Automotive
Energy & Power Analysis
Field Service
Environmental
Research & Development

Combustion Analyser

User Manual 7.0.5

Re-inventing Data Acquisition

worldwide
DEWETRON

About the content of this document

The information contained in this document is subject to change without notice.

DEWETRON elektronische Messgeraete Ges.m.b.H. (DEWETRON) shall not be liable for any errors contained in this document. DEWETRON MAKES NO WARRANTIES OF ANY KIND WITH REGARD TO THIS DOCUMENT, WHETHER EXPRESS OR IMPLIED. DEWETRON SPECIFICALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. DEWETRON shall not be liable for any direct, indirect, special, incidental, or consequential damages, whether based on contract, tort, or any other legal theory, in connection with the furnishing of this document or the use of the information in this document.

Restricted Rights Legend

Use austrian law for duplication or disclosure.

DEWETRON GesmbH
Parkring 4
A-8074 Graz-Grambach / Austria

Printing History

Please refer to the page bottom for printing version.

Agenda

1 Introduction and Basics

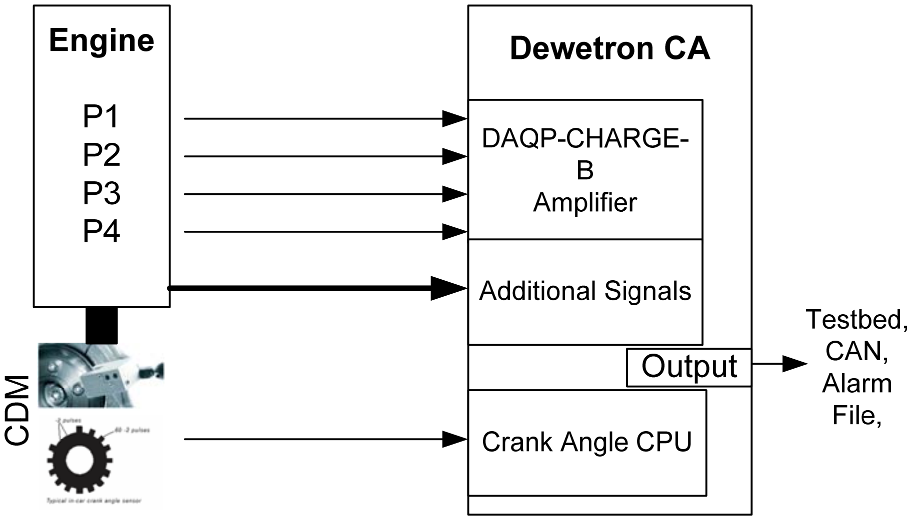
The Dewetron Combustion Analyser (CA) is used to indicate almost any reciprocal engine. The target is to measure, angle or time based, the indicating pressure and calculate online the main thermodynamic parameters out of it. The Combustion Analyser is used in various applications around reciprocal engines, for example Mapping of ECUs, knocking evaluation, general engine development and any other application where indicating is required. Dewetron CA systems support direct sensor inputs for high and low pressure, and also provides additional inputs such as CAN, XCP, to get the full picture of your engine.

1.1 System Overview

Pressure sensor(s) are used to measure the cylinder pressure, of the engine.
An angle sensor, CDM (CrankDiscMarker) could be mounted on the crank shaft to get the angle position of the crank shaft, which is required for the CA calculations. However, sometimes it is not possible to mount a CDM sensor on the engine due to space limitations, perhaps when the engine is installed in a vehicle rather than on a test bed. In this case the native CDM sensor (60-2, 37-1, ..) of the engine can be used to provide the angle information. Both signals are connected to the Dewetron Crank Angle CPU (CA-CPU). The CA-CPU can handle various input signal types from CDM sensors, and also provides interpolation in real time to increase the angle resolution of the CDM sensors. For example the 60-2 signal, which has a resolution of 6 degree, could become a 3600pulses/rev CDM. Interpolation is carried out by the CA-CPU with up to 0.1deg resolution.

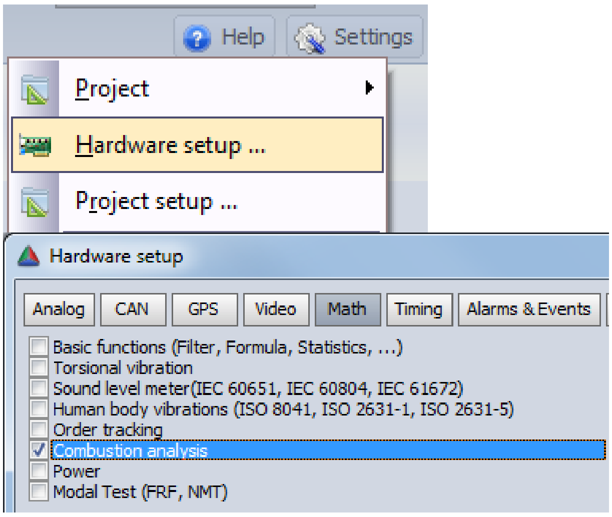
Additional signals such as temperatures, the absolute pressure of inlet manifold, ignition or injection signals, or any other analogue or digital signal, could be connected to the appropriate input.
CAN, XCP, or GPS, could be also acquired during indication of the engine.

Results can be exported into various file formats for further processing. In addition Dewetron CA provides various interfaces such as CAN, RS232, and TCP/IP, to transmit data. Dewetron CA can also be controlled via these interfaces, to achieve control and data transfer from a testbed.



2 Enabling CA functionality

The CA functionally in Dewesoft must be enabled under → Setting → Hardware Setup → Math

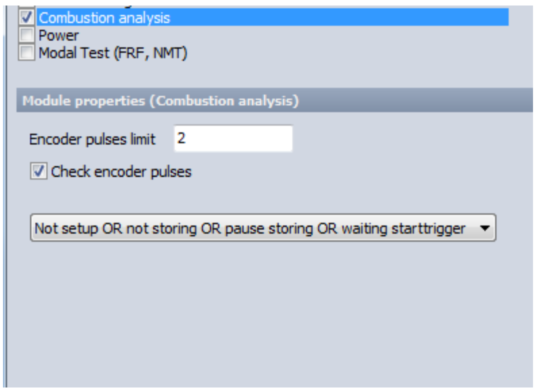


2.1 Encoder pulses limit an Scope mode

Additional CDM pulses, caused by electrical noise, or interpolation errors of the CA-CPU, could produce incorrect angle results, so the CA software checks the number of pulses per revolution for every cycle. If the number of pulses differs by more than the set limit, the Cycle is not calculated.
At angle resolution of 0.1 deg, 2 pulses would give 0.2deg.
At angle resolution of 0.5 deg, 2 puses will give 1deg.

If **Scope mode** is enabled, CA skips cycles. In other words it does not calculate all cycles. There are several levels of scope mode available. Depending on this setting, CA-Plugin also skips calculations depending on measure mode (storing, not storing, trigger,…).

The default setting which should be used is: **NEVER**
If this is set to NEVER, CA will calculate, store and visualize all cycles.



The setting on the left would be interpreted in the follwing way:

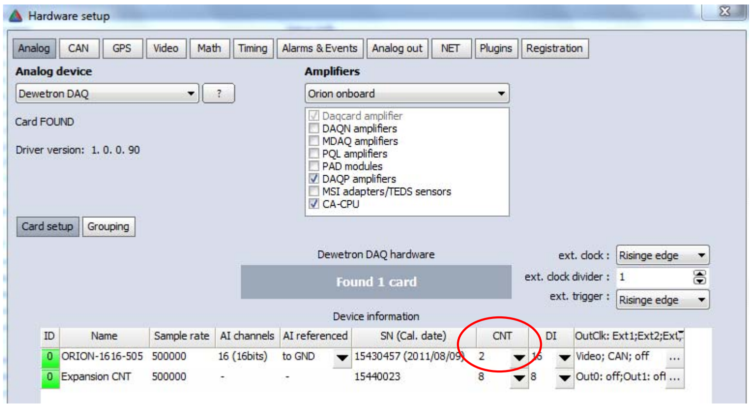
<u>SCOPE MODE is not active in SETUP or</u>
(in SETUP all cycles are calulated continuously)
<u>SCOPE MODE is not active during Storing or</u>
if Data is stored all cycles are calulated and stored
<u>SCOPE MODE is active if storing is paused or</u>
<u>SCOPE MODE is active during waiting for Starttrigger.</u>

Scope mode can be used to skip cycles, to achieve higher rates.

2.2 Enabling DAQP amplifier and CA-CPU

In the analogue section of the hardware setup, the CA-CPU and the DAQP amplifiers must be enabled. CA is also available without CA-CPU, in this case CA-CPU is unchecked. If CA-CPU is not used no interpolation or reduction of CDM sensors pulses can be done. It is also not possible to use the native 60-2 or 34+1 CDM signals of the engine at angle domain measurement, because interpolation and gap filling can only be done with the CA-CPU.

Also make sure that the 2 base counters of the A/D card are enabled.



Note: Your CA is already preinstalled when the system arrives.

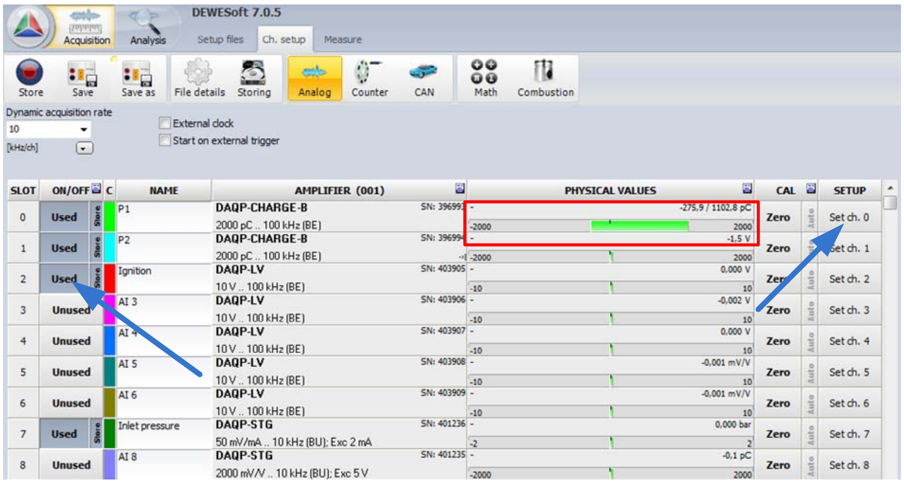
3 Analogue Input, CA-Plugin Setup

3.1 Analogue Input Configuration

The analogue input section in the setup screen shows all DAQP amplifiers which are actually installed in the CA system.

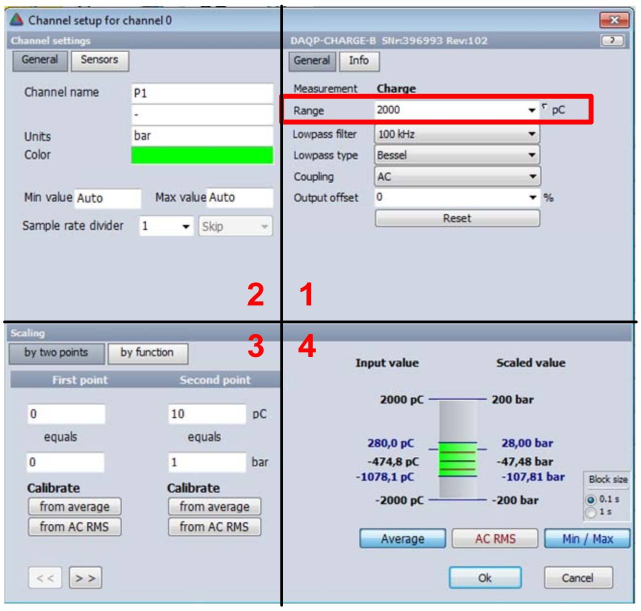
The high pressure sensors used in the combustion chamber are typically charge based and connected to the DAQP-Charge-B amplifiers of the CA. If external charge amplifiers are used, the voltage output of the charge pre-amplifier will be connected to a DAQP-LV amplifier or any other analogue voltage input on the CA. Additional inputs such as ignition, injection, are also connected to an analogue voltage input.

If piezoresistive absolute pressure sensors are used, to measure inlet manifold pressure, this sensor is bridge based and requires a constant current bridge supply. The DAQP-STG module is the appropriate amplifier for this type of sensor, and supports current excitation for these sensors.



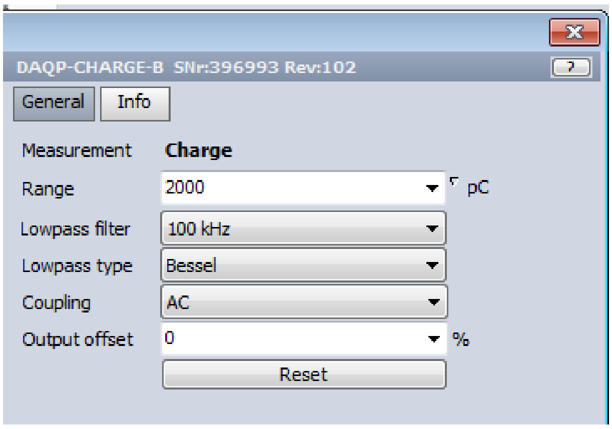
A typical channel setup screen, with the installed DAQP amplifier's shown on the left.

Connected channels are activated and renamed according to the input. Active signals can be observed immediately in the setup, so input range selection can be simplified.

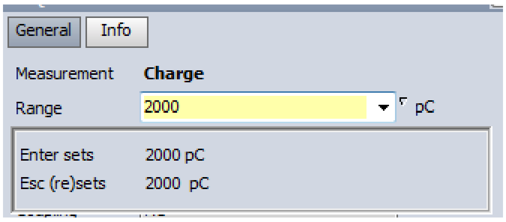


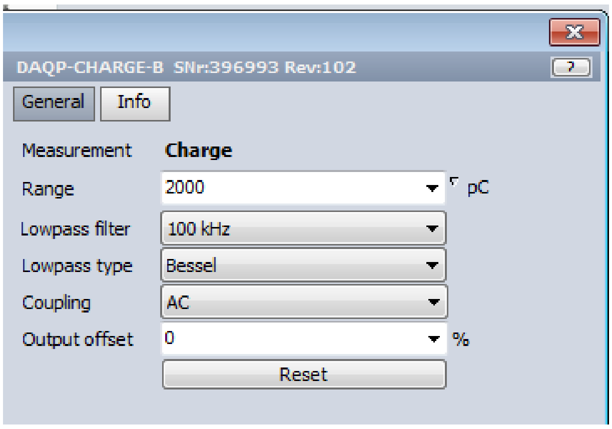
In the channel setup the amplifier settings and also the scaling can be defined. The channel setup is split into 4 sections, and configuration is carried out through sections 1 to 4.

Section 1 holds the amplifier settings. In section 2 channel name and unit will be set. Section 3 is used to scale the sensor from electrical to physical units, so that physical values can be used. Section 4 provides live information about the input value and the scaled value.



Input range can be selected from a predefined list, or entered manually.



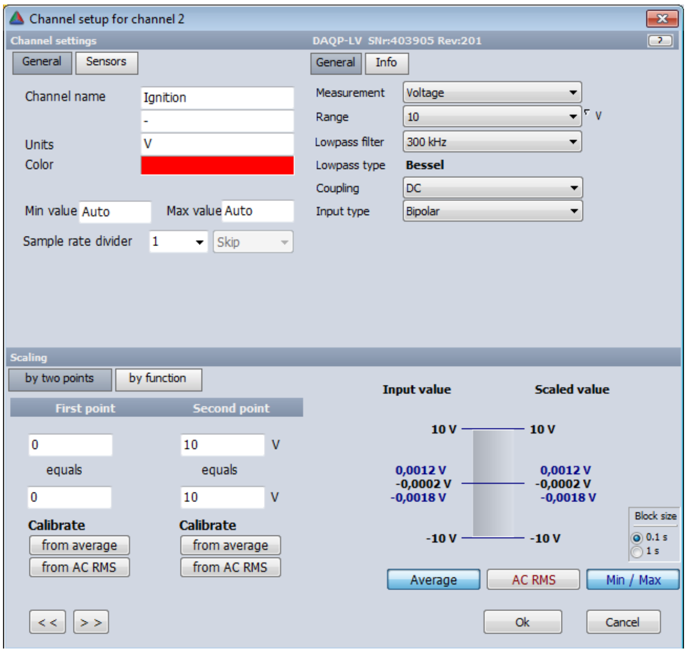


Filters should be set to 100kHz and Bessel characteristic.

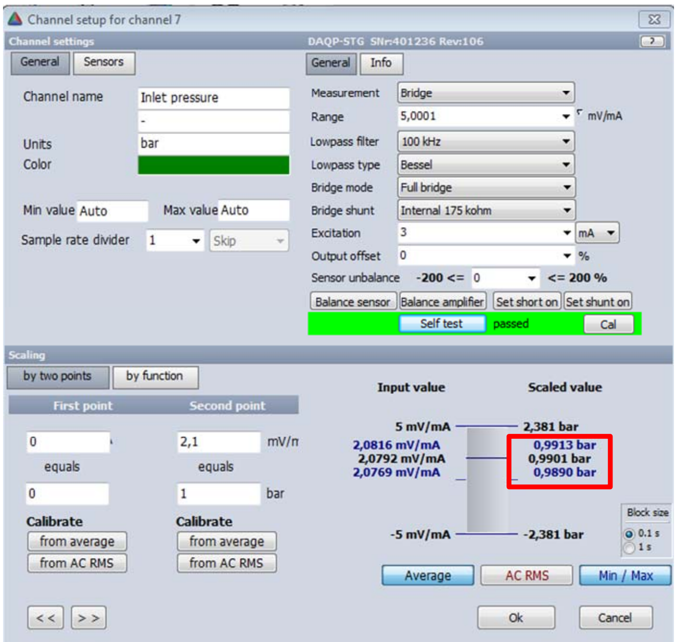
High pressure sensors are exposed to heat shocks, which can cause the signals to drift, but AC coupling will reduce this drift, and avoid the signals exceeding their input range.

The high pass filter frequency is connected to the input range. In the range from 100 to 2000pC it is set to 0.07Hz. Above 2000pC the high pass filter is about 0.005Hz.

After connection the input could be overloaded, caused by a static charge during connection. Reset will eliminate this and set the amplifier back to 0.



For all other input channels setup is done in a similar way. The DAQP-LV low voltage amplifier is used for ignition. Ignition uses 10V range and 300kHz filter. Scaling is not required because it will only indicate the ignition start.



For piezoresistive absolute pressure sensors, The DAQP-STG amplifier is used, typically with full bridge, and with excitation set to current.

The sensor datasheet will provide the required calibration current, typically 4mA, and the sensitivity at this calibration current in mV/bar.

The input range of the amplifier is scaled in mV/mA, and must be considered in the scaling process.

Example Datasheet of sensor:

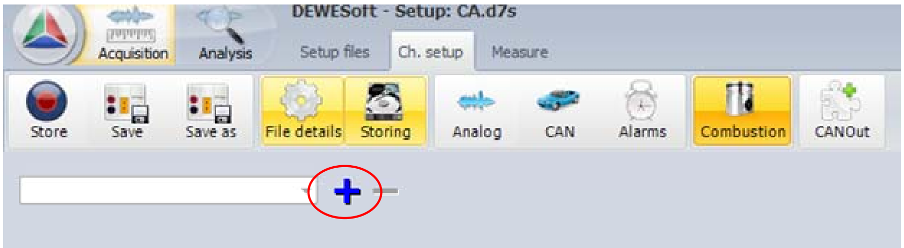
Sensitivity at Ical = 8,4mV/bar
Reference current = 4mA
Input impedance = 3kOhm

Example:
We get 8,4mV/bar @ 4mA, which equates to 8,4mV/4mA = 2,1mV/mA/bar.
The scaling is set to 2,1mV/V equals 1 bar. The sensors input impedance is about 3000 Ohms. If we were to set the excitation current to 4mA, this would require an excitation voltage of 3000R x 0,004A = 12V. The DAQP-STG compliance voltage is limited to 12V. Therefore, to avoid the compliance voltage limit beyond which current cannot be regulated, the current is set to 3mA. This results in a compliance voltage of around 9V, which should give enough margin to regulate compliance current effectively.

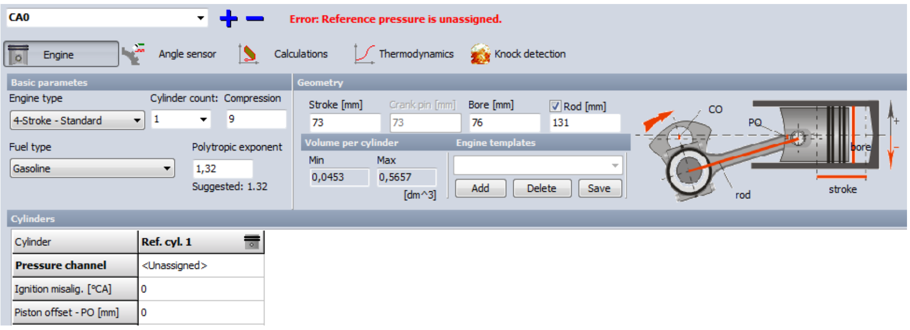
After setting this we should see ambient pressure if the engine is stopped.

3.1 Engine, Channel Setup

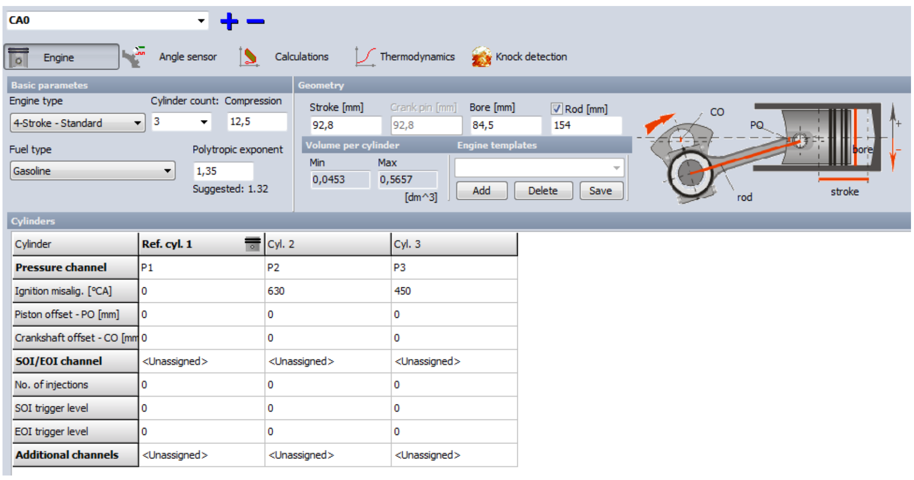
After the analogue input setup, we have to select the Combustion setup, and add the calculation template.



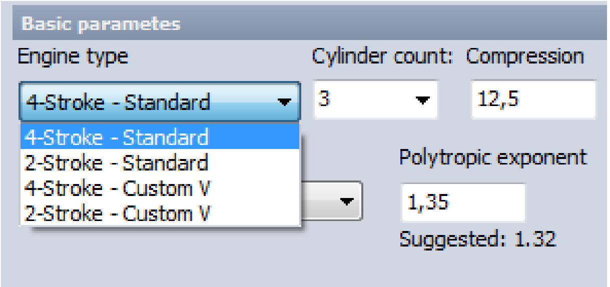
The calculation template is split into 5 sections. The engine section where all engine parameters and measured channels are applied. The angle sensor section, where the CDM sensor and top dead centre (TDC) is defined. In Calculation, Thermodynamics, Knock detection, and the calculation results are defined.



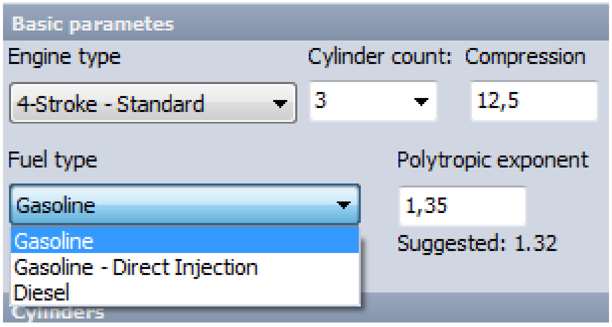
Engine, Channel Setup



In the Engine setup the engine parameters, pressure channels, additional channels and also start of injection - end of injection (SOI/EOI) signals are defined. Also ignition misalignment (firing order) and reference cylinder will be set up.



In the basic parameters the **Engine type** is defined. 4-Stroke and 2-Stroke, with either standard or custom volume calculation can be selected. If standard volume is defined, the volume calculation is done according to standard volume (see section formulas for further information).
If custom volume is selected, a user defined volume calculation can be entered.

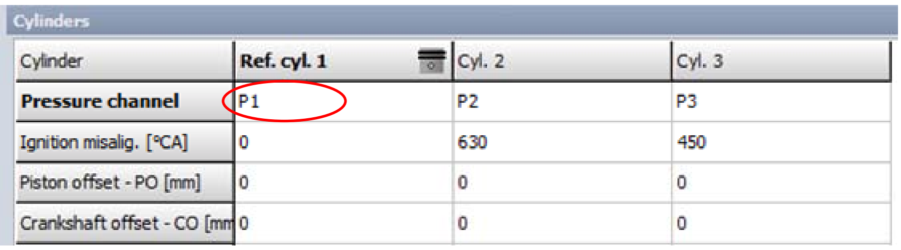


Fuel type defines the fuel of the engine. Depending on this setting a polytrophic exponent which is used for thermodynamic calculations is suggested. The defined value must be entered manually into the polytrophic exponent field.

