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M151 TRANSMISSION FOR MARK II HYDROFOILS

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Abstract

Marine Propulsion Systems of the type described in this paper have been in existence for more than twenty years. Whenever a new advanced transmission system for a high performance marine vehicle is contemplated it is a challenge to all concerned. The 5000 horsepower MARK II transmission is no exception.

Time from inception to sea trials has spanned three and one half years. This paper takes the reader through the concept, design development, manufacture and testing of this transmission. Descriptive material explores the transmission system in detail. Transmission supporting systems are also discussed. The manufacturer's back-to-back testing followed by shipyard land based full load testing represents a major step forward in developing reliable, lightweight, high performance marine propulsion systems.

I. Introduction

The M151 Transmission is a Grumman owned design manufactured by the Western Gear Corporation for MARK II Hydrofoils utilizing one transmission per craft for foilborne propulsion. This same transmission can be utilized for multiple engine installations if required.

The MARK II installation is comprised of an Allison 501 KF free turbine engine of 5000 nominal horsepower operating at 14,000 R.P.M., connected to the transmission which drives a single, 48 inch, 4 bladed, controllable pitch, super cavitating propeller with an overall gear ratio of 14 to 1.

II. Transmission Design Characteristics

Maximum Power Input	5400 HP
Input Torque Limit	25,000 Lb. In.
Input Shaft Speed Range	0 to 14,500 RPM
Input Shaft Foilborne Operating Range	8000 to 14,500 RPM
Overall Reduction Ratio (in 4 Gearboxes)	14.01 to 1
Transmission System Weight	4800 lbs.
Overall Efficiency	96%
Accessories (HMGB)	Propeller Pitch Control Hydraulic Pumps D.C. Generator A.C. Generator
Lubricating Oil	Shell Omala 68
Oil Temperature into Gearboxes	120°F
Oil Temperature out of Gearboxes	160°F
Environment - Ambient Air	0°F to 148°F
-Sea Water	28°F to 87°F
Minimum Overhaul Period	5000 Hrs.
Gear and Shaft Life	20,000 Hrs.
Bearing B - 10 Life	5000 Hrs.
Overtorque Protection	Shear Coupling
Anti-rotation Device	Disc Brake

III. System Description

A "Zee" drive configuration is used (Figure 1) consisting of four gear boxes, one located in the hull, and three in the steerable aft strut. The primary reduction gear box has a ratio of 3.1 to 1 and contains a spur pinion and gear set. This hull located primary reduction gear box also provides the following accessory drives:

- Transmission lube oil supply pump
- Primary reduction gear box scavenge pump
- Propeller pitch control pump
- Foil borne hydraulic pump
- Emergency A.C. and D.C. generators.

The upper bevel gear box located at the top of the aft strut is a spiral bevel box with a 1.02 to 1 hunting tooth ratio. The only accessory drive on this box is for the scavenge pump. Mounted on the input shaft is a hydraulically operated disc brake. The brake is used to prevent propeller wind milling during extension and retraction of the aft strut and during struts down, hullborne operation.

The shaft connecting the primary and upper bevel gear boxes passes thru the transom where a support bearing is mounted. Each end of the shaft has a crown tooth coupling. The primary gear box coupling is of conventional design and lubricated. The upper bevel box coupling has a non lubricated Delrin(R)** male member riding in a stainless steel female member. This connecting shaft is hydraulically actuated to connect and disconnect the transmission at the aft strut to hull interface; This arrangement coupled with the transom bearing allows main engine operation for maintenance and check out purposes with the aft strut retracted.

The lower bevel gear box is also a spiral bevel gear box with a 1.02 to 1 hunting tooth ratio. The accessory drives for this box include the lower bevel scavenge pump and the planetary scavenge pump. The upper and lower bevel boxes are connected by a 3 Inch solid shaft with a diaphragm coupling at the upper end, and a crown tooth coupling at the lower end. The shaft and bearings are housed in a water tight tunnel built Into the aft strut. The aft strut steering axis is coincident with the vertical shaft center line. The upper and lower bevel gears while identical are also integral with their respective shafts, and as such are not interchangeable due to the shaft geometry.

