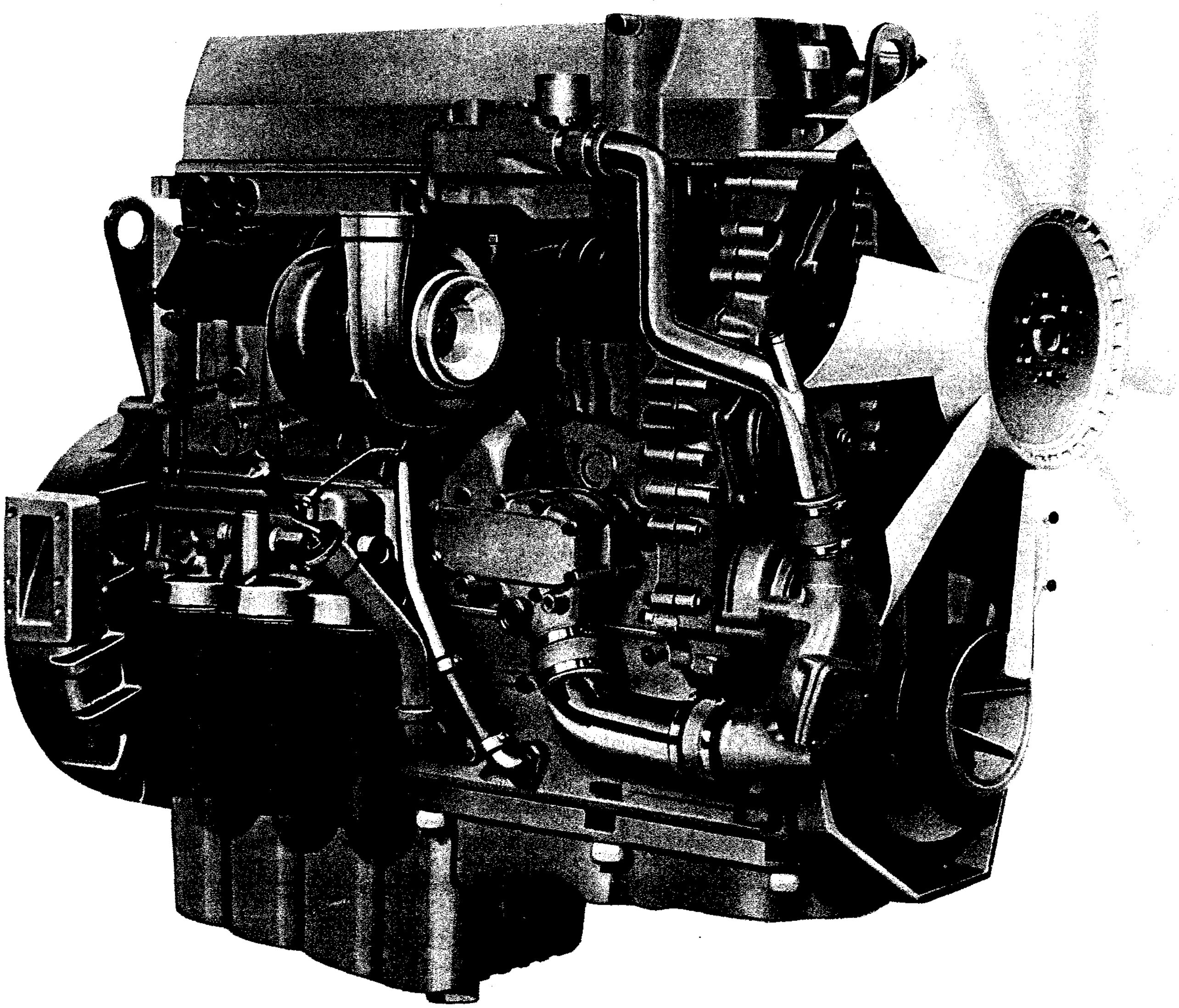
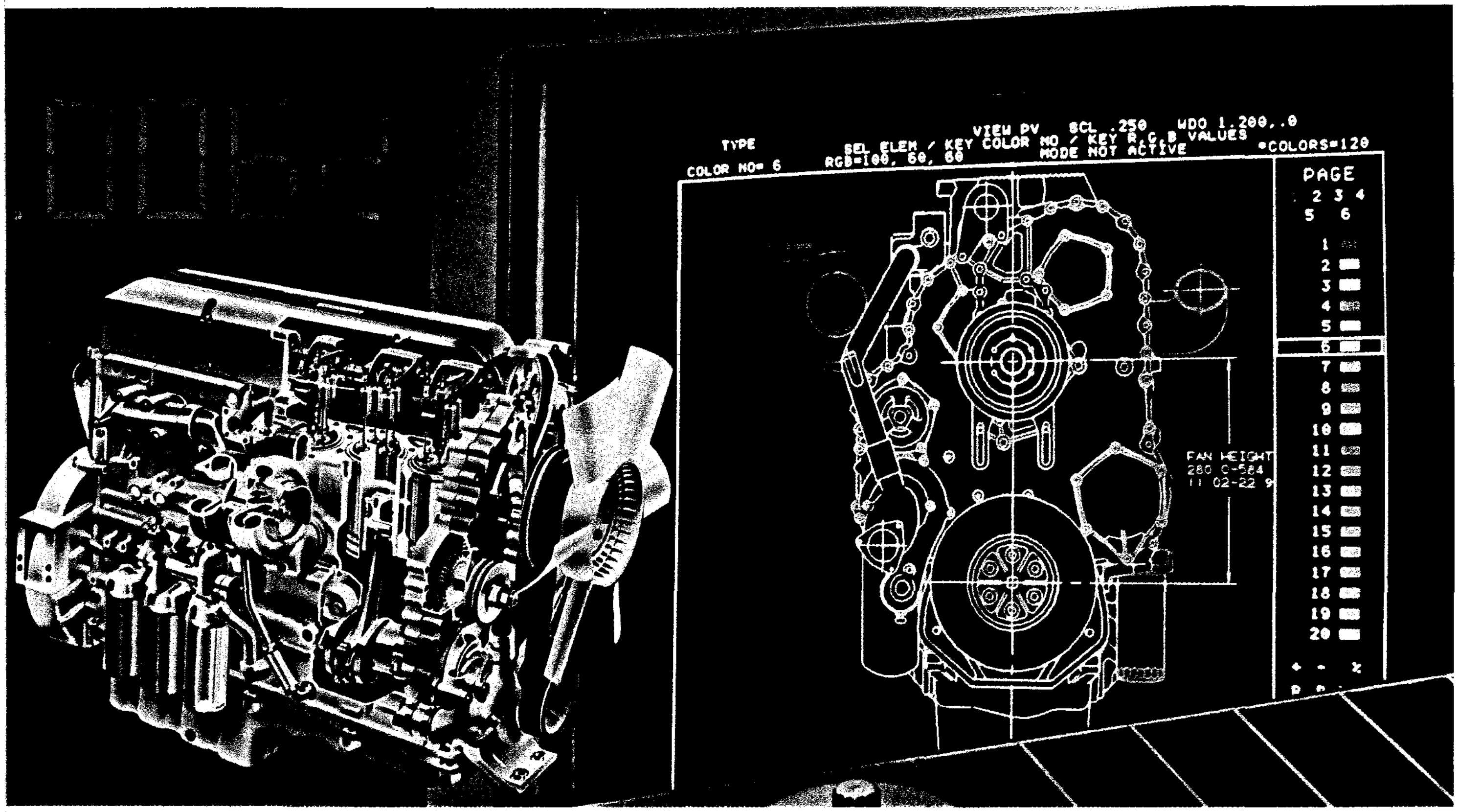
DETROIT DIESEL Series 60

First in Electronic Technology





We've Rewritten The Book On Innovative Diesel Design

The DETROIT DIESEL Series 60 is the most advanced diesel engine ever designed and manufactured. It is a new product from Detroit Diesel Corporation. The Series 60 is new in concept. New in the way that it's tested. New in the way that it's built. So new that DDC has rewritten the book on innovative diesel design. This is the world's first production diesel engine to offer integral electronic controls as standard equipment.

The result is an engine with significantly lower initial cost, high fuel efficiency, excellent reliability and durability, engine diagnostics and low maintenance.

The Series 60 is the culmination of a $300 million investment; a tribute to the enormous efforts of one of the most experienced diesel engine manufacturers in the world.

A Beautifully Simple Design

The 6-cylinder, 4-stroke cycle Series 60 is one engine with two displacements (11.1 and 12.7 liters), ranging from 250 to 425 HP. There are only eight different part numbers between the two displacements. This design simplification has many benefits. For instance, truck builders only have to engineer the Series 60 into a truck once. Parts inventory is substantially less since all but eight parts fit both displacements. It also simplifies mechanic training.

