

Diagnostics Design Process for Developmental Vehicles

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ABSTRACT

In this paper a diagnostic design process is proposed for developmental vehicles where mainstream design process is not well-suited. First a review of current practice in on-board vehicle fault diagnostics design is presented with particular focus on the application of this process to the development of the Ford Escape Hybrid Electric Vehicle (HEV) program and a demonstration Fuel Cell Electric Vehicle (FCEV) program. Based on the review and evaluation of these experiences, a new tool for diagnostics design is proposed that promises to make the design more traceable, to reduce the repetition of work, and to improve understandability and reuse.

INTRODUCTION

OVERVIEW

The purpose of this paper is to evaluate the current processes employed at Ford for the design and implementation of on-board vehicle fault diagnostics. Based on this evaluation, recommendations are made as to how the process can be improved. This endeavor in particular focuses on new developmental vehicle programs that do not necessarily fit into the mainstream processes employed with a mass produced vehicle.

Many of the lessons learned and examples drawn upon in this paper come from the Ford Escape Hybrid Electric Vehicle (HEV) program and a demonstration Fuel Cell Electric Vehicle (FCEV) program. Challenges in diagnostics development, however, are not limited to developmental programs. Some representative statistics are that 32% of warranty costs are attributable to dealership visits where no identifiable problem could be found [1] and that by some

estimates over 50% of electrical problems are initially diagnosed incorrectly [2].

GOALS & CHALLENGES

The primary goals of a diagnostic system are to make the vehicle system robust and to facilitate its repair. From an overall design point of view, a robust vehicle will be built to prevent or minimize the occurrence and effect of faults that adversely affect drivability, safety, or regulatory compliance. If a fault cannot be altogether prevented, then it is necessary that the fault be identified and action be taken to mitigate its effects. It is the province of the diagnostic system to perform the fault detection and isolation so that appropriate control actions can take place. The second responsibility of the diagnostic system is to issue information to help the driver and/or service technician to take action that will resolve the fault. This is accomplished by setting indicators (like a dashboard lamp or a chime) and by storing diagnostic trouble codes (DTCs) that a service technician can read to help pinpoint the underlying fault. The actions taken to ensure that a production vehicle is serviceable by a technician also facilitate the management and resolution of vehicle problems during the development process.

One of the challenges with designing the diagnostics for a modern vehicle is that the systems are increasingly complex. The number of sensors and actuators, electronics, and lines of software code continue to increase as car manufacturers push to improve vehicle quality, performance, adaptability, and customization. This complexity makes it infeasible to consider all aspects of the system at once. The natural solution to this problem is to consider the system on a piece-by-piece basis. The difficulty that arises here is that the components of the larger vehicle system are also increasingly

