Ignition Timing & Knock Control

Concepts

Ignition

> For more information on how fuel is delivered, see our documentation page on Fueling & Injection

Ignition, Flame, and Degrees BTDC

Gasoline engines operate on the principle of fuel combustion. Typically in a direct injection system, first, fuel is directly injected into a cylinder some time before the spark is ignited. Additionally, it is compressed during the compression stroke as the piston travels upwards towards top dead center (TDC). Relative to the top dead center position, and with its timing precisely controlled by the tuner's map, the spark plug is electrically ignited by a signal sent from the ECU to start the process of combustion.

Once combustion is started ideally with the spark plug, a flame front propagates evenly throughout the cylinder at a specific speed relative to factors such as the fuel sprayed and the air-fuel ratio. Due to the flame's propagation speed and a goal of complete combustion, the ignition of the spark plug should be timed early enough in the piston's movement that the flame can fully propagate within the available time window up to the end of the exhaust stroke, helping to ensure that the air-fuel mixture is entirely combusted before the gasses are exhausted. Additionally, the timing of the flame propagation can be precisely controlled by the spark's timing to exact an idealized amount of force on the piston as it travels downwards during the power stroke, encouraging efficient energy extraction from the fuel-air mixture.

To control this ignition timing, the ECU has a series of maps that define when the ignition spark should take place relative to the top dead center position of the piston as it ends the compression stroke. Typically, and in the Subaru DI logic, this timing is measured in degrees before the top dead center position, or BTDC. In this case, the degrees in the measurement relates to the degrees of crankshaft rotation of the engine, with a 4 stroke engine (such as the FA24) taking two full revolutions (or 720 degrees) for all 4 strokes to take place. Here is a reference of BTDC values and the timing they are associated with relative to cylinder events:

Degrees Before Top Dead Center (BTDC)	Relative to TDC	Event
`180.00°`	Before	End of intake stroke, beginning of compression stroke.
`90.00°`	Before	Half-way through compression stroke, piston travels upwards towards the valves.
`0.00°`	TDC	Top dead center, power stroke begins.
`-90.00°`	After	Half-way through power stroke, piston travels downwards towards the crank-shaft.
`-180.00°`	After	End of power stroke, beginning of exhaust stroke.

Detonation (or "Knock")

Detonation and Pre-detonation

In the ideal scenario, the ignition of the air-fuel mixture in a cylinder will result in a single, evenly propagating flame front that expands outward from the spark plug at a predictable and controlled rate of expansion. This controlled expansion of the flame front results in a linear, even pressure across the cylinder walls and the piston's surface. However, it is unfortunately possible for the air-fuel mixture to spontaneously ignite in various conditions, causing one or more flame fronts to propagate throughout the cylinder's volume in an uncontrolled manner.

This spontaneous ignition of the air-fuel mixture is referred to as **detonation** due to the (sometimes audible) sound that is produced by multiple flame fronts colliding with each-other and creating extremely high pressure spikes inside the cylinder. Due to this sound, detonation is sometimes referred to as *knock;* not to be confused with *rod knock*, which is an entirely different phenomenon. These collisions can directly cause damage to the cylinder walls, valves, head surface, and piston surface.

Pre-detonation is similar to detonation, but occurs *before* the spark ignites the air-fuel mixture, as opposed to detonation which occurs at some point *after* the spark ignites the air-fuel mixture.

In either case, the unpredictable pressures generated by any form of detonation can exact chaotic forces on the piston surface, suddenly forcing its connecting rod into the crankshaft, possibly

damaging the [rod bearing](). This is especially true for pre-detonation, where the spontaneous ignition can occur as the piston is completing its upwards travel to complete the compression stroke, violently interrupting the piston's only available direction of travel in possibly its most *critically* pressurized moment.