The design simplicity of the Series 60 makes it an exceptionally reliable and durable engine as it contains from seven to thirty percent fewer parts than competitive engines. Fewer parts mean fewer wearing surfaces, making it less expensive to maintain.

Vital features of the Series 60 include an overhead camshaft, parallel ports, an electronic control system and turbocharged air-to-air charge cooling.

Detroit Diesel— The Right Choice

Customers in the power generation market have many choices—spark - ignited or compression ignition, medium-duty or heavy-duty, 2-stroke or 4-stroke. There is a great deal of confusing, often conflicting information in circulation, much of which can be attributed more to four-stroke salesmanship than fact. When the half-truths and wives tales are exposed and are made to stand up to independent, unbiased comparison testing we find similarities in the true performance of both designs in most areas. However, the results confirm the superiority of the two-stroke design in a power generation application in those critical areas that are often not discussed by the four-stroke advocates—the ability to start reliably, accelerate to speed, accept rated load, and return to stable frequency and voltage output in the shortest time possible... isn't that really what you expect from a generator set?

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6SA341 9005 As technical advancements continue, specifications will change. Litho in U.S.A.

standby applications the name of the game is single-step load acceptance from a cold start. In hospitals, office buildings, and computer facilities, all other considerations pale in comparison to the requirement that a standby generator set start quickly, accelerate to speed and accept its rated load in the shortest possible time. In this most critical area, marked differences in performance are evident.

In the first load acceptance test each generator set was operated for a period of time sufficient to bring all temperatures up to normal operating levels. The generator sets were then turned off and immediately the test began. A signal was sent initiating the start sequence. The engines cranked, fired, and accelerated toward synchronous speed. A transfer switch was installed which automatically dropped the load on the generator sets as soon as they had achieved a predetermined generator voltage and frequency, thereby eliminating human error in the timing of load application. As voltage and frequency reached the preset level, the switch connected the generator sets to a load bank which was calibrated to apply precise load increments. The time required to accept the load and return generator frequency to 60 hertz +/- 0.5 hertz was recorded.

The results—using identical generators, voltage regulators, governors, and control systems under identical conditions, it took the four-stroke engine 75 percent longer to accept full load and return to stable frequency and voltage conditions.

When the power goes off, who wants to wait 75 percent longer than they have to?

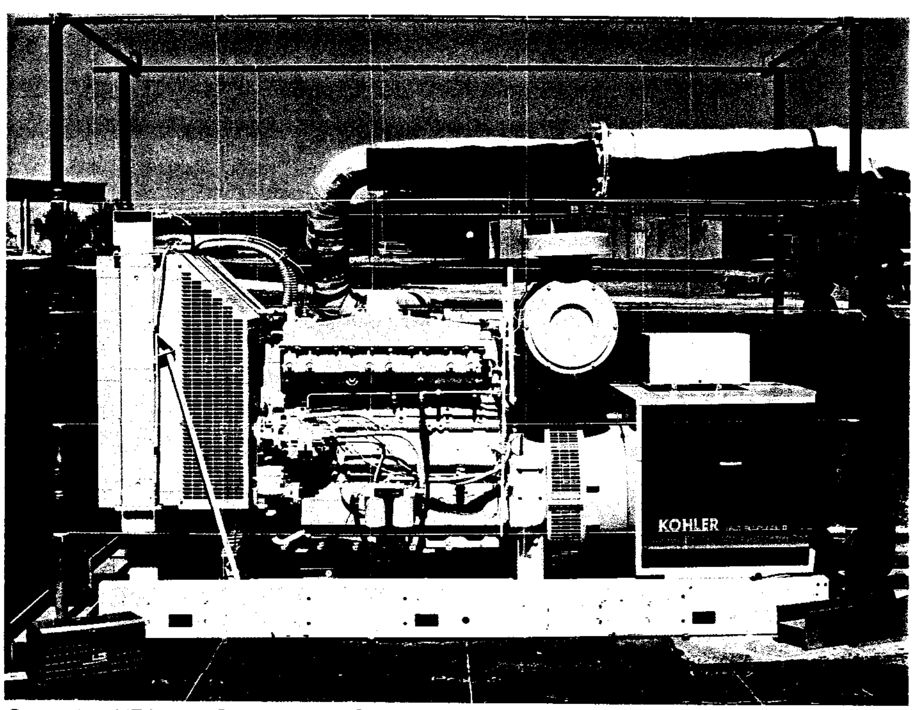
The next test followed the same procedure only the generators were left to cool overnight. All starting aids and block heaters were disconnected and first thing the next morning the single-step, full-load acceptance test was run. The ambient temperature was 56°F. Under these conditions, **the four-stroke engine was unable to assume its rated load of 300 kW in a single step—the two-stroke did so successfully.**

The independent research technicians felt that such a test was perhaps too severe and did not realistically imitate true standby conditions. Hence, a third test was prepared.

In this test, every effort was made to duplicate "real-life" conditions—the engines were left to cool overnight, but block heaters were connected and maintained the engine's coolant at manufacturer recommended temperatures. Because it was felt that standby generator sets are often slightly oversized to provide a margin for error and permit load growth the load applied was 91.67 percent of the standby rated load (275 kw applied, 300 kw standby rating). The procedure was the same as in the previous tests.

The results—**It took the four-stroke powered set 70 percent longer to accept 91.67 percent of its rated load and return to 60 hz +/-0.5 hz than it took the two-stroke, Detroit Diesel powered generator set.**

The results of these independent, side-by-side tests are conclusive. When you cut through all of the sales hype and get down to what is really important in a power generation application, the two-stroke design demonstrates a clear advantage in load acceptance capability and transient load response.



Cummins NTA 855-G2 Powered Gen Set

Side-By-Side Testing is Proof of the Pudding

While the preceding discussion provides the basis for an interesting, if somewhat academic, debate of the relative merits of the two-stroke and four-stroke designs, it can be said that much of the discussion is not necessarily relevant to the needs of the power generation customer. After all, the most important requirement of a generator set is that it start reliably, accept load quickly, and provide constant voltage and frequency under varying loads.

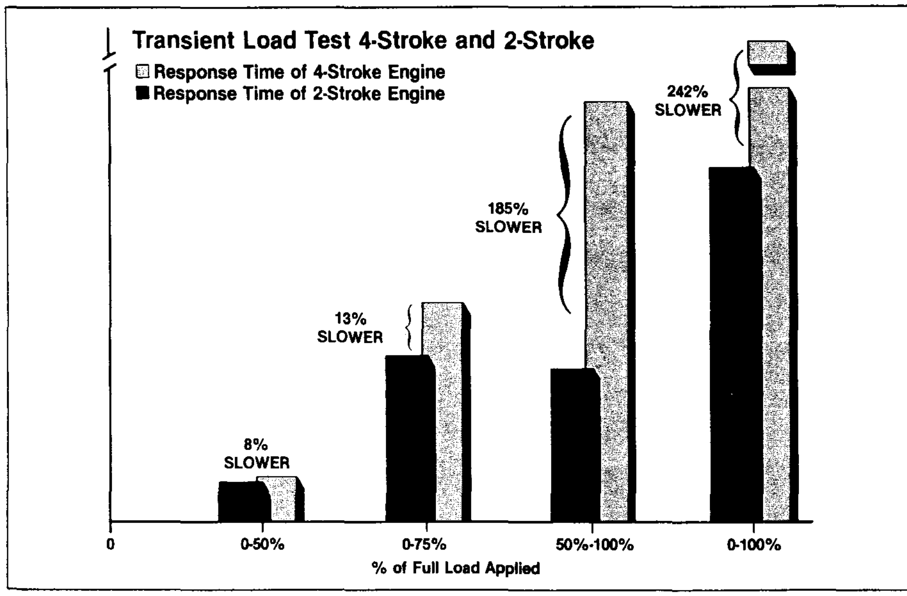
In order to determine if either the two-stroke or four-stroke engine holds an advantage in these critical areas, a side-by-side test was arranged at a major independent testing laboratory in 1989. Two Kohler 300ROZ generator sets using identical generators, voltage regulators, governors, and control systems were employed. The only difference between the two generator sets was the engine used—one had a Cummins NTA855-G2 and the other a Detroit Diesel 6V-92TA. Both units carried stand-by ratings of 300 KW.