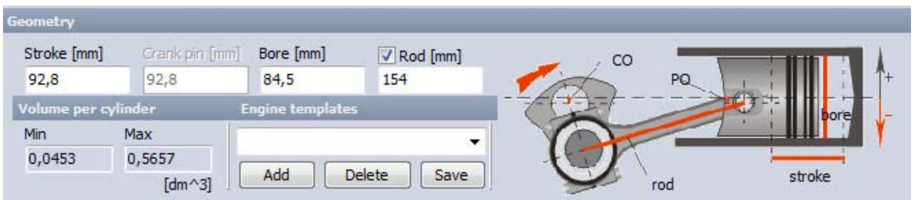
Start of combustion (SOC) and end of combustion (EOC) are provided as results. EOC is defined where integrated heat release reaches 95%, which is valid for diesel and gasoline fuel types.
With gasoline, SOC is defined when the integrated heat release reaches 5%, and with diesel, SOC is defined when the integrated heat release crosses 0% (Due to the injection of diesel fuel the integrated heat release goes negative first).

Compression defines the relation between swept volume and clearance volume. For more details see the formulas section.

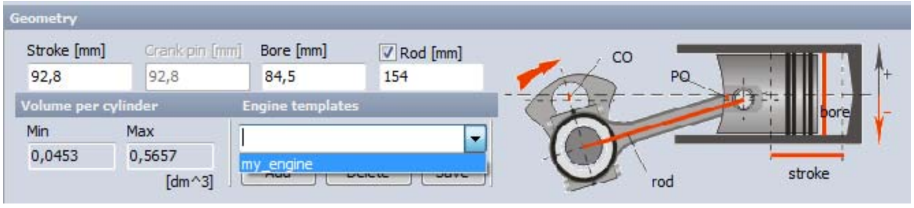
Cylinder count defines the number of cylinders which are indicated. The cylinder template will be expanded automatically, and the analogue pressure channels can be applied.



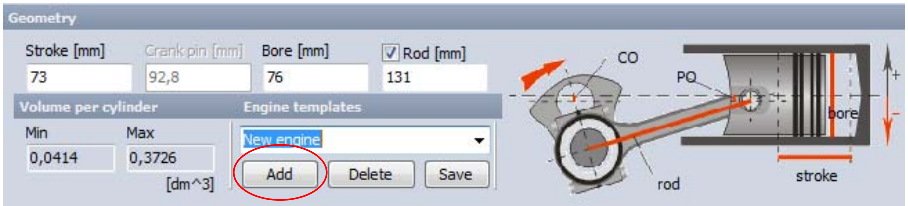
Cylinder	Ref. cyl. 1	Cyl. 2	Cyl. 3
Pressure channel	P1	P2	P3
Ignition misalig. [°CA]	0	630	450
Piston offset - PO [mm]	0	0	0
Crankshaft offset - CO [mm	0	0	0



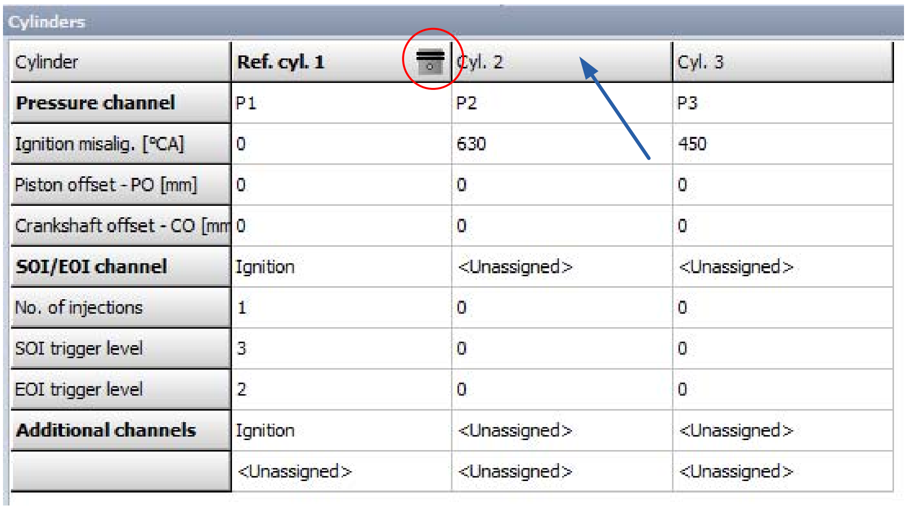
Under Geometry the engine parameters are added, and the template will automatically calculate the min and max volume.



The engine template can be used to store engine parameters, number of cylinders and ignition misalignment, to save time for future CA setups.



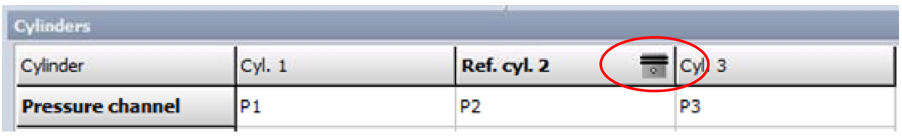
To create a template, add a new template first, rename it according to the engine, and then enter the engine parameters. At the end Save it to create the template.



Cylinders

Cylinder	Ref. cyl. 1	Cyl. 2	Cyl. 3
Pressure channel	P1	P2	P3
Ignition misalig. [°CA]	0	630	450
Piston offset - PO [mm]	0	0	0
Crankshaft offset - CO [mm	0	0	0
SOI/EOI channel	Ignition	<Unassigned>	<Unassigned>
No. of injections	1	0	0
SOI trigger level	3	0	0
EOI trigger level	2	0	0
Additional channels	Ignition	<Unassigned>	<Unassigned>
	<Unassigned>	<Unassigned>	<Unassigned>

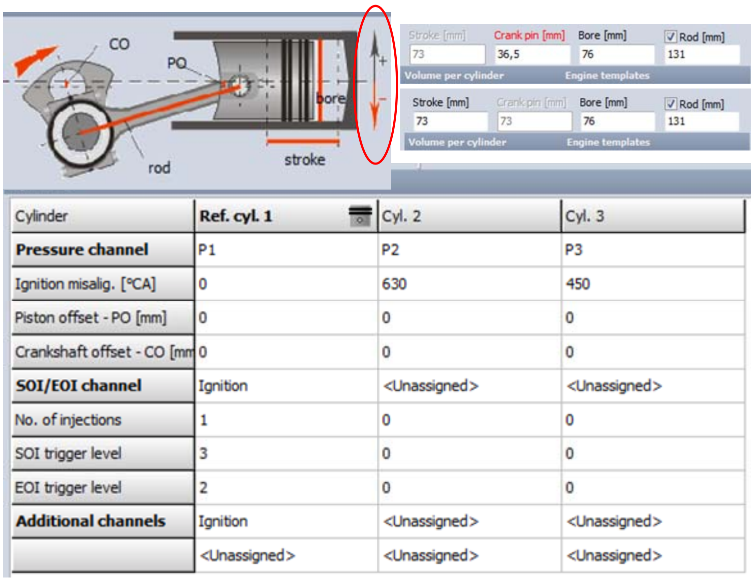
In the cylinder template the analogue pressure channels are applied. Also the reference cylinder is defined here in this section. The reference cylinder is indicated with a piston, and could be applied to any cylinder. Simply click on the target cylinder, (Cyl.2) and it will become the reference cylinder. Ignition misalignment is related to the reference cylinder, and will be entered in degrees.



Cylinders

Cylinder	Cyl. 1	Ref. cyl. 2	Cyl. 3
Pressure channel	P1	P2	P3

Additional channels can be applied to specific cylinders. These channels will be available in the CA- Scope diagram, and are aligned with the corresponding cylinder. This can be very helpful for signals which require angle based investigation. If the ignition signal is also applied to the additional channel, it can be used in the CA-Scope. See chapter 6 - Display Setup.



Cylinder	Ref. cyl. 1	Cyl. 2	Cyl. 3
Pressure channel	P1	P2	P3
Ignition misalig. [°CA]	0	630	450
Piston offset - PO [mm]	0	0	0
Crankshaft offset - CO [mm	0	0	0
SOI/EOI channel	Ignition	<Unassigned>	<Unassigned>
No. of injections	1	0	0
SOI trigger level	3	0	0
EOI trigger level	2	0	0
Additional channels	Ignition	<Unassigned>	<Unassigned>
	<Unassigned>	<Unassigned>	<Unassigned>

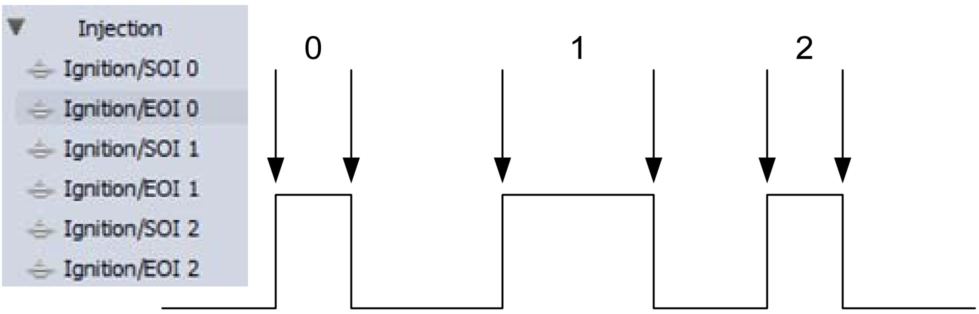
If the engine has a crank offset, this needs to be entered in the piston and crankshaft offset of each cylinder. Here it is very important to consider the running direction of the crankshaft. Depending on which the values must be entered with the correct '+' or '-' sign.

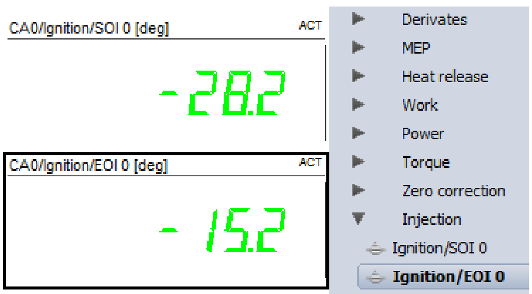
Info: If PO or CO is entered, stroke is not available any more, crank pin must be entered!

Start of injection (SOI) and also end of injection (EOI) channel is also applied to the cylinder. The setting is called SOI/EOI but can handle various signals. The result will be the start and the stop position [deg] of the applied signal.

In this example an ignition signal is applied. The Number of injections is set to 1, and the trigger level for SOI is set to 3V, where EOI trigger level is set to 2V. If the ignition signal crosses 3V it will return the angle position, related to the cylinder where it is applied [deg].
The same for EOI, if the signal crosses 2V (neg. edge) the position will be returned[deg].
The unit of the trigger levels are related to the channel scaling on the analogue input.
In this case Ignition is scaled in voltage [V].

If multiple events occur, for example on a injection signal, the no of injections must be set, and the function will return the start and stop position for every event.



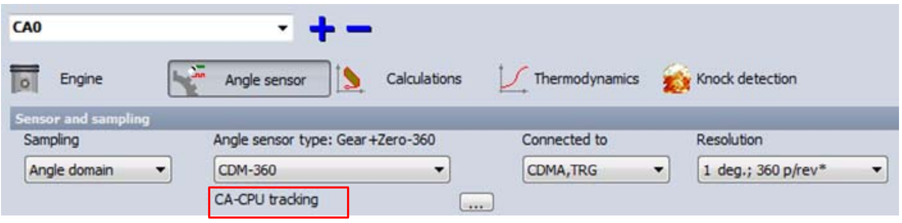


3.2 Angle Sensor Setup

The angle sensor setup defines the sampling type as Time domain or Angle domain (internal or external clocking), and also the various CDM sensors which can be used.
For Angle domain sampling, the CDM sensor is clocking the A to D card of the CA. So every pulse which comes from the CDM sensor is clocking the A to D card. In other words an analogue value is acquired at every pulse, which results in a constant angle recording. The sampling rate is not constant, because engine speed is changing, and therefore also the sampling rate.

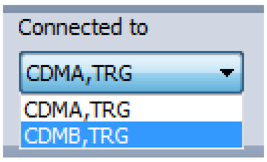
In comparison, time domain CA measurement records the pressure signal and angle signal coming from the CDM sensor with a fixed sampling rate 200kHz. This has the advantage that all time domain related functions are not influenced by changes of the sample rate due to shaft speed, and will stay the same. For example a power calculation is only working in time domain (fixed sampling rate). Of course CA is still calculated in angle domain, and the CA data will be recalculated into the angle domain.
The only disadvantage is that very high calculation power is required to recalculate time based signals into angle based. For more information also check chapter 4.2 - Measurement Modes in CA-Noise setup.

3.2.1 Angle Domain



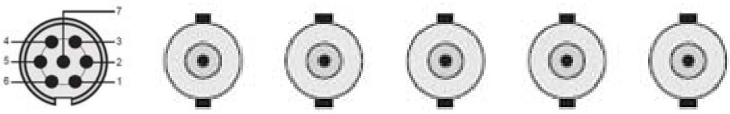
First the sampling type is selected.
This can be either Angle domain or Time domain.

CDM Sensor:

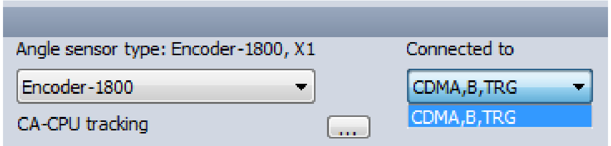


If Angle domain, then the CA-CPU is shown if it is installed in the CA system. The Angle sensor is selected and connection is chosen. In this example a CDM-360 sensor was selected. The CDM sensor provides 2 signals, CDM (360p/rev) and TRG signal. These signals are connected to CDM-A and TRG of the CA instrument. On the encoder connector CDM-A and TRG is also provided. If CDM-B and TRG is selected, CDM-B is only accessable on the encoder input.

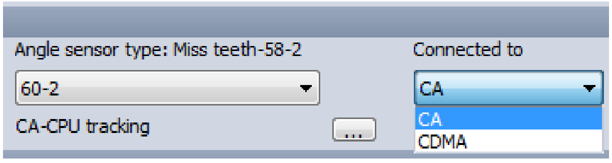
1.) +15V
2.) -15V
3.) +5V
4.) GND
5.) CDM-B
6.) CDM-A
7.) TRG



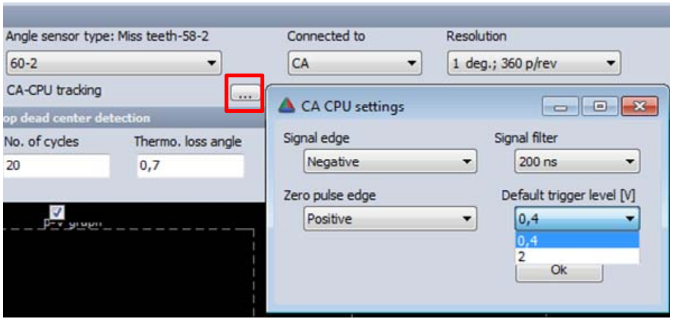
Encoder AUX1 AUX2 CDM-A TRG CA



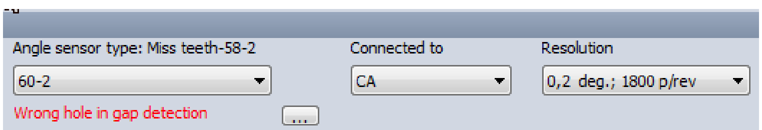
If encoder is selected, CDM-A,B, and TRG must be connected to the encoder connector.

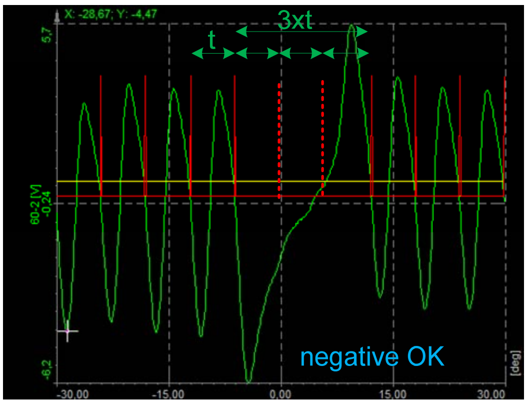


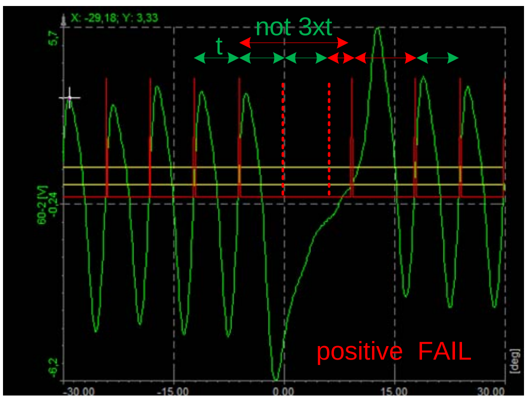
A CDM sensor with missing teeth (60-2), can be connected either to CA or CDM-A input of the CA-CPU. If the 60-2 signal is an analogue signal (green), it must be connected to the CA input. The CA input can handle voltage up to 60V and has 2 trigger levels available. In comparison CDM-A can only handle TTL (0 to 5V) input. Some conditioned sensors provide a TTL signal on the output.

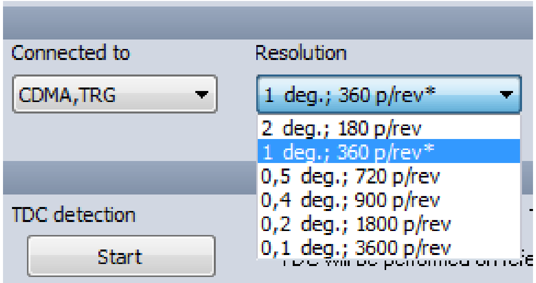


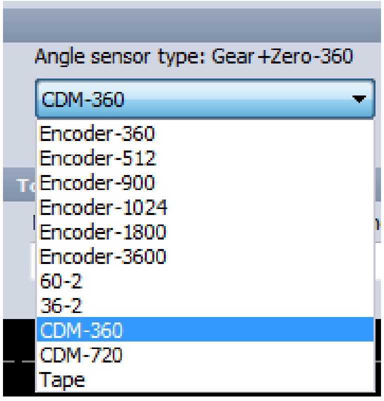
In the properties of the CA CPU the trigger level and the signal edges and also the filter can be defined. Trigger level is only valid for the CA input connector. Here an analogue signal is expected, and for this the trigger level can be set (default value 0,4V). If a filter is set, the signal must be high or low for the defined duration that it is valid. In harsh electrical environments where spikes could disturb the signals, this can be used to filter the input signal. The signal edge defines the direction of the input signal, and depending on the input sensor this can be set for signal and zero pulse. In the case of a 60-2 signal (green), the negative edge must be set, to detect the gap correctly. The picture below gives an example why positive edge will not work. During the gap, positive slope is undefined, negative slopes are defined. If the 60-2 is not detected in the right way a simple change of the edge usually solves the problem. If this does not help, connect the signal to an analogue input, and record it with sufficient sampling rate, 20 times the signal frequency and check the signal to find out why detection doesn't work. Below the angle sensor setting, messages will indicate possible errors.









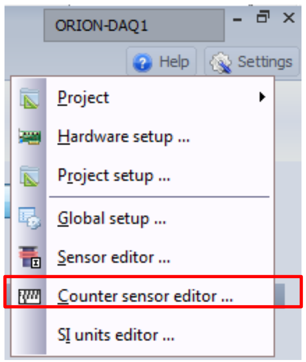


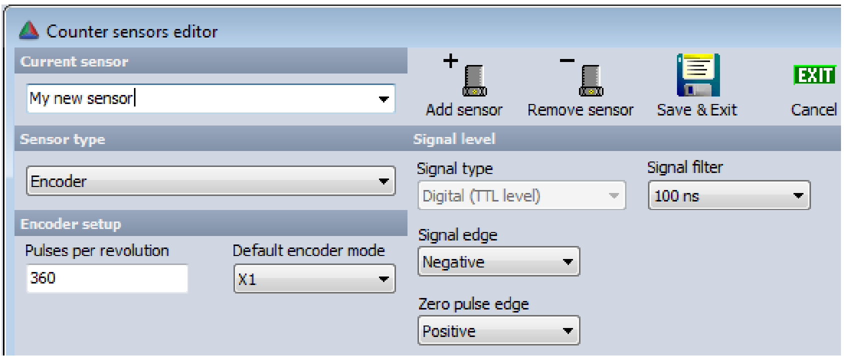
Under resolution the angle resolution can be set. The '*' indicates the native resolution of the sensor. Higher and lower resolutions are achieved via interpolation or dividing, done by the CA-CPU.

For angle domain measurements, Dewetron CA supports 4 kinds of sensor.

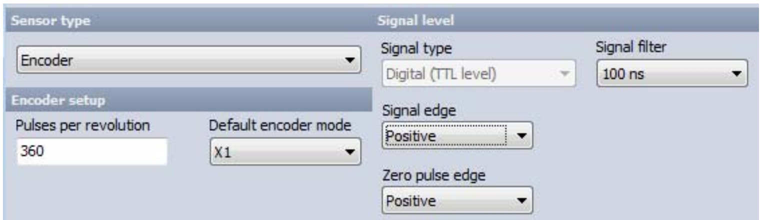
Encoder:	CDMA,B,TRG	3 signals	digital
CDM Sensors:	CDMA, TRG	2 signals	digital
Geartooth with missing teeth:	CA, CDMA	1 signal	analogue, digital
Geartooth with double teeth:	CA, CDMA	1 signal	analogue, digital

The major sensors are predefined in the Angle sensor setup. But if a used sensor is not available in the list, it can be added in the counter sensor editor of DEWEsoft.

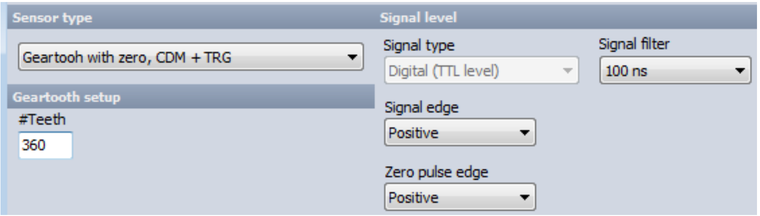




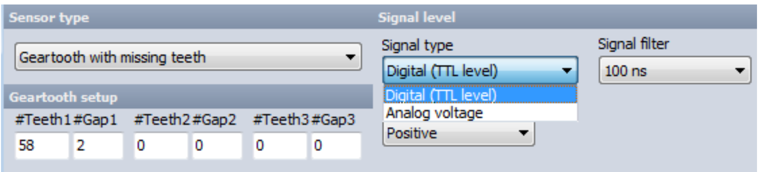
Here a new counter sensor can be defined. Add sensor will create a new sensor, and the sensor can be renamed, and settings can be applied depending on the selected sensor type. For every sensor type signal filter and signal slopes can be defined.



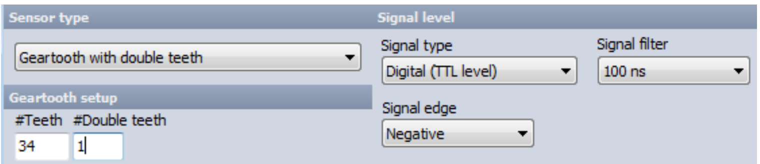
in encoder mode pulses/revolution and counting mode must be set.



CDM + TRG sensors only require the pulses/revolution.

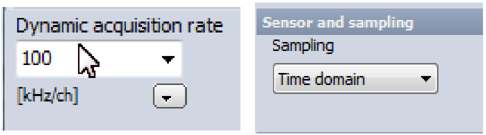


A 60-2 sensor is defined via the geartooth with missing teeth. Here the number of teeth and the number of missing teeth are defined. Additionally signal type can be defined for this sensor type, and the signal can be digital or analogue. Depending on this setting, the sensor is only available for selection if the input can handle the signal type.

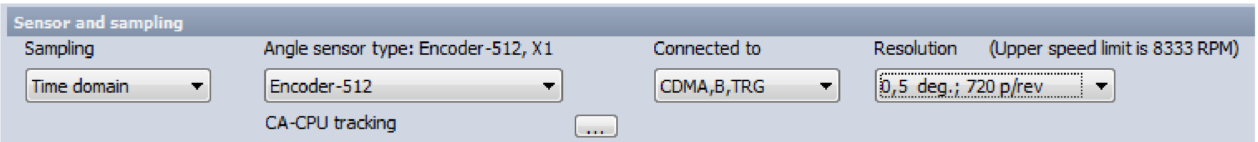


For a geartooth with double teeth, the number of teeth and the number of double teeth are specified.

3.2.2 Time Domain

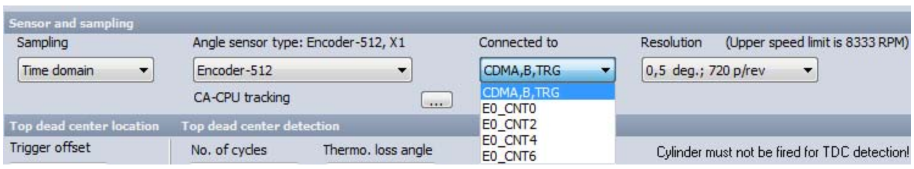


For time domain sampling sensor settings are similar. The only difference is that the sampling rate must be defined in the analogue channel set up first.

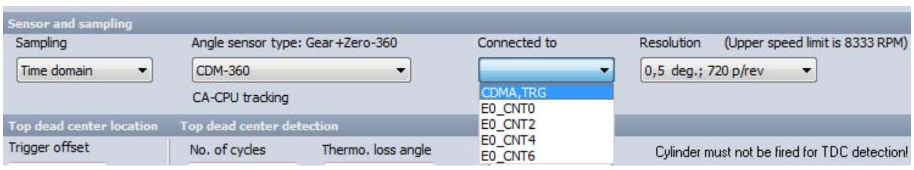


Beside the selected angle resolution the maximum engine speed is shown which could be achieved with the set sampling rate and the selected resolution.

