Technical Note

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Content

Continuously Variable Camshaft Control

Introduction

This document describes the control of continuously variable cam shaft timing on MoTeC's 'hundred series' ECUs - M400, M600, M800 and M880 with the Continuously Variable Camshaft Control upgrade enabled. The required control software is included with this upgrade.

The cam shaft timing varies the point at which the intake and/or exhaust valves open and close. In continuously variable systems the cam can be placed at any point within its travel range at any time while the engine is running. The travel range is limited only by the mechanical setup. Usually, the control is based on a specific map.

Variable Camshaft Control - VCC is used to increase the torque range of the engine.

Note: This system differs from “switched” cam control (e.g. Toyota 20v 4AGE, Honda B16 VTEC, Mitsubishi 4G92 “Cyborg”) where the cam position is switched from the fully retarded mechanical stop to the fully advanced mechanical stop in one movement. Switched cam control requires no upgrades for the Hundred Series ECUs and is also possible with MoTeC's M4, M48 and M8 ECUs.

Scope

This document is based on the current Version 3 ECU Manager software (release version 3.52P2) but is applicable to most versions before this.
This document assumes knowledge of Ref/Sync setup and PID control. For information on PID control loop tuning see Technical Document DTN0003: Introduction to PID.

VCC Valves and Actuators

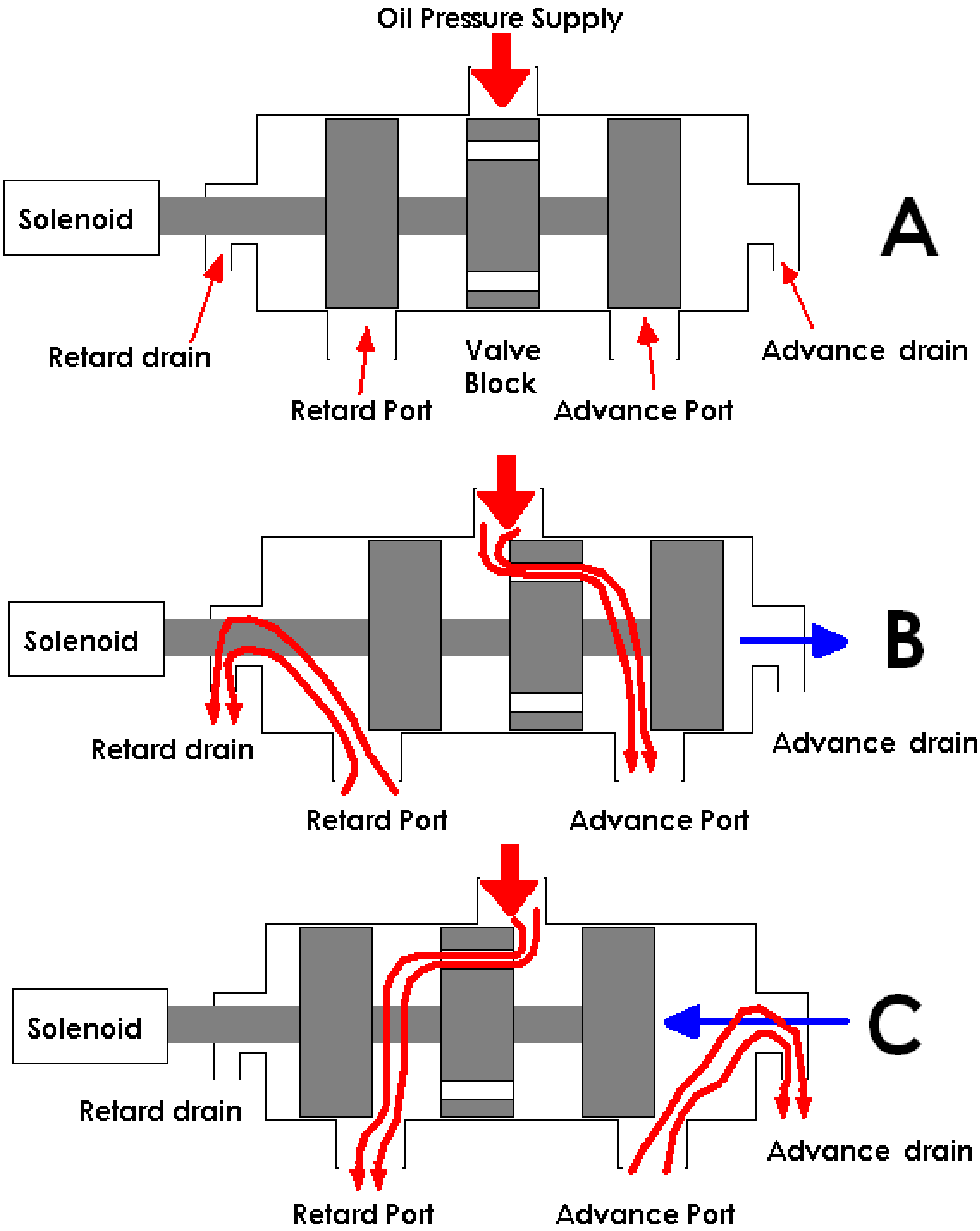
VCC is generally actuated using a valve controlled by engine oil at the pressure supplied by the engine's lubrication system. Some systems have secondary pumps specifically for cam control (e.g. some BMWs) that raise the engine oil pressure. Nissan employs a system that uses an electro-magnetic coupling.

Most common systems use a segmented valve that directs pressurized oil to the cam advance side or the cam retard side of the actuator or stops the oil flow to lock the cam in a desired position. The ECU varies the position of the valve with a closed loop, duty cycle signal. This also controls the oil flow rate to vary the speed at which the cam position is changed.

The following diagrams show the basic principle of the cam control system, although there can be variations in actuators and valves. It shows three different positions for the valve:

A. A duty cycle signal to the solenoid holds the valve in the middle position. This duty cycle depends on the physical system and will generally be different for different makes and models of car. The valve blocks the oil pressure supply from the engine's oil system to both the advance and retard ports and also to the advance and retard drains, effectively locking the cam in a fixed position.

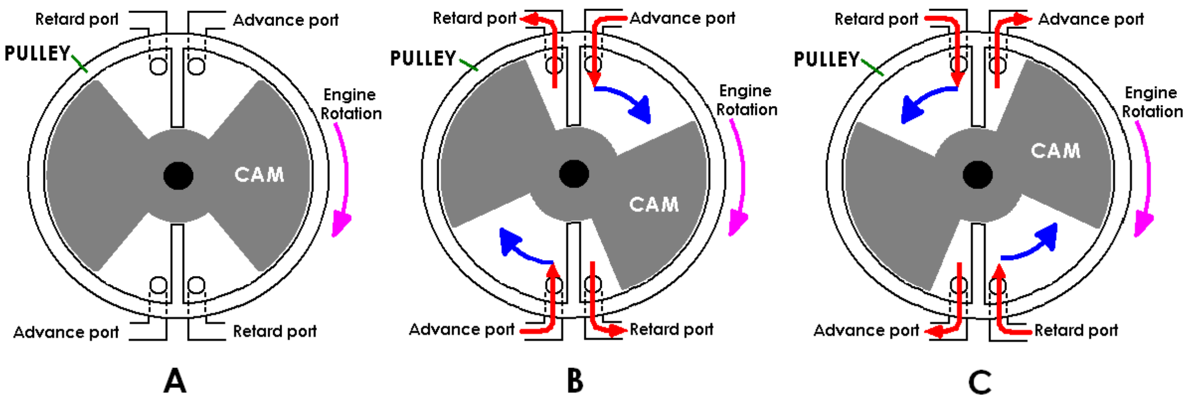
B. The duty cycle signal to the solenoid allows a path from the engine oil pressure supply to the advance port. At the same time, this opens a path from the retard port to the retard drain. The required duty cycle will depend on the engine and the cam control tuning.
C. The duty cycle signal to the solenoid allows a path from the engine oil pressure supply to the retard port (opposite direction from the advance direction).



