ZIPWAKE DYNAMIC TRIM CONTROL SYSTEM

OUTLINE OF OPERATING PRINCIPLES BEHIND THE AUTOMATIC MOTION CONTROL FEATURES

ZIPWAKE

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OUTLINE OF OPERATING PRINCIPLES BEHIND
THE AUTOMATIC MOTION CONTROL FEATURES

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1 INTRODUCTION

The Zipwake Dynamic Trim Control System is a state-of-the-art stand-alone trim control system that optimizes the performance and ride comfort of planing and semi-planing boats between 6 m and 18 m (20-60ft).

The system uses patented high-precision interceptors for precise control of running trim, heel or heading. Since near full beam interceptor arrangements are much more efficient at generating lift compared to conventional trim tabs with narrow span, the required interceptor blade stroke becomes small – just 30mm. In addition, interceptors are significantly faster than conventional trim tabs and their use consequently enables the possibility to rapidly respond to external forces acting on the boat to maintain the boat's desired pitch and roll angles for better performance, fuel economy, comfort and safety. This control can be done manually with a unique 3D control, or - most conveniently - fully automatically by the push of a button.
This document outlines the operating principles behind the automatic motion control features of the Zipwake Dynamic Trim Control System.

2 SYSTEM COMPONENTS

The Zipwake Dynamic Trim Control System incorporates both automatic pitch and roll control. When operating in automatic control mode the system actively controls the boat attitude, i.e. generates the proper lift force at each side aft to level the boat to the desired pitch and roll angles. This requires rapid adjustment of the interceptor blade extension that will depend on several parameters, e.g. boat hydrodynamic properties, speed, as well as external forces acting on the boat, such as wind and waves. To accomplish this task the system is equipped with a built-in GPS receiver and three-dimensional accelerometer and gyroscope sensors, also known as a 6 degree-of-freedom (6-DOF) inertial measurement unit (IMU). These sensors, along with information about interceptor configuration, the boat length, width, and weight, enables determination of the boat attitude and computation of the required interceptor extensions that will regulate the attitude to the desired state. This is done separately for pitch and roll and the methodology between the two differs in that the pitch controller determines the commanded interceptor extensions in a curve-based manner, using either a curve computed by an integral proprietary generalized hydrodynamic craft model or a curve derived from sea trials, whereas the roll controller uses the generalized craft model together with a feedback regulator to keep the boat at a desired roll angle.

3 PITCH AND ROLL ANGLES

Accurate determination of the boat's attitude (roll, pitch, and yaw angles as measured between boat-fixed and an Earth-fixed frame of reference) at all times is critical for the system functionality. This state estimation of the boat is achieved by sensor fusion of the signals acquired from the 6-DOF IMU and GPS receiver. The sensor fusion includes the laws of motion to take into account the forces acting on the boat due to its motions so that its attitude relative to the inertial frame can be determined. The pitch and roll angles are presented in the main view of the Control panel (Fig. 1).

Fig. 1. Illustration of the Control panel display with its pitch and roll angle indicators.

4 AUTOMATIC PITCH CONTROL

The generalized craft model provides the system with a pitch control curve that controls the interceptor extension at each speed to achieve the desired trim or pitch angle (Fig. 2). The shape of the curve reflects the reduction in hull resistance when running at optimal trim or pitch angle.

The interceptors are not engaged until the boat moves forward at idling speed. During transition from displacement to planing regime, the interceptors are quickly fully extended to generate as much lift as possible thereby swiftly bringing the boat up on plane. As speed further increases, the interceptor blades are successively retracted to eliminate drag until fully retracted when the boat naturally trims correctly.

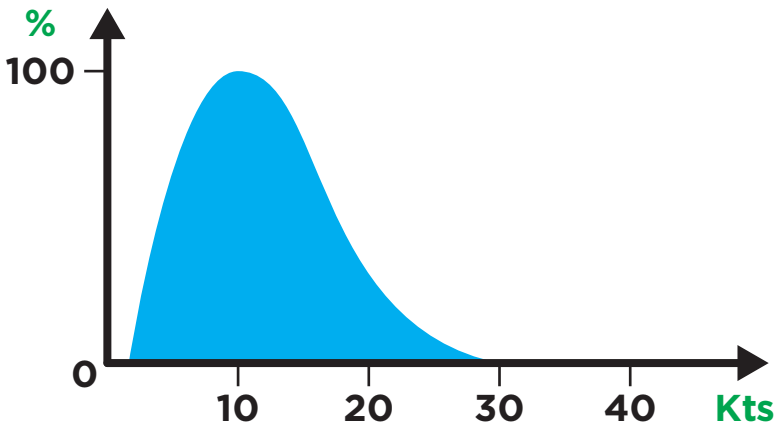

Fig. 2. Example of interceptor extension versus boat speed curve for pitch control.

