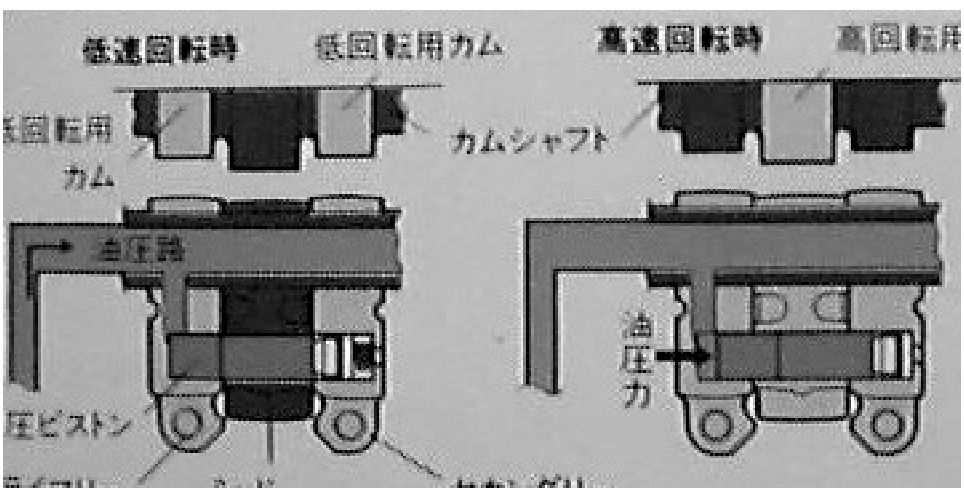
VTEC Explained

VTEC is one of Honda's greatest invention. Though an undisputed expert in
turbo-charging as evidenced by years of Formula-1 domination while Honda was active in the sport, Honda's engineers feels that turbo charging has disadvantages, primarily bad fuel economy, that made it not totally suitable for street use. At the same time, the advantages of working with smaller engines meant that smaller capacity engines with as high power output as possible (ie very high specific-output engines) are desirable for street engines.

Thus Honda invented VTEC which allows it to extract turbo level specific output from its engines without having to suffer from the disadvantages of turbocharging (though VTEC introduces disadvantages of its own).

The Basic VTEC Mechanism

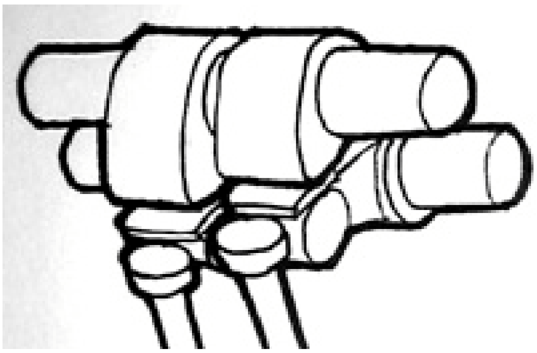
The basic mechanism used by the VTEC technology is a simple hydraulically actuated pin. This pin is hydraulically pushed horizontally to link up adjacent rocker arms. A spring mechanism is used to return the pin back to its original position.



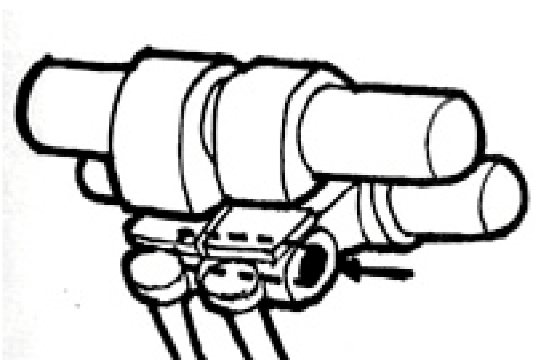
The VTEC mechanism is covered in great detail elsewhere so it is redundant to go through the entire mechanism here. Instead we will look at the basic operating principles which can be used in later sections to explain the various implementations VTEC by Honda.