The independent test laboratory ran a battery of transient and single-step load pick-up tests from a stopped condition. The results of these tests show a dramatic difference in the performance of the two designs—**a difference which could be critical in an emergency situation.**

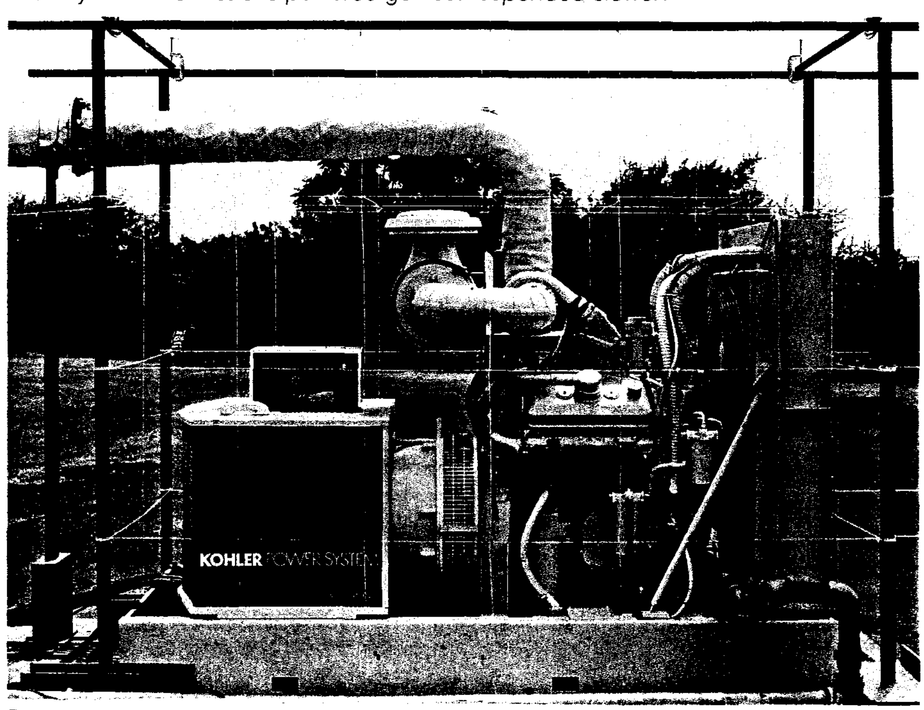
The first battery of tests involved the application of loads equal to 50 percent, 75 percent, and 100 percent of the standby rating to each machine in a single step. Prior to load application, the engines were brought up to operating temperature and were at synchronous idle of 1800 rpm. The independent testing laboratory reported the results listed below:

These tests clearly show that the Detroit Diesel two-stroke engine, under identical conditions, demonstrates a dramatic advantage over the four-stroke in the truly important area of delivering high-quality power under varying load conditions.

While the delivery of high-quality power under varying conditions is extremely important, in



In every case the 4-stroke powered gen set responded slower.

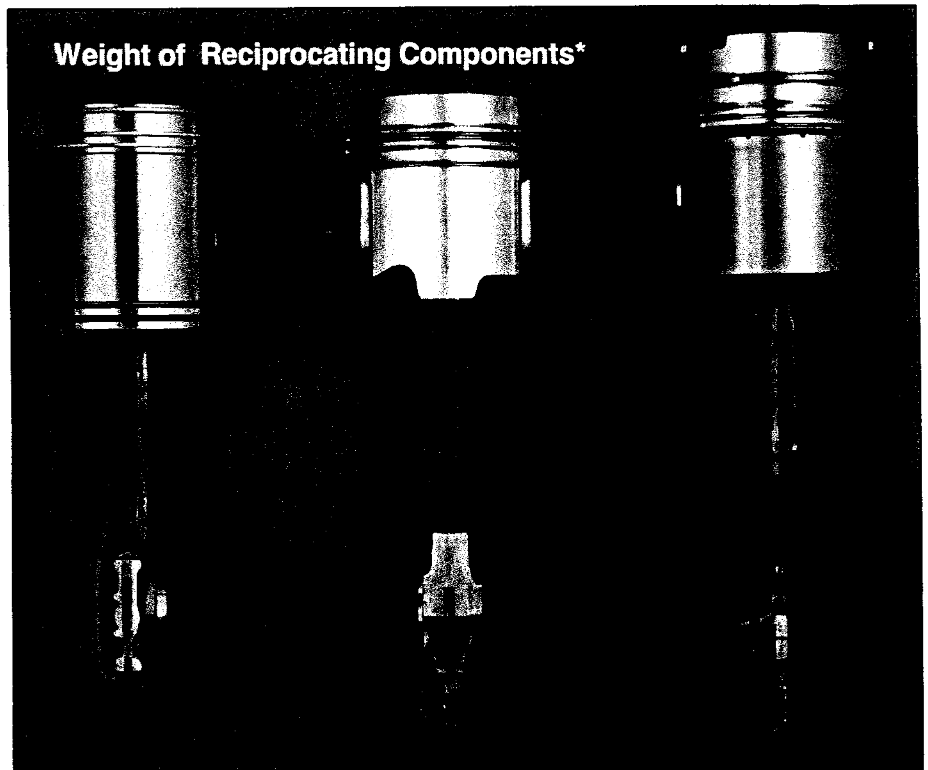


Detroit Diesel 6V-92TA Powered Gen Set

The statement that long pistons and extra rings add substantially to reciprocating mass is a valid claim when taken in isolation but keep in mind that the typical four-stroke must have a displacement 55 percent greater than that employed in the two-stroke of the same output.

The reciprocating masses of two and four-stroke engines are indicated to the right:

Hence the claim that the additional piston length and rings represent a disadvantage for the two-stroke in terms of reciprocating mass is inaccurate.



Detroit Diesel 6V-92TA	Caterpillar 3406B	Cummins NTA-855-G2
13.16 lbs	13.20 lbs	16.28 lbs

**Comprised of piston dome, rings and 2/5 connecting rod, piston pin, bearing, seals and retaining clips*

The final myth regards emissions and odor of exhaust gases.

Exhaust pollutants come from fuel and oil, not air. As previously described, the fuel input to both engines should be similar assuming proper control of the combustion process is maintained. But under widely varying loads and ambient conditions which design can better maintain control? Efficient combustion requires that air and fuel be mixed in precise proportion. While fuel control is comparatively simple and extremely precise through the use of Detroit Diesel unit injector technology in conjunction with electronics, the control of air is another matter altogether. Whether turbocharged or not, the air handling capacity of a four-stroke is a function of engine speed and load. When a substantial load is applied to a four-stroke engine in a single step, the engine responds with more fuel but must wait for the exhaust energy driving the turbocharger to slowly rise before sufficient air is available. The result is slow acceleration toward full load and lots of black smoke.

Detroit Diesel two-stroke engines employ a positive displacement blower which pushes 50 percent more air through the cylinder than is required for the combustion process. Some of this excess air is available to improve response to transient load conditions. The two-stroke design presents less restriction to the passage of air and the by-pass blower helps the turbocharger to catch up with the demand for air during transient load conditions. In the same way that electronics are being added to the fuel control systems of modern diesels, Detroit Diesel is adding them to the bypass valves on our blowers thereby permitting control of both components of the combustion process—air and fuel—independent of engine speed and load and independent of each other. It is this unique capability that has made the two-stroke much more adaptable to the use of alternative fuels such as methanol. Detroit Diesel has methanol-powered generator sets already in operation in environmentally sensitive areas.

The next claim is equally easy to disprove as it is quite simply inaccurate. "Since the intake ports are located in the cylinder wall, the wall can be water-cooled only down to a point just above these ports. The ports are, therefore, subjected to high heat, and, since the wall is weakest at that point anyway, due to the holes, cracking sometimes results."

Detroit Diesel, two-stroke engines have water cooling passages above and below the intake ports. In addition, the incoming air serves to cool the port area itself. It should also be noted that Detroit Diesel takes extra steps in the manufacturing process of the cylinder liners used in our two-stroke engines. Unlike those used in competing four-stroke engines, our liners are heat treated and tempered which provides improved wear resistance and fatigue strength.

This criticism is a statement of the obvious: "Any carbon build-up around or in the ports greatly decreases engine breathing."

No mention is made of how carbon buildup is supposed to have occurred. Carbon buildup is normally associated with improper engine timing or misapplication and occurs in the 2-stroke and 4-stroke engines alike. Carbon build-up has been attributed to engines with extended operation at idle or low-speed conditions. Typically, neither of these conditions occurs in constant speed power generation applications.

Two-stroke engines use high efficiency air handling system components: turbochargers, positive displacement blower with automatic bypass system (which unload the blower when the turbocharger is capable of supplying the required flow), intake ports and four exhaust valves per cylinder which present much less restriction to the flow of air and exhaust gases. In normal operation, a two-stroke circulates 50 percent more air than a four-stroke of equivalent output and are, therefore, less sensitive to air starvation. It is for this reason that two-stroke engines are derated far less than four-strokes in high ambient and high altitude applications.

