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DEVELOPMENT OF A MECHANICAL SYNCHRONIZATION SYSTEM OF THE DIESEL GENERATORS IN ORDER TO MINIMIZE THE FORCES TRANSMITTED TO THE HULL

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Vibration on board which might result in structural damage to the vessel, damage to the machinery and equipment or discomfort or annoyance to passengers and crew is generated by ship machinery. Since high vibration levels detected in a public space of a new generation cruise were dependent from the mechanical phasing between the diesel generators (DDGG), a dedicated system which has to perform a synchronisation on a pole that correspond to a specific mechanical phase angle has been developed in order to minimise the total forces transmitted to the hull, avoiding in this way complicated, expensive and invasive structural modifications. A detailed description of the "comfort phasing system" installed on board and the improvements obtained such as reduction of vibration levels at the studied area are reported.
Keywords: DDGG, shipbuilding, phasing, hull, vibration

1. Introduction

High vibration levels detected in a public space of a new generation cruise vessel has led to a wide vibration measurement campaign, carried out on board in order to identify the dependency of the vibration levels detected in the space.

Therefore, according to evaluations and studies undertaken in the period prior to the ship delivery and additional campaigns performed during the first cruises, it appeared that the origin of the vibratory problems and their non-stationary characteristic could be explained and summarized with the concurrence of the following factors:

1. High exciting forces from the DDGG;
2. High structure response;
3. Mechanical phase between the DDGG.

Regarding the **high exciting forces from DDGG**, measurements carried out by engine maker have shown that the diesel engines, and in particular the 14 cyl. configuration, apply very high exciting forces and moments on the hull structure. Because of these, engine maker studied some improvement actions with success on the 14 cyl. engines before the ship delivery, by means of application of dedicated balancing masses on the flywheels, in order to reduce the vertical force, which have been found to be the most influent component on the vibration levels.

Regarding the **high structure response**, according to the impact tests made after the sea trials, it has been verified that the natural frequency of the structures with high vibration levels was slightly higher but still very close to the exciting frequency (fundamental frequency of the engine). Additionally, the presence of local large non-structural masses on the spans under investigation may have further increased the response reducing the natural frequency. As a consequence, some structural improvement measures have been studied, such as additional pillars and beams.

Nevertheless, taking into consideration the advanced stage of construction of the ship, these actions have been considered invasive and not feasible.

On the other side, the considerable variability and randomness of results achieved under the same condition (DDGG configuration and load), have suggested that the overall levels basically depend on the **mechanical phasing between the DDGG** and thus between the exciting forces. The measured levels are therefore the result of a random combination between the set of forces and moments applied by diesel engines, with a phase set by the electric synchronization system. Because of this phenomena, a dedicated feature of the synchronization system has been developed, which through a specific software could allow to perform a mechanical synchronization between the DDGG, appropriately choosing one of the available electric poles; the optimal mechanical phasing between the diesel engines can be set in order to minimize the resulting forces and moments transmitted to the hull and thus minimize the vibrations induced on the ship structure

2. DDGG Phasing effect on vibration levels

2.1 Vibration measurement

Dedicated Vibration measurements have been taken during one of the first cruises. Measurements were performed for four different positions of a passenger public space where the phenomenon was evident, as illustrated in Figure 1. A time signal of 90 seconds was registered for each measurement.

