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Recommendation of Sensors for Vehicle Transmission Diagnostics

by Kwok F. Tom

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14. ABSTRACT

The U.S. Army Research Laboratory (ARL) had entered into a Technical Program Agreement (TPA) with the U.S. Army Tank and Automotive Research and Development Center (TARDEC) for research on Prognostics for Ground Vehicles. One of the tasks under this agreement was to survey/investigate sensors for diagnostics related to ground vehicles as related to transmissions.

15. SUBJECT TERMS

Sensors, diagnostics, transmission, FMECA, FMEA

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1. Introduction

The U. S. Army Tank and Automotive Research and Development Center (TARDEC) is performing research and development on programs related to ground vehicles. One of the primary components associated with the mobility of ground vehicles is the transmission. Its basic operation converts the engine's energy into a form that can be used to operate the drive train. The transmission is a series of mechanical components such as gears, bearings, and clutches that operate in a synchronous motion in order to change the engine speed rotation into torque. Due to the contact between the components and the heat generated in this process, transmission fluid is used as a lubricant and coolant for the rotating components within the transmission housing.

To assist in TARDECs efforts, the U.S. Army Research Laboratory (ARL) entered into a Technical Program Agreement (TPA) with TARDEC on TPA, #TA-SE-2010-05. As part of the TPA, ARL agreed to perform the following task: Perform survey/investigation of sensors and algorithm application to providing diagnostic capabilities as related to ground vehicle, e.g., Allison 2500 transmission.

The Allison 2500 transmission is used on the Mine Resistant Ambush Protected (MRAP) vehicle, RG-31A2. This vehicle has a five-speed Allison SP series automatic transmission. The transmission is electronically controlled by the Transmission Control Module (TCM) to operate the transmission gear selector. Cooling of the transmission fluid is provided by remote-mounted oil cooler in front of the vehicle (*1*). In addition to this particular transmission, other transmissions were reviewed to formulate a sensor list for transmission in general.

2. Data Sources

A survey of various documents was conducted in order to formulate sensors candidates for diagnostic capabilities as related to transmissions. These documents dealt with the Allison transmission as well as other manufacturers. Some documents provided a great detail investigation of the transmission as conducted as part of a Degrader Studies by Applied Research Laboratory, Pennsylvania State University (ARL–Penn State) and the Failure Mode Effect, Cause, and Criticality (FMECA) Study on the Bradley Transmission by Global Technology Connection, Inc. A FMECA is a reliability analysis tool used to identify the failure mode and its effect on performance, and to rank the impact of such failures. These studies identified the sensors that would be appropriate to help detect and diagnose associated failure mechanisms. In a Degrader Study, analysis is performed by using a FMECA study along with other information—parts replacement data, customer interviews, and Original Equipment

Manufacturer (OEM) survey. Part replacement data is derived from the Operating and Support Management Information System (OSMIS) and Logistics Support Agency (LOGSA) databases (*2*).

The Degrader Studies were performed on the M2/M3 Bradley Fighting Vehicle and the M1 Abrams Tank. The transmission in the M2/M3 Bradley Fight Vehicle is the HMPT-500-3EDB by L3. An Allison X-1100-3B transmission is used in the Abrams Tank. The FMECA was performed on both the Bradley and Abrams transmissions. A Failure Mode and Effects Analysis (FMEA) had been performed on the Allison 2500 SP transmission by ARL–Penn State. Other documents used were Army Technical User and Maintenance Manuals, in addition to other documentation from Allison.

3. Transmission as Line Replaceable Unit (LRU)

One of the components that was identified as a top replacement item is the transmission based on the Degrader Studies. For the Bradley Fighting Vehicle, 16% of the Field Service Representatives (FSR) report indicated that the transmission is a high replacement item. The transmission is treated as a LRU that is replaced without minimal troubleshooting process. Better fault isolation would be of great benefit (*3*). Results from the Abrams Degrader Study indicated that 55% of the FSR reports were related to the transmission. This is significantly high, but the report indicates that failure rates have improved recently. The paradigm on the Abrams Tank is to treat the transmission as a LRU that is sent back to the depot for repairs. Part of the difficulty is because the embedded diagnostic is fairly limited and maintainers are not well-trained in servicing the transmission (*4*).

