Electrically Driven Supercharger “TurboClaw®” for Small Gasoline Engine Downsizing

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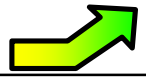
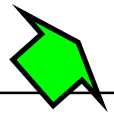
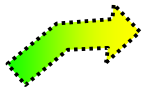
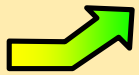
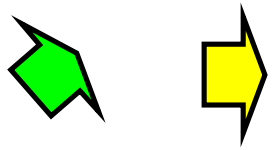
Electrically Driven Supercharger 'TurboClaw®'

- Rationale
  - Technology Trends for Small Gasoline Engines
  - Engine Charging Technologies
  - TurboClaw® - A low speed turbocompressor
- Electrically Driven Supercharger "TurboClaw™"
  - Objectives
  - Design and Manufacture
  - Hardware and Preliminary Data
  - Test Rig Setup
  - Preliminary Test Results
  - Future Development Activity

Technology Trends for Small Gasoline Engines

Technology \ Capacity [L]	<1.0	1.0-1.5
Variable Charge Motion		
Variable Valve Lift (2/3 Step)		
Variable Valve Lift (Continuous)		
NA Homogeneous GDI		
TC Homogeneous MPI/GDI		

General Market Trends:

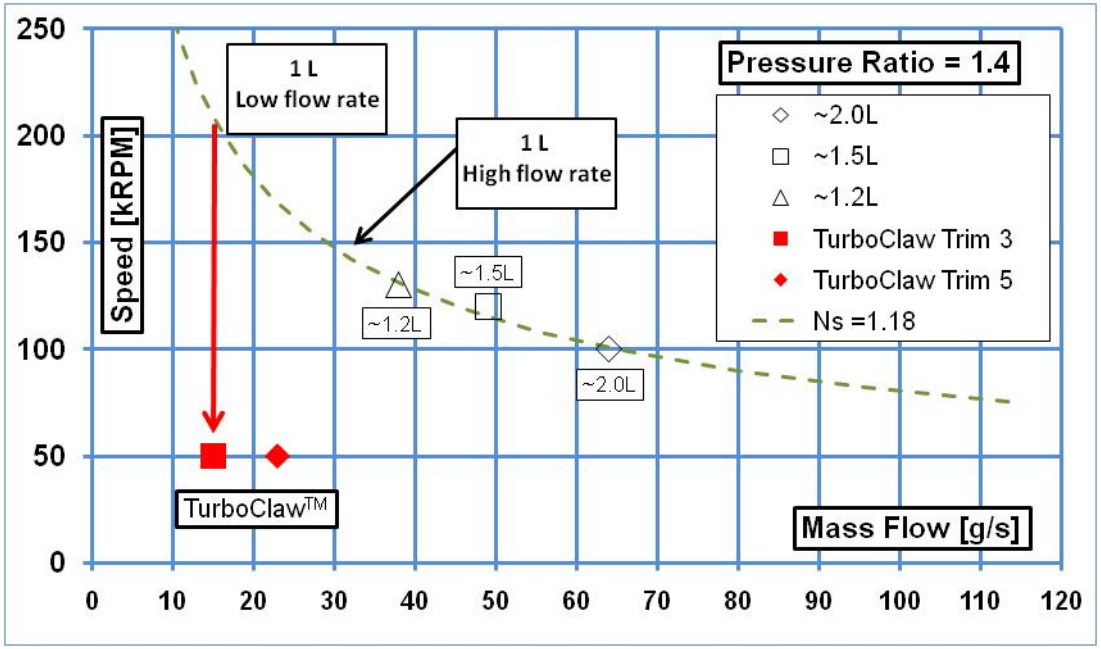


New /current Mainstream:

Down-sizing with charging is the front runner in reducing gasoline engine CO_2

Engine Charging Technologies

- Turbochargers (driven by exhaust stream)
- Positive displacement Compressors (usually belt driven)
- High speed turbocompressors driven mechanically



Turbocharger Impeller	Low Flow-Rate 12 g/s	High Flow-Rate 32 g/s
Speed, krpm	260	160
Diameter, mm	18	29
Blade height, mm	3.7	6

- ✓ These technologies are engine driven hence dependent on engine speed
- ✓ Low Flow-Rate is a problem for turbochargers