To start on the basic principle, examine the simple diagram below. It comprises a camshaft with two cam-lobes side-by-side. These lobes drives two side-by-side valve rocker arms.

The two cam/rocker pairs operates independently of each other. One of the two cam-lobes are intentionally drawn to be different. The one on the left has a "wilder" profile, it will open its valve earlier, open it more, and close it later, compared to the one on the right. Under normal operation, each pair of cam-lobe/rocker-arm assembly will work independently of each other.



VTEC uses the pin actuation mechanism to link the mild-cam rocker arm to the wild-cam rocker arm. This effectively makes the two rocker arms operate as one. This "composite" rocker arm(s) now clearly follows the wild-cam profile of the left rocker arm. This in essence is the basic working principle of all of Honda's VTEC engines.

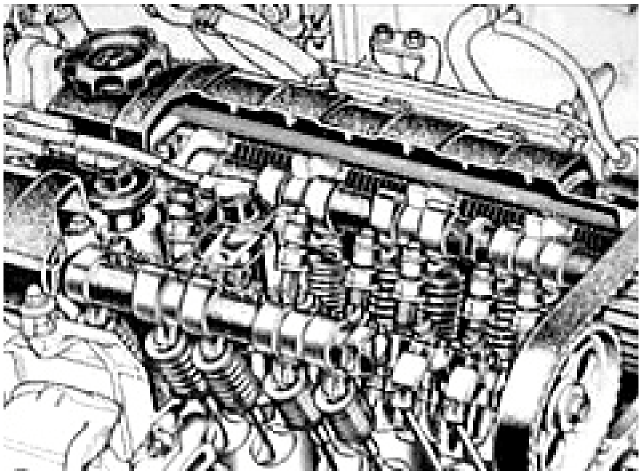


Currently, Honda have implemented VTEC in four different configurations. For the rest of this feature, we will examine these four different implementations of VTEC.

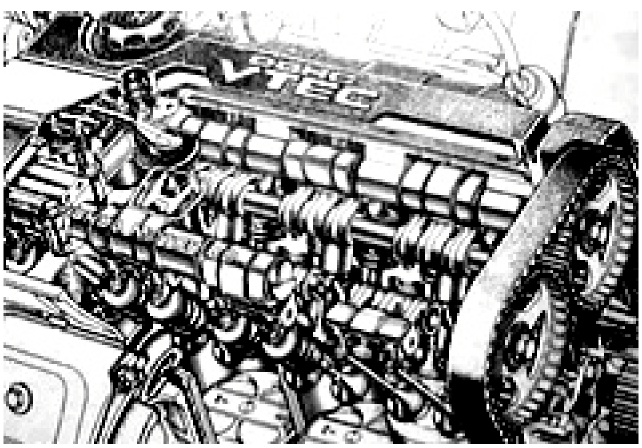
DOHC VTEC

The pinacle of VTEC implementation is the DOHC VTEC engine. The first engine to benefit from VTEC is the legendary B16A, a 1595cc inline-4 16Valve DOHC engine with VTEC producing 160ps and first appearing in 1989 in the JDM Honda Integra XSi and RSi.

Examine the diagram of a typical Honda DOHC PGM-Fi non-VTEC engine on the left, in this case the 1590cc ZC DOHC engine. Note that each pair of cam-lobe and their corresponding rocker arms though adjacent, are spaced apart from each other.



In the DOHC VTEC implementation, Honda put an extra cam/rocker in between each pair of intake and exhaust lobes/rockers. The three cam/rocker assemblies are now next to each other. The new middle lobe is the "wild" race-tuned cam-lobe. Using VTEC to link up all three rocker arms together, Honda is able to use either the mild or the wild cam-lobes at will.



Note : Though the ZC and B16A are well-suited to illustrate the difference between plain-DOHC and DOHC-VTEC, the B16A engine is not derived from ZC. In fact, ZC and B16A have different bore and stroke. The same applies for the B18A and B18C engines used in the JDM Integra series.

