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# Use of Anti Rolling Gyro (ARG) Optimization Systems For Planing Boats

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## Abstract

In addition to the basic classification rules that must be taken into account during the design, products and purchase of a marine vessel; it is seen that the measures to increase comfort and safety have gained more importance in recent years. The engineering design of a boat has been conveyed to the customers as an advantage by the mass production companies, as a gain, as well as the efficient use of the volumes and the safety and comfort. Apart from the universal design, the qualities sought in many designs; It is inevitable that all technological progress will increase in parallel with the winning and marketing stages. In this context, it can be said that the main purpose of the design is to use the existing volumes effectively with the least physical effort. Especially since the early 1990s, when the understanding that yachts and recreational boats are the object of the upper class consumers, that is, the rich class, began to collapse, the production of planing boats gained speed. From 2000 to today, the competition of mass production companies, not only in the field of design, but also in the damping of excessive yaw and trim movements of marine vehicles; the comfort of the passenger and crew and the safety of the boat contributed to the development of these motion stabilization systems. In this study, gyro stabilizers (ARG) in order to balance the movements caused by the forces that a ship is exposed to in the water; working principle and basically application examples in slide boats are examined.

**Keywords:** Gyro, Gyro stabilizer, Roll, Planning boats.

## *Kayıcı Tekneler İçin Yalpa Sönümleyici Cayro Sistemlerinin Kullanımı*

***Özet***
*Bir deniz aracının tasarımı, imalatı ve teslimi aşamalarında göz önünde bulundurulması gereken temel klaslama kurallarına ek olarak; konforu ve güvenliği attırıcı önlemlerin son yıllarda daha fazla önem kazandığı görülmektedir. Bir teknenin mühendislik tasarımın da hem hacimlerin etkin kullanımı, hem de güvenlik ve konforu bir kazanım olarak, seri üretim yapan firmalar tarafından müşterilere avantaj olarak sunulmaktadır. Evrensel tasarım olarak sunulan ve sürdürülebilirlik açısından da birçok tasarımda aranan niteliklerin; tekne üretiminde ve pazarlama aşamalarında tüm teknolojik gelişmelere paralel olarak artması'da kaçınılmazdır. Bu bağlam da tasarımın temel amacı mümkün olan en az fiziksel çaba ile mevcut hacimlerin etkin bir şekilde kullanılabilmektir, denilebilir. Özellikle 1990'lı yılların başlarından itibaren yat ve gezinti teknelerinin bir üst sınıf tüketicilerin, yani zengin sınıfının objesi olduğu anlayış yıkılmaya başlandığında kayıcı tip teknelerin üretimi hız kazanmıştır. 2000'lerden günümüze gelindiğinde ise özellikle seri üretim yapan firmaların rekabeti, sadece tasarım alanında değil aynı zaman da deniz araçlarını aşırı yalpa ve trim hareketlerinin sönümlendirilmesi; yolcu ve mürettebatın konforu, tekne emniyetinin sağlaması amacıyla bu hareket dengeleyici sistemlerin geliştirilmesine katkı sağlamıştır. Bu çalışmada, bir geminin suda maruz kaldığı kuvvetlerin sebep olduğu hareketleri dengeleyebilmek amacıyla cayro stabilizörlerin (ARG); çalışma prensibi ve temel olarak kayıcı teknelerdeki uygulama örnekleri irdelenmiştir.*

***Anahtar Kelimeler:*** *Cayro, Cayro stabilizör, Yalpa, Kayıcı tekneler.*

## 1. Introduction

Gyroscopes are found in turbine rotors, planing boats, mobile facilities in ships, spacecraft, aircraft. It is generally used to provide automatic control of the movement. In order to balance the movement in the seawater, they are used to change the direction of the torpedoes.

When gyro discs begin to rotate around the axis of symmetry at high angular velocity in a certain center, there is a constant rotation on the same axis. With the studies presented by researchers using this feature, the design of systems that stabilize the rotational motion of objects with larger inertia has begun.