Solution to Charging Technologies for Small Engines

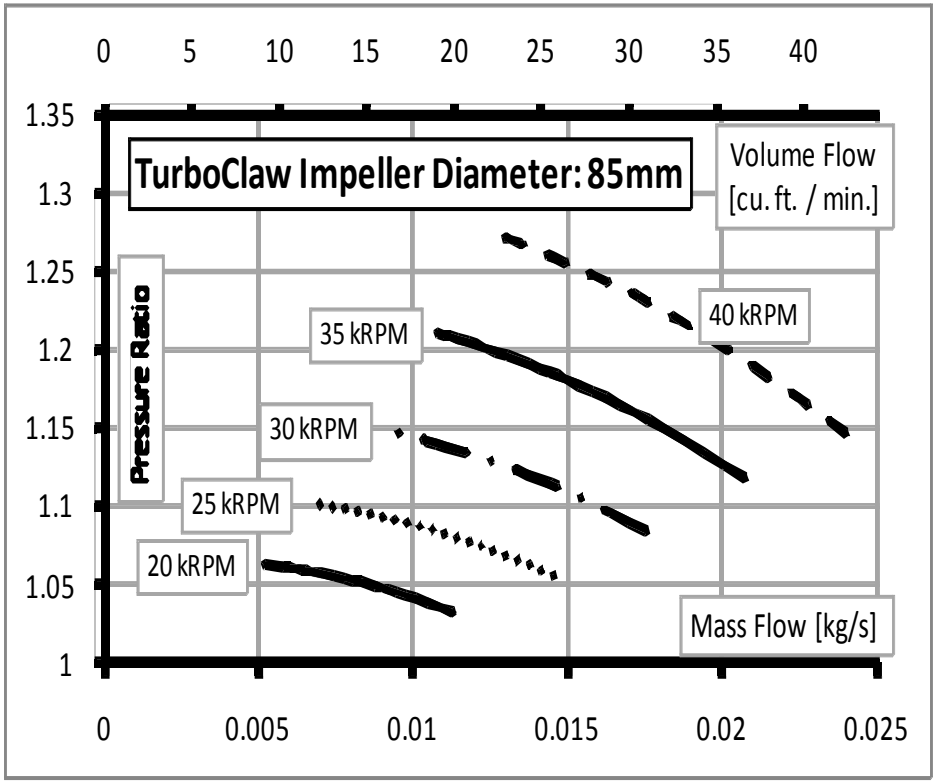
Dual- Charging

- A turbocharger for higher engine speeds
- A low flow-rate engine speed independent charging system for the lower engine speeds to boost power and overcome turbo-lag.

	Speed	Drive	Comment
PD	Low	Belt	•Engine dependence •High cost
PD- Electrically driven	Low	Electric motor	•Motor •Drive •Bearings •High cost
Turbocharger	Ultra-high	Exhaust driven turbine	•Engine dependence •controls
Turbocompressor- Electrically driven	Ultra- high	Electric motor	•High speed motor •High speed drive •High speed bearings •High cost

TurboClaw® – A low speed turbocompressor

- TurboClaw® is a patented low speed turbocompressor
- Electrically driven so engine speed independent

