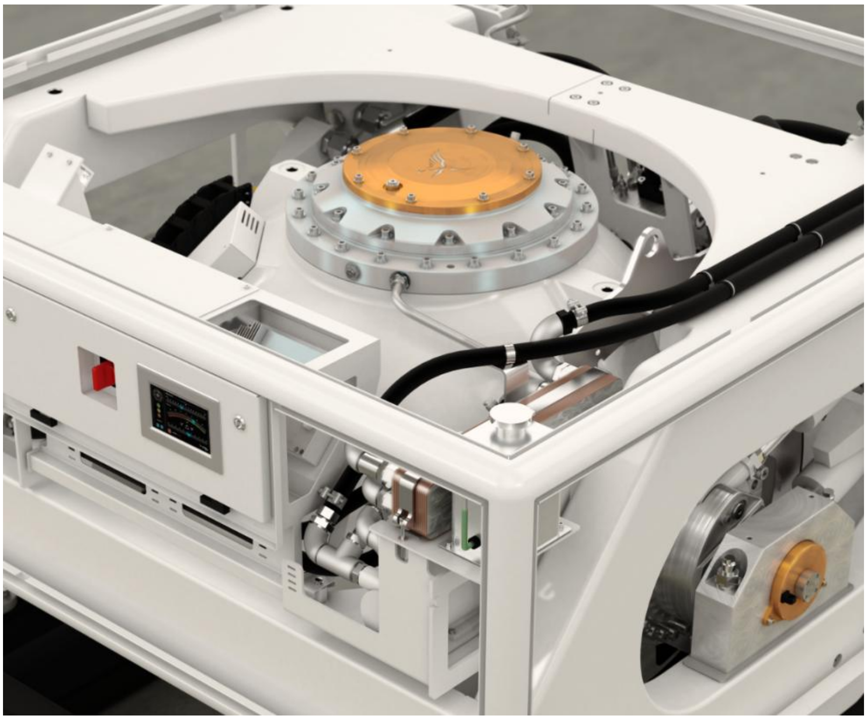
Design Loads for Supporting Structure

Technical Note 1404
Revision 8 - Sept 2021

Topics Covered

- Generated Gyrostabilizer Torques
- Loading Combinations
- FEA Model Guidance
- Design Accelerations
- Maximum-Loading Design
- Fatigue-Loading Design
- Bolted Connections
- Multiple Gyrostabilizers



Technical Note 1404: Design Loads for Supporting Structure

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Introduction

This technical note provides guidance on the loading cases to be considered in designing the structural interface between the VEEM Marine Gyrostabilizer and the vessel. The recommended approach is to use Finite Element Analysis models for the vessel structure and to apply loads to this structure as described in this document. Alternately, a maximum loading approach can be taken. In this case, onerous combinations of loads must be considered and compared with approved allowable design stresses.

The VEEM Marine Gyrostabilizer models have been designed to allow the gyrostabilizer to be mounted on a longitudinal girder or a transverse frame. The arrangement and sizing of this structure is the responsibility of the customer's designers.

This document offers guidance only. VEEM Ltd accepts no responsibility whatsoever for the capacity or performance of the structure in the vessel to which the gyrostabilizer is mounted. Accepted and rigorous design procedures must be followed as the gyrostabilizer imparts significant local and global loads to the vessels structure.

Design Loads for Supporting Structure

The anticipated maximum loads that a VEEM Marine Gyrostabilizer will exert on its supporting structure are specified in tables on the relevant installation drawing. A simplified analysis can be performed by using the worst possible combinations of these loads when designing both the local and the global hull structure that supports the gyrostabilizer. These loads are the summation of the largest torques created by the gyrostabilizer and the worst anticipated vessel accelerations[1]. Vertical loads shall be assumed to fully reverse at the vessel's natural rolling period. Horizontal loads will fully reverse at half the natural roll period, *i.e.* twice the frequency.

By its nature, a gyrostabilizer is designed to produce its maximum stabilizing torques on a frequent basis. These torques are fully reversing and hence the structural design is generally driven by fatigue concerns. Thus, it is recommended that a comprehensive Finite-Element Analysis of fatigue be carried out by following the methodology outlined below.

