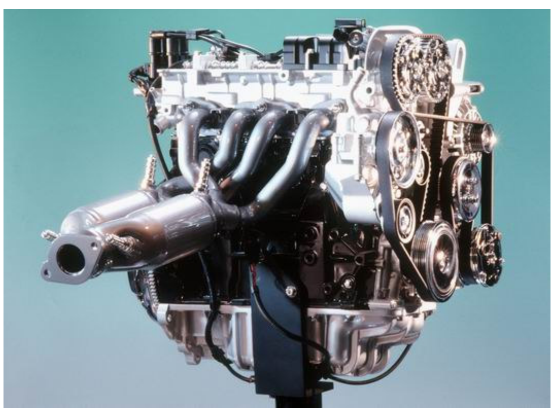
Ford Duratec 1.6 Ti-VCT

Four cylinders, 16 valves, two fully variable camshafts

In their pursuit of improving the automobile, developers have traditionally had their eye on ever stronger engines. Ever since internal combustion engines began powering vehicles nearly 120 years ago, generations of engineers have considered larger valves with longer opening durations as the "yellow brick road" towards their dreams of greater engine performance.

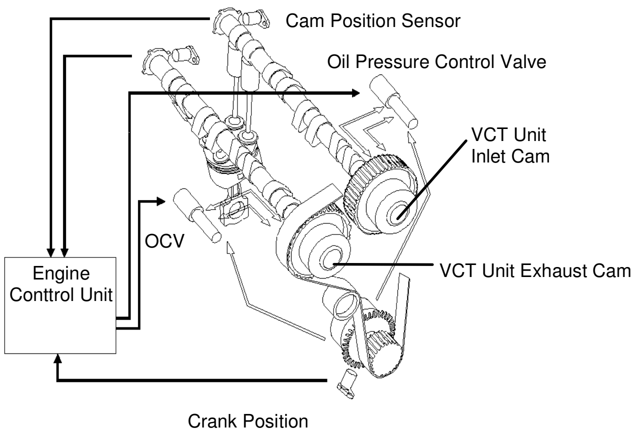
The internal combustion engine's 120 year development has been marked by this quest for additional power. Engineers mostly focused their attention on longer valve duration and increased overlap to achieve this. Racing engines were often the prototypes for later production engines. The traditional dominance of pure power increases has only taken a back seat to other developments in recent decades as exhaust technology and its numerous implications began to drive engine development. Racing technology has also by and large ceased to provide the model for production series development. Only now is the focus of vehicle engineers shifting back to power train technology emphasising driving dynamics and hence driving pleasure. Greater flexibility in valve timing promises to deliver a higher quality engine that is more fun to drive, without compromising on low exhaust emissions and good fuel economy.



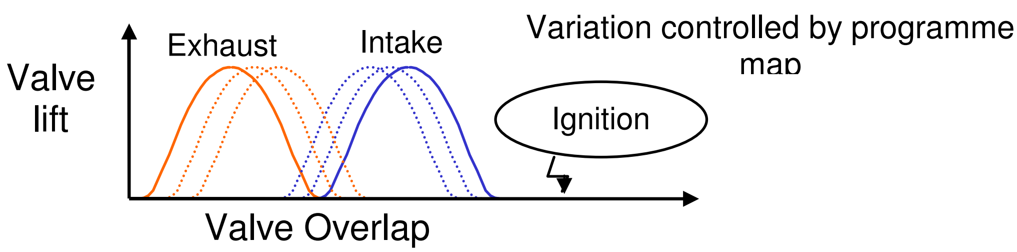
The Ford Duratec Ti-VCT engine uses a double-flow catalytic converter. All of the mechanical components of this modern variable cam timing system are located inside the wheels driving the double overhead camshaft.