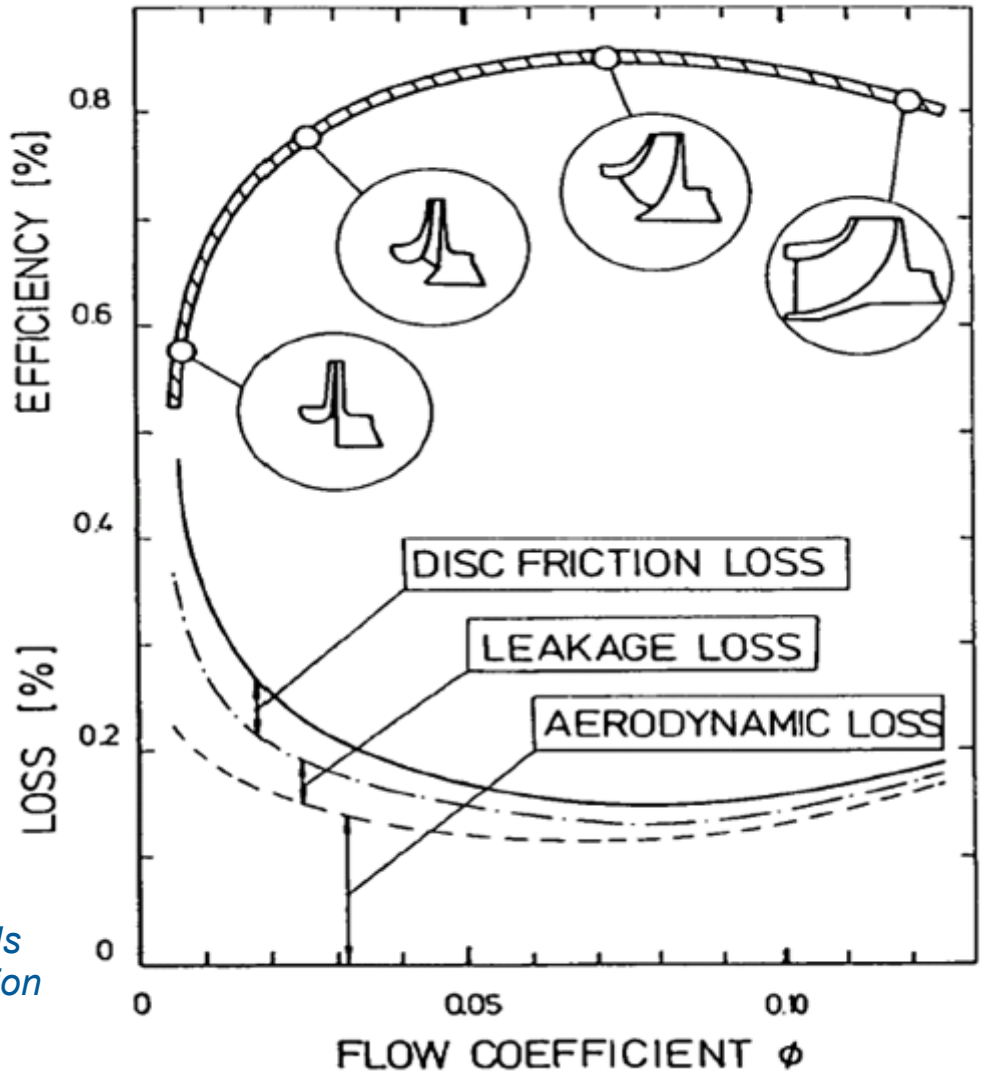


1.0L Engine low-rate specification PR=1.25 and 12.5 g/s

	Turbocharger Impeller	TurboClaw® Impeller
Speed, krpm	185	40
Diameter, mm	20	85
Blade height, mm	4	5.5

Why can’t we drop the speed of a standard turbocompressor?

⇨ **Effects of reducing specific speed**

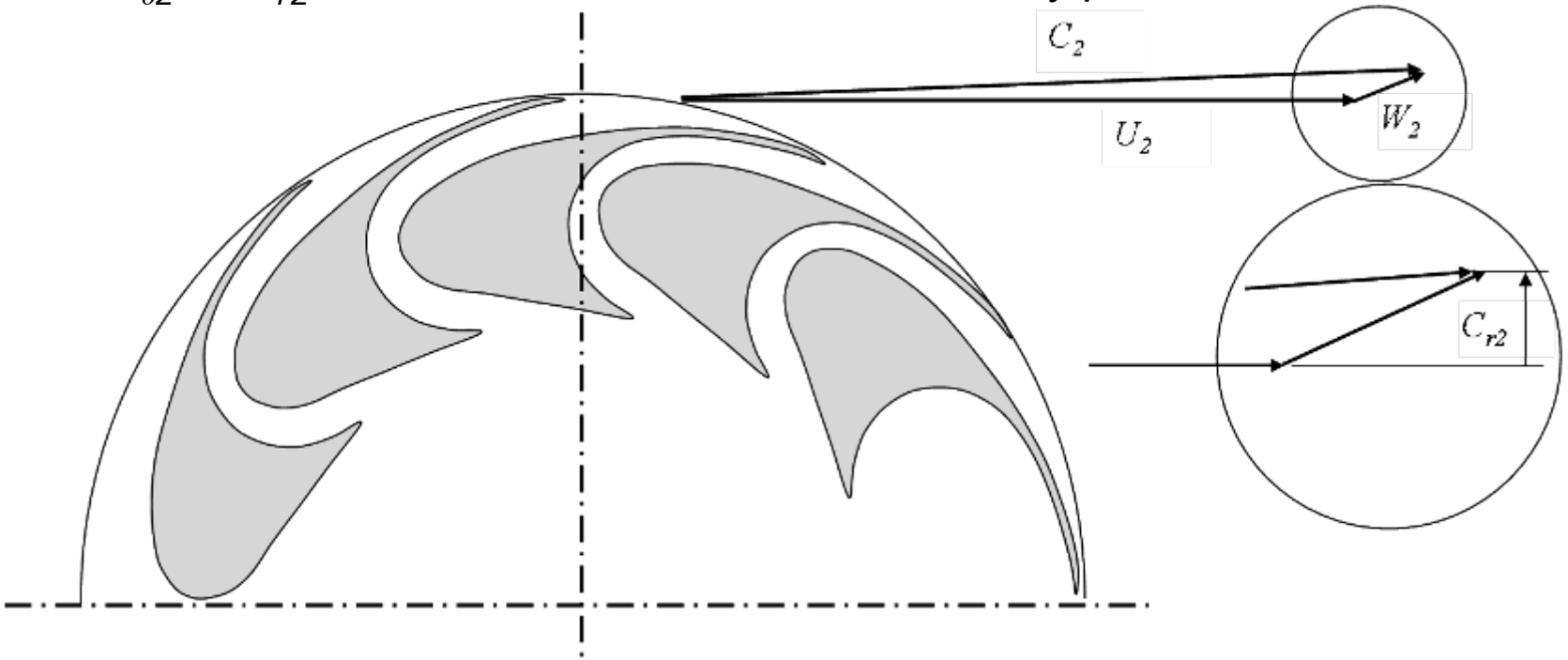


Ref : Casey, M V *Computational Methods for Preliminary Design Geometry Definition in Turbomachinery*