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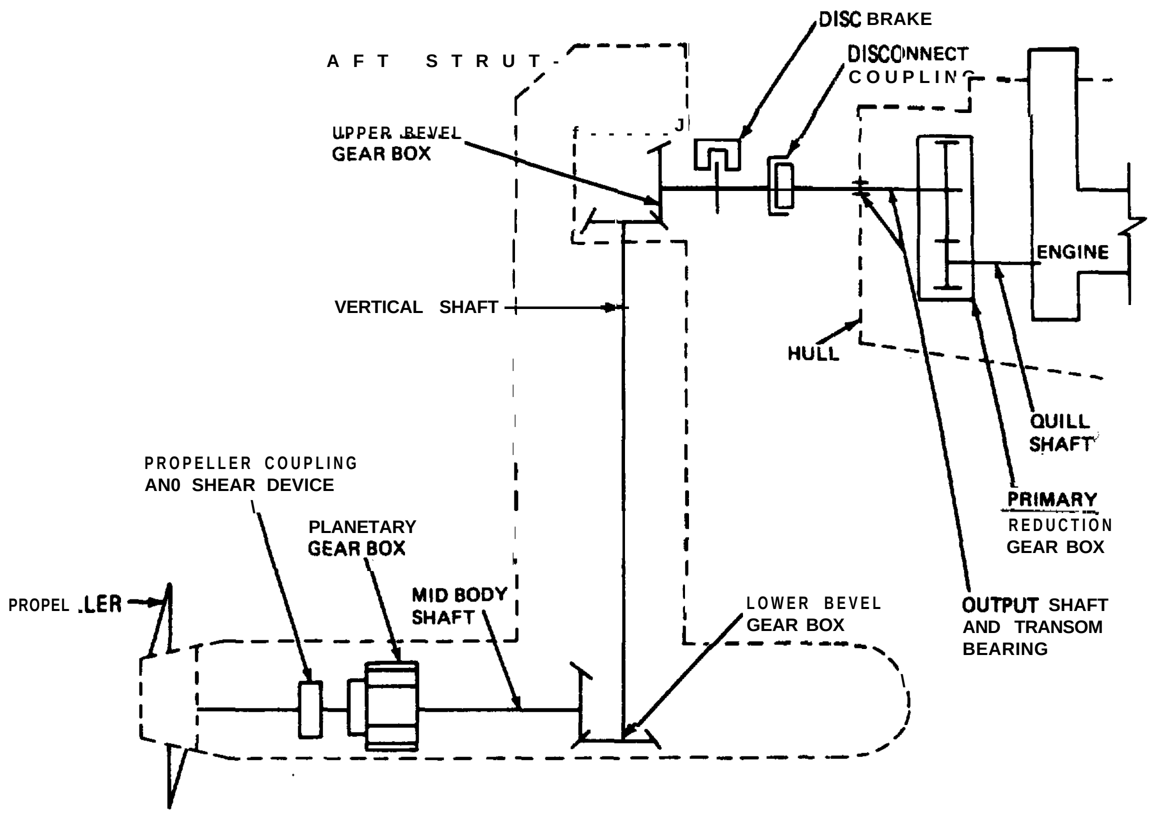

Fig. 1 M151 Transmission

Leading aft from the lower bevel box is a short shaft in a water tight tunnel which connects to the sun gear of the planetary gear box. The reduction ratio is 4.33 to 1 and of spur gear design. Power to the propeller shaft is taken from the planet carrier thru a pin type shear coupling. The planetary box is scavenged by a pump driven from the lower bevel gear box.

Sleeve bearings are used on the pinion shaft of the primary reduction gear and on the vertical shaft. All other bearings are of the rolling element type with a B - 10 life in excess of 5,000 hours.

All gear boxes are fully instrumented with vibration pickups, chip detectors, and resistance temperature detectors for all bearings and in the scavenge lines.