[1] The estimated vessel accelerations are outlined in Table 6 below. These values are estimated from typical vessel speeds and lengths. If the vessel type or operation results in higher design accelerations, then the loads should be adjusted accordingly.

Generated Gyrostabilizer Torques

In order to calculate the loads generated by a VEEM Marine Gyrostabilizer, an understanding of the different torques produced is required. The VEEM Marine Gyrostabilizer Whitepaper 1403 provides a thorough overview. Briefly, the instantaneous torque produced by a gyrostabilizer is the product of the flywheel angular momentum, p [N.m.s] and precession rate, p_{pppp}p[rad/s]:

gyro prec [1]

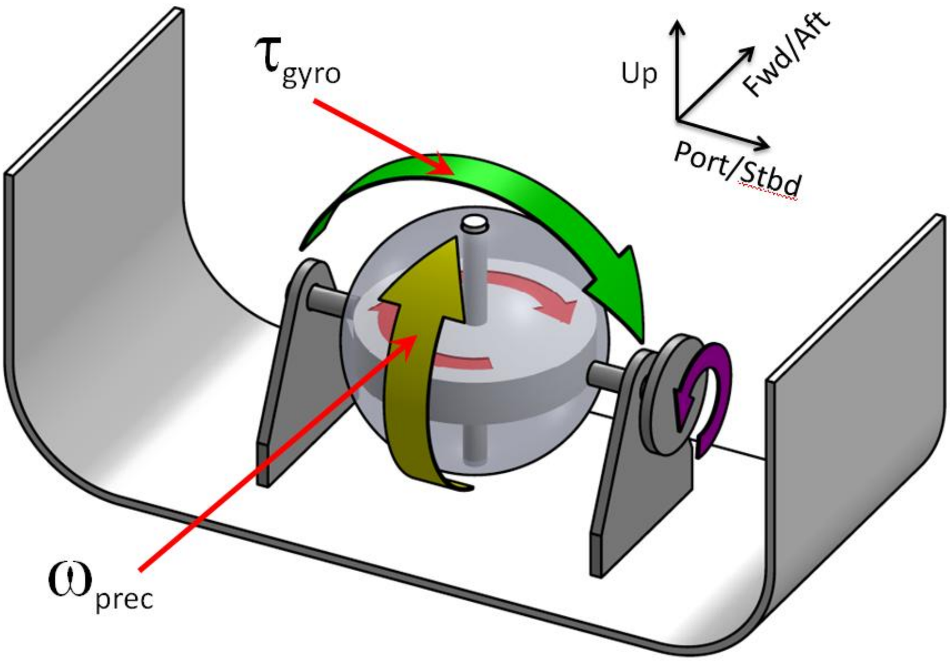

Figure 1 - Precession Dynamics

As the gyrostabilizer precesses, the torque it produces rotates through the precession axis. Thus, the resulting gyrostabilizer torque can be described by two orthogonal components, stabilizing torque $pp_{pppp}p$ and yaw torque $pp_{ppp}p$, given by the two formulas below.

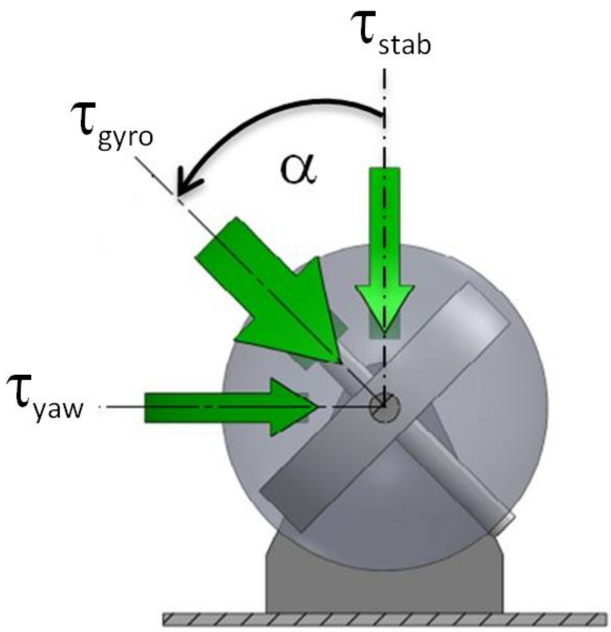

Figure 2 - Gyrostabilizer Torque Components

st b prec [2]

y prec [3]

where p is the precession angle measured from the vertical.