The TurboClaw compressor

Substantial forward sweep

Ratio $C_{\theta 2}$ to C_{r2} can be as low at 25:1 without stability problems



Electrically Driven Supercharger TurboClaw®

Project Funded by TSB 'Low Carbon Vehicles'
[EDS TurboClaw™ *BS088J*] :

Dynamic Boosting Systems

AVL Powertrain

and Turbocam Europe

Specification:

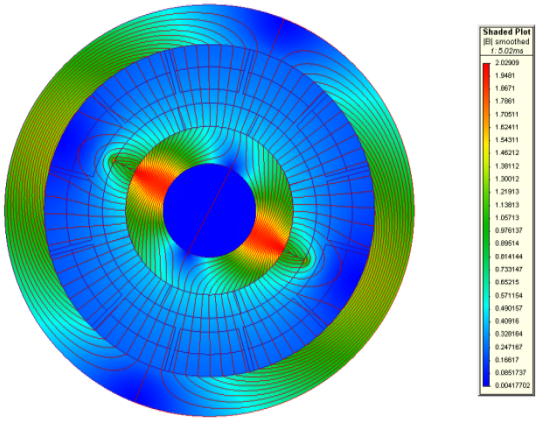
- Engine 1.0L Engine speed up to 2000 rpm
- Electrically Driven Supercharger: Low cost- durable operation using TurboClaw® compressor for PR=1.25 and 12.5 g/s
- Electric motor and drive; High efficiency- durable operation- low cost

Electric Motor and drive

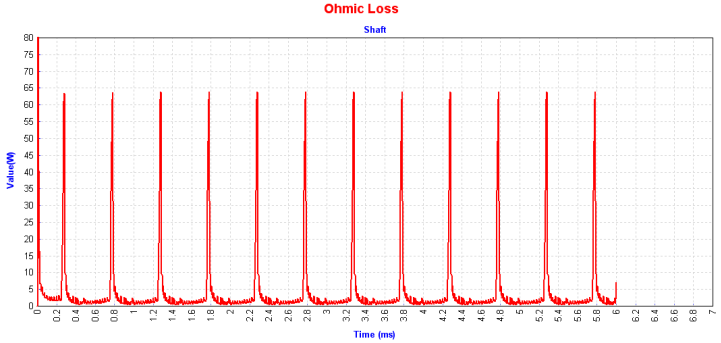
DBS machine is Slotless DC- topology (Sinewave BEMF)

- High efficiency
- Ease of manufacture
- Smooth Torque Profile
- Proprietary dedicated controller chips
- Sensorless control
- Hysteresis Current Control or Space Vector modulation
- For best performance, switching frequency > 50 kHz

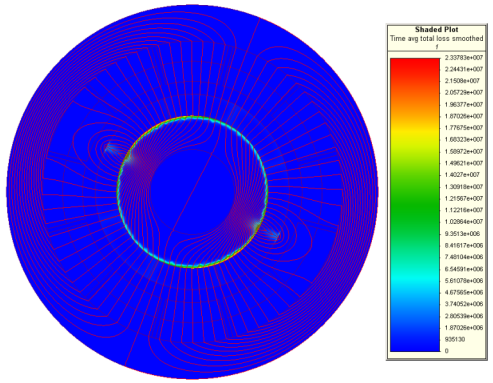
Slotless Brushless DC –Full Load



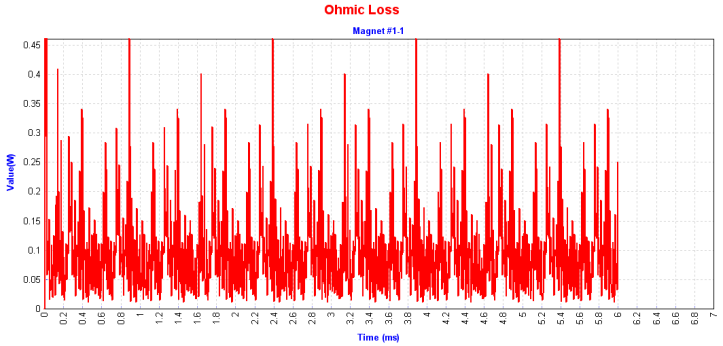
Flux Density Distribution – Full Load



Shaft Losses – Avg 4.33 W

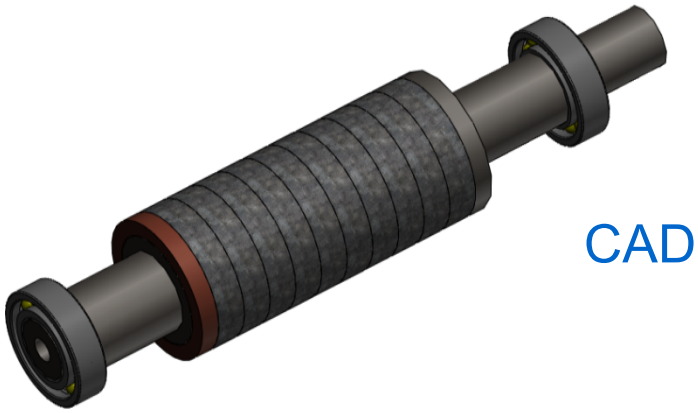


Total Loss Distribution – Full Load



Magnet Losses – Avg 0.1 W

Slotless Sine BEMF Motor Rotor Topologies



CAD MODEL

Ring Magnet

- No need for magnet retention
- Ease of rotor construction
- Magnet utilization not optimal

