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IMPROVED ENGINE PERFORMANCE AND EFFICIENCY UTILIZING A SUPERTURBOCHARGER

Ed VanDyne
CEO
VanDyne SuperTurbo Inc.
Fort Collins, CO

Thomas Waldron
VP Operations
VanDyne SuperTurbo Inc.
Fort Collins, CO

ABSTRACT

VanDyne SuperTurbo Inc. has recently completed Phase I of an Army SBIR project entitled "Diesel Waste Heat Recovery Utilizing a SuperTurbocharger". The project focused on modeling a SuperTurbocharger for a specific Army application and evaluating the potential benefits from a single device capable of supercharging, turbocharging and turbocompounding. The modeling effort resulted in predicted efficiency gains from both air flow management and mechanical waste heat recovery. Additionally, the modeling program revealed additional engine power available that was inaccessible with the engine's current turbocharged configuration. This paper will cover the fundamentals of the technology, the Phase I engine modeling results and the path forward for the Phase II prototype testing project.

BACKGROUND

A problem with turbocharged engines is that they tend to have poor transient response relative to larger naturally aspirated engines. The typical solution is to operate the engine at relatively higher engine speeds where the response is better; however running at higher speeds negates some of the fuel consumption benefit. One option is to use multiple turbochargers in series, but that solution can be costly and complex to control properly. Another possible solution is a transmission driven turbocharger; called a SuperTurbocharger. This one device takes the place of three devices: a turbocharger, a supercharger and a turbocompounder. All three functions can be achieved in a very efficient manner because the turbine is either doing most of the work needed by the compressor or extra work. When the turbine power exceeds the required compressor power turbocompounding is performed. The system is very cost effective because it has all three functions in a single device. The system is also expected to reduce soot emissions in diesel engines with its ability to supercharge.

INTRODUCTION

VanDyne SuperTurbo is currently testing and building 3rd generation prototypes for customers in the defense, automotive, agricultural, and industrial engine sectors. The SuperTurbocharger is a single device that is capable of supercharging, turbocharging and turbocompounding. This is accomplished mechanically by combining a Continuously Variable Transmission (CVT) with a high speed drive system that controls the speed of the compressor/turbine. The system effectively provides on demand boost pressure to the engine at any given operating point. During supercharging transients a small amount of engine power is used to bring the system to full boost. This effect is quickly aided by the exhaust energy collected by a custom designed high efficiency turbine. When turbine power exceeds the compressor power, the CVT acts as a brake and the system reverses the torque flow, thereby turbocompounding excess exhaust energy back to the engine.

With speed control over the compressor and turbine, the restrictions in turbine mapping and design are different than those required in a turbocharger. The turbine can be designed to achieve efficiencies in excess of 80% and the waste-gate can be eliminated. The system is accelerated using crankshaft power, thus reducing boost lag time and allowing for higher inertia turbine designs. A normal supercharger receives all of its power from the engine, while the SuperTurbocharger only requires the delta between the compressor power and that of the turbine. Power from the engine is only used during a small percentage of the operating time, and at most engine operating points the system returns turbocompounding power to the engine. Figure 1 shows a recent prototype design that is on test now and will be similar to the Army Phase II SuperTurbocharger.

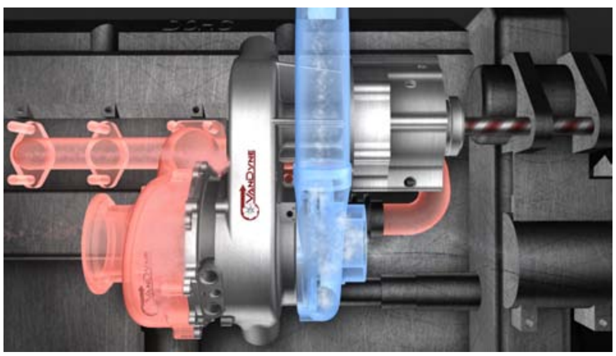

Fig 1: Diesel SuperTurbocharger

For the SBIR Phase I project, the Army requested that VanDyne model and present the results for a SuperTurbocharger application on the Heavy Equipment Transport (HET A1) utilizing the Caterpillar (CAT) 18 Liter diesel engine. The engine model showed that there are efficiency improvements available across the lug curve and at the part load conditions. The SuperTurbocharger was also shown to be capable of making significant additional power available to the engine from both additional boost pressure and turbocompounding power.

MODELING APPROACH

GT Power was selected as the modeling software utilized in this research project. The original SuperTurbocharger software block for GT Power was developed by Southwest Research Institute (SwRI) and has been utilized on several different projects. In order to insure accurate results, several items are critical inputs to the engine model, including: 1. Baseline engine information; 2. Custom turbine design; 3. Accurate system losses.

VanDyne worked in direct collaboration with CAT in designing the baseline engine model. CAT provided the necessary engine parameters and data from actual results of their testing for VanDyne to build a matching engine model. Once the baseline model was complete and running, CAT reviewed the assumptions and model performance. The custom turbine was developed by VanDyne's chief scientist, who has 20 years of experience designing turbines for power plants and 25 more years working for a European automotive company. The parasitic losses in the system are based upon actual testing and accrued knowledge from a similar SuperTurbocharger prototype program.

