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EFFICIENT PTO DEVELOPMENT PROGRAM

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ABSTRACT

Southwest Research Institute (SwRI) in partnership with Ker-Train Research Inc. is developing an advanced Bradley Fighting Vehicle (BFV) power take-off (PTO) drive system to improve fan drive efficiency and increase on-board electrical power generation. This presentation provides information on the integration methods, advantages of the Ker-Train drives and electronic controls, and future plans for this TARDEC project. Fan drive, PTO Generator drive and Accessory Alternator drive system information, hardware design and controls are presented. Plans for testing at SwRI are also discussed.

INTRODUCTION

The production BFV fan drive has a variable fill fluid coupling with mechanically controlled speed variation, and efficiency inversely proportional to slip. The subject project intends to replace the fluid coupling with compact Co-planar gear sets with Polycone clutches and electronic control to enhance efficiency. Modeling and simulation completed at TARDEC shows a multi-speed stepped ratio drive provides improved BFV fuel economy over the baseline fluid coupling. A prototype fan drive is designed into the space constraints of the current BFV powerpack with less lubrication needs than the fluid coupling.

As BFV on-board electronics' peak load requirements increase, additional electrical generation is required from the powerpack. The BFV PTO Generator is directly driven from the engine through a transmission geartrain. An optional BFV Accessory Alternator is belt driven at the engine nose. The generation of BFV on-board electrical power is increased with the addition of integrated, compact, two speed drives, which allow increased PTO Generator and Accessory Alternator speed and power at low engine speed conditions. The PTO Generator and Accessory Alternator, both being electrical generation devices, are such named in this document to clearly differentiate between the two.

BASELINE SYSTEM

The baseline BFV powerpack includes a Cummins VT903 engine and an L3 HMPT hydromechanical transmission. A PTO geartrain arrangement, directly driven by engine output through the transmission, powers the PTO Generator and fan drive. Features to reduce the influence of diesel engine torsional vibrations are included in this drive arrangement. A schematic of the drive gear arrangement is shown in Figure 1. The intention of the project is to minimize modifications to the baseline system to reduce impact to manufacturing cost, technical documentation and logistics.

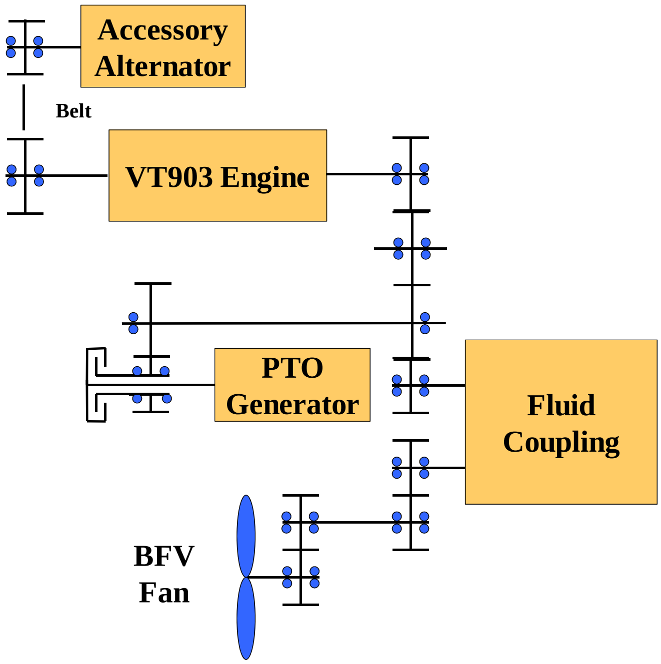

Figure 1: BFV PTO and Accessory Alternator Baseline Schematic.

Reverse engineering of baseline hardware is required to develop package envelopes for integration of new drives. A portable CMM is used to generate powerpack surface models, the basis for the package envelope.

PTO Fan Drive

A mechanical controller senses oil temperature from the BFV transmission to control the baseline fan fluid coupling speed. With this continuously variable device the number of fan drive ratios is infinite. The fluid coupling efficiency is inversely proportional to slip. When the fluid coupling is at its lowest efficiency point the fan power is low meaning mechanical losses are low. At high fan power conditions slip is small and maximum efficiency is achieved. The weak point for the fluid coupling appears to be at mid-lower ratios where the fluid coupling power loss peaks. Figure 2 illustrates this with two different fluid coupling power loss curves at constant engine speeds over a range of slip conditions. Fan power is a cubic function based upon speed as shown in Figure 3.