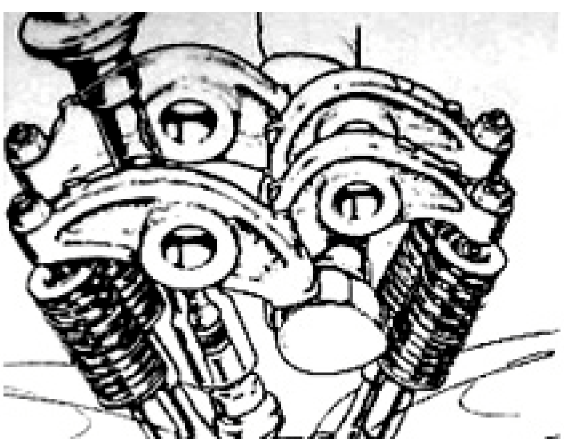
DOHC VTEC implementations can produce extremely high specific outputs. The B16A for standard street use first produced 160ps and now 170ps. In the super-tuned B16B implementation used for the new JDM EK-series Honda Civic Type-R, 185ps was produced from the same 1595cc.

DOHC VTEC can also easily offer competitive power outputs to turbo-charged engines for normal street use. For eg, the E-DC2 Integra Si-VTEC produces 180ps from the 1797cc DOHC VTEC B18C engine. This compares favorably to the 1.8l version of the RPS-13 Nissan 180SX which uses a 1.8l DOHC Turbo-Intercooled engine which produced 175ps.

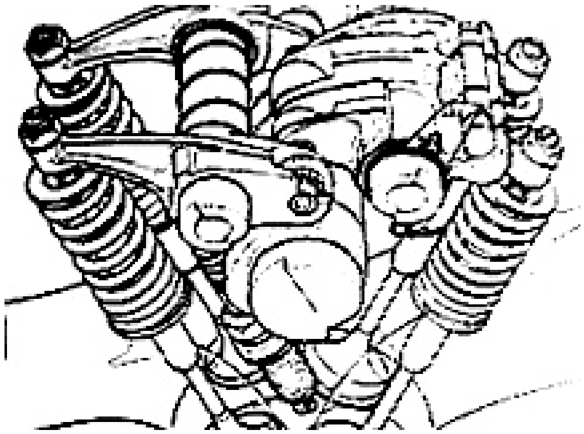
SOHC VTEC

An alternative implementation of VTEC for high (versus very high) specific output is used in Honda's SOHC engines. SOHC VTEC engines have often been mistakenly taken as a 'poor' second-rate derivative of DOHC VTEC but this is not the true case. An SOHC engine head has advantages of a DOHC head mostly in terms of size (it is narrower) and weight. For more sedate requirements, an SOHC engine is preferable to the DOHC engine. SOHC VTEC is a power implementation of VTEC for SOHC engines with the express intention of extracting high specific output.

Examine the diagram of a standard SOHC cam assembly on the below. Note that the pair of intake rocker arms are separated but adjacent to each other.