At Ford, the road towards this type of progress is being paved by a new technology: fully variable valve timing, or Ti-VCT which is the engineers' abbreviation for "Twin independent Variable Cam Timing." Ti-VCT uses two camshafts controlled by continuously variable actuators. This is a second-generation system with hydraulic variation of the camshafts in the direction of rotation, helping change the duration of the valves' opening relative to the piston position.
A number of similar variable valve timing mechanisms have been used in past engine systems. These systems typically only offered a choice between two timing options: "early" or "late" – that is a choice between two positions of the camshafts.

Unlike previous systems, the hydraulically actuated positions of the camshafts are not limited to just "early" or "late". The Ford Duratec Ti-VCT system is map-controlled according to the required engine load; in other words according to the relationship between the position of accelerator pedal and engine speed. The system's ability to respond to a wide range of situations is a supported by measurement of 2000 parameters in various program maps, all of which have been carefully and continuously refined by Ford engineers during the course of the development project.



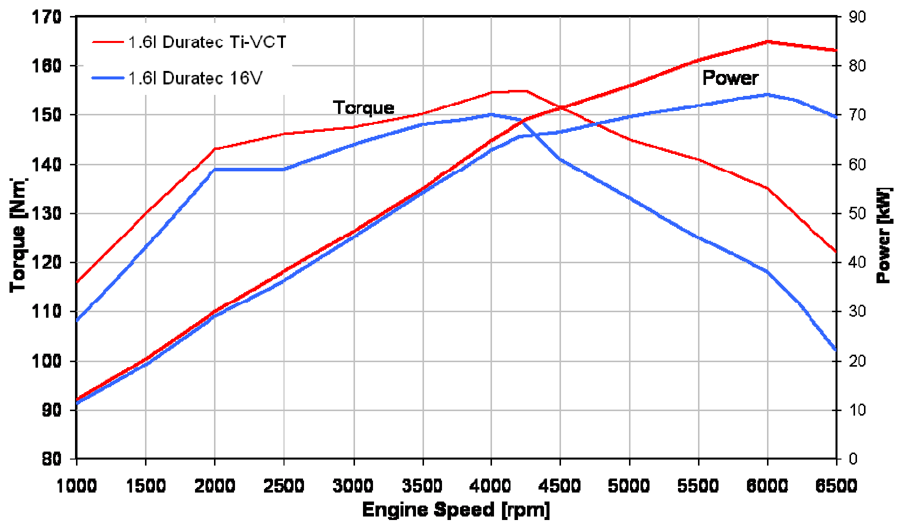
The characteristic trait of the Ford Duratec Ti-VCT system is its fully variable control of both camshafts, driven by the parameters



The novelty of Ford's approach is the application of this complex independent twin cam technology to a fuel-efficient 1.6-litre petrol engine. This engine had already undergone optimisation to achieve excellent fuel economy and low emissions of untreated exhaust gas. Fitting this unit with a map-controlled variable camshaft timing system significantly expands the engine's potential. The power delivered by Ford Duratec 1.6 L Ti-VCT has been increased by a respectable 15 hp over the original from 100 to 115 hp. Remarkable, as well, is the engine's peak torque development of 155 Nm. Impressive as these figures are, these power improvements were not the primary motivation for the new developments.

Variable control of both camshafts is performed by two vane-type rotors inside the wheels driving the camshafts. This control is based on a precisely defined programme map and powered exclusively by the engine's

The fact that the Duratec 1.6-litre DOHC engine develops its high torque levels across an unusually wide range of engine speeds is a true breakthrough. This can be seen in the fact that while the engine develops its peak torque of 155 Nm already at 4000 rpm, it already comes very close to doing so at 2000 rpm. For a naturally aspirated engine, the torque curve shows exceptional, plateau-like characteristics, rising quickly and then levelling out across a wide range of engine speeds in a way normally found only in more complex, turbo-charged engines.



Ford Duratec 1.6 Ti-VCT shows an impressive torque curve over a wide range of engine speeds.