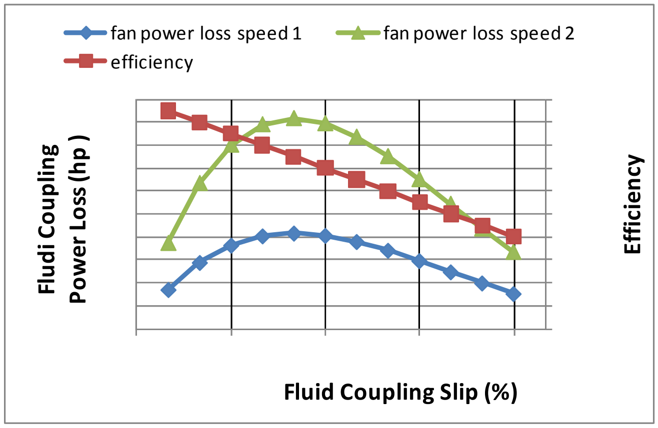

Figure 2: BFV Fan Power and Torque.

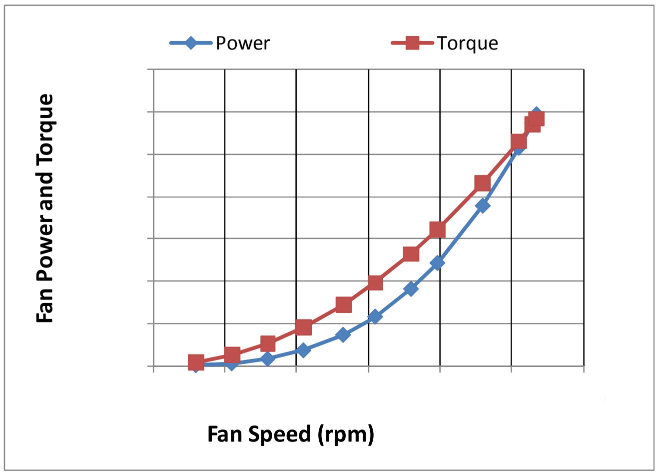

Figure 3: BFV Fan Power and Torque.

PTO Generator and Accessory Alternator Drive

The PTO Generator is gear driven at a single overdrive speed with respect to engine speed. Similarly, the Accessory Alternator is belt driven at a single overdrive speed. A plot of baseline Accessory Alternator and PTO Generator power is shown in Figure 4 from engine idle speed to maximum generator speed. Since the power curves rise with increasing speed, adding a speed increasing multispeed drive will increase power generation at low engine speed conditions.

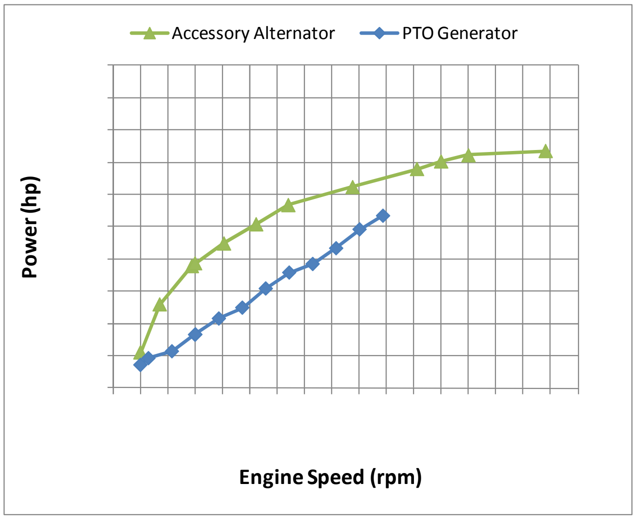

Figure 4: BFV PTO Generator Power.

While both electrical generation devices produce nearly the same power at low engine speeds, the Accessory Alternator has greater potential electrical power available by increasing speed.

The Accessory Alternator uses sealed bearings and a belt drive, requiring no external oil lubrication; addition of an advanced drive requires considerations for a lubrication system. The PTO assembly is lubricated with HMPT oil, however. The PTO housing is a two piece design with its split line parallel to the gear faces. Cantilevered off the front of the housing is the PTO Generator. Along the same axis, but on the back side is an integral slip clutch. Since the casting strength limits support of cantilever loads, any new drive system would have to be installed on the back of the housing, which has diameter and axial length limits.

The PTO Generator and Accessory Alternator can both be configured for J1939 communications. This enables speed, current and voltage signals without the need for additional sensors.