4. Current Capabilities

There are different diagnostic capabilities around the spectrum of transmissions. Even on the same vehicular type, the configuration varies in terms of embedded diagnostic capabilities. In the case of the Bradley Fighting Vehicle, there are two configurations—standard and enhanced models. With the Chassis Modernization and Embedded Diagnostics configuration, an embedded diagnostic capability is provided through the addition of sensors on several systems. Diagnostic capability is available on the generator, batteries, starter, fuel pumps, fuel filter, engine, and transmission oil pressure and temperature. Part of the problem associated with the transmission is the capability of diagnosing the failure classification to be mechanical or electronic in nature. FSR reports that there is a lack of proper diagnostic tools. One unit indicated that a Tech2Scan diagnostic tool device was extremely helpful, but not supplied as part of their arsenal of tools (*3*).

There are many sources of diagnostic capabilities offered by the OEM and independent diagnostic developers. One such company is the Nexiq Technologies Company, which produces the Pro-LinkiQ scan tool. Their scan tool is flexible enough to accommodate various manufacturers such as Detroit Diesel, Caterpillar, International, Mack, and Volvo. The scan tool is application-specific where software unique to a particular manufacturer is installed to a common tool. This application permits the reading of proprietary fault codes, clearing of proprietary fault codes, viewing and reset of trip information, viewing of data lists (for example, sensors, switch status, proprietary data lists), and performance of special tests (for example, cylinder test, injector test) (*5*). This is just an example of secondary diagnostic capability being offered through after-market service tools.

The OEMs have spent a great deal of time in the development of their transmission and have provided some level of diagnostic capability. These transmissions are fully automatic torque-converters with electronic controls. In the case of the Allison 2000 series transmission, there are five major components connected through a wiring harness:

- TCM
- Engine throttle position sensor or direct electronics communication of throttle information
- Engine, turbine, and output speed sensors
- NSBU switch
- Control value module

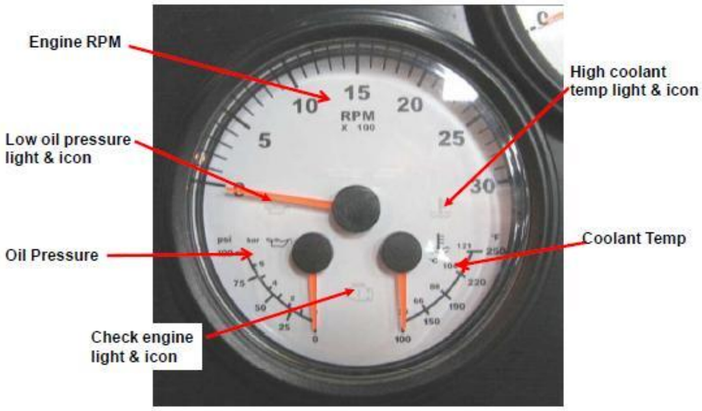
This transmission has adaptive shifting through the monitoring of critical parameters for clutch engagement. Solenoids and a pressure switch module form the Control value module. A thermistor is contained within the pressure switch module in order to monitor the sump fluid temperature. Sensor information is provided to the TCM through various sensors such as throttle position, speed sensor, pressure switch module, and NSBU switch. Activation of specific solenoids on the Control value module is executed through the processing of the sensor information. This provides for closed-loop adaptive shifting that optimizes the clutch engagement and makes ongoing adjustments to improve subsequent shifts (*6*).