Once the baseline model was matched, the SuperTurbocharger and custom turbine were included. The modeling process was run iteratively, with the turbine design changed a few times to optimize the overall result. The Army identified, based on current operations, the B75 to B100 operating range as the most critical for needing efficiency gains. The model and turbine were adjusted until those operating conditions were optimized without significantly sacrificing the overall benefit across the full operating spectrum.

EFFICIENCY IMPROVEMENT

In order to determine the efficiency benefit available, the engine model was evaluated by balancing in cylinder efficiency along with power consumed or produced by the SuperTurbocharger. In low RPM operation there are several conditions where overall efficiency benefits from a supercharging effect. The system is able to supercharge with a small amount of drag on the engine, thanks to the assistance being received from the turbine. Additional air flow at these lower RPM conditions allow for a significant improvement to combustion characteristics. When the in-cylinder benefits outweigh the power consumed by a certain level of supercharging, the overall efficiency of the engine improves. This is only possible with a SuperTurbocharger; since a normal supercharger's parasitic drag at steady state conditions takes all its power from the crankshaft and normally produces a net loss in efficiency without engine downsizing included.

In the higher RPM operating conditions, the available exhaust energy outweighs the required input energy of the compressor. In these cases, the turbine is trying to accelerate beyond the desired speed setting. The CVT then becomes a mechanical brake and turbo-compounding automatically results as the direction of torque in the system reverses. The results for all the modeled operating conditions are given in Table 1.

BSFC	900 RPM	1200 RPM	1600 RPM	1900 RPM	2300 RPM
Load	100%	100%	100%	100%	100%
%Change	-5.49	-8.68	-5.77	-6.73	-8.24
	900 RPM	1200 RPM	1600 RPM	1600 RPM	1900 RPM
Load	50%	70%	70%	50%	85%
%Change	-1.44	-3.39	-6.07	-7.78	-6.61

Table 1: BSFC Reductions vs. Operating Condition

POWER IMPROVEMENT

The most obvious power improvement is associated with the transient response improvement enabled by the supercharging capability of the technology. In this specific model the baseline stock turbocharged engine at 1200 RPM full load transient takes almost 5 seconds. With the SuperTurbocharger that same transient can be reduced to 1 second.

The added benefit revealed to the military by this modeling project was the SuperTurbocharger's ability to increase total engine power for short term use. The use of this extra engine power for the vehicle must include the consideration of its effect on engine life. Operating at higher cylinder pressures will decrease life, and thus the selection of the stock boosting system. In order to increase the engine power to achieve its pressure limited maximum power, the addition of a second turbocharger or a supercharger would normally be required. However, the SuperTurbocharger can make that power available and limit that availability electronically. With the extra boosting power of the SuperTurbocharger there can be times when high and even emergency power can be accessed as outlined in Table 2.

Engine Power	900 RPM	1200 RPM	1600 RPM	1900 RPM	2300 RPM
High	+41%	+48%	+32%	+18%	+21%
Emergency	+56%	+68%	+38%	+32%	+44%

Table 2: Lug Curve Power Increase Over Stock

It should be noted that a 7% to 8% increase in power comes from the SuperTurbocharger's ability to turbocompound, thereby placing no additional stress on the base engine for that power increase.

PHASE II

In Phase II VanDyne will be designing, producing and testing prototype units at TARDEC in a laboratory environment. CAT will again be participating with necessary assistance in the areas of hardware integration, controls integration and test assistance. The goal for the Phase II project is to validate the modeling work from Phase I, demonstrate engine power and efficiency enhancement and prepare for a vehicle demonstration.

The project is expected to demonstrate the following:

- Lower engine out soot emissions
- Higher boost pressure possible in one stage
- Lower engine backpressure over most of the range
- Highest efficiency supercharger for improved low rpm torque and leaner A/F Ratios
- Turbo lag of 1 second or less
- The highest amount of waste heat recovery
- Replace the existing turbocharger

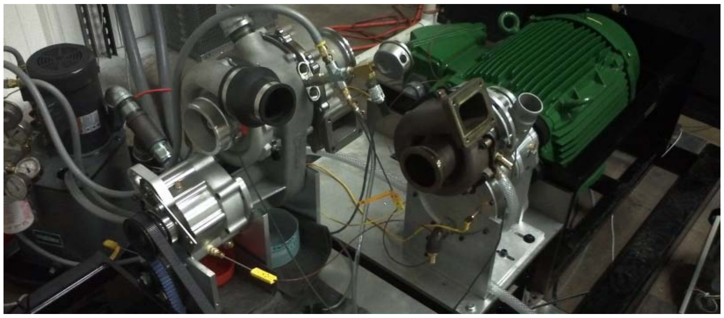

Fig 2: Current Generation SuperTurbocharger Hardware

Fig3: Current Generation SuperTurbocharger Hardware

Two SuperTurbocharger sizes are currently being tested. These represent units designed for large diesel applications as well as smaller gasoline engines. The photos in Figures 2 and 3 show recent rig testing with both sizes. On engine testing is also being conducted on two dedicated test engines located at the VanDyne facility as part of a Colorado State University research program.

For more information contact:

Tom Waldron at Tom@VanDyneSuperTurbo.com