Once the pressurized oil leaves the valve it travels to the actuator located inside the cam pulley. The pulley is separated into two parts that can move independently from each other. One part is the outer pulley where the cam belt/chain runs to turn the whole mechanism; this part has a fixed relationship to the crank.

The second part is attached to the end of the cam shaft and is not locked in any way to the outer pulley. When pressurized oil is introduced through the advance or retard ports the cam moves in relation to the outer pulley and therefore the crankshaft, changing the cam timing.

The diagram below shows the same three steps (A, B and C) from the cam pulley assembly.

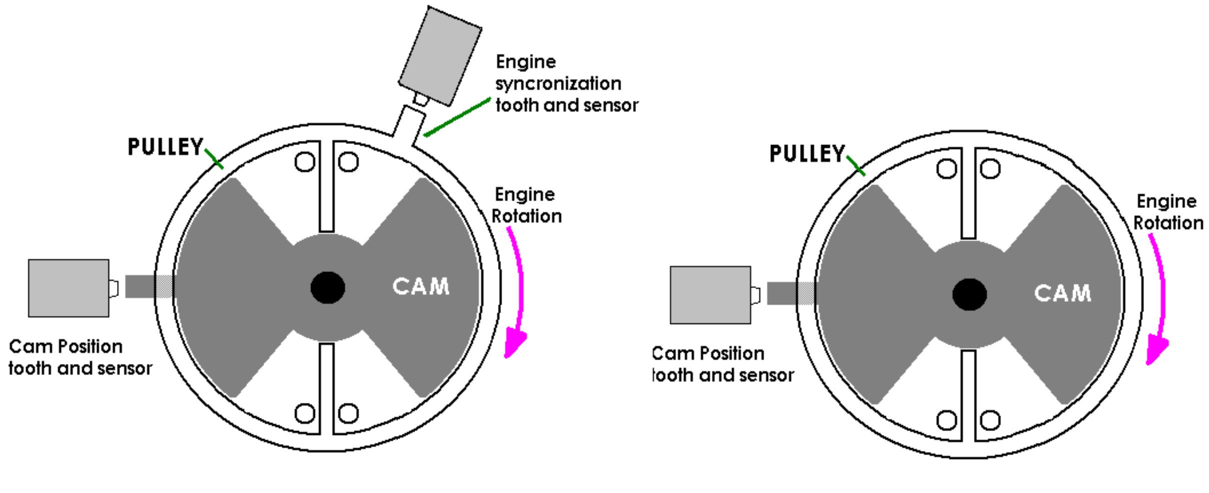


Crank and Cam Triggers

With a VCC system, the ECU needs extra information to not calculate the engine cycle position but also the cam position relative to the crank shaft, i.e. the ECU must be able to calculate the cam “timing”.

A. Some earlier engines with VCC had a cam and crank trigger set that always stayed in the same relative position to each other. These engines have the cam synchronization, or Sync trigger teeth connected to the outer pulley; the part that does not move relative to the crank. The engines needed a secondary cam position trigger tooth to be connected to cam shaft; this will vary its position relative to the crank along with the cam shaft.

B. Most current engines have one cam trigger tooth set connected to the cam shaft to vary its position relative to the crank. This means that the engine cycle position and the cam timing position are both calculated from the one trigger tooth set.



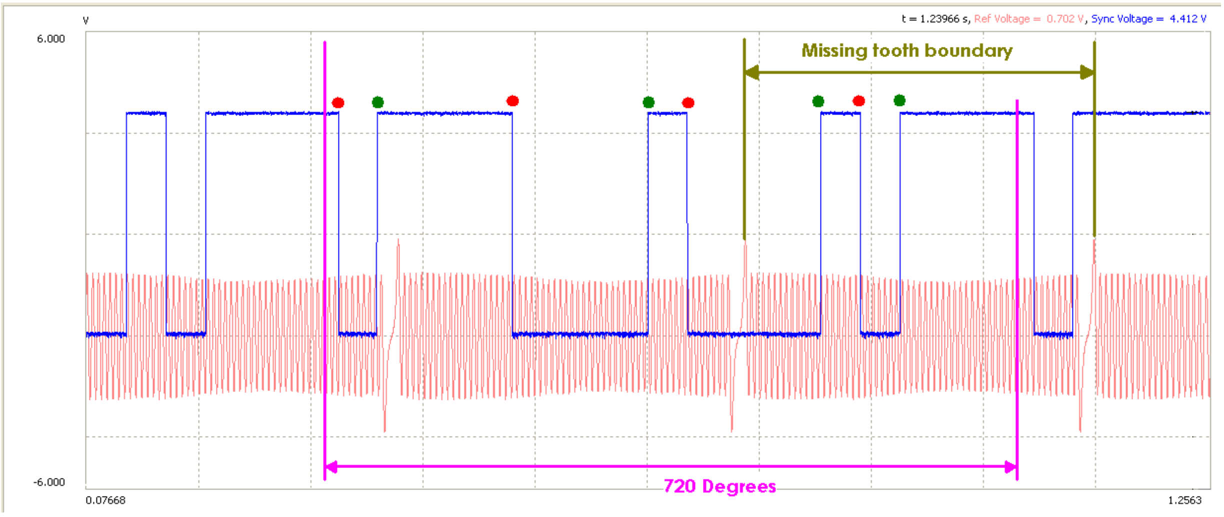
A B

Note: The above diagram is a simplified example; a single tooth for each situation is extremely uncommon. Normally the combination of the crank and cam triggers results in quite complex tooth patterns.

Both earlier and current VVC engines have a clearly defined reference point on the crank, e.g. a missing or additional tooth. The cam will have a set of teeth that makes a specific pattern for 720 degrees of crank rotation. The cam tooth pattern will have a reference point for calculation of engine cycle position used for synchronization of the engine. The pattern will also have a number of tooth edges used for cam position measurement. Normally the more teeth per engine cycle the more accurately the cam position can be controlled.

The diagram below shows an example of a crank (pink) and cam (blue) trigger signal.
Note: The diagram shows the voltage output of the sensors and not the shape of the teeth.

The cam trace shows that the falling edges of the signal (red dots) are evenly spaced. This is perfect for cam position measurement but can not be used for synchronizing the ECU to the engine cycle as there is no clearly defined reference point to decide which of the four edges to use. The rising edges (green dots) are not evenly spaced; the last two edges are much closer together than the others. This can be used as a reference point for synchronizing the engine.



The closely spaced rising edges can be used as a synchronization point that can be referenced to the missing teeth on the crank. The ECU can calculate where the engine is in its cycle and control the injection and ignition points precisely to start and run the engine. Once the engine is running, the evenly spaced edges are used in a separate calculation to work out the cam position.

Each manufacturer has a different cam and crank trigger pattern. It is the combination of these patterns that allows the engine to run. MoTeC software decodes the cam and crank signals relative to each other and provides modes to suit each trigger setup. This is the Ref/Sync Mode.