The hull located primary gear box is atmospherically vented and the split line sealed with a single O-ring. The output shaft is fitted with labyrinth seals pressurized to 10 psig with air from the ships service compressed air supply. The transom bearing is mounted in an elastomer boot. The upper bevel gear box is also sealed with an O-ring at the mating faces and with face seals on the input and output shafts. The vertical shaft and bearing tunnel has some removable sections which are sealed with double O-rings with an oil filled annulus between the O-rings. The pressurizing oil is from a separate static supply. The double O-ring seal system is also used to seal the lower bevel and planetary mating surfaces. A shaft seal on the planetary output shaft seals the transmission from the propeller system. A propeller shaft seal is also installed. The propeller bearing lubricant and hydraulic oil are the same type as the transmission lube oil. In the event of leakage across the planetary output shaft seal in either direction there would be no contamination of either system.

IV. Lube Oil System

The pressure circulating type lube oil system is used for the transmission and supplies oil at 60 gpm, 35 psig. In addition to the integral pumps previously mentioned, there is an electrically driven lube system of reduced capacity used to prelube the transmission, circulate oil without operating the main engine, and off load oil if required. The scavenge system is the dry sump type, that is, the scavenge pumps have a greater capacity by 2 to 1 than the amount of oil supplied to each gear box. In this respect, the lube oil system is quite conventional for transmissions of this type.

The venting system is unique and a brief description is in order. In the past, when transmissions utilizing dry sump systems were used the nature of the design allowed large quantitites of moisture laden air to be continuously entrained with the scavenge oil which was returned to the reservoir where it would be vented overboard. This system promoted internal corrosion of the gear boxes. To alleviate this condition, a system was developed that recirculated the same air continuously and avoided introducing external atmospheric air during operation, except for start up and shutdown. As seen in Figure 2, the upper bevel gear box, vertical shaft tunnel, lower bevel gear box, planetary gear box, and the reservoir have been combined into a pressure tight system via a vent line from the top of the upper bevel gear box to the reservoir. The key to the operation of this system is a transmission lube oil pressure operated control valve and a relief valve set at 8 psig.