The manufacturers have provided some level of diagnostic capabilities that can be accessed through the Controller Area Bus (CAN) interface. This communication interface provides a digital exchange of information between the Allison transmission and TCM. Diagnostic information can be collected and provided through Allison or secondary service tools. Allison Diagnostic Optimized Connection (DOC) is a software tool that was developed to provide diagnostic monitoring of its transmission. This communicates with the TCM to read the status of transmission clutches and summary of Diagnostic Trouble Codes (*7, 11*).

Similar capabilities are offered by other OEMs. On the Bradley Fighting Vehicle, the transmission is the Hydromechanical Power Transmission (HMPT). Combat Propulsion Systems

(L-3 CPS) developed and designed this transmission. The electronics is comprised of two assemblies: Transmission Electronic Controller (TEC) and Transmission External Memory Module (TEMM). The function of TEC is to acquire the various transmission sensors outputs and desired operation in order to properly execute the necessary activation of the stepper motors and solenoids. Contained in the TEC are all control algorithms, and fault detection logic and communication interfaces. The other electronic assembly, TEMM, is a memory storage device that retains the transmission history, usage, and faults. Critical fault parameters are stored with information around the event. This information can be accessed through a scan tool and is beneficial for troubleshooting (*12*).

Typically, the sensor information is processed by the OEM and fault codes generated and stored on the vehicle computer. Scan tools that are accessing this information can provide the capability for troubleshooting. In general, the OEM provides some simplified diagnostic summary through dashboard indicators. Figures 1 and 2 are images for the Heavy Expanded Mobility Tactical Truck (HEMTT) that uses the Allison 4500 SP/5 automatic transmission (*8*).



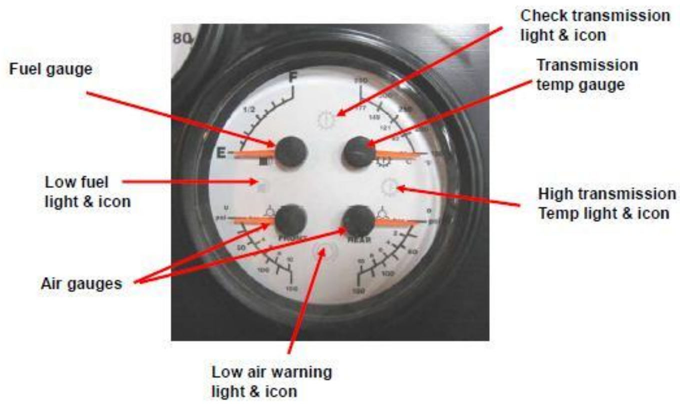
Icons (indicators)

a. **Low oil pressure**

b. **High coolant temperature**

c. **Check engine indicating engine has logged a fault code event**

Figure 1. Tachometer and diagnostics gauge



Icons (indicators)

a. **Check Transmission (get fault messages from TCU)**
b. **Low fuel warning**
c. **High transmission temperature**
d. **Low air warning from front or rear system**

Figure 2. Fuel and diagnostics gauge

5. Common Essential Parameters

A significant amount of testing has been conducted by the various transmission manufacturers in order to evaluate the performance and reliability of their products. One of the outcomes of these types of testing has been the OEM specification of fluids and interval for servicing. This information has been reduced to recommendations that hopefully represent the typical usage. In this situation, it is very difficult to estimate what represents the typical use in military vehicles. The function of the transmission fluid is to cool, lubricate, and transfer hydraulic power to drive the vehicle. A simple, but very important parameter is the proper fluid level. When the fluid level is low, there is a lack of adequate fluid to function optimally. This will impact the life and reliability of the converter, bushings, bearings, and clutches. A high fluid level will result in aeration. In this state, the transmission will shift erratically or overheat. Temperature and fluid level are simple parameters that can be measured.

Transmission components are sensitive to contamination of its fluid. Solid particulates are an indication of a serious problem. The durability of the transmission internal components, such as bushing, bearings, and gears, can be seriously affected. Fine particulates have a potential to affect the functionality of the control value module. This could degrade the operation of the solenoid to the point that there is a failure or the clutch plates could stick.

