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White Paper

Vehicle Prognostics to Enable Optimized Maintenance and Logistics

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Vehicle Prognostics to Enable Optimized Maintenance & Logistics

Identified need: At SAE (Society of Automotive Engineering) and other conferences Army TARDEC and TACOM representatives have described the excessive wear out conditions occurring with wheel bearing and other suspension components on wheeled military vehicles in service in Iraq and Afghanistan. The harsh environment in these theaters, combined with the extra weight of the up-armor modifications, reduces the lifetime of the wheel bearings and other mechanical components. Coupled with this is the hard and often unpredictable service the vehicles are experiencing. It is of significant value to the warfighter to be able to predict when a bearing or other suspension component is nearing the end of its service life so it can be replaced and failure in the field during a mission can be avoided.

Mr. James McLeish, at DfR Solutions, has expertise with several methods of monitoring and quantifying suspension behavior including motion and severity. We believe his methods of gathering data, in combination with DfR Solutions' expertise in product development and physics of failure based degradation models, will provide a solution to TACOM's needs with a high chance of success.

The proposed system will function as an on-board prognostic system that will allow the maintainer in the field to schedule maintenance before a field failure occurs instead of performing emergency repairs, often in hostile environments, after a failure. It allows for 'Just in Time Maintenance' with 'Just in Time Logistics.' and pre mission state of health /remaining life assessment of critical suspension components.

Vehicle Data Gathering: The current proposed method uses existing sensors on the vehicle as well as additional sensors between the sprung and unsprung components of the suspension. The feedback from these sensors is used by an onboard computer to determine the loads applied to the bearing. For example, the vertical distance and the frequency of the suspension travel is used to calculate the radial loads applied, and the vehicle speed is used to calculate the bearing RPMs. The micro-computer then creates histograms that track the loading conditions and stress environment experienced by the vehicle's suspension components that drive wear out conditions. This data is used to determine the damage accumulated using fatigue/wear models and to predict the component health and life consumption.

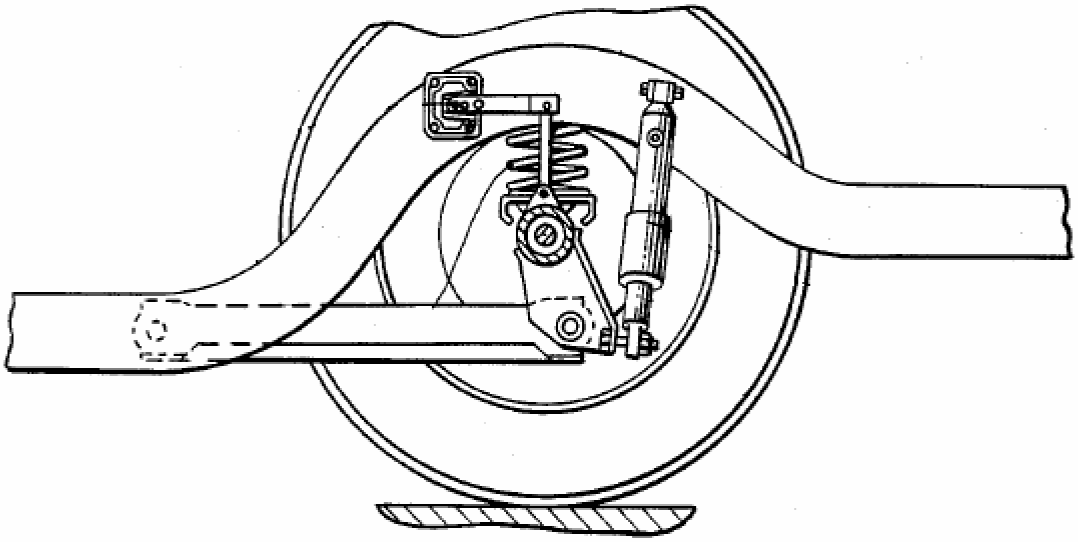

Figure 1: Side elevation view of a vehicle suspension of sprung and unsprung masses including the suspension means, shock absorber, and level sensor