It can be seen that the stabilizing torque is maximum at 0° precession, whilst yaw torque is zero. At 45° precession, the yaw torque is maximum with equal magnitude to the stabilizing torque (~55% of maximum gyrostabilizer torque). At 70° precession, the torques are both zero due to a zero precession rate.

There is also a third torque that is imparted on the vessel structure from the gyrostabilizer during operation. This is the control torque. VEEM Marine Gyrostabilizer use an actively-braked control system with a single or dual pair of hydraulic cylinders. A braking control torque will always oppose the precession motion of the gyrostabilizer and be transmitted into the ship's hull. Further discussion of this torque is beyond the scope of this document, however the effects have been included in the load tables below.

Loading Combinations

The torques described above will combine to output a varying load at each mounting foot of the gyrostabilizer. There are 6 different combinations of loading where one of the torques is maximum. These load cases are outlined in Table 1. It can be seen that the yaw torques reverse at twice the rate of the stabilizing torques. Note that at 70° precession angle, the precession rate is zero, hence all torques are zero.

Load Case	Precession Angle	Precession Rate	Stabilizing Torque	Yaw Torque	CW Flywheel Control Torque	ACW Flywheel Control Torque
Case #1	0°	+ve	100%	0%	100%	-100%
Case #2	45°	+ve	55%	100%	71%	-71%
Case #3	45°	-ve	-55%	-100%	-71%	71%
Case #4	0°	-ve	-100%	0%	-100%	100%
Case #5	-45°	-ve	-55%	100%	-71%	71%
Case #6	-45°	+ve	55%	-100%	71%	-71%

Table 1 - Load Case Combinations

If the front panel of the gyrostabilizer faces forward in the vessel, then the gyrostabilizer flywheel will be set to spin clockwise. Alternatively, if the front panel faces aft, then the gyrostabilizer flywheel will be set to spin anti-clockwise. The control torques should be set accordingly, referring to the reference frame shown in Figure 3. The front panel contains the gyrostabilizer touchscreen.

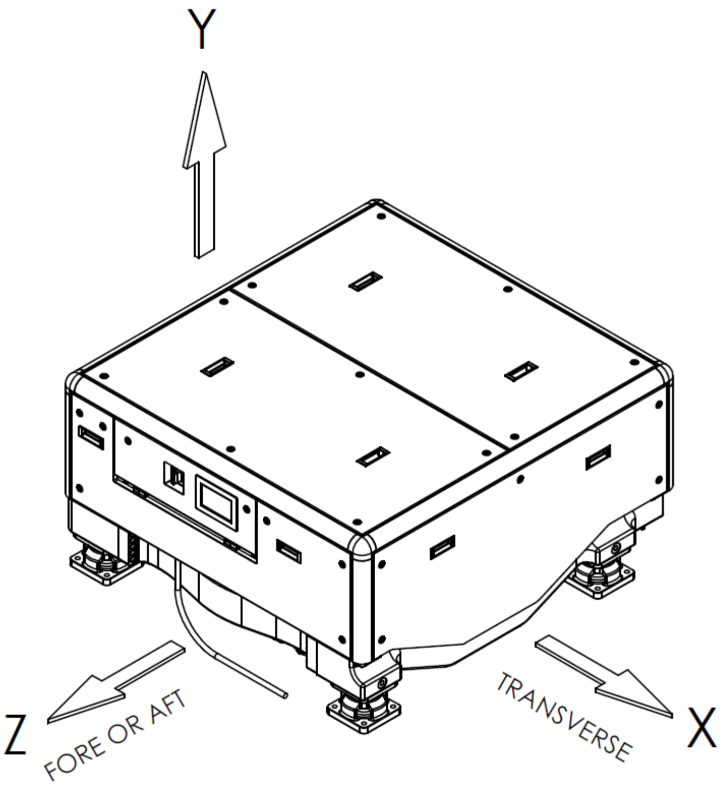

Figure 3 - Gyrostabilizer Reference Frame

The maximum torques are given for each gyrostabilizer in Table 2 below. These can be multiplied by the factors given in Table 1 to derive the load condition for each load case.