Depending on the selected angle sensor, it can be connected to various inputs.

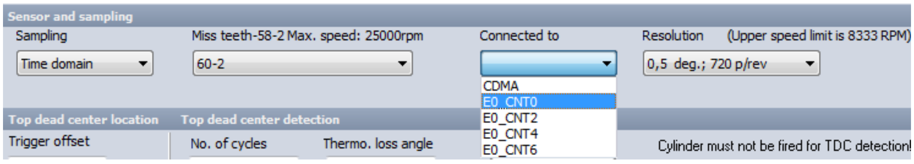


Encoder can be connected to CDMA,B,TRG on the CA-CPU input, or to counter inputs if they are available on the CA system.

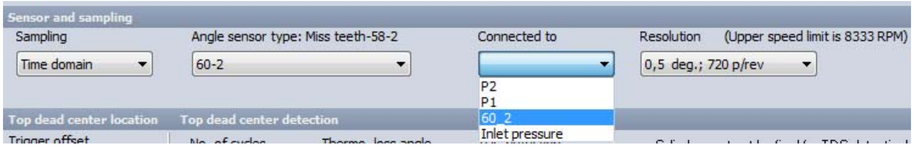


The same with CDM sensor. This could be connected, at CDMA and TRG input of the CA-CPU, or to a CNT input.

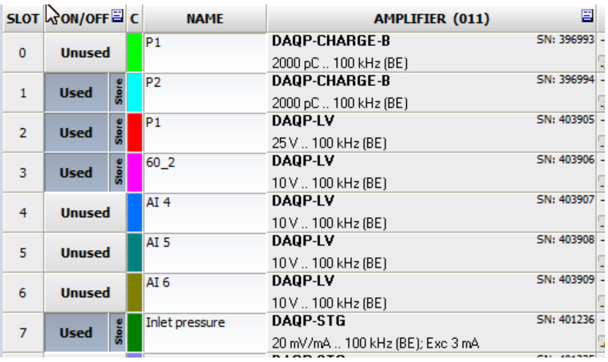
For the Geartooth with missing teeth , or double teeth, the sensor connection depends on if sensor has analogue output or digital output.

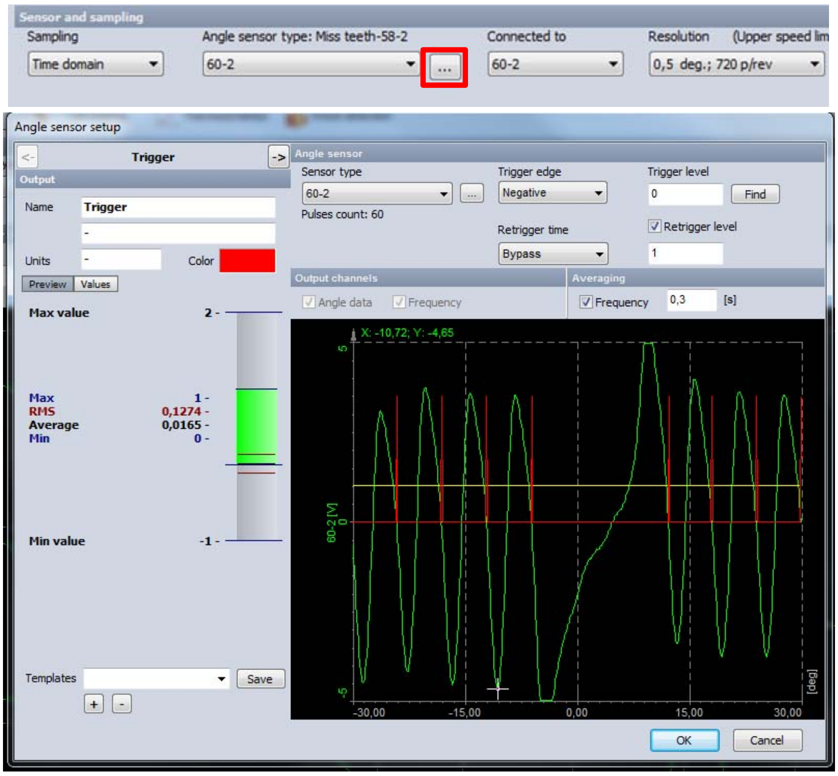


If a 60-2 sensor (geartooth with missing teeth) is defined as a digital sensor, in the counter sensor setup, it can be connected to CDMA, or to any counter input.



If it is defined as analogue, it must be connected to an analogue input channel.





Under properties, the trigger levels must be set up. First the trigger edge is defined, according to the signal (see chapter 3.2.1 about 60-2 slope detection). Also trigger and retrigger level are set. It is recommended to use retrigger level to avoid false triggers. False triggers will disturb CA operation, caused by incorrect angle information.

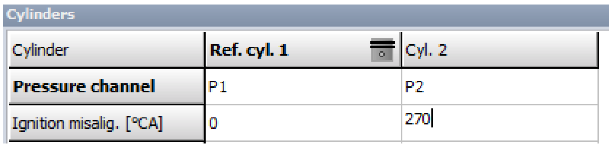
Retrigger: After a trigger occurs, the retrigger level must be crossed, after which the trigger is armed again. So noise around a trigger will not cause any false triggers.

The possible routings for angle and time domain are shown in the table.

Angle domain	Type	CA-CPU	no CA-CPU
Encoder	TTL	CDMA,B,TRG	*
CDM	TTL	CDMA or CDMB, TRG	ext.Clock, ext.Trg. on DIO-connector
Gearthooth with missing, double teeth	TTL	CA or CDMA	*
Gearthooth with missing, double teeth	Analogue	CA	*

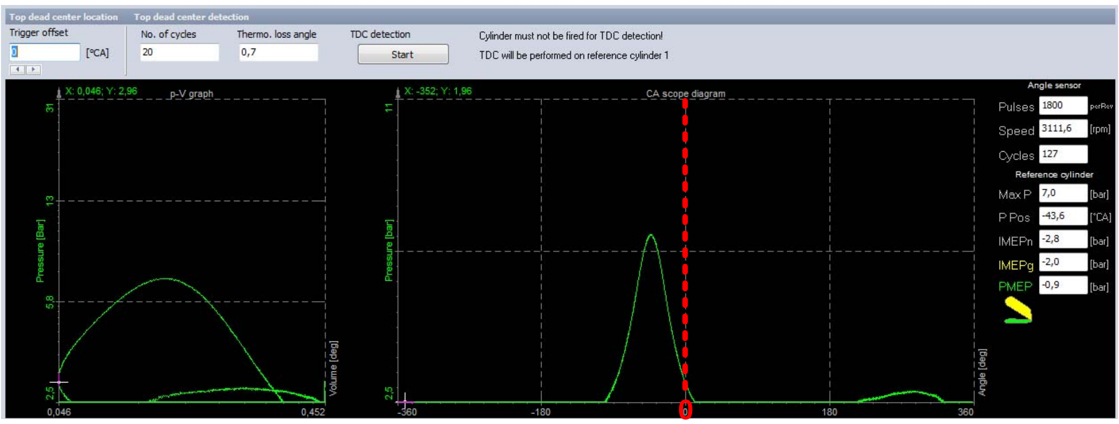
Time domain	Type	CA-CPU	no CA-CPU
Encoder	TTL	CDMA,B,TRG or CNT-Input	CNT-Input
CDM	TTL	CDMA, TRG or CNT-Input	CNT-Input
Gearthooth with missing, double teeth	TTL	CDMA or CNT-Input	CNT-Input
Gearthooth with missing, double teeth	Analogue	analogue Input	analogue Input

3.2.3 TDC Detection

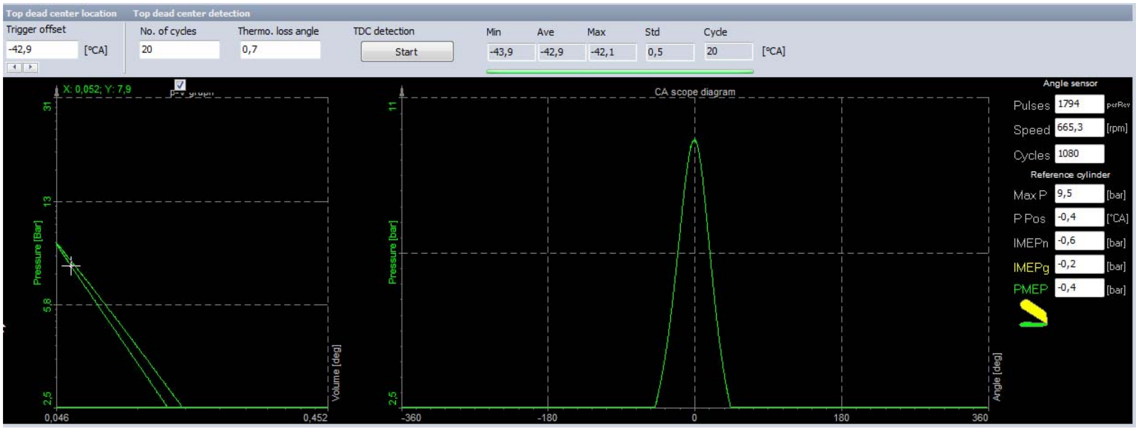


Top dead centre detection is used to shift the reference cylinder pressure to 0deg. An angle sensor can rarely be mounted, so that Top Dead Centre (TDC) of the reference cylinder fits to 0deg of the angle sensor.

The offset between angle sensor zero and TDC position of the reference cyclinder is called trigger offset. This can be entered manually, or it can be measured.



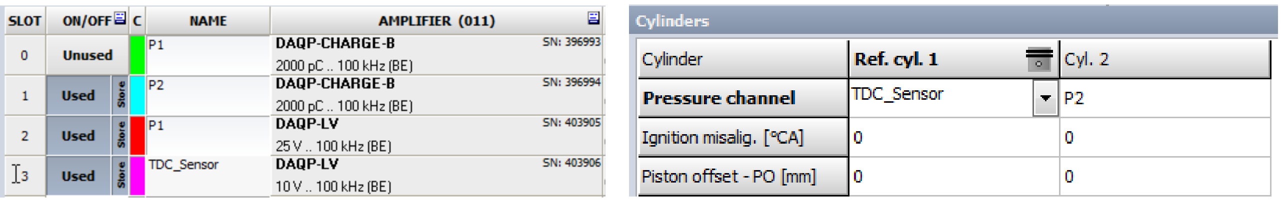
This picture shows the offset when the engine is cranked (not fired). The offset can now be entered manually or automatically measured and applied. For automatic measurement (START), the no of cycles has to be entered. CA will measure the average offset of the set of cycles automatically. The Maximum pressure will appear before the real TDC of the piston, which is caused by thermodynamic losses and blow by. That's why the measured value is corrected with the thermodynamic loss angle.

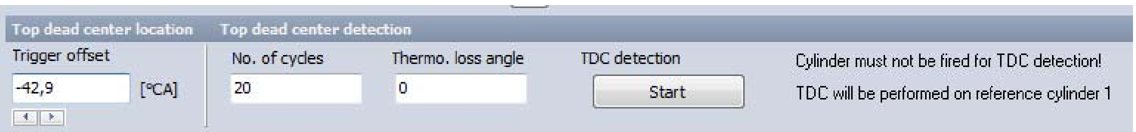


After TDC detection is finished, the average value (which includes the Thermodynamic Loss angle) will be set automatically for the trigger offset.

The example above was using the installed pressure sensor to measure the TDC. This is a very convenient and fast way of doing it. The only variable is the thermodynamic loss angle.

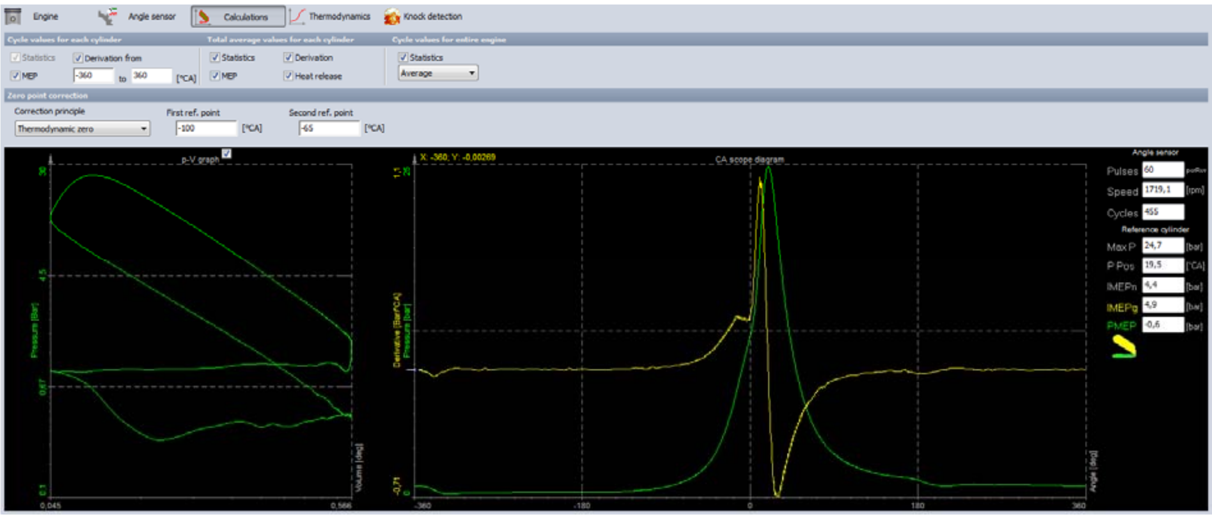
Instead of a pressure sensor, a TDC sensor can be used, whereby the TDC sensor will be connected to an analogue input and applied to the reference cylinder in the CA setup. The thermodynamic loss angle must be set to 0, and the automatic TDC detection can then be started again. After the measurement the pressure channel must be applied to the CA setup.





3.3 Calculations, Zero Point Correction

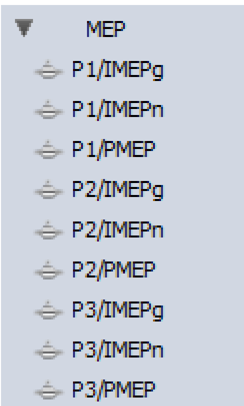
In the calculations section the derivation, MEP, statistic values and the zero point correction of the pressure signal will be defined. Also the pV-diagram, pressure curve, and derivation of the pressure signal is shown here., where on the right side of the display the major parameters are indicated, for a fast check during set up.

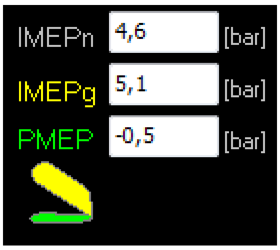


Under Cycle values for each cylinder, the result channels for mean effective pressure (MEP), and also the derivation can be selected for calculation.

If **MEP** is checked: IMEPg, IMEPn, and PMEP will be calculated for each cycle.

Indicated mean effective pressure g (IMEPg) = gross [bar]
Indicated mean effective pressure n (IMEPn) = netto [bar]
Pump mean effective pressure (PMEP) [bar]

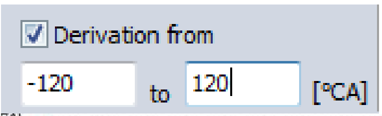




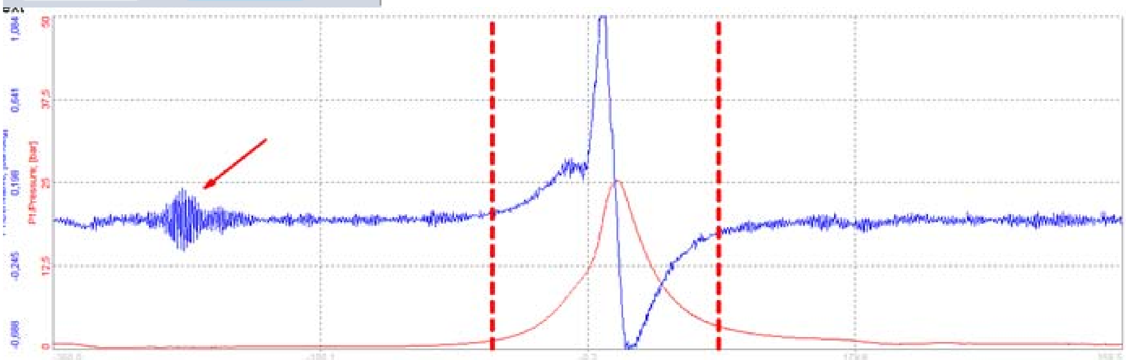
IMEPg + PMEP = IMEPn

If **Derivation** is checked, it will calculate the derivation cycle based parameters for every cylinder.

Max D	[bar/deg]
Max D Pos	[deg]

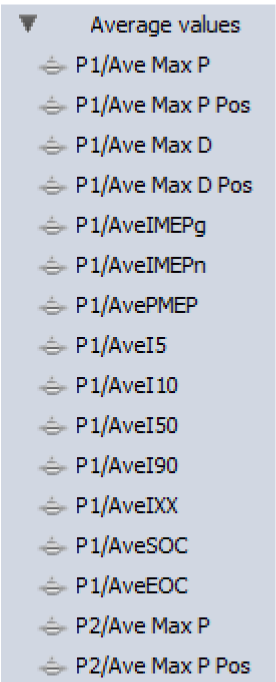


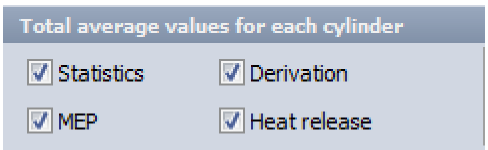
Derivation provides a FROM – TO range selection. In this case the maximum derivation will be searched in the area which is specified.



The upper example shows some noise on the derivation of the pressure signal, caused by an opening or closing valve. The range selection will exclude this area for the derivation result.

Total Average:

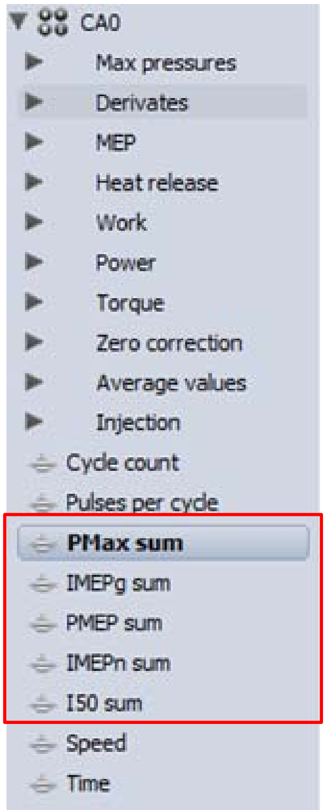


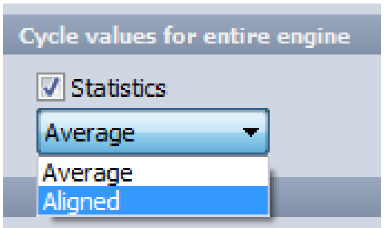


Total Average will calculate the overall average of the cycle based values, and will return 1 value at the end.

Statistic:	Ave Max P, Ave Max P Pos
MEP:	AveIMEPg, AveIMEPn, AvePMEP
Derivation:	Ave Max D, Ave Max D Pos
Heat release:	Ave Ixx, AveSOC, AveEOC

Cycle based average of engine:





If this option is checked, statistic values are calculated over the cycle based results of each cylinder. The result channels are indicated with NAME + **sum.**

The picture on the left of the display will show these results.

If **<u>Average</u>** is selected, PMax sum is the average over all cylinders.

(P1/Max P + P2/Max P + P3/Max P)/3 = PMax sum = 1 value/cycle

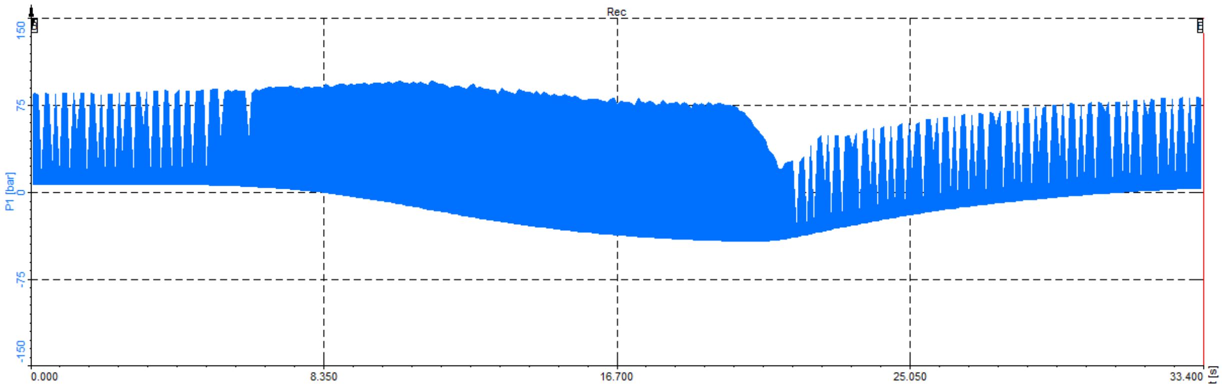
If **<u>Aligned</u>** is selected, PMax sum will output the maximum pressure of every cylinder aligned to create a single channel.

P1/Max P, P2/Max P, P3/Max P, P1/Max P, P2/Max P, P3/Max P, P1/Max P,…… = 3values/cycle.

In this case the maximum pressure of every cycle and every cylinder is applied to one channel, this could be visualized in the recorder to see the maximum pressure fluctuation of each cylinder in one channel.

For MEP and I50 values it is done in the same way.

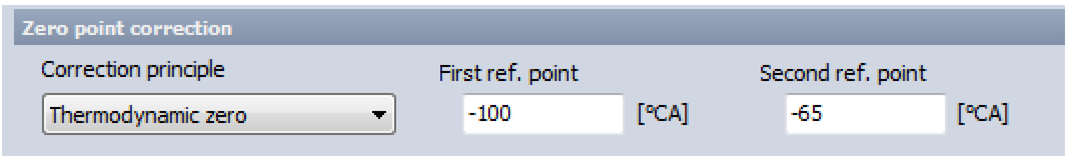
Pressure channels which are used for indicating, are typically charge based sensors. These sensors can handle high temperatures up tp 200deg, but they cannot measure the absolute pressure, and the offset changes with temperature (engine load).



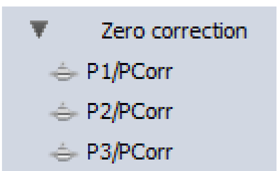
However, the absolute pressure is required for all the CA calculations, so the offset must be corrected.

Dewetron CA provides 3 different correction principles:

Thermodynamic zero:

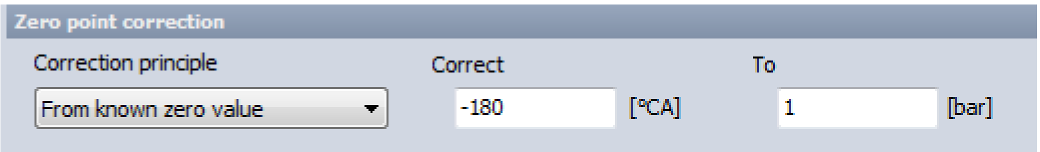


With this method, two points (default -100, -65deg) of the pressure curve, the volume and pressure are measured. Out of the volume and pressure difference, and the entered polytrophic coefficient, the inlet pressure is calculated. The pressure curve is shifted (offset only) to get the right pressure at bottom dead centre.



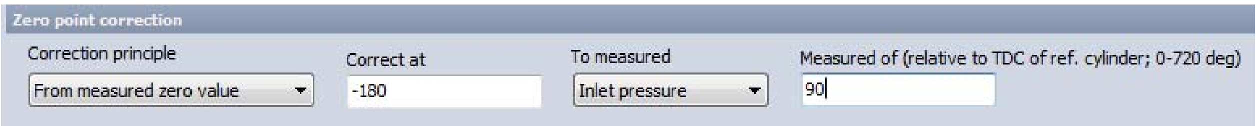
The zero correction offset is also provided as a result output, for each cylinder.

From Known value:



Using this method the pressure curve is set to a defined (static) value.
“Correct” specifies the position related to TDC where it should be corrected.