Detonation and pre-detonation can be caused by several factors, often compounding together simultaneously:

1. Faulty spark plugs or fuel injectors.
2. An air-fuel mixture that is too lean or too rich for proper combustion with cylinder conditions.
3. Low [fuel octane](), the measurable capability of a fuel to resist detonation. Fuels such as 93 or E85 have a higher octane rating than perhaps 87 or 91, but it is possible for fuel to lose octane after sitting for a long period of time. Fuel octane can be affected by any contaminants such as oil or coolant mixing with the air and fuel in a cylinder.
4. An ignition timing value that is too advanced (earlier in time).
5. A [compression ratio]() incompatible with cylinder conditions and the commanded ignition timing. Compression ratios can be increased by carbon deposits (buildup) inside a cylinder.
6. Excessive temperatures inside the cylinder, including air temperature and hot spots within the cylinder surfaces. Carbon deposits can also be sources of these hot spots.

Subaru Knock Control

Introduction

Mitigation

As detonation and pre-detonation can be dangerous events, entirely eliminating all forms of detonation (or "knock") is an extremely important goal of any gasoline ignition strategy. By reducing (also referred to as retarding or pulling) the base ignition timing *later* in the engine cycle or by modifying the air-fuel ratio, it is possible for an ECU to significantly mitigate detonation events. While pre-detonation can be mitigated this way as well, it is likely that additional factors are involved if it is occurring.

Unfortunately, delaying the ignition timing implies that torque would likely be lost due to the decreased mechanical advantage imparted by the piston on the crankshaft from the flame front's delayed propagation. However, this is a valuable trade-off, as an engine won't be making *any* torque (or, at best, significantly less) if severe detonation event(s) occur and cause damage to cylinders or other engine components.

Why Pull Timing?

It is important to note that if we are reducing (pulling back) ignition timing, we are effectively delaying (or retarding) the spark event's occurrence in time relative to the engine's cycle. This has

effects that help mitigate detonation, with one primary advantage being that we are allowing for more time for [entropy](#) to do its job and to enabling the air and fuel to mix within the volume of the cylinder.

Additionally, the environment within the cylinder becomes less favorable for detonation as the piston moves past its top dead center (0 degrees BTDC) and travels downward in the power stroke. This downward motion has the important effect of increasing the cylinder [volume](#), which correspondingly decreases the air-fuel mixture's [density](#) as the valves remain during the power stroke. This reduction of density reduces the cylinder's pressure and temperature, both highly advantageous effects to mitigate detonation.

Sensors

Knock Sensors

On the Subaru FA platform, two [piezoelectric sensors](#) called [knock sensors](#) are bolted directly onto the factory [short block](#). With both positioned in the rear of the [crankcase](#), nearest the [bell housing](#), each sensor is allocated to a [cylinder bank](#). As Subaru engines utilize the [boxer engine](#) layout, this means that the knock sensors are assigned to each case half, with the left sensor corresponding to cylinders #3 and #1, and the right sensor corresponding to cylinders #4 and #2.

Acting as microphones, the knock sensors perceive vibrations propagating throughout the block in a similar manner a traditional microphone would record pressure waves in open air. By filtering and analyzing the signal received and restricting the recording time window to the firing cylinder's ignition time window, the ECU can take advantage of these sensors to approximate an extremely important feedback on the occurrence detonation, which itself is a noisy (and sometimes even audible) event.

Mitigation Stategies

Introduction

The Subaru factory logic, including that of the DI models such as the FA20 and FA24, utilize three distinct methods to manage detonation (or "knock") in its ignition timing system. Each relies on the principle of reducing (or pulling) ignition timing. All three systems are permanently active and each can affect the ignition timing directly at any point in time if necessary.

Feedback Knock (FBK)

Feedback Knock is the component of the OEM strategy responsible for the **short-term** component of detonation mitigation. The ECU leverages the knock sensors to continuously analyze and perceive suspected detonation events in the form of recorded audio events in real-time. Once the intensity of an event exceeds a threshold defined in the table group **Knock Control - Threshold**, a binary signal is generated that indicates the presence of ongoing detonation.