The viscosity of the fluid is critical to the lubricity of the transmission components. Contamination of the fluid with water and/or ethylene glycol coolant mixtures affects the reliability and durability of the components. A mixture of this type will have a deterioration effect on both the non-metallic components, such as gasket material, and on the metallic bearings and gears. Allison recommends that transmission protection and fluid changes can be optimized by monitoring the oxidation according to the test and limit shown in table 1 (*6*, *9*).

Table 1. Fluid oxidation measurement limits.

Test	**Limit**
Viscosity	25% change from new fluid
Total Acid Number	+3.0* change from new fluid (mg of KOH required to neutralize a gram of fluid)

The transmission fluid temperature is one of the most important indicators of transmission health. Temperature effects on transmission operation are summarized in table 2. This table lists the effect for standard transmission oil (Synthetic Universal Automatic Transmission Fluid), but the information is applicable for most transmission oil.

Table 2. Operating oil temperature range.

Temperature (Fahrenheit)	**Effect**
150° F	The minimum operating temperature.
175–200° F	Normal pan oil temperature operating range.
275° F	Maximum allowable oil pan temperature for short durations during long hill climbs.
300° F	Damage occurs to internal transmission parts, including warping of metal parts, degradation of clutches, and melting of seals. Transmission oil oxidizes, (forming varnish like substances causing further clutch slippage and compounding heat buildup) and transmission oil life is extremely short.

The automatic transmission fluid should be able to provide 100,000 miles of service before replacement at an operating temperate of 175 °F. Oil oxidation rate doubles with each 20 °F increase in oil temperature. Table 3 illustrates the temperature effect on the standard transmission oil life as a function of temperature (*10*).

Table 3. Transmission oil temperature versus distance of service.

Temperature (Fahrenheit)	Distance (Miles)
175^{O}	100,000
195^{O}	50,000
215^{O}	25,000
235^{O}	12,500
255^{O}	6,250
275^{O}	3,125
295^{O}	1,500
315^{O}	750

6. Summary of Proposed Sensors

Reports and analysis were reviewed for various transmissions on different ground vehicles. Information for Allison X-1100-3B, Allison 2500 SP, and L-3 Combat Propulsion Systems' HMPT transmission were part of this review. Identification of sensors that may be used can be easily derived from FMECA and FMEA analysis. Although these transmissions are different in design and hardware, the basic functions are similar. From these evaluations, it is clear that there are some embedded sensors and processing presently on transmission from the OEMs. The diagnostic capability exists at a fundamental level. Another piece of information to come out of these reports was the importance of "human perception." The human being is also a sensor with processing capabilities, but is not necessarily accurate in terms of correctly diagnosing the problem (*3*, *4*).

Part of the hurdle in using the capability is the lack of access to the scanning tools to read the diagnostic fault codes. In addition, since the transmission is complex machinery, the knowledge and necessary facility does not exist to perform repair function out in the field. The transmission is treated LRU, but proper diagnostic ability would reduce the necessary actions that result from incorrect or improper classification of fault. Some of the sensing information is binary as a result of the switches on the oil pressure, temperature, and oil filter in the case of the Abrams Tank (*4*). This is very limited in terms of diagnostic resolution, with enhanced diagnostic capability derived with replacement with higher fidelity sensors.

The sensing capabilities between various transmissions are not necessarily identical, but similar sensors would be needed to provide common sensing capabilities. The lists of sensors are as follows:

- Viscosity
- Fluid level
- Fluid pressure

- Temperature
- Contaminant
- Voltage & Current
- Vibration (Advanced with signal processing techniques)

The addition of these sensors is only part of the solution for diagnostic capabilities. Proper interpretation of these signals will have to be developed. Algorithms, framework, and methodology are necessary and very important elements that will be required, in addition to incorporating sensors. Sensors provide the data, and information is developed from the processing of the data. Correct interpretation of the information provides the knowledge for correct and enhanced diagnostic capability.

