Turbo Compounding

A Technology Who’s Time Has Come

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OUTLINE

- History
- Rate Limiters
- Environmental Factors
- Electric Turbo Compounding
- System Architecture
- Drivers
- Analysis
- Testing
- Summary
Turbo Compounding History

- 1953  Douglas DC-7 (Wright 3350 TC)
- 1954  Napier Nomad (12 Cyl Diesel 2-stroke)
- 1968  Mitsubishi 10ZF (V10 2-stroke Diesel)
- 1981  Cummins NH
- 1983  Cummins V903 (Military Application)
- 1986  Cat 3406 & 11.3L
- 1988  Hino 8.82L
- 1990  DAF
- 1991  Scania 11L (Current Production)
- 1998  Cat 15L (21st Century Truck)
- 2002  Isuzu Ceramic IDI (Experimental)
- 2002  Volvo (Current Production)
Napier Nomad
Circa 1955

Fig. 8—Diagram of Nomad engine
Two-Stage Mechanically Coupled System

Scania Production System – Double Gear Reduction w/Fluid Coupling

Engine Exhaust

Power Turbine

Flywheel
Technology Limiters

- System Complexity
  - High Ratio Gear Trains
  - Torsional Couplers
  - Impact on Turbocharger and Engine
  - Machine Placement
- Control Issues
- Costs
Factors Favoring TC

- Increasing Fuel Costs
- Availability of Low Cost Controls
- Availability of Cost Effective Power Electronics (Automotive Hybridization)
- EGR Requirements for NOx Control
- High Pressure Ratio VG Turbos
Electric Turbo Compounding

- Simple Architectures Possible
  - Flexible Placement
  - Isolated Coupling
- Integrated Electronic Control
- High Efficiency
- Modest Cost
TurboCompounding
Drivers

- Improved Fuel Economy - 10+%
- Increased Power Density - 20+%
- Emissions & After Treatment Benefits
- High Exhaust Pressure Requirement – EGR
- Maturation of Electrification Technology
Emissions Impact

- Increased Output Directly Impacts Specific Emissions
- Power Turbine Reduces Net Impact of Retarded Injection Timing
- Improved Transient Response Lowers Emissions
- Electrical Output Can Power Emissions Control Devices
Power Density Growth Enablers

- After Cooling (1975 – 2005)
- Turbo Compounding (2008 - ....)
TC System Schematic

Electrically Coupled Deere System
Turbo Generator on Gas Stand
Analysis

Pressure Distribution

Heat Flux

CFD - Flow Around Vanes

Blade Stresses
Turbocharger Assembly
Advanced TurboCharger
Power Electronics
Engine Testing
Engine Testing
System Parameters

- 50 kW Turbo Generator
- 340V DC Output
- Wastegate Control For Overspeed Protection
- 50 kW Motor/Generator
- No Energy Storage
- Integrated Control Engine/Turbo Generator
- Advanced High Pressure Ratio Turbocharger
Efficiency Targets

- Power Turbine: 85%
- Turbo Generator w/Controller: 95%
- Turbocharger Compressor: 78%
- Turbocharger Turbine: 85%
- Motor/Generator w/Controller: 95%
- Engine w/TurboCompounding: 46%
WAVE Performance Predictions

Turbocompound Effect On Performance

- AFR = 23
- AFR = 26
- AFR = 30

Efficiency Improvement [%]

Power Turbine Power As A Percentage Of Total System Power [%]

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Engine Test Data

TurboGenerator Power vs. Engine Speed and Load

- 2300 RPM
- 2100 RPM
- 1900 RPM

TG Power - kWe

Engine Load (%)
Application Selection Criteria

- Steady-State High-Duty Cycle Operation
- High Annual Usage
- Power Growth Requirement
- Vehicle Electrification Benefits
Potential Applications

9000 Tractor

8000 Tractor

Combine

Truck

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DoE Program Focus

- Define Application Scope
- Develop and Evaluate Second Generation Hardware
- Integrate Turbo Compounding With Engine for Optimal Performance and Emissions
Summary

➢ Proven Technology
➢ Significant, Economy, Power, and Emissions Benefits
➢ Must be Integrated With Emissions Strategies and Vehicle Electrification
➢ Benefits in Specific Applications to be Defined
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Questions?