Balancing systems with the Gyro principle are used in many areas such as maritime, aviation, mining and space. In addition, gyrascopes are frequently used in the military field. (Veljović, 2010).

A gyroscope is a homogeneous, axisymmetric rotating body that rotates at high angular velocity around its axis of symmetry, as shown in Fig. 1.

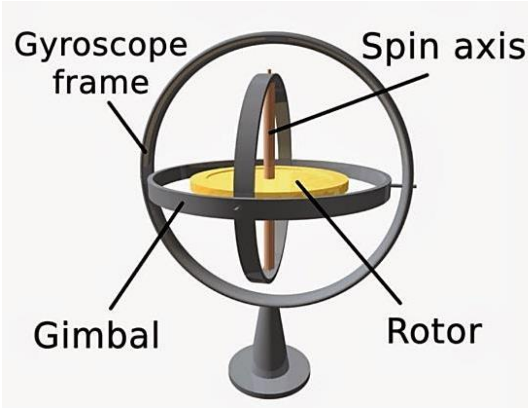


**Figure 1.** Schematic representation of gyroscopes (URL-1, 2020)

Except for aesthetics and cost criteria in the design, manufacture and purchase of a marine vessel; in recent years, comfort and safety design details have gained more importance.

In the engineering design of a boat, the effective use of designed volumes as well as safety and comfort are offered to customers as an advantage. As a result, it is inevitable to develop systems that increase comfort and safety at sea in the commercial environment.

In 1909 a model gyro was produced in Washington to provide stabilization. This gyro model was installed in US Destroyer Worden. Operating the gyroscope and creating all stabilizing forces; these forces were planned to be recorded. This gyroscope is given in Fig. 2.

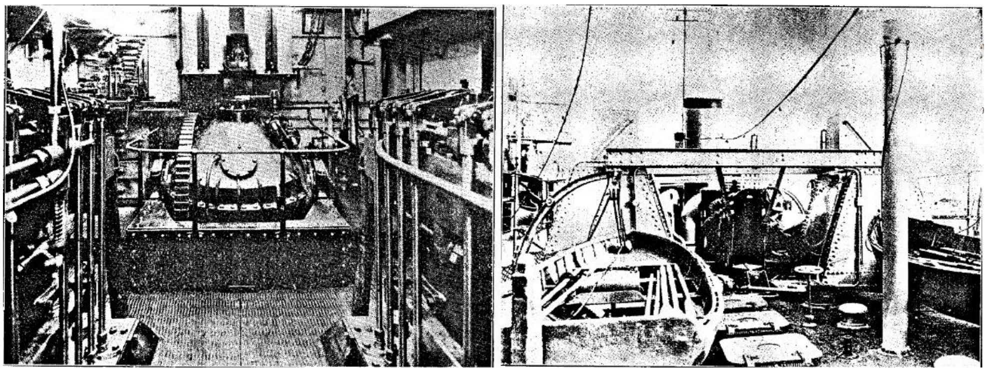

**Figure 2.** First installed stabilizer

Since 1912 active stabilization systems have been developed and applied in different fields (Sperry E.A., 1923). Later it was used in private yachts. With the increase in the production of planing boats from the 1990s to the present day, the application of ARG gyroscope stabilizers has also increased linearly.

In the 2000s, these systems found a wide application area. Research and development activities continue actively in the USA, Europe and Japan for commercial ARG products. It has been and is still being applied to many existing civilian, military, small and medium-sized ships. The historical development of gyro applications is given in Fig. 3.