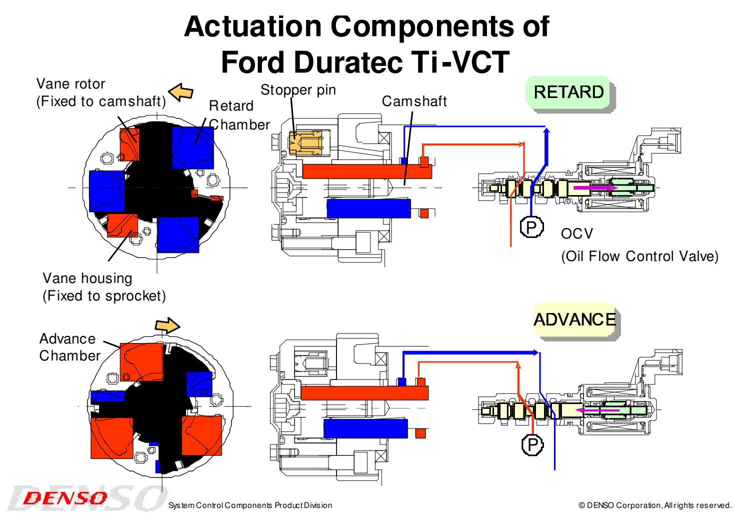
Engine Performance Indicator: Specific Mean Pressure

Specific mean pressure, p_{me}, is a particularly good factor for describing the performance of modern engines. It is determined by dividing maximum torque (expressed in Newton metres) by engine size (expressed in litres) and multiplying the quotient by the non-variable factor of 0.1279 ($p_{me} = Md_{max} / V_h \times 0.1279$). The result of this calculation represents the mean combustion pressure inside the cylinder in bar. Regardless of the size of the engine, this value provides a measure for the quality of the engine's torque. The Ford Duratec 1.6L **Ti-VCT**'s p_{me} of 12.4 bar is exceptionally high for a naturally aspirated engine. Moreover, the fact that this value shows only minor variations across wide ranges of the engine speed band is further proof of the unit's high quality. This factor, in and of itself, marks Duratec **Ti-VCT** as an effective and efficient engine, offering high levels of agility across a wide range of engine speeds.

Technological Basis

In essence, the fully variable valve timing system used by Ford Duratec Ti-VCT only requires three different elements. Two hydraulic control elements, so-called phase actuators, are located inside the wheels driving the camshafts. The effects of oil pressure and spring action enable these elements to vary the camshafts, according to engine speed and load range.

Two hydraulic, four-to-three-way-type valves serve as control elements. These assist in either retarding or advancing the valve timing. The hydraulic connection between the oil circuit and the variable camshaft control system is provided by a newly designed bearing support for the camshafts. This construction contains the ducts for the hydraulic control elements in addition to the usual oil ducts supplying the camshaft bearings. In the Ford Duratec system, these are "driven" exclusively by the respective operating oil pressure of the engine.



Two variable control elements drive the rotation of the vane-type phase actuator fixed to each camshaft. The variable control is performed, powered only by the operating oil pressure of the engine, distributed via two 4.3-way valves.

Basic Characteristics of Engineering Design

To understand better the way in which Ford's variable valve timing system works, it may be helpful to briefly review the conventionally known extremes of engine characteristics. Back in the nineteen-fifties and sixties, standard production engines typically used somewhat "restrained" valve timing, characterised by short duration and overlap. While this resulted in low engine output, it gave very stable idle speeds. This gives these old engines their characteristic feel of a lot of "muscle," always a surprise to someone driving one of these "oldies" for the first time today. A 1.6 litre engine of that time delivered 55 to 60 hp, then, was roughly half of that produced by a modern engine.