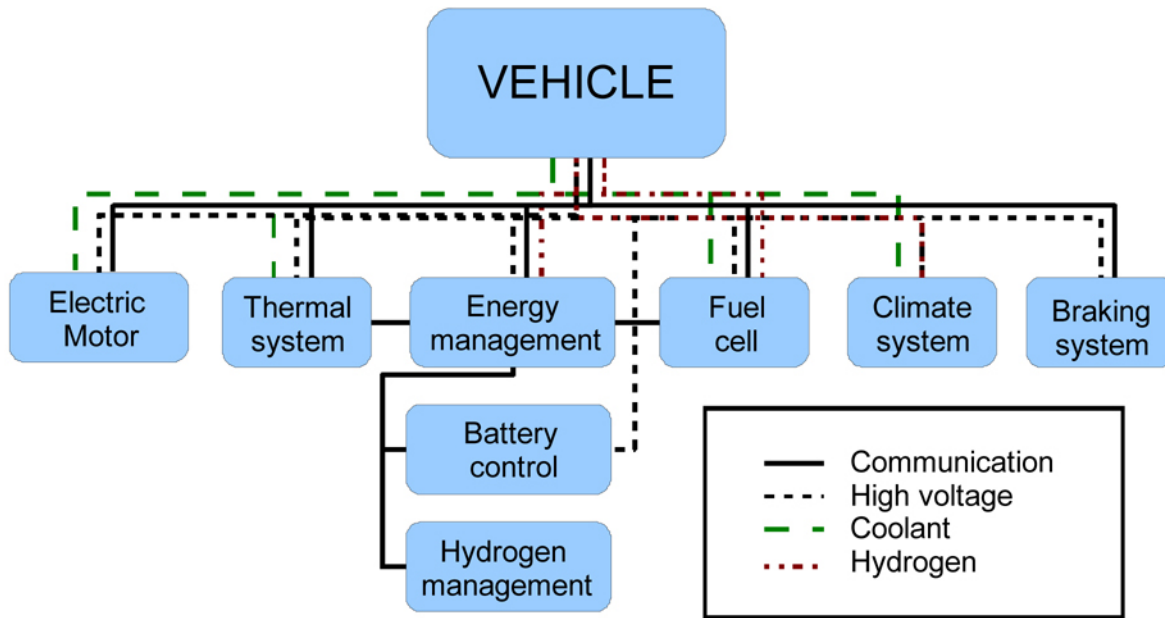


Figure 1. Fuel Cell Electric Vehicle (FCEV) Architecture

coupled. For example, consider the representation of a hypothetical FCEV system shown in [Figure 1](#). Within this figure, each box represents a separate hardware module and each of the lines indicates that information from the associated physical subsystem is needed by the connected module for diagnostic and control decisions. This diagram illustrates just how coupled each of the hardware modules are. A further complication to this process is the pressure to lower system cost and shorten the overall design cycle to meet customer demands and to stay competitive in a constantly changing market. Developmental vehicle programs additionally face the problem that there isn't always a historically comparable vehicle from which to draw elements of the design.

<figure 1 here>

CURRENT DESIGN PROCESS

PRODUCTION VEHICLES

A focus for designing vehicle systems at Ford is the avoidance of failure modes. Specifically, a Failure Modes and Effects Analysis (FMEA) is relied upon for identifying the causes and effects of various failure modes. This information is then employed to make design and process changes to avoid or minimize the occurrence of these faults. This information is also used to develop testing plans to help validate the design. The design of the diagnostic element of the vehicle system historically has relied on the FMEA along with in-depth fault tree analysis for the most severe faults. As evidenced by recent J.D. Power quality rankings, this approach to design has worked well for Ford.

In addition to this design process, guidelines exist for assisting engineers in the design of the Failure Modes and Effects Management (FMEM) and in the setting of DTCs. It is recommended, for example, that FMEM actions should be designed such that there are no customer discernable effects and they should prevent OBD-II faults from occurring where at all possible. OBD-II refers to those emissions faults that are covered by the current set of government regulations. Therefore, if there are no customer discernable effects and no OBD-II faults then an indicator lamp is not necessarily set along with a DTC.

This philosophy is in-line with guidelines put forth on setting DTCs. Specifically, a DTC should only be set when a customer noticeable symptom can occur; a DTC does not necessarily need to be set by a module entering a fault management strategy. In general, it is the goal that the smallest replaceable component be identified by a unique DTC. Other DTCs may identify when a subsystem is forced to take a customer noticeable back-up strategy based on interaction with another subsystem, or due to operating environment or customer actions. More specifically, each DTC should have an associated repair action or a reason that can be explained to a customer. In order to limit the logging of spurious DTCs, filtering and retry strategies should be employed. Additionally, CAN missing message DTCs should be inhibited under various conditions like start-up and low battery voltage. It is also required that DTC names be chosen from a master database that is consistent with existing SAE standards.

The architecture employed in production powertrain on-board diagnostics (OBD) is set up such that each fault is identified

locally. Once identified, the fault is then announced to everyone. Individual modules can then use this information to determine whether or not some of their tests need to be inhibited. This information is then employed by a centralized diagnostic executive to determine which DTCs should be set. These diagnostic decisions can be made in a centralized manner like this since most of the information and complexity lies in a single controller unit, the powertrain control module (PCM).