In the above example the closely spaced cam tooth rising edges (sync reference point) will not move outside the boundary of the preceding and following missing tooth events in the crank signal. This condition is hardcoded into the software. When modifications to the alignment between the crank and cam trigger teeth sets are made and this condition becomes invalid, the signals cannot be decoded. This prevents the ECU from running the engine. With factory systems that have very close tolerances this can happen with only a few degrees out.

MoTeC Cam Control Function

The 'hundred series' ECUs required require the Continuously Variable Cam Control upgrade to control the output.

Note: Without the upgrade it is still possible to use the cam position measurement for logging purposes.

The cam control system advances or retards a cam, based on the crankshaft degree measurement, i.e. if the cam is advanced 15 degrees it has advanced 15 degrees of crankshaft rotation.

The cam control system can only move the cam in the range between two mechanical limits inside the actuators. Regardless of the position requested by the ECU, the cam cannot move past these points.

The cam position is measured based on a zero position that is set in software. The zero position can be set anywhere in the cam's range and is up to the user's reference, but best practise is to use the position the cam sits in with the cam control solenoid unplugged.

Note: The zero point is not directly related to overall cam timing, i.e. fully retarded does not directly relate to any “classical” way of measuring cam timing, it is not related to a specific lobe separation or any other cam profile specification. The range of cam movement is what is appropriate for that particular engine according to the engine manufacturer.

The range of cam movement between the mechanical limits is designed by the manufacturer to work in a “non-interference” manner. This means that in any cam position between the limits the inlet and exhaust valves will not contact each other or the piston.

WARNING

Severe engine damage may occur if any modifications are made to the valve clearance or the mechanical limits of the cam control. Check to ensure that there can be no contact in any cam position when using larger cam shafts or different pistons or when machining engine block decks or cylinder head faces.

Wiring

Each cam position to be measured requires one ECU input pin.
For example: a V8 engine with variable inlet and exhaust cams requires four cam position inputs.

Similarly, each solenoid controlling a cam requires one output. Each cam is individually controlled in a closed loop operation; therefore cam control outputs cannot be spliced to more than one cam shaft (not even if they have the same desired position).
For engines with an advance solenoid and retard solenoid per cam (e.g. BMW S62B50 V8), eight outputs are needed for the four variable cams.

The wiring of the “syncing” cam position sensor depends on the Ref/Sync mode.

- In some modes the “syncing” cam position sensor is wired to the Sync input pin. Its position is read with the Sync Cam Position function.
- Other modes will not allow the syncing cam position to be calculated using the Sync input pin. In this case the signal must be spliced to a Digital input.
- Some modes require the Ref signal to be wired to both the Ref and Sync input pins, so the Sync signal must be wired to Digital input 1.

The Digital inputs on the hundred series ECUs are designed for use with Hall sensors but magnetic sensors can normally be used. When a magnetic sensor with a weak signal at low RPM is used for a cam position into a Digital input, it may be necessary to use a Dual Magnetic Converter (DMC).
For example: The Ford BA/BF, six cylinder exhaust cams signal is too low under approximately 1200 rpm to trigger the input. A DMC is required if the engine idle rpm is below this trigger.

For engines that MoTeC has characterized, specific wiring details may be available. When contacting MoTeC, ensure all details of the engine are available; in particular a Ref/Sync capture is useful.

Software Setup

Ref/Sync Setup

For the purpose of this document, you are assumed to be familiar with the Ref/Sync setup.
The Ref/ Sync Mode number refers to the tooth pattern seen by the ECU on the Ref and Sync (and possibly the Digital 1) inputs, however the synchronization of the engine and the cam position measurement are two completely separate calculations.

NOTE: The cam position will only be calculated once the ECU has synchronized and the engine is started. No cam position will be reported if the ECU has not synchronized.

Sync Cam Position

The Sync Cam Position setup is only used for Ref/Sync modes which allow the syncing cams position to be calculated from the Sync *i*nput pin. To decide if this method can be used in your application, contact MoTeC for specific details on the variable cams Ref/Sync modes on your vehicle.

To set up Sync Cam Position

- On the **Adjust** menu, click **Sensor Setup**,
- Click **REF/SYNC Sensor setup** and then **SYNC CAM Position**

When using the Sync Cam Position the signal edge and number of teeth are specified in the Ref/Sync mode and cannot be changed. The setup of the parameters - Channel, Offset, Zero and Filter is similar to Digital Input Cam Position setup, discussed in the next section.

Digital Input Cam Position

To set up Digital Input Cam Position

1. On the **Adjust** menu, click **Digital Input Functions**,
2. Click **Dig In 1** and then **Function**
3. Enter **19** for Cam Position
4. Press **ESC** and then click **Parameters**
5. Setup the parameters **Edge, Offset, Channel, Teeth, Filter, Zero** as discussed in the following sections

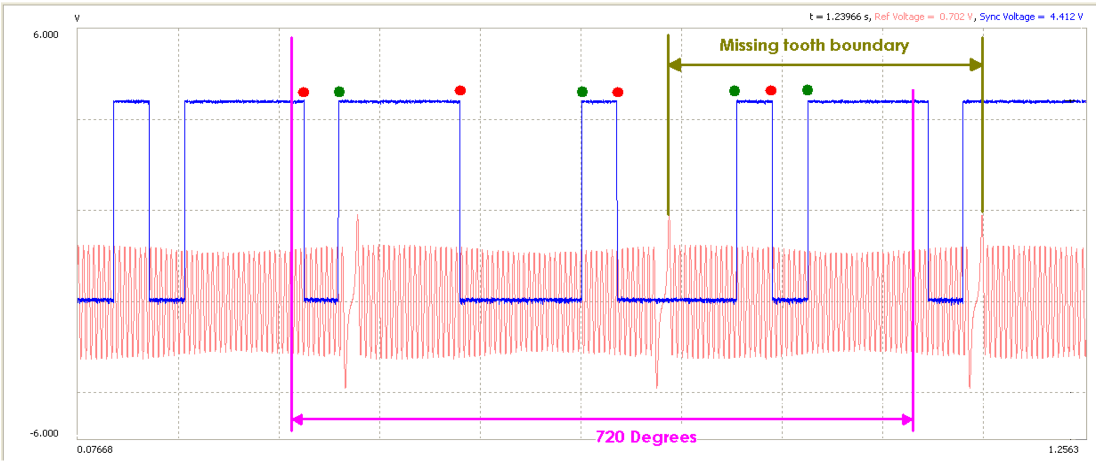
Edge

The calculation for the cam position uses the rising or the falling edge of the cam signal.

For magnetic sensors the same logic as Ref/Sync setup applies, only one edge is valid and this can be determined by using the Ref/Sync Capture.

For Hall sensors the evenly space edges are used. If both edges are evenly spaced then either edge can be used successfully.