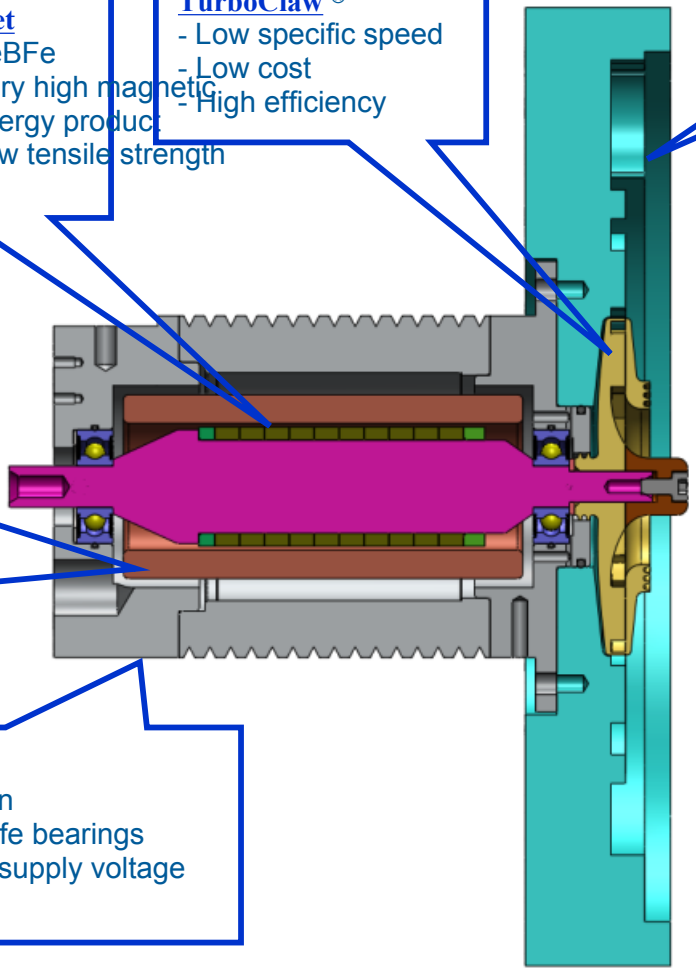
Actual Hardware from
a 500 W motor

General Motor Layout

Permanent Magnet
- NeBFe
- Very high magnetic energy product
- Low tensile strength

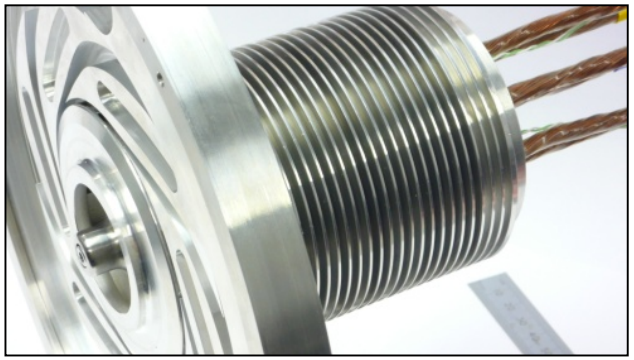
TurboClaw ®
- Low specific speed
- Low cost
- High efficiency

Diffuser
- Machined aluminium
- Low tolerance



Copper Windings
- Multi-stranded
- Low loss
- Continuous coils
- Large surface area

BLDC Motor
- Simple low cost design
- Grease packed long life bearings
-Changeable control & supply voltage
- Sensorless

