U.S. Navy Experience with SSS (Synchro-Self-Shifting) Clutches

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In the late 1940's and early 1950's, various navies began to consider the use of aero-derivative gas turbines for marine propulsion because the gas turbine was seen as a compact, high-power-to-weight ratio engine that would reduce engine room space, reduce ship size or increase space for armaments, etc., reduce the time required to get a ship underway, and potentially reduce manpower requirements. As the gas turbine, unlike the steam turbine, was not particularly efficient at part load, it was seen that multiple engines would be needed per propeller shaft and a reliable means to connect each engine to a propulsion system/shaft line at rest and at speed would be needed.

Both the British Royal Navy and U.S. Navy explored the addition of cruising steam and later cruising gas turbines for steam turbine main propulsion plants in the late 1950's and early 1960's; and the first SSS (Synchro-Self-Shifting) clutches were supplied for the Y-100 marine main propulsion plant for the British Royal Navy in 1958. The successful operation of this SSS clutch paved the way for future consideration for naval gas turbine applications.

Recognizing that a combined propulsion machinery unit with gas turbines for boost power would require reliable propulsion clutches to disconnect the engines when not in use, the U. S. Navy initiated an evaluation of various means of disconnecting a gas turbine engine and ultimately selected and tested 7500 hp capacity clutch designs including a forced synchronizing friction/tooth clutch and overrunning clutches. After considerable testing and evaluation, the clutch designs were considered acceptable for high-power propulsion with reasonable requirements for differential speed at engagement.

In 1968, the U. S. Navy decided to proceed with its first, combined all gas turbine powered (COGAG) naval ship class, the Spruance Class Destroyers, and the main reduction gearbox manufacturer supplied forced synchronizing/dental tooth clutches. In the late 1960's, the U. S. Navy initiated the construction of a large number of single-shaft ships, the Admiral Perry Class (FFG) Frigates, and SSS clutches were recommended and supplied by the main reduction gearbox manufacturer who had gained valuable experience with SSS clutches on U. S. Coast Guard High Endurance Cutters.

In 1980, SSS clutches were chosen for the U. S. Navy Ticonderoga Class Cruisers (CG-47 Class), and the main reduction gearboxes were the same as the Spruance Class Destroyers except SSS clutches were chosen by the U. S. Navy instead of forced synchronizing/dental tooth clutches because of operating experience problems on Spruance Class Destroyer clutches. Within ten years most of the Spruance Class clutches were retrofitted with SSS clutches. From the mid-1980's all future U.S. Navy gas turbine propelled ships utilized SSS main propulsion clutches. SSS clutches were also being adopted for auxiliary drives as well.

SSS CLUTCH DESIGN & OPERATING PRINCIPLES

The SSS clutch is a freewheel-type, overrunning clutch which transmits torque through concentric surface-hardened gear teeth. Unlike a servo-actuated tooth coupling which is difficult to shift into mesh at rest or at speed, phasing and engagement of the SSS clutch teeth at synchronous speed is accomplished automatically without any external controls and without possibility of error. Also, unlike a tooth coupling, disengagement of the clutch will occur whenever the input slows down relative to the output without the need to maintain an unloaded turbine condition for disengagement.

The principle of operation of the SSS clutch can be seen in Figure 1. When the speeds of the clutch input and output reach synchronism, the pawls on one clutch element engage with ratchet teeth on the other to phase the teeth precisely for engagement. A few degrees of relative rotation causes the pawls to provide the small force to move the sliding component axially along helical splines, thereby engaging the driving and driven teeth smoothly and positively.

The pawls do not transmit any driving torque because they move axially out of contact with the ratchet teeth as the clutch teeth shift into full engagement.The clutch completes its engagement when the sliding component moves axially against an end stop, and then full torque passes through the helical splines and the fully engaged clutch teeth.