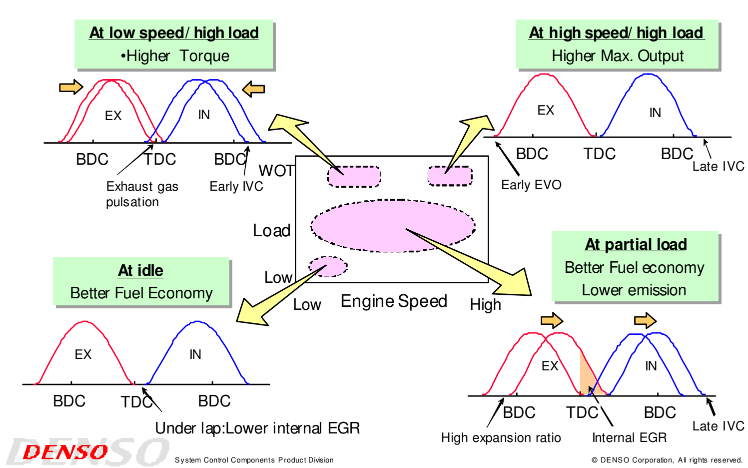
Engines dating back even further to the fifties even top this. They practically "pull the torque-rabbit out of their hat" at such low engine speeds that, by today's standards, comparing them with a locomotive may seem more appropriate than with an automobile. One of Ford's long term successes in those days was the legendary Model T, of which 16 million units were produced. The car developed 20 hp from 2890 cc of cubic capacity, delivered by the crankshaft (stroke: 101.5 mm, bore: 95 mm) with commensurate ease at roughly 1,800 rpm. This was enough, as the British auto magazine "Motor" observed in 1912, to accelerate the car from zero to 40 mph (65 kph) in roughly 40 seconds. The shortest gear of "Tin Lizzy's" planetary gear set had a speed range up to about 14 km/h and the vehicle itself was suitable for "carrying two tons of hay or pulling a plough across a farmer's field." No doubt, the motto, "nothing beats cubic capacity," dates back to those days.

The other valve timing extreme is typically found in racing engines. These fully exploit the power potential of the engine by using maximum valve lift and uncompromisingly long opening duration. Today, the Fiesta Cup racing version of Ford Fiesta's 1.6-litre performance engine delivers approximately 200 hp. However, this uncompromising output of power is reflected clearly by the engine's sound, particularly at idle speed. At idle, the engine rumbles strongly, showing its lack of smoothness. This characteristic is due to the engine's enormous valve durations and lifts, which do not allow an even distribution of cylinder charges and combustion. The rumbling sound at idle is the result of a compromise in tuning the engine, which has been optimised with a clear emphasis on delivering maximum power at 8,500 rpm. The remainder of the engine speed range was simply of no concern to the race engineers.

Variable cam timing, as used by the Ford system, now aims to combine the advantages of both extremes, without producing the disadvantages of either.

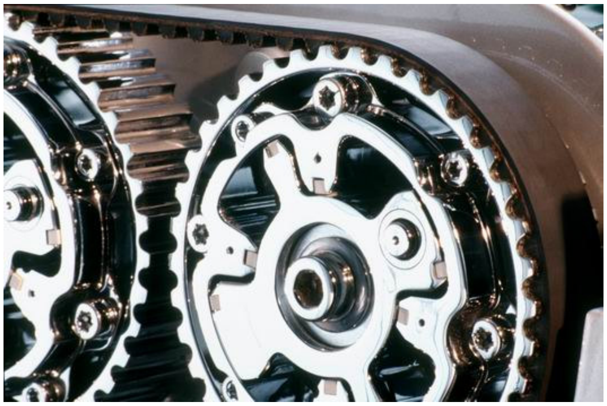
The Ford Duratec 1.6-litre Ti-VCT's fully variable valve timing expands the scope of advantages in both directions, without compromising on refinement, smoothness, power or performance. At near idle speed and in the lower load ranges, valve timing is such that the intake valves open and close relatively late. Instead of the usual overlap, during which intake and exhaust valves remain open at the same time, Ford Duratec even uses underlap, which means that both valves of a combustion chamber remain closed for a very brief time span. This results in stable idle as well as low exhaust emissions.
Load is the first factor that drives valve timing. In case of high loads at low engine speeds - for example, while the car is being accelerated without the driver bothering to shift down in time - both camshafts will change towards higher overlap. Suitable controls, particularly of the exhaust camshaft, produce an appropriate flushing effect of the combustion chamber, and the exiting exhaust gas draws fresh gas into the combustion chamber behind it. The result is a particularly good development of torque while maintaining good fuel economy.