Using the example below the falling edge (red dot) is the correct edge for the cam position. The **Edge** parameter must be set to **0** : Falling edge



Offset

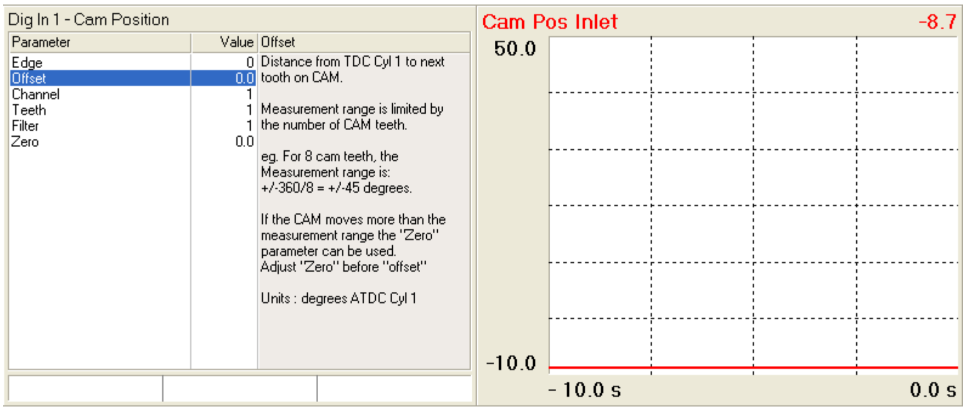
The Offset parameter is the index for the cam position (similar to the "CRIP" for the crank position). The Offset is the distance in degrees from Top Dead Centre (TDC) on number one cylinder to the next cam trigger tooth.

Note: Unlike CRIP it does not really matter which tooth is chosen to be the "next" tooth after TDC, the cam position will still work. Before the Offset can be set, first decide on the most retarded position of the cam and then on the zero position.

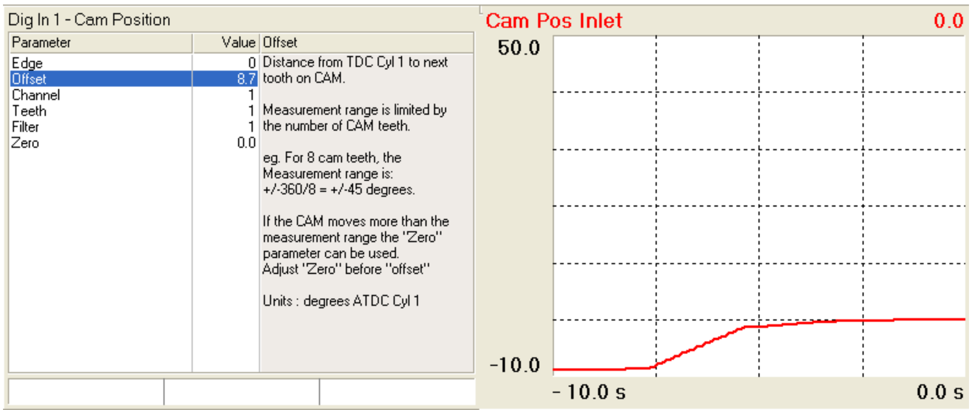
For example: If the cam has a range of 30 degrees, the most retarded position can be the zero position, giving a cam measurement range of 0 to 30 degrees. If preferred, the zero position can be set halfway, giving a measurement range of -15 to +15. The choice is completely up to the personal preference.

Test to set the Offset parameter

6. Unplug the cam solenoids and start the engine
   The cam will naturally be pushed to the most retarded position
7. Make a chart recorder in ECU Manager for the relevant cam position.
8. With the Offset parameter set to 0.0, check the cam position.
   In the following example the cam was reading -8.7 degrees.



9. Assuming the desired fully retarded reading is 0 degrees:
   With **Offset** selected (Offset is highlighted), press **PAGEUP** until the cam position reading equals zero.
   This does not change the actual cam position, only the reference point used in the ECU calculation.



In this example the Offset number is set at 8.7.
However, this particular engine had four cam teeth, so there are four possible settings for the Offset that would be equally correct. The four cam teeth are 180 degrees separated (720/4 = 180 degrees). The four correct Offsets are 8.7, 188.7, 368.7 and 548.7. If the desired fully retarded cam position is achieved with the cam control solenoid unplugged it does not matter which of the four Offset numbers is chosen.

Note: The starting position for the cam measurement is based on TDC number one cylinder. This TDC position is based on the CRIP value; if the CRIP ever needs to be changed the Offset will need to be changed by the same amount.

Channel

The Channel parameter links the Digital input (or Sync input) measurement to the correct cam control output.

It is important that the digital input sensor for position measurement and the auxiliary output that controls that particular cam shaft are labelled the same (e.g. Left Inlet). In reality it does not matter how the cams are labelled as long as the position sensor is wired to the same cam as the matching Auxiliary output that will be used to control that cam, e.g. a Digital input sensor and the Auxiliary output solenoid for a particular cam are **both** labelled as “left cam”.

If the engine is an inline configuration and it only has one variable inlet cam then best practice is to set the Channel parameter to 1 : Inlet (as opposed to left or right inlet).

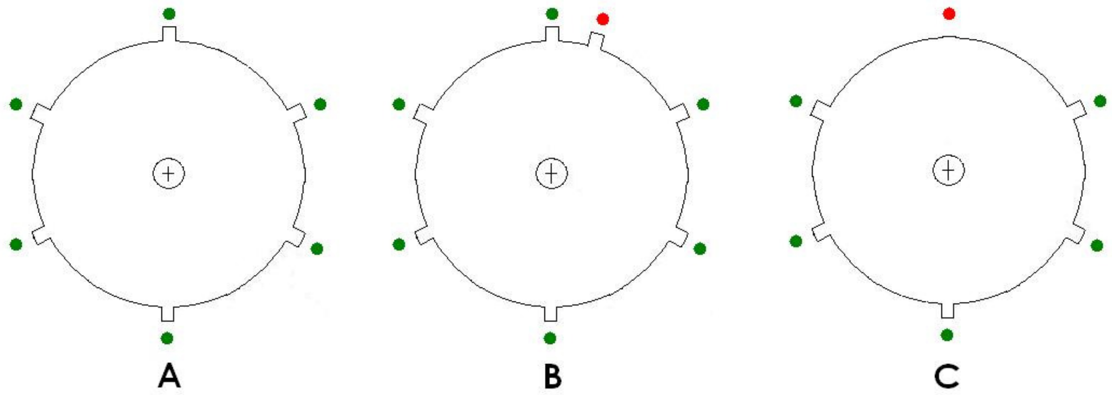
Teeth

The cam control teeth setup is similar to the Ref and Sync setup; only the evenly spaced tooth (or more correctly edges) count is required.

Tooth Count Examples

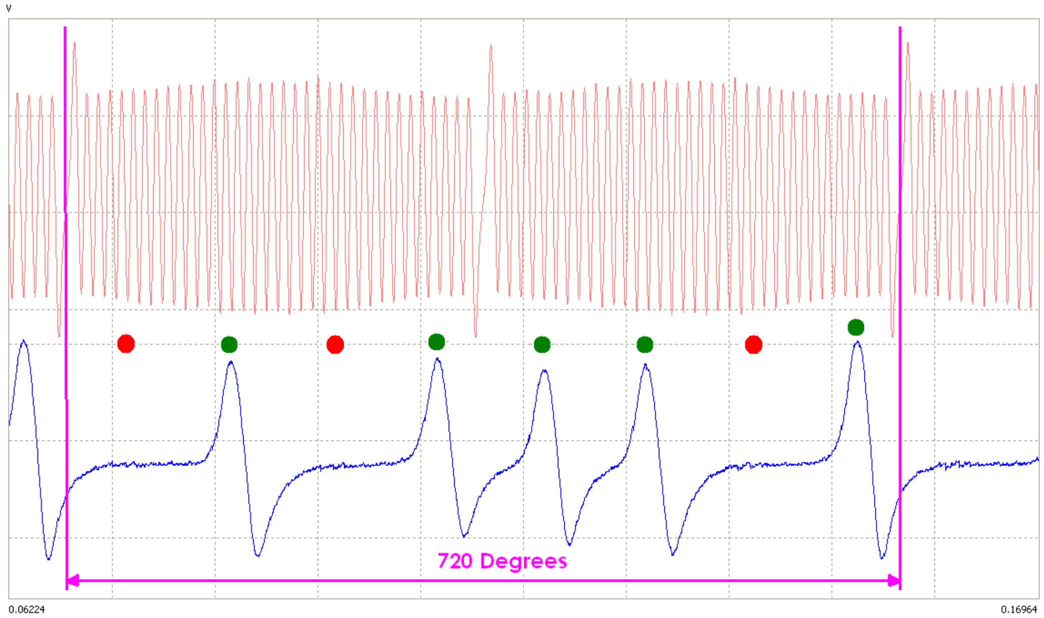
The following three different tooth sets are all counted as six teeth.

