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Development of Air Supply Controller for FCV Based on Model-Based Development Approach

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Abstract

In Toyota's 2nd generation FCV, an electric turbo-type air compressor has been adopted for downsizing and cost reduction. Automotive Fuel Cell applications present several challenges for implementing a turbo-type air compressor. When operating a fuel cell in high-temperature or high-altitude locations, the FC stack must be pressurized to prevent dry-up. The flow rate vs pressure conditions that the FC must pass through or in some cases operate at are typically within the surge region of a turbo-type air compressor. Additionally, Toyota requires quick air transient response (< 1 sec) for power generation, energy management, and FC dry-up prevention. If the turbo-type air compressor is not precisely controlled during quick transients, it can easily enter the surge region. To solve the above issues, we developed a new air supply controller which can avoid compressor surge by controlling 3 variables, 'FC stack air flowrate', 'FC stack air pressure', and 'FC stack air Bypass' independently with high accuracy. The controller was designed using a model-based development approach. At first, the physical characteristics of the air systems compressor, valves, pipes, and FC stack were modeled and integrated into a system level simulation that can run real-time on-board the vehicle Engine Control Unit (ECU). Next, the feedforward and feedback (PI) control were developed by implementing inverse models of the air system component equations. We confirmed that this control development approach could achieve Toyota's air supply control performance requirements and prevent turbo-type air compressor surge.

Introduction

Toward reducing the CO_2 emission which causes the global warming, Toyota has developed FCVs along with HVs, PHVs, and EVs. Toyota released the 1st generation commercial FCV in 2014 [1] and the 2nd generation FCV in 2020.

In the 2nd generation FCV, the auxiliary parts of the fuel cell system are updated from the 1st generation FCV due to downsizing and cost reduction. One of the main updates is that an electric turbo-type compressor is used for air supply to the fuel cell stack. One characteristic of a turbo-type compressor is that if the compressor is operated at low-flow-rate and high-pressure ratio, an uncontrolled air flow oscillation can suddenly occur, which is known as compressor surging. The main issue of using a turbo-type compressor for air supply is how to avoid compressor surging while supplying the optimal amount of the air to the fuel cell stack for power generation.

There has been significant research and development conducted for turbo-type compressor surge avoidance [2]. However, practical surge avoidance control has not been developed and implemented for commercial FCVs. In this article, we describe the air supply and surge avoidance control method for the 2nd generation FCV. To solve the surge avoidance challenge, we developed a new controller which can control 3 variables, 'FC stack air flowrate', 'FC stack air pressure', and 'FC stack air Bypass' independently with high accuracy.

Air supply control strategies for fuel cell systems have been discussed in detail [3-6]. These studies focus on how to control the oxygen stoichiometry accurately by using the compressor where the control system is modeled as a one input (compressor input voltage) system. In contrast, our system must control 3 actuators (the compressor and two throttle valves) dynamically for the surge avoidance control. Thus, this control system is modeled as 3 inputs system. We designed the controller using a model-based development approach. There are two main reasons why a model-based development approach was chosen for this application. The first reason is that the air supply system is nonlinear and a multi-input-multi-output (MIMO) system. Thus, to realize the more accurate control required for a turbo-type air compressor in an FCV application, an on-board high accuracy first principles based system level simulation was necessary. The second reason is that the model-based numerical simulation can be used as a virtual test bench to increase development efficiency, improve initial control quality, and reduce the required testing hours with the actual system [7].

FIGURE 15 Vehicle test result of air supply controller in high-altitude location

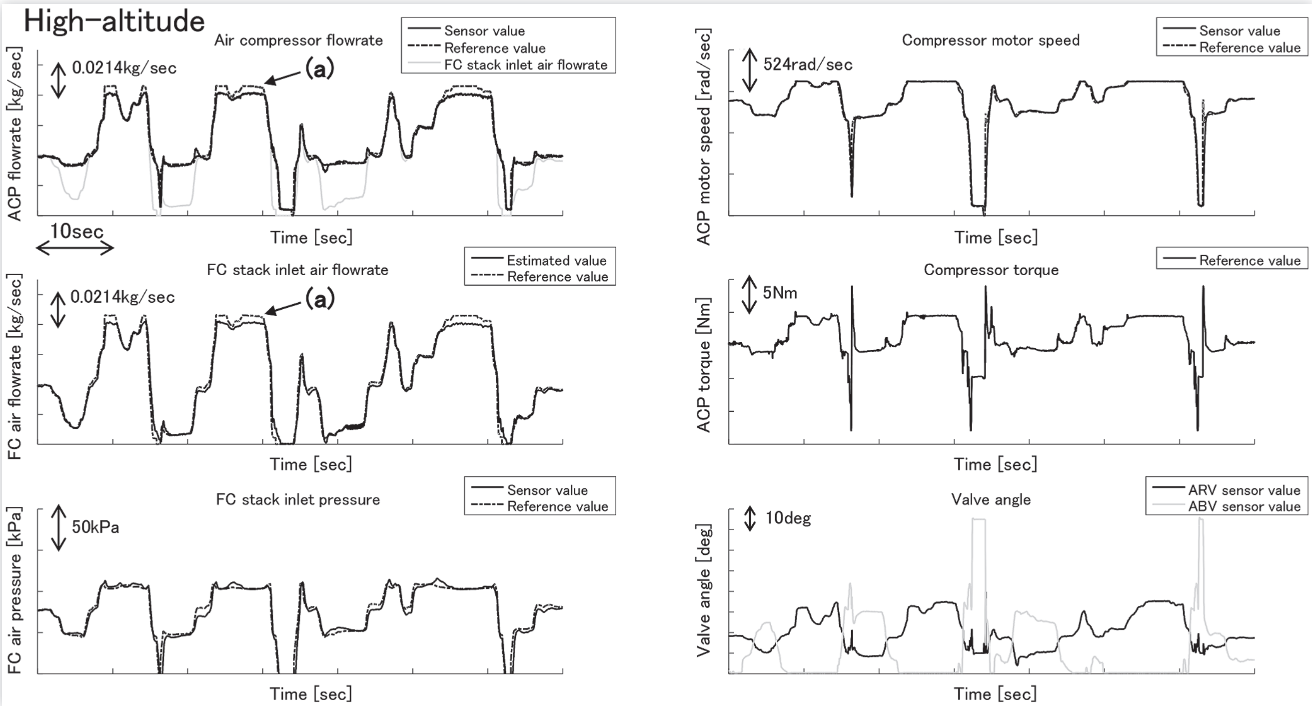
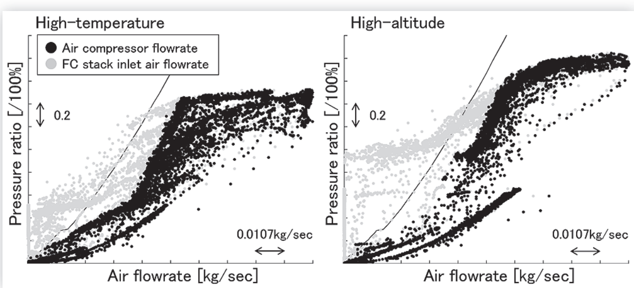


FIGURE 16 Vehicle test result of actual trajectory of compressor (sensor and estimated values)



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