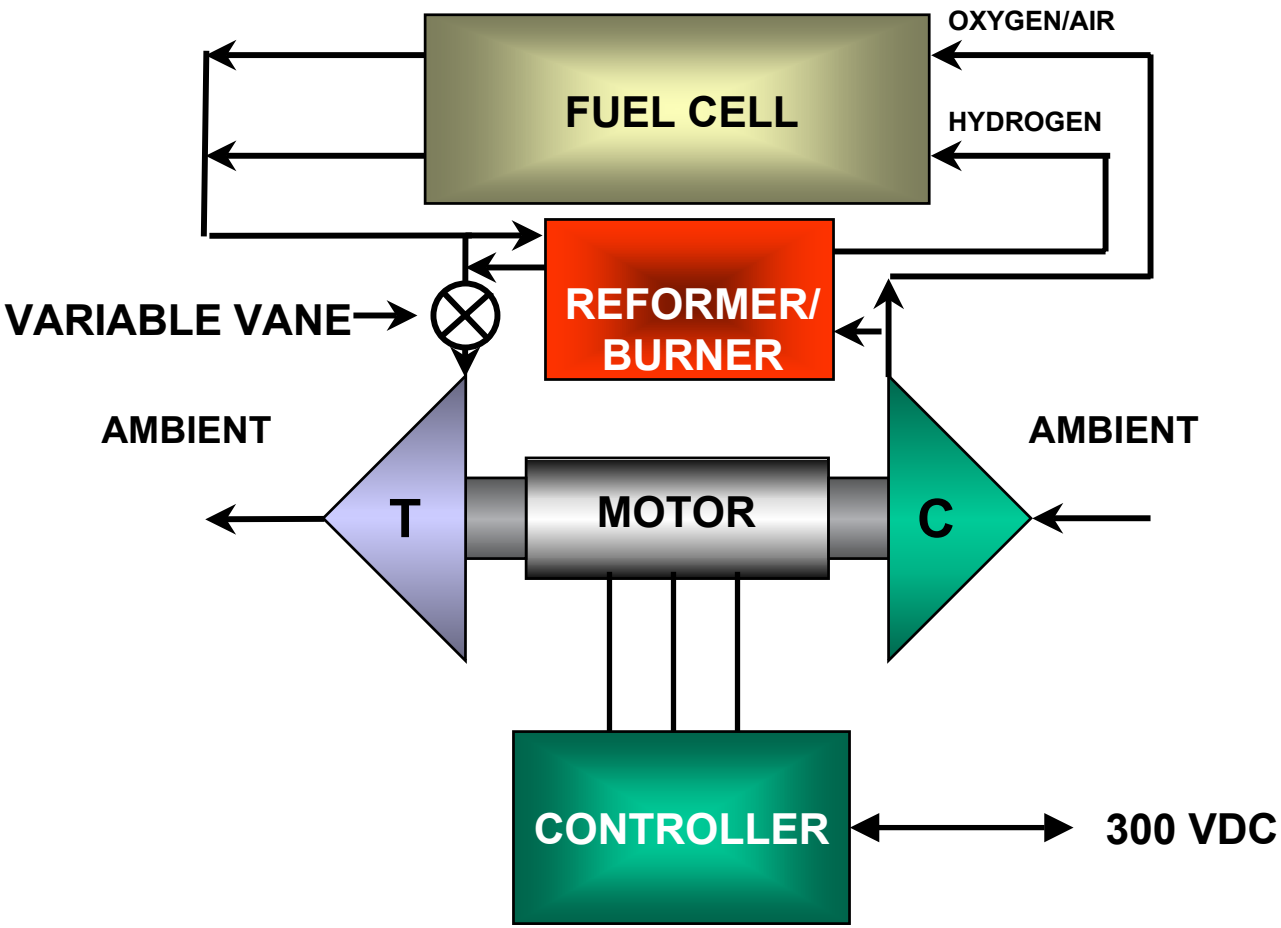
FUEL CELL TURBOCOMPRESSOR

MAY 22, 2003

CLAREMONT RESORT & SPA
BERKELEY, CA

FUEL CELL SYSTEMS AND AIR MANAGEMENT RELATIONSHIPS

OPERATING PRINCIPLES & GENERAL DESCRIPTION



FUEL CELL SYSTEMS AND AIR MANAGEMENT RELATIONSHIPS

- FUEL CELL SYSTEM AIR MANAGEMENT PROVIDES:
  - AIR AT THE APPROPRIATE PRESSURE AND FLOW FOR THE FUEL CELL STACK AND IF PRESENT THE FUEL PROCESSOR
  - ENERGY RECOVERY FROM FUEL CELL EXHAUST TO REDUCE PARASITIC POWER REQUIRED FOR THE AIR MANAGEMENT
- FUEL CELL SYSTEM AIR MANAGEMENT CONSIDERATIONS:
  - FLOW RATE: AFFECTS THE FUEL CELL STACK EFFICIENCY AND THE PARASITIC POWER REQUIRED FOR THE AIR MANAGEMENT
  - PRESSURE: AFFECTS THE FUEL CELL STACK EFFICIENCY AND THE PARASITIC POWER REQUIRED FOR THE AIR MANAGEMENT
  - TEMPERATURE: THE AIR SUPPLY TEMPERATURE USUALLY TO BE WITHIN A SPECIFIC RANGE OF THE FUEL CELL STACK TEMPERATURE
  - HUMIDIFICATION: SOME FUEL CELL STACKS (E.G. PEM) REQUIRE HUMIDIFICATION TO MAINTAIN THE ELECTROCHEMICAL REACTION
  - WEIGHT AND VOLUME: DEPENDENT ON PRESSURE AS WELL AS COMPRESSOR TECHNOLOGY

DOE/FreedomCAR/Hydrogen technical barriers

4.4.4.2 Technical Barriers

- Although many issues are discussed below, it should be noted that cost and efficiency present two of the more significant technical barriers to the achievement of clean, reliable, cost-effective systems.

Transportation Systems Technical Barriers

- A. **Compressors/Expanders**. Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. To validate functionality in laboratory testing, current systems often use off-the-shelf compressors that are not specifically designed for fuel cell applications resulting in systems that are heavy, costly, and inefficient. Automotive-type compressors/expanders that meet the FreedomCAR program technical guidelines need to be engineered and integrated with the fuel cell and fuel processor so that the overall system meets packaging, cost, and performance requirements.

