The Autopilot Primer

Patented

by
Cetec Benmar

THE WORLD'S LARGEST PRODUCER OF MARINE AUTOPILOTS

Price: $2.00

INTRODUCTION

An autopilot is one of the most useful accessories a boat owner can have for his boat. Often, it is a necessity. Unfortunately, it is also one of the least understood accessories, with the result that many boat owners deny themselves the pleasure and convenience afforded by an autopilot simply because they are unaware of its many benefits.

To help you better understand autopilots and their various differences, Benmar has prepared this Autopilot Primer. It explains the uses, basic types, methods of operation, advantages and disadvantages, and the important features to consider when making an autopilot selection. Also, a Glossary of common terms relating to autopilots is included at the end of the Primer.

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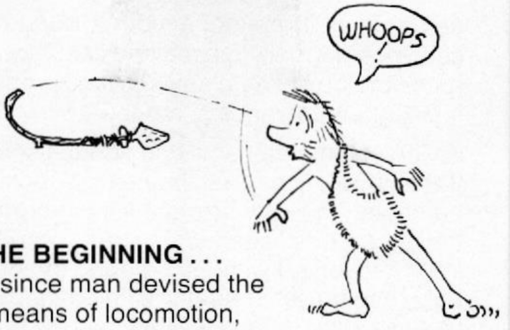


IN THE BEGINNING . . .
Ever since man devised the first means of locomotion, he has searched for a method of automatic guidance. By stretching the imagination a bit, you might even consider primitive man's attempt to improve the flight path of his spear by tying feathers to one end as an initial effort to apply principles of self-guidance to a moving object. Unfortunately, however, any progress beyond controlling the flight of spears was about as slow as man's own historic development. It wasn't until the blossoming of aircraft technology that a level of electro/mechanical sophistication was reached where the word *autopilot* would be known by all.

JUST WHAT IS AN AUTOPILOT?
Basically, an autopilot is simply an automatic system for controlling the heading or attitude of a moving vehicle or object. In the case of a marine autopilot, it is a system designed to maintain a boat on a pre-selected course. An important additional function is to serve as a direct or remote controlled power steering system.

WHO USES THEM? AND WHY?
Just about anyone who owns or commands a boat can use an autopilot. Often they are an absolute necessity because they make the difference between enjoyment and drudgery. They are to the boat owner what power steering and cruise control are to the automobile driver; more so, since many times there are no targets to which a course can be aligned, and manual steering must be done while watching the compass which is frequently tedious and fatiguing.

One of the primary uses of the autopilot is for control of the boat on long cruises, freeing the skipper for observation, either directly or by radar. It also allows the skipper to assist in any normal or emergency duties which might be required. Then too, a more accurate course is normally maintained with a quality autopilot, providing a savings in fuel and a subsequent increase in range.

To the commercial and avid sports fisherman the autopilot is a great time saver. Tackle can be rigged on the way to the fishing grounds, trolling accomplished under pilot control, fishing nets worked without the need of additional help, and power steering handled through the use of a remote hand switch to provide control of the boat from the fishing station.

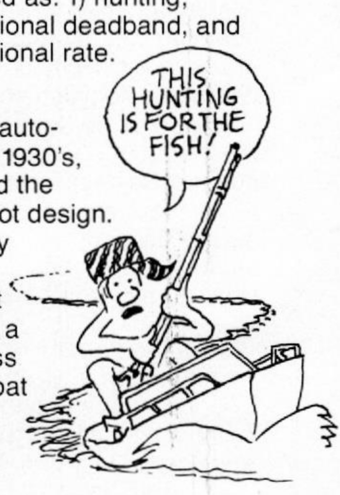
To the pleasure boater, the most obvious advantage is that he can "join the party". He need not be tied to the helm while others in the boating party are enjoying themselves. Operation by autopilot requires only an attentive and alert observer.

TYPES OF MARINE AUTOPILOTS

At the present time there are three different types of marine autopilots that are most commonly used on vessels from 18 to 125 feet. They are classified as: 1) hunting, 2) non-hunting proportional deadband, and 3) non-hunting proportional rate.