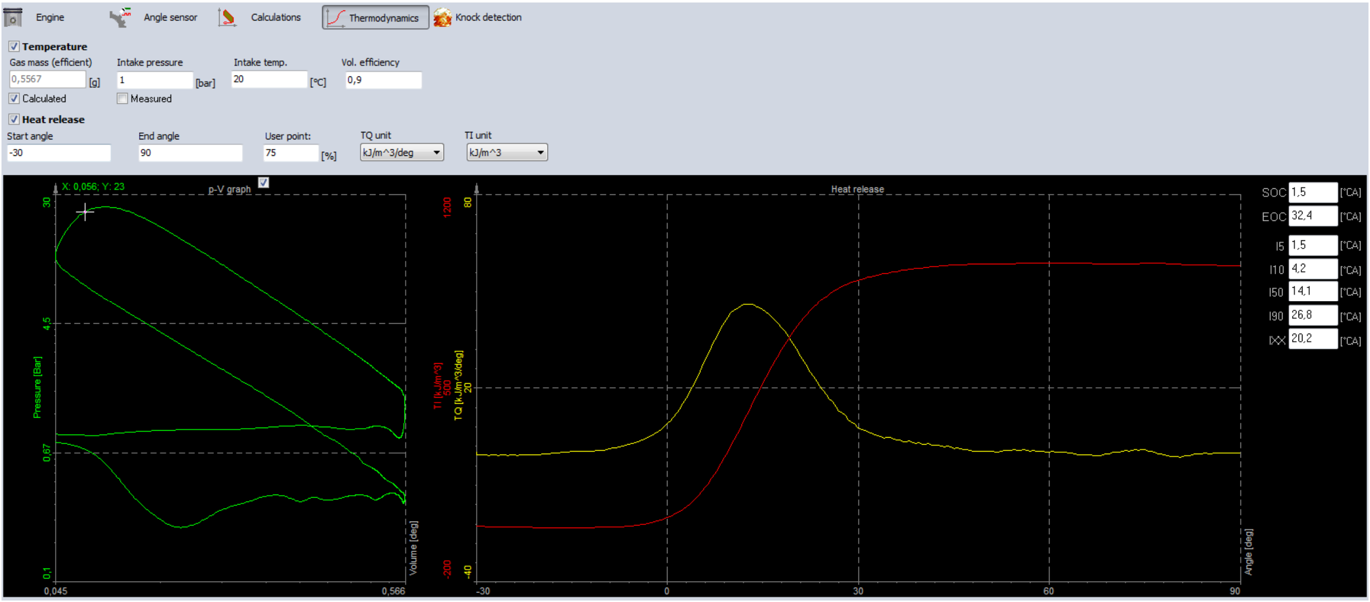
From Measured Value:



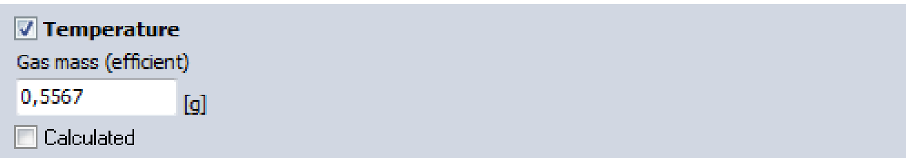
Finally if selecting ‘From Measured Value, a pressure sensor is used which measures the absolute pressure at the inlet manifold of the engine. From the template we can define where the inlet pressure should be measured related to TDC. So we can define a position where the inlet pressure is stable (near bottom dead centre).
“Correction at”, defines the position on which the pressure should be corrected.

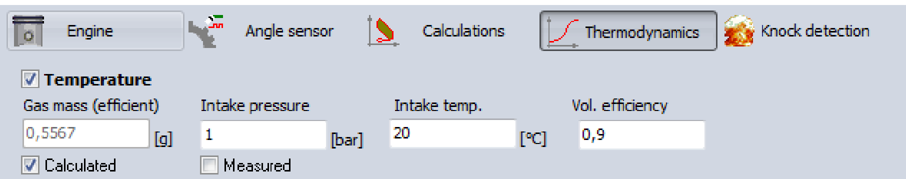
3.4 Thermodynamics, SOC, EOC, I50

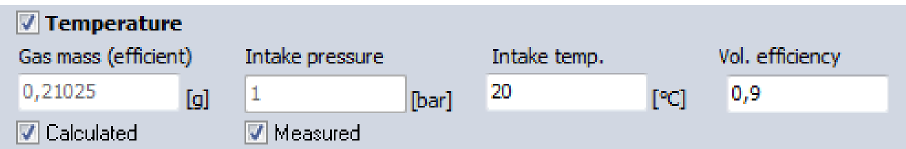
In the thermodynamic section, the temperature and heat release calculations are set up. Temperature over crank angle, heat release, integrated heat release, SOC, EOC, and also the burned mass fraction levels are calculated.



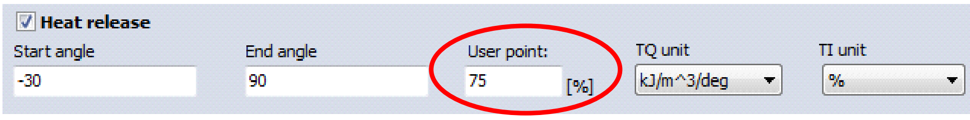
For the **Temperature** calculation the gas mass is required. This can be either manually entered, or calculated. If from Calculated is used: the intake temperature, intake pressure, and also the volumetric efficiency (0.9= 90% filled) must be entered. If measured is selected, the intake pressure is measured from the zero point corrected high pressure curve.

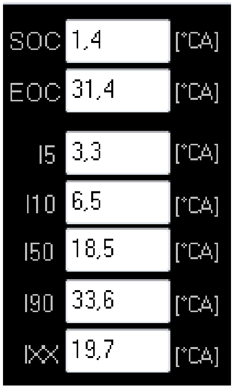






For the **heat release** calculation, the start and end positions for calculation must be defined. The typical range is from -30deg to 90deg, an earlier injection start angle must be set according to injection (-65deg).

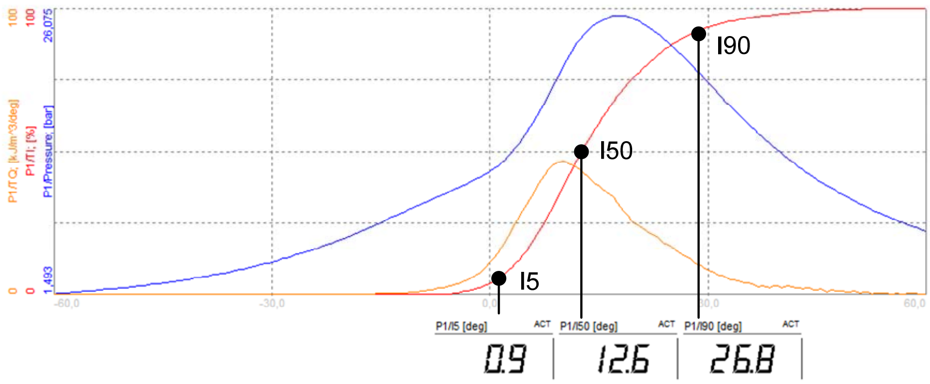


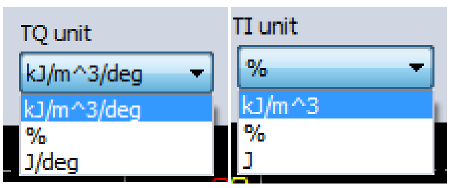


SOC, EOC and also the burned mass fraction (BMF) points I5, I10, I50, I90 and Ixx (User point) are calculated if heat relase is activated.

Depending on fuel type (Diesel/Gasoline) selected in the engine setup (4.1) SOC is defined differently: Gasoline where BMF =5%, and for Diesel BMF crosses 0%.

Burned mass fraction is calculated out of integrated heat release TI. The maximum of the integrated heat release corresponds to 100%, and the angle positions for I5%, to I90% are extracted .





For heat release (TQ) and integrated heat release (TI) various output formats are available.

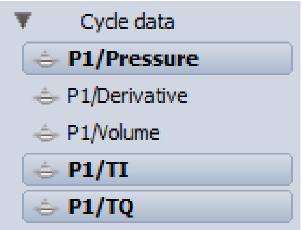
TQ:

kJ/m³/deg	related work[kJ] to 1m³ per 1deg volume is related to Vs = swept volume
%	scaled to sum of 100% (integrated signal =100%)
J/deg	related work[J] per 1deg

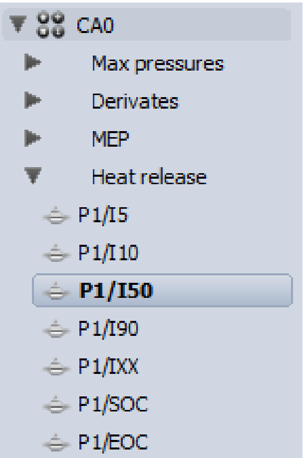
TI: Integrated heat release

kJ/m³	work[kJ] to 1m³ per 1deg volume is related to Vs = swept volume
%	scaled to maximum of integrated value = 100%
J	related work [J]

Thermodynamic Result Channels:



Angle based results(-360, 360 deg) are heat release (TQ) and integrated heat release (TI).



Cycle based results (1 value/ 2rev.) are:

Ixx, I5 to I90 burned mass fraction, and also SOC and EOC.

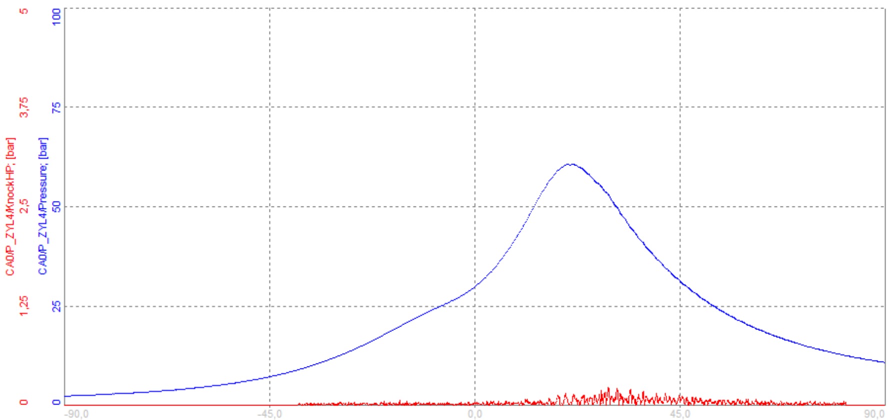
3.5 Knock detection

3.5.4 Knocking Basics

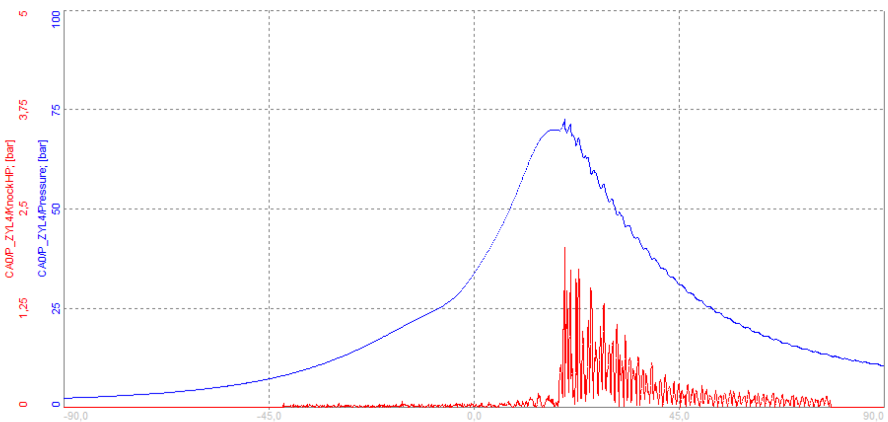
Knocking is an uncontrolled burning of fuel in gasoline and gas engines. In normal operation, the fuel-air mixture is ignited by the spark plug and burns continuously. When the engine is knocking, a self-ignition starts in the outer side of the combustion chamber causing high pressure transients, which will overload the engine mechanically and thermally. This can seriously harm the engine’s parts, especially the piston. The knock detection algorithm indicates this knocking, so that the user can react to this abnormal condition.

The pressure signal is the input into a knocking filter which lets the higher frequency components pass around the maximum cylinder pressure to be investigated further. The knocking frequencies are typically between 5 kHz – 12 kHz.

Here the maximum pressure value is one indication for knocking.

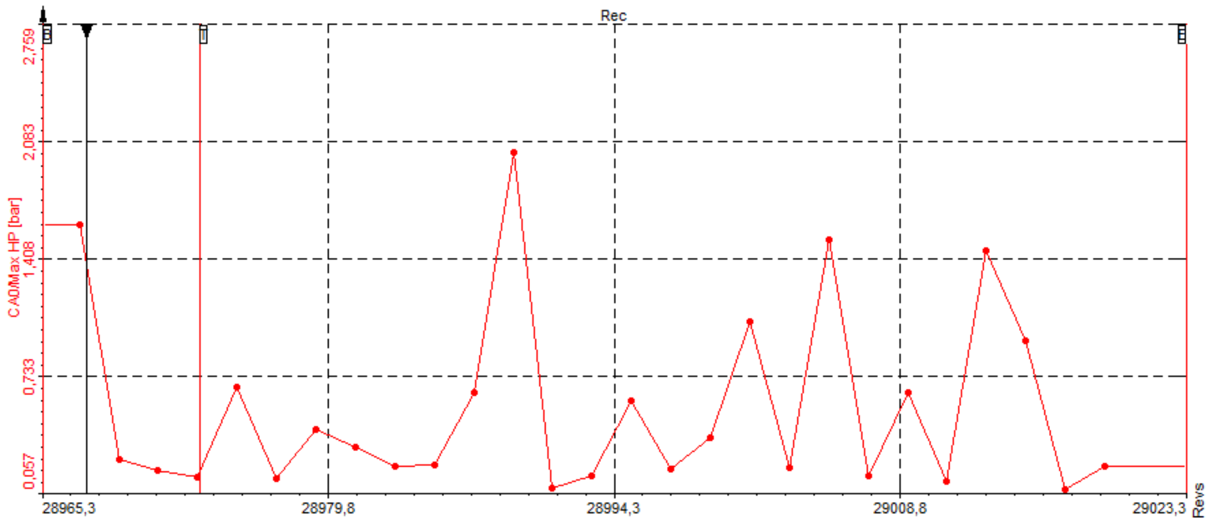


The example shows a standard internal combustion pressure curve.
The high-pass (HP) filter (red) extracts frequency components which are above the cut-off frequency.



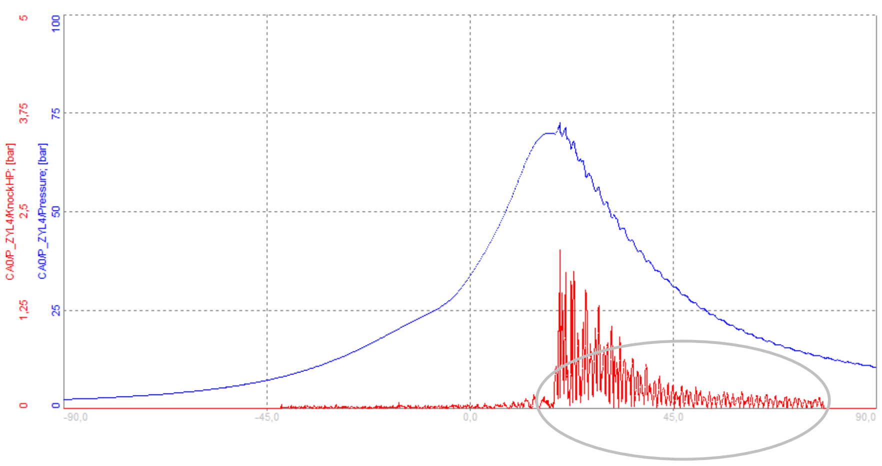
In comparison to the upper curve, we can see pressure fluctuations on the falling slope of the pressure curve (blue). The combustion pressure curve can reach very high pressures >>100 bar, so sometimes it is hard to observe it on top of the main combustion pressure curve. If we only extract the high frequency components above 5000 Hz we can analyse knocking much easier. The high-pass filtered pressure signal (red line) indicates now the pressure fluctuation around the maximum of the pressure curve.

Another important value is the maximum pressure of this high-pass filtered signal (red), which can be extracted and visualised in a recorder display, immediately reflecting the pressure transients of the previous cycles.



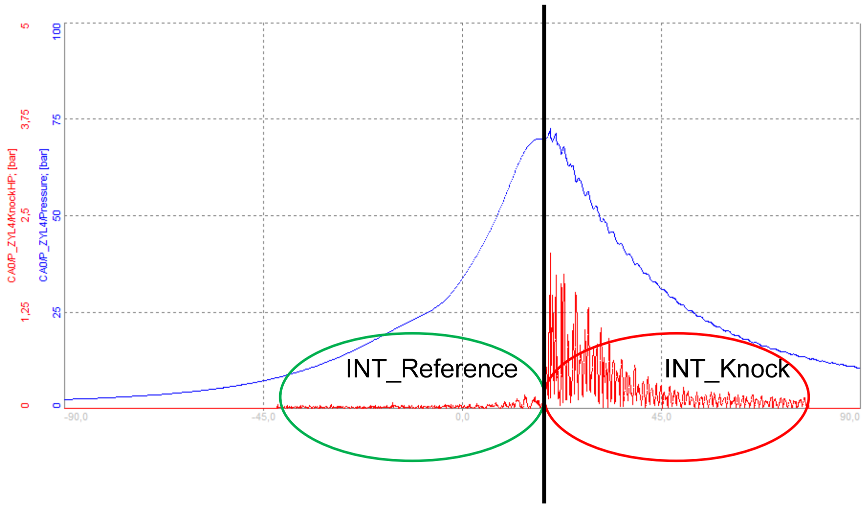
This value is a good indication of knocking, but in some circumstances it can show incorrect information.

When the pressure curve is very noisy, or a spike caused by some external electrical signal, is present, the maximum value extracted out of the high-pass filtered signal shows high values, which are not related to knocking.



Knocking typically starts at the pressure maximum, and continues on the falling slope of the pressure signal.
So instead of taking only one value (peak), we could integrate the high-pass filtered signal of the negative part of the pressure slope.

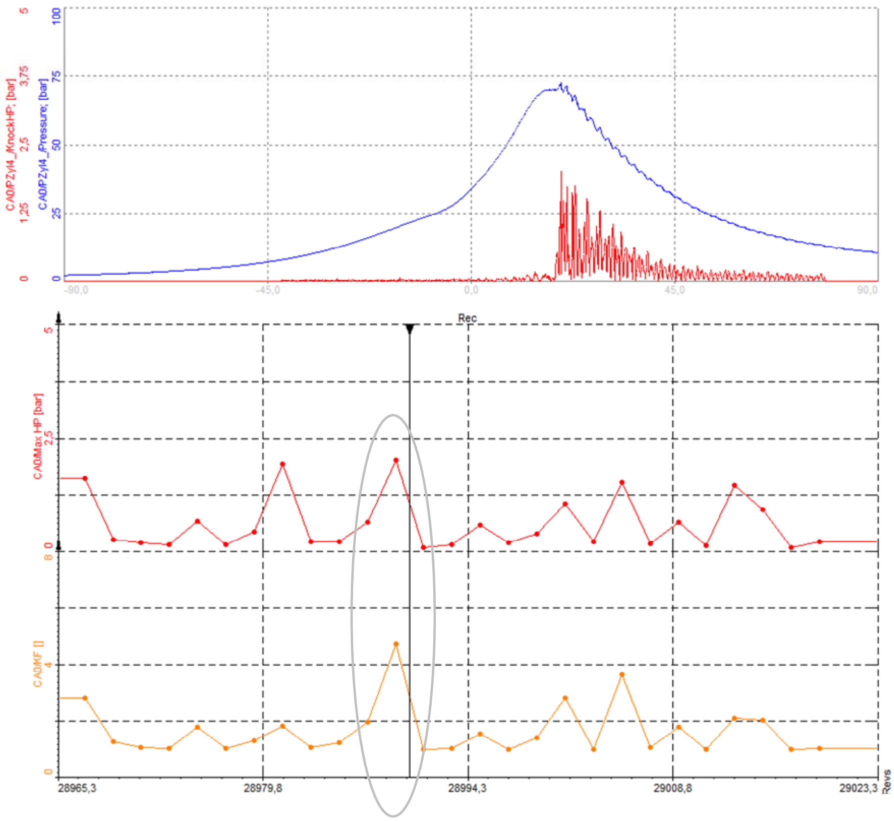
This integrated value (**k**nock **i**ntegral = KI) will give a more stable value for single transient noise peaks. The high-pass filter outputs the absolute pressure (positive values only). So if we integrate the signal, we can reject a single transient, but will also sum up the noise which may be present all the time. Depending on the engine speed, the noise will also increase and hence the integrated signal also. With a single integration it will be hard to determine: Is this knocking, or simply noise?



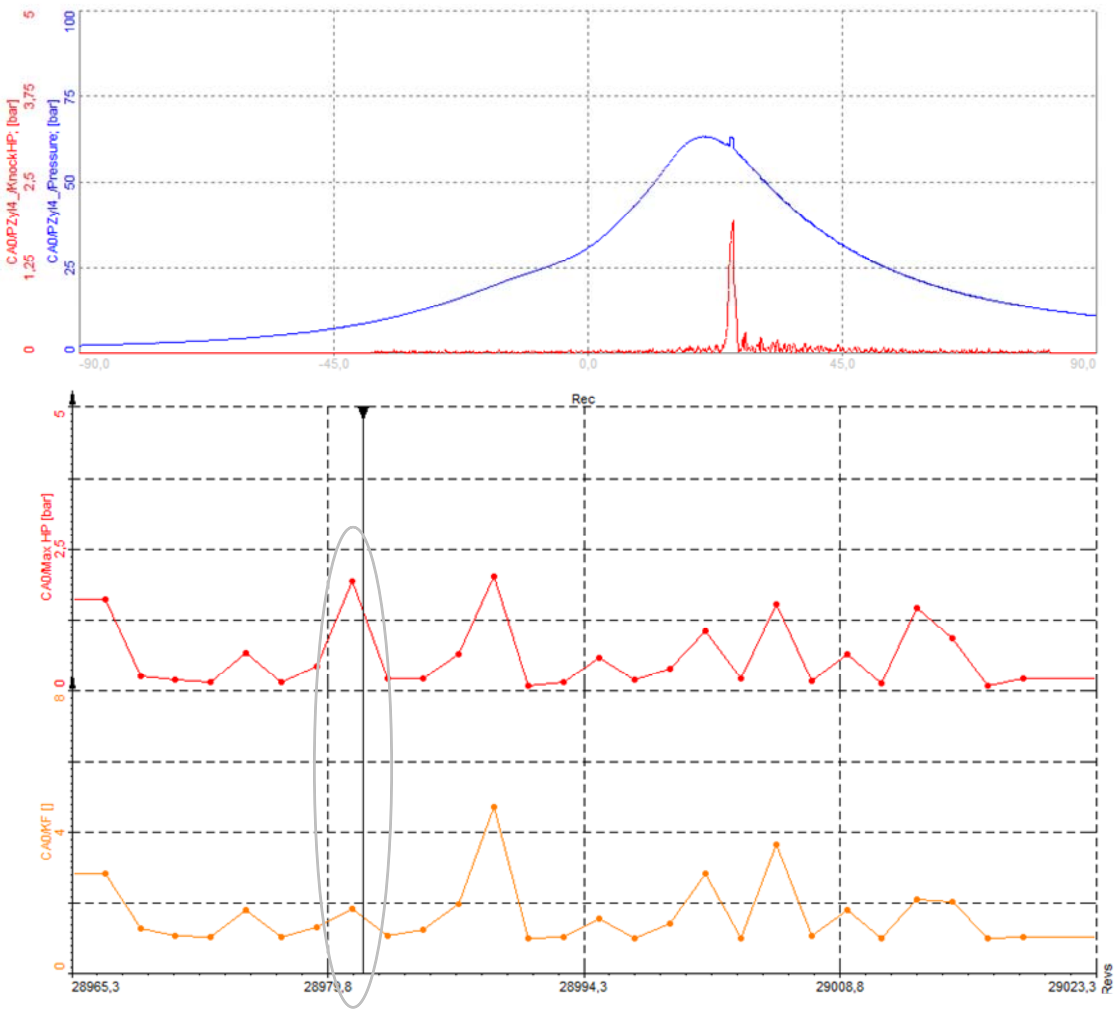
To overcome this, the integration can also be done before the maximum pressure, and the results before and after can be compared to each other.

Knock**F**actor = INT_Reference / INT_Knock

So the KF will give a weighted result related to knocking.
Without any knocking present the KF is around 1.
The integration windows (reference window; knock window) will separate at the **average maximum** pressure position.

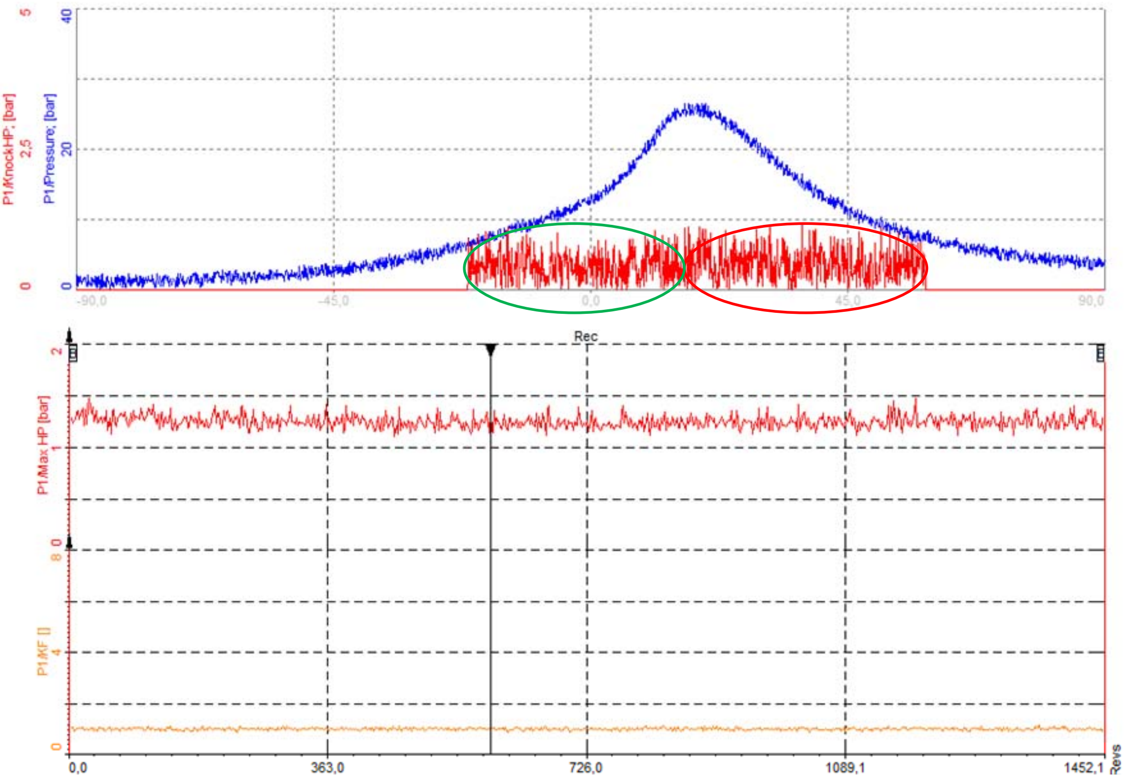


This example shows the pressure curve (blue) and the high-pass filtered signal (red) in the upper diagram, and then below, the maximum pressure extracted from the high-pass filtered signal (red) and also the calculated KF (orange). Both maximum graphs show peaks, so knocking is present and could be detected in either way – as long as no spikes are present.