Additionally, the communication between subsystems for powertrain OBD is done as directly as possible. A disadvantage of this approach is that the relationships between the subsystems can be confusing, tightly coupled, and not very reconfigurable. The advantages of this approach are that there is less CAN traffic and the communication is more reliable since it does not have to pass through any intermediate subsystems. One of the primary motivations for employing this communication architecture is that it minimizes the number of subsystems that can directly affect vehicle emissions and thus would have to be covered under related warranty as regulated by OBD-II.

FORD ESCAPE HEV PROGRAM

The Ford Escape HEV program basically followed the typical production vehicle development process; though the process was spread out over a longer time period to allow for the design and test of new HEV specific technologies. The aforementioned production vehicle diagnostic guidelines were also adhered to. One difference was that the architecture employed on the Escape HEV for setting DTCs was decentralized, as opposed to the OBD diagnostics for most production vehicles where diagnostic decisions are made by a centralized executive. The Escape HEV program originally tried to send all diagnostic information to a high-level supervisor in this manner, but the amount of CAN traffic proved to be too great.

Following the launch of the developmental vehicle fleet, the HEV systems group commenced evaluating vehicle data to improve the on-board software and diagnostic systems. A challenge experienced by the group was that an inordinately large amount of DTCs were being pulled from each of the vehicles in the fleet. The large number of DTCs was due in part to the fact that a single underlying fault could lead to a cascade of other DTCs. One mechanism for this was that a fault in one subsystem would interact with another subsystem, degrading its performance and causing another DTC to be triggered. Another mechanism for this cascade was that the originating fault would cause a mitigating action to be taken which would then lead to other DTCs being set. The number of DTCs being produced made managing the information and resolving the underlying causes of the DTCs difficult. Another factor that made identifying the causes difficult was that multiple faults could map to the same DTC,

this was due in part to the decentralized implementation of the diagnostics.

In order to manage all of this data, a considerable amount of energy was invested in generating tools and processes to track and resolve problems. In particular, a comprehensive Vehicle Information Database was generated that mapped underlying causes to indications like DTCs, lamps, chimes, integrated circuit text messages, and user observed effects. Additional information such as the action taken and how the DTC is cleared were also included. This database was used to try to identify patterns of observations that could be mapped to a single underlying fault. A web-based tracking tool was also developed to follow and share information on unresolved DTCs. Prior to the introduction of this tool each scan averaged 10 DTCs, after the tool 0.15 DTCs were averaged per pull. Previously existing tools were also used for tracking other software and system issues. The knowledge gained from these tools and processes was then used to improve the vehicle software and diagnostics.

Some reasons why the Escape HEV program experienced more difficulty in tracking and resolving diagnostic information than with a conventional production program was because there were more hardware modules which were distributed but tightly coupled, and much of the technology had not been implemented on a Ford vehicle before. Some lessons taken away from the development process of the Escape HEV program were that the interaction between modules and the vehicle-level diagnostics must be modeled, a database of vehicle diagnostic information is helpful, early analysis of DTCs will reduce defects and cost, shared processes and templates should be employed, and IT support should be provided to developmental programs. Subsequent generations of HEVs have tried to learn from and improve upon the diagnostics and processes of the Escape HEV developmental vehicles.

DEVELOPMENTAL FCEV PROGRAM

The developmental FCEV fleet was a technology demonstration program, in contrast to the Escape HEV, which was eventually destined for production. In part because of this, the FCEV program had fewer resources and some process guidelines were not followed in order to get the vehicles on the road in a timely manner. Another reason for the deviations was the large number of suppliers operating on the program. Additionally, for some suppliers the demonstration FCEV program was the first automotive program they had ever participated in.

The diagnostic system design was performed primarily on a component basis and DTCs were assigned to many items that are not customer noticeable or safety critical. The motivation for this approach to DTCs was that the 30 vehicle fleet would be geographically distributed and the DTCs would provide