The following claim covers a lot of ground before arriving at its erroneous conclusions: "Since it is necessary to keep oil out of the intake ports, the piston has one or more extra rings at the bottom of the longer piston. These rings remain below the ports at all times, to keep oil from being splashed onto the ports. This has several disadvantages. First, the upper rings are forced to operate on a dry cylinder wall, greatly increasing wear. Secondly, piston rings are one of the greatest consumers of internal power due to their friction on the cylinder walls. Since more rings are required, more friction horsepower is involved, and more wasted fuel results. These long pistons and extra rings are heavy, meaning more reciprocating mass to be moved, and they are expensive. Because of the less efficient combustion, noxious exhaust emissions are apt to be higher, and the smell of most two-stroke engines is more disagreeable."

It is quite true that oil control rings exist in two-stroke engines as they do in four-stroke diesels. Their function is the same in both cases—to apply a metered film of oil to the cylinder wall. In the same way the top ring of a four-stroke gets its lubrication, the oil control rings of a Detroit Diesel carry oil to a point where it can be picked up by the other rings, hence the cylinder walls of a two-stroke engine are no more "dry" than are those of a four-stroke diesel. The second point, regarding fuel consumption, has already been addressed, but the argument used points to a major inconsistency in the four-stroke position. In earlier discussion, the following claim was made:

"The third reason for lower outputs is the parasitic load on the engine produced by the blower. A surprising amount of horsepower is absorbed by this mechanically-driven blower. That fuel is wasted as far as usable power is concerned."

The positive displacement type blower is an efficient, industrially-proven air handling device. The piston and rings of a four-stroke engine moving in the intake and exhaust strokes are not as efficient because, as the four-stroke argument states:

"Piston rings are one of the greatest consumers of internal power due to their friction on the cylinder walls."

	Displacement	Bore	Stroke
Caterpillar 3406B	893 cu. in.	5.4"	6.5"
Cummins NTA-855-G2	855 cu. in.	5.5"	6.0"
Detroit Diesel 6V-92TA	552 cu. in.	4.84"	5.0"

Dispelling the Two-Cycle Myths

For many years, documents purporting to represent an unbiased comparison between the two-stroke and four-stroke design have been in circulation. The majority of the conclusions drawn can be attributed more to good, four-stroke salesmanship than sound, objective engineering analysis.

In 1988, Detroit Diesel Corporation broke with company tradition and began supplying heavy-duty, two-stroke diesel engines to two major generator set manufacturers—Kohler Co. of Kohler, Wisconsin, USA, and F.G. Wilson (Engineering) Ltd. of Belfast, Northern Ireland. In each case, the DDC two-stroke engines replaced competing four-stroke engines in the manufacturer's line of generator sets. One result is that it became possible to perform side-by-side comparisons of similarly rated generator sets making use of identical generators, governors, control systems, and voltage regulators, assembled under identical design, manufacturing, and test conditions.

Let's now compare the claims of the four-stroke advocates to the hard data collected during side-by-side testing of two-stroke and four-stroke generator sets.

The first claim generally made by four-stroke advocates is that, "Instead of turning out twice the horsepower per unit of displacement, the average two-stroke produces only 1.6 to 1.9 times as much as the four-stroke, yet burns twice the amount of fuel. That is to say, per horsepower developed, the two-stroke cycle engine often uses 20 percent more fuel."

To test the accuracy of this claim, the fuel consumption of two Kohler model 200ROZ, 200 kW generator sets were measured. The first set was powered by a Cummins Model NT-855-G4 four-stroke engine and the second by a Detroit Diesel 6-71T two-stroke engine. The results are summarized in the following table.

		NT855G4	6-71T
Standby Rating	200 kW	15.9 gph	15.9 gph
Prime Rating	170 kW	13.9 gph	13.5 gph
75% load	150 kW	12.5 gph	12.4 gph
50% load	100 kW	9.2 gph	9.1 gph

Far from suffering a 20 percent fuel consumption penalty, the two-stroke engine demonstrated equivalent performance at fuel load and better performance at partial load as compared to the four-stroke.

The next claim put forward, though not documented, regards noise: "Since exhaust in a two-stroke is bled from the engine at higher pressures, more exhaust noise results. Plus the mechanical blower further adds to engine noise level."

In comparison testing of four-stroke and two-stroke powered gen sets ranging from 200 to over 1200 kW, Kohler found no set pattern of engine noise differential in favor of either design. In some sizes, the two-stroke was quieter, and in others, the four-stroke held the advantage. In no case measured, did the differential in engine noise level achieve the perceptible limit of the human ear of 3 dbA, and like all unenclosed, diesel generating sets, neither the four-stroke nor the two-stroke would meet existing regulations for extended exposure without acoustic enclosures. The testing did indicate a marked difference in the noise spectrum emanating from the different designs. While total noise levels were similar, the two-stroke tended to show more high frequency noise and the four-stroke more low frequency "rumble." It should be noted that when acoustic treatment is required to meet OSHA or other noise regulations, it is much easier and less costly to attenuate high frequency noise than low frequency rumble.

Fuel Injection Systems

The fuel injection system is sometimes described as the heart of the diesel engine. It must inject fuel at the right time, in the right amount, fully atomized, and in the proper spray pattern. The injection system must be efficient and dependable under all speed and load conditions. Three of the most common types of fuel injection systems are described here.

Multiple Pump System

Originally designed for slow-speed diesels, the multiple pump system is an assembly of high-pressure pumps mounted on the outside of the engine. Leading from these pumps to injector nozzles in each cylinder are long, high-pressure fuel lines which are vulnerable to leaks and damage. Some multiple pump systems are difficult to service. The system must be bled of air after it has been disconnected.

Pressure-Time System

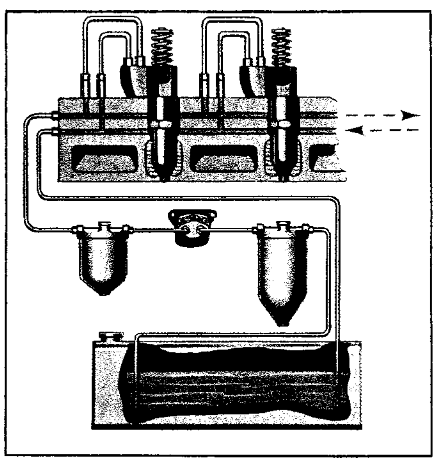
The Pressure-Time System has an individual plunger type injector at each cylinder which times and pressurizes the fuel at each injection. Fuel flows into the injector cup before each injection through a fixed orifice. At any given speed, the orifice is open for a specific time and the amount entering the cup depends on the pressure of the fuel flowing to the injector. This pressure is controlled by a throttle and a governor.

With individual pressurizing injectors at each cylinder, this system eliminates the high-pressure lines found in the multiple pump system. However, the Pressure-Time System is relatively complicated and expensive, involving five fuel control components (not including filters) ahead of the injector. Failure of any component other than injectors usually requires disassembly of the fuel pump and control system.

Detroit Diesel Unit Injector System

This system also has individual pressurizing injectors at each cylinder. It is the simplest design, with all high-pressure functions taking place inside of the injector—measuring, timing, pressurizing. A low-cost transfer pump constantly circulates fuel through low pressure lines to each injector.

The Detroit Diesel unit injector system is easy to service. The system is self-bleeding, and no complicated priming procedures are necessary.

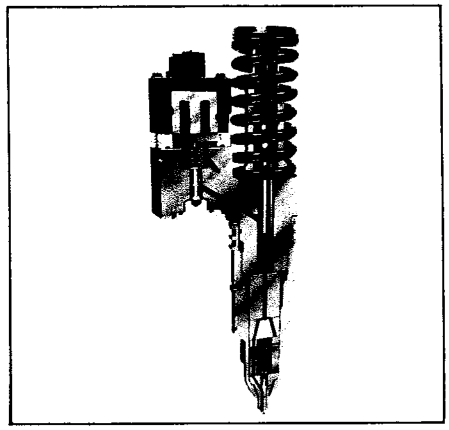


Detroit Diesel Unit Injector System

For reliability, the injectors are cooled and lubricated by circulating fuel, and the system includes the most thorough fuel filtering of any injection system.