A bit earlier in time, we can see an error spike (red curve). While the maximum of the filtered signal still shows a peak here, the KF algorithm does not indicate knocking at all, and the value obtained is close to 1.

So **robust knock detection** is provided, even if there are accidental spikes in the signal.



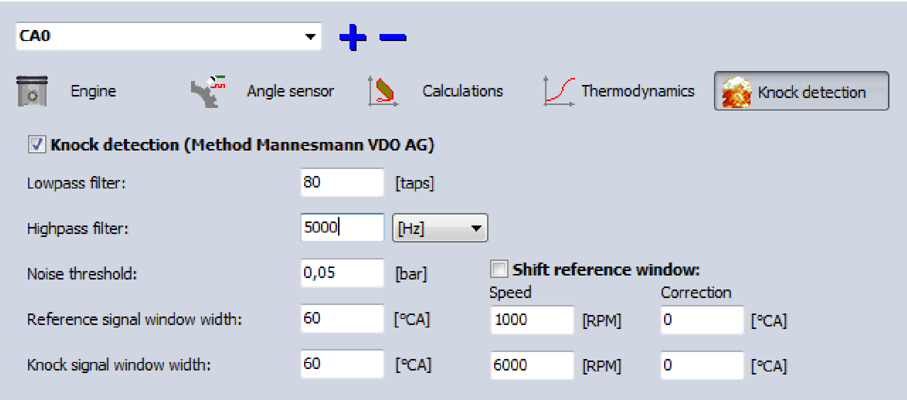
If the pressure signal contains noise, the KF (orange) will stay around 1,
because integrated noise is similar in the reference (green) window and knock (red) window.

3.5.5 Setup of Knocking (Mannesmann VDO AG)

In the ‘Knocking Basics’ section, it was described which signals can be obtained from the knock detection algorithm.

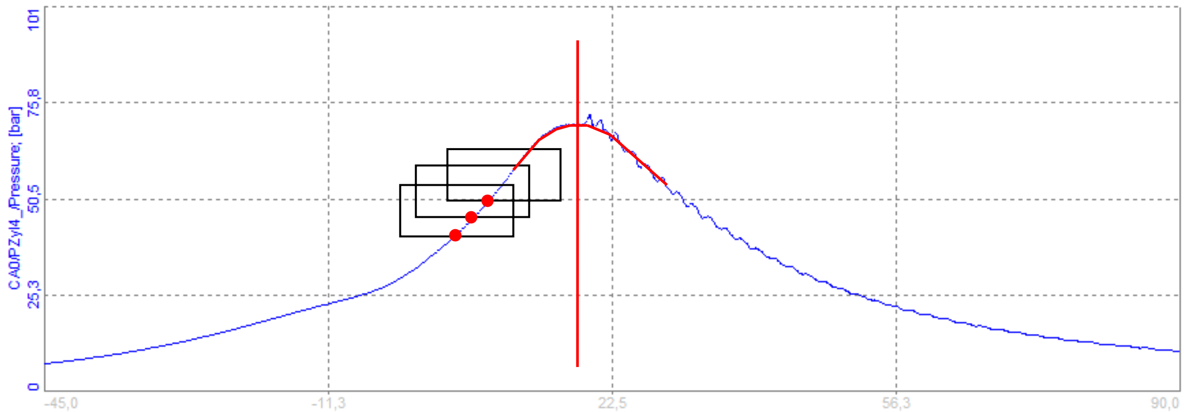
- HP filtered pressure signal
- Maximum value of HP filtered pressure signal
- Knocking factor

To get this value, knock detection must be enabled in the CA setup in Dewesoft.



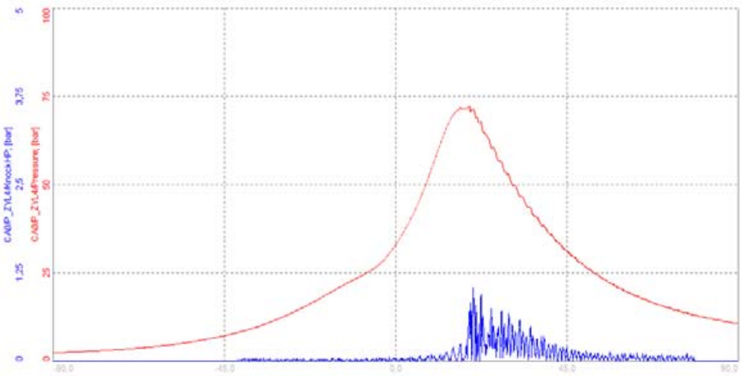
Low-pass filter: The reference window and the knocking window are separated at the maximum pressure point (red curve), without the influence of noise or already present knocking peaks. A running average filter is used here, with setup taps equaling angle resolution. If the angle of the CA is set to 0.1 deg and 80 taps are set, this will create a moving average window (smooting) of 80*0.1 deg= 8 deg. Out of the filtered (smoothed) curve the maximum pressure position is the knock and reference window separation position.

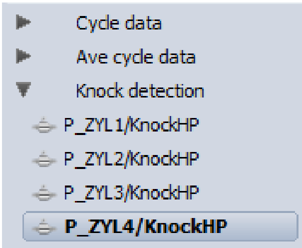
recommended value [deg]: 4-10 deg → Info TAPS = xdeg/angle resolution!!!!



<u>High-pass filter:</u> Here the high-pass filter frequency is set in Hz. The pressure curve is high-pass filtered (blue) and the result can be shown in the CA-Scope. The channel is named *CylinderChannelname*/**KnockHP.**

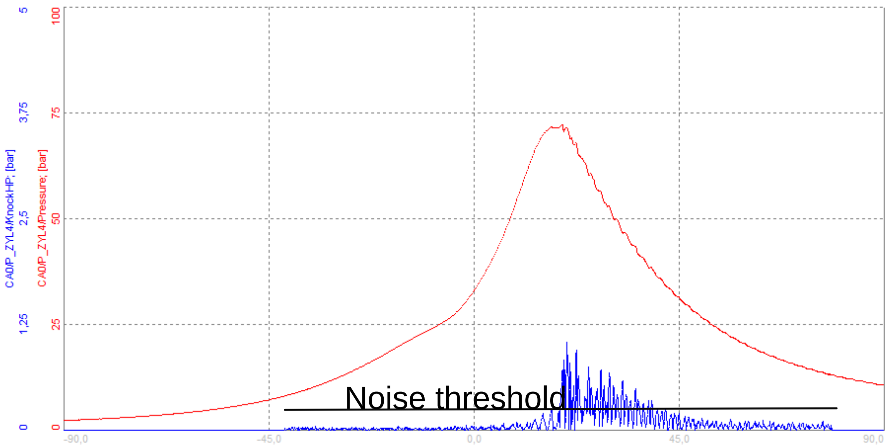
recommended value [Hz]: 5000 Hz





<u>Noise threshold:</u> For the Knock Factor, the quotient of the integrated signal of the Knock window and the Reference window is obtained. If the pressure value is lower than the set threshold, then the set threshold value will be used for integration. This is done to reduce the influence of different base noise levels between the reference window and knocking window.

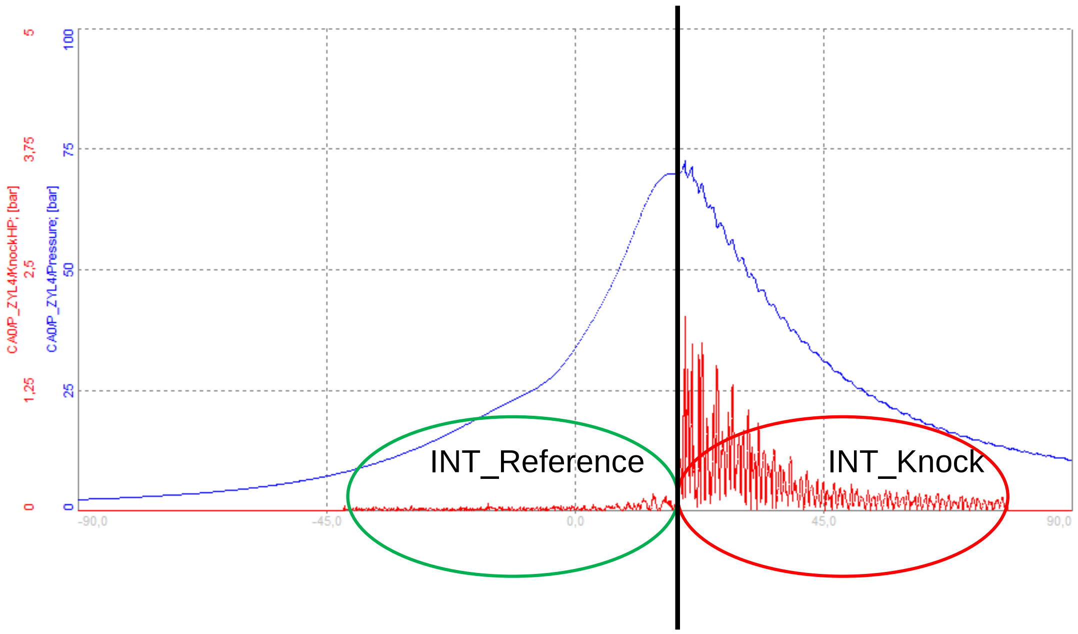
recommended value [bar]: 0.1 – 0.5 bar



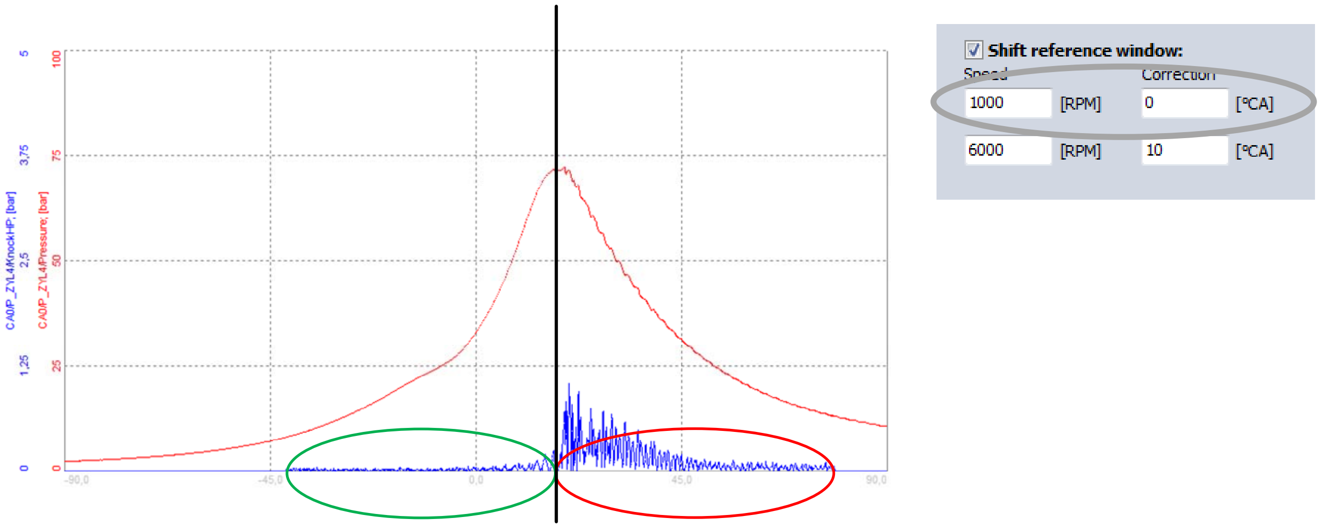
<u>Reference, Knock signal window width:</u> The width of the reference window and the knock window is defined here. It is recommended to set both windows to the same length. If this is done and the noise threshold is set to a reasonable level, the KF will be about 1 without knocking. If the window sizes are set differently, the base value without knocking is the quotient between the two window lengths.

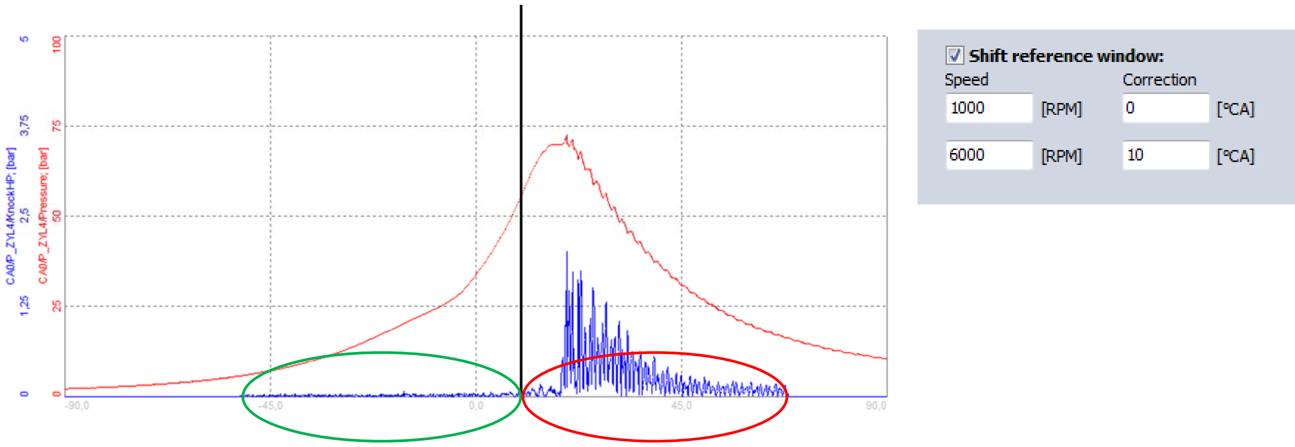
e.g.:

reference window size [° CA]	knocking window size [° CA]	knocking factor KF, base value
30	30	1
60	30	0.5
30	60	2



Shift reference window: At higher RPM it can happen that knocking already starts before maximum pressure.
In this case part of the knock signal will fall into the reference window area, which reduces the knocking factor value. To avoid this, the knocking window and the reference window can be shifted depending to the actual engine speed.



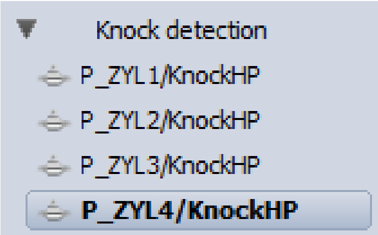


In the upper two examples, the Reference window and the Knocking window are shown at different engine speeds with the 'Shift reference window' option selected.

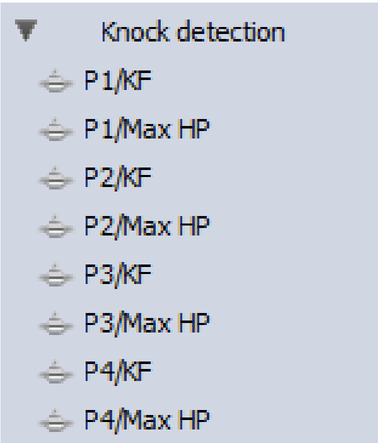
The first diagram at lower rpm shows the separation line between reference and knocking window exactly at the maximum pressure point.

The second diagram shows the shifted separation line (dependant on current rpm), and accordingly both integration windows shifted to the left by 10° crank angle. If any knocking before the maximum pressure point occurs now, we don't get an increased KF reading, as no knocking leaks into the reference window when shifted correctly.

<u>Where are the output channels of the Knocking filter located?</u>



If CA-Scope is selected (2D diagram), the KnockHP channel is located in the Knock detection group for all cylinders.



If a recorder window, or a digital instrument is selected, the KnockFactor (KF) and the maximum value out of the high-pass filter for each cylinder can be selected.

Background Information

Combustion Analysis is mostly carried out in angle domain, in other words, the CDM sensor is clocking the A/D card. In this case, every sample represents a specific angle value depending on the CDM resolution. So the pressure curve is measured at fixed angle intervals (e.g. 0.1 deg), independent from engine speed.

If we now take a look at time, the interval between samples will change with the engine speed. So we get different sampling rates at different engine speeds - a normal IIR filter cannot be used in this case.

A high-pass filter is created from a moving average window with a specific width, which is subtracted from the original signal, and as with all filters, a minimum sampling rate is required for the filter to work properly.

minsamplerate [Hz] >= high-pass frequency [Hz] * 9 /2

Example:
5000 Hz * 9 / 2 = 22,500 Hz
With the high-pass filter set to 5000 Hz a sampling rate of at least 22,500 Hz is required.

22,500 Hz / 3600 * 60 = 375 rpm
At 0.1 deg resolution (3600 pulses per revolution) we need at least 375 rpm for the sampling rate to be high enough for proper filter operation.

In the table below the minimum engine speed is shown depending on resolution and a set HP filter of 5000 Hz.

Resolution	HP filter	min. engine speed
[deg]	[Hz]	[rpm]
0.1	5000	375
0.2	5000	750
0.4	5000	1500
0.5	5000	1875

In case the engine speed is lower than required, the HP filter will be set to a lower frequency until minimum engine speed is reached.

Resolution	engine speed	HP filter max.
[deg]	[rpm]	[Hz]
0.2	600	4000
0.4	600	2000
0.5	600	1600

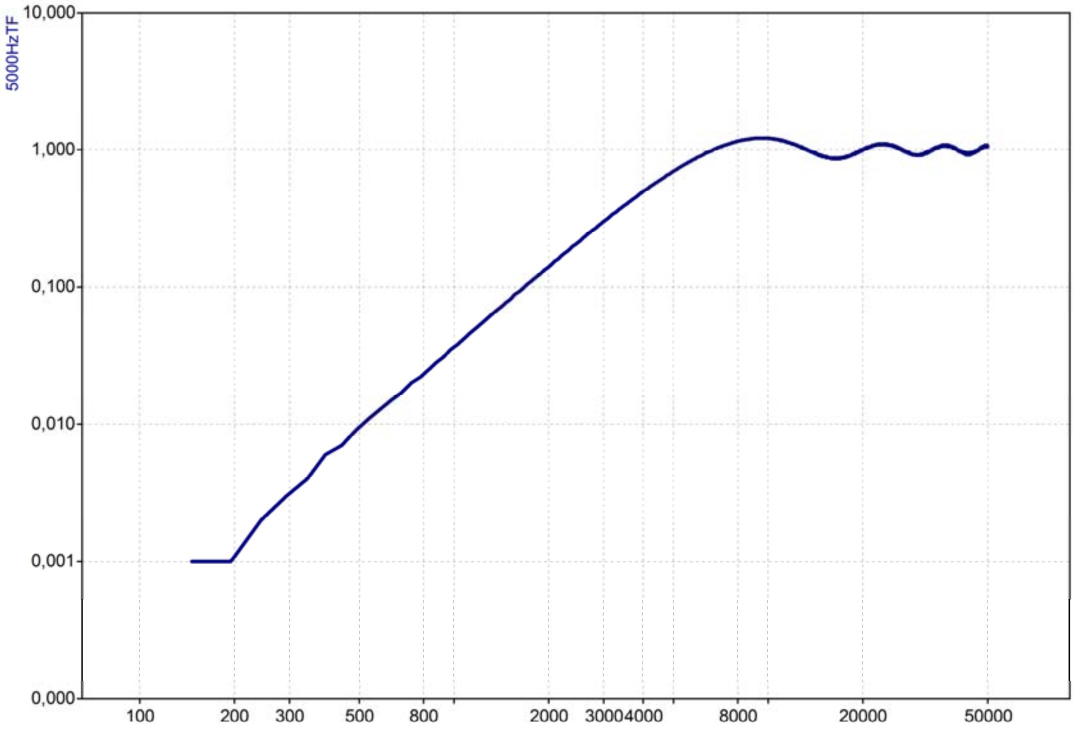
The tables on the left give an example of the maximum possible HP filter frequencies, depending on resolution and engine speed.

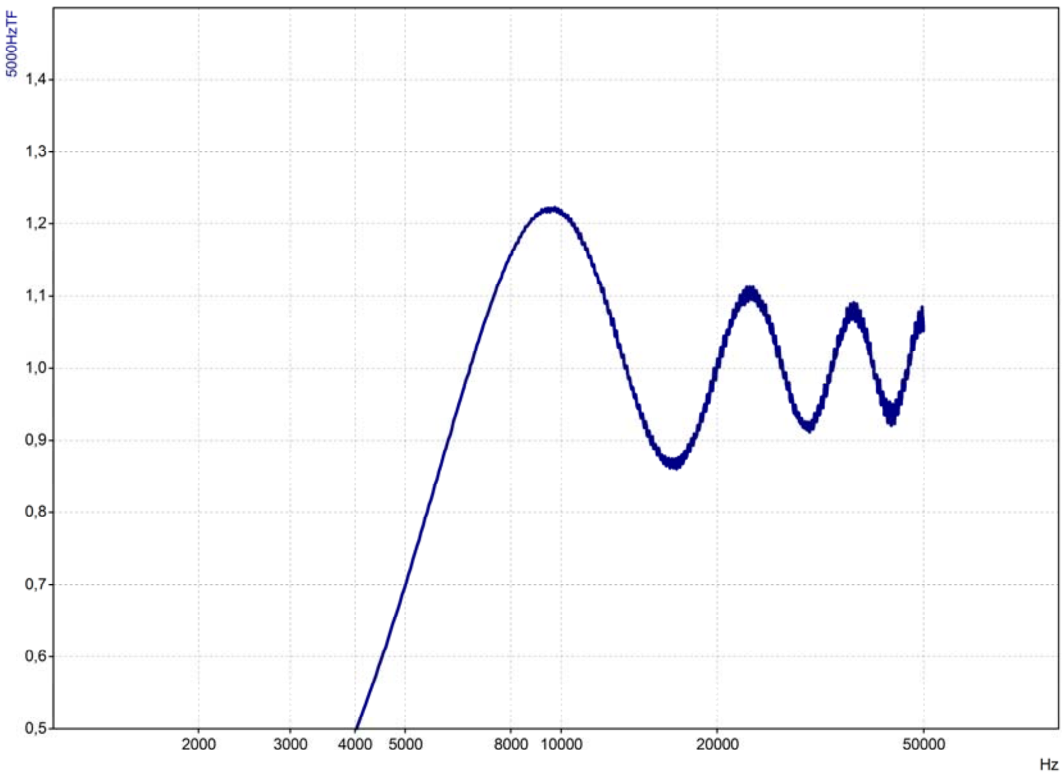
We see that at 0.2 deg resolution and 600 rpm engine speed, the maximum HP filter which can be calculated is 4000 Hz, at 720 rpm the maximum will be 4800 Hz.

Resolution	engine Speed	HP filter max.
[deg]	[rpm]	[Hz]
0.2	720	4800
0.4	720	2400
0.5	720	1920

So if the required engine speed is not reached, the HP filter frequency could be lower than it was set, until the required engine speed (sampling rate) is reached.

Typical transfer function of HP filter (5000 Hz)





Amplitudes can deviate ±25% depending on frequency.

4 CA-Noise Setup

4.1 Introduction and Basics

CA Noise measurement is used to calculate the external noise from an internal combustion engine, using the cylinder pressure. In other words , the cylinder pressure (explosion) causes an external noise.

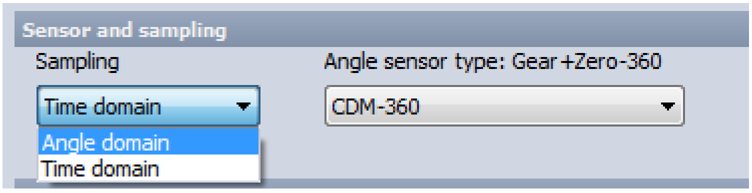
For the measurement the cylinder pressure is recorded and transferred using a filter, whereby this filter reflects the transfer characteristic between internal combustion pressure and outside noise.

4.2 Measurement Modes

The Dewetron combustion analyser (CA) supports two different recording modes.

These modes are:

- Time domain
- Angle domain



In **angle domain** the AD card is clocked from a CDM (Crank Disc Marker) sensor. Such sensors create up to 3600pulses per revolution, and clock the AD card. Depending on the engine speed the sampling rate of the AD card changes.

Example: CDM Sensor with 360pulses/rev engine speed 600rpm/60= 10Hz*360=3600Hz actual sampling rate. If the engine runs at 1200rpm the sampling rate changes to 7200Hz.

In angle domain mode every clock pulse represents a specific angle, so for a CDM 360 sensor 1pulse = 1deg, independent from the engine speed. So there is no need to recalculate the acquired samples to angle data.

The disadvantage is the changing sampling rate. From the example above we can see that, depending on the engine speed we get different sampling rates, and this is the reason why some instruments in the software do not show [s] or [Hz] when using external clocking.

Example: Recorders x axis becomes [rev]=revolutions and FFT x axis become [Ord.]

This is of no real relevance to normal CA measurement because all results of CA are typically based on revolutions, angles, and cycles.

In **time domain** the AD card of the measurement system (CA) is set to a fixed sampling rate, whereby the angle signal from the CDM sensor is recorded with a counter input. In comparison to angle domain mode, the sampling rate does not change with engine speed. So we still have time information, and all instruments such as recorders and FFT displays are referenced to time.