Hunting Autopilot

The so-called hunting autopilot, developed in the 1930's, is generally considered the original marine autopilot design. Its principle is relatively simple. The helm is continually moved port and starboard through a small angle. A compass detects whether the boat is to port or starboard of the proper heading, and the helm is driven



appropriately to correct the error. As the helm is driven, the boat will obviously cross the heading to the other side. The helm will then be driven back in search of, or hunting, for the desired heading. In this manner the boat will zig-zag. The amount of zig-zag will vary from boat to boat.

It is obvious that the hunting autopilot, although simple in concept, must be working all the time. This results in high power consumption and excessive wear on the steering and pilot system.

Non-Hunting Proportional Deadband Autopilot

Along came the 40's and a significant refinement to the hunting autopilot was made by introduction of a *deadband* into the system. Within this deadband the helm is inactive. When the heading error exceeds the deadband, however, the helm is moved in the appropriate direction by an amount proportional to the heading error. In this manner, larger errors provide more helm, but if the boat maintains its desired course within the limits of the deadband, no autopilot action is initiated. The majority of current marine autopilot designs employ this proportional deadband principle.

The proportional deadband type system was used by the aircraft industry in the early days, but was eventually discarded for all but the simplest control functions. A much more versatile system is one which uses proportional rates as the basic control criteria.

Non-Hunting Proportional Rate Autopilot

In this system, heading error and the rate (or turn speed) of change of heading error is detected and it commands the correct helm action to reduce this change to zero. This proportional rate system was introduced to marine autopilots in 1975, and is used in the Benmar Course Setter*® and Course Keeper autopilots. No deadband is employed. Instead, the autopilot controls the helm at various rates or speeds. The system automatically selects the appropriate helm rate to reduce the heading error (and heading rate) to zero. This provides significant advantages in simplicity and performance since the pilot becomes adaptable to a wider range of boats and many of the normal operator controls can become automatic. In short, the proportional

* Patented

rate autopilot steers the boat in the same manner that an experienced helmsman steers whereas the hunting and proportional deadband systems do not.

STEERING SYSTEMS

One of the major factors to be considered when selecting an autopilot is the type of steering system involved. Steering systems are either mechanical or hydraulic, and with various classifications in each.

Mechanical

The simplest mechanical steering system is the open cable type used on outboards, ski boats and wheel-steered sail boats. The two most common classes are the push/pull cable and dual cable types, both of which are used on inboard/outboard boats and many medium sized ruddered boats. Push/pull systems are mass produced and come in a few standard types from major steering manufacturers. Another type of mechanical steering system is the chain and shaft system which generally is found on larger or custom-built boats.

Hydraulic

Hydraulic steering systems fall into two categories: a manual helm pump is utilized to drive the power cylinder (or ram), or a power assisted hydraulic system uses an engine driven pump and valves to control hydraulic fluid flow.

The manual pump system is normally found on most pleasure and small commercial boats. Some manual systems have an additional shaft from the rear of the helm unit for the single purpose of connecting an autopilot; other systems offer special helm units for autopilot connections. When provisions for autopilot connections are not available, an autopilot having its own hydraulic pump must be used.

BOAT DYNAMICS

It is important that the autopilot be properly matched to the characteristics of the boat, primarily the boat's response to turn commands, the amount of torque (or energy) necessary to turn the boat and the amount of offset in the rudder center position expected over the boat's operating range.

Turn Time

The turn time, or the boat's response to turn commands, is the time it takes the boat to make one 360-degree circle with one full turn from center position on the helm. The turn time of the boat is equivalent to the inverse of the boat's gain. In other words, the longer the time for the turn, the lower the boat's gain. A boat which takes 20 seconds to make a 360-degree turn is said to have a gain of 1/20 or .05. Turn time will vary with speed and can vary from port to starboard turns.

To measure a boat's turn time, one need only take the boat to an open stretch of water and record the time it takes to make a 360-degree turn, both to port and starboard, with one full turn* on the helm. Such turns should be made at cruising speed and also at the slowest speed.