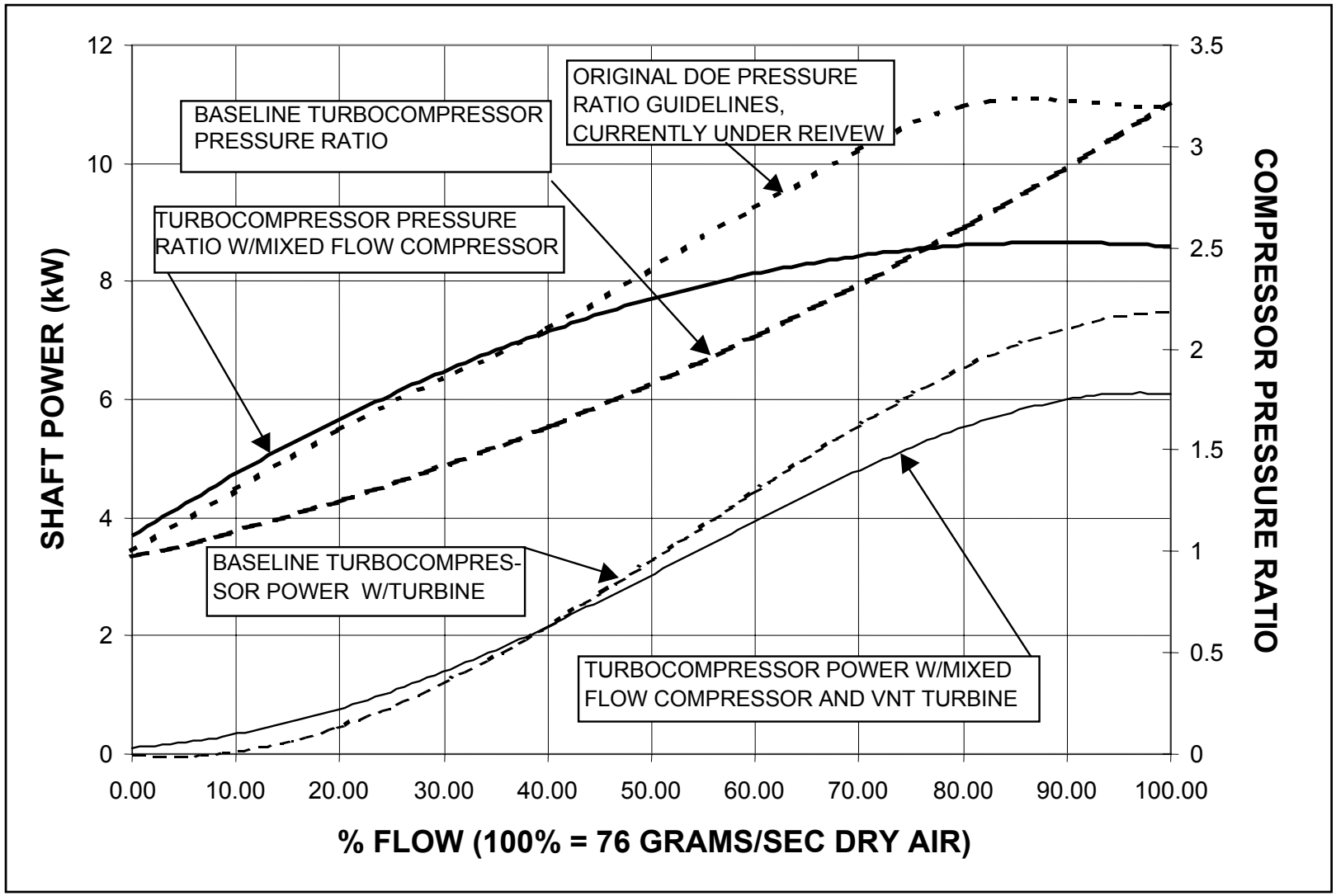
FUEL CELL TURBOCOMPRESSOR OBJECTIVES

- DEVELOP AN OPTIMUM (I.E. LOW COST, EFFICIENT, COMPACT AND LOW WEIGHT) TURBOCOMPRESSOR CONFIGURATION BY WORKING WITH FUEL CELL SYSTEM MANUFACTURERS AND CONTINUING THE WORK CURRENTLY BEING PERFORMED.
- REDUCE TURBOCOMPRESSOR/MOTOR CONTROLLER COSTS WHILE INCREASING DESIGN FLEXIBILITY.
- DEVELOP AND INTEGRATE THE TURBOCOMPRESSOR/MOTOR CONTROLLER INTO A FUEL CELL SYSTEM.

FUEL CELL TURBOCOMPRESSOR CONCEPT

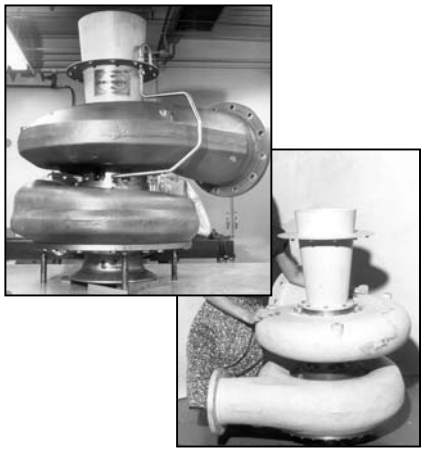
- CONTAMINATION FREE AIR FLOW TO FUEL CELL
  - •COMPLIANT FOIL AIR BEARINGS (NO LUBRICANTS)
- LIGHTWEIGHT - <18lb (8.2 Kg)
- COMPACT - 12 in x 8 in dia (9.9 liters)
- EFFICIENT
  - 70% COMPRESSOR
  - 80% EXPANDER/TURBINE
- HIGH TEMPERATURE CAPABLE EXPANDER/TURBINE
- VARIABLE GEOMETRY TURBINE (CAN BE USED AS BACKPRESSURE VALVE)
- ZERO MAINTENANCE
- RELIABLE
  - •ONE MOVING PART
- LOW PRODUCTION COST POTENTIAL INCLUDING MOTOR AND CONTROLLER

