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TECHNICAL MEMORANDUM 3-77

A LOW COST ADAPTABLE HEADING
HOLD SYSTEM FOR ALVIN

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HOLD SYSTEM FOR ALVIN

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Summary

This report describes a low cost heading hold system that has been operational on the DSV ALVIN since October 1975. This system reduces pilot fatigue during straight line transits and allows the pilot to more effectively monitor the overall operation.

A Low Cost Adaptable Heading Hold System For ALVIN

I. Introduction

Ship and aircraft autopilots were developed because they substantially reduce pilot fatigue during extended straight line transits. They allow the pilot to monitor the overall operation without making constant heading corrections. Indeed, the vehicle electronic instruments are more sensitive than the pilot to heading changes and can make corrections sooner. This results in a smoother straight line transit.

The usual approach to ship control system design includes an evaluation of vehicle dynamic coefficients and computer optimization of the control variables. This process is very costly in terms of both time and money. The prototype heading-hold system for ALVIN, described in this report, is designed with a sufficient range in the controlled variables to allow for an in-vehicle adjustment for optimum performance. The system is inexpensive because of the design approach and simple hardware implementation. It has been in use on ALVIN for nearly two years and is part of the normal operations on nearly every dive.

II. System Operation - Pre-Heading Hold

The ALVIN stern propulsion unit (rudder) was positioned by a hydraulic ram drive that utilized simple on-off flow control. The pilot actuated a momentary switch to open hydraulic valves for right or left rudder movement. Stern prop (or rudder) position was monitored by a potentiometer meter display. The potentiometer was located on the rudder and had the wiper connected to a meter. Submersible heading was monitored by the gyrocompass and displayed to the pilot. The pilot monitored heading and manually positioned the rudder for heading control. Operations also included repositioning the rudder to the zero position prior to starting a new maneuver. This was accomplished when the pilot activated the rudder and monitored the rudder angle indicator.

III. Theoretical Control Loops

A basic ship steering control system is shown in Figure 1. This diagram represents most conventional ship steering control loops. The command heading (ψ_c) is compared to the actual ship heading (ψ_a) and a resultant heading error (ψ_e) is generated. This is transformed to ordered rudder (δ_r). As a function of ship dynamics, the ratio of ordered rudder to heading error (δ_r/ψ_e) may be varied. With a ratio of 2, there will be 2° of ordered rudder for 1° of heading error. This gives a quick response. A ratio of 0.2 could give a very slow response. Actual ship heading is differentiated to provide heading rate ($\dot{\psi}_a$). This signal is used to provide damping and, when subtracted from ordered rudder, results in rudder command with rate (δ_c) that is used to drive the rudder. Actual rudder position (δ_a) is compared with commanded rudder (δ_c) to give rudder error (δ_e). Since the rudder drive on ALVIN as well as many ships is an on-off system some dead zone is necessary to provide a zero drive or rest zone. A small dead zone will provide a very tight rudder control with many corrections per minute. A large dead zone will provide a loose rudder control with few corrections and lower accuracy heading control. This basic loop exists on ALVIN with the pilot providing the judgement on the variables and directly controlling rudder rate and position. Fully automatic systems function like the prototype system described in the following section.

Functional System

The ALVIN heading hold system is shown in Figure 2 and will be described with reference to the Heading Hold Functional Diagram in Figure 3. The existing ALVIN circuits are shown separately and the interface cable connection is in the center. The existing connectors are parted and then mated with the control system. If necessary, the entire control system can be removed by reconnecting the existing connectors. The propulsion control box switch directly activates the "right" or "left" and "unblocking" hydraulic solenoids to move the steering ram and position the stern prop. Stern prop position is monitored by a potentiometer that indicates on a meter in the sphere.

The heading hold section has an actual heading (ψ_a) input from the vehicle gyrocompass or magnetic compass. Both of these devices have $\pm 2.5V$ DC = $\pm 180^\circ$ to drive the Brush Recorder. Actual (ψ_a) and command heading (ψ_c) are compared to find heading error (ψ_e). This heading error is the product of two linear d.c. voltages and therefore does not have continuity at the ± 180 crossover. This is adjusted by two comparitors and a summing amplifier. If the heading error is between -180° and $+180^\circ$, no correction is necessary. The control loop will drive to a proper null through a minimum distance. (Refer to Figure 4). If the heading error is greater than $+180^\circ$ then a constant 360° must be subtracted from the error to obtain a null by driving a minimum distance. This is accomplished by a comparitor that has an output of zero degrees if the error is less than $+180^\circ$ and an output of $+360^\circ$ if the error is greater than $+180^\circ$. This output is fed to the summing amplifier. In a similar manner, if the heading error is more negative than -180° , a constant 360° must be added to the error. A second comparitor provides this function, and feeds the same summer amplifier. A simple example of this situation is an actual heading of 5° (ψ_a) and a desired heading is 355° (ψ_c). The heading error will be $+350^\circ$ (ψ_e) and the control loop would attempt to drive clockwise 350° . It is necessary however to subtract 360° from (ψ_e) to obtain -10° (ψ_e) so that the control loop drives counter clockwise 10° . As the actual heading crosses the $0^\circ/360^\circ$ point the actual heading becomes 360° and the heading error becomes -5° , thus the comparitor no longer has to subtract 360° and the system continues to drive counter clockwise the additional -5° . Other examples can be worked out using the diagram of Figure 4. The rudder position control loop has an input selected by the relays and is either a heading hold signal or a zero rudder signal. This is compared to the actual rudder position (δ_a) and a rudder position error (δ_e) is generated. Dead zone is controlled by using comparitors to switch drive transistors also have LED indicator lights to give a visual indication of the operation.