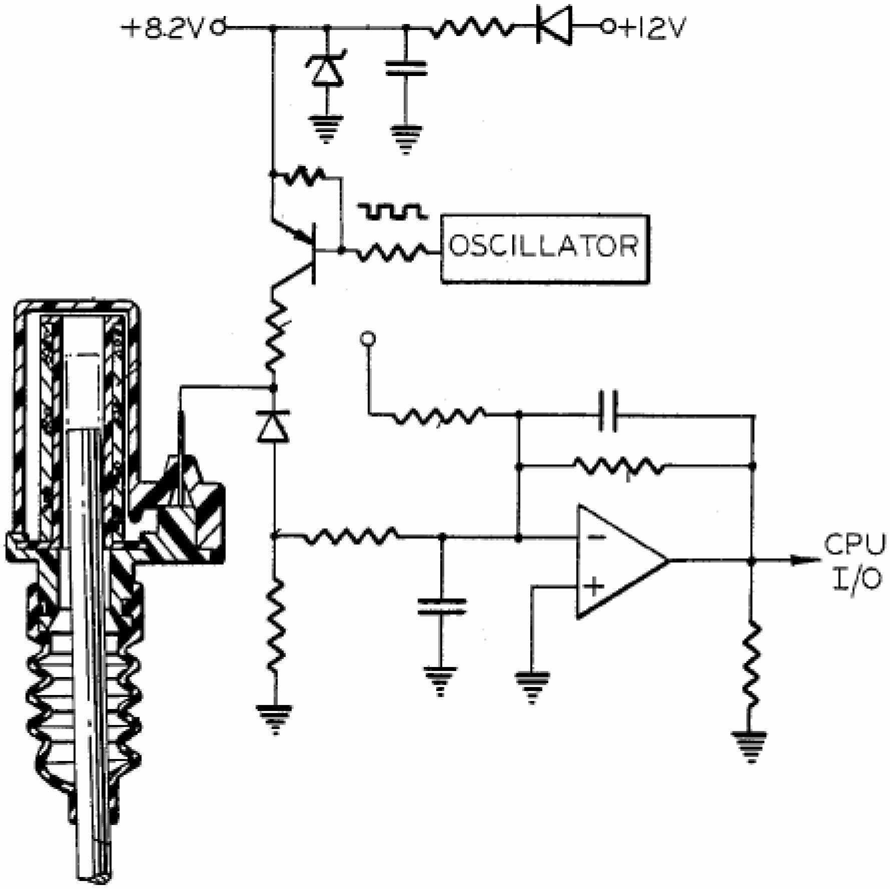

Figure 2: Alternative level sensor and cirucit

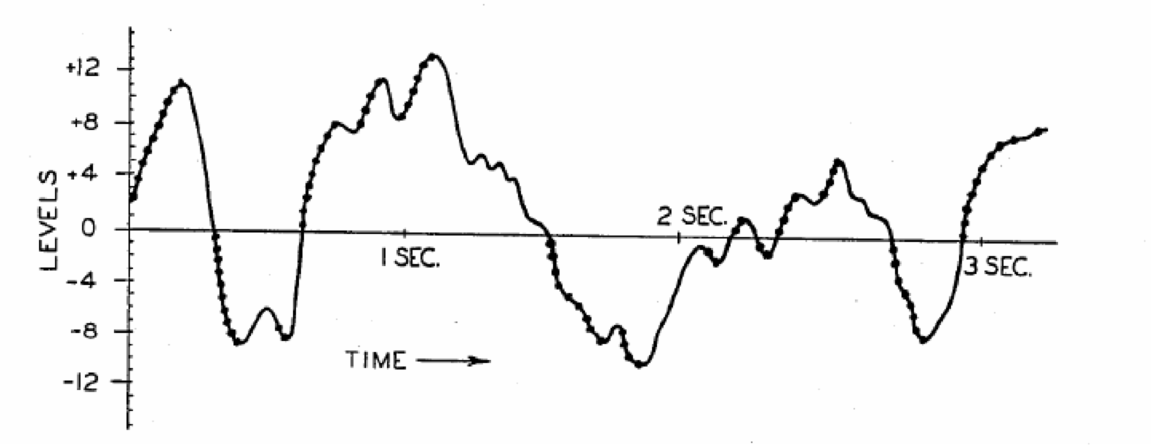

Figure 3: Example load levels over time

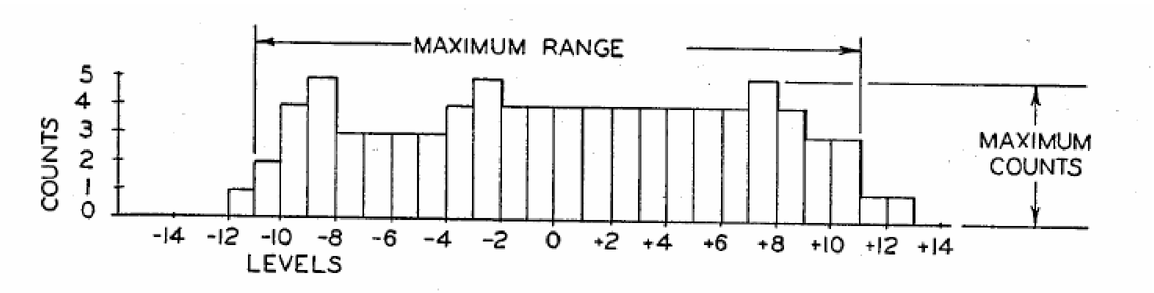

Figure 4: Counts of load levels used in characterizing system wear.