FUEL CELL TURBOCOMPRESSOR CONCEPT

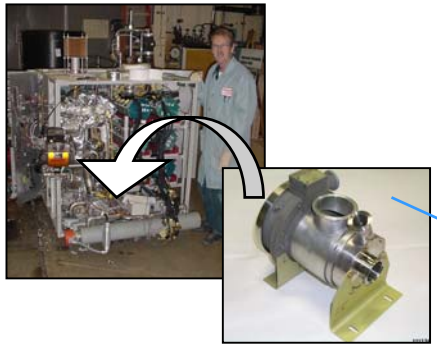


Honeywell

FUEL CELL TURBOCOMPRESSOR HISTORY



2 Bootstrap Turbocompressors
(Full and Partial Flow Sizes)
TEPCO 5MW
Phosphoric Acid
Fuel Cell Power Plant
1981



Demonstration of Motor Driven Turbocompressor w/Increased Temperature Capability Turbine in DoE/Honeywell 50kW PEM Fuel Cell System
2001

Motor Driven Turbocompressor
DoE 50kW PEM Fuel Cell System
for Light Duty Vehicle
2003

Demonstration of Motor Driven Turbocompressor w/Mixed Flow Compressor and Variable Nozzle Turbine
DoE 50kW PEM Fuel Cell System
for Light Duty Vehicle
2001

Demonstration of Motor Driven Turbocompressor
DoE 50kW PEM Fuel Cell System
for Light Duty Vehicle
1997

Honeywell

FUEL CELL TURBOCOMPRESSOR HISTORY

- CUSTOMER: DEPARTMENT OF ENERGY
- PHASE 1:
  - USING DOE GUIDELINES: ANALYZED, DESIGNED, FABRICATED AND DEMONSTRATED A TURBINE ASSISTED MOTOR DRIVEN COMPRESSOR (I.E. TURBOCOMPRESSOR) FOR A DoE 50kW PEM (PROTON EXCHANGE MEMBRANE) FUEL CELL SYSTEM
- PHASE 2:
  - USING DOE GUIDELINES, MODIFIED THE PHASE 1 UNIT AND INVESTIGATED IMPROVING THE COMPRESSOR OPERATING RANGE WITH INLET GEOMETRY
  - AGAIN, MODIFIED THE PHASE 1 UNIT BUT WITH AN INCREASED TEMPERATURE CAPABLE TURBINE (~300 DEG C) THAT WAS DEMONSTRATED IN A HONEYWELL 50kW PEM FUEL CELL SYSTEM