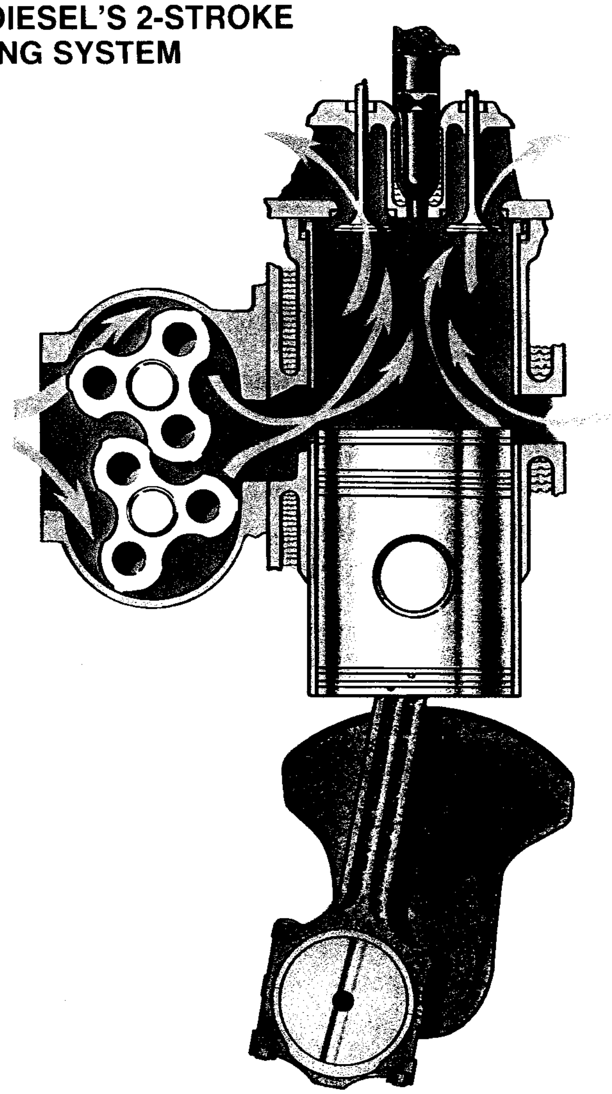
There is a small filter in each injector plus both a filter and a strainer in the main fuel supply line.

The system is inherently tamper-resistant since maximum fuel rate is limited by injector size. This aids in preserving engine life, fuel economy and clean exhaust.



DDEC Electronic Unit Injector

As emission laws have become more stringent and electronics have been added to diesel engines, virtually all heavy duty diesel engine manufacturers, both two and four-stroke alike, have moved toward the incorporation of the Detroit Diesel unit injector system, into their engines. The precise control of injection timing and metering afforded by the unit injection design, coupled with the instantaneous monitoring and control now possible through the use of electronic engine controls such as Detroit Diesel's DDEC system, have made it the diesel fuel injection system of the future.



Scavenging

Combustion is less efficient if the fresh air charge is contaminated by burned gases left in the cylinder after the previous cycle. Therefore, it is desirable to remove all of the burned gases from the cylinder after each power stroke. Detroit Diesel's blower provides superior scavenging. Air flowing in through intake ports at the bottom of the cylinder sweeps the burned gases out through the exhaust valve openings at the top. Since it is unnecessary to have intake valves in the head the cylinder head can accommodate four large exhaust valves that afford easy exit of exhaust gases and scavenging air.

Internal Cooling

Internal cooling of the cylinder and cylinder head is provided by circulating liquid in both the two-stroke and four-stroke engines. In the two-stroke, internal cooling is also provided by scavenging air. A fresh air charge is blown in during each cycle, sweeps out all of the burned gases and cools the piston, cylinder and valves.

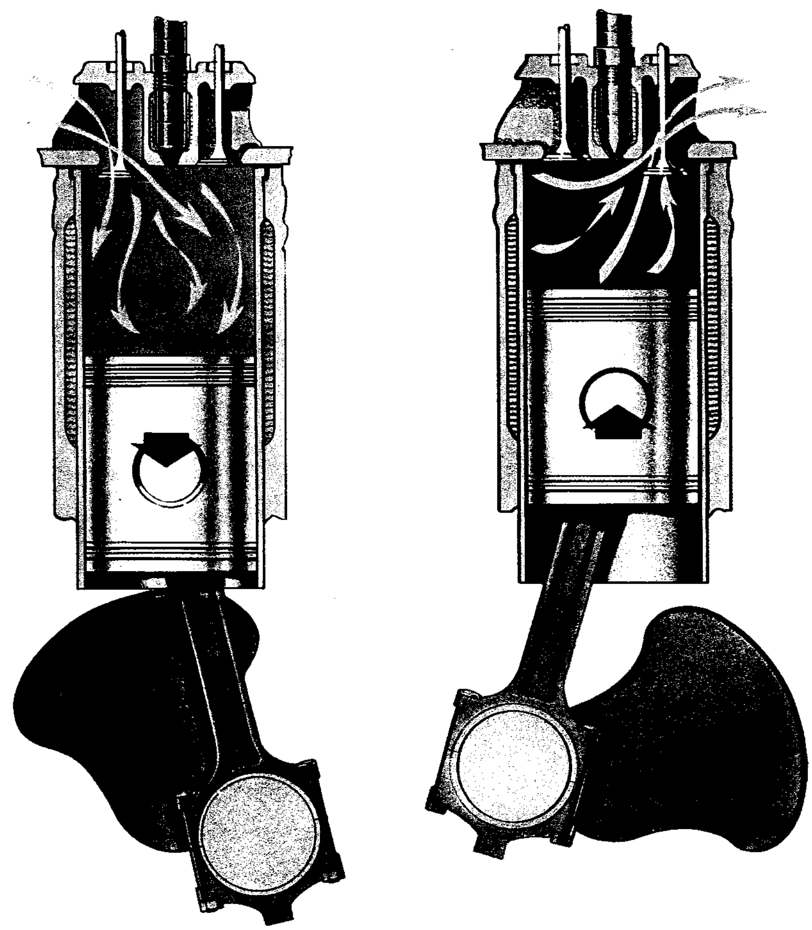
Proven Design

Two-stroke design, which has achieved an international reputation for dependability, is found in Detroit Diesel generator set engines. This same efficient two-stroke design has been applied to larger diesel engines used to power locomotives, ships, and the very largest, most efficient reciprocating engine generator sets. Detroit Diesel two-stroke engines are currently used in 70% of all marine pleasurecraft applications over 40' OAL, and 90% of all intercity and transit buses sold in North America. Detroit Diesel two-strokes also power 55% of all military vehicles operating in the free world. Three million Detroit Diesel two-stroke engines have been put into service since 1939 and well over one million are still operating.

Air Pumping vs Scavenging

All diesel engines must take in air for combustion. Whether it's a two-stroke or four-stroke engine, combustion air must be pumped in and the engine must use horsepower to get the air into the cylinder. Manufacturers of four-stroke engines sometimes claim that no power is consumed for intake air pumping, but they consume power and waste two-strokes using their pistons to pump out exhaust gases and draw in fresh air. The gas-tight pistons and cylinders, designed for power production, serve as inefficient, high-friction air pumps during the intake and exhaust strokes. In a two-stroke Detroit Diesel Engine piston action is used only to compress air and produce power. The process of removing the exhaust gases is called scavenging the cylinder and it is performed by an efficient low friction rotary blower. Breathing efficiency is assured by generous intake port and exhaust valve areas. Since the exhaust valves do not have to share space with intake valves, the exhaust valves can be larger or there can be more of them. Detroit Diesel two-stroke engines have four exhaust valves per cylinder. Four stroke engines typically have only one or two exhaust valves.

4-STROKE CYCLE AIR PUMPING SYSTEM



Air Pumping

Even though a two-stroke engine takes in air at a faster rate, it still uses less horsepower for air pumping at the engine speeds normally encountered by heavy-duty diesels. For example, a typical four-stroke diesel engine diverts 23 horsepower to pump 25 pounds of intake air per minute at 2000 RPM. A Detroit Diesel two-stroke engine of the same power rating uses only 15 horsepower at 2000 RPM to pump 45 pounds of air per minute. In this example the Detroit Diesel's efficient rotary blower consumes 35 percent less horsepower to pump 80% more air through the engine. This advantage generally applies throughout the load range.

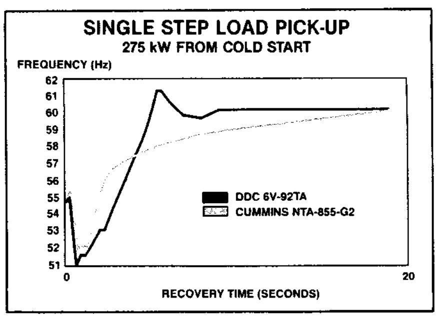
Advantages of the Two-Stroke Design

Weight and Power

With twice as many power strokes per engine revolution, a Detroit Diesel two-stroke engine produces more power than a four-stroke diesel of the same displacement.