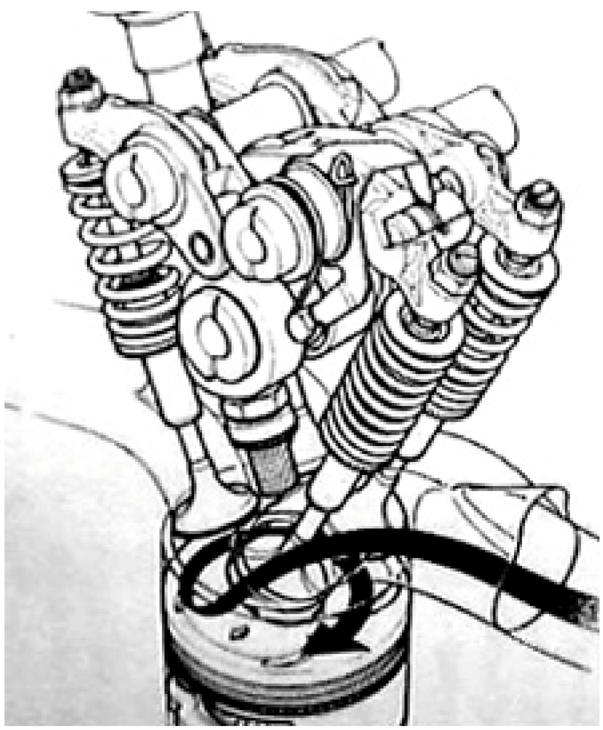


In the SOHC VTEC implementation (diagram on the below), Honda put a wild-cam lobe for the intake valves in the space between the two rocker arms.



Note that the two exhaust rocker arms are separated by the two intake rocker arms and the "tunnel" for the sparkplug cable connector. This is the reason why Honda implemented VTEC on the intake valves only.

SOHC VTEC engines are high specific output forms of the standard SOHC engines. The D15B engine used in the Civic/Civic Ferio VTi models (EG-series 1991 to 1995) gives 130ps from a 1493cc capacity. Bear in mind this kind of power levels are normally associated with 1.6l DOHC or even milder-tuned 1.8l DOHC fuel-injected engines !



VTEC-E

A novel implementation of VTEC in SOHC engines is the VTEC-E implementation (E for Economy). VTEC-E uses the principle of swirling to promote more efficient air-and-fuel mixing in the engine chambers. VTEC-E works by deactivating one intake valve. Examine the diagram below.

In the SOHC VTEC-E implementation, only one intake cam-lobe is implemented on the camshaft. Actually it is really a flat "ring". In operation this means the relevant rocker arm will not be activated causing the engine to effectively work in 12-valve mode. This promotes a swirl action during the intake cycle. VTEC is used to activate the inactive valve, making the engine work in 16-valve mode in more demanding and higher rpm conditions. Honda was able to implement air-fuel mixture ratios of more than 20:1 in VTEC-E during the 12-valve operating mode. The SOHC VTEC-E engine EG-series Civic ETi is able to return fuel consumptions of as good as 20km/litre or better!!

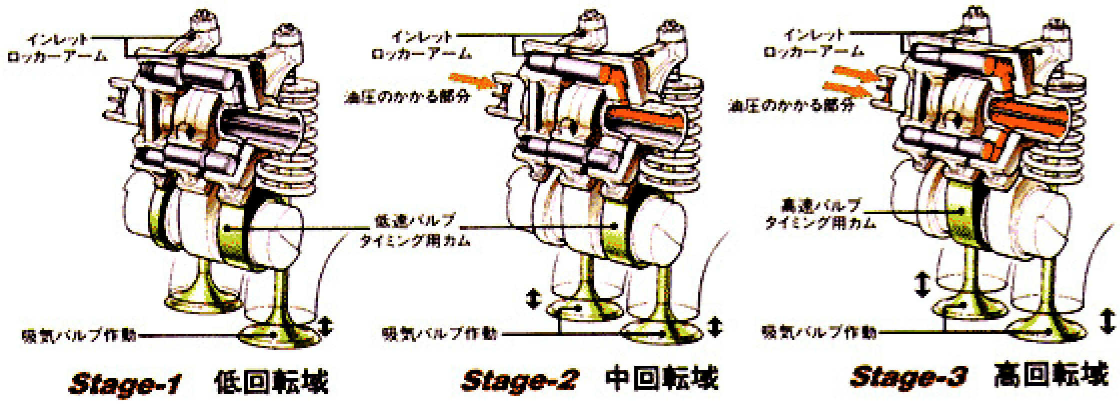
SOHC VTEC implemented for power is often mistaken as SOHC VTEC-E which is implemented for economy. It is worthwhile to note that the 1.5l SOHC VTEC-E used in the JDM Honda Civic ETi produces 92ps. This is in fact less than that produced by the standard 1.5l SOHC engine's 100ps which uses dual Keihin side-draft carburetors. SOHC VTEC in the D15B produces 130ps. This is 30% more than the standard SOHC implementation !