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Appendix

Analysis of FMEA on Allison 2500 SP Transmission. Extracted from ARL-VTD Mechanics Division TPA Year-End Report, TPA TA-VT-2010-02, Condition-Based Maintenance Plus for Ground Vehicles.

Failure Mode	**Potential Causes**	**Sensing Strategies**	**Sensor Availability**
Contaminated transmission lubrication	Internal transmission failure; Clogged filter; Excessive heat	Transmission fluid contaminant sensing; Fluid temperature sensing	Fluid contaminant sensor; Fluid temperature sensor
Engine excessively revs on full throttle up shifts	Internal transmission failure; Incorrect calibration; Incorrect fluid level; Erratic speed sensor signal	Current/Voltage sensing at sensor terminals; Fluid level sensing	Current/Voltage sensor measured at sensor terminals; Fluid level sensor
Excessive slippage and Clutch chatter	Internal transmission failure; Faulty torque converter; Clutch pressure low; Fluid level low; Aerated fluid; Transmission control module incorrectly calibrated; Throttle position sensor failed; Incorrect fluid level; Worn clutch pack; Incorrect speed sensor	Fluid pressure sensing; Contaminant sensing; Electrical disconnect sensing at sensors; Fluid level sensing	Fluid pressure sensor; Contaminant sensor; Current/Voltage sensor at terminals/wiring; Fluid level sensor
Excessive stationary vehicle creep in first and reverse gear	Internal transmission failure; Engine idle speed set too high	Fluid pressure and temperature sensing; Contaminant sensing; Analyze Engine PHM	Fluid pressure sensor; Temperature sensor; Contaminant sensor; Investigate Engine PHM sensing
Fluid leak at output shaft	Seal at output flange damaged; Worn output shaft bearing; Flange worn at seal surface	Fluid temperature/Pressure sensing; Contaminant sensing	Fluid temperature/Pressure sensor; Contaminant sensor
Fluid leaking from fluid filler tube and/or breather	Fluid contaminated with foreign liquid; Blocked breather; Incorrect fluid level; Dipstick loose or seal worn	Fluid contaminant sensing; Fluid level sensing	Fluid contaminant sensor; Fluid level sensor
Fluid leaks	Transmission input seals worn/damaged; Damaged gaskets; Blocked breather; Cracked casing; Loose fluid filler or drain plug; Worn output shaft bearing; Fluid level too high	Fluid level sensing; Fluid temperature/pressure sensing	Fluid level sensor; Fluid temperature/pressure sensor

Intermittent noise – buzzing (acoustic wave)	Low main pressure causes main regulator to oscillate; Internal transmission failure; Air leak in oil suction screen canister; Clogged filter; Transmission fluid level low; Incorrect sump filter installed; Faulty torque converter; Aerated fluid	Fluid level sensing; Fluid pressure sensing; Contaminant sensing	Fluid level sensor; Fluid pressure sensor; Contaminant sensor
Low lubrication pressure	Excessive internal fluid leakage; Converter relief value sticking; Lubrication regulator value sticking; Incorrect fluid level; Blocked suction filter; Cooler lines restricted or leaking; Faulty pump	Fluid level sensing; Oil pressure sensing across pump; Pressure sensing in cooler lines	Fluid level sensor; Pressure sensor
Low main pressure in all ranges	Internal transmission failure; Incorrect fluid level; Faulty pump; Blocked suction filter	Fluid level sensing; Pressure sensing across pump & suction filter	Fluid level sensor; Pressure sensor
Low main pressure in specific ranges, normal pressure in other ranges	Internal transmission failure; Faulty pump	Fluid pressure sensing across pump	Fluid pressure sensor
Low stall speeds	Engine not performing efficiently due to blocked injectors, dirty air filter, throttle linkage problem, etc.	Examine sensing for Engine PHM	Integrate appropriate Engine PHM sensors
No transmission control module light at ignition	Incorrect wiring to and from transmission control module; Faulty light bulb; Transmission control module connected to battery power instead of ignition power	Current/Voltage sensing for control module wire harness	Current/Voltage sensor
Overheating in all ranges	Cooler flow loss due to internal transmission leakage; Engine overheating; Fluid cooler lines restricted; Air flow to cooler obstructed; Incorrect fluid level; Aerated fluid	Fluid temperature sensing; Fluid pressure sensing; Air flow to cooler pressure sensing; Fluid level sensing; Contaminant sensing	Fluid temperature/Pressure sensor; Air flow pressure sensor; Fluid level sensor; Contaminant sensor
Shudder when shifting into forward or reverse	Internal transmission failure	Fluid level sensing; Fluid temperature/pressure sensing; Contaminant sensing	Fluid level sensor; Fluid temperature/pressure sensor; Contaminant sensor
Transmission control module light flashes intermittently	Loose wire to transmission control module light; Faulty vehicle wiring; Faulty ground connection	Current/Voltage sensing on wiring harness	Current/Voltage sensor for wire harness (wire chafing)