Response and Acceleration

Since every cylinder of a two-stroke engine produces a power stroke every revolution, there is fast response to quick load changes.



Durability

The two-stroke "spreads the load," each cylinder producing two lighter power impulses per two revolutions instead of the single heavy impulse of a four-stroke engine. The Brake Mean Effective Pressure, which is an indication of average pressure within the cylinder, is shown below:

BMEP at Full Load (1800 RPM)

	BMEP
Caterpillar 3406B	234 psi
Cummins NTA-855-G2	239 psi
Detroit Diesel 6V-92TA	189 psi

At normal loads and speeds, there is no load reversal on pistons, rods, and bearings; this continuous downward loading reduces impact load effects. Lighter loading permits two-stroke Detroit Diesel Engines to use more compact structural and load-bearing parts without over-stressing. The lighter power impulses are produced by smaller-displacement cylinders, which mean smaller pistons, shorter connecting rods for comparable engine performance. Shorter stroke lowers piston speed and piston speed is a major factor in cylinder kit life.

Piston Speed at 1800 RPM

	(Average Feet Per Minute)
Caterpillar 3406B	1950
Cummins NTA-855-G2	1800
Detroit Diesel 6V-92TA	1500

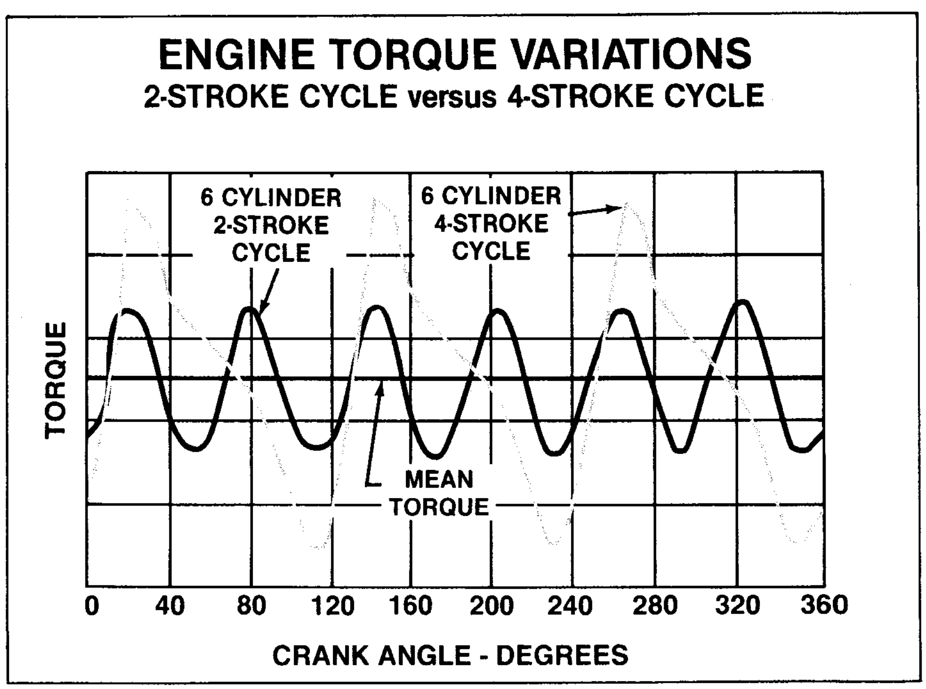
Yet all of these weight and size advantages are achieved without sacrificing engine life.

Smoothness

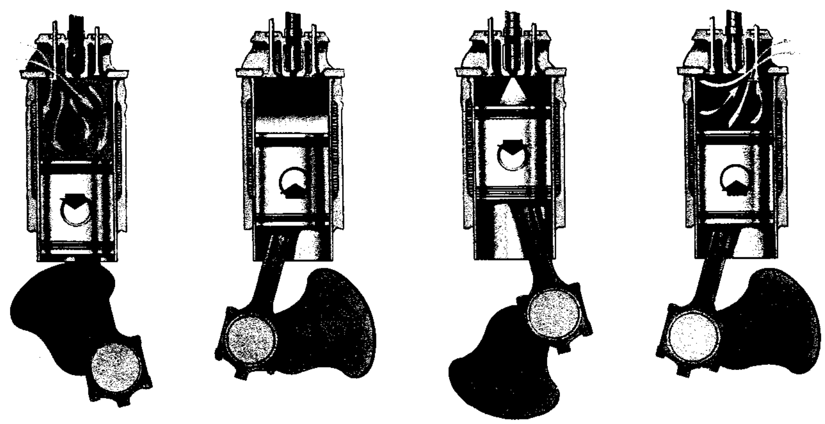
Two-stroke engines run smoother than four-stroke engines. This is because two-stroke engines have twice as many power impulses at the same RPM as the four-stroke engines. The lighter, more frequent power impulses mean less damping is required from the flywheel, hence smaller, lighter flywheels can be used. This permits more rapid acceleration and unsurpassed transient load response.

Lower Exhaust Temperatures

More air goes through a two-stroke engine than a four-stroke for the same amount of fuel consumed. This results in lower exhaust temperatures for two-stroke diesels and longer valve life.



The Four-Stroke Cycle



STROKE 1 INTAKE — STROKE 2 COMPRESSION — STROKE 3 POWER — STROKE 4 EXHAUST

Intake

The intake valve opens near top dead center. The piston descends and, acting as a positive-displacement pump, draws in fresh air through the open intake valve.

Compression

After the piston passes bottom dead center, the intake valve closes. The piston ascends, compressing the air.

Power

Near top dead center, fuel is injected and ignites. Hot combustion gases drive the piston downward.

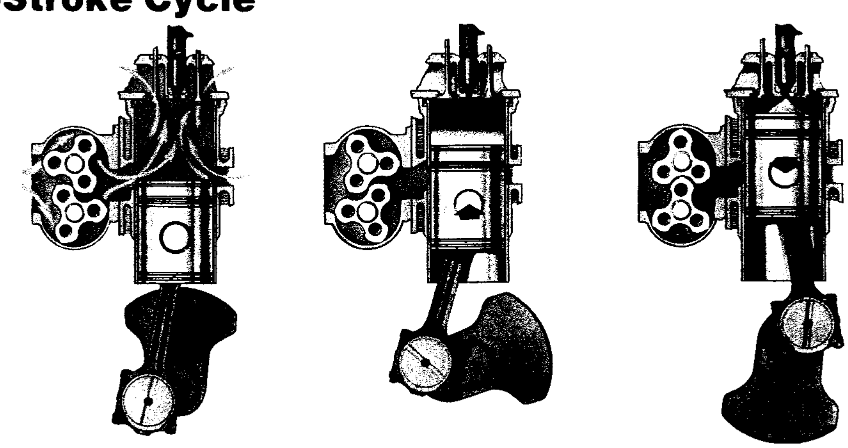
Exhaust

Near the end of the power stroke, the exhaust valve opens. As the piston ascends, it again acts as a positive-displacement pump, pushing the burned gases out of the cylinder. After the piston passes top dead center, the exhaust valve closes.

Two crankshaft revolutions are required for each power cycle. The piston serves as a pump during two of the four strokes.

The Detroit Diesel Two-Stroke Cycle

Only two strokes—"compression" and "power"—are required. Exhaust and intake take place as the piston approaches and passes through the bottom dead center position. Intake air is supplied by an external blower.



EXHAUST AND INTAKE — STROKE 1 COMPRESSION — STROKE 2 POWER

Intake

The descending piston uncovers intake ports and fresh air is blown into the cylinder under pressure from a blower. The incoming air forces out the remaining exhaust gases, cools the piston and cylinder with fresh clean air.

Compression

As the piston rises from bottom dead center, it closes off the intake ports and the exhaust valves close. The air is compressed as the piston continues to ascend to top dead center.

Power

Near top dead center, fuel is injected and ignites. Hot combustion gases drive the piston downward.

Exhaust

As the piston descends in the latter part of the power stroke, the exhaust valves in the head open, releasing burned gases through the exhaust manifold.

Only one crankshaft revolution is required for each power cycle.

Heavy Duty vs Medium & Light

Focusing on diesel engines alone, we see there are options for the power generation customer here as well. Because of their rugged construction, and their common use in tough, dirty jobs and long hauls, diesels are strong, dependable and long lasting. That is a true image of heavy-duty diesels, but not all diesel engines are designed as heavy-duty engines.