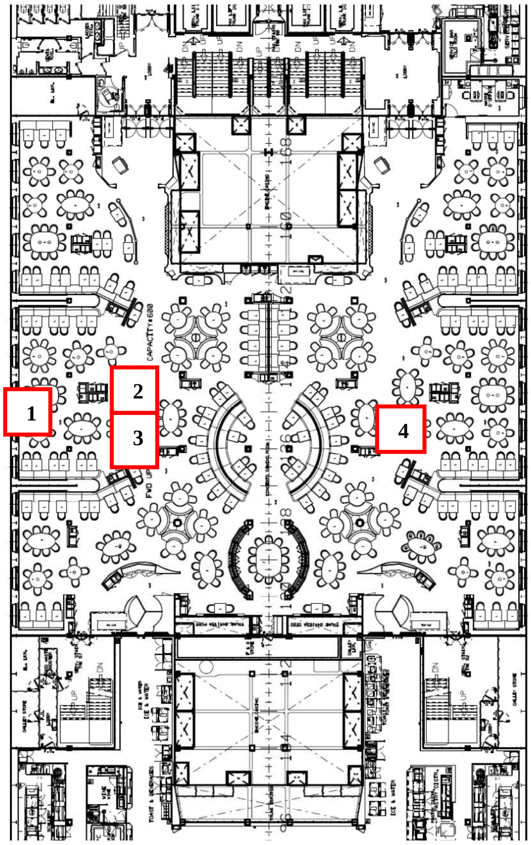

Figure 1 – Measurement locations in a passenger public space

The ship is equipped with diesel electric propulsion containing four main engines (2 x 14 cylinder engines and 2 x 12 cylinder engines), each coupled to an electric generator. Each main engine is running at constant speed of 600 rpm.

The source of vibration is found to be the 1st order external moment of the generator sets. This is related to the mass/inertia forces of the rotating crank shaft. These low frequency forces are not absorbed by the resiliently mounts and are transferred to the ships structure in way of the engine foundations. The graph below in figure 2 shows a typical frequency spectrum in the affected public space.

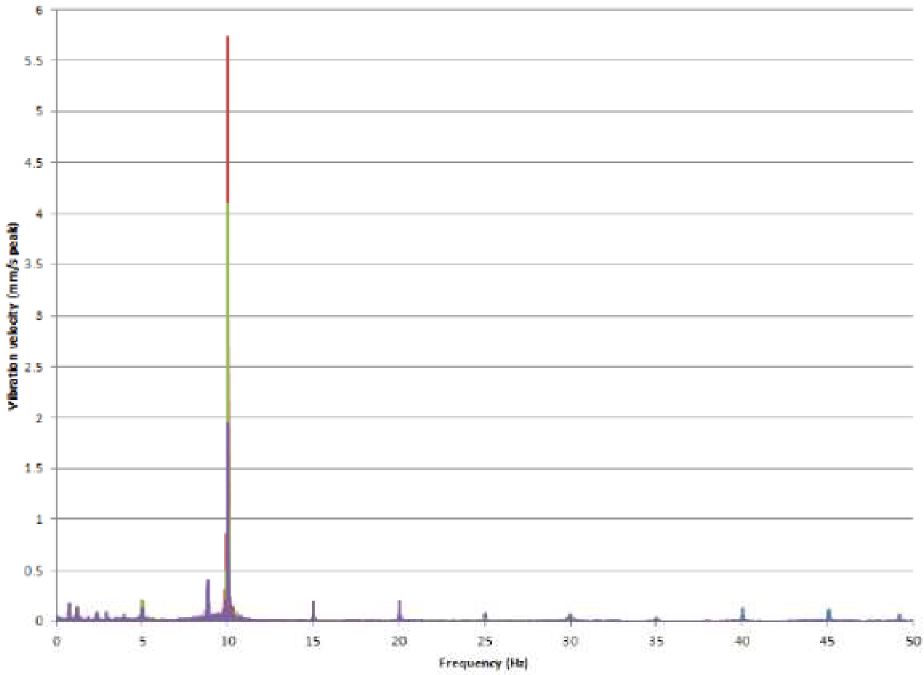

Figure 2 – vibration levels.

As seen from the graph above there is a distinct peak at about 10 Hz. This corresponds to the 1st order excitation frequency from the generating sets running at 600 rpm.

The graph in Figure 3 shows the vibration levels at three locations indicated in Figure 1 for different engine configurations. The vibration levels are given as single peak velocities at 10 Hz. It can be observed that there may be significant changes in the resulting transfer function from the engines depending on the number of engines running together.