3-stage VTEC

Examine the SOHC VTEC and SOHC VTEC-E implementations. The clever Honda engineers saw that it is a logical step to merge the two implementations into one. This is in essence the 3-stage VTEC implementation. 3-stage VTEC is implemented on the D15B 1.5l SOHC engine in which the VTEC-E mechanism is combined with the power VTEC mechanism.

Many of us probably has laughed at the poor ignorant layman who said "I want power AND economy from my Honda". We know of course that power and economy are mutually exclusive implementations. Honda decided not to abide by this rule. Now, with 3-stage VTEC, we get BOTH power and economy !.

The diagram below illustrates the 3-stage VTEC implementation. The intake rocker arms have two VTEC pin actuation mechanisms. The VTEC-E actuation assembly is located above the camshaft while the VTEC (power) actuation assembly is the standard wild-cam lobe and rocker assembly.



Below 2500rpm and with gentle accelerator pressure, neither pin gets actuated. The engine operates in 12V mode with very good fuel combustion efficiency. When the right foot gets more urgent and/or above 2500rpm, the upper pin gets actuated. This is the VTEC-E mechanism at work and the engine effectively enters into the '2nd stage'. Now D15B 3-stage works in 16V mode (both intake valves works from the same mild cam-lobe).

Stage 2 operates from around 2500rpm to 6000rpm. When the rpm exceeds 6000rpm, the VTEC mechanism activates the wild cam-lobe pushing the engine into the '3rd stage', the power stage. Now the engine gives us the full benefit of its 130ps potential !

The 3-stage VTEC D15B engine is used on the current EK-series JDM Civic/Civic Ferio VTi/Vi together with Honda's new Multimatic CVT transmission. Stage-1 12V or "lean-burn" operation mode is indicated to the driver by an LED on the dashboard. The 2500rpm cutover from lean-burn to normal 16V operation in fact varies according to load and driver requirements. With gentle driving, lean-burn can operate up to 3000rpm or higher. Stage-3 may not always be activated. The Multimatic transmission has a selector for Economy, Drive, and Sports mode. In Economy mode for eg, the ECU operates with a max rpm of around 4800rpm even at Wide-Open-Throttle positions.

The essence of 3-stage VTEC is power AND economy implemented on a 1.5l SOHC PGM-Fi engine. Many people mistakes 3-stage VTEC as a "superior" evolution of the power oriented DOHC VTEC implementation, describing DOHC

VTEC as "the older 2-stage VTEC" and implying an inferior relationship. This is totally wrong because DOHC VTEC is tuned purely for high specific output and sports/racing requirements. 3-stage VTEC is in truth an evolution of SOHC VTEC and VTEC-E, merging the two implementations into one.

Implementations of VTEC in Honda models

DOHC VTEC is the implementation producing the highest-powered engines and used in the highest performing models in the Honda line-up. The smallest DOHC VTEC engine is the legendary B16A. A 1595cc 160-170ps engine that first appeared in the 1989 Honda Integra XSi and RSi, it now powers the famous Civic SiR models. The B16B is a special hand-tuned super high output derivative of the B16A giving 185ps and used in the Civic Type-R.

The B18C is a 180ps 1797cc engine that appears in the high performance Integra line-up. The B18CSpec96 is a special hand-tuned super high output version of the B18C giving 200ps and used in the legendary Integra Type-R.

DOHC VTEC implementations now appear in most of Honda's great line-up. The Accord SiR used to have a de-tuned 190s H22A 2.2l DOHC VTEC which was also used on the same period Prelude Si-VTEC in which it gave 200ps. The current Accord line now has a 2.0l DOHC VTEC engine that gives 180ps and 200ps in the Accord SiR and SiR-T models respectively while the current Prelude SiR still uses the H22A 2.2l DOHC VTEC engine giving 200ps. A special hand-tuned version of H22A is used in the Prelude Type-S and gives 220ps.