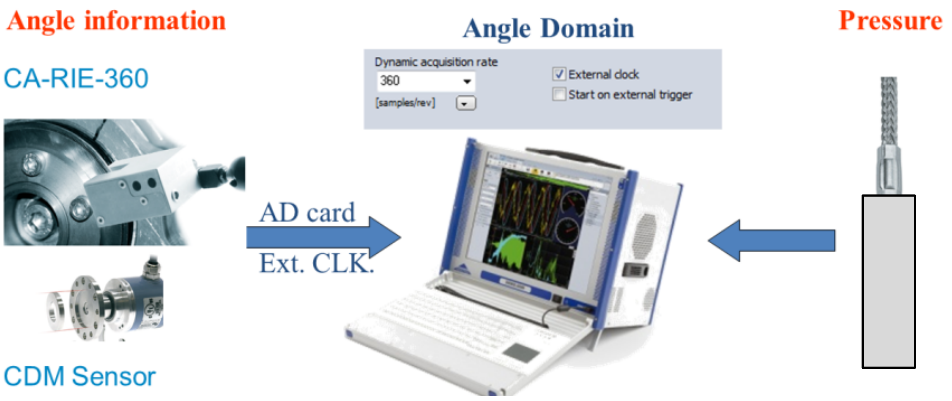
CA Math expects a pressure and an angle signal which is equidistant, so in 0.1, 0.2, …1, 2deg, which is immediately available from an angle domain measurement. Now, because of the fixed sampling rate, and various engine speeds, the angle and pressure signals could not be captured on this fixed angle interval.

So CA Math now gets an additional task: it must recalculate (resample) the pressure and angle signal to the required (set) resolution. Depending on resolution and engine speed this takes a lot of CPU power.

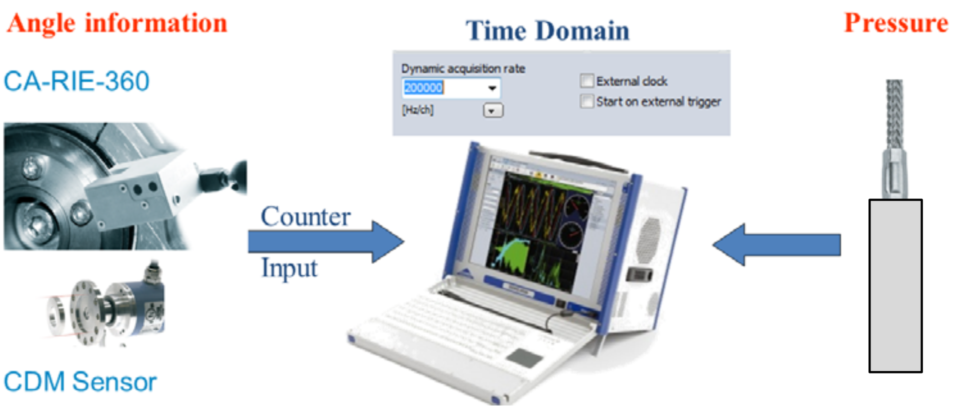
Nevertheless, DEWE-CA is able to do the post processing. This mode is mainly used if additional time information of a signal is needed. So during measurement CA parameters are only rough additional information, which can be calculated with less resolution 0.5, 1deg to save performance. In post processing the data could be recalculated with higher resolution.

For pure CA measurement, done on a test bed, Angle Domain measurement is mainly used, because real time data with high angle resolution is required.

Angle domain:



Time domain:



4.3 CA Noise Setup

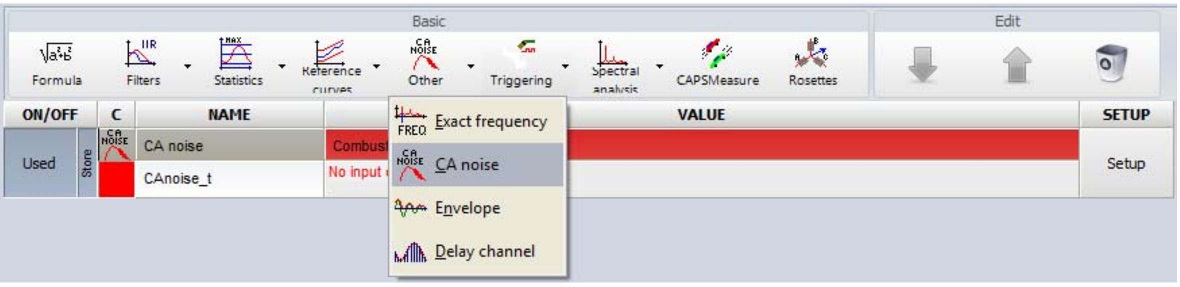
The setup for CA Noise depends on the sampling method (Time / Angle Domain) of the CA instrument.
As described in chapter 4.2, DEWE-CA is operated with a fixed (internal), or variable (external) clock, and depending on this, the CA noise setup is different.

CA-Noise calculation requires a filter calculation (transfer filter), so we have to know the sampling rate to apply the right filters.

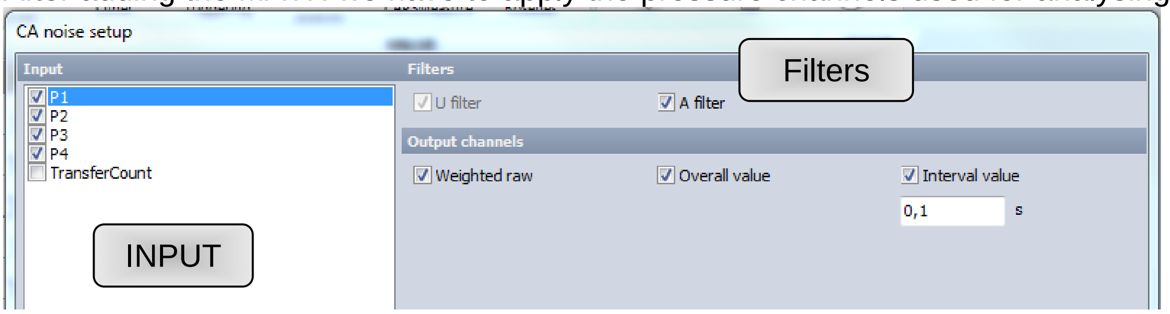
4.3.1 Setup for <u>TIME DOMAIN</u>

To calculate the CA noise in time domain, a prepared MATH function will be used.

→INFO: CA Noise module will output 0, if external clocking (Angle Domain), and DEWESoft version is 7.0.4 or higher is used. CA noise math is only allowed for <u>TIME DOMAIN</u> sampling, otherwise results are wrong!



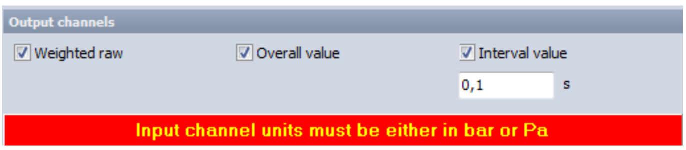
After adding the MATH we have to apply the pressure channels used for analysing CA noise.



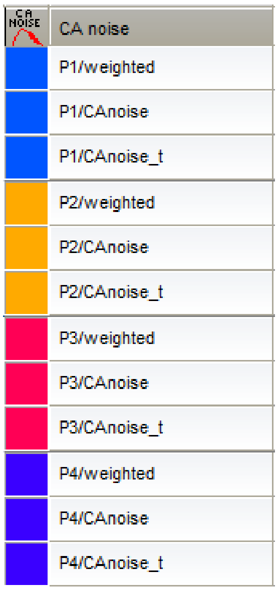
On the left, 'INPUT', the indicating pressure channels to be analysed for CA Noise are selected. Here multiple channels can be selected.
On this channel(s) the U Filter (Transfer Filter) is applied for the CA Noise calculation.

Additionally, we can use the A filter (human hearing filter) to determine the human perception of the noise produced by the engine.

→ INFO: The unit of the selected channels must be [bar] or [Pa]!



There are 3 output channels for each selected input channel available.



Weighted raw: time domain signal with applied U- and optional A – filter. This signal can be further analysed in the Sound Level Meter.

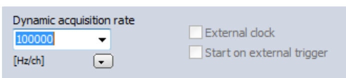
Overall value: calculates the CA noise over the whole measurement. At the end of the measurement we will get one value, which is stored.

Interval value: here the CA noise is calculated in intervals. The interval span can be set in seconds.

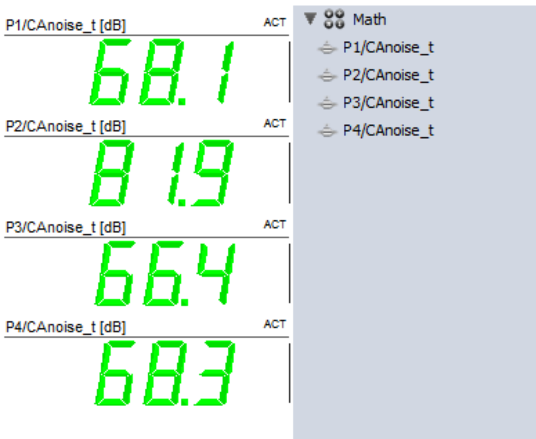
It is recommended to set the interval so that at least 1 or 2 cycles are included. Here only the lowest rpm has to be considered. At 600rpm / 60= 10Hz = 100ms. So for a 4 stroke engine we have to set at least 200 or 400ms to cover 2 cycles. For higher speed engines, more cycles are covered for the same interval and therefore the result will be averaged and more stable.

For each input channel one or more output channels are available.

Sampling



rate:

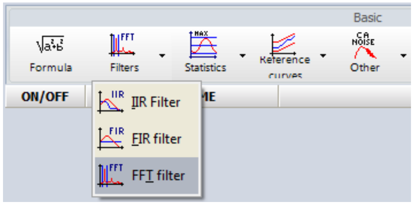


The U filter and also the A filter, and human noise are located in a frequency range of 18Hz to 20kHz, so the sampling rate should be at least 36kHz .

For time domain CA measurements this is no problem, because to get a sufficient angle resolution at high engine speeds, the sampling rate is always higher than 36kHz. 0,5deg @ 4000rpm would give 4000rpm/60=66.66Hz*720= 48kHz.

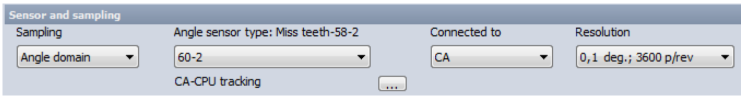
4.3.2 Setup for ANGLE DOMAIN

(!only available/allowed in Version 7.0.4 or higher!)



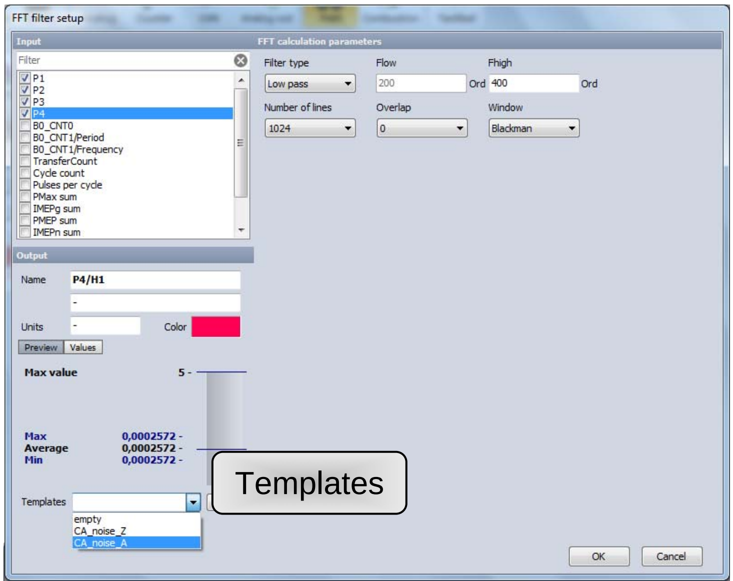
For Angle domain CA Noise is calculated via an FFT filter. The FFT filter will return an RMS pressure value calculated over approximately 8 revolutions.

The Angle resolution in CA should be set to <= 0.2deg, to have high enough sampling rate at low engine speed.



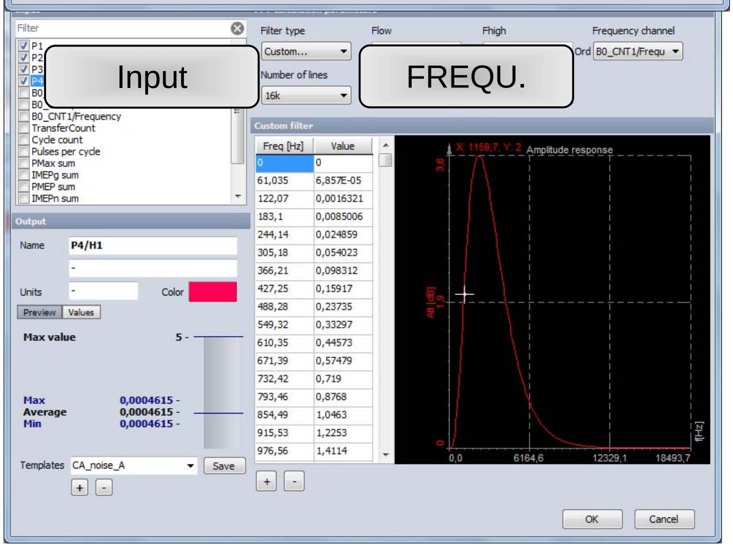
The FFT Filter is located in MATH section → Filter → FFT filter

As described in the section 2, in the Angle Domain, the sampling rate changes with engine speed, so that has to be taken into account for the calculation.
For the external clock this filter gets an additional input to which the actual sample rate must be applied.



To simplify the setup, 2 prepared templates for either LIN(Z) or A weighted filters are prepared. If this is not available, please refer to section 4 of this manual → ADD Filter Template.

These templates are available for Version 7.0.4 and higher.
For previous versions this will not work and is not allowed.

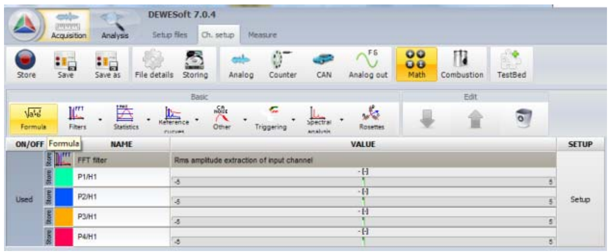


After selecting the Template for either LIN(Z) or A weighted filter, the frequency channel has to be applied.

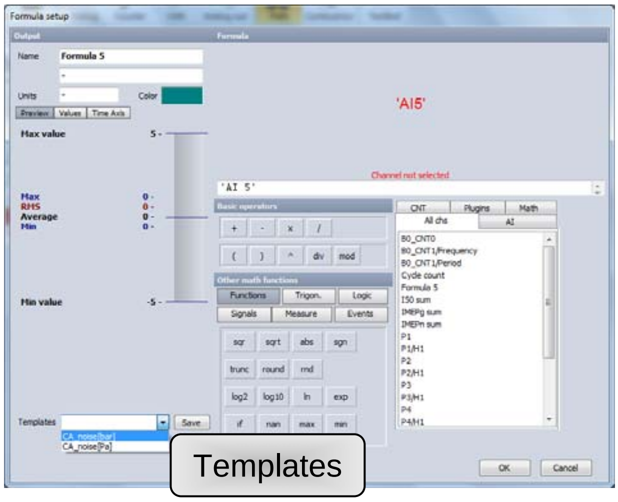
Here B0_CNT1/Frequ(counter input channel) must be selected.

After Input channel selection, setup is almost complete.

All other settings such as 16k number of Lines, Overlap = 0, and Window= Hanning, are set already by the template.

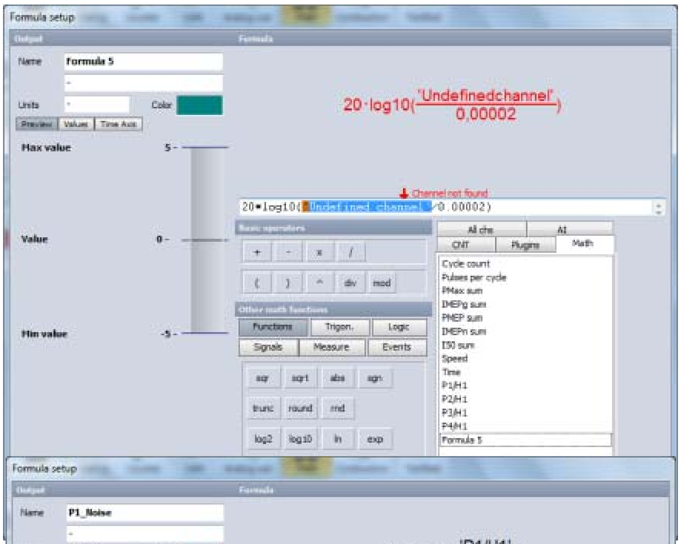


The filtered ouput value (RMS) must be recalculated into dB.



This is done with a formula for all the filtered pressure channels.

Prepared Templates will help to set this up. In case the template is not available it is recommended to type the formula manually. Depending on the pressure channel unit (bar, Pa), used in the FFT filter, the corresponding Template or formula has to be used.



Select the undefined channel, delete it and apply the FFT filter values.
Repeat this with new formulas for all the pressure channels.

P1/H1, P1/H2,…..

Formulas to convert FFT filter value into dB.

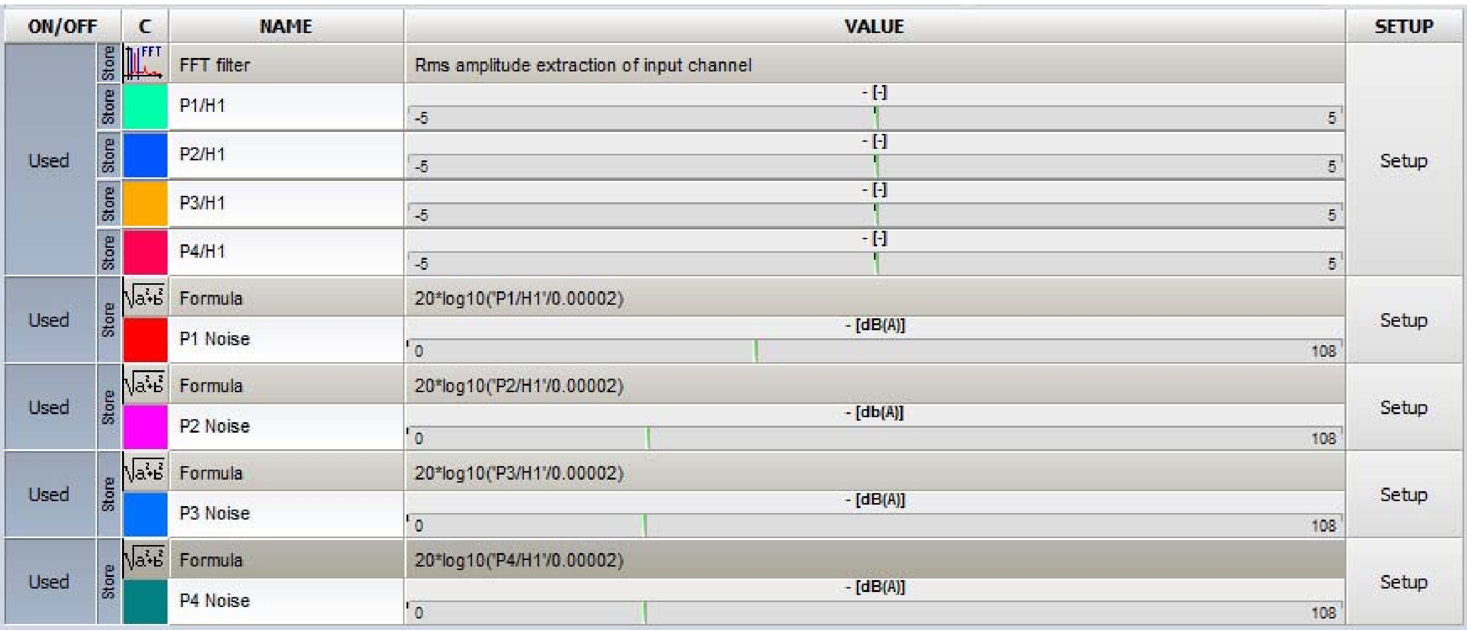
Pressure channel unit = bar:

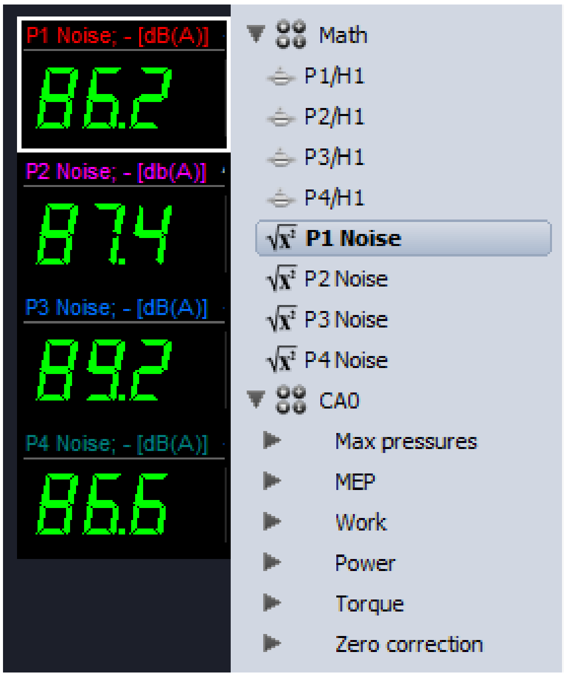
20*log10('**FFTFILTERCHANNEL**'/0.00002)

Pressure channel unit = Pa:

20*log10('**FFT FILTERCHANNEL**'/2)

If all calculated noise channels are set up, they can be displayed in a recorder or digital display.





4.4 ADD Filter Template

In section 3.2 “Angle domain CA Noise set up”, a custom filter curve has to be selected.
This is either already available in the Template selection of the FFT Filter, or has to be manually created and stored into the Template Data base.

To get this filter there are two possibilities available:

4.4.3 Prepared Templates.xml file

This holds the defined Templates is provided by Dewetron, and must be copied into the folder:

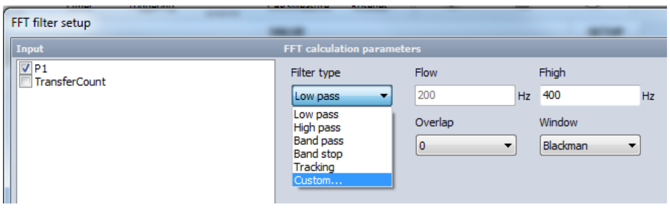
DEWESoft7\System\V7_0

➔ Note if you have already stored other templates in DeweSoft, the new Templates.xml file will overwrite the current one, and therefore delete all your previous templates.
This should be done only, if no template has been used before, otherwise proceed with section 4.4.4 manually copy and store Templates .

4.4.4 Manually Copy the 2 Custom FFT Filter Curves

to the FFT Filter and store it into your existing Templates.xml file located in the DEWESoft7\System\V7_0 folder.

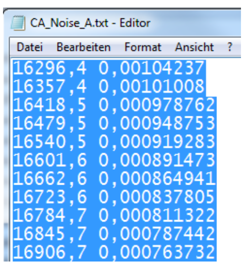
To do this, open the FFT filter in section MATH → Filter → FFT filter,
select CUSTOM Filter and copy the Filter coefficients into the TABLE.



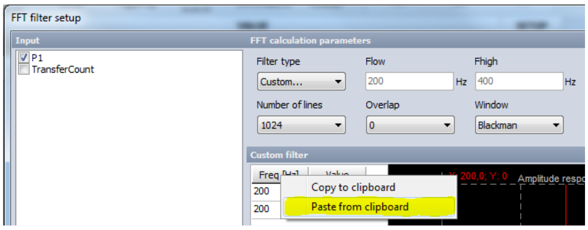
The Filter coefficients are provided by Dewetron via two text files,

CA_NOISE_A.txt for the A weighted, and
CA_NOISE_Z.txt for the linear.

Mark all the values of one file, copy them from the file, and paste them into the CUSTOM Filter.

➔ 

Select all values in txt file and copy them.



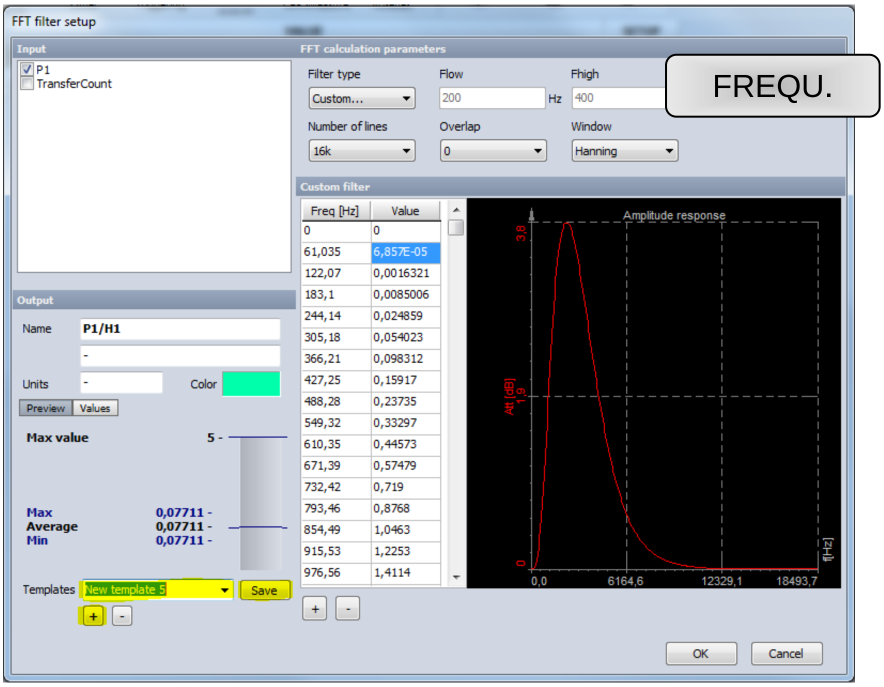
Right click to **Freq** column and PASTE it.

