

THE ENGINE OF THE FUTURE

The CEI/SED Variable Compression Ratio, Low Friction, Lean Burn Engine

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The ideal, practical, highest efficiency internal combustion engine is one that operates on what is known as the Otto cycle, with maximum compression ratio (CR), leanest air-fuel ratio (AFR), fastest burn, and lowest frictional losses both from air-throttling and piston rubbing. Such an engine is also the cleanest engine as long as it can use a homogeneous air-fuel mixture, as in a gasoline engine, so that at light engine loads it can operate as a lean burn, fast burn, high CR engine with low exhaust emissions, and at high loads, it can operate with a stoichiometric mixture for best use of the 3-way catalyst for lowest tailpipe emissions.

Such a gasoline engine has been considered an idealization, relegated to the visionaries, given the realities of tough emission standards. The result has been the abandonment by the industry of the pursuit of lean burn, variable CR/low friction technology, as an impossible dream, along with the potential **60 mpg** that could be achieved in a vehicle that currently gets 30 mpg. In its place, the gasoline-electric hybrid and fuel cell technologies are being pushed, which have serious technical and cost problems of their own.

That can all change to achieve what was considered only a theoretical possibility before. Three visionary inventors, Dr. Michael Ward, CEI, Bob Sanderson and his brother Dr. Al Sanderson, SED, are combining forces to solve both halves of the problem, above the piston and below the piston. Both Michael and Al obtained Ph.D.'s under Prof R.W.P. King at the Engineering and Applied Physics Division of Harvard University in the 60's, but went in totally different directions. Bob and Al invented the ideal SED mechanism, and Michael with two other colleagues, have invented the ideal combustion system, that together make up the ideal, but practical, Otto cycle engine mentioned above.

CEI realized lean burn, ironically, in a more effective and lower cost way than was ever thought possible, to achieve the best of what can be done **above the piston**, in the ignition and combustion process. Likewise, SED achieved the best that can be done **below the piston** in the form of a low cost, low friction, variable CR mechanism. Put together, in the form of a 2-valve, dual ignition engine, we have an engine that is without precedent in its ability to achieve the theoretically highest efficiency with low emissions, at a low cost that greatly outperforms diesel-electric hybrids and fuel cell engines.

To add to what has already been achieved, referred to as "The Holy Grail of Car Engineers" by the prestigious *Economist* magazine, the SED engine naturally allows for the realization of what is known as the mild hybrid, or integrated hybrid. This provides the most efficient and lowest cost form of regenerative braking, idle stop-start, and acceleration boost required to deal efficiently with the real world drive cycle of stop-starts, and acceleration and deceleration which aggravate tailpipe emissions, which can be substantially reduced with the integrated hybrid. With this feature, a car that gets 30 mpg can achieve twice the gas mileage of **60 mpg**, and be able to meet the ultra-low-emission standards, even for SUV's or light trucks, in dire need of better fuel economy and emissions.

In the typical light load city driving of 0.3 to 0.4 load, this engine will be able to operate at a 16:1 CR and 30:1 AFR, with minimum best timing (MBT)* as low as 25° E, to achieve a 40% higher efficiency than that of an engine operating at 9:1 CR and 15:1 AFR. Add to that the all but eliminated air-throttling and piston friction losses, and that efficiency gain can be raised to 70%. Finally, including the integrated hybrid-hydraulic feature natural to SED engine, we can double its gas mileage from 30 to **60 mpg** with the lowest emissions. Below is a brief description of each half of the system, and the results achieved and expected.

In its simplest terms, lean burn is the process of operating an engine with a high ratio of

air to fuel, i.e. with lots of air and little fuel, which when properly done, can provide a 20% to 40% gain in fuel economy, depending on the CR. More specifically, to make lean burn work, the engine must be able to: 1) ignite and burn an ultra lean mixture above the 24 to 1 AFR for low NOx emissions and high efficiency; 2) it must speed up the burn of the normally slow burning lean mixture to achieve close-to-constant volume heat addition for maximum Otto cycle efficiency and low hydrocarbon emissions; and 3) it must burn the mixture in a homogeneous form to avoid any rich hot spots where high NOx is formed, or any overly lean cool spots where high HC is formed. Achieving these three things simultaneously is a requirement for lean burn to work and to meet the ultra-low-emission standards. This has not been possible using conventional ignitions and conventional ideas of the role of ignition.

Following 25 years of dedicated work and three major technical breakthroughs, CEI was able to develop an ignition/combustion system that could meet the above three requirements, ironically using the simplest, lowest cost 2-valve homogeneous charge engine. At a CR of 11:1 and an AFR of 25:1, CEI successfully ran a single cylinder, 2-valve engine, with an ignition MBT of only 25.1 BTC, to achieve a part-load efficiency comparable to the Diesel, but without the emissions, weight, size and cost problems of the Diesel. The lean limit of this engine was 30:1 AFR at a CR of 11:1, and higher than that at higher CRs. See SAE paper 2001-01-0548.