Transmission control module light will not extinguish after engine has started	Faulty transmission control module light relay; Faulty transmission control module; Fault harness	Current/Voltage sensing on wiring harness	Current/Voltage sensor for wire harness (wire chafing)
Transmission does not shift properly (rough shifts, shifts occurring at too low or too high speeds)	Sticking valves in control valve body; Leaking trim solenoids; Low main pressure; Faulty speed/sensor/circuit; Loose or damaged speed gear; Faulty throttle sensor/circuit; Incorrectly calibrated electronic speedometer; Incorrect fluid level; Contaminated fluid; Engine idle speed too fast	Fluid level sensing; Fluid temperature/pressure sensing; Current/Voltage sensing for possible electrical disconnects at sensors and on wire harness	Fluid level sensor; Fluid temperature/Pressure sensor; Current/Voltage sensor at sensor terminal& on wiring harness (wire chafing)
Transmission will not make a specific shift	Extreme fluid temperature; Low engine power; Incorrect shift calibration; Faulty speed sensor/circuit; Faulty temperature sensor/circuit	Fluid temperature sensing; Current/Voltage sensing for sensors & wiring harness	Fluid temperature sensor; Current/Voltage sensor (wire chafing)
Transmission will not select	Low hydraulic pressure; Throttle position sensor or linkage not functioning properly; Faulty speed sensor; Faulty wiring in Transmission control module	Fluid pressure sensing; Fluid level sensing; Current/Voltage sensing for sensors and wiring harness	Fluid pressure sensor; Fluid level sensor; Current/Voltage sensor (wire chafing)
Transmission will not stay in forward or reverse	Faulty solenoid; Low hydraulic pressure; Control main filter clogged; Transmission fluid level low	Fluid pressure sensing; Fluid level sensing; Current/Voltage sensing at solenoid	Fluid pressure sensor; Fluid level sensor; Current/Voltage sensor

List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
ARL–Penn	Applied Research Laboratory, Pennsylvania State University
CAN	Controller Area Bus
DOC	Diagnostic Optimized Connection
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode Effect, Cause, and Criticality
FSR	Field Service Representatives
HEMMTT	Heavy Expanded Mobility Tactical Truck
HMPT	Hydromechanical Power Transmission
LOGSA	Logistics Support Agency
LRU	Line Replaceable Unit
MRAP	Mine Resistant Ambush Protected
OEM	Original Equipment Manufacturer
OSMIS	Operating and Support Management Information System
TARDEC	U.S. Army Tank and Automotive Research and Development Center
TCM	Transmission Control Module
TEC	Transmission Electronic Controller
TEMM	Transmission External Memory Module
TPA	Technical Program Agreement

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