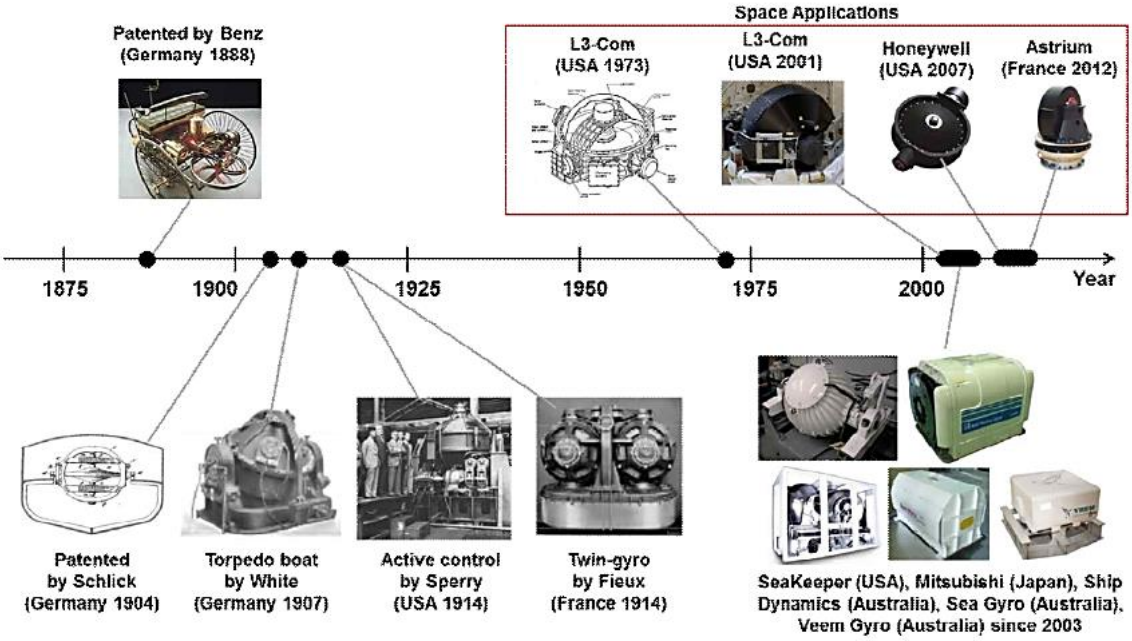


**Figure 3.** Historical Development of Gyro-stabilizer (Lee S. H., 2014)

Especially since the early 2000s, the understanding that yachts and recreational boats are objects of the upper class consumers, that is, the rich class, has begun to collapse. Production of planing type boats that can be used in many fields such as tourism, water sports, fishing, etc. has gained momentum.

Of course, changes are an inevitable part of the product development cycle. It should be handled with effective design. If a boat is not designed with the right strategy, the volumes to be produced and the parts in the assembly have to be redesigned. This saves both time and costs. Seen in a gyro Fig. 4 mounted on a aluminum planing boat.

**Figure 4.** Carina mounted gyro

Competition of mass production companies has contributed greatly to the development of these systems. Damping of excessive roll and trim movements of marine vehicles, not only in the design area; they contributed to the development of automatic stabilization systems for the comfort and safety of passengers and crew.

Gyro stabilizers can improve stability and marine performance due to their location. But the volumetric places and weights on the boat are still a disadvantage. A gyro mounted on the body can be seen in the Fig.4. These systems work by consuming electrical power. Generally, it can compensate 60% to 90% of the boat's roll and trim motion (Townsend, Murph, Shenoi, 2007).

As a standard feature, gyro systems are offered as a safety feature for more comfort and safety. Nowadays, the range of boat models that can be assembled in parallel with today's technological developments is quite diversified (Demir, Yalçın, 2017).