A. Six evenly spaced teeth (green dot). Normally not used for ECU synchronization because there is no clearly defined reference point.
B. Six plus One (6+1). The additional tooth (red dot) is ignored in the tooth count. This is an example of a tooth set that could be used for ECU synchronization.
C. Six minus One (6-1). In this example the teeth must be counted as if they are evenly space so the missing tooth (red dot) is counted and six is the correct number.

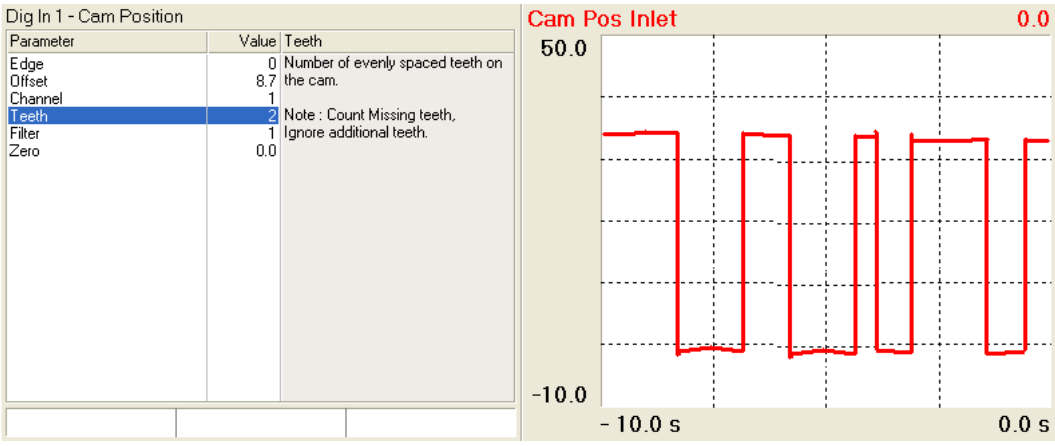


Tooth sets can be deceptive to count and might require knowledge of the Ref/Sync mode.

For example: For the following ref/sync capture (from a Ford, 32 valve, variable cam, V8) the tooth count is eight and not four; this is an 8-1-1-1, not a 4+1.



An incorrect Teeth parameter will result in an incorrect cam position calculation. With the engine running the cam position calculation will jump between two or more different positions. See the following example.



Some current factory cam position tooth patterns can be difficult to work out the number of even teeth, as a simple test the tuner could cycle through the Teeth setting numbers until a smooth cam position measurement is found. It is recommended that this only be done with the cam solenoid unplugged to ensure the ECU does not try to control the cam with an incorrect setting, this could lead to confusion as the cam position jumps around due to an incomplete setup.

Note: To correct this problem, use the Ref/Sync Capture utility to determine the correct tooth; do not used the Filter parameter.

Filter

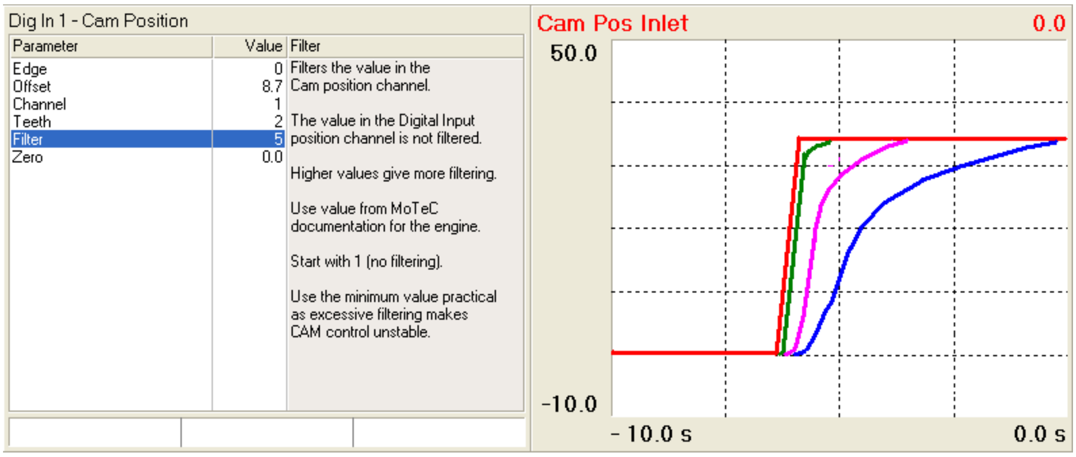
The Filter is used to smooth out 'noisy' cam position calculations.
Use filtering with care as it is possible to “over filter” the position calculation. Over filtering will result in the

cam position calculation being slow to respond and this will affect the control. Aim for the lowest filter value that produces an acceptable result.

Noisy cam position calculations are due to variations in load on the cam shaft caused by the valve springs and cam profile. The cam shaft will not turn smoothly and this “notchy” cam rotation can influence the cam position calculation.

When the cam control requests to hold the cam in one position, the variations in cam position should be less than the Dead Band and only minimal filtering may be required. If the variations are outside the Dead Band, higher filtering may be required to prevent the cam control function to act upon 'noise'.
Note: More on Dead Band in the Cam Control Output Setup

Example: The red trace is the requested cam position.
The green trace is a lightly filtered cam position where the ECU is controlling the actual cam position to follow the red trace, although there is some slight lag in cam response.
The violet and blue traces show the effect of an over filtered cam position; the actual cam position lags a long way behind the requested position, causing control problems.
Note: This should not be confused with problems due to poor tuning of the PID control loop.



Zero

The Zero parameter, shifts the cam range to any desired position. It is quite rare to use this parameter, in general it should remain 0.

In the ECU software, the cam measurements range is 720 degrees of engine cycle divided by the number of teeth, distributed evenly either side of zero degrees.
For example: In a cam with eighth teeth, 720/8 = 90 degrees; the cam measurement range is +45 degrees to -45 degrees.

If the Zero parameter is set to for example 15, the cam range is shifted:
Cam maximum position = +45 + 15 = 60
Cam minimum position = -45 + 15 = -30
New cam measurement range = +60 degrees to – 30 degrees

Note: This will not require a reset of the Offset parameter.

Cam Control Setup

The recommended outputs on a 'hundred series' ECU for the Cam Control function are Auxiliary outputs 1, 2, 5, 6, 7 and 8.

If required the function can be set up on any other spare output. An external flyback diode is recommended when using an Injector, Ignition (M800 only) or Auxiliary Output 3 and 4.