VEEM Marine Gyrostabilizer	Stabilizing Torque [kNm]	Yaw Torque [kNm]	Control Torque [kNm]
VG52SD	123	65	50
VG70SD	145	78.5	50
VG100SD	258	142	100
VG520SD	1,000	550	350

Table 2 - Load Case Combinations

FEA Model Guidance

Applying Gyrostabilizer Torques to Model

The torques created by the gyrostabilizer are transmitted through the vibration mounts into the vessel structure. It is recommended to model the gyrostabilizer as a rigid body. The model can then be loaded by applying torques anywhere on this rigid body, according to the torque combinations in Table 1. A possible arrangement is illustrated in the figures below for information only. The development and interpretation of any FEA model is the responsibility of the designers retained by the owner.

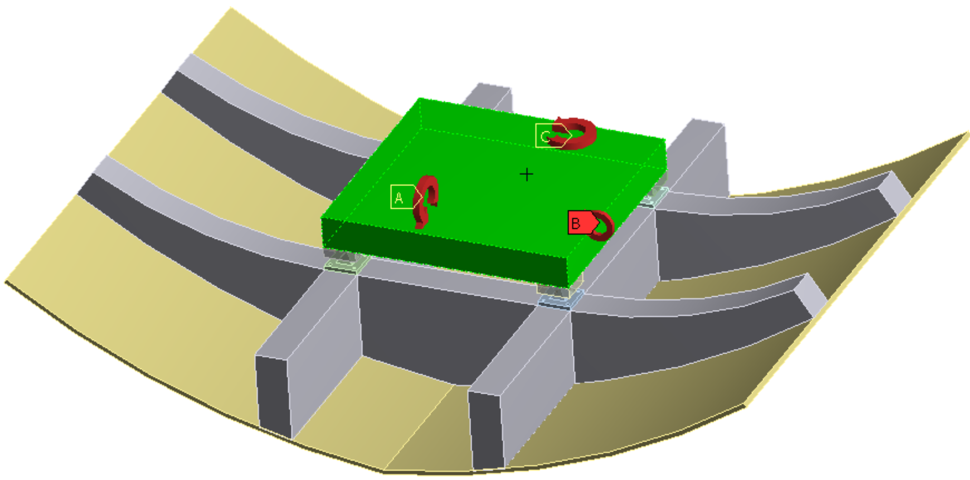

Figure 4 - Torques Applied to Gyrostabilizer in FEA Model

Gyrostabilizer Connection to Vessel Structure

It is recommended to model the connection of the gyrostabilizer to the vessel structure at each of the mounting feet via 3 orthogonal springs. This will accurately load the supporting structure in a more even manner. An ANSYS model is illustrated below by way of example.

It is also recommended that the bolted connections between the base of the mount feet and the vessel structure are modelled in order to capture local effects. The supporting structure will be subjected to high cycle fatigue, so good engineering practice in the design of fatigue loaded connections should be applied.