ADVANCED DRIVE SYSTEM

A tradeoff study was conducted to review drive technology for the BFV application. Planetary gearing, continuously variable and infinitely variable mechanical drive technologies, and hydraulic drives are candidates for integration into the PTO and accessory drive systems. The highest ranked attributes are power capacity, efficiency, fuel consumption, reliability, performance, safety, survivability and availability. Much of the space surrounding the accessories is claimed by baseline hardware; during the design phase compactness was also found to be an important attribute. Ker-Train drive technology was selected to integrate into the three advanced accessory drives (See Figure 5).

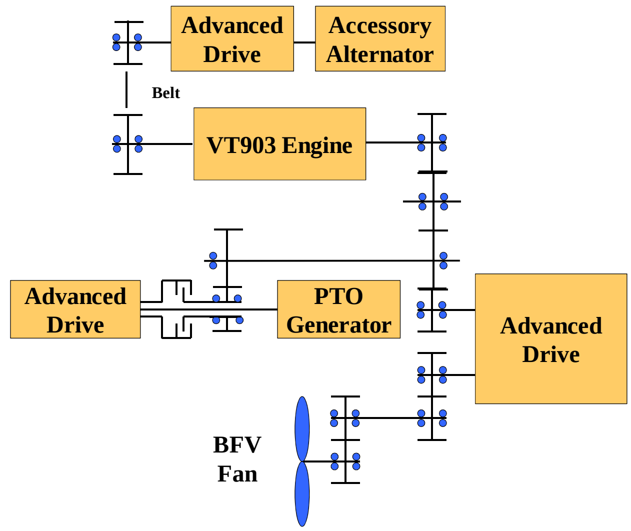

Figure 5: BFV PTO and Accessory Alternator Advanced Drive Schematic.

Advanced Drive Technology

Ker-Train Research Inc. develops binary drives with coplanar gear technology for use in mobile and stationary applications. The basic component is the coplanar gear set which includes the pinion, cluster gear and ring gear as shown in Figure 6. The cluster gear can be removed from the assembly to create an internal-external gear pair similar to hydraulic pumps (See Figure 7). Either gear arrangement incorporated into a gear module can be “engaged” to create a gear ratio or disengaged to enable a 1:1 drive ratio. Both gear arrangements were candidates for integration into the advanced drives and both gear arrangements use patented addendum contact tooth profiles to increase contact ratio and reduce individual tooth loads for greater capacity and durability.

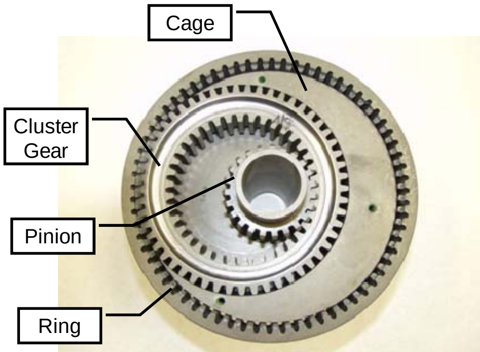

Figure 6: Coplanar Gear Arrangement.

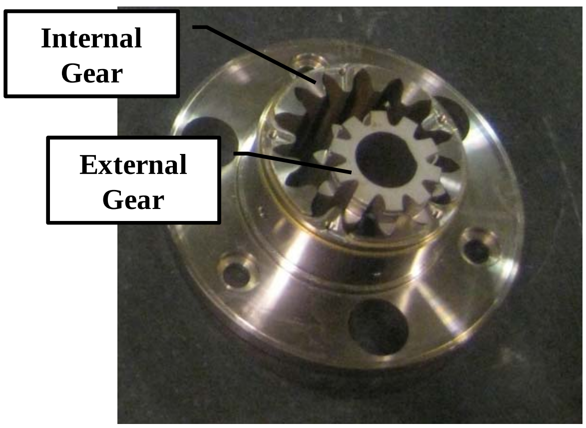

Figure 7: Internal-External Gear Arrangement.

Ker-Train Polycone clutches have multiple cones, each at a different diameter that meshes with a mating cone on the complimentary clutch plate. The cone design allows for high contact pressure on the cone surfaces with less axial force than a conventional clutch. One polycone clutch arrangement can replace a mutli-plate flat clutch assembly (See Figure 8). Since a single or double interface is all that is required between polycone clutch plates and since the polycone clutch can be opened to a position where the plates do not touch, drag losses can be reduced over mutliplate clutches.