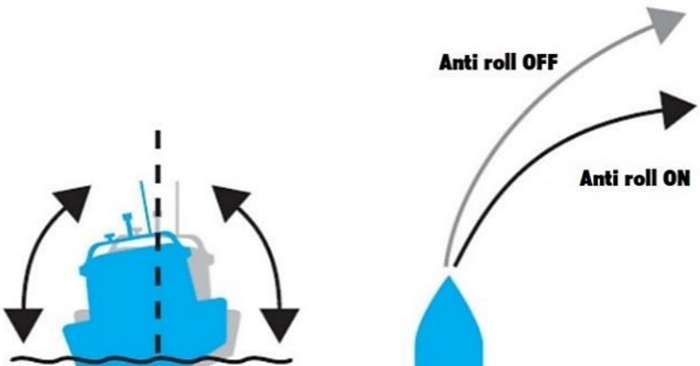


**Figure 5.** Anti Rolling system on and off

It can also be said that these systems have improved seaway resistance ($R_{sr}$). As a result of the related studies, it is presented as a graphical representation in Fig.5. In this figure, the route line when the system is active and inactive can be seen.

## 2. Case study

Besides the advantages of ARG systems, the theoretical description of the system, moment calculations and working condition of the weight-based balancing principle are shown in Fig.6. Relevant moment equations are given in Equations (1), (2), (3), (4), (5).

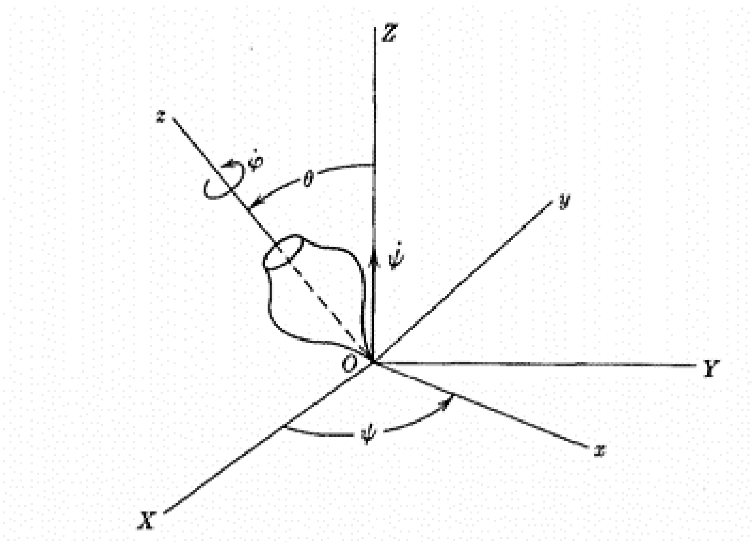


**Figure 6.** Definition of the gyro-axis system

$M_x, M_y, M_z$ : moments directions

$\dot{\omega}_x, \dot{\omega}_y, \dot{\omega}_z$ : angular acceleration +x, +y and +z directions

$\omega_x, \omega_y, \omega_z$ : the rate of rotation in free axis

I and $I_Z$ : moment of inertia; total and z direction

$\dot{\psi}$ : spin rate

General equations of motion for moment:

$$M_z = I(\dot{\omega}_x - \omega_y\omega_z) + I_z\,\omega_y(\omega_z + \dot{\psi}) \quad (1)$$

$$M_y = I(\dot{\omega}_y + \omega_x\omega_z) - I_z\,\omega_x(\omega_z + \dot{\psi}) \quad (2)$$

$$M_z = I_z\,(\dot{\omega}_z + \dot{\psi}) \quad (3)$$

Gyro-moments in +x and +y directions:

$$M_x = I_z \omega_y \dot{\psi} \tag{4}$$

$$M_y = -I_z \omega_x \dot{\psi} \tag{5}$$

## 3. The Basic Working Principle of Gyro Stabilizers and Method

Figure 7 gives an outline of the gyro stabilization system. Based on the principles outlined in Chapter 2, free axes, In order to balance ship yaw and trim motions for gyroscopic effects, ARG systems have to produce opposite moments by operating at a certain power. These forces, torques and moments are shown schematically in Figures 7 and 8.