Control Strategies for Ford Duratec Ti-VCT



In the medium engine speed and load range, timing is optimised to produce higher overlap. At idle and high engine speeds, these valve positions are avoided. Such sophisticated

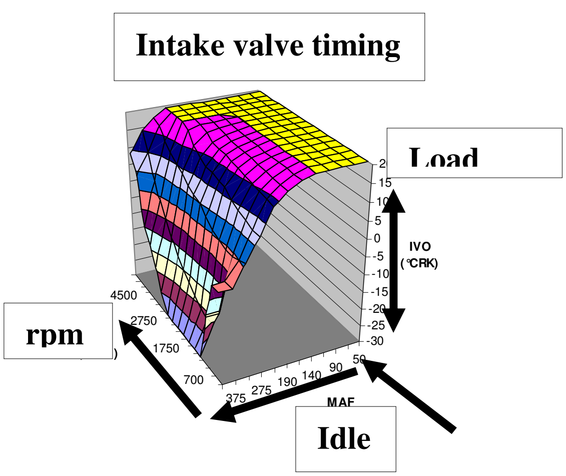
Particularly in the medium load range, both camshafts are gently retarded so that the valves open late. In this case, the engine management system carefully times the overlap so that it causes a certain amount of internal exhaust gas recirculation in the lower load range, which helps to reduce the nitrogen oxides in the exhaust gas typically generated under high loads.

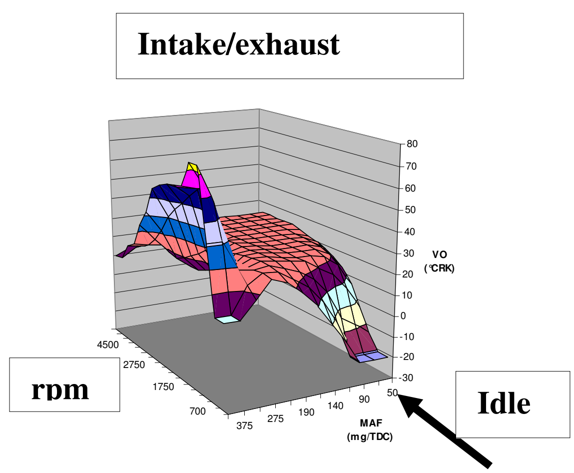


Many active valve timing systems previously used were only able to vary timing between early and late. With its Duratec Ti-VCT system, Ford is now using the first map-controlled variable cam timing system in smaller engines: high-tech for better fuel economy and higher torque.

Only as load and engine speed increase, is valve overlap gradually reduced. This is motivated by the physics of the pulsating gas column on the intake side. The intake system has been fine-tuned to produce a highly effective pulsating charge caused by the gas column vibrating heavily at high engine speeds. Without degrading the cylinder charge, it is thus possible to time the intake camshaft – similar to the process at idle – for late closing of the intake valve and minimum overlap, which minimises short circuiting between fresh gas and exhaust. Despite the fact that valve duration at 6,000 rpm is within the range of merely a few hundredths of a second, this allows the combustion chamber to be filled with a good charge nonetheless.