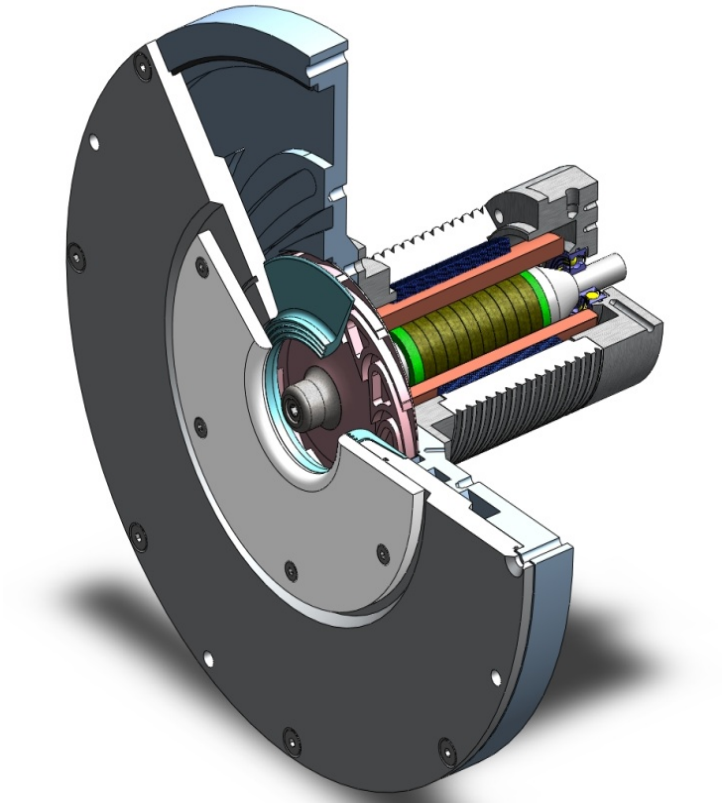


Actual hardware with a 1 kW motor

Motor Drive Controller

- Wide operating voltage (12 – 56 VDC)
- Wide operating temperature range.
- Low-cost, robust solution.
- Analogue and digital control input (speed demand)
- Possibility for sensorless control
- CAN-bus communication

Electrically Driven Supercharger “TurboClaw™” Project Design and Manufacture



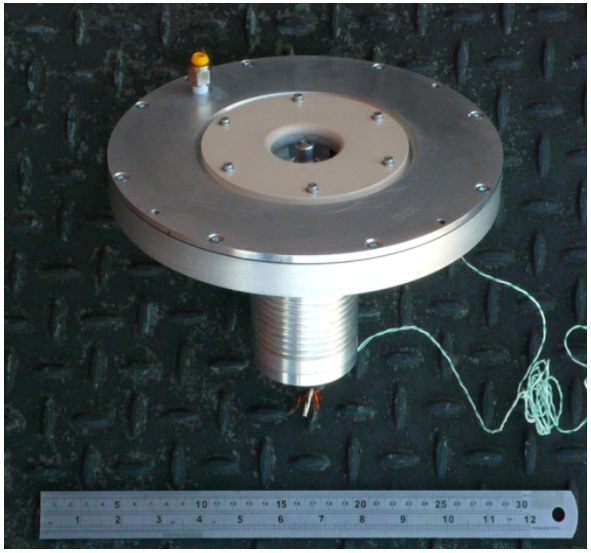
Designed by DBS

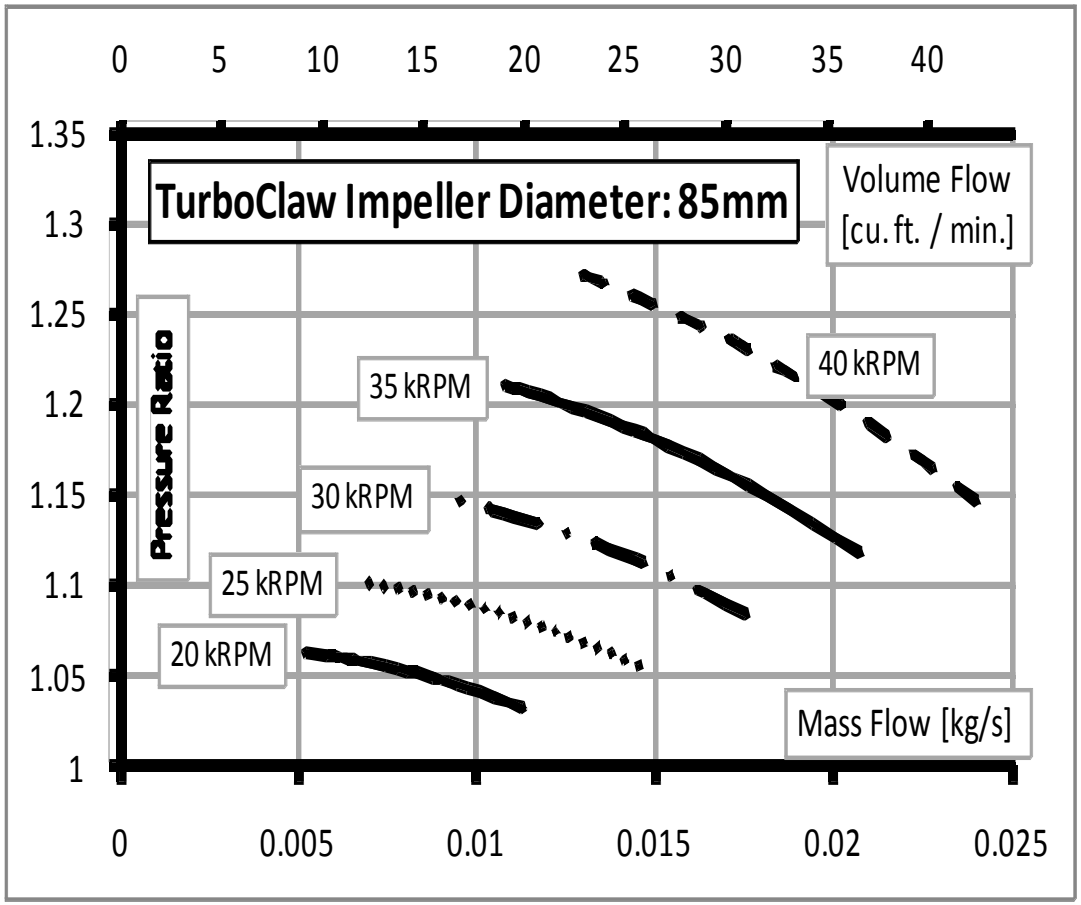
Turbomachine components manufactured by Turbocam