The vibration measurements showed vibration levels between about 0,8 to 4,2 mm/s depending on the engine configuration and location of measurement, being found the highest vibration levels for location 2. Although, these results did not indicate that one of the engines is generating higher vibrations than any other.

2.2 Vibration phase analysis

The first order external moment of the main engine excites a longitudinal pitching mode of the engines. The 1st order moments are related to the angular position of the crankshaft. The relative position of the crankshafts between the different engines vary arbitrarily when the engines are connected to the electrical circuit, and hence vary the phasing between the engines.

The graph below shows the vibration levels in each location at different engine configurations. The vibration levels are given as single peak velocities at 10 Hz, corresponding to the 1st order of the main engine. For the positions shown with equal engine configuration, one of the engines has been disconnected from the electrical circuit, and then reconnected again. This causes the engines to operate at same configuration but a probability of about 83 % that the phase will change relative to the other engines.

As seen from the figure 3, the vibration levels are varying significantly depending on the phasing between the engines. One example is the configuration where engine 2, 3 and 4 is running and the vibration level in channel two is varying from about 5.8 mm/s to 2.2 mm/s

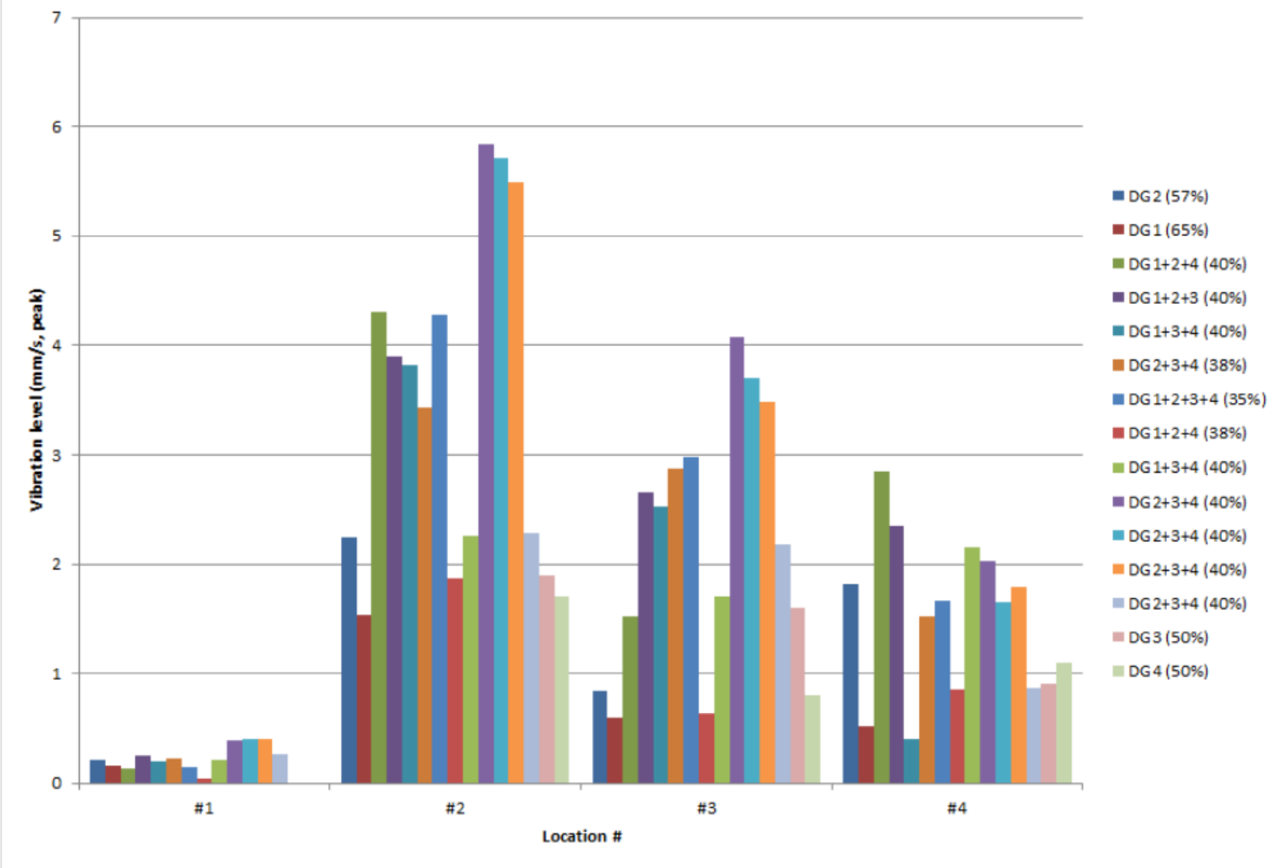

Figure 3 - 1st order vibration levels at 3 different positions of accommodation deck for different mechanical engines phase.

3. Comfort phasing system

On the basis of such results, a dedicated feature in the synchronisation system has been developed, called “Comfort Phasing System”.

The system has been first developed and adopted on the sister ship delivered one year later; the sister ship has been improved with local structural modifications, but has been chosen as a test bench for the setting of the system in view of a possible retrofit to the prototype ship. Therefore the results can be considered valid in terms of relative variation of the measured levels.

3.1 Description

The system includes a sensor placed on the axis of each generator, which sends continuously the measurement of the shaft angle to the synchronizer system.

When a generator is to be connected to the grid, the system has to perform the synchronization on the pole that corresponds to a specific phase angle. This angle is set on the base of the engines connected on the grid in order to minimize the total transmitted forces and the response on the hull.

The choice of the correct phase is done by the software with a logic developed by vibration measurements taken on the hull.

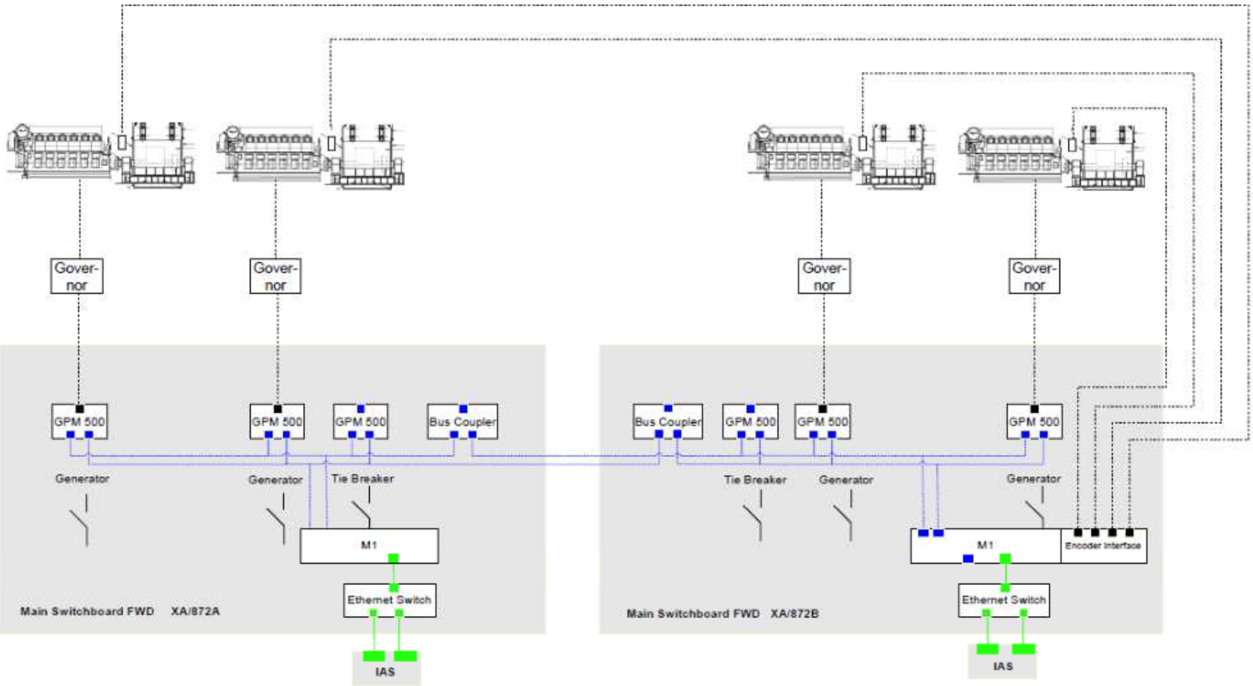

Figure 4 - Comfort Phasing System block diagram.