The highest level of DOHC VTEC implementation is of course in the NSX. Implemented V6 DOHC VTEC, originally in 3.0l and now in a larger 3.2l form, it tops the 280ps "legal" limit imposed by the Japanese government for stock street cars.

SOHC VTEC appears in more guises in the Honda line-up. The smallest SOHC VTEC engine is the D15B, used on Civic and Civic Ferio VTi/Vi models in Japan. The D16A 1590cc SOHC VTEC (power) engine giving 130ps is also used on the Civic Coupe and the Civic Ferio EXi (a 4WD model). SOHC VTEC also appears on the Accord models but not the Integra or Prelude line-up. In fact in markets which Honda considers not sufficiently advanced to warrant the DOHC VTEC engines (Malaysia being one of them), Honda markets SOHC VTEC as the top engine for their line-up.

VTEC Explained

VTEC Information

Read the definitions first!
Volumetric Efficiency, Torque, Power, The Camshaft, Engine Breathing, ECU

VTEC

VTEC uses two camshaft profiles, one will lower duration for good low speed torque, and one with longer duration and valve lift for good high speed torque. The computer switches camshafts at about half engine speed to combine the best features of each camshaft. Sounds simple! The resulting torque curve is M shaped - it has a torque peak for the low speed camshaft (at about 3500 rpm in my car) and a torque peak for the high speed camshaft (at about 7000 for my engine). The part of the torque curve in between the low and high speed camshaft peaks, has a torque dip because the low speed camshaft torque is dropping off and the high speed camshaft torque is picking up. When the camshafts switch, you are actually at the lowest point of engine torque from about 2000 - 8000 rpm! I avoid this engine speed and try to keep the engine at the low speed camshaft torque peak (for normal driving) or the high speed camshaft torque peak (for getting somewhere fast).

The Non-VTEC Arrangement

The DOHC (non-VTEC) engine camshafts have one cam lobe (the oval shaped part that opens the valves) per valve. The cam lobe is above a short rocker arm, which is fixed at one end and sits on top of the valve at the other end. Some engines have the cam lobe directly in contact with the valve head, but Honda did not do it this way so that they could get more valve lift, and open the valve quicker. Using a rocker made the valve train heavier, which uses more power and limits engine speed, so Honda hollowed out the cam lobes (as well as the camshaft) to save weight.

The VTEC Arrangement

The VTEC head looks similar to the DOHC head. There is a small rocker arm for each valve, and the camshaft is positioned above this about half way along it. The difference is that there are three cam lobes for each set of two valves (two intake or exhaust for each cylinder). When using the low speed camshaft, the outer two cam lobes press on the rockers and open the valves in much the same way as the DOHC head. The third cam lobe (which is in the middle) just follows the cam lobe profile without doing anything else.

Switching Camshafts

When the computer decides to switch camshafts, it closes a valve that forces oil along passageways through the camshaft into the third rocker. It has little pistons which are forced outwards (I'm a bit fuzzy here, but I think this is right) into the outer two rockers. All three rockers are then locked together and operate as one. The middle cam lobe has more lift than the outer two so it then controls the lift and duration of the set of valves. When switching back to the low speed cam the ECU just opens the valve, lets the oil out of the rockers, the pistons unlock the rockers and everything operates as before.

When to Switch Camshafts

The ECU is constantly comparing the torque curves of the low and high speed camshafts. It calculates the expected volumetric efficiency of the engine based on the current environmental conditions (air temperature and pressure) and the engine conditions (temperature, engine load, throttle position), and then derives the expected torque from the volumetric efficiency for each camshaft. Most of this has to be done anyhow in order to determine how much fuel to inject.

When conditions are right (the revs are over about 4500 rpm, the engine is warm, there is enough oil pressure to activate the pistons and the car is moving) the ECU will switch from the low to high speed camshaft when the expected torque of the low speed camshaft equals the torque of the high speed camshaft. The ECU closes a solenoid valve that then forces engine oil, under pressure, along the camshafts to active the third rocker arm.