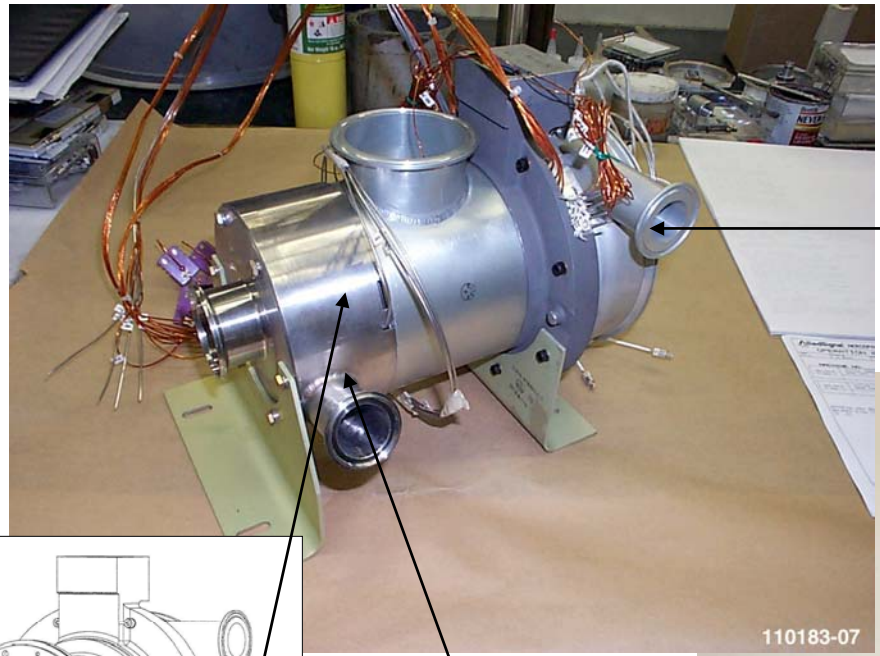
FUEL CELL TURBOCOMPRESSOR HISTORY

- PHASE 3:
  - USING MODIFIED DOE GUIDELINES: ANALYZED, DESIGNED, AND FABRICATED A MIXED FLOW COMPRESSOR AND TURBINE WITH VARIABLE INLET GEOMETRY
    - SACRIFICED HIGH PRESSURE RATIO TO IMPROVE THE LOW FLOW PRESSURE RATIO AND EFFICIENCY CHARACTERISTICS
  - ANALYZED, DESIGNED, AND FABRICATED A VEHICLE READY MOTOR CONTROLLER
  - FABRICATION AND PRELIMINARY TESTING COMPLETED
- PHASE 4:
  - PERFORM A TRADE STUDY TO DEFINE A COST AND PERFORMANCE ENHANCED TURBOCOMPRESSOR CONFIGURATION
  - DESIGN AND FABRICATE THE ENHANCED TURBOCOMPRESSOR
  - DESIGN AND FABRICATE THE ENHANCED MOTOR AND MOTOR CONTROLLER
  - TEST THE ENHANCED TURBOCOMPRESSOR/MOTOR CONTROLLER

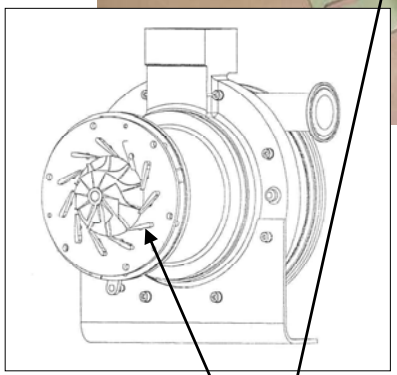
PHASE 3: TURBOCOMPRESSOR WITH VARIABLE GEOMETRY FOR PEM FUEL CELLS

- PROGRAM CLOSED OUT MID 2002
- TECHNICAL OBJECTIVE #1: TRADE STUDY
  - FINDINGS OF HIGH SPEED COMPRESSOR/EXPANDER SELECTED PRESENTED TO DOE
- TECHNICAL OBJECTIVE #2: TURBOCOMPRESSOR UPGRADE
  - ANALYSIS, DESIGN AND FABRICATION COMPLETED
    - MIXED FLOW COMPRESSOR
    - VARIABLE GEOMETRY TURBINE
      - USE OF ENGINE BOOSTING SYSTEMS DESIGN
- TECHNICAL OBJECTIVE #3: MOTOR CONTROLLER UPGRADE
  - UNIT 70% REDUCTION IN VOLUME FROM PHASE 2
  - INCORPORATES AUTOMOTIVE REQUIREMENTS
  - RUGGED DESIGN
  - LOW-COST ARCHITECTURE
  - TESTING COMPLETED PRIOR TO INTEGRATION WITH TURBOCOMPRESSOR