Ford Duratec Ti-VCT: Valve Timing Variation

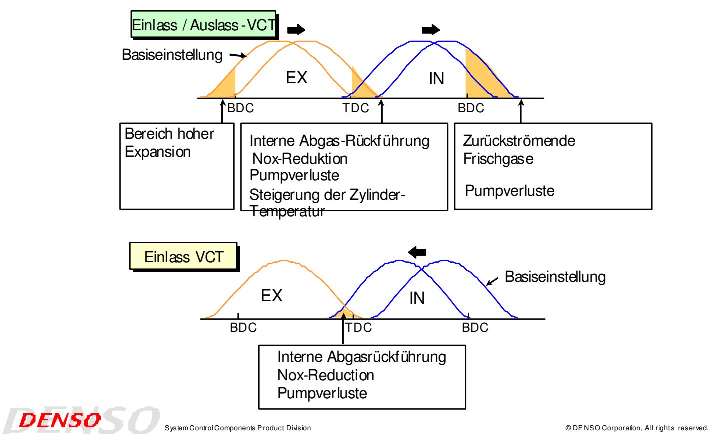




Characteristic of the timing map for the intake camshaft (left) is the fact that, starting at idle (lower right-hand corner), variable timing is passive up to just under 50 percent of the load (yellow field in diagram), then progressively moving towards advance, whereby extremely early intake opening occurs only in the lower engine speed range under full load. The right-hand diagram shows the overlap between both durations, characterised by an extensive range of

constant timing (orange field) at medium load and engine speed. Extremely large overlap occurs in the medium engine speed range and at full load, significant underlap only when the engine operates at near idle speeds.

Fuel Economy Improvement in the Medium Load Range



Ford Duratec Ti-VCT also allows fine control over effects which may degrade the cylinder charge. Exhaust gas recirculation caused by larger overlap reduces nitrogen-oxides and improves fuel economy.

In summary, the cylinder head of Ford Duratec **Ti-VCT** 1.6 L has been endowed with a few more capabilities than those possessed by engines with conventional valve timing. Despite staying below the peak values of power and torque typically delivered by engines with a greater cubic capacity, the improvements in available torque and power offered by Ford Duratec **Ti-VCT** 1.6 L make this modern engine highly attractive. The distribution of high torque levels across a wide range of engine speeds could make the driver feel that he or she is driving a car powered by a much larger engine. Together with its basic feel of considerable "muscle," the new Ford engine provides remarkably enhanced driving dynamics and, not to forget, about a five-percent improvement in fuel economy.

Postscript:
In the good old days of Ford’s Model T such qualities were not even pie in the sky. It took almost another century before such highly sophisticated features related to valve timing appeared on the horizon.
In 1912, Ford’s Model T had two tiny, lateral valves per cylinder positioned upside-down from today's perspective, each with a diameter of about 30 millimetres. Valve lift of 5 millimetres was minimal as well. Underlap, in other words, the phase during which both valves were firmly closed, was "one eighth of the rotation of the crankshaft", according to the garage manual published in 1912 – and this translates into 45 degrees to this day. As a piece of consolation: Fuel consumption was roughly 28.5 miles per gallon (10 litres per 100 km). When pulling a plough, however, according to sources from those days, consumption was a lot higher. A full tank (10 US. gallons, 38 litres) was said to roughly suffice for ploughing one hectare of land.

To compare, Ford’s Model T, which was apparently suitable for farming, the valve diameter (30 mm) and lift (5 mm) resulted in an open valve surface of 3.5 cm² per cylinder, opened across a total angle window of 225 degrees each, measured at the crankshaft.
As a four-valve engine, Ford Duratec Ti-VCT naturally opens up more available valve space, although, with 1.6 litres of displacement, it is a much smaller engine than its ancestor with its proud 2.89 litres. Above the 79-mm bore in the Duratec Ti-VCT engine, approximately 20 centimetres of free valve space is available, which opens across a time window of about 232 degrees. This surface alone is six times as large as that of the old Model T. It is remarkable that, in addition to its six times larger valve space, the nominal speed of the modern engine has sextupled as well. Ford Duratec 1.6 Ti-VCT, in a manner of speaking, has evolved by a factor of six. The fact that this evolution does not make the engine feel merely like a hot racing machine is attributable – among other factors – to its map-controlled variable cam timing.

However, unlike its ancestor, the Ford Duratec engine is no longer fit for farming. But in our day and age, Ford Motor Company’s product offering includes a large selection of much more suitable equipment for this purpose.

In the good old days of Ford’s Model T, engineers had not yet invented maximum engine speed. Instead, the engine’s large cubic capacity was fully exploited to develop torque: “Tin Lizzy” delivered impressive 20 hp at 1800 rpm from its 2.89-litre displacement, and the veteran’s maximum torque of 110 Nm at 900 rpm was not to be sneezed at either.

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