The logic of the system is the following:

- Optimum position of shafts already set on the system
- Measurement of rotor position by incremental encoders at shaft of each generator
- Detection of allowed synchronization window by computer inside switchboard room
- the computer transfers the release to the individual protection module of each breaker.
- This release is used as an additional precondition for synchronizing
- protection module synchronizes and closes the breaker

The comfort phasing system is normally not active and it can be selected by the operator in Propulsion Management System Overview mimic via a dedicated pushbutton, which is common for all DG sets.

As a safety feature, if using the comfort synchronization function the circuit breaker should not be closed within a defined time (set during commissioning), the PMS automatically de-select the comfort synchronization function.

3.2 Results

After applying and setting the comfort phasing system, the optimal mechanical phasing respect the angular position of the DDGG has been defined (see Table 1), in order to minimize the resulting forces and moments transmitted to the hull. The angular position of the DG 1 crankshaft has been taken as reference. These angles are for a configuration of all four DDGG running at 72% power.

DG 1	0°
DG 2	60°
DG 3	300°
DG 4	240°

Table 1 – Shaft optimal angles.

Table 2 shows the measured vibration levels on three positions in accommodation decks for different engine configurations when the phasing system is switched-off. Instead, table 3 shows the improvement achieved when the phasing system is activated, optimized for all four engines running (DDGG 1 2 3 4) at about 75% power.

For the other engine configurations including 3 engines in operation, the adopted setting allow, in general, a reduction of vibration levels, although in some positions a slight increase can be noted, due to the fact that the system is optimised for the potentially worst condition with 4 engines running at the same time. Nevertheless, the other conditions can be considered less dangerous due to the reduced number of engines running, and in all cases show levels below the 4 engines conditions.

SYSTEM OFF						
DDGG on	**#**	**1 2 3**	**1 2 4**	**1 3 4**	**2 3 4**	**1 2 3 4**
DDGG load	**%MCR**	75	75	75	75	72
Passenger Public Space	**#2**	0,8 mm/s	1,5 mm/s	1,1 mm/s	1,3 mm/s	1,1 mm/s
Passenger Public Space	**#3**	1,4 mm/s	1,2 mm/s	1,0 mm/s	1,1 mm/s	1,9 mm/s
Passenger Public Space	**#4**	0,8 mm/s	1,9 mm/s	1,8 mm/s	1,4 mm/s	1,9 mm/s

Table 2 – Results without phasing system activated.

SYSTEM ON						
DDGG on	**#**	**1 2 3**	**1 2 4**	**1 3 4**	**2 3 4**	**1 2 3 4**
DDGG load	**%MCR**	75	75	75	75	72
Passenger Public Space	**#2**	0,4 mm/s	1,0 mm/s	0,7 mm/s	0,5 mm/s	0,3 mm/s
Passenger Public Space	**#3**	1,6 mm/s	0,9 mm/s	0,8 mm/s	1,3 mm/s	1,7 mm/s
Passenger Public Space	**#4**	0,7 mm/s	1,1 mm/s	0,5 mm/s	0,7 mm/s	0,7 mm/s

Table 3 – Results with phasing system activated.

4. Conclusions

The development of the “Comfort Phasing System” has provided a smart solution that allowed to deal with mechanical issues with an approach based on the optimisation of the automation system.

The system therefore permit, in some cases, to avoid complicated and expensive structural modifications, but in the same time can be considered an optional feature, that can be adopted in order to reduce the overall forces transmitted to the hull by machinery causing vibration issues due to a negative random effect of their phases.

5. References

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