TWIN DISC
POWER TRANSMISSION EQUIPMENT

TWIN DISC SURFACE DRIVES

A System Whose Time Has Come

1328 Racine Street
Racine, WI 53403 USA
Phone : (414) 638-4000
Fax : (414) 638-4480

INTRODUCTION

When the name Surface Drives is mentioned, most people have an image of an off-shore racing boat pounding over the waves. The Surface Drive was, indeed, born into that rugged environment with numerous records being established along the way. Reliability of the Surface Drive in the off-shore circuit is second to none.

However, this is not the world of reality. Twin Disc, Incorporated manufactures a wide range of Surface Drives covering applications from the sport boats to high horsepower megayachts/ commercial and patrol boats in excess of 150 feet in length. Depending upon the application, our largest Surface Drive unit (the ASD18) has a torque input limit of over 40,000 ft-lbs! That translates roughly into 10,000 hp at 1300 shaft rpm.

Today, TDI Surface Drive Systems are in use throughout the world as an option for many pleasure boat builders. Designers are recognizing the many benefits that are offered by the use of Surface Drives and are designing these units into new applications. Over 20 government agencies around the world have recognized the many advantages of the Surface Drives and have built patrol boats and other craft that utilize the Surface Drive System. Commercial operators have long recognized the benefits and reliability of the Surface Drives and have applications ranging from small utility craft to ferry boats. Fuel savings realized by use of the Surface Drive on some commercial applications alone are substantial.

HISTORY

Surface-Piercing Propellers

Shortly after the development of the marine screw propeller as we know it today, the partially submerged or surface-piercing propeller was proposed as an alternate to the paddle wheel. The first patent was issued to Mr. C. Sharp of Philadelphia in 1869 for a unit that incorporated many of the features found important in current surface-piercing propellers, notably cupped blades for improved performance and multiple blades to reduce the unsteady forces of propellers operating on the surface.

The first surface-piercing propellers were designed primarily for shallow water applications. A variety of other inventors have been involved in the development of surface-piercing propellers since the first patent was issued, although the emphasis gradually shifted from the original shallow water applications to high speed applications.

Admiral D.W. Taylor ran the first known model tests on partially submerged propellers, showing that these propellers had low thrust and torque coefficients and high efficiency.

Albert Hickman, the inventory of the sea sled, used surface-piercing propeller technology almost exclusively prior to 1920.

Starting in the 1950s, with the Unlimited Hydroplane, Slow Motion IV, the surface propeller started becoming more accepted in the racing circuit. This has progressed to a point where virtually all high speed racing applications are surface-piercing propellers in one form or another.

Surface Drives

In 1984-1986, Howard Arneson won numerous races with his unlimited offshore race boat and went on to win the world's offshore championship in 1987.

The recent 1988 world championship held in Guernsey, England proved that the surface drive concept was unbeatable. The Surface Drive (ASD) equipped vessels were on 35 percent of the entrants, with the ASD-equipped vessels taking 2nd, 4th, 5th, 6th and 8th place. All of the open class race boats that used Surface Drives were catamarans. It should be noted that this was one of the roughest offshore races held to date and no Surface Drive component failed or contributed to any other problems.

The development of the Surface Drive started in the mid to late 1970s with Howard Arneson desiring a faster and more reliable propulsion system that would hold up under the rugged ocean racing conditions than was commercially available at that time.

WHY A SURFACE-PIERCING PROPELLER?

Diameter

Intuition suggests that a propeller in which the blades are out of the water for half of each revolution will be inherently less efficient than that of a fully submerged propeller. However, often the unsteady process of a surface propeller can outperform its continuous fuller submerged counterpart.

Traditional propeller/application design is almost exclusively an exercise in trading off diameter against several other performance-limiting parameters. Shaft angle, blade tip clearance from the hull, maximum vessel draft, engine location, etc., all tend to limit the maximum feasible propeller diameter to something considerably smaller than the optimal size. While this may, at times, make life easy for the designer, the diameter is simply the maximum that fits; it can also result in a considerable sacrifice of propulsive efficiency.

Basic momentum theory tells us that for a given speed and thrust, the larger the propeller, the higher the efficiency. While there are exceptions, most notably the effects of frictional resistance on large propellers, it is generally borne out in practice that a larger propeller will be more efficient than a small one.

The surface-piercing propeller frees the designer from these artificial limitations. The designer is thus able to use a much deeper reduction ratio, a larger and more lightly loaded propeller. There is virtually no limit to the size of the propeller that will work.

Cavitation

As we all know, cavitation is an inherent evil we have had to live with for years on heavily loaded and high speed applications. Cavitation is a major source of propeller damage, vibration and loss of performance.

The surface-piercing propeller effectively eliminates cavitation by replacing it with ventilation. With each stroke, the propeller blade brings a bubble of air into what would otherwise be a vacuum cavity region. The water ram effect that occurs when the vacuum cavity collapses is suppressed by this entrained air which is at atmospheric pressure.