Three patented developments led to this landmark success. One was the discovery and implementation of a process called **ignition-flow-coupling** to produce a torch-like ignition by interacting a special type of high-energy spark with the purposely generated squish-flow in the engine, to substantially speed up the initial burn (noting that the first 10% of the burn takes 90% of the time). The second development was a revolutionary, **coil-per-plug ignition** that not only produced the kind of high-energy, flow-resistant spark needed for ignition-flow-coupling, but provides the kind of high-energy-density coil-per-plug ignition sought by the industry, but far superior to what was thought possible. And the third development was the realization that the **2-valve homogeneous charge engine** was ideal for this application, since it naturally accommodates dual ignition and two squish lands for producing the high squish flows needed at the spark plug sites, to speed up the burn of the very lean mixtures, even at relatively low engine speeds where engine flow are normally low.

Efficiency gains of 20% to 30% at part load were achieved. However, the CR had to be limited to 11:1 because of engine knock. If a practical variable CR mechanism were available, so that the CR could be raised at light load where most of the driving is done, even higher efficiency would be achieved. Ordinarily, the CR could be raised to only 13:1 because beyond that the higher frictional losses and heat transfer losses offset any further gain in efficiency due to the higher CR, as shown by Komatsu (SAE paper). But if lean burn is used with its lower combustion temperatures, and a variable CR mechanism is available which has lower than normal friction, then a higher CR, such as 16:1 can be used. The result would be an increase in efficiency to approximately 40%, as already mentioned, but not just because of the increase in CR, but because of the fact that with the CEI combustion chamber, the lean limit would be higher at the higher CR, up to 40:1 AFR.

Since the SED variable CR mechanism essentially eliminates the piston sidewall forces, then when this advantage is combined with the essentially eliminated air-throttling losses from lean burn, the efficiency gain is raised to approximately 70% at light loads, or to **50 mpg** from the 30 mpg baseline. Finally, as already mentioned, that mileage gain can reach 100%, or **60 mpg**, when an efficient, integrated hybrid feature is added. But that is exactly what the SED drive naturally provides, i.e. a very efficient, integrated hydraulic-hybrid feature that is naturally built into the engine, as discussed next.

In its simplest terms, the Sanderson Mechanism developed by SED is a variable-stroke system for multi-cylinder piston engines, using a patented configuration of universal joint and rocker arms to achieve remarkably low friction, small size, and high horsepower to weight ratio. Other features are simple variable stroke adjustment, and very low noise and vibration.

The stroke is variable on all pistons simultaneously from a single point control, easily controlled during engine operation even under all engine power conditions. This feature is particularly valuable in increasing engine efficiency through higher CR, and reducing emissions during acceleration, cruising, and idle since optimum emission settings depend on the CR, among other factors, as is well known. As stated above, the advantages of the CEI combustion system are substantially enhanced when combined with a variable CR engine.

The low friction of the Sanderson Mechanism is a result of its rocker arm and universal joint drive connection that transfers power from the pistons to the rotating crank. This mechanism is revolutionizing linear to rotary power conversion and rotary to linear conversion in devices such as hydraulic pumps and motors, air compressors and motors, and gasoline engines. The mechanism requires no side load on the pistons to make the power transformation in either direction. In both directions the mechanical efficiency is in the high ninety percent range. In gasoline IC engines this leads immediately to less heat loss, to greater part-load efficiency, to a flat torque curve down to low RPM=s, and in one test, to the ability to idle without loping to less than three hundred rpm. This leads to better mileage, better acceleration, and less emission when stopped in traffic.

Friction is also reduced by the low number of main bearings compared to those in a conventional engine; only three are needed regardless of the number of pistons. The pistons are arranged axially around the main axis of the engine, all driven by their own rocker arms, which share a common U-joint. For greatest power to weight ratio, the engine can be double-ended, with two pistons per piston throw, adding length but not circumference, yet retaining the ability to control CR from a single point.

Balancing the Sanderson Mechanism can be done to near perfection. The motion of the pistons is almost perfectly sinusoidal for all values of CR; all even harmonics are missing, and the third harmonic is the largest at about one percent. There are no net forces with a symmetrical arrangement of three or more pistons. The only concern then is primary moment balance, and this turns out to be a matter of adjusting two counterweights to cancel the rotating couple generated by the piston motion. The smoothness of the mechanism is phenomenal, better (our balancing consultant says) than a precision balanced electric motor of similar size. Some advantages of such fine balancing are of course simpler engine mounts, less engine wear, less noise, and greater passenger comfort.

The present range of proven scalability is from a fractional horsepower air compressor to a 500 horsepower slurry pump. We anticipate easy scalability to much larger or smaller devices that will work just as successfully. Several- thousand-horsepower devices are already in the works.

We estimate that an automobile getting say, **30 mpg** with a conventional engine, if equipped with a CEI/SED engine of the same horsepower, could achieve a mileage in the neighborhood of **50 mpg**. A car of the same horsepower in a Sanderson hydraulic hybrid configuration should be able to reach over **60 mpg**, according to our calculations, with the lowest possible tailpipe emissions, and other features already mentioned, such as smooth operation. Equally important, when viewed from a cost and simplicity perspective, the CEI/SED engine provides advantages that are expected to be staggering when the very low cost and simplicity of the system are factored in. Widespread adoption could potentially mean oil independence for the United States, and being able to provide such low tailpipe emissions would satisfy projected requirements for the engine of the future for the next two decades or more, possibly even until a new form of energy is discovered.