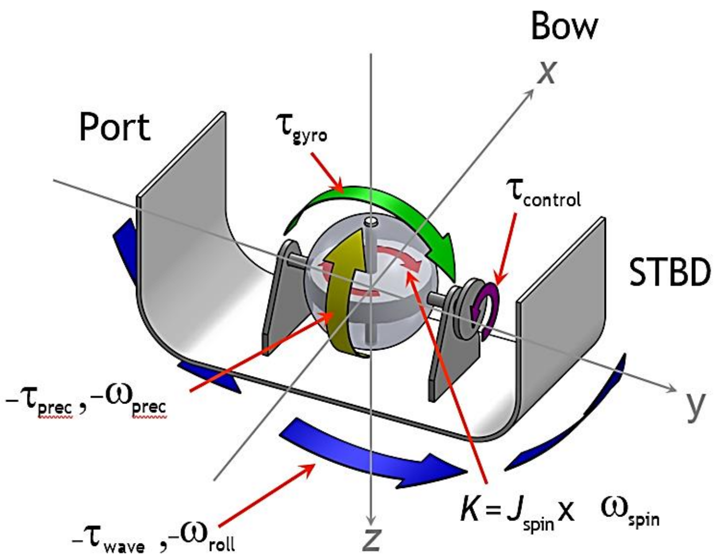


**Figure 7.** Demonstration of forces on gyro in coordinate system (URL-6, 2019)

Gyro torque given in Eq. (6) and angular momentum give in Eq. (7).

Gyro Torque = Angular Momentum x Angular Velocity

$$\tau = J_{spin}\omega_{spin}\,\omega_{prec} \tag{6}$$

$\tau$ : the gyro torque [Nm]

$J_{spin}$ : the rotational moment of inertia in the spin axis [kg.m$^2$]

$\omega_{prec}$ : the spin speed [rad.s$^{-1}$]

$\omega_{spin}$ : the spin speed [rad.s$^{-1}$]

Angular momentum (K);

$$K = J_{spin}\omega_{spin} \tag{7}$$

The angular roll rate ($\omega_{roll}$) combines with the flywheel angular momentum (K) to generate a precession torque ($\tau_{prec}$) on the flywheel (yacht's pitching axis) given Eq. (8);

$$\tau_{prec} = K\omega_{roll} \tag{8}$$

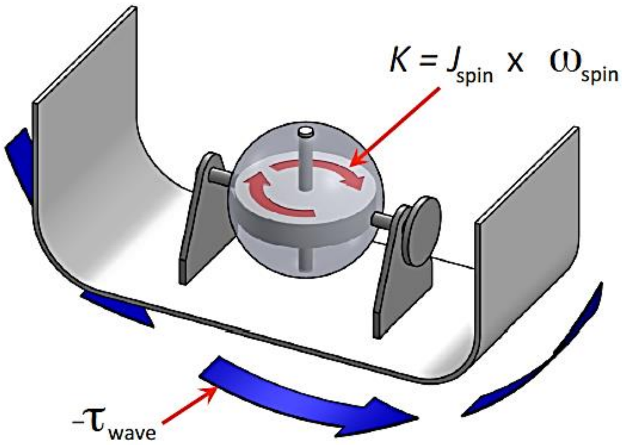


**Figure 8.** Representation of momentum K and τ wave torque versus the direction of yaw (URL-7, 2019)

The basic working principle of gyro stabilizers is that ARG's rotation axis can be freely selected. It can maintain its angular speed while rotating (URL-6, 2019).

The direction of the axis is independent of the direction of the stop when rotating. Therefore, it cannot be overthrown. The center of mass is fixed, it can be called a mass with a rotation in every direction, a wheel or a disc. Also, the double balancing ring is a wheel or disc used (Zhang, 2014).

## 4. Gyroscopic Stability

Gyroscopes consist of one rotatable or several nested discs placed on axes. These devices work on the principle of conservation of angular momentum.

When the gyroscope disk is rotated at a certain speed, the tool increases an angular momentum. The force of gravity creates a force against the gyroscope. With increasing momentum, the gyroscope continues its motion against this force.