- ➔ Set Number of Lines to 16k
- ➔ Set Overlap to 0%
- ➔ Window to Hanning
- ➔ + Add Template
- ➔ Rename it to CA_Noise_x

Where x is either A or Z weighting, depending on which table was copied.

- ➔ SAVE

With the CA Module, in external clock mode, the Frequency channel is also shown in the right upper corner.
Apply the B0_CNT1/Frequ counter channel to the frequency channel.
More details in chapter 5.3.2.



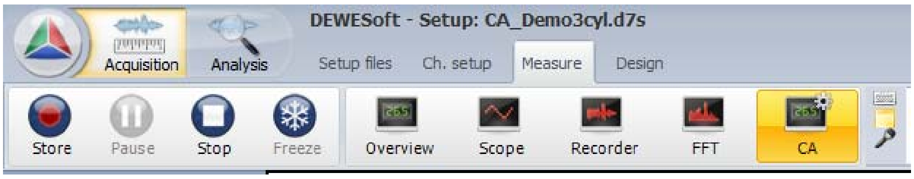
Repeat the same procedure with the second custom filter curve.

After that both templates will be available for the next setup, and the configuration can be done according to point 5.3.2.

5 Display Setup and Result Output

After changing to the measure screen, an automatically generated CA display is provided. The provided display setup holds the major signals and channels for a fast start.

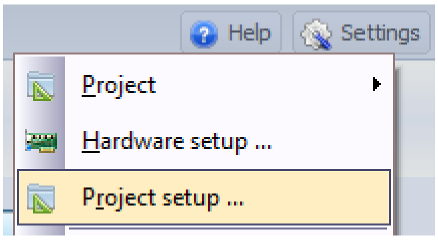
If CA display setup is not provided after a new setup was created, the automatic mode is not activated.

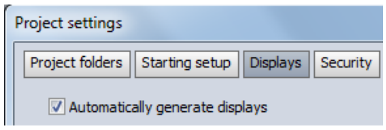


5.1 Activate Automatic Display Generation

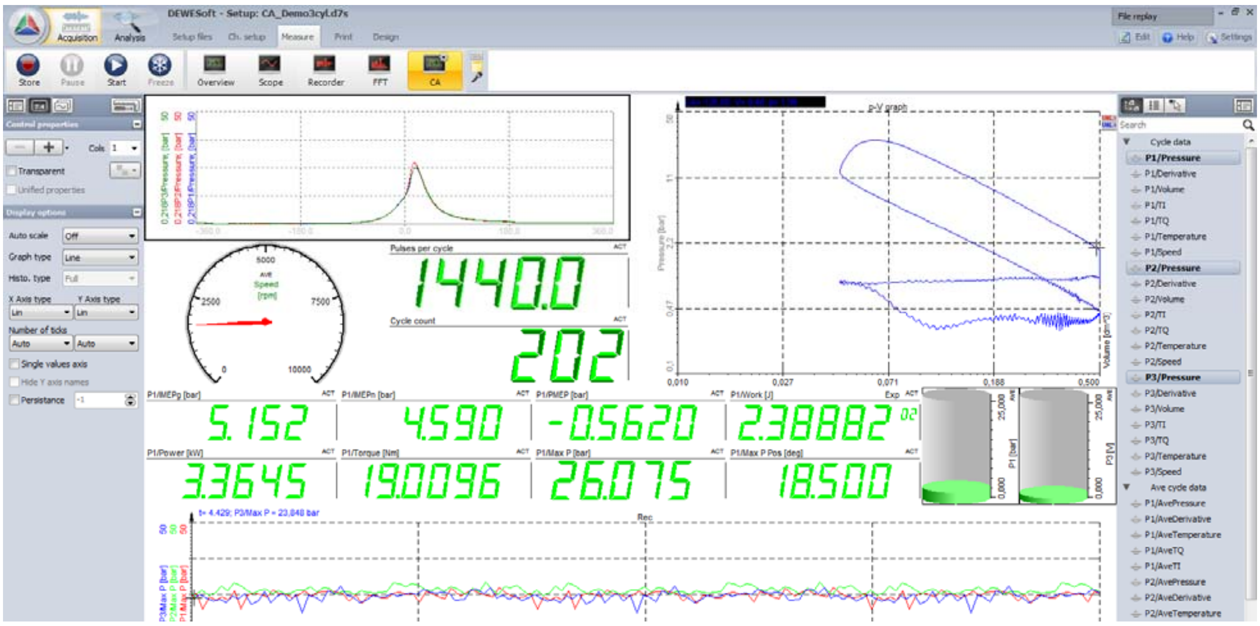
This can be activated in the global settings of DEWESoft under:

→ Settings
→ Project setup
→ Displays

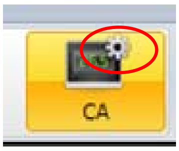




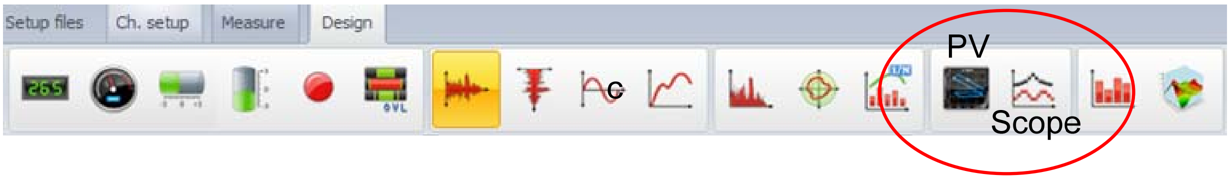
Below the automatic display configuration is shown. The selected instrument is the 2D diagram, which can hold an angle based result.



If channels are applied or configuration is changed , automatic mode must be disabled, otherwise, if we change back to channel setup and back again, settings are overwritten from automatic mode and settings are lost.



Automatic mode is indicated through a tooth wheel. It is disabled if design mode is activated once.

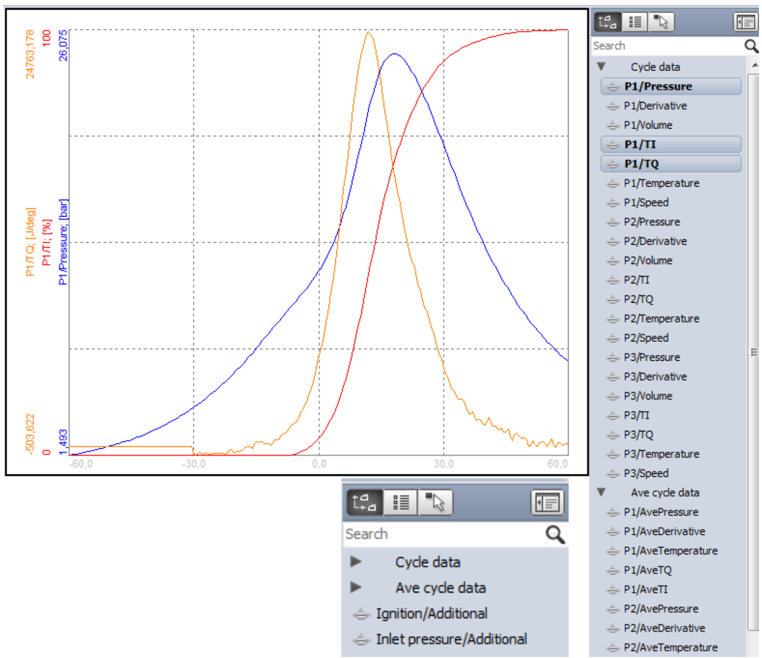


In the design mode displays can be added, removed, or modyfied.
Depending on the selcted display, angle based or cycle based channels are available.

The two major displays are the CA-Scope and the p-V diagram.

If this is added and selected, DEWESoft will only show angle based results in the channel selector.

5.2 CA-Scope:



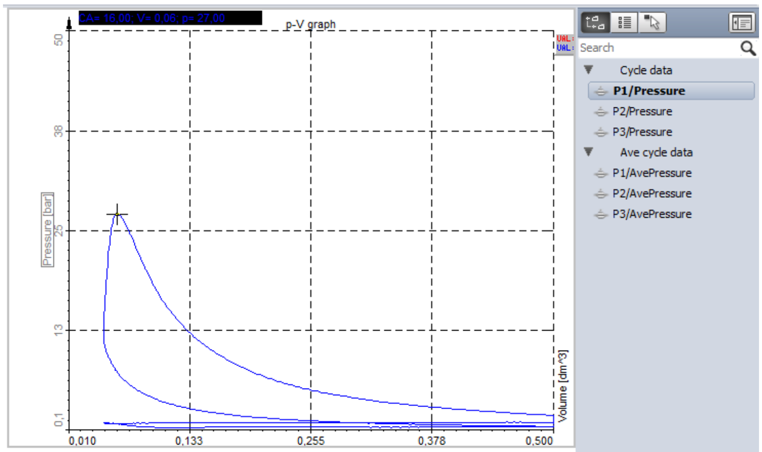
Anlge based results

- Pressure Cyl. x
- Derivate Cyl. x
- Heat release TQ Cyl. x
- Int. Heat release TI Cyl. x
- Temperature Cyl. x
- Speed related to Cyl. x

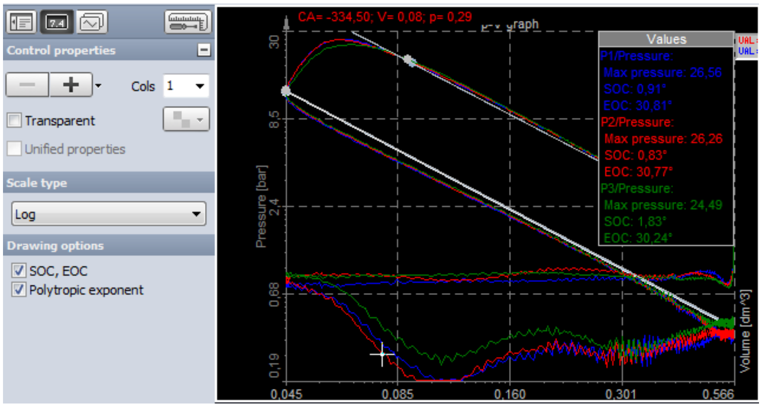
The results are available for actual (Cycle Data) and averaged (Ave cycle data) cycles.

Additional channels are also available for the CA-Scope. Additional channels could be any analogue channel, aligned with the corresponding cylinder where it was applied to.
See chapter 3.1 additional channels.

5.3 p-V diagram:



In the p-V diagram, actual and averaged pressure channels can be shown.



Properties of the p-V diagram provide Lin or Log scaling. SOC, EOC and also Polytropic exponent can be shown.

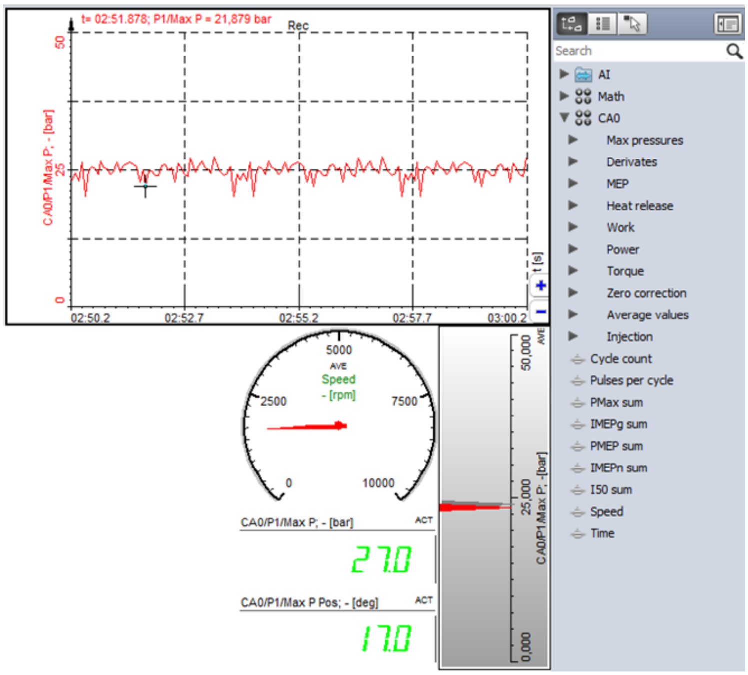
5.4 Cycle Based Results

Cycle based results such as MaxPressure are calculated for every cycle. So we get a single value every two revolutions for 4 stroke engines, and one value for every revolution in 2 stroke engines.

Cycle based results can be shown in various displays. The common displays for cycle based results are: Digital, Analogue, Bar and Recorder.

Digital, Analogue, Bar

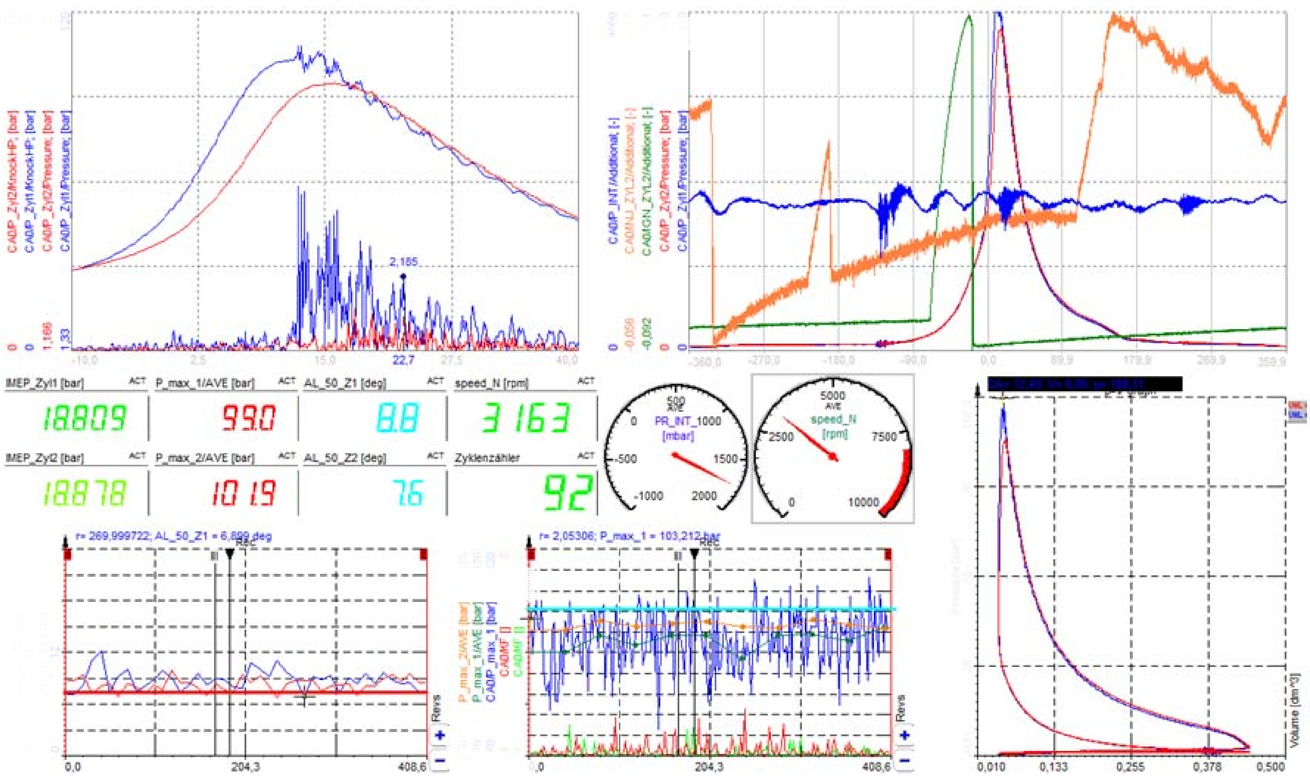
Recorder



If one of these instrument is selected or added in the design mode, the channel selector of DEWESoft will come up with the cycle based result channels.

All these channels could be applied to the instruments, so an individual measure screen(s) can be configured.

Typical measurement screen.



5.5 Result Channels

In chapter 5.3 and 5.4 we could already see the result channels in the channel selector depending on the used instrument. This list should give an overview of the calculated result channels of the CA-Plug IN.

Cycle Based Results

Name	Unit	Description
Px/Max P	bar	max. pressure of cylinder x
Px/Max P Pos	deg	position of max pressure cylinder x
Px/Max D	bar/deg	max. derivation
Px/Max D Pos	deg	position of max. derivation cylinder x
Px/IMEPg	bar	indicated mean effective pressure gross
Px/IMEPn	bar	indicated mean effective pressure net = IMEPg-PMEP
Px/PMEP	bar	pump mean effective pressure
Px/I5	deg	position where integrated heat release reach 5 %
Px/I10	deg	position where integrated heat release reach 10 %
Px/I50	deg	position where integrated heat release reach 50 %
Px/I90	deg	position where integrated heat release reach 90 %
Px/IXX	deg	position where integrated heat release reach xx % customer definable
Px/SOC x	deg	position where SOI signal starts
Px/EOC x	deg	position where EOI signal stops
Px/Work	J	
Px/Power	kW	
Px/Torque	Nm	
Px/Pcorr	bar	calculated pressure of thermodynamic zero correction
Px/SOI x	deg	position where SOI signal starts
Px/EOI x	deg	position where EOI signal stops
Px/KF	-	knock factor
Px/Max Hp	bar	max. value after knock hp-filter
Cycle count	-	cycle counter
Pulses per cycle	-	pulses per cycle
Pmax sum	bar	average or aligned max pressures of all cylinders
IMEPg sum	bar	average or aligned indicated mean effective pressure gross
IMEPn sum	bar	average or aligned indicated mean effective pressure nett = IMEPg-PMEP
PMEPg sum	bar	average or aligned pump mean effective pressure
I50 sum	deg	average or aligned position where integrated heat release reach 50 %
Speed	rpm	engine speed
Time	s	time

Ave. Cycle Based Results		
Name	**Unit**	**Description**
Px/Ave Max P	bar	averaged max. pressure of cylinder x
Px/Ave Max P Pos	deg	averaged position of max pressure cylinder x
Px/Ave Max D	bar/deg	averaged max. derivation
Px/Ave Max D Pos	deg	averaged position of max. derivation cylinder x
Px/Ave IMEPg	bar	averaged indicated mean effective pressure gross
Px/Ave IMEPn	bar	averaged indicated mean effective pressure net = IMEPg-PMEP
Px/Ave PMEP	bar	averaged pump mean effective pressure
Px/Ave I5	deg	averaged position where integrated heat release reach 5 %
Px/Ave I10	deg	averaged position where integrated heat release reach 10 %
Px/Ave I50	deg	averaged position where integrated heat release reach 50 %
Px/Ave I90	deg	averaged position where integrated heat release reach 90 %
Px/Ave IXX	deg	averaged position where integrated heat release reach xx % customer definable
Px/Ave SOC x	deg	averaged position where SOI signal starts
Px/Ave EOC x	deg	averaged position where EOI signal stops

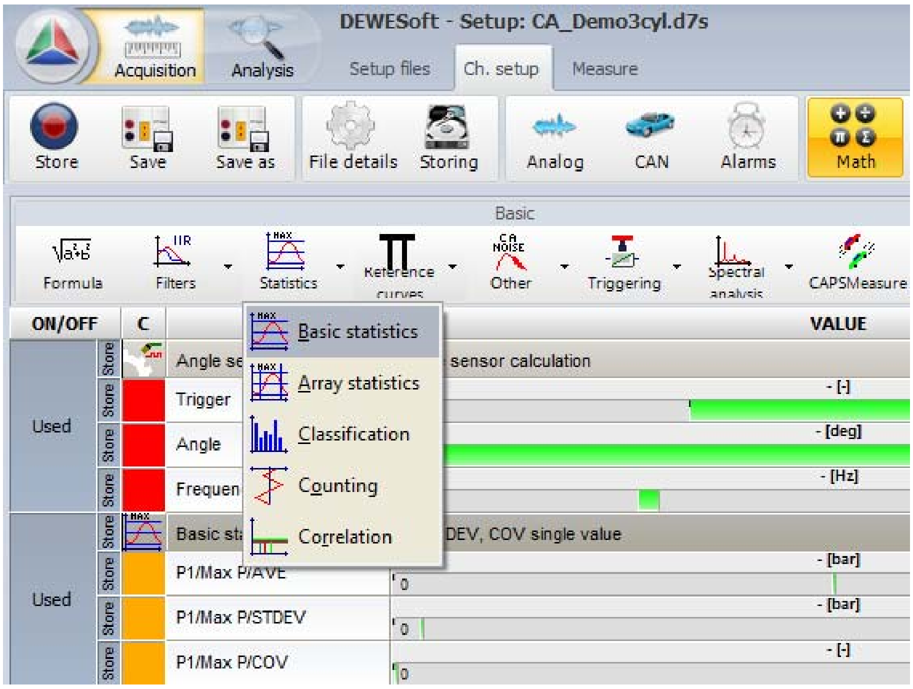
Angle Based Results		
Px/Pressure	bar	
Px/Derivative	bar/deg	
Px/Volume	dm³	
Px/TI	J, %, kJ/m³	integrated heat release
Px/TQ	J/deg, %, kJ/m³/deg	heat release
Px/Temperature	K	
Px/Speed	rpm	

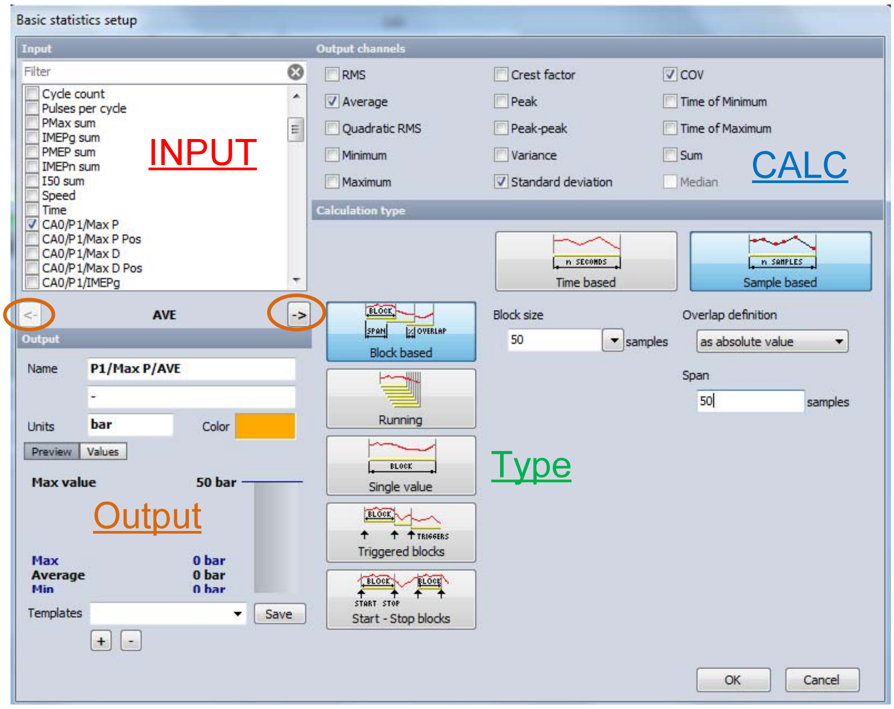
Ave. Angle Based Results		
Px/AvePressure	bar vs. Deg	
Px/AveDerivative	bar/deg vs. Deg	
Px/AveTemperature	K	
Px/AveTI	J, %, kJ/m³	integrated heat release
Px/AveTQ	J/deg, %, kJ/m³/deg	heat release

Please refer to storing options chapter 7 for averaged results calculation, and reset of averaged calculation values.

6 Statistic Values, COV, Standard deviation

If further statistic calculations of cycle based data are required, this can be done with the Basic statistic function located in the mathematic section of DEWESoft.





In the INPUT section cycle based results, can be applied to the statistic module.

In the CALC area the type of calculation is defined, for all selected input channels.

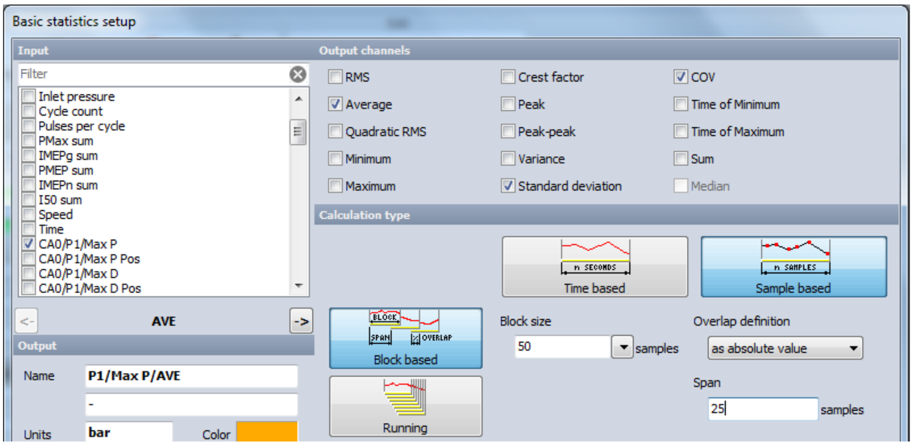
The TYPE defines the type of calculation. Here Sample based calculation should be used.

Do not use Time based, as the time based statistic module resamples cycle based values to the full sampling rate which takes lot of processing power. It is also not possible to set exact calculation duration in this mode.

In the OUTPUT area result channels are provided, with the buttons ← , → it is possible to switch trough the result channels, in case renaming is required.