Degradation Modeling: DfR Solutions has expertise in predicting component life using wearout/fatigue equations. This includes mechanical fatigue as well as the wearout of electronics. Using this knowledge and the load histograms, the health of the component can be calculated. These calculations will be done continuously by the onboard computer which updates the health record of the component in real time. An example of this calculation for ball bearing wearout:

$$L = \left[\frac{f_c Z^{a_1} D_a^{a_2} (i \cos \alpha)^{a_3}}{P} \right]^p$$

Z = number of balls
D_n= ball diameter in inches
i=number of rows
α = contact angle
P=bearing load in pounds
L=number of million revolutions that a specified percentage of bearings will fail, if the percentage is 10 then L=L_{10} and is termed the rating life.
p, a_1, a_2, a_3, a_3, f_c, are unknown parameters that must estimated on given data

Knowing the rated life, as provided by the bearing manufacturer, the amount of damage incurred by an exposure to different loads and number of revolutions can be determined.

Damage:

1. Calculate the L_{10} value for the load experienced by the bearing: the life of the bearing at that load value
2. Determine the average speed of the vehicle over the load sampling window, Calculate the revolutions of the bearing and divide by the total life (calculated in step one). The result is the damage accumulated by the bearing due to the exposure to the load.
3. Damage calculated from steps 1 and 2 are aggregated with other damage events using Miner's rule
4. A damage ratio of 1 indicates eminent bearing failure.

The prognostic computer will be set to alert the maintenance crew to replace the bearing when the damage ratio reaches a predetermined value, for example 0.7 to 0.9 i.e. 70% to 90% of the bearing life has been consumed.

This is only one example of the type of calculations that can be performed. The equations will be modified to account for additional environmental and usage conditions.

System integration: The onboard mechanical health monitoring and prognostic system will combine the data gathered by the sensors with the prognostic software and field data to provide the maintainer in the field with the information necessary to ensure maintenance occurs before field failures.

The integrated system will be retrofitted in to existing vehicles and could be integrated into vehicles on the production line. The system will consist of an onboard computer, suspension sensors, and a wiring harness.

The on board micro-computer can be a dedicated stand alone unit for existing vehicles. For future vehicle the sensor interface and software functions system can be integrated into a multifunction Electronic Control Unit (ECU). The onboard sensors for this system will be ruggedized to survive the harsh environment.

The onboard computer will provide information in multiple ways. Based on the amount of accumulated stress that mechanical components have endured, the onboard computer can communicate with the operator or fleet maintainer, using a dash panel warning light or display. Initial communication to the operator, the warning light, will indicate when these parts are near the end of their useful life and require maintenance. A display could be used to indicate operational life consumption and remaining operational life for each suspension component. More detailed data collected by the onboard computer can be accessed via a connection similar to modern on-board diagnostics (OBD) systems. The data can be used by the maintainer to schedule maintenance and ensure that the right parts are ordered and delivered at the right time. The maintainer can also use this interface to reset the onboard system after maintenance procedures have been performed or to update the programming and wear out reference libraries of the on board micro computer as new updates become available or as new features for the system are developed.

Fielding the system and use: An onboard mechanical prognostic system can be quickly developed with the initial capability of monitoring wheel bearing and suspension component life and still retain sufficient upgradeability for later additional capabilities as needed.

Initial fielding would be a field or depot mechanic installable kit consisting of a sensor package, a wire loom, and a cabin mounted computer. Install time including set up calibration of the system for the current readiness state of the vehicle would be approximately 2-4 hours.

The mechanical system prognostic computer will have a warning light or LCD readout that would give an 'at a glance' read of the health of the vehicle suspension. A data output port will be available for reading detailed information by a laptop or other diagnostic tool. Data available on the laptop would consist of total use of the wheel bearings and other suspension components as well as provide a predicted life for these items based on continued service in the current environment.

Summary: The Army has a need for predicting the failure of wheel bearings of combat services support vehicles in harsh environments under high usage and loading conditions. DfR Solutions has the technology to monitor the accumulated stress damage/life consumption absorbed by the vehicle's suspension components. DfR Solutions has the technical expertise to combine the mechanical data from the vehicle with a sophisticated prognostic model of component lifetime reliability. Implementing this proposed mechanical onboard prognostic system will give the maintainer in the field the ability to avoid operational failures.

This will have a positive impact on the logistics of supporting a fleet of vehicles. The state of health and remaining life of critical suspension components can be assessed, minimizing the risk of break down during a critical mission. Instead of having a large warehouse of parts and not having the part needed, the maintainer will be able to schedule maintenance and avoid mechanical failures. This moves the operators and maintainers to a 'Just in Time Maintenance and Logistics' paradigm.