Figure 1. SSS Clutch Principle of Operation

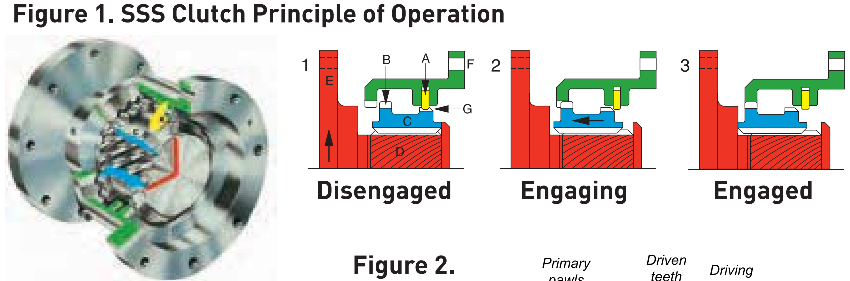
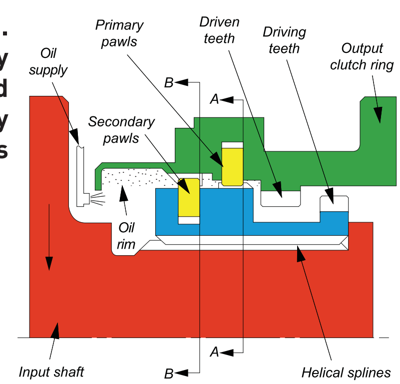


Figure 2. Primary and Secondary Pawls



As soon as the clutch input speed reduces relative to the clutch output speed, the clutch automatically disengages due to the reversal of torque on the helical splines. To enable the clutch to engage at low and high speeds, but also to prevent sustained ratcheting action of the pawls with the clutch output at high speed and the clutch input stopped or at low speed, primary and secondary pawls are used, as can be seen in Figure 2.

The primary pawls are mounted on the clutch output and are spring-loaded into engagement with ratchet teeth on the clutch sliding component. Unbalance relative to the pawl central pivot pin causes the primary pawls to retract from the ratchet teeth due to centrifugal force when the output exceeds a predetermined speed; typically about 500 rpm.

The secondary pawls, which are mounted on the clutch input, usually the clutch sliding component, are used to engage the clutch in the high-speed range, which is to say when the clutch input accelerates to the same speed as the output. When the input rotates, unbalance relative to the pawl central pivot pin engages the pawl with the ratchet teeth in the clutch output. However, when there is high differential speed between the pawls and ratchet teeth, the pawls skim on the oil within the clutch output. Therefore, both sets of pawls are inert when the clutch output is rotating at high speed and the clutch input is at rest or at low speed, and both sets of pawls are separated axially from their ratchet teeth when the clutch is engaged. Hence the pawls have a very long life; in many cases they last the life of the ship.

ADDITIONAL SSS CLUTCH FEATURES

In addition to the basic SSS clutch design and operation, additional features are available for high-power and/or high-speed applications. These features include an oil dashpot inside the clutch, continuously supplied with oil from the lubrication system, to "cushion" clutch engagement under high relative acceleration conditions and to prevent disengagement under transient negative torque conditions. An additional feature is a relay clutch built within the main SSS clutch to enable SSS clutches to transmit high power yet keep the synchronizing mechanism (pawls and ratchets) within the clutch small and reliable. To suit various arrangement and operating requirements, optional features such as Manual Lock-Out, Servo Lock-Out, Servo Lock-In, and a Lock-Out/Lock-In feature can also be provided.

MOUNTING ARRANGEMENTS

SSS clutches are typically an in-line, flange mounted drive arrangement, or mounted on the end of the gearbox input shaft that extends through the center of the high speed pinion (quill shaft mounting). For Combined Gas Turbine or Diesel (CODOG) or combined gas turbine and diesel (CODAG) gearboxes, the clutches are sometimes mounted in the intermediate shaft position as often one gas turbine and two diesel engines are used per reduction gear. The U.S. Navy and other navies have also designed main reduction gears with electric motors for auxiliary or cruise propulsion and gas turbines for boost power (CODELAG), and again the clutches are mounted in either configuration.