In answer to the growing demand for diesels, some light and medium-duty engines have appeared, promising diesel fuel economy with less weight or lower price. You can buy these for a little less than heavy-duty diesels, and they may be a good buy if they meet your needs. But first consider your long-range requirements. The big savings offered by heavy-duty diesels are maintenance and upkeep costs, and longer engine life. In addition, heavy-duty diesels offer superior reliability. You can be confident that your engine will start and operate dependably when you need it.

Before investing in a light, medium or heavy-duty engine, evaluate your application requirements. If reliability is essential, or if your application involves load transients, motor loads or high load factors, then your choice should be a heavy-duty diesel.

Medium-Duty Diesels

Medium-duty diesel engines are similar to spark-ignited engines in that they do not have the rugged structural components or completely replaceable wearing parts that permit repeated rebuilding into "like new" condition. Such an engine is usually good for only one major overhaul, after which the owner is faced with the cost of total engine replacement.

Heavy-Duty Diesels

A heavy-duty diesel is designed for long life. It is built with strong, high-quality parts, and all moving and wearing parts can be easily replaced at overhaul. With adequate periodic maintenance, it operates a long time between overhauls. One of the main advantages of the heavy-duty diesel is its overhaul capabilities. When cylinder liners and other major wearing parts can be replaced, the heavy-duty diesel has almost unlimited life.

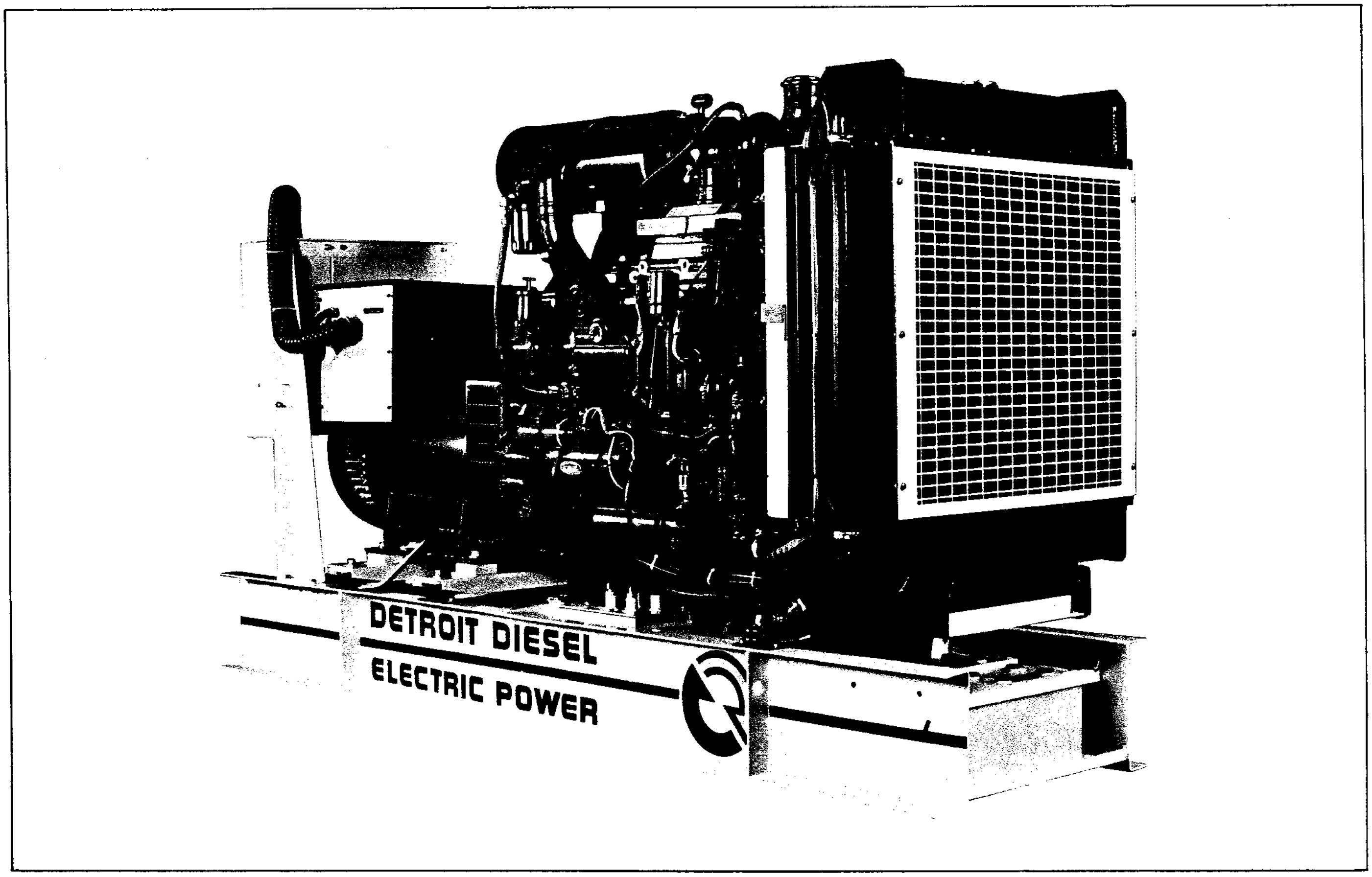
The initial cost of a heavy-duty diesel engine is usually higher than the cost of a medium-duty diesel. But the virtually unlimited life of the heavy-duty engine reduces net cost. This coupled with maintenance savings, reduces total ownership cost over the life of the diesel-powered equipment, which often makes the heavy-duty diesel engine the more economical purchase based on total costs.

Two and Four-Stroke Designs

There exist two types of heavy-duty diesel engines, "two-stroke" and "four stroke." Both designs have been available for many years and both are proven and well accepted in the power generation industry. To understand their differences one must first be clear on the basic design characteristics of each.

Every diesel engine has a combustion cycle of intake, compression, power and exhaust for each power impulse. Some engines, identified as "four-stroke" or "four-cycle," use four piston strokes and two crankshaft revolutions to accomplish these functions. A "two-stroke" or "two-cycle" engine performs intake, compression, power and exhaust in two piston strokes and one crankshaft revolution. Thus each cylinder of a two-stroke engine fires once per crankshaft revolution, twice as often as a four-stroke engine, and this big difference gives two-stroke engines remarkable advantages in a power generation application.

There are many manufacturers of heavy duty, four-stroke cycle diesel engines. Some of these manufacturers, also make medium-duty diesel engines. Two-stroke cycle diesel engines are also manufactured by a large number of domestic and international manufacturers including some of the best-known names in the power generation field. In late 1989 and early 1990 a number of major engine manufacturers announced development programs for two-stroke engines stating that the two-stroke is the engine of the future. Detroit Diesel Corporation builds both types of engines. All Detroit Diesels are heavy-duty diesel engines but not all four-stroke engines are. While best known for our two-stroke engines, DDC also manufactures the four-stroke Series 60 engine—the most successful engine in the on-highway trucking market today. DDC knows and understands both designs and is in a unique position to objectively evaluate the advantages and disadvantages of each in a power generation application.



Diesel Engines Demonstrate Other Advantages Over Spark-Ignited Engines as Well

Diesel Reliability

Simplicity of design makes the diesel more dependable. The diesel engine avoids the complications associated with spark ignition and carburetors. You can depend on a diesel engine to start in wet weather which often causes ignition problems for spark-ignited engines.

Diesel Durability

Most diesel engines are built for long life in rugged applications. A heavy-duty diesel engine may outlast three spark-ignited engines, and usually can be restored to "like new" condition by a major overhaul.

Of course, a diesel engine's precision, high-quality, high-strength parts cost more and usually weigh more than spark-ignited components. Most diesel engines are used in commercial applications where reliability, safety, durability and lower operating costs are most important.

Total Diesel Profitability

Most diesel engines are reliable, long lasting, save fuel, don't require tune-ups and diesel fuel is less difficult to store on-site. Spark-ignited engines require more volatile fuels. Fuel handling and storage requirements for propane and gasoline are more stringent and costly. Natural gas cannot be stored on-site and must be supplied from a continuous source such as a natural gas pipeline. In the case of emergency systems, whether stand-by generators or fire-pumps, the uninterrupted supply of natural gas can be jeopardized by fire or earthquake, thereby precluding the use of the emergency system at the very time it is most needed.