The system has three variables that govern the vehicle response. These are adjustable via the dials on the front panel and include rudder angle to heading error ratio (δ_r/ψ_e), damping (D), and dead zone (DZ). The ratio of actual rudder angle voltage (δ_a) to modified heading error

(ψ_e) voltage determines the rudder angle to heading error ratio that can be controlled on the front panel. This ratio has a maximum value of 2 and a minimum value of 0.2. Actual heading (ψ_a) is differentiated electronically to obtain heading rate ($\dot{\psi}_a$). This is subtracted from rudder command to provide variable yaw damping. A low damping gain will result in a fast response system that tends to over-shoot the desired heading. A high damping gain will result in a slow response without over-shoot. The damping can be varied from an arbitrary value of zero to one. The dead zone is a variation around the desired rudder position. When the actual rudder position is within the dead zone there is no rudder command. When the actual rudder position is outside of the dead zone, the rudder drive solenoids are activated. The dead zone can be varied from $\pm 1^\circ$ to $\pm 5^\circ$.

Circuit Design

The following paragraphs describes the system schematics (3 pages). On page 1 of 3, the input is from the gyrocompass D/A converter and is scaled by the first op-amp (ICI).

The heading reference signal, (test point A) TP-A, is ± 5 volts dc and equals $\pm 180^\circ$ azimuth. The desired heading has the same scale factor. Since these signals are subtracted in 1C2 to obtain heading error, (ψ_e) this signal at TP-B has a scale of ± 10 volts which equals $\pm 360^\circ$ of azimuth.

Due to the discontinuous function at 180° , the system could attempt to drive in the wrong direction unless the following correction is made. Heading error is compared to both +5 volts and -5 volts in 1C3 and 1C4 and if the signal is greater than these values, a 10 volt signal is subtracted or added in 1C5 to obtain the corrected heading error (ψ_e) TP-C. The scale at this point is ± 10 volts equals $\pm 25^\circ$ heading error.

The rudder angle to heading error ratio is set at the low limit to 1/10 of the full signal by a trim pot. Damping ratio is obtained by differentiating heading at 1C6. This signal does not have a scale factor but is subtracted

from the rudder command signal at 1C7 after some fraction of full signal is selected by the panel potentiometer. The corrected rudder command due to heading error is on TP-E in the heading hold mode. Both the rudder position reference and zero reference have a scale factor of ± 10 volts full scale or 0.2 volts/degree and are on TP-E in the rudder mode.

The rudder angle indicator on page 2 of 3 is isolated from the rest of the electronics by the photoisolator MCT2. The output of the MCT2 is adjusted by 1C8 to have ± 0.2 volts/degree. The output of 1C8 is actual rudder position (δ_a). The rudder set signal and the rudder zero signal is the desired rudder position (δ_c) and is scaled by 1C9. Relays A or B select heading or rudder modes. Actual rudder and desired rudder are subtracted in 1C10 to obtain rudder error at TP-G and the scale is 1 volt/degree. Rudder error is compared with the dead zone selected by 1C11 and 1C12. If the dead zone is exceeded, the drive transistors are activated.

Operational Experience

The heading hold system was installed on ALVIN two years ago. The best system operation occurred with a "Rudder Angle to Heading Error Ratio" set at 2, "Damping" set at 1, and dead zone set at $\pm 3^\circ$. Using these settings ALVIN will maintain the desired heading with a $\pm 3.5^\circ$ heading variation due to the dead zone, when the main prop is operating at "one motor/40 amps." A step input in "desired heading" results in a $1.5^\circ/\text{Sec}$ slew rate and a single 5° overshoot before settling on the new course. The prototype system has provided a reliable and convenient heading hold system that is used in nearly every dive on ALVIN. The system was inexpensive to build and provides performance well matched to the steering system on ALVIN.

Improvements can be made in system performance. However, this will require changes in the steering actuators as well as in the hardware used in the heading hold system. A proportional activator to drive the rudder should replace the bang-bang system presently used. Position sensors should be synchros instead of potentiometers. When the mission requirements indicate a need for an improved heading hold system these changes can be considered.

ψ_C	COMMAND HEADING	$\dot{\psi}$	HEADING RATE
ψ_A	ACTUAL HEADING	δ'_r	RUDDER COMMAND WITH RATE
ψ_e	HEADING ERROR	δ_r	RUDDER ANGLE

Figure 1 Ship Steering Control System

Figure 2 ALVIN Heading Hold Electronics

$-\psi_e$

Figure 4 Heading Error vs Voltage

Figure 5 System Schematic (page 1 of 3)

Figure 7 System Schematic (page 3 of 3)

Figure 8 System Cable Diagram