Fine tuning of running trim is left to the operator by allowing manual offset of the automatic pitch setting to compensate for variations in sea and load conditions. The pitch-control offset appears as green numbers in the main view of the Control panel (Fig. 3a).

By pressing and holding the Control panel's roll control wheel, the pitch control curve is locally altered around the current boat speed (Fig. 3b). Saving a preferred trim setting in this manner, at a few different boat speeds, is a very quick way to build the optimum curve for a specific boat and load condition.

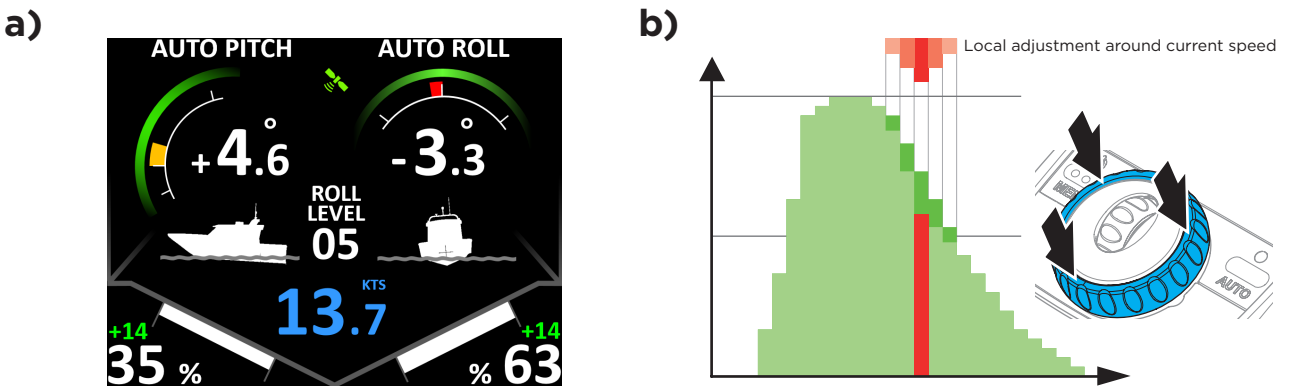

Fig. 3. a) Panel view showing applied pitch-control offset as green numbers. b) Depiction of quick save of pitch-control offset.

5 AUTOMATIC ROLL CONTROL

On a straight course the Zipwake roll controller automatically and actively keeps the boat as close to zero roll angle as possible (Fig. 4a), regardless of weight changes such as passengers moving around or other forces from wind and waves that tend to roll the boat. During turns, on the other hand, the roll controller attempts to bring the boat to an angle that makes the resultant force of gravity (***g***) and the inertial force due to the turn (F_y) parallel with the boat's centerline, hence a coordinated or perfectly balanced turn is achieved, so that passengers are not experiencing lateral forces (Fig. 4b).

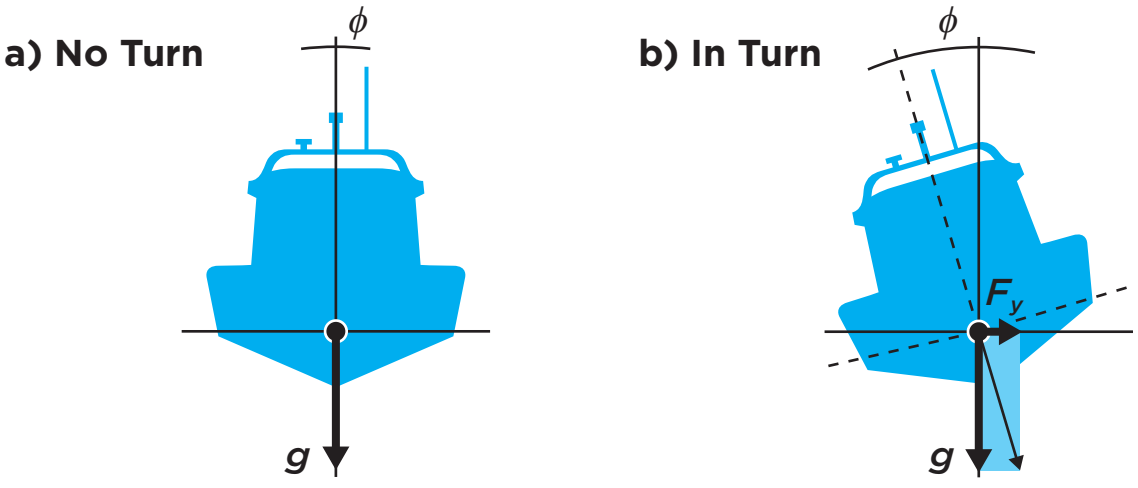

Fig. 4. Illustration of the desired roll angle ϕ, a) at straight course and b) during turn.