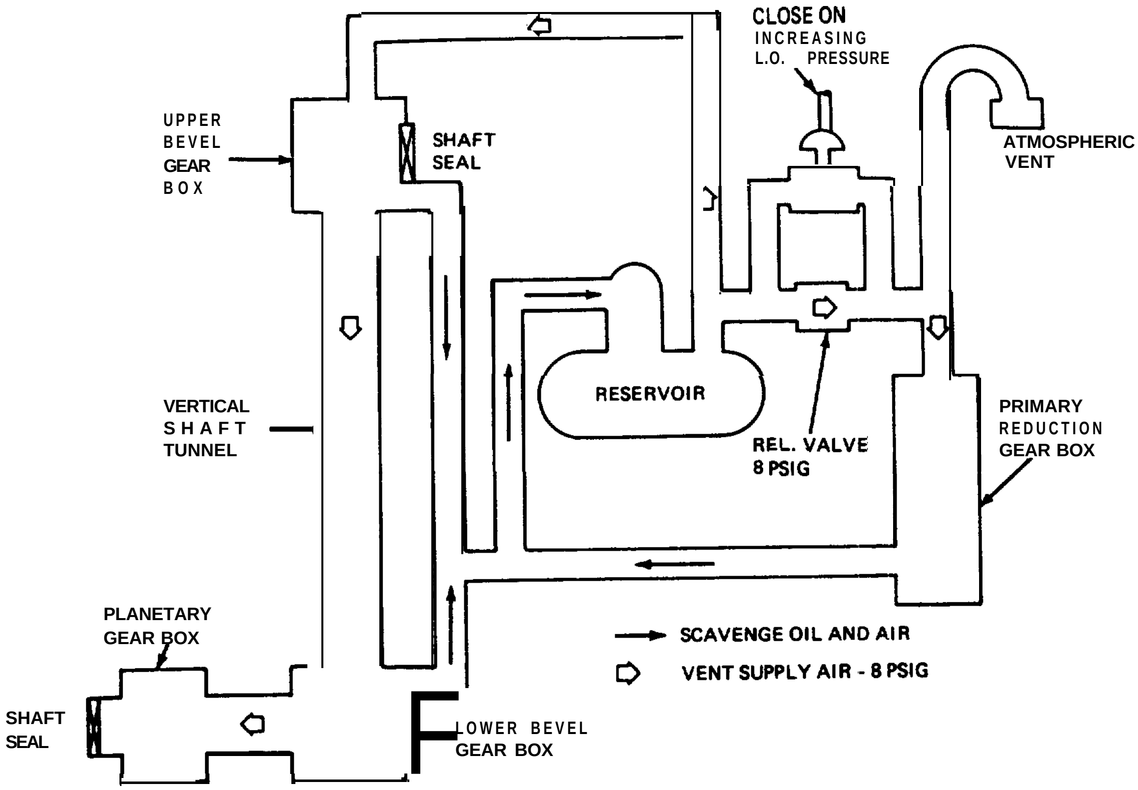

Fig. 2 Vent System Schematic

With the system static the entire pressure closed system is at atmospheric pressure thru the primary box vent and the open control valve. When the system is started and the oil pressure reaches 5 psig the control valve closes and makeup scavenge air is drawn into the system thru the atmospheric vent. The air becomes pressurized in the scavenge pump and returned to the closed reservoir deaerator. This process continues for about 3 minutes until the pressure builds up to 8 psig (relief valve setting), and then dumps into the primary gear box vent line close to the gear box. At this time, the system scavenge pumps are ingesting the recirculated air and not drawing in atmospheric air. The scavenge pumps and the relief valve keep the system at 8 psig. Vent system pressure changes due to thermal effects, and engine speed changes are taken care of by the relief valve. During a shutdown the control valve opens when the lube oil pressure drops below 5 psig, and discharges the 8 psig vent system air pressure to atmosphere. The reservoir contains a fitting to use ships service air to pressure check the vent system. The reservoir must be designed as a pressure vessel in this application.

V. Manufacture

The M-161 Transmission system has fabricated from materials commonly used for lightweight high efficiency aerospace gearing systems.

The structural housings internal to the ship were of aluminum A356-T6 castings. All other housings, those external to the craft, were fabricated of stainless steel or high strength, low alloy steel suitably protected for marine environment.

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As a weight efficient design feature, a "wet pod" structure was utilized with the double O-ring pressurized seal system described previously. This system was machined integral with each housing, and appears at each interface which is or could be underwater.

Material used for the gears was AMS-6265 with the exception of the planetary ring gear which was made from Nitralloy 135D modified. Power gears were protuberance hobbed, carburized , shot peened and ground on Maag grinding machinery.

Spiral bevel gears are of relatively fine pitch. This was done in order to take advantage of higher bending stress allowable of the AMS-6265 material, while keeping the scoring index to a minimum.

Spiral bevel gears were developed in the conventional manner on Gleason machinery, fitted into actual housing, static torque tested, and reground as necessary to achieve at least an 80% full load pattern. In most cases, a 90% load pattern was realized.

Male and female gear tooth couplings were fabricated of Nitralloy 135D modified and fully force lubricated.

The unique disconnect coupling was fabricated using a stainless steel female member and a Delrin(R)† male member. This coupling transmits the full engine horsepower to the over the stern drive. It also allows the aft strut to be retracted.

Bearings are ABEC or RBEC Class 5, standard, and calculated for 5000 hours B 10 life. They incorporate silicon bronze separators.

The one exception to standard bearings are the ones used in the planetary final drive **planets.** They are extended length, double roller bearings using a heat treated chrome-moly steel cage material. Inner and outer races are separable from the planet pin and the planet.

VI. Testing - Verification of Design

Vendor Testing

Vendor Testing was accomplished on a large A-frame type test stand suitable for accepting two complete M- 151 transmission systems back-to-back as shown in Figure 3.

A variable pressure torque device was installed in the low speed shafting between two back-to-back planetary gear boxes, and had the capacity to produce up to 50,000 lbs ft torque at 1000 **rpm.**

A total of 138 hours was logged during all phases of testing for the manufacturer's factory test and the Grumman 50 hour verification test. Figure 4 shows the systems under test.

Both systems were tested in full configuration meaning that all accessories were in place and loaded; all subsystems were functioning.

The test stand simulated the craft's lubrication system. Testing verified the design calculations for temperature rise and heat rejection.

Parameters for ships operation were established at this time.

Shiovard Testing

Transmission Systems No. 1 was installed into the lead MARK II Hydrofoil at the shipyard. At that time the ship was in a "high stand" which is a land based test and erection facility. (See Figure 5.)