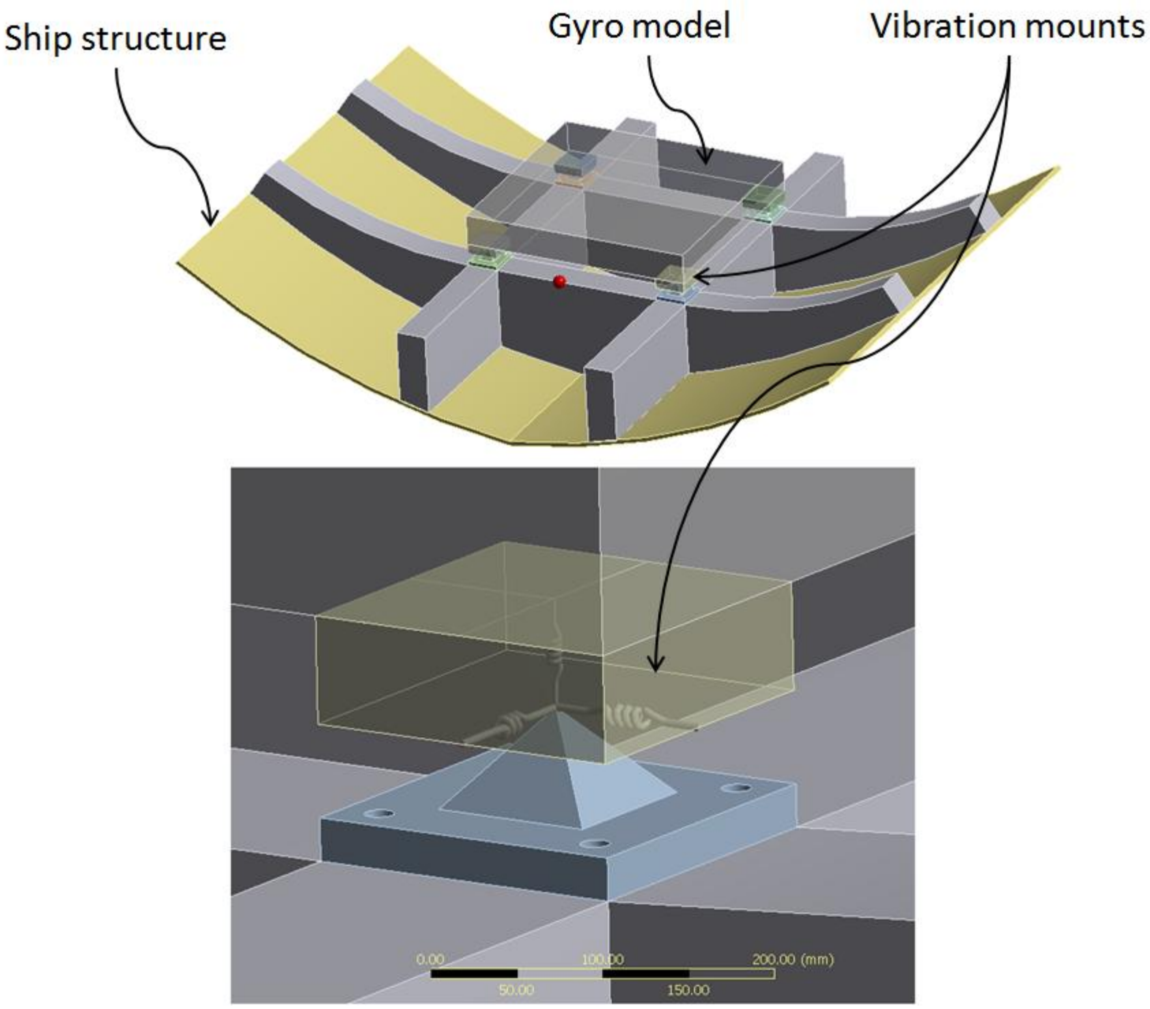

Figure 5 - FEA Model of Rigid Body Gyrostabilizer Attached to Nominal Vessel Structure

Vibration Mounts

The vibration mounts are elastomer components pre-loaded between two steel components. The loads are applied to the vessel structure through the centre of the mount as defined in the illustration below. Vibration mount assembly is shown in Figure 6. Relevant dimensions of the vibration mount assembly are listed in Table 3.