The output must be rated to a maximum current greater than the current used by the valve.

MoTeC recommends checking the resistance of any VCC valve before making a wiring loom. Most VCC valves will only require a small amount of current (0.5 A continuous or less), so any outputs can be used, but some engines have high current valves (greater than 0.5 A continuous) and may need to be wired to the high current outputs; Auxiliary output 1 or 2.

To set up Cam Control

1. On the **Adjust** menu, click **Auxiliary Output Functions**,
2. Click **Auxiliary Output x** - for x choose the number of output in your application
3. Click **Function** and enter **117 or 123** – see next section in this document
4. Press **ESC** and then click **Parameters**
5. Setup the parameters **Source Channel, PID gains, Dead Band, Aim Source, Frequency, Polarity and Output mode, Lo and Hi limit** as discussed in the following sections

Function

Choose function to match the VCC system on the engine. There are two options:

- Function 117 : Cam Control 1. Used for VCC systems with a valve that only requires one output to both advance and retard the cam position. The valve will have only two pins in the connector.
- Function 123 : Cam Control 2. Used for VCC systems with a separate advance valve and retard valve. These systems are quite uncommon and possibly only used on first generation BMW VANOS V8s and Inline 6 cylinder, “M” engines (S50B30 and S62B50).
  Note: Function 123 uses two Auxiliary outputs for each cam. When the function is set for one particular output, the next output will automatically be assigned as its slave.
  For example: Function 123 is set on Auxiliary output 4. Auxiliary output 5 will automatically be assigned as the “slave” for that cam. This must be accounted for in the wiring loom design.

Parameters

Source Channel

The Source Channel links the cam control output to the cam position input. The specified channel of the cam control output must match the channel setting for the position sensor of the particular cam.

Tip: Use a multi meter to measure which cam position sensor is wired to which cam shaft???, to ensure the correct source channels are set,

PID Gains

The Proportional component of the PID control loop moves the control valve proportional to the requested cam position. Typical values range from 2 to 5.

The Integral component of the PID control loop is generally not required for Cam Control Function 123 and should be left at the default (0).

The Derivative component of the PID control loop, should be a positive value:
Positive values calculate the Derivative duty from the cam position error (error = aim position – actual position) while negative values calculate the Derivative duty from the cam position.

Derivative Gain is generally not required for Cam Control Function 123 and should be left at the default (0).

NOTE: For further information on tuning of PID control loops please refer to DTN0003 "Introduction to PID Control".

Dead Band

The Dead Band is a range around the Aim position where the actual cam position is considered to be close enough to the required position. Within the dead band, the cam control function will not adjust the cam position any further to reduce unnecessary control.

For example:

> The cam aim position is 20 degrees and the Dead Band is 0.5 degrees:
> Aim Position + Dead Band = 20.5 degrees
> Aim Position – Dead Band = 19.5 degrees
> Any cam position between 19.5 and 20.5 degrees will be considered to be at the Aim Position.

Typical values for Dead Band are between 0.2 degrees and 0.5 degrees.

Aim Source

The Aim Source directs the auxiliary output to the cam aim position table.

When using **0 : Use own table**, the aim position will come directly from the auxiliary table associated with that auxiliary output.
Any other setting (1-6) will direct the auxiliary output to find the aim position using other auxiliary outputs.

Example 1: An inline 4 cylinder engine with VCC from both inlet and exhaust cams.

- One auxiliary output is set as Source Channel **1: Inlet** and one as Source Channel **2 : Exhaust**.
- Each output Aim Source is set to **0 : Use own table** to allow independent control of both cams.

Example 2: A boxer 4 cylinder engine with VCC on the inlet cams. The two inlet cams should always have the same aim position.

- One Auxiliary output will be set as Source Channel **3 : Left Inlet** and the other as Source Channel **3 : Right Inlet**.
- The left inlet cam auxiliary output is set to Aim Source **0 : Use own table.**
- The right inlet cams auxiliary output is set to Aim Source **3 : Left Inlet** to direct it to use the left inlet cam aim table.
  Both cams will follow the same aim table position, so only one cam table has to be tuned.

Frequency (Output Function 117 only)

The Frequency parameter sets the output frequency. Output Function 117 uses a fixed frequency and variable duty cycle.

The MoTeC ECU should use the same frequency as the factory ECU. To decide on the correct frequency, investigate the factory ECU before the engine electronics are modified.

Frequencies can range from 200 Hz to more than 300 Hz.

Offset (Output Function 123 only)

The Offset using function 123 is the minimum pulse width needed to make the cam move (similar to the dead time of a fuel injector).

The PID control loop must have an accurate value for Offset to calculate a pulse width based on the cam position error at the time.

To find the Offset value

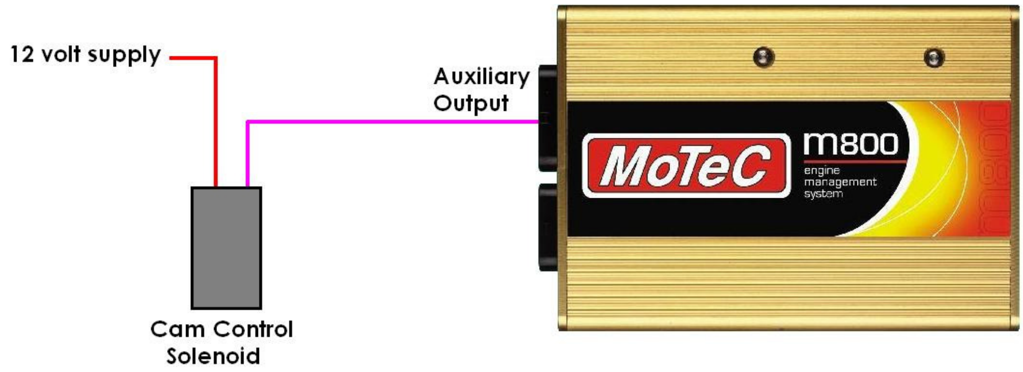
- Set P, I and D to 0, effectively turning the PID control off.
- Increase the Offset until the cam just starts to creep forward

Polarity and Output Mode (Output Function 117 only)

The Polarity and Output Mode parameter set the switch logic. The polarity sets whether the duty cycle for the output increases or decreases to advance the cam position.

Low Side Drive

The first two settings **0 : 100% duty = output low** and **1 : 100% duty = output high** are used for Low Side Drive where the output is switched to ground and the cam control valve is wired with a 12 V supply.



The default setting **0 : 100% duty = output low** is used when the duty cycle needs to increase to advance the cam (cam position gets larger).