BLDC motor designed and manufactured by DBS

Electrically Driven Supercharger “TurboClaw®” Hardware and Preliminary Data

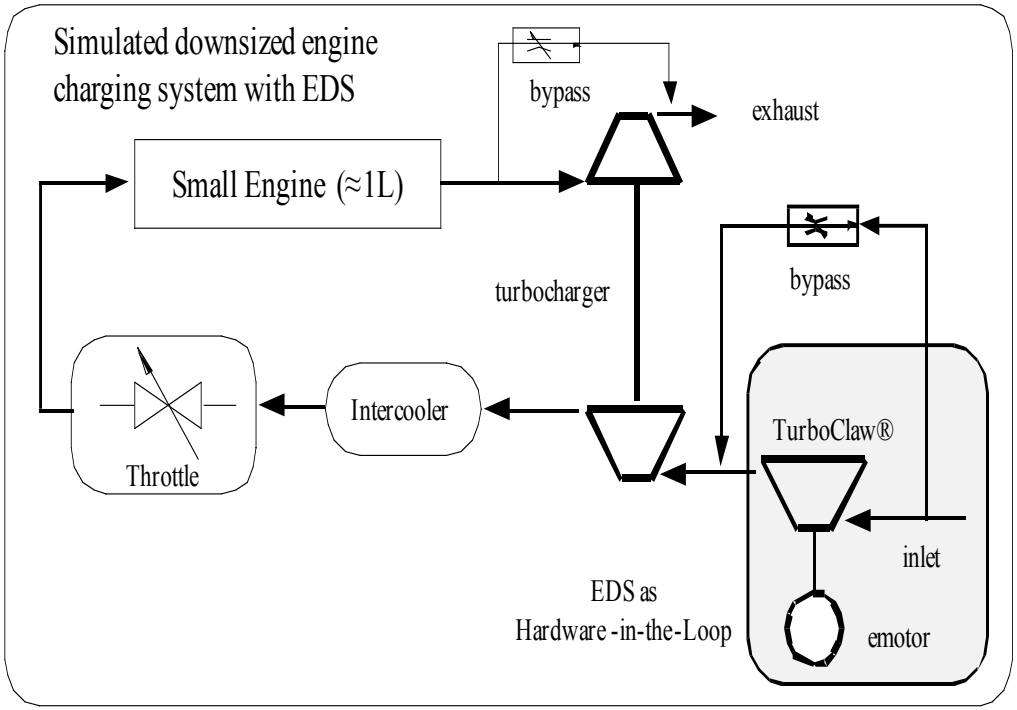
Hardware
after rig testing

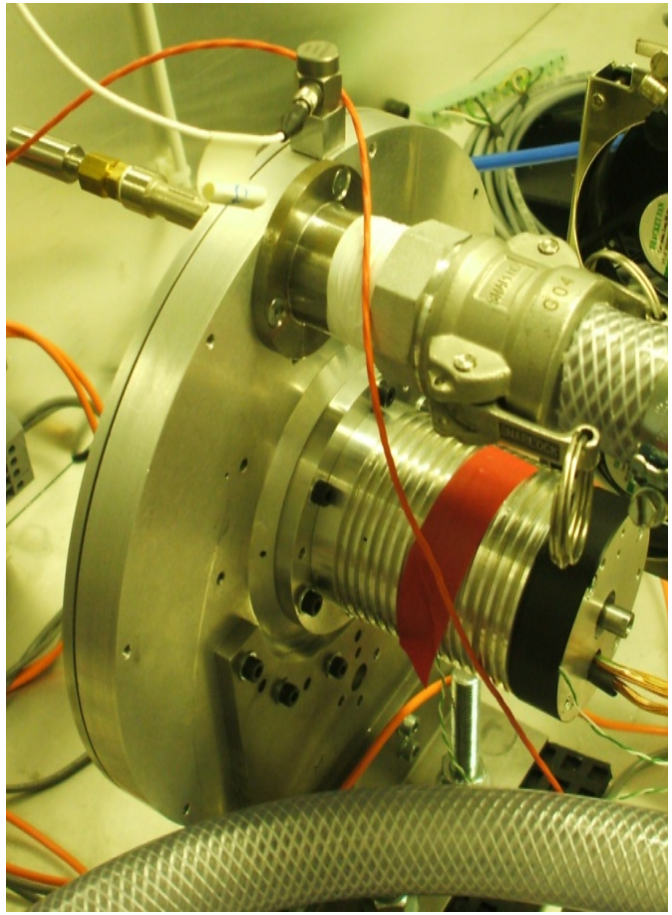