It will rotate as long as the gyro discs can maintain the moment without changing the direction of rotation. Electricity is required for this balancing in large systems. To specify technically; A rotor rotating at high speed around its axes will generate force against all forces against the plane of rotation.

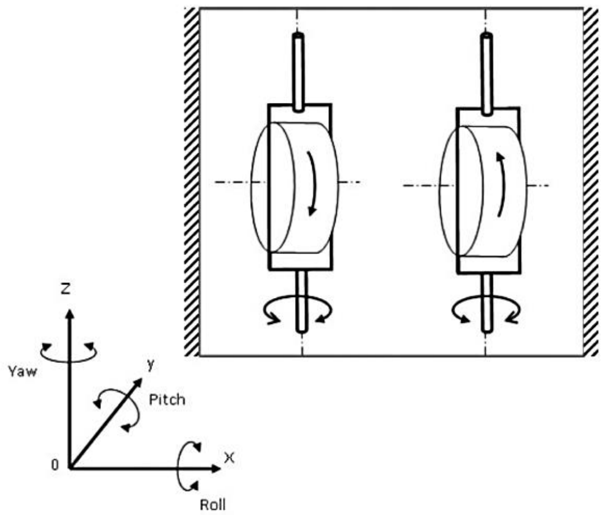


**Figure 9.** Schematic representation of twin type gyroscopic balancers (Townsend, and Shenoi, 2014)

As shown in Figure 9, momentum begins to gain when the Gyro rotor mounted in the center of the three axes starts to rotate rapidly. Then the stabilizing forces will start working against the force of gravity. Gyros works on this principle. The precession force exerts a force 90 ° opposite the axis of rotation. For the force applied to the rotor rotating rapidly around its own axis, the rotors will not remain stationary, they will continue to rotate in their direction of rotation. In this way, the rotational speed, forces and moments are determined. (Townsend, Shenoi, 2014).

Newton's second law of motion states algebraically that the acceleration of an object is inversely proportional to the mass of that object and directly proportional to the net force applied to that object. The net force acting on a body is equal to the mass times the acceleration. At this stage, the rotation of the gyroscope about the axis of rotation will give it an angular momentum. This moment will remain constant until the torque generated by the Gyro is stabilized. (Kim, Tilbury, 1998).

Gyro is used in planing boats to prevent the ship from rolling. While this system is active on boats, it can maintain its stability. It can soften dumping in Gyro Z axis. When the right hand rule is applied, the spin vector for the yaw motion is in the upward direction (+z direction). The direction of the Y axis is called pitch motion. On the X axis, a counter torque is generated. These defined vectors are perpendicular to each other (Talha, Asghar, Kim, 2017).

### 4.1. Motion Equations of Ships

The waves move in 6 different degrees of freedom (6-DOF) shown in the Fig. 10. The movements defined in the x, y, z axes are given.

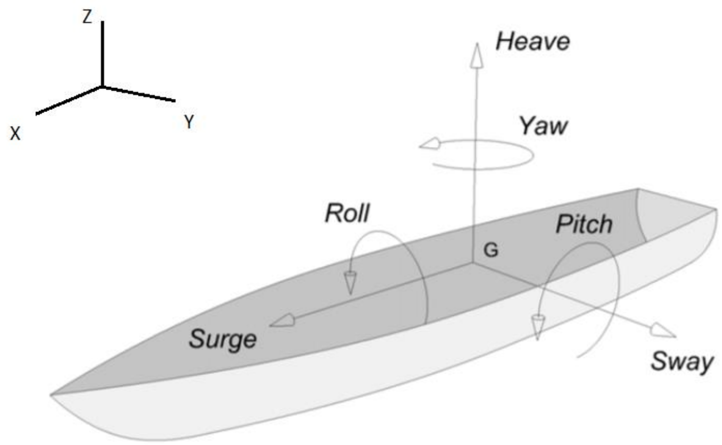


**Figure 10.** Ship motion is divided into six components in the six degrees of freedom (Varela, Soares, 2011)

Some definitions should be made for motion equivalents.