VTEC Controllers

A few people have asked what VTEC controllers are, and how they affect the engine. A VTEC controller is basically just a RPM activated switch that connects to the VTEC control valve and switches cams at a pre-determined engine speed, rather than letting the ECU figure things out. I have reverse engineered a commercial VTEC controller to see how one works, and found that they also look at the oil pressure and water temperature sensors like the ECU normally does, so that the cams are not switched if something is wrong. I have heard of people using an off the shaft rpm switch as a VTEC controller.

VTEC controllers are useful if the engine has been modified, and the ECU switches cams too early/too late, and for certain engines where Honda has got the cam switch point wrong. The only example of this that I know is the VTEC prelude, which has a huge jump in the torque curve because the cams are switched too late. Rumour has it that Honda did this deliberately to get a good EPA gas mileage, but there definitely are benefits from getting the prelude to switch cams earlier.

With the stock B16 engine this is little to be gained from changing the cam switch point - the ECU does a much better job than a VTEC controller because it can compare the torque curves of each cam and switch where they overlap. If you need a VTEC controller then it will be evident from a jump (up or down) in the torque curve when the cams switch. This may be difficult to judge even from a dyno because the cams should switch at different speeds with different engine loads, but a dyno print out would be the way to check.

Definitions:

Volumetric Efficiency

The engine produces a certain force from every power stroke as a result of burning air/fuel expanding. This force generally gets less for every power stroke as the engine revolves faster, as the air/fuel mixture has less time to get sucked into the cylinder. The volumetric efficiency of a engine at a certain speed is the pressure of air/fuel mixture inside the cylinder when the piston has finished sucking in the mixture, as a percentage of the atmospheric pressure. Thus an engine with 80% volumetric efficiency at a certain speed will have a mixture pressure of 80% of atmospheric pressure when the piston is at bottom dead centre after the intake stroke.

Torque

The torque of an engine is the total force the engine produces at a certain speed. This is a rotating force, but the easiest way to think of torque is to imagine an engine with a drum attached to it, winching up a weight vertically. The torque of the engine is the force that raises the weight.
The torque of an engine will increase as the engine rotates faster, because the number of power strokes per time period increases. However, the volumetric efficiency of an engine will drop after a certain speed, so each power stroke has less force. The point where the increase in force (from the increased number of power strokes) is equal to the drop in force (because of less efficiency) is the point of peak torque. This occurs anywhere from 2000 - 7000 rpm, depending on the engine.

A higher performance engine will generally have a higher efficiency and maintain this longer, so will have peak torque at higher revs. In the case of my B16A VTEC engine, the torque peak is at about 7000 rpm, which is one of the highest of any mass produced vehicle engine.

Power

The gearbox modifies torque from the engine to torque at the wheels. If one engine produces the same torque as another, but at a higher engine speed, then force at the wheels will be higher for the first engine one the engine speed is converted by the gearbox to the same wheel speed. The power of an engine is the measurement of the torque of an engine at different engine speeds. Going back to our engine winching analogy, it is easy to see that if the engine is geared down so that the drum rotates half as fast, then weight will be raised slower be more weight can be lifted.

The peak power point for an engine is the point where, ideally geared, the most force will be available at the wheels. The peak power point will always be above the peak torque point. In my B16A engine, the peak power occurs at about 7800 rpm.

More Volumetric Efficiency

The volumetric efficiency of an engine is largely determined by the engine's ability to suck in fuel/air mixture and expel the exhaust gas. An engine with small openings, tight corners and constricting passages either in the inlet or outlet flow paths will not be able to suck in mixture or expel exhaust as well as an engine with larger openings, and so will have less volumetric efficiency and therefore less torque.