Lubrication System

HMPT lubricant flow normally directed to the baseline fluid coupling is used as a pressurized lubrication source for the advanced drives. Allocation of the known available flow was made for lubrication and clutch actuation at each drive. During all anticipated operating modes the HMPT will provide more than sufficient lubrication flow. Further, shift scheduling strategies in the control code ensures sufficient lube will be present for reliable operation.

Figure 8: Polycone Clutch.

PTO Fan Drive

Theoretically three modules are required to generate eight speeds for the fan drive assembly. Review of design options indicated a fourth module would reduce the ratio of each module, improve packaging and improve robustness of the design. This architecture was carried forward into the detailed design. With four modules and integration hardware the fan drive fit within the space constraints of the existing fluid coupling hardware. Each module is actuated by a pressure control valve and monitored with a pressure sensor. The modules are supported by a common center output shaft, which is concentric with the input shaft. A representative sectional view of the fan drive is shown in Figure 9.

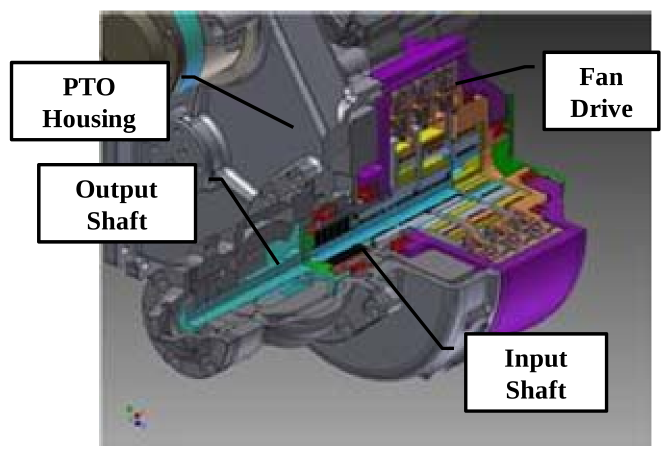

Figure 9: Advanced Fan Drive Arrangement.

The baseline fluid coupling hardware is removed from the assembly and modifications to the input gearing are made to integrate with the advanced fan drive; no output gearing adaptation or major PTO housing modifications are required.

Hydraulic manifolds which support clutch actuation and lubrication are mounted on the drive housing.

Modeling and simulation of a BFV with an advanced fan drive system was completed at TARDEC to confirm fuel economy improvement. Multiple ratio spans and gear ratios were selected to evaluate the range of possibilities. The final selected drive design demonstrated a fuel consumption improvement over the baseline hardware.

PTO Generator Drive

The available PTO Generator drive has diameter limitations based upon baseline hardware positioning. This requires compact design in a radial direction. A single coplanar module is needed for the two speed drive, which has concentric input and output shafts. A sectioned view of the PTO Generator is shown in Figure 10.

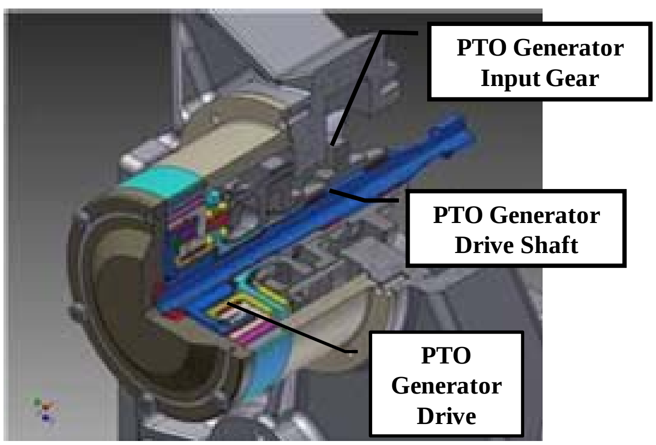

Figure 10: Advanced PTO Generator Drive Arrangement

Integration of the PTO Generator drive requires replacement of the baseline generator drive shaft. A new drive housing assembly replaces the baseline cover and the baseline PTO housing remains untouched in this region. The resulting increase in output power from integrating the two speed drive is shown in Figure 11.