m : mass of ship

$I_z$ : moment of inertia [z]

X, Y, Z : external force [x, y, z]

u : velocity on x direction

v : velocity on y direction

r : snapin of angular velocity

According to the second law of newton motion equivalents can be written:

$X = m\,\dot{u}$

$Y = m\,\dot{v}$

$Z = I_z\,\dot{r}$

## 5. Applications for Boats

Patrol boats, coast guard boats and attack boats spend a large part of their operational time at low speeds, where traditional foil stabilizers do not work. ARG systems can significantly increase the operability of a ship and the safety and comfort of the crew. The increase in operational availability is an important criterion as it will increase the effective availability of the fleet. Application examples are seen in figure 11,12 and 13.

In addition, ARG systems, which enable the efficient use of weapons, increase the safety and efficiency of all operations in the sea. As a general disadvantage of traditional foils; The risk of collecting seaweed and mussels under water (beard as an old definition) will be eliminated (Giallanza, Elms, 2019). They contribute to adhering to the principle of maximum confidentiality for patrols, with a reduced underwater acoustic signature.

**Figure 11.** Military boats applied to the gyro system (URL-5, 2019)

**Figure 12.** A sportfiherman yacht applied to the gyro system (URL-2, 2014)

**Figure 13.** Motor yachts with gyro system (URL-3, 2019; URL-4, 2020)

## 6. Discussion and Result

The results of published scientific studies have proven that these applications are suitable for practical use. In addition, the simulations obtained as a result of these studies have taken their place among the theoretical studies in the literature. One of them is presented in figure14, specifically using the MatLab software program and a graphical representation of a boat when these systems are active and inactive. In the study the roll angle when ARG is active on the ship and the angle of roll measured when ARG is passive are given. (Talha, Asghar, Kim, 2017).

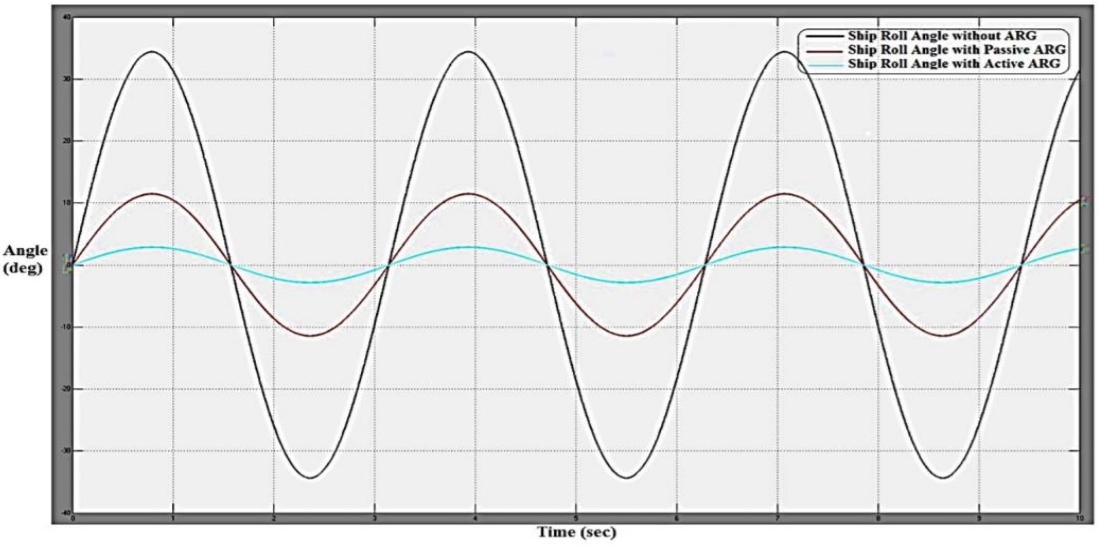


**Figure 14.** Ship roll angle response

In parallel with this, another study has been published including similar results. In this study, analyzes are shared for one mega yacht (Δ=180 tons). In addition, by examining the results obtained, ARG systems were also applied to this yacht. As seen in Figure 15, in this study, the estimated cornering rate and natural roll time achieved on the yacht are given. (Takeuchi, Umemura, Maeda, 2011).

