

Hydrogen Leak Detection Method Derived using DCOV Methodology

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ABSTRACT

Hydrogen is the most abundant element in the universe, accounting for more than 90% of the molecules and more than 75% of the mass [1]. However, due to the small molecule size and high buoyancy, it is not available in its free form on Earth. In recent years, hydrogen has gained the attention of the automotive industry [2–12] as an environmentally friendly alternative fuel.

As a fuel, hydrogen is unique - it is odorless, colorless, tasteless, and burns invisibly in sunlight. Detection solutions such as the odorants used in natural gas are not yet feasible for automotive hydrogen because the available additives can poison the fuel cell catalyst. Additionally, the lower flammability limit of hydrogen is lower, and the flammability range wider, than fuels such as gasoline. For these reasons, hydrogen leaks must be detected reliably so that appropriate action can be taken [13].

Placing hydrogen sensors in areas of potential accumulation is presently the most widely used solution for detecting hydrogen leaks in vehicle applications. However, cost, sensitivity to environmental factors, and reliability concerns are driving leak-detection alternatives that do not require chemical sensors. Ford Motor Company, in cooperation with Daimler and NuCellSys, has implemented a control strategy utilizing pressure decay measurements inside the hydrogen system to identify leaks. Although this strategy has shown to be very reliable and procedurally very simple, it temporarily overrides normal control of the fuel cell system and is time intensive in or-

der to achieve the desired sensitivity and accuracy.

In this paper, a leak detection method based on monitoring control signals in the hydrogen subsystem is proposed. Hydrogen system pressure is controlled based on system conditions and load. The setpoint is maintained utilizing closed-loop control. At idle, for example, the control effort required under defined environmental conditions can be predicted and shown to be repeatable. Deviation from the predicted range can be an effective indicator of leakage from the hydrogen subsystem. Detection can be fast and transparent to fuel cell system operation.

Six-sigma methodologies were applied to develop the necessary transfer functions, define the thresholds at which different failure modes can be assumed, and determine the necessary mitigation actions.

INTRODUCTION

Historically, major technical obstacles and high manufacturing costs have made fuel cells uncompetitive with existing energy technologies [14], limiting applications to specialty areas such as spaceflight. Recently, due to increased environmental concerns [15], rising gasoline prices [16, 17], and the uncertainty caused by geo-political factors [18, 19], the automotive industry has stepped up efforts to develop more fuel efficient and environmentally friendly vehicles. This has resulted in a number of prototype fuel cell powered vehicles such as Ford P-2000 [5–7], Ford FCV Focus [9], Daimler-Chrysler NECAR, Mazda Premacy [8], Honda FCX [11], and Toyota FCHV [10], to

name a few. A number of cities around the world (Amsterdam, Barcelona, Hamburg, London [2], Luxembourg, Beijing [3], Madrid, Porto, Reykjavik, Stockholm, Stuttgart, Perth [4] e.t.c.) have introduced fuel cell bus fleets as a part of their mass transit system, while other areas are gearing toward custom designed fuel cell based transportation solutions [20]. As the number of fuel cell vehicles increase and plans emerge for FCV sales to the public, the focus of development shifts from proof-of-concept to practical implementation that can be put into production in high volumes. This means, among the other things, a shift from prototype and lab sensors to more traditional automotive sensors and other alternatives that can be implemented robustly and inexpensively.

Many of the concerns about hydrogen usage stem from the differences between its characteristics and those of gasoline (and similar fuels). Hydrogen has a wider flammability range and lower ignition energy than gasoline. Pure hydrogen is colorless, odorless, and burns invisibly. Because odorants such as mercaptan (used in natural gas) are not yet viable for hydrogen in PEM fuel cell applications due to the detrimental effects on the fuel cell stack, hydrogen leaks generally cannot be detected without special equipment and/or processes.

In this paper we present a hydrogen leak detection strategy developed using six sigma methodology.

DEFINE - PROBLEM STATEMENT

Limited operational experience with hydrogen powered vehicles has resulted in multiple layers of safety features that may include both sensors and control strategies. Flammable gas detectors and hydrogen concentration sensors are most often used to detect hydrogen accumulation directly, while indirect detection can be accomplished using various control strategies such as pressure decay monitoring.

The reliability of hydrogen sensors is location sensitive. Packaging of hydrogen sensors in the vehicle must take into consideration the buoyancy and diffusion characteristics of hydrogen, as well as the limitations of the sensor itself. If the sensing technology is sensitive to liquid water or high humidity, it must be taken into consideration, or the result may be false positive detections. High cost and lack of robustness of available sensing technologies is driving the development of alternative detection methods.

In addition to the sensors, controls strategies that monitor for leaks can be implemented if the fuel system is well-enough characterized to anticipate proper behavior under

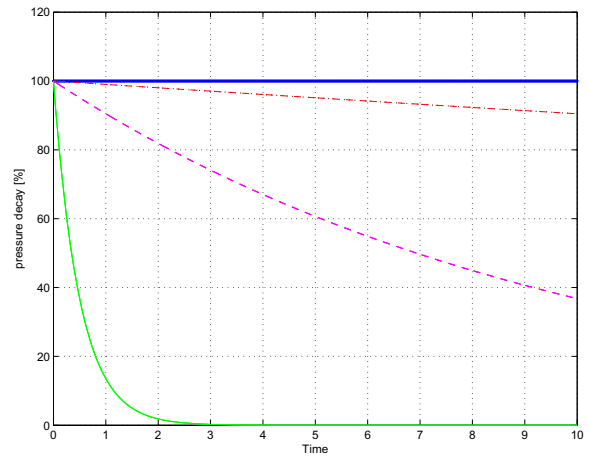


Figure 1: Pressure decay: Tight system (no leaks) - thick line; Small leak - red dash-dot line; Medium leak - purple dashed line; Large Leak - thin green line

various conditions. A pressurized test setup includes a valve with a known flow rate that is venting outside of the system. To maintain the pressure in the system, a known flow-rate of the feed gas must be supplied. If that pressure is not supplied, pressure decay will result. If more flow is needed to maintain a pressure, or if the pressure decay is more rapid than expected, it may indicate a leak in the system. The problem is to identify the effect of a given leak rate on the system (pressure, flow, etc.) and to program the system controller adequately. The pressure decay is illustrated in Figure 1; if there is no leak, pressurized system would maintain the pressure along the thick line. With a small leak or permeation through walls of the vessel, small pressure decay, shown by red dash-dot line, can be observed over time. When a larger leak is present, a rapid decay in the pressure can be observed, as shown by thin green line in Figure 1. The time needed for this test represents an inherent disadvantage of this method. For this reason, an alternative measure was introduced - control effort needed to maintain hydrogen pressure on the fuel cell anode.

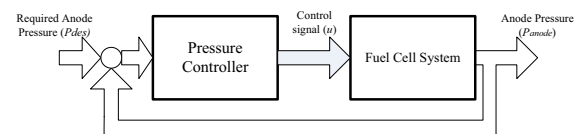


Figure 2: Hydrogen Pressure Control Loop

A block diagram for hydrogen pressure control is shown in Figure 2. Based on measured hydrogen pressure in the fuel cell anode (P_{anode}) and desired pressure for the operating conditions (P_{des}) the controller computes the control effort (u) needed to drive P_{anode} to the P_{des} value. The ex-