Helm Torque

The helm torque is the amount of force that is required to turn the helm. This is generally greatest during a turn at high speed. Torque is

*Obviously, on some boats a full turn will be too much helm to apply at cruise speed. In this case, one needs only to apply an amount of helm which will give a comfortable turn. Make a 360° turn, measure the time, and normalize this time to one full turn of the helm by dividing the helm angle used by 360° and multiplying this by the time of the turn (i.e., if one-half turn of helm is used, then: turn time = measured time multiplied by $\frac{180°}{360°}$).

measured in inch/pounds, which is the number of pounds of force required to turn the helm times the number of inches from the center of the helm to the point at which the force is being applied.

Helm torque can be measured by use of a fish scale and a loop of string around the helm. The boat should be pulled into a sharp turn at various speeds and the amount of force (in pounds) noted. Then by multiplying the distance (in inches) by the pounds of force required, the wheel torque in inch/pounds is determined.

Rudder Offset

Rudder offset is the amount in degrees that the rudder will vary from the center position as a result of boat trim, boat speed, or different sea conditions. Rudder offset referred to the helm can be determined by choosing and marking a center position for the helm and noting how many degrees this center position must be moved to provide a constant heading while varying the engine speed and boat trim. If trolling under pilot control is desired, the offset should also be measured under these conditions.

SELECTING THE RIGHT PILOT FOR YOUR BOAT

Based on the measurements mentioned above, the following information should enable you (or your dealer) to determine the proper auto pilot for your boat. If the boat gain does not vary more than 2 to 1 over the desired range of boat operation, nearly any autopilot with sufficient torque will satisfactorily steer the boat. On the other hand, if the boat turn time (and gain) varies more than 2 to 1, it will be necessary to select an autopilot with either adjustable or automatically variable rudder ratio. The Course Setter and Course Keeper series of Benmar autopilots are capable of controlling boats (without adjustments) over a 5 to 1 variation in boat gain.

Rudder offset affects the operation of the pilot in a proportional deadband system. As a rule of thumb, 10 degrees of offset at the helm will provide about 1 degree of heading error. If the offset gets above 20 degrees with varying conditions, the pilot should contain a means to trim out this offset. If the anticipated offset exceeds 45 degrees at the helm and can change with varying sea or engine conditions, the trim control should be automatic to ensure accurate course keeping over long cruises. Proportional rate systems have automatic trim control.

It should be noted that hydraulically steered boats using a proportional deadband autopilot system require some form of feedback from the rudder to the pilot. The feedback requirement is due to the slip of the steering system and means that a feedback device must be connected to the rudder or outdrive unit. This is not necessary for proportional rate systems such as the Course Setter or Course Keeper series.

On many hydraulic systems, rather than add another helm, a more economical approach is to use an autopilot with a self-contained pump such as the Benmar Course Setter 21H. These pump units are connected directly into the hydraulic lines, contain their own check valve system, and provide simplified installation.

FEATURES TO LOOK FOR

There are many autopilots on the market and all have different features. Some are necessary, some superfluous. Many units have such a multitude of controls that it takes an engineer to operate the pilot. Others, such as

the Course Setter and Course Keeper series, feature minimum controls while optimizing the system performance through automation. Discussed below are some of the major features a boat owner should be aware of when considering various types of autopilots. Additional information on features is presented in the Glossary at the end of this Primer.

Rudder Ratio

This control sets the basic gain of the autopilot system. To correctly control a boat over a wide speed range, it must be manually adjustable or automatic as in the Course Setter/ Course Keeper series. Pilots with fixed rudder ratio are usually limited to a narrow speed range of operation. That is, they operate well at one speed but performance suffers when the boat is operated above or below the optimum speed.

Variable Rudder Rate

Rudder rate is varied in one of three ways: 1) with the changing of sprockets between the pilot power unit and the helm or rudder, 2) by an electronic adjustment either internally or on the front panel of the pilot, or 3) automatically as with the Course Setter and Course Keeper series. Variable rudder rate simplifies installation since it makes the choice of drive sprocket ratios less critical and often allows direct drive to the helm.

Sea State Controls

All pilots have some form of sea state control to reduce pilot action in heavy seas. The conventional manner is to adjust the deadband of the system so that no correction is made when the heading is within a prescribed tolerance from the selected heading. The Course Setter and Course Keeper series use a low pass filter which can be set to ignore heading errors caused by wave action, but will still maintain the average selected course.