PHASE 3: TURBOCOMPRESSOR WITH VARIABLE GEOMETRY FOR PEM FUEL CELLS



MIXED FLOW COMPRESSOR

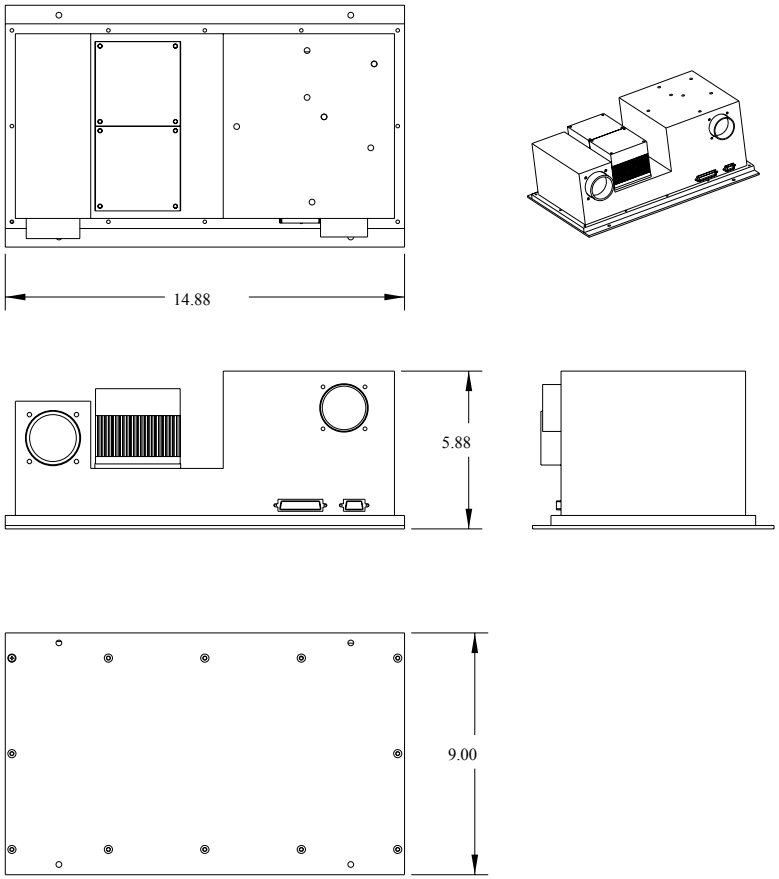


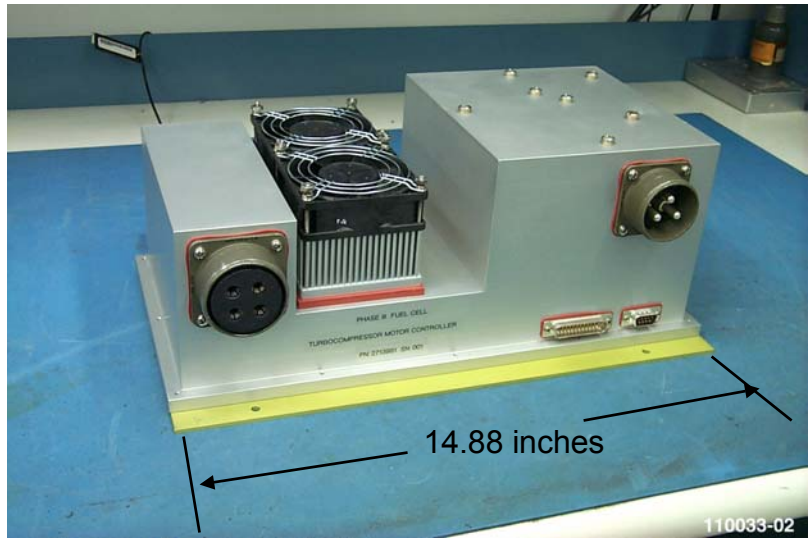
TURBINE

VARIABLE NOZZLE

Honeywell

PHASE 3: TURBOCOMPRESSOR WITH VARIABLE GEOMETRY FOR PEM FUEL CELLS





PHASE 3: TURBOCOMPRESSOR WITH VARIABLE GEOMETRY FOR PEM FUEL CELLS

- TECHNICAL OBJECTIVE #4: TURBOCOMPRESSOR TESTING WITH MOTOR CONTROLLER UPGRADE
  - COMPRESSOR MAPPING COMPLETED
    - EXPANDED SURGE MARGIN AND FLOW RANGE DEMONSTRATED
    - GOOD EFFICIENCY DEMONSTRATED
    - WHEEL TO BE MODIFIED TO FULLY MEET PERFORMANCE OBJECTIVES
    - MODIFICATIONS TO BE INCORPORATED INTO PHASE 4 DESIGN
  - UNIT OPERATED WITH MOTOR UP TO FULL SPEED AND POWER
  - STILL TO BE COMPLETED IN PHASE 4 PROGRAM
    - TURBINE MAPPING
    - POWER CONSUMPTION