The mixture being sucked into the engine has mass and therefore momentum. Once the inlet valves shut, the mixture will keep moving for a while and compress the mixture in front in it, eventually stopping. If the inlet value opens again just as the mixture has stopped moving, then the mixture will be forced into the cylinder. This will increase the volumetric efficiency of the engine (more mixture = more power from the power stroke = more torque etc.). Some engines can achieve over 100% efficiency using this effect.

The same applies to the exhaust. The gas will leave the cylinder under pressure, move into the exhaust system and expand. Once the exhaust valve closes, then the gas will keep moving and cause a slight vacuum next the exhaust value. Next time the exhaust value opens, the exhaust will be sucked out of the cylinder. With four exhausts going into the same pipe, a further effect is created where the moving exhaust gas from the last power stroke will suck out the exhaust gas from a different cylinder.

Why not make all these openings as big as possible? If (say) the inlet path into the cylinder is made bigger, then the gas velocity will be lower for the same gas mass . Lower velocity = less momentum = less pressure forcing the mixture in = lower efficiency = less torque = less power. Same applies to the exhaust, but it is not as sensitive as the intake path. With only one intake or exhaust valve per cylinder there is only so much mixture/exhaust that can flow through the opening, so two valves doing the same job allow more mixture/exhaust to flow and therefore increase efficiency. This is most noticeable at high engine speeds which is why four valve heads have a reputation for having more power at higher engine speeds.

The Camshaft

The camshaft has a very big influence on engine breathing. The camshaft controls how long the intake and exhaust valves are open, and how high they open. The intake valves always open before the piston is at the top of the cylinder (and started sucking) and close after the piston is at the bottom of the cylinder (and stopped sucking). The shape of the cam lobes limits the valve opening and closing to a gradual opening from closed to fully open, then a gradual closing to fully shut. (Otherwise the value train will destroy itself at high speeds) So while the value opens before the cylinder is sucking, it is not open that much.

There is a trade off in terms of efficiency with the camshaft. It is possible to open the values earlier, and have the valve open further for a longer period while the engine is sucking in mixture (it works the same for the exhaust). The valve will be open before the piston has reached the top of the cylinder, and some of the mixture will be pushed out of the cylinder but the piston. Because of the momentum effect of the intake mixture, this loss is less at higher revs, and more at lower speeds, when the intake mixture has not much momentum to overcome mixture being forced out of the cylinder.

A camshaft that opens the values early and closes them late (called long duration, or 'wild' or 'lumpy') will be more efficient at higher engine speeds and less efficient at lower engine speeds. A camshaft that opens later and closes earlier (called short duration, or 'mild') will be more efficient at lower engine speeds and less efficient at higher engine speeds.

Engine Breathing

To get more power you can sacrifice low speed torque (and have an engine that is difficult to drive around town in) for high speed torque (and more power) by altering one or more of the components that affect engine breathing. The trick is to know what will give the best high speed gain for the least low speed loss. Honda has tuned the size of all the components and the camshaft profile to get the best possible compromise between low speed torque and high speed torque of the engine (I think that they do a pretty good job of this).

There are many other factors that influence the power that an engine produces, such as internal friction, rotating and reciprocating mass, arrangement of various components, which I have skipped over for simplicity.

ECU

The ECU (electronic control unit = the fuel injection computer) is the heart of the engine. Basically the purpose of the ECU is to control fuel injection and ignition for the engine, for all the conditions which the engine can be expected to run under. This is a fairly complicated job considering the number of external factors that can influence the amount of fuel that needs to be injected into the engine, and the rate at which events happen. At 8500 rpm the ECU has to control 280 injector openings/closing per second and 280 ignition signals per second, while coping with 2400 signals from the distributor per second. Plus there are another 16-odd signals and sensor reading from the engine and outside world that ECU needs to know about. It is expected to do this flawlessly, under conditions that the designers may not have anticipated, for the lifetime of the car without servicing. It does this fairly well, the only common problems are from external components failing (e.g. the distributor bearing failing and destroying the sensors) or from 'user mis-use' (e.g. getting an air pocket in the cooling system and feeding the water temperate sensor an incorrect reading).