While the flow over a superventilating propeller blade bears a superficial resemblance to that over a supercavitating blade, the vibration, cavitation erosion, and underwater noise are absent.

Appendage Drag

Rudders, exposed shafts, struts, etc., all contribute to parasitic drag. Inclined exposed shafts not only produce form and frictional drag, but there is induced drag associated with the magnus effect lift caused by their rotation.

Surface-piercing propellers virtually eliminate drag from all of the underwater appendage sources. The only surfaces to contact the water are the propeller blades and a small skeg.

As the planing speed increases, the total parasitic drag caused by these appendages in some instances can greatly exceed the total bare hull resistance.

Variable Geometry

When a surface propeller is used in conjunction with an articulated drive system, you have the ability to adjust the propeller submergence underway. This has roughly the same effect as varying the diameter of the fully submerged propeller and allows for considerable tolerance in selecting propellers or it allows one propeller to match a range of vessel operating conditions. This capability is somewhat analogous to adjusting pitch on a controllable pitch propeller.

ARTICULATION REASONS

There are many other desirable characteristics in the use of surface-piercing propellers. These include: shallow draft capability, flexibility in machinery arrangement, ease of maintenance and repair, simplified installation, etc. In some cases, this involves hybrid propulsion systems with the ability to retract one set of propellers completely clear of the water, thus further reducing parasitic drag.

Trimmability

The obvious advantage for the trimmability of the Surface Drive is one of shallow water operation. No longer do the propellers have to be tucked away in tunnels or compromising hull shapes with excessive rise of keel aft to make a successful shallow water vessel. With the Surface Drives, the bottom of the hull now becomes the limiting factor for navigational draft rather than the bottom of the propeller tips.

The ability to trim the Drive allows for the propeller submergence to match the engine horsepower output, thus more power is converted to producing thrust while the engine is operating closer or at its rated power curve. Having this capability again is somewhat analogous to adjusting the pitch on a controllable pitch propeller.

We have noticed on a variety of applications that when the Drives are trimmed to their optimum high speed running position, and left in that position, the vessel never reaches its maximum potential speed.

However, if the operator trims the Drive down and allows the propeller to absorb the engine horsepower, adjusting the trim as the vessel speed increases, this will result in a speed increase of sometimes over seven to eight percent (7 to 8%), indicating that fixed Surface Drives may not be operating to their maximum advantage. This is an area that needs to be further investigated to determine the reason for this effect.

Another advantage of the trimmability aspect of a Surface Drive is during bollard tests. We have conducted bollard tests against existing outdrives to existing large application water jets on a direct comparison. In all cases, the Surface Drive clearly outperformed other means of propulsion. One of the main reasons we feel that this happened is the ability to trim the Drive up, allowing the Drive to ventilate freely from the surface, then trimming the Drive down until full engine power is absorbed.

Steerability

We feel that many of the advantages of having a steerable drive have been underestimated. It is well known that the Surface Drives' capability for turning at high speed is second to none.

The main reason for the effective steering is one of direct vectoring of the propeller thrust rather than emerging a rudder at some angle of attack in a slip stream. It should be noted that the Surface Drive is one of the few means of propulsion that directly vectors steering thrust and is the only system that directly vectors steering thrust for high speed applications.

Slow speed maneuvering of vessels equipped with Surface Drives is exceptional. We have had many operators throughout the world exclaim that, "It is just like handling a small boat." On most applications, with either engine forward and the Drive turned hard over, the vessel will turn inside its own length.

The "come home" capability is being more and more respected especially by designers and builders in Australia where, typically, on a large catamaran when a single engine goes out, the vessel steerage consists of how large a diameter circle do you wish to maintain. With Surface Drive-equipped vessels utilizing the positive vectored thrust, these catamarans with a large steering moment have the ability to limp home on one engine. This is an area which has shown to be of benefit on an SES vessel equipped with Surface Drives that was done several years ago by Halter Marine.

Reversibility

The Surface Drive seems to have the reputation for poor reversing characteristics. Many of these statements are indeed unfounded. Historically, Surface Drive equipped vessels have been high speed vessels (i.e., the original ASD-equipped vessels were all race boats). No matter whether your race boat is equipped with a Surface Drive, a fixed surface drive, or underwater propellers, the propellers designed for these high speed applications, either fully ventilated or fully cavitating, have an extremely inefficient blade shape for reversing.

On numerous sea trials on all sizes of vessels where "crash stops" were conducted, the customers in many instances have been very impressed by the stopping ability of the vessel. In a particular 42', 60+ knot high speed patrol boat operating out of the Far East, the vessel is able to stop from full speed to zero in less than two boat lengths.

Several years ago, a test project was conducted by a Scandinavian country's navy comparing underwater propellers/water jets/Surface Drives. In all cases, the Surface Drive equipped landing craft was able to back off the beach with heavier loads than all the other configurations. The primary reason for this, as put by the operator of the vessel, was "wagging the tail". The ability to have positive thrust steering allowed the operator to steer the Drives from full hard over to hard over, thus breaking the vessel free of the beach much sooner than just a static unidirectional thrust being applied.