PHASE 4 PROJECT DESCRIPTION

- TECHNICAL OBJECTIVE 1: PERFORM A TURBOCOMPRESSOR SYSTEMS PEM FUEL CELL TRADE STUDY TO DETERMINE THE ENHANCED TURBOCOMPRESSOR APPROACH
  - UTILIZE EXPERIENCE FROM PHASES 1-3
  - COMPRESSOR CONFIGURATION
  - TURBINE CONFIGURATION
  - TRADE PERFORMANCE IMPROVEMENTS VERSUS COMPLEXITY, COST, WEIGHT, AND VOLUME
- TECHNICAL OBJECTIVE 2: USING THE RESULTS FROM TECHNICAL OBJECTIVE 1, AN ENHANCED TURBOCOMPRESSOR WILL BE FABRICATED. THE DESIGN MAY BE MODIFIED TO MATCH THE FLOW REQUIREMENTS OF A SELECTED FUEL CELL SYSTEM DEVELOPER.
  - DESIGN FLEXIBLE FOR USE BY VARIOUS SYSTEM DEVELOPERS
  - LOW COST AND IMPROVED PERFORMANCE BEARINGS
  - IMPROVED SHAFT SEALS

PHASE 4 PROJECT DESCRIPTION

- TECHNICAL OBJECTIVE 3: DESIGN A COST AND PERFORMANCE ENHANCED COMPACT MOTOR AND MOTOR CONTROLLER
  - TRADE BETWEEN MOTOR TYPES
    - TWO POLE TOOTHED VS TOOTHLESS CONFIGURATION
  - 55% REDUCTION IN MOTOR CONTROLLER VOLUME FROM PHASE 3
  - 30% REDUCTION IN MOTOR CONTROLLER WEIGHT FROM PHASE 3
  - LOW COST DESIGN
- TECHNICAL OBJECTIVE 4: TURBOCOMPRESSOR/MOTOR CONTROLLER DEVELOPMENT
  - TEST MODIFIED TURBOCOMPRESSOR WITH NEW CONTROLLER

PHASE 4 PROJECT STATUS

- CONTRACT SIGNED MID DECEMBER 2002
- 27 MONTH PROGRAM SCHEDULED TO BE COMPLETED APRIL 2005
  - TECHNICAL OBJECTIVE #1: TRADE STUDY, JULY 2003
  - TECHNICAL OBJECTIVE #2: ENHANCED TURBOCOMPRESSOR, NOVEMBER 2004
  - TECHNICAL OBJECTIVE #3: ENHANCED MOTOR AND MOTOR CONTROLLER, SEPTEMBER 2004
  - TECHNICAL OBJECTIVE #4: INTEGRATED ENHANCED TURBOCOMPRESSOR, MARCH 2005

PHASE 4 PROJECT STATUS

- TECHNICAL OBJECTIVE #1: TRADE STUDY
  - INTERVIEWS WITH VARIOUS DEVELOPERS UNDERWAY
    - TO BE COMPLETED APRIL 2003
  - DEVELOPERS SHOWING INCREASED INTEREST IN TESTING TECHNOLOGY
    - LOW COST POTENTIAL
    - NO CONTAMINATION
    - SIZE AND WEIGHT ADVANTAGE
- TECHNICAL OBJECTIVE #2: ENHANCED TURBOCOMPRESSOR,
  - TEAM MEMBER REQUIREMENT DEFINITION UNDERWAY
    - USING RESPONSES FROM TECHNICAL OBJECTIVE #1
  - LAYOUT AND ANALYSES INITIATED
    - AERODYNAMIC
    - THERMAL
    - ROTORDYNAMIC
    - MATERIALS
    - BEARING

PHASE 4 PROJECT STATUS

- TECHNICAL OBJECTIVE #3: ENHANCED MOTOR AND MOTOR CONTROLLER
  - TEAM MEMBER REQUIREMENT DEFINITION UNDERWAY
    - USING RESPONSES FROM TECHNICAL OBJECTIVE #1
  - MOTOR DESIGN INITIATED
- TECHNICAL OBJECTIVE #4: INTEGRATED ENHANCED TURBOCOMPRESSOR
  - EFFORT TO START NOVEMBER 2004

QUESTIONS/COMMENTS?

MARK K. GEE

PROGRAM MANAGER - FUEL CELL TURBOCOMPRESSORS

Turbomachinery - Torrance, CA

Phone: 310-512-3606

E-mail: mark.gee@honeywell.com