For example:

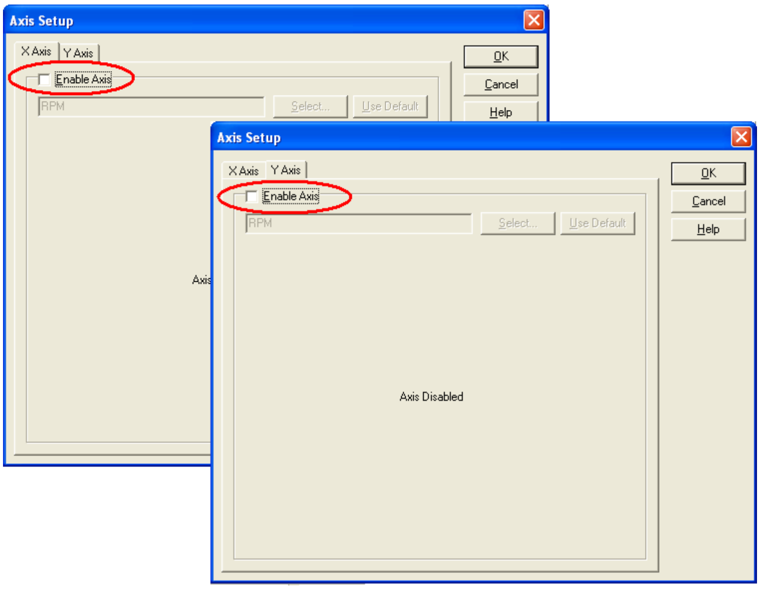
The holding duty cycle for a cam is 35% and if the cam needs to advance, the duty cycle will increase to greater than 35%. To retard the cam, the duty cycle will decrease below 35%. This is common for inlet cams.

The Polarity and Output Mode should be set to **1 : 100% duty = output high** if the duty cycle needs to decrease when the cam needs to be advanced.

NOTE: The polarity is only used in the calculation. The **reported** duty cycle in the ECU manager software and data logging will be an increasing number when the cam is advanced even when the polarity is set to **1.** This can cause some confusion in the setup process.

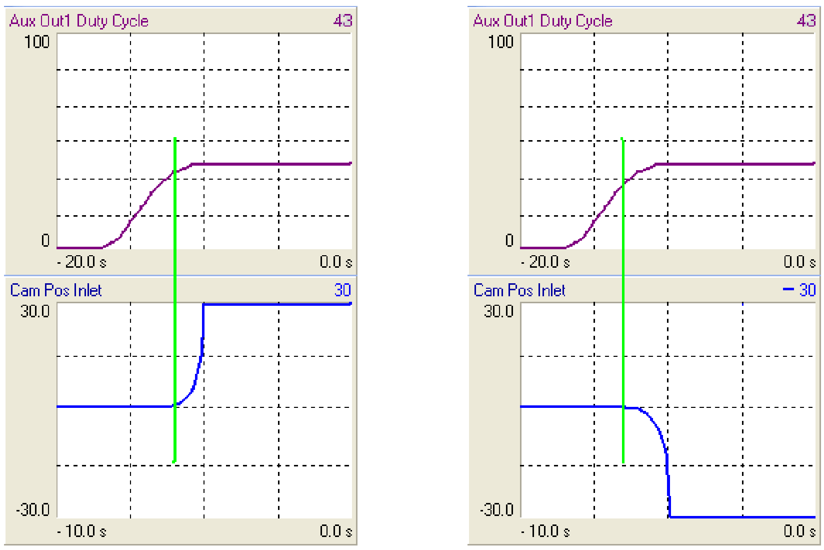
To decide the correct polarity for the control of a particular cam

1. On the **Adjust** menu, click **Auxiliary Output Functions**,
2. Click **Auxiliary Output x** - for x choose the number of output in your application
3. Click **Function** and enter **3 : Auxiliary Table**.
4. Press **ESC** and then click **Parameters**
   Set the parameters for the Auxiliary table as follows:
   - PWM/Switched – **0 : PWM (Pulse width Modulated)**
   - Output Mode – **0 : Low Side**
   - Polarity – **0 : Output Hi for 0% duty**
   - Frequency – (to match the valve)
   - Minimum Duty Cycle – **0**
   - Maximum Duty Cycle – **100**
   - Hysteresis – **0 : Hysteresis Off**
5. Press **ESC,** then click **Table** and press **A** (Axis Setup)
6. Clear the **Enable Axis** check box on both the X-Axis and the Y-Axis tab. This will turn the table into one value



7. With the engine running slowly, press **PAGE UP** to increase the duty cycle
8. If the cam moves in a positive direction, set the Polarity to **0 : 100% duty = output low**, if the cam moves in a negative direction set the Polarity to **1 : 100% duty = output high**

Example

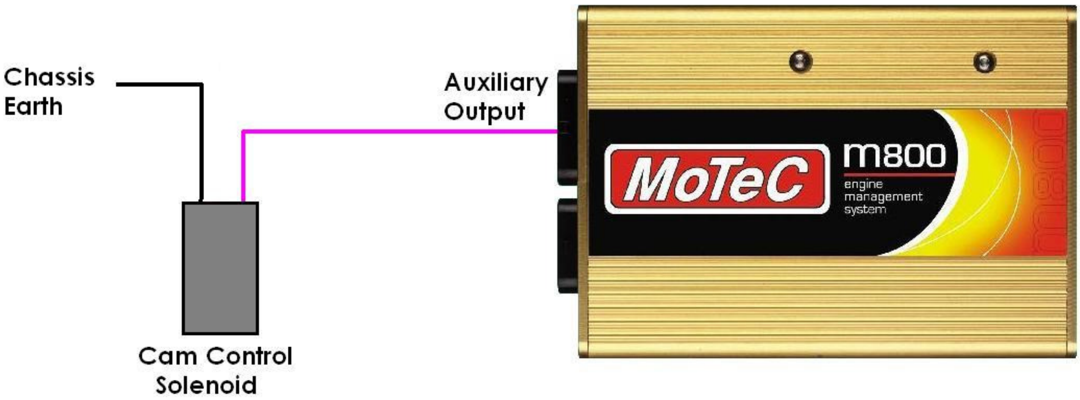


In both these examples the cam starts to move at approximately 40% Duty Cycle but the left one advances (increasing cam position) while the other retards.

The right example is most common. The exhaust cam will start at a fully advanced position with the solenoid unplugged and an increase in Duty Cycle will retard it. These cams will have Polarity **1 : 100% duty = output high**.

High Side Drive

Polarity and Output Modes **2 : 100% duty = output low** and **3 : 100% duty = output high** are used for High Side Drive where the output is switch to battery power and the cam control valve is permanently wired to ground.



The same method can be used to decide the correct polarity for the control of a particular cam, only in step 4 the Output Mode in the parameters for the Auxiliary table should be set to **1: High Side**

Note: High Side Drive of cam solenoids can only be used on Auxiliary outputs 1, 2, 5, 6, 7 and 8. Low Side Drive wiring is recommended

Polarity and Output Mode (Output Function 123 only)

The Polarity sets which of the two outputs for a particular cam shaft will advance the cam. There are no setup parameters for the slave output; the slave output will automatically be the other direction.

Similar to deciding the correct polarity with Output Function 117, use Auxiliary Output Function **3 : Auxiliary Table** to activate each output in turn and establish which ones advance the cam and which one retard the cams.

Output Function 123 uses the same options for High Side and Low Side drive.
Only Auxiliary Outputs 1, 2, 5, 6, 7 and 8 can be used with High Side driven cam control valves.