How A Compression Ignition Engine Works

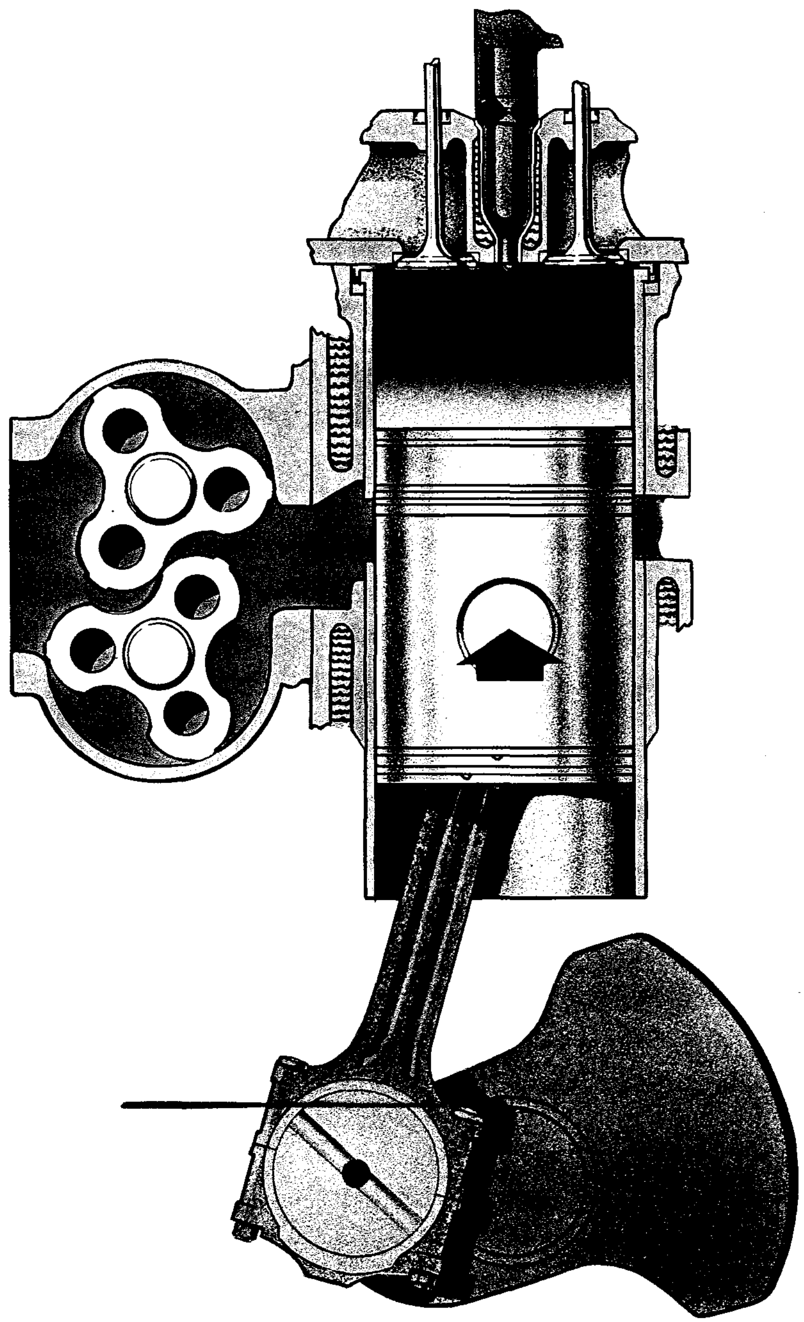
The other major class of engines are "compression ignition" engines. When air is compressed, it gets hot. Fuel will be ignited by the temperature of the hot air. That is the principle upon which compression ignition or diesel engine operation is based.

Unlike a spark-ignited engine, which draws in a mixture of fuel and air, a diesel engine takes in fresh air only. When the diesel piston is near the top of its compression stroke, atomized fuel is injected directly into the cylinder and is ignited by the high temperature of the compressed air. The compression ratio of a diesel engine is approximately twice that of a spark-ignition engine in order to provide air temperatures high enough to ignite the fuel.

Higher Compression for Higher Efficiency

The thermal efficiency of any internal combustion engine, whether spark-ignited or diesel, largely depends on compression ratio. A high-compression engine utilizes more of the energy that is available in the fuel and less energy is wasted in heat loss to coolant and exhaust. Since a diesel engine uses a high compression ratio to achieve the high temperature needed to ignite the fuel, its thermal efficiency is much higher than that of a spark-ignited engine. Thus a diesel engine consumes less fuel than a spark-ignited engine to perform the same work.

In a typical comparison test, a diesel's fuel economy at full load is about 40 percent better than a spark-ignited engine, at half load about 50 percent better, at idle up to 100 percent better.



COMPRESSION IGNITION PRINCIPLE

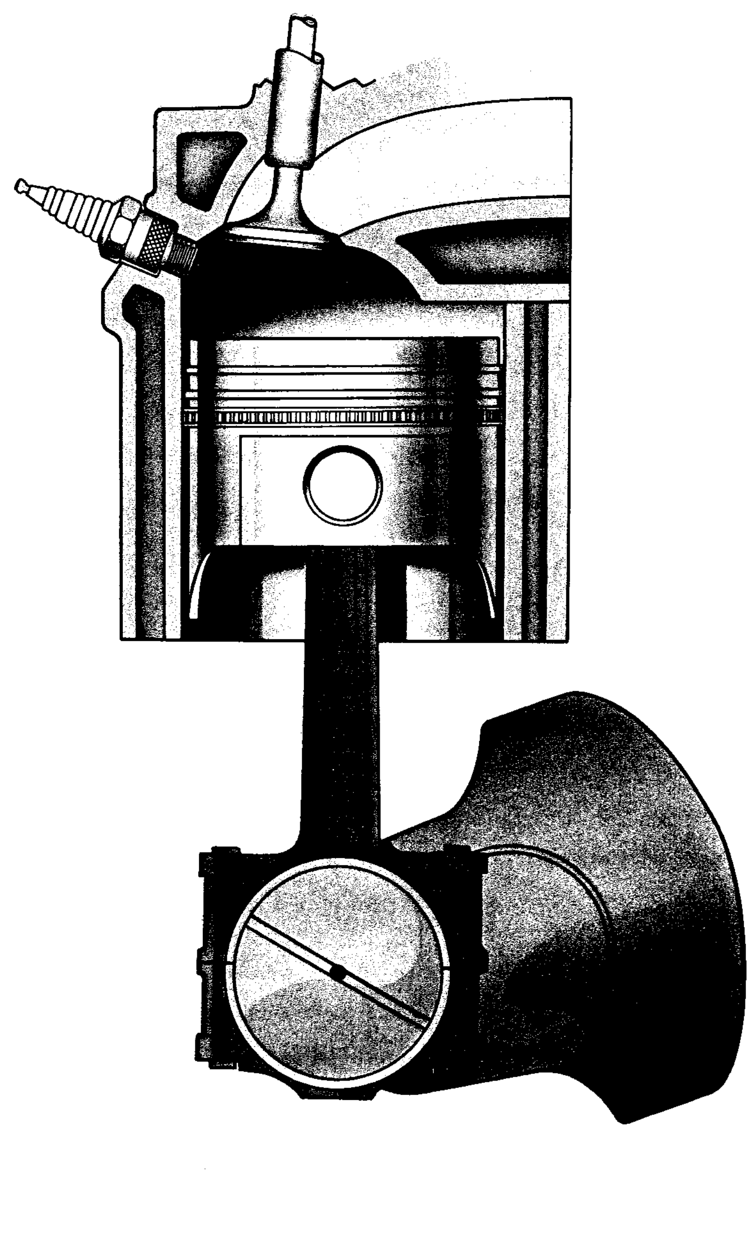
Detroit Diesel The Right Choice for Power Generation

For many years, customers in the power generation industry have faced the dilemma of selecting the proper engine for their application. Options have included both spark-ignited and compression ignition engines. Spark-ignited engines operate on liquid fuels, such as gasoline, or gaseous fuels, such as natural gas or propane. Compression ignition engines operate on fuel oil, although alternate fuels such as methanol are being developed.

How a Spark-Ignition Engine Works

Air is mixed with gasoline, natural gas or propane outside the cylinder, in the carburetor. The fuel vapor is drawn into the cylinder by the suction as the piston moves down. As the piston moves up, the mixture is then compressed to a ratio of from 7.5:1 to 10:1. Ignition is caused by a spark from the electrical system. The piston moves down on its power stroke, then forces burned gases out through the open exhaust valve as it moves up.

Typically, spark-ignited engines found in the power generation industry today are derived from automotive gasoline engines. These engines are designed to be "disposable" meaning they are expected to have a useful life of a predetermined number of miles or hours before they must be replaced. Major overhaul is not recommended as the engine cannot be returned to "like new" condition through the replacement of normally wearing parts.



SPARK IGNITION PRINCIPLE