The advantages of testing out of the water are numerous. It allows for all support systems to be adjusted, full load to be applied to the main propulsion system, complete functional checks of the propeller, double seal system, and all monitoring and support equipment. It also allows more test recording equipment to be utilized without the attendant problems of telemetry.

Full load testing was accomplished using a 5000 hp eddy current absorption dynamometer connected to the propeller shaft. A fresh water to sea water cooling system was used to cool the dynameter .

During land based shipyard trials data was **collected,** reduced and compared with data obtained from the transmission manufacture% results.

Parameters such as lube oil flows and pressures, transmission lube oil inlet temperatures, lube oil outlet temperatures, transmission bearing temperatures,

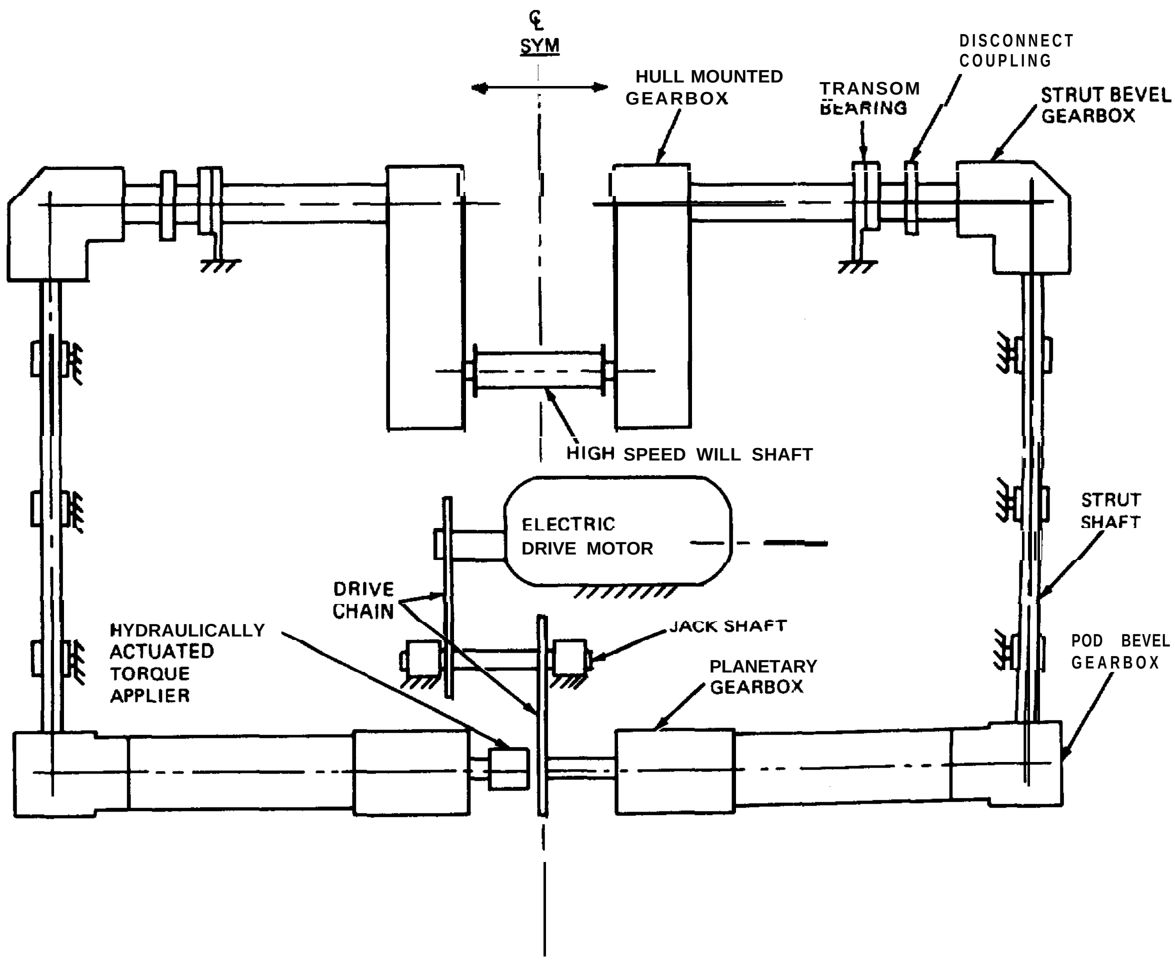

Fig. 3 M151 Test Stand Back-to-Back Loading Arrangement

and vibration levels at each gear box compared very **well** with manufacturers' Iimits established during testing. In this way, high degree of confidence regarding transmission performance prior to sea **trials** was **realized.**