Lo Limit and Hi Limit (Output Function 117 only)

The Hi and Lo Limits for the cam control function serve two purposes:

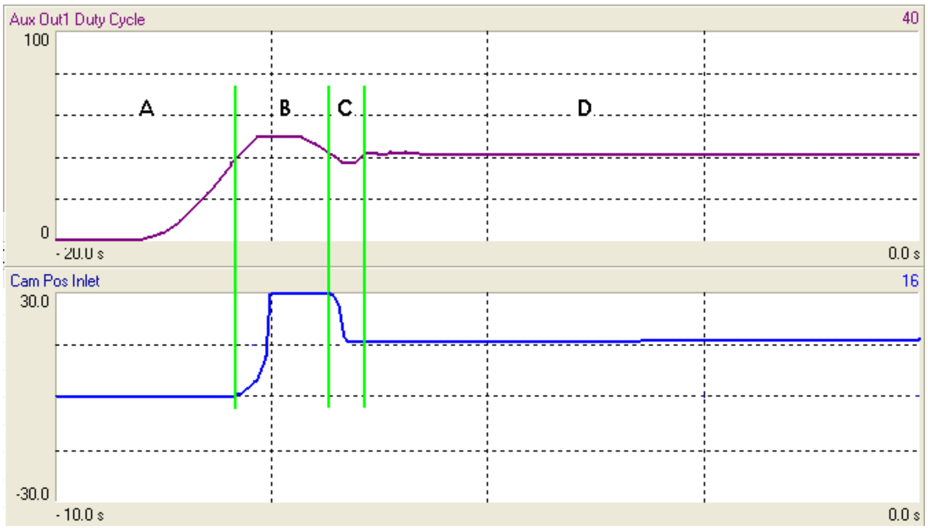
1. It sets the maximum and minimum duty cycle for the Integral part of the PID control loop
2. It sets the Normal Position Duty Cycle for the PID control loop

The Normal Position Duty Cycle is the duty cycle needed to hold the cam in one fixed position (a position not against the fully retarded or fully advanced mechanical stop). In normal operation the ECUs PID control loop assumes that this Normal Position Duty Cycle is exactly halfway between the Hi and Lo Limit Duty Cycles.

To test the Normal Position Duty Cycle

1. On the **Adjust** menu, click **Auxiliary Output Functions**,
2. Click **Auxiliary Output x** - for x choose the number of output in your application
3. Click **Function** and enter **3 : Auxiliary Table**.
4. Press **ESC** and then click **Parameters**
   Set the parameters for the Auxiliary table to suitable values matching the cam control function.
5. Press **ESC,** then click **Table** and press **A** (Axis Setup)
6. Clear the **Enable Axis** check box on both the X-Axis and the Y-Axis tab. This will turn the table into one value
7. With the engine running at an RPM that ensures enough oil pressure for cam control (1200-1500rpm should be sufficient), press **PAGE UP** to slowly increase the duty cycle
   As the duty cycle increases it will get to a point where the cam starts moving
   The speed of the cam will increase rapidly for and extra 1-2% Duty Cycle past this point
8. Press **PAGE UP** and **PAGE DOWN** to find the duty cycle to hold the cam position at one point (not fully advanced or fully retarded)

The following diagram shows a result from the test for the Normal Position Duty Cycle.



A. The duty cycle is increased but the cam position remains at 0.

B. The cam starts to advance and with increasing duty cycle the speed of the cam increases rapidly until it gets to the fully advanced mechanical stop.

C. The duty cycle is decreased until the cam starts to retard away from the mechanical stop and then slightly increased to hold one position.

D. A duty cycle of 40% holds a constant position on the cam shaft which in this example is 16 degrees of advance. 40% is the Normal Position Duty Cycle value.

The Normal Position Duty Cycle is the duty cycle that will hold the cam at a steady advance or retard, independent of the actual position; a rise or drop in duty cycle will move the cam and as soon as the cam reaches the new desired advance or retard position the duty cycle will go back to the Normal Position Duty Cycle value to hold the new cam position.

The Normal Position Duty Cycle value is not entered directly into the ECU software; it is simply calculated as the middle of the range between the Hi and Lo Limits.

The total range from the Hi to Lo Limit can vary depending on the engine; this is after all the limits of the Integration for the PID control loop. As a guideline, the Hi and Lo Limits will be respectively 10% above and 10% below the Normal Position Duty Cycle value.

In the example above the Hi Limit will be 40+10 = 50% and the Lo Limit will be 40 –10 = 30%. With these Hi and Lo Limits set, the Normal Position will be calculated as 40%.

For cams that have a Polarity setting of 1 or 3, the Hi and Lo limits are set from the 100% duty cycle:

Hi Limit = (100%-40%)+10% = 70%
Lo Limit = (100%-40%)-10% = 50%.

It is important to set the Hi and Lo Limits so that the Normal Position Duty Cycle value is accurate.

Once the Hi and Lo Limits are set, the PID gains can be tuned. When alterations are required to the Hi and Lo Limits during PID tuning, always set the limits evenly above and below the tested Normal Position Duty Cycle value.

The Hi and Lo limits range will depend on the mechanical characteristics of the engine. Always aim for the smallest range that that produces an acceptable result as this will reduce *Integral wind up*.

Note: Ensure the Normal Position Duty Cycle is tested correctly before PID and Cam Control tuning.

Cam Control Table

The table associated with the Cam Control function is in crank degrees of cam shaft advance, i.e. a value of 10 in the table means the cam advances 10 degrees of crank shaft rotation.

The mechanical stops in the engine will limit the actual achievable range of cam shaft movement and overrules any requested value in the table outside that range. The range between mechanical stops can vary greatly between engines.

The values in the table do not represent specific valve opening and closing points in relation to the crank shaft. They relate to the angle in degrees from the mechanical stop. The actual cam specifications and lobe centres are not relevant to the control system.

The table values should be tuned on an engine dyno (similar to tuning the fuel and ignition tables).

Additional Tables

Inlet and Exhaust Cam Actuator Normal Position

Some Variable Cam Control systems use a Normal Position that varies with an engine condition for example engine oil temperature or engine RPM. When required, create a 2D or 3D table based on any ECU channel using the Cam Actuator Normal Position table located in: *Adjust – Functions - Cam Control.*

The only difference in setup compared to the previous cam control setup is for the Hi and Lo Limits. When the Cam Actuator Normal Position table is **not** used the Normal Position is calculated as half way between the Hi and Lo Limit settings. When the Cam Actuator Normal Position table **is** used, the Normal Position is obtained from the table and the Hi and Lo Limits are set as the additional duty cycle.

> **Example:**
>
> Using the same values as the previous example, enter the tested Normal Position of 40% in the Cam Actuator Normal Position table and enter the Integral limit of +/-10% as Hi Limit = 10 and Lo Limit = -10.

A cam output assigned as an inlet or exhaust will automatically use the Inlet or Exhaust Cam Actuator Normal Position table.

Only use this table is specifically required. In this case carry out additional testing to setup the table. If the table is not required, it is good practice to turn both axes off and zeros all values.

Inlet and Exhaust Cam Actuator Duty Correction (*Adjust – Functions – Cam Control*)

PID control loops are best setup for linear control systems.

In a linear system each increase step in duty cycle results in the same increase in valve position

> **Example:**
>
> 10% duty cycle == 5% valve opening
> 20% duty cycle == 10% valve opening
> 30% duty cycle == 15% valve opening etc.
>
> When the increase in duty cycle is known the resulting valve opening can easily be predicted.

In a non-linear system the relationship between each incremental duty cycle step produces a different result.

> **Example:**
>
> 10% duty cycle == 5% valve opening
> 20% duty cycle == 14% valve opening
> 30% duty cycle == 31% valve opening etc.

In a non-linear Cam Control system the speed of cam movement is non-linear with duty cycle, making the cam control more difficult.

The Cam Actuator Duty Correction “linearizes” the relation between cam speed and duty cycle by adding or subtracting a non-linear part to the calculated duty cycle. The table values are in duty cycle.

Generally, cam systems are linear and don not need this correction. If the table is not required, it is good practice to turn both axes off and zeros all values.