Trim Control

An adjustable or automatic trim control is necessary for accurate course keeping over varying conditions. These conditions can consist of the effect of wind, current, or boat trim.

Output Power Ratings

It is difficult to compare torque ratings and helm speeds between various systems. Generally, proportional rate autopilots require approximately one-fourth the output power of a proportional deadband autopilot. This is because in the deadband system the heading error must exceed the selected deadband before the pilot will be activated. By then the boat has already started to turn away from the correct heading and the rudder must be moved much faster (greater helm speed) to correct the error. Since the proportional rate system has no deadband, an instantaneous change in boat heading will be detected and a smaller immediate correction at much slower helm speed can be made.

Ease of Installation

The primary factors affecting the ease of autopilot installation are its size, number of components in the system, and the cost and availability of ready-made kits to connect the pilot to the helm (or rudder). With some of the larger pilots and with sail boats, an additional consideration is whether the DC current drain of the pilot exceeds the electrical capability of the boat.

WHAT WILL IT COST?

Along with performance and reliability the next most important question to the boat owner is "what will it cost?" This consideration should include the cost of the autopilot plus the cost of installation.

The price of autopilots varies radically, ranging slightly over $600 to over $3,000, and price in no way is truly indicative of the pilot's performance or quality. Rather, the price is greatly affected by the complexity of the system, the quantity that the manufacturer builds and sells, the manufacturer's capability for mass production, and his investment in tooling and engineering. The buyer should weigh all such considerations carefully when evaluating an autopilot and not automatically assume that the higher priced, more complex unit will best serve his purposes.

Installation costs, when handled by a qualified marine dealer, may run from $25 to $35 an hour plus materials. Some pilots can be installed in from 2 to 4 hours while others may take two days or more. In general, installation depends on the ease of attaching to the steering system, the number of components in the pilot system, the ease with which they are interconnected, and the amount of space available to accommodate the autopilot.

A mechanically inclined boat owner (for example, one who does his own engine maintenance) can install some models of autopilots, particularly if the manufacturer offers kits for modifying the steering system. Some manufacturers, such as Benmar, offer kits for the more common steering systems, consisting of replacement steering shafts and pilot mounting brackets for use with chain or direct drives. In handling unusual or specialized pilot installations, it is generally necessary to have access to a machine shop and to expect that a fair amount of ingenuity will be needed. We suggest that you contact your dealer regarding any such unusual requirements.

NOW YOU WANT AN AUTOPILOT, HERE'S WHAT TO DO

Hopefully this Primer has provided sufficient information to enable you to make a sound decision as to the type of autopilot best suited for your particular boat and personal requirements. Also, we hope it has convinced you that nearly any boatman can truly benefit from the addition of an autopilot, and that it will prove to be one of the most valuable investments a boat owner can make. In fact, a recent survey indicated that an autopilot is second only to a depth indicator in usage.

Should you decide that now's the time to take action, you should make the measurements of the characteristics of your boat as previously described. We then suggest that you take this information to your Benmar dealer who will advise you on the proper pilot selection and related installation costs. If you prefer to handle the installation yourself, his advice on installation should prove most helpful.

We hope this Primer has proved helpful and will make your first autopilot selection the right one.

Happy Boating...
from Ben[redacted]r

GLOSSARY

AUTOPILOT (Automatic Pilot): An automatic system for controlling the heading or attitude of a vehicle. In the case of a marine autopilot, a system for controlling the heading of a boat.

AUTOPILOT, PROPORTIONAL DEADBAND: An autopilot which contains a deadband around the desired heading and in which the amount of rudder correction is proportional to the course error.

AUTOPILOT, PROPORTIONAL RATE: A non-hunting autopilot which has no deadband; stability is achieved by maintaining the rudder rate proportional to the heading rate.

BACKLASH (Slop): Looseness in the steering system where movement of the helm does not provide movement of the rudder until a certain threshold is exceeded.

BINNACLE: Case containing the compass.