Preliminary data
Compressor map validated to 40 krpm

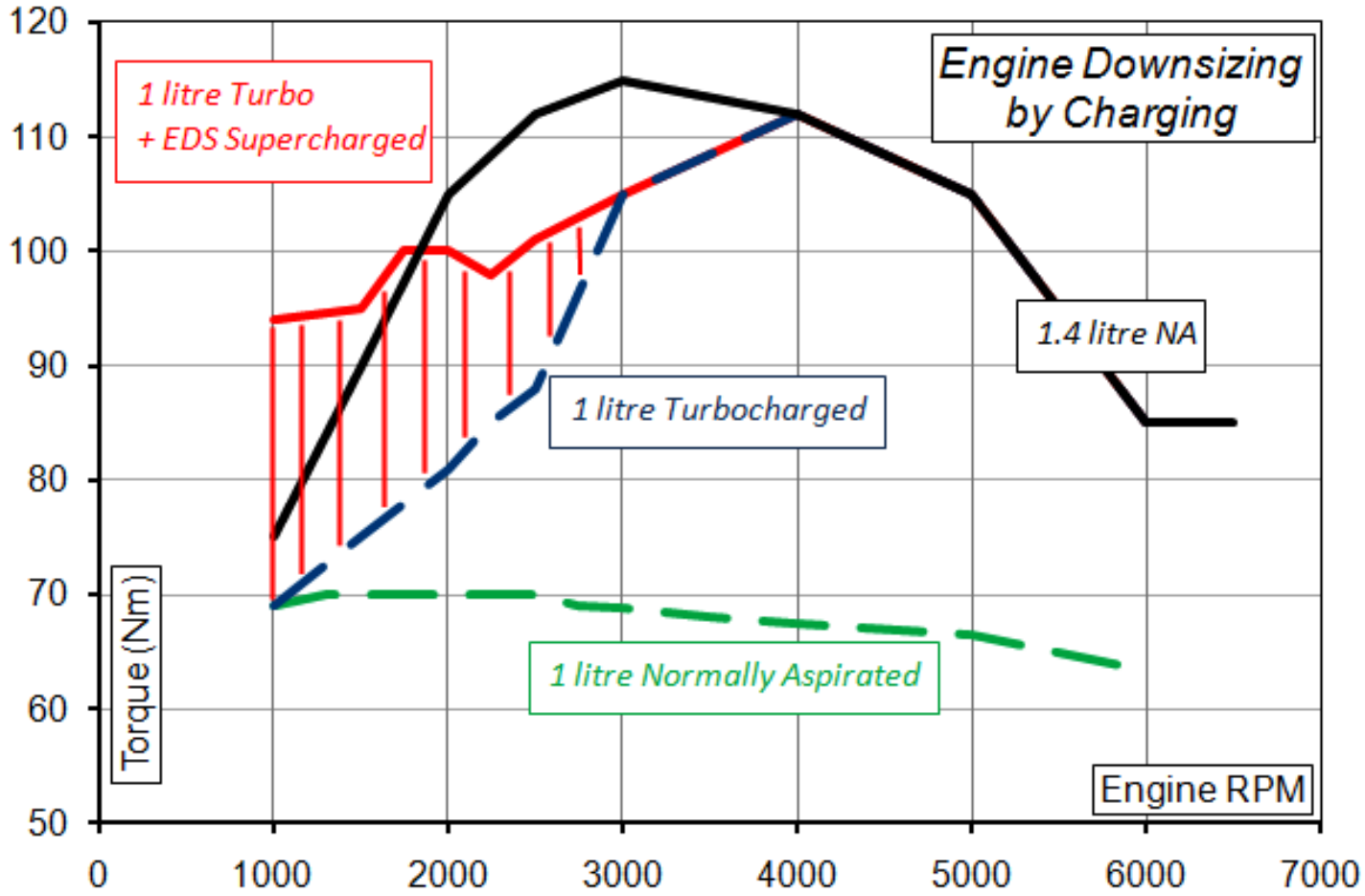
Hardware in the loop test set-up





Hardware on test

Test Results



EDS “TurboClaw®” delivers high speed acceleration target performance