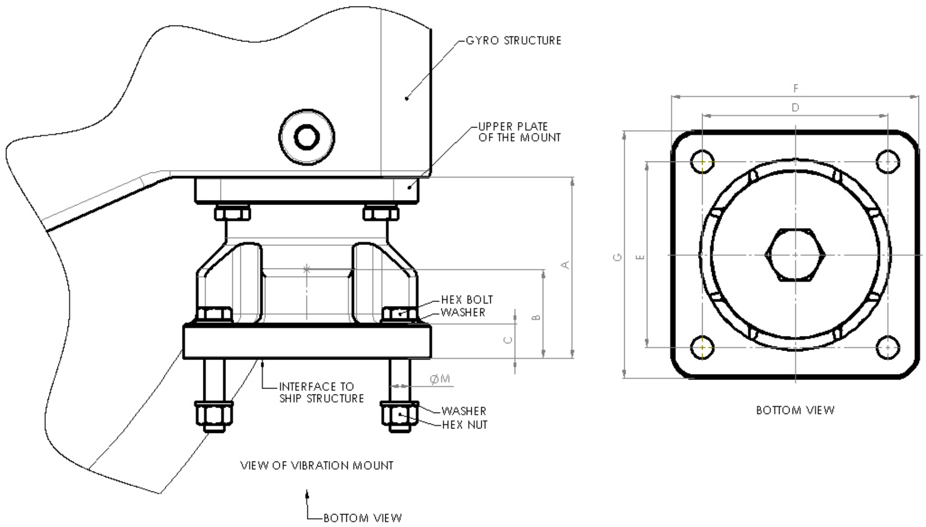

Figure 6 - Vibration Mount Assembly

VEEM Marine Gyrostabilizer	Dimensions [mm]							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**M**
VG52SD & VG70SD	147	28	82	150	150	200	200	16
VG100SD	261	151	25	210	210	290	290	24
VG520SD	261	151	25	210	210	290	290	24

Table 3 - Principal Dimensions of Vibration Mounts

The vibration mount stiffness values are given in Table 4 below. The elastomer components in the mounts are circular, so the horizontal stiffness is the same longitudinally and transversely.

VEEM Marine Gyrostabilizer	Vertical Stiffness [kN/mm]	Horizontal Stiffness [kN/mm]
VG52SD & VG70SD	20.0	5.0
VG100SD	25.0	5.0
VG520SD	35.0	6.5

Table 4 – Vibration Mount Stiffness Values

The arrangement of the vibration mounts for the various VEEM Marine Gyrostabilizer models are described in Figure 7, Figure 8, and Table 5 below.