COMPASS, FLUX GATE MAGNETOMETER: A magnetic compass which does not use a rotating magnet card, but instead uses a stationary electromagnetic device to sense the relative position of the earth's magnetic field.

COMPASS, GYROCOMPASS: A compass consisting of a motor-operated gyroscope whose rotating axis, when kept in a horizontal plane, takes a position parallel to the axis of the earth's rotation and thus points to the geographic North Pole.

COMPASS, HALL EFFECT MAGNETIC: A magnetic compass using a Hall effect generator to sense the earth's magnetic field directly, or more usually, a compass using a Hall effect generator to sense the position of a magnet on a compass card. (See Hall Effect Generator).

COMPASS, MAGNETIC: A device for sensing the relative direction of the earth's magnetic pole. A magnetic compass generally consists of a rotating card containing a permanent magnet which will align itself with the earth's magnetic field. The position of the compass is observed visually or may be detected with a sensing device, the most common being a lamp and photocell arrangement.

CRAB: The tendency of a boat to follow a course that differs from the boat heading. This is generally due to wind, currents, trailing gear, or other side loads. The autopilot cannot automatically compensate for crabbing since the pilot is aligned to the center line of the boat. Crabbing may be compensated for by re-adjusting the desired heading, but it should be noted that the ship's compass, since it is aligned to the center line of the boat, can not be used as a reference.

DAMPING: The manner in which a control system approaches its desired value. A lightly damped system will have many overshoots, while a highly damped system will slowly come into the desired value. Damping controls are sometimes added to autopilots to optimize the system or the individual control loops. Heading rate control is a type of damping control.

FILTER: An electric circuit which will pass a certain range of frequencies while excluding others. For example, a low pass filter will only pass frequencies below a certain frequency called its cut-off frequency.

FILTER, SEA STATE: A low pass filter used the Course Setter and Course Keeper autopilots instead of a deadband control. This filter can be varied to program the autopilot to ignore rapid changes in heading caused by wave action but to maintain a correct average heading. The operation is significantly different from a deadband control in that the correct average heading is always maintained.

GAIN: The ratio of two quantities. For example, if 1° of heading error gives 10° of rudder, the gain would be 10.

GAIN, BOAT: The relative heading response of the boat to a change in helm position. For example, if one turn of the helm will introduce a turning rate of one turn of the boat per 30 seconds, the boat gain is said to be 1/30 = .033 turns per second. The boat gain generally will vary with boat speed and often will differ between port and starboard turns.

HALL EFFECT GENERATOR: A semiconductor device which converts a magnetic field to a voltage output.

HEADING DEADBAND CONTROL (Threshold, Sensitivity, Null or Yaw Control): In a proportional-deadband system, the control which adjusts the width of the deadband in terms of heading degrees. This is generally variable so the operator can optimize pilot operations to the conditions of the seas. When the heading error is within the deadband, the pilot does not attempt to correct the error.

HEADING, MAGNETIC: The heading of the ship with respect to the magnetic North Pole. This differs in general from geographic heading and will vary from area to area. Generally, most navigational information is given in magnetic heading rather than geographic heading.

HEADING RATE: The rate of change of heading generally in degrees per second.

HEADING RATE CONTROL (Heading Anticipation or Counter Rudder): Control of the boat's heading rate by the autopilot. This form of control can anticipate the eventual heading and therefore re-position the rudder to minimize over-steering. The autopilot can also be operated at higher rudder ratio settings if heading rate control is used. Rate control is generally a front panel control or, in the case of the Course Setter and Course Keeper autopilots, is automatic.

LIMIT SWITCHES (Rudder Limit Switches): Switches connected to the rudder to limit the travel of the rudder under automatic control. In mechanically steered systems, the switches may be connected to the helm.

RUDDER, DEAD (Rudder Deadband): A characteristic of some boats that when the rudder is amidship, small movements to either side will not cause an appreciable change in heading. This is similar in effect, but theoretically different, from backlash.

RUDDER FEEDBACK: A mechanical or electrical signal generated by rudder position and used by the autopilot for comparison against the heading error. Rudder feedback is not required by a proportional rate autopilot.