The automatic roll controller is a proprietary adaptive PID-regulator developed for the Zipwake Dynamic Trim Control System. The system block diagram is shown in Fig. 5. The PID-regulator minimizes the difference between the desired roll angle, $\phi_{desired}$, and the actual boat roll angle, ϕ, obtained from the sensor fusion. The PID-regulator produces a regulation roll angle, ϕ_{reg}, that by means of the generalized craft model is converted into commanded interceptor extensions, u_a, that are expected to produce the required roll moment to bring the boat to the desired roll angle. The actual roll moment, τ_a, that the interceptors apply will, together with external forces, w, bring the boat to a new roll angle, which is measured and fed back to close the regulator loop. Note that while turning the target angle $\phi_{desired}$ is not equal to zero but depends on the speed and the radius of the turn, i.e. the amount of inertial force experienced by the boat (and passengers) due to the turn. Consequently, the system also includes an identifier for whenever the boat leaves a straight course and enters a turn, and then adjusts $\phi_{desired}$ to make the turn comfortable. The reverse applies when the boat returns from a turn into a straight course. The turn recognizing method is non-trivial and relies heavily on the accurate motion measurements.

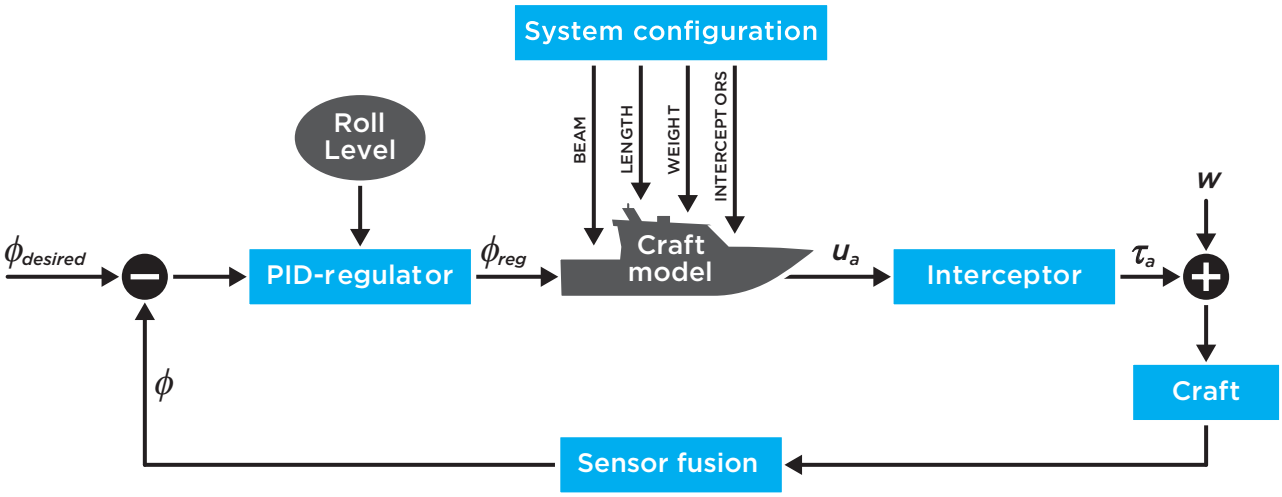

Fig. 5. Block diagram of automatic roll controller.

The system allows operator adjustment of the roll controller's activeness by adjusting the Roll Level, which can be positive in certain sea states or when automatic roll control is used in combination with course keeping systems that sometimes cause interference. The Roll Level adjustment is easily accessible by turning the Control panel's roll control wheel (when operating in automatic roll control mode) and the current Roll Level setting is displayed in the center of the main view of the Control panel (Fig. 1). There are ten different roll levels, 5 being the default and a good average for most planing craft.

6 CONCLUSION

Zipwake Dynamic Trim Control System provides robust automatic motion control features to effortlessly keep the boat at an optimum attitude when running in calm water or in a seaway. It brings the boat up on plane at lowest possible speed, improves fuel efficiency, optimizes forward visibility, and eliminates unpleasant roll at both straight course and during turns. All to bring the best out of every boat and everyone's ride experience. Choose comfort. Enjoy performance.