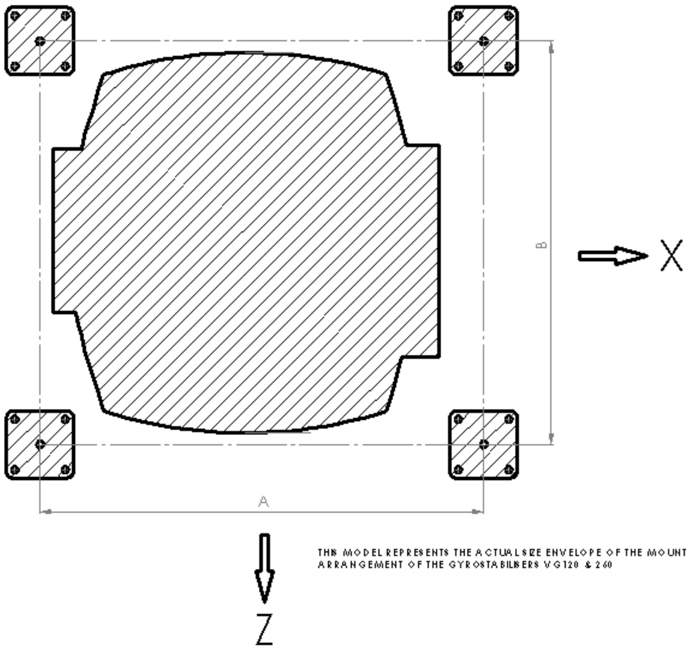

Figure 7 – Arrangement of Mount Feet on VG52SD, VG70SD and VG100SD Models

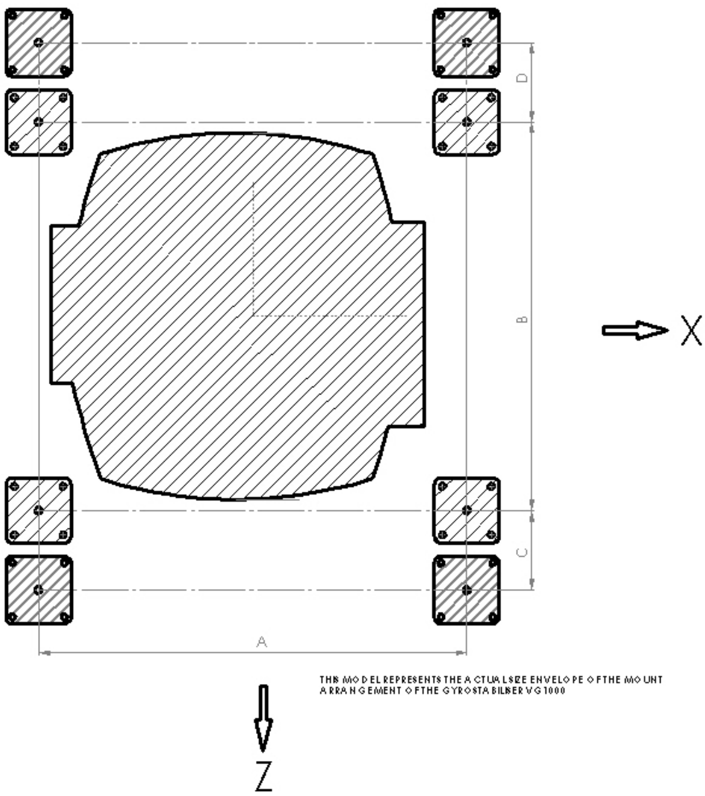

Figure 8 - Arrangement of Mount Feet on VG520SD Model

VEEM Marine Gyrostabilizer	Dimensions [mm]			
	A	B	C	D
VG52SD & VG70SD	1320	1200	-	-
VG100SD	1780	1500	-	-
VG520SD	2794	1740	330	330

Table 5 - Mount Feet Arrangement Dimensions

Design Accelerations

In the Gyrostabilizer installation drawing, the maximum load values are stated based on an assumed set of vessel design accelerations. The design accelerations may vary from this if the vessel is high speed and/or it operates in large sea states. Additionally, if the gyrostabilizer is located forward of 70% LWL, or more than 2m above the vessel rolling axis, then the design accelerations will also increase.

The assumed accelerations are given below as calculated by typical Class requirements. If any of the actual design accelerations are greater than these values, then the maximum loads should be increased accordingly.

Gyrostabilizer	Vertical Acceleration	Longitudinal Acceleration	Lateral Acceleration
VG52SD & VG70SD	±13.53 m/s^2 (1.38g)	±6.71 m/s^2 (0.68g)	±8.45 m/s^2 (0.86g)
VG100SD	±9.94 m/s^2 (1.01g)	±6.71 m/s^2 (0.68g)	±8.45 m/s^2 (0.86g)
VG520SD	±7.31 m/s^2 (0.75g)	±5.04 m/s^2 (0.51g)	±6.22 m/s^2 (0.63g)

Table 6 - Load Case Combinations

Maximum-Loading Design

Each of the six load cases outlined in Table 1 only includes gyrostabilizer-generated torques. The maximum loading design should be carried out with the inclusion of suitable vessel accelerations applied to the gyrostabilizer mass. The scantling design for maximum loads should be evaluated against the allowable stresses as stipulated by the relevant authority, *i.e.* a Class Society or Flag Administration.

It is worth noting that it is considered unlikely that all of the maximum torques and accelerations will occur simultaneously. However, it is still technically possible and thus it is recommended that the supporting structure be designed accordingly.

Fatigue-Loading Design

As mentioned earlier, the local scantlings supporting a VEEM Marine Gyrostabilizer should also be sized with due consideration to the fatigue loading. In fact, it may be found that this analysis is the determining factor when sizing local scantlings. Brackets, welds and other connections local to the gyrostabilizer should utilise structural details with good fatigue properties.

The gyrostabilizer produces a fully reversing set of loads in phase with the vessel's natural rolling period. Thus, in a 25-year lifetime, a gyrostabilizer can produce in excess of 5×10^7 alternating load cycles. The operating lifetime cycles for a particular vessel can be calculated using the formula:

——— [4]

where

= fatigue cycles for vertical loads

= fatigue cycles for horizontal loads

= lifetime in years [years]

= operating hours per year[hours]

= vessel natural roll period [seconds]

The load cases given in Table 1 are to be cyclically applied in a fully reversing manner for the calculated operating life of the gyrostabilizer. In general, the external accelerations on the gyrostabilizer are not in phase with the torques produced and are not required to be included in a fatigue analysis.

The allowable stress in fatigue design should be based on S-N data for the hull structural material. Various codes can be used to find a suitable S-N curve for the structural detail under consideration. Alternatively, test data can be used, with an S-N curve plotted 2 standard deviations below the mean. It is recommended that the allowable fatigue stress be read from the S-N curve at p cycles as per the figure below.