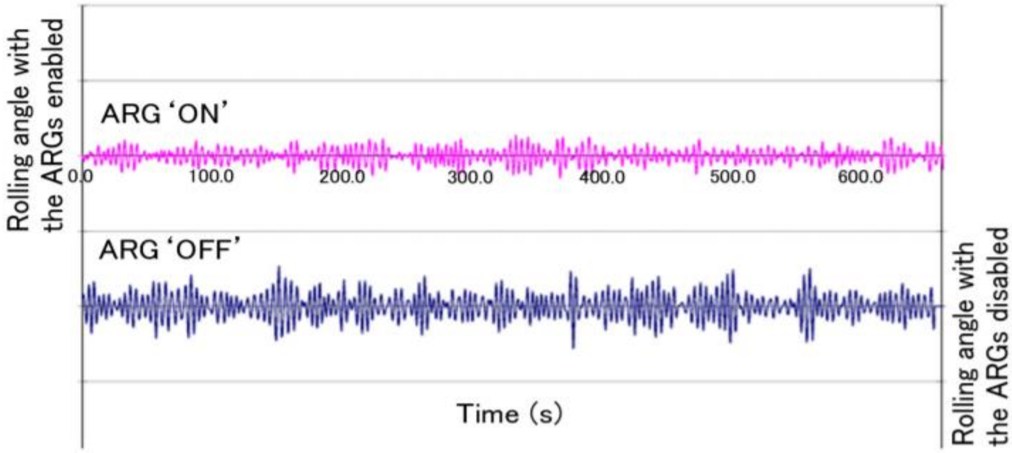


**Figure 15.** The results of ARG roll reduction performance on mega yacht

Comfort and safety is a priority for yachts. Large manufacturing companies offer works that increase comfort and safety by emphasizing aesthetic designs as special applications. An ARG has an effective function to provide extreme roll and dumping reduction in all conditions. With a suitable mode of operation, ARGs can ensure the stability of the boat in all conditions and reduce seaway resistance.

It is possible to see different applications in sport fishing yachts, flybridges, center console..vb and many planing boats. ARG stabilizers can be produced today in smaller volumes and weights. And this situation provides more efficient use of the volumes in the boats (Veljovic, 2010).

**Table 1.** ARG systems applied in some yachts (Takeuchi, Umemura, Maeda, 2011)

| | **Ferreti 430** | **Ferreti 680** | **Ferreti 731** |
|---|---|---|---|
| ARG-Output Torque | 12,500 Nm | 25,000 Nm | 37,500 Nm |
| LOA | 14.15 m | 20.63 m | 22.50 m |
| B | 4.34 m | 5.63 m | 5.50 m |
| Δ | 18.2 t | 45.0 t | 56.9 t |

As an advantage of the system, there is no extension from the hull to the water. ARG dynamically rotates the rotors of the high speed steel flywheel in a vacuum controlled chamber. The boat movements are reduced by the balancing moments produced and almost no noise or vibration is produced. Sometimes they can be successfully mounted in front of center consoles, even under guest cabin beds. Related samples can be seen in Fig. 14, Fig. 15, and Table (1). In the table, displacement weight (Δ), overall length of the boat (LOA) , beam of the boat (B), torque values of the gyro used are given (ARG-Output Torque).

Looking at all these application examples, it is obvious that ARG systems increase comfort and safety. However, the electricity consumption of these systems is inevitable. Today, studies for reducing electrical energy consumption are still ongoing. With technological developments, the use of low electricity consumption and more efficient ARG devices in production will increase even more.

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