SURFACE DRIVE PROPELLERS

Cleaver

The propeller that comes to mind to most people when discussing surface drives is the cleaver style propeller. As the drive does have its roots in the racing background, this is understandable. The cleaver propeller is typically made out of stainless steel with some of the larger configurations made out of Nibral bronze. Heavy cambered wedge sections typical of supercavitating propellers are standard with a blunt, squared-off trailing edge. Cleaver style propellers, up to eight-blades, have been used to allow smoother operation and an increase in efficiency with reduced propeller submergence. In general, vessel speeds of over 60 knots mandate the use of cleaver propellers.

High Rake Propellers

The high rake propeller was developed primarily as a "poor man's cleaver". This is a propeller that is easily manufactured and has evolved from the standard wedge-shaped cleaver propeller. These propellers generally are for use on the lighter, high speed, small vessel applications.

Low Rake Propellers

Low rake propellers have a very similar appearance to conventional propellers. Typically, blade areas range from .7 for a three-blade, to a 1.05 for a four-blade. These propellers have a cambered blade section with a trailing edge cup. Sometimes, for slow speed applications, the cup will be extended forward of the maximum radius on the propeller. This is an area where propeller technology has come a long way in the last several years.

The design of the surface-piercing propeller has made tremendous strides in the last several years. Five years ago, the low rake propeller design was in its infancy. Today, this propeller is available in up to six-blade configurations with vessel speeds in excess of 50 knots. Historically, the development of the surface-piercing propellers has been by empirical methods rather than through the use of open water test results.

ANALYSIS

Prop Analysis/Selection

The propeller performance prediction method is based on the Kq (thrust coefficient) and Kt (torque coefficient) curves for two propeller models as reported by Hadler & Hecker. Hadler & Hecker have published some of the most useful experimental results to date. Although their study did not include a complete family of propeller designs, the models that were tested can be used as benchmarks from which the thrust, torque, and efficiency characteristics of a reasonable range of propellers can be estimated. The published data is for three-bladed, superventilating designs, having an expanded blade area ratio of about 0.50.

Empirical adjustments are made to account for the number of blades, differences in expanded area ratio, cavitation number, etc. An upper limit is set on allowable propeller slip that can sometimes arise if the propeller is optimized for top speed only.

The accuracy of this method is, of course, somewhat limited due to the scarcity of data points. However, there has been considerable progress in the detail design of surface-piercing propellers since this data was published in 1968. Therefore, propeller performance estimates based on this data obviously tend to be somewhat conservative despite the limitations of the method.

GENERAL VESSEL CHARACTERISTICS

Speed/Power Prediction

Twin Disc has established credibility in many markets other than just the race market. Twin Disc is involved in patrol boats, motor yachts, small runabouts, ferry boats, landing craft, etc.

The first task in developing an application of a Surface Drive is generating the speed and resistance data. This often must be done at early stages with relatively little specific data. But, this is true for early stages of most vessel design. In general, speed and power predictions for vessels equipped with Surface Drives proceed in a fashion similar to that for vessels propelled by other propulsion systems. We recommend that builders and designers contact us in the earliest stage possible. We have developed a wide range of experience and techniques in speed and resistance prediction.

There are a wide variety of speed and power prediction methods used by Twin Disc that go from a simple horsepower per ton rule to using the Savitsky/Brown method, as well as others. Power savings due to the elimination of appendage drag can be taken either as additional speed or reduced power. If the latter option is taken, this can result in substantial savings in engine weight, engine cost, and reduced machinery space.

As the propeller and rudder are aft of the hull rather than under it, the navigational draft of the vessel can be to the keel line itself rather than the lowest point of the running gear.

LCG control is important to keep in mind. Some designers/builders are relatively careless about allowing the LCG to creep around, intending to use trim tabs to compensate after trials. Compensating with trim tabs can only go one way. Likewise, some designers/builders intentionally use trim tabs as they are thought to have high lift draft ratios. Careful control of LCG is important if this is the intent.

The rise of keel is generally provided on some planing vessels to reduce navigational draft, to allow for better shaft angle and engine placement, and to reduce the hump drag in a pre-planing condition. With Surface Drive units, the rise of keel is only that which may be required in the hump speed considerations.

CONTROL SYSTEMS

Steering and trim control for the Surface Drives are hydraulically driven. Trim control for the smaller units comes from an electro/hydraulic trim pump. On the larger Surface Drive units, this trim control, in many cases, is incorporated into the steering hydraulics.

Steering hydraulics generally consists of a power-assisted steering system. However, on many of the small applications, a manual hydraulic steering system is used quite successfully.

Many of the larger Surface Drive applications are using an electric/hydraulic steering system. The development of the full follow-up steering system has allowed input into the steering system from a variety of external devices, such as exhaust temperature, rack setting, etc., allowing the Surface Drive to have an automatic trim control. This, in turn, unloads the diesel engine from overload conditions. Catamarans can use these electric steering systems for independent control of each Drive, resulting in much better steering control.