be identified at the engine front, rear, and under the generator. Symmetry about the centre of gravity was essential, and a wide enough footprint laterally to maintain stability in a seaway. While the engine rear provided good attachment points, both the generator and engine front were rather more complicated, due to complexity of plumbing and other features at the engine front and the lightweight nature of the generator feet. The final design utilized a one inch thick slab under the generator with rails for the mounts, and a complicated bracket at the engine front. This allowed the entire DG assembly to flex relatively unconstrained about its midpoint.

With suitably low vibration levels demonstrated at the Cullen test bed it was now required to design the intermediate raft, acoustic enclosure, and all flexible connection arrangements which must also be two stage.

It was decided to utilize the same mount for both the upper and lower stages, six for the upper as was noted above, and ten for the lower stage which accommodated the extra mass of the raft and enclosure. Mount loading in excess of 80% capacity was achieved for all mounts. The selected mount was the 6A6/900lb from CFTO

D03-003-021/SG-005, the DND's standard for noise, shock and vibration isolation hardware. Figure 1 provides a schematic of the final arrangement.

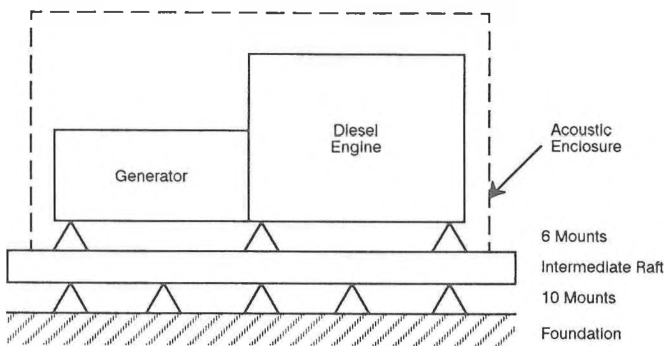

Figure 1: Schematic of Final Arrangement

A concept design for the raft was developed, based upon a solid slab as the main top plate, with longitudinal vertical and horizontal plates to provide lower stage mount attachment points. The structure was stiffened by transverse "T" sections. Once completed to a degree suitable for FE analysis, the design was checked for coincident resonances between engine forcing frequencies, mounting system natural frequencies, and raft structural natural frequencies. A few modifications to the raft design were subsequently implemented. This analysis required that masses, CG's, and moments of inertia be known or estimated for all components.

Flexible connection arrangements were then conceived for all non-structural interfaces including: diesel fuel (in and out); cooling water; exhaust; supply/ventilation air (enclosure only); and all electrical connections. As with the mounts, the fluid connections were selected from the CFTO. Adequate length was necessary to accept the imposed seaway motions, and provide the required degree of isolation. The cooling hoses were designed using an "L" configuration. Dynamic stiffness data on the hoses was compared to that known for the mounts, to confirm that the hoses would not compromise the isolation provided by the mounts. The exhaust connections were particularly challenging due to the larger diameter, stiffer metal hoses required, and the fact that the attachment to the middle stage of the mounting system needed to be achieved at the enclosure top.

To complete the mounting system design YARD was required to assess the ship's structure for suitability for attachment, and propose a foundation design. As the vessel is constructed of 7mm plate, this was not an inconsiderable challenge. The final foundation design utilizes 4*8 inch steel angle, suitably stiffened and gusseted to the ship's structure. This provided a low, squat arrangement, and good dispersion of the point loadings of the mounts out into the lightweight plating. This structure was analyzed by FE as well, the analysis revealing that the areas of plating forming the ship's structure had a tendency to be exited, at a variety of frequencies. Stiffening was proposed to raise these resonances above the range of concern.

The acoustic enclosure was required to provide easy disassembly for maintenance access, and a door with window for local gauge inspection. As was noted above, it was also necessary to provide adequate stiffness at the location at the enclosure top where the exhaust flexible was attached. Calculations showed that more than adequate noise isolation was provided.

Tests And Trials

A comprehensive series of measurements conducted at strategic milestones was necessary to support this design activity. As was noted above, this commenced with Cullen obtaining suitably low vibration levels on a baseplate system supported above resilient mounts. This activity included repeated testing on the original failed baseplate design, and subsequent retest with the final baseplate pieces.

Following this initial testing, the design of the module was completed. Each of the following seven DG sets was also tested to confirm consistency with the vibration levels recorded for the first.

The first complete module constructed, including raft and acoustic enclosure, was tested at the Cullen works, utilizing a dummy foundation attached to the concrete floor of the test bed. While not a true representation of the foundation conditions on board the vessel, the design activity had required/presumed a neutral foundation without significant resonances. Vibration levels were measured on the DG set baseplate above the upper stage mounts, and on the intermediate raft below the upper stage mounts and above the lower stage mounts. See figure 2 for the results. These measurements confirmed that the upper stage of the mounting system was performing as expected, and that no raft amplification resonances existed. Airborne noise measurements around the enclosure confirmed the performance of that aspect. These tests were conducted by Boeing Canada, and witnessed by the DND and the noise and vibration consultant to WCM.

Two of the completed modules were then installed in the first of class vessel. Near-field hydrophone measurements indicated satisfactory underwater noise levels which were later confirmed by sound ranging. The follow on three vessels have since been delivered with similar success.

Summary

It is hoped that this paper has provided an insight into the design process and interrelationships necessary to achieve successful isolation of machinery fitted to a research vessel. Effective cooperation and continued dialogue between the various contributors were essential to the satisfactory completion of this project.

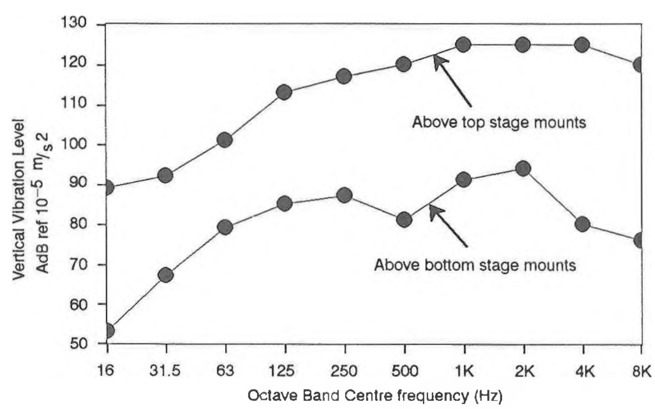

Figure 2: Measured Results, Top Stage

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