U.S. NAVAL MARINE EXPERIENCE

The U.S. Navy has nearly forty years of experience using SSS clutches in main reduction gears of gas-turbine-driven ships and propulsion systems with combinations of gas turbines and diesel engines or electric motors, and in steam-turbine propulsion plants for use with electric motor drives. Over 900 SSS clutches have been installed in fourteen different classes of U.S. Navy ships, with some having been in service for over thirty years. SSS clutches have accumulated approximately 15,278,000 hours of operation.

Clutch duty on U.S Navy ship Classes, each nominally rated at a 50,000 SHP, is considered to be more strenuous than the original design requirement due to the increased operating time (and cycles) at high torque. The highest percentage of ship operations is performed in a single engine driving / trail shaft mode (on twin shaft ships) in order to minimize fuel usage and to maximize range. The end result is operating at a higher torque (that exceeds full power torque) on the driving shaft. Fleet data indicates that ships operate in this mode 68% of the time. Full power operation is performed 10% of the time, and the remaining 22% is at the less than 50% power level. As the SSS clutches are "operating" whenever they are engaged or whenever they are disengaged or overrunning (as would be the case with the off-line clutch when the ship is in single engine propulsion mode) the average total number of clutch operating hours could be up to 68% greater than total engine operating hours on any given ship.

Operational Availability (Ao) is the Navy's primary measure of system material readiness and is a function of a system's inherent reliability and maintainability attributes as well as the support network sustaining the system. Ao is defined as the probability that the system is ready to perform its specified functions, in its specified operational environment, when called for at a random point in time.

Ao is defined as:

$$Ao = \frac{\text{Uptime}}{\text{Uptime + Downtime}} = \frac{\text{MTBF}}{\text{MTBF + MTTR + MLDT}}$$

MTBF = Mean Time Between Failures in Hours
MTTR = Mean Time To Repair in Hours
MLDT = Mean Logistics Delay Time in Hours

MTBF is a function of reliability, and MTTR is a function of maintainability that only accounts for time associated with active repair (including failure isolation, repair, part replacement, and restoration checkout times). MLDT is a function of the onboard spares depth and breadth (sparing policy) as well as the time it takes to obtain parts not available at the shipboard level.

MTBF for U.S. Navy clutch applications, is relatively high (271,550 hours) based on the operational hours accumulated and the total number of failures that have occurred. The maintenance and repair strategy used for U.S. Navy SSS clutches is similar to a Performance Based Logistics (PBL) arrangement where the Navy maintains a rotatable pool of ready for issue clutches, and in the event of a problem or failure, the clutch is changed out with an available spare. The removed clutch is returned to SSS for repair, refurbishment, and returned to the rotatable pool. This type of approach minimizes MTTR and MLDT and yields a substantially high Ao of .998, indicating that the SSS clutch is available for operation 99.8% of the time.

The basic design of the size 140T clutch, designed for the FFG-7 Class ships and adopted for DDG-51, CG-47, DD-963 and Sealift ships, is now being utilized for additional U.S. Navy applications including the LHD-8, LHA-6, and LCS-1 and LCS-2. 140T SSS clutches have also been supplied for the U.S. Navy's experimental ship X-Craft, and reduced scale clutches (120T), are being used for the electric motors on the LHD-8 and LHA-6 ships. SSS clutches have been used in the propulsion plants of hovercraft by other navies, and are a candidate for use aboard the U.S. Navy's new Ship To Shore Connector (LCAC) replacement program.

A SOLUTION FOR THE FUTURE

SSS clutches are currently used by more than forth navies for gas turbine driven, diesel driven, and electric motor driven main propulsion systems. With an increasing requirement for reliability and flexibility, together with high performance ships with high power-to-weight ratios, higher efficiency and lower emissions, innovative propulsion systems utilizing proven components such as the SSS clutch are being adopted by many navies of the world. SSS clutches used in other marine and industrial applications have operating and design limits that exceed those of the clutches currently used for naval applications. SSS clutches capable of operation at speeds up to 17,000 rpm, combined acceleration rates of up to 1,600 rpm/sec, and powers up to 300 MW at 3000 rpm demonstrate that the basic clutch design is suitable for future higher power, high speed requirements.