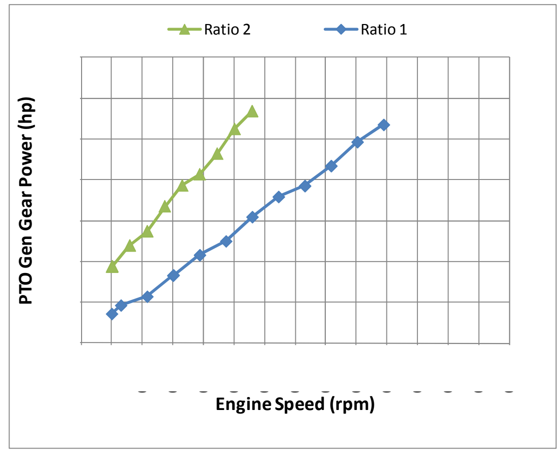

Figure 11: Advanced PTO Generator Assembly Power Generation

Accessory Alternator

The Accessory Alternator uses a similar two speed drive system as the PTO Generator, but has a completely different set of integration hardware. The Accessory Alternator's location near the bottom of the powerpack assembly requires a scavenge pump to return lubrication provided by the HMPT transmission back to the HMPT transmission. The drive belt system requires upgrading for greater torque capacity; an advanced drive cantilever shaft arrangement was required to support belt loads for the new drive system. An adapter plate between the drive housing and the Accessory Alternator reroutes cooling air flow. A subassembly view of the Accessory Alternator hardware is shown in Figure 12.

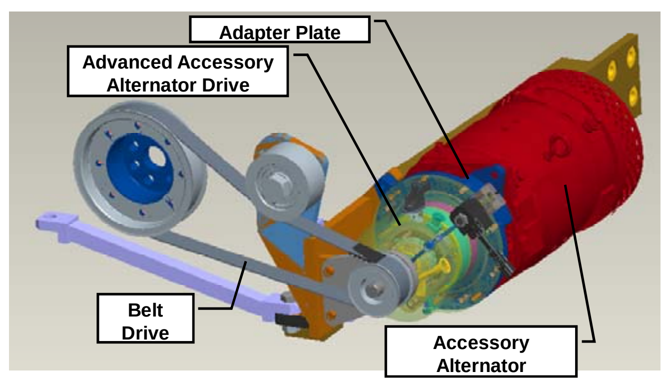

Figure 12: Advanced Accessory Alternator Drive Arrangement

The improvement in Accessory Alternator electrical power generation with addition of a two speed drive is shown in Figure 13.

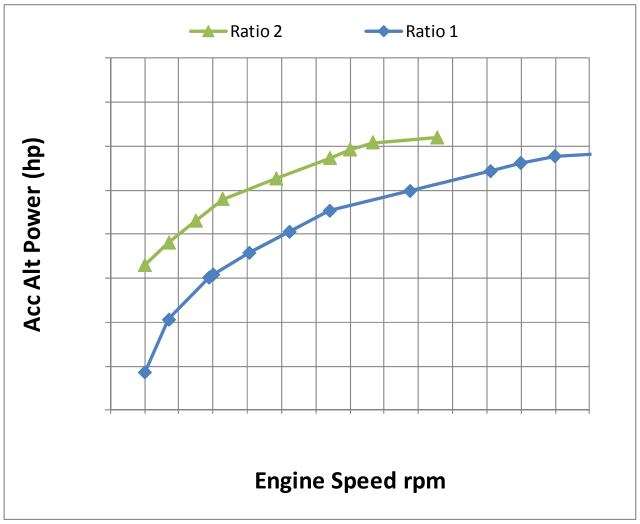

Figure 13: Advanced Accessory Alternator Assembly Power Generation

CONTROLLER

An ETAS controller was selected for the project based upon flexibility, ability to read J1939 data and the ability to support all input-outputs necessary for the program. A single device controls all three drives.

In addition to the J1939 information provided by the generators, speed, pressure and temperature sensors are required for development of shift timing, clutch actuation pressures profiles, hardware health monitoring and diagnostics. Although most sensors are mounted in the new drive hardware, two speed sensors are integrated into the existing PTO assembly.

DEVELOPMENT AND FUNCTIONAL TESTING

After fabrication and assembly of the advanced drives are completed developmental and functional testing of the system will be completed. An operational HMPT transmission will be mounted to a dynamometer test stand and act as the test base for the PTO assembly. On the same test stand, opposite side of the dynamometer, the Accessory Alternator will be mounted. This configuration which mimics the powerpack arrangement allows generation of hydraulic pressure in the HMPT which will be provided to all three accessory drives, simultaneously.

Software safety checks will first be completed followed by a wear-in procedure for the drives. Developmental testing will enhance shift schedules, shift timing and confirm lubrication requirements to each drive are met with the current HMPT PTO lube flow rate. Performance testing will be completed to confirm electrical power generation by the PTO Generator and Accessory Alternator Drives and efficiency of the fan drive.

After test stand evaluation is complete the drive system will be installed in an operational vehicle for full system in-vehicle evaluations.

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