At the time this paper was prepared, sea trials were beginning. From the information gathered to date, the transmission system is performing in the same manner as it did during **successful** manufacturers' testing and the **land** based shipyard **trials.**

VII. Summarv

The information presented in this paper has not **dwelled** on design, manufacture or test problems. There were some; however, none of them were **particularly** unique or **disimilar** to problems encountered in previous programs of this type. The entire production of this transmission syatem from inception to customer acceptance has been straight forward, and resulted in a rugged, reliable, light weight, high performance, link in the **foilborne** propulsion system **for M161,** Ml71 and **other Hydrofoil** Craft.

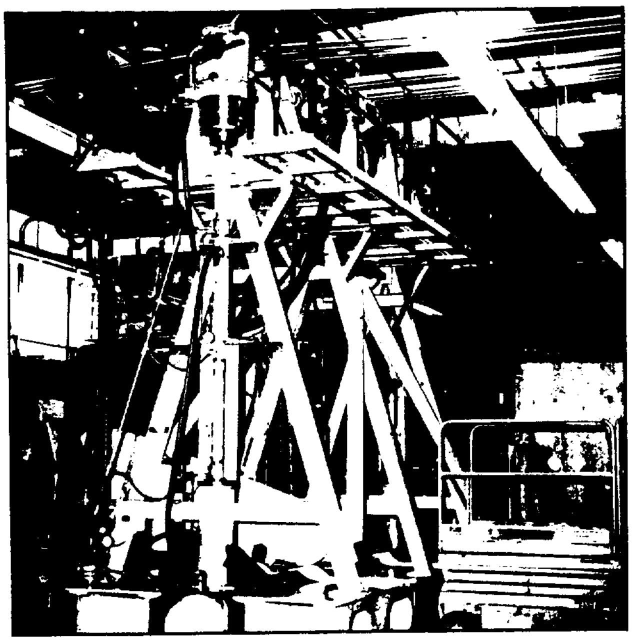

Fig. 4 Ml51 Vendor Test Stand

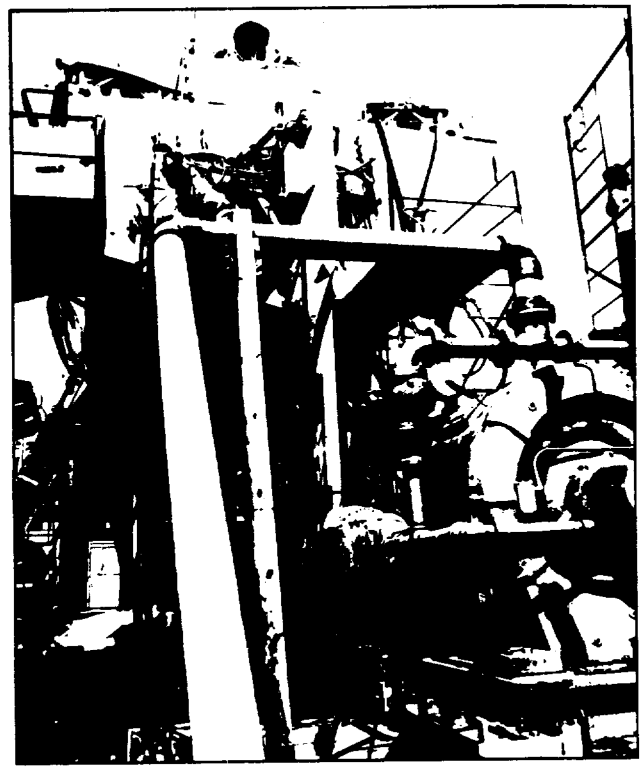

Fig. 5 Shipyard Dynamometer Test