The **Feedback Knock** value will be decremented according to a magnitude corresponding to a calibration value. As the detonation event is mitigated or is resolved, the Feedback Knock value will return to a value of 0.0. Greater values seen from the Feedback Knock parameter are indicative of a more significant detonation event. Steadily or sharply increasing values are indicative of an event requiring more negative timing to mitigate, while small (-1.41, etc.) values that do not increase are indicative of possible noise or a much shorter event.

The value of the Feedback Knock parameter is directly used as a **subtraction** from the **final ignition timing**. It is always active. In this way, the Feedback Knock is effectively able to respond quickly to transient detonation events for future cylinder firing events, but has the disadvantage of not being capable of preventing the first events that trigger it. This is, of course, due to the fact that it relies on these events occurring to react in the first place, even if it may be quick to mitigate them.

When troubleshooting the Feedback Knock parameter demonstrating timing subtractions for a possible tune modification, it is important to classify the problem by analyzing the overall event and the engine conditions during it. For example, was the negative value seen during deceleration, light load, heavy load (a pull), or transient (quickly changing) conditions? What fuel was used, and what was its octane rating? Were new parts or mounts installed on the vehicle that may have increased vibrations? What parameters were recently modified in the tune?

If it is difficult to reproduce the subtraction in an identical environment and condition, it likely would have been noise, especially for smaller feedback values. If it is readily repeatable, even semi-consistently, there likely is either an real issue with true detonation or the sensors are consistently recognizing noise from vibrations present only during certain conditions.

Fine Knock Learn (FKL)

To account for the shortcomings of the Feedback Knock strategy, Fine Knock Learn provides the **long-term** component of detonation mitigation, as a subtraction in degrees before top dead center (BTDC). As detonation events are observed, the ECU records these events and persists them in a long-term storage system called the [EEPROM](). Internally, the ECU records these ignition timing subtractions in a small table based on the engine speed (RPM) and the calculated load (g/rev) at the time of the events.

Fine Knock Learn can return to its normal state of 0.0 degrees subtracted from the ignition timing, but only when detonation events have not been seen in the affected operating condition's cells.

By looking up this table before ignition occurs, the Fine Knock Learn parameter can express an engine condition-specific value that assists in mitigating detonation before it can occur, unlike Feedback Knock. However, Fine Knock Learn cannot react to transient events, so these two systems operate in tandem to provide continuous short and long-term coverage for both transient and recurrent detonation activity, respectively.

Troubleshooting the Fine Knock Learn parameter can be slightly easier than troubleshooting the Feedback Knock parameter, as the important question of replicability has likely already been

answered - values present in this learning table are normally recurrent. First, identify which cell(s) in the table the ignition subtraction(s) have been recorded to. Using this engine condition, run through the same troubleshooting steps as the Feedback Knock parameter, but instead with the assumption that these events have likely been recurrent.

Dynamic Advance Multiplier (DAM)

A third, broad-stroke strategy used by the Subaru ignition timing control system is the **Dynamic Advance Multiplier**. Unlike the Feedback Knock and Fine Knock Learn parameters, the Dynamic Advance Multiplier (or "DAM") parameter is a number ranging from 0.0 to 1.0, and acts as a scaling (activation) value against the Ignition **Dynamic Advance** tables.

To determine a base ignition timing value, first the base ignition timing tables are calculated for the current engine speed (RPM) and load (g/rev). Then, the Dynamic Advance tables are processed. But, before adding this additional timing advance on top of the base timing, it is first multiplied by the Dynamic Advance Multiplier value. In this way, the Dynamic Advance Multiplier acts as an activation for additional timing in the map.

The Dynamic Advance Multiplier can be decreased (reducing the base timing advance) if detonation events are seen, similar to how the Feedback Knock system works, but instead of directly controlling ignition timing, these events (if significant enough) can reduce a multiplier. Unlike Feedback Knock, however, increases to the Dynamic Advance Multiplier behave more similarly to Fine Knock Learn, where the DAM value will increase as detonation events are *not* seen during critical operation such as heavy acceleration (a pull).