RUDDER RATE (Rudder Speed): The rate of change of the boat's rudder under autopilot control. This can be either automatic or user adjustable, which may be an internal or front panel adjustment. In the case of the Course Setter and Course Keeper series, rudder rate is variable and is controlled automatically.

RUDDER RATE FEEDBACK: An electrical signal indicating the rate of change of the ship's rudder and used as a feedback input by a proportional rate autopilot. This signal is compared against the rate of change of the ship's heading to maintain heading stability.

RUDDER RATIO: In a proportional deadband autopilot, the ratio of rudder degrees per degree of heading error. In a proportional rate autopilot, the ratio of rudder rate to the detected heading rate. In a proportional deadband system, rudder ratio can be a fixed or variable adjustment, and if variable, is generally a front panel control. Rudder ratio is adjusted to compensate for changes in boat response due to different boat speeds. In a proportional rate system, rudder ratio is generally variable internally and need not be adjusted for varying boat speeds.

STEERING, HYDRAULIC: A steering system in which the rudder is positioned by the movement of hydraulic fluid provided by the helm directly, or through the use of a booster pump. The system is generally of higher efficiency than mechanical systems and allows for the easy installation of multiple helms. These systems differ from the hydraulically powered steering on automobiles in that there is no direct mechanical connection between the rudder and the helm.

STEERING, MECHANICAL: A steering system which provides direct mechanical connection between the helm and the rudder. Rudder feedback can be obtained from the helm but will be in error by any backlash in the system.

STEERING, HYDRAULIC SLIP: The characteristic of a hydraulic steering system that allows the helm to lose index from the rudder. In other words, the amidship position of the rudder cannot be determined by the position of the helm.

TRIM CONTROL (Rudder Off-Set): A control to compensate for changes in the centered position of the rudder due to side loads or trailing gear. Generally a front panel control, but is automatic in some autopilots, including the Course Setter and Course Keeper series. Automatic trim is a definite advantage on long cruises with varying current and wind conditions or while operating with heavy side loads.

BOAT DYNAMICS AND SPECIFICATION

FILL OUT DATA SHEET CARD
THEN COMPLETE INFO BELOW
FOR YOUR OWN RECORD.

1. Boat Builder ____________________

2. Model ____________________

3. Year ____________________

4. Length ____________________ Feet

5. Weight ____________________ Lbs.

6. Number of Engines ____________________

7. Type of Drive: Inboard ____________

   In/Out ____________ , Jet ____________

8. Horsepower ____________________

9. Cruising Speed ____________________ Knots

10. Helm Mfr. ____________________

11. Helm Model ____________________

12. Helm Torque ____________________ Lbs.

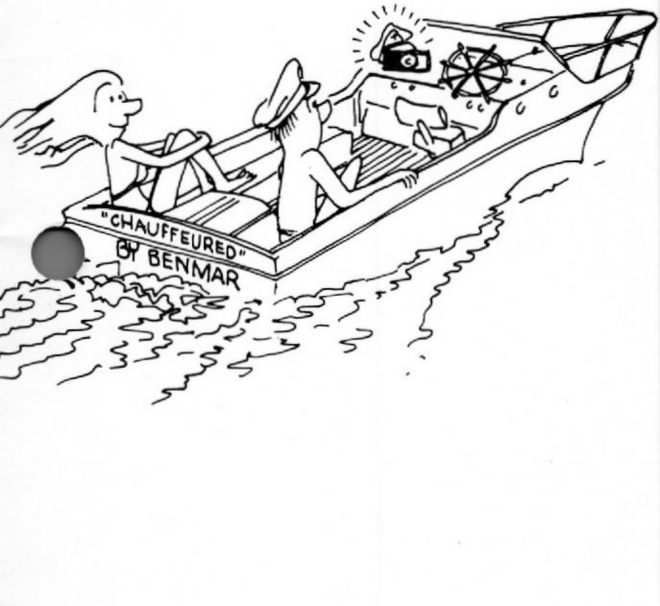
    @ ____________________ Inches

13. Helm Turns to Lock ____________________

14. Turn Time (360°) ____________________ Seconds

15. Amount of Helm Used for 360° Turn:

    ½ __ , 1 __ , 1½ __ , 2 __ , Other __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