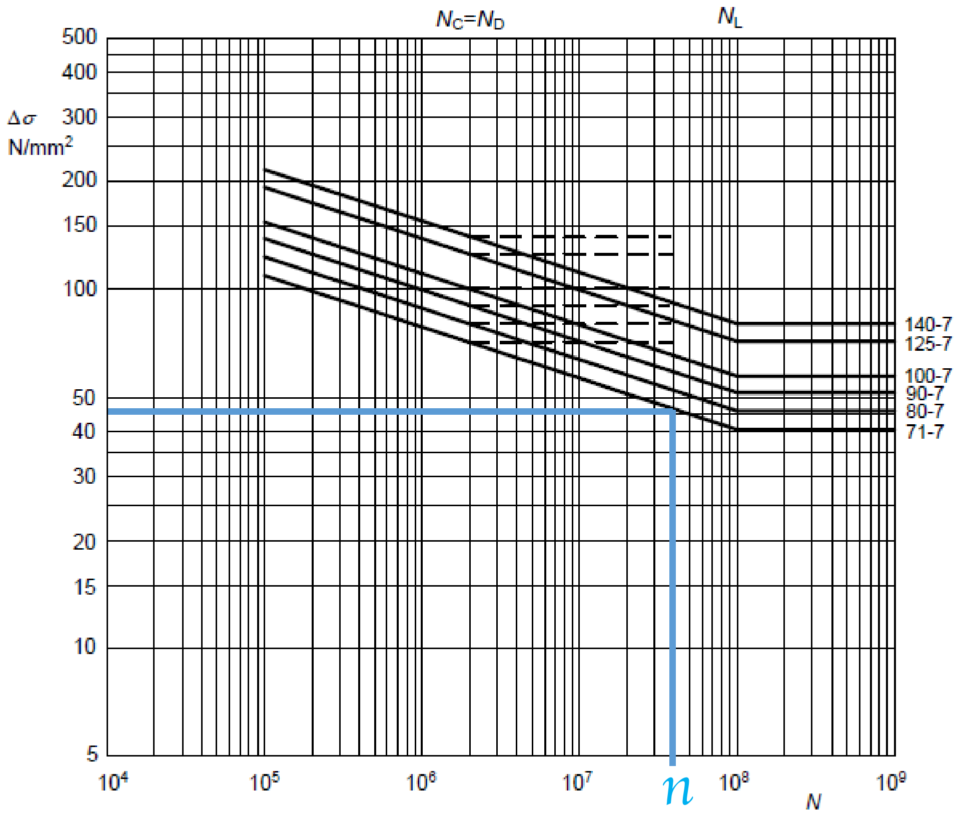

Figure 9 - Sample S-N Curve

Bolted Connection to Hull Structure

Each mounting foot on a VEEM Marine Gyrostabilizer is to be bolted directly to the hull structure using the 4 bolting holes provided. The installation drawing details the required bolt size and minimum preload. It is important that each bolt is torqued up to the minimum bolting preload as this ensures a structurally adequate connection. Failure to reach the correct preload may result in premature failure of the mounting bolts.

Multiple Gyrostabilizers

If multiple VEEM Marine Gyrostabilizer are fitted to a vessel, then the calculations described above are still valid. Multiple installations of gyrostabilizers will not change the natural rolling period of the vessel, but they will add more roll damping to the vessel. This means the roll and precession amplitudes are reduced which in turn reduces the gyrostabilizer precession rate. In general, this means that the forces produced by a gyrostabilizer are individually less in multiple unit installations.

VEEM Marine Gyrostabilizer are able to operate with the flywheel spinning in either a clockwise or anti-clockwise direction. If a pair of gyrostabilizers are fitted to a vessel, then they will be set up to spin in opposite directions in order to cancel out the total yaw moment on the vessel. This means that the gyrostabilizers will precess in opposite directions and thus the applied control torques will also be in opposite directions. This is likely to only be a concern if the supporting hull structure is not symmetric about the centre of the gyrostabilizer.

Contact

If you do need to cont ct VEEM's engineering group, please email gyro@veem.com.au

Further information about VEEM Marine Gyrostabilizer models is available at www.veemmarine.com