For the calculation Type, various options are available:

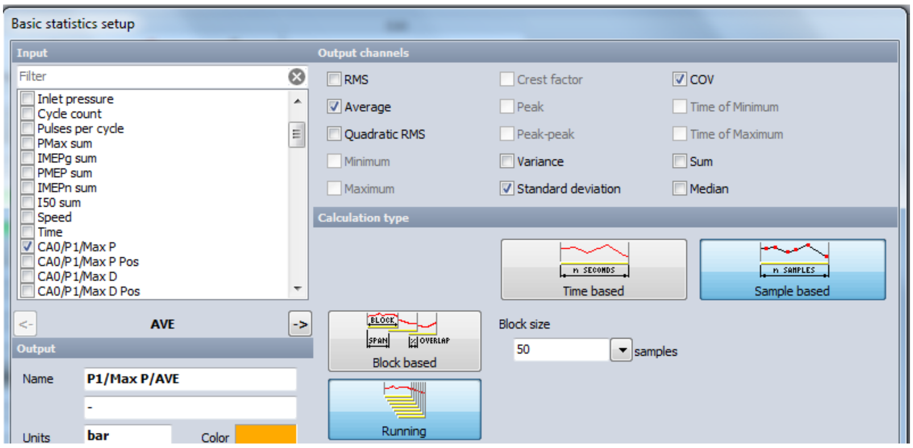
6.1 Block based



For block based calculation, one value will be calculated after a number of samples, defined in Block size, are available.

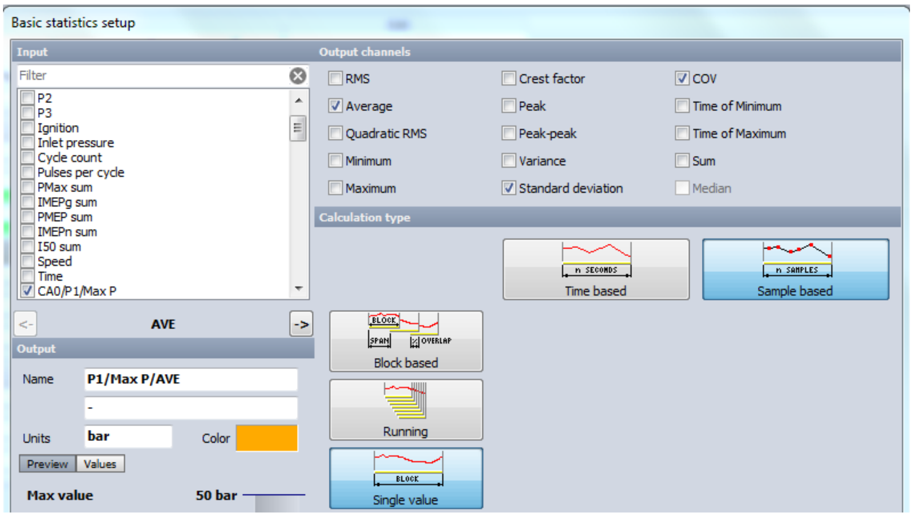
Overlap definition, defines the start position of the next block. Overlap can be defined in % or via Span definition.

6.2 Running



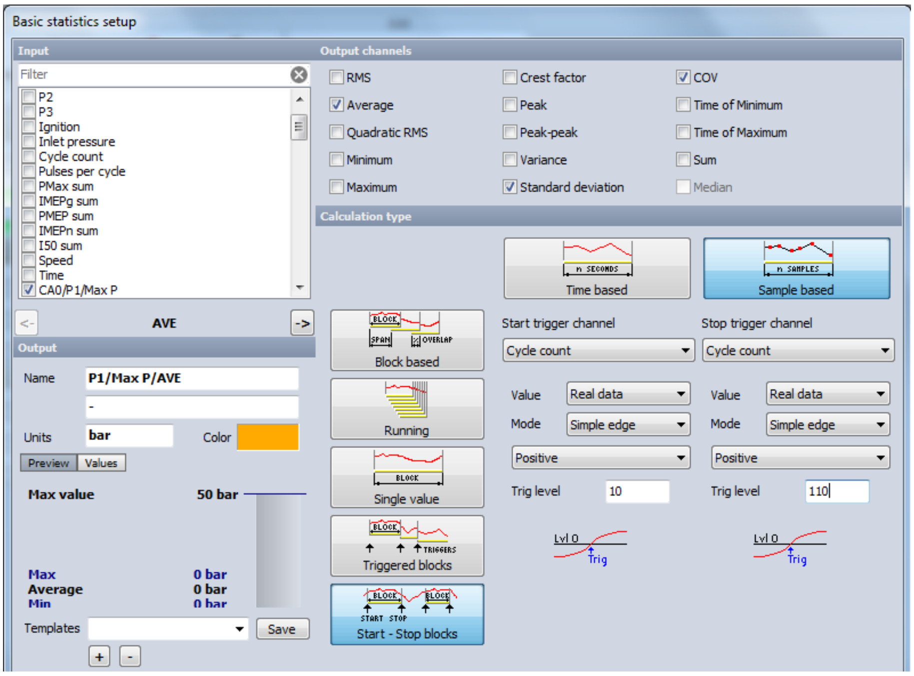
Running calculations will calculate statistic values of the last xx samples specified in the Block size. In comparison to block based, at every new input value a new output value over the last xx samples will be calculated. Where as with block based, the number of samples specified in Block size must be available to get a new output value. If overlap is set to 50% a new result will be calculated after samples/2 .

6.3 Single value

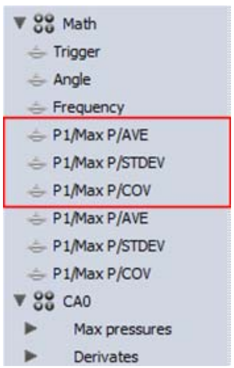


For single value calculations, one value is calculated over the whole measurement.

6.4 Triggered calculation



In Start – Stop mode, the start and end of calculation can be defined via triggers. For a trigger, any channel can be used. In the example we can see that the calculation is done over 100 cycles, starting at 10 cycles and stopping at 110 cycles.



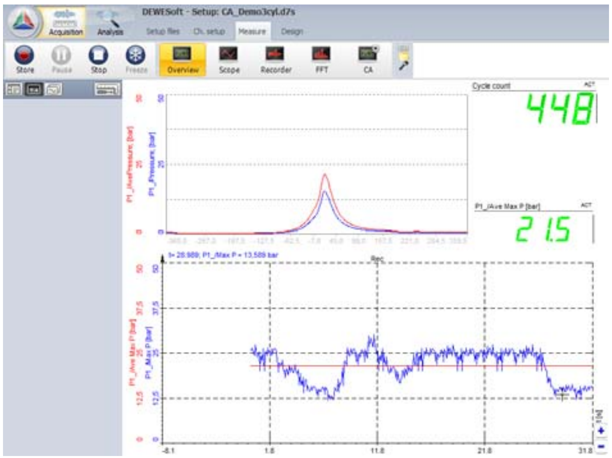
The results are available in the Math section of the channel list. Because these are cycle based results, and channels can be shown in any instrument which can handle cycle based results (recorder, bar graph, digital meter, analog meter, …). See chapter 5.4 cycle based results.

7 Storing Data, Averaged Results

Data can be stored in different ways. Either manually, or automatically with a trigger.
If data is stored manually, the user will define the start and stop of storing. In comparison with triggered or automatic storing, trigger condition(s) will control start and stop.

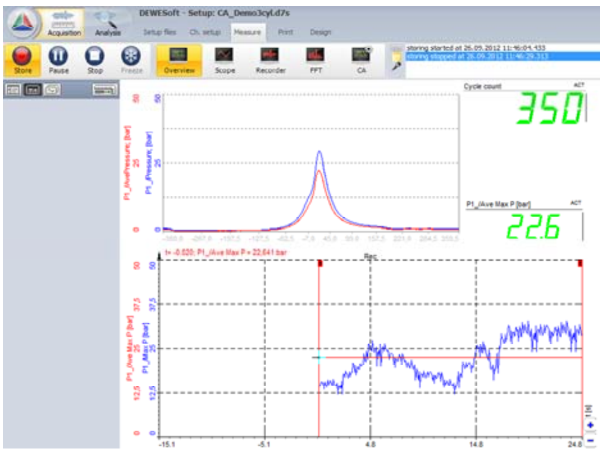
7.1 Manually Store of Data

If data is stored manually, ALWAYS FAST is set as the storing type in the storing option.

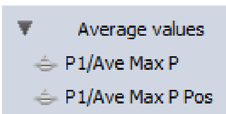


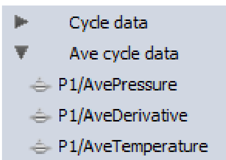
At the measure screen, actual and averaged values (red) are provided.

Average values are calculated from start of measurement.

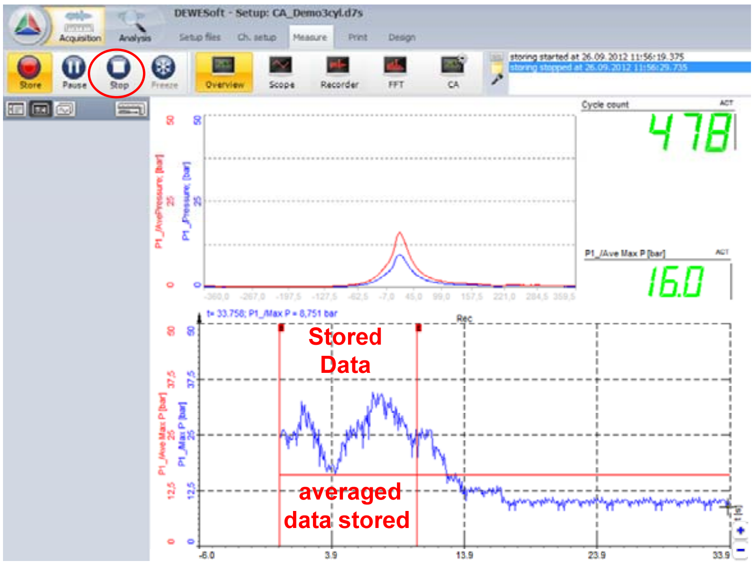


→Storing data into data file will reset all statistic values, and calculate average values over the storing duration until Stop is pressed.





Cycle- and angle-based average values correspond to stored data.



Do not press Pause!

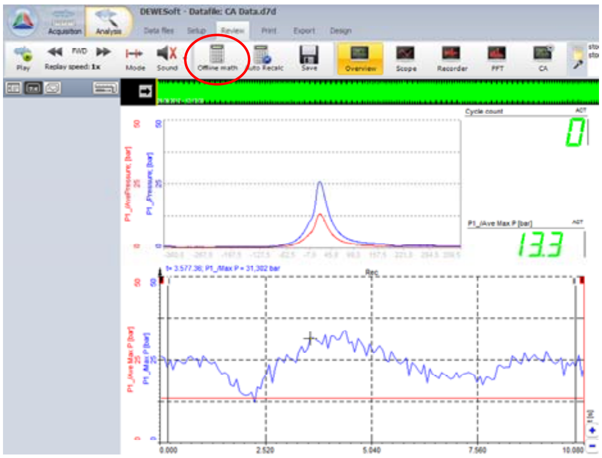
Pause will stop storing data into file, but averaging of average channels will go on. After Stop, averaged channel values are stored.

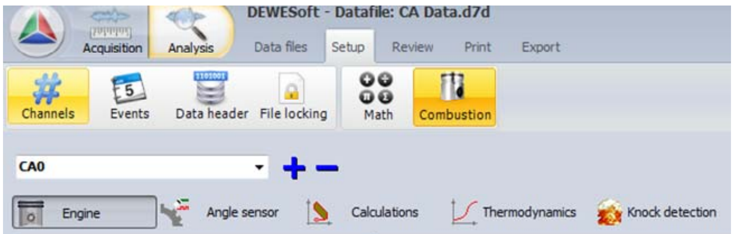
In the example, PAUSE was pressed first, and later STOP.
We could see that stored average was calculated for the whole duration, and not only for the stored data!

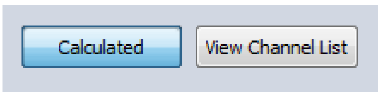
→ Manually Storing should be always terminated with STOP if average values are used in analyse, to prevent wrong averaged data stored into data file!

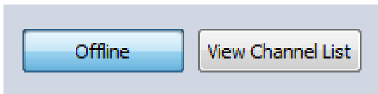
7.1.1 Recalculate Average Values:

In case this was overseen, and averaged data is required, it can be recalculated in the analyse mode.

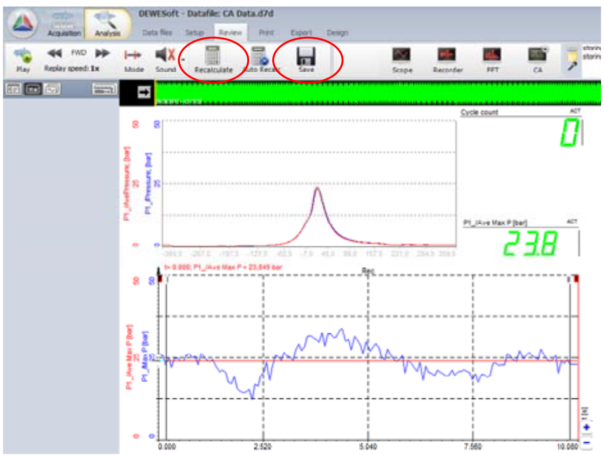








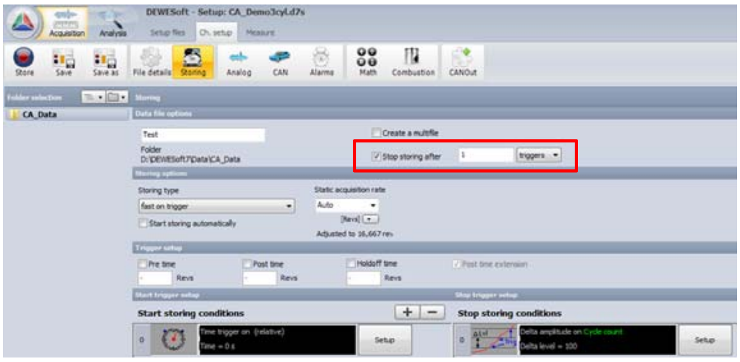
Change to Offline math, Combustion, and set calculation to from Calculated to Offline.



Change to Review, and Recalculate.
After recalculation Save it into the data file.

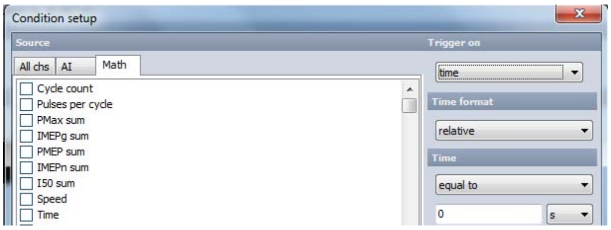
7.2 Triggered Storing, Store XX cycle

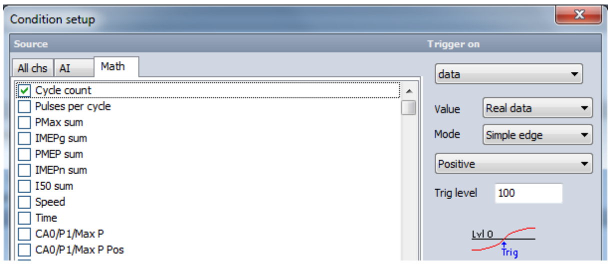
Instead of storing data manually, as described in chapter 7.1, data can be stored automatically via the trigger options of DEWESoft.



Under storing options Fast On Trigger is selected. Start storing condition is set to relative time of 0s. This will cause storing immediately after ARM is pressed in measure mode.

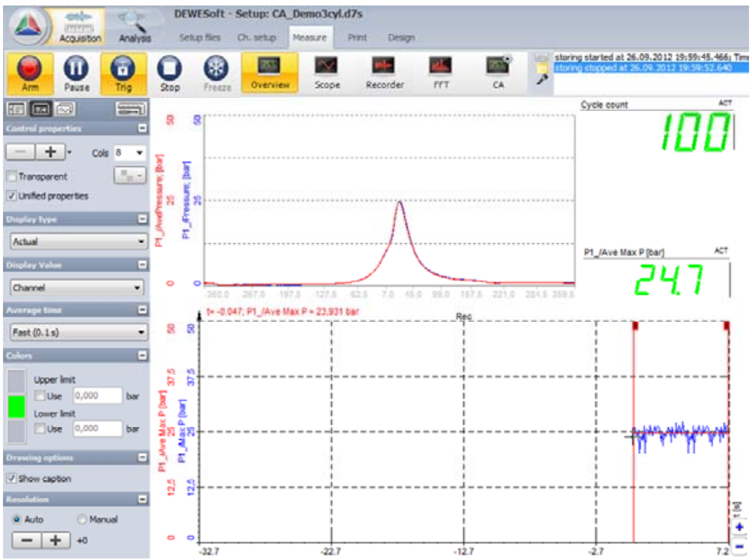
→ Statistic values are reset when ARM is pressed, that's why storing should start immediately after ARM!





So start trigger is set to relative time and should start at 0s[rev].
For Stop we can use any channel and select various trigger conditions.

Mostly, storing should stop if xx cycles are recorded, so stop trigger is set, if cycle count crosses The number of desired cycles. ARM will reset all values including cycle count.



So that the measurement also stops immediately after the stop trigger condition, STOP Storing After 1 Trigger, must be selected. Otherwise only storing into datafile is stoped, but measurment will go on, and therefore also averaging of average channels.

This is the standart setting how to store xxx cycles into data file.

After ARM, all will be reset, and storing will start. After 100 cycles storing and measurement will stop. Averaged values will fit to stored cycles.

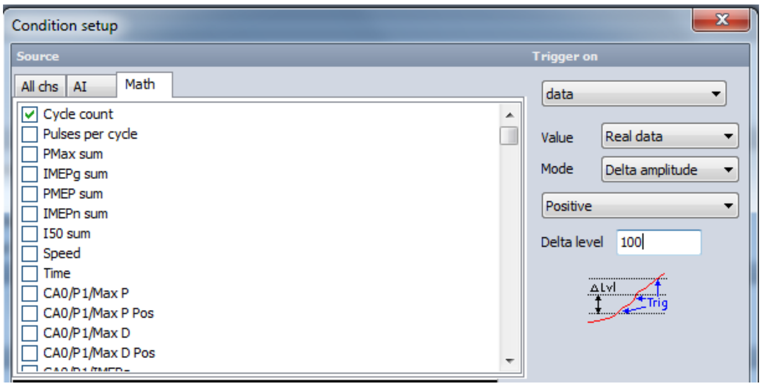
The aim of triggered storing is, to store on some events. So a channel or channels should be observed, and in case storing should be started and stopped. The first target was to store exactly a defined number of cycles into a data file, where also the averaged channels are calculated over the stored cycles.

Start-trigger can be also any other channel for example Px/Max P, and in case maximum pressure exceeds a certain level, storing should start, stop should be xxx cycles later, or on a different condition.

If start is set on a channel condition such as maximum pressure, it is helpful to see what was going on before it happened.

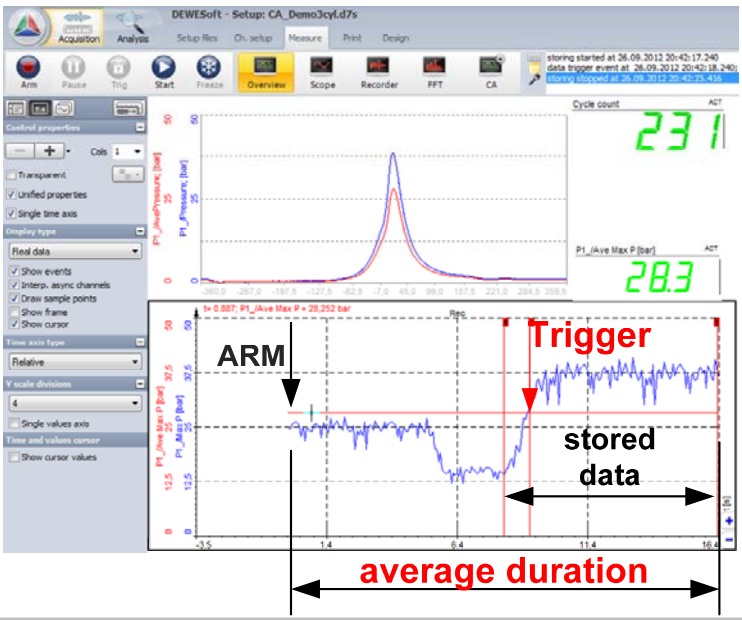
For this, pre-trigger in time or revolutions can be set.

Optionally a post-trigger can be set, to record for an additional period after a stop condition.



If only a number of cycles should be stored after a trigger event, we can set the stop-trigger to the cycle channel.

The trigger condition must be set to Delta Amplitude. This is required because after ARM the cycle count will reset but now it is waiting for a trigger, it will trigger at cycle x, and it should stop at cycle x+number. Delta Amplitude will do this it remembers start and will stop after x + Delta level.



If this is done, the average channels are reset at ARM of measurement. Average channels will include the cycles before trigger event.

If average values are required, for further analysis, it must be recalculated in post processing and stored.

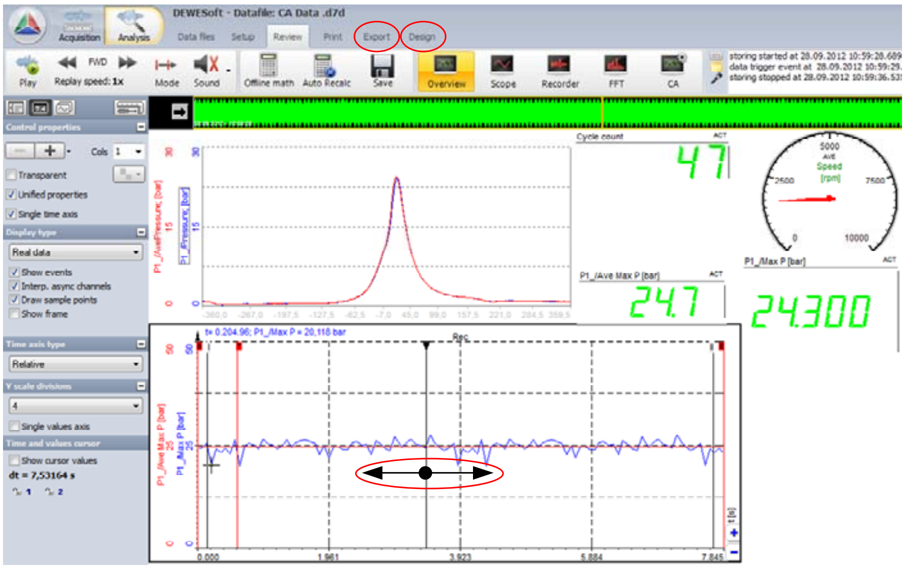
The procedure is the same as described in chapter 7.1.1 recalculate average channels.

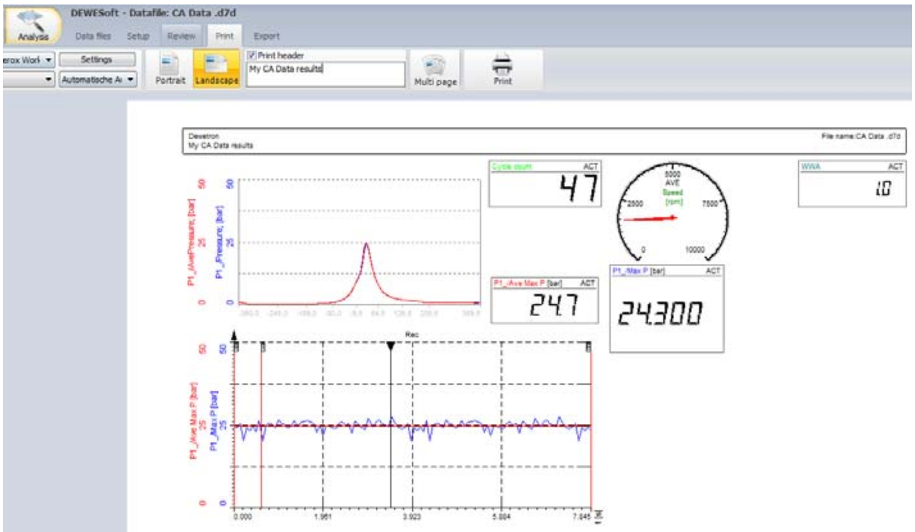
8 Analyse, Data Export

In the Analyse section DEWESoft provides, data review, recalculation and also the export of the data in various file formats.

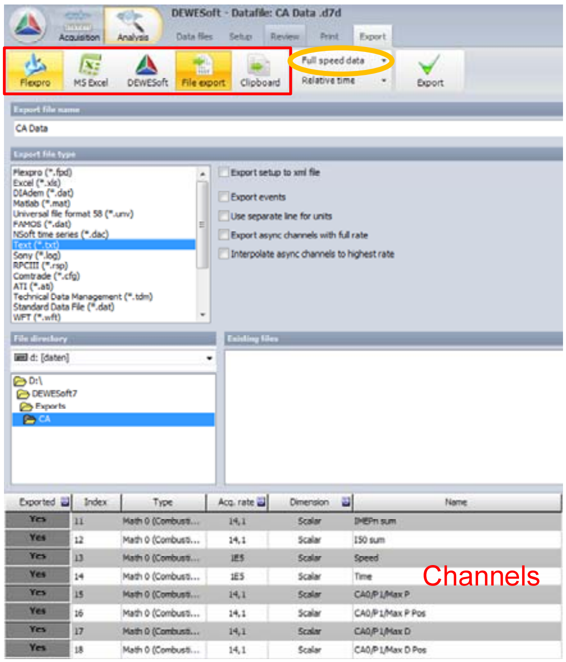
To Analyse the recorded cycles, the black or yellow cursor is used in the recorder to browse through the cycles. A recorder must be available on the analyse screen to do this.

Display setup can be adapted → Design or data can be exported → Export.





Print will print the actual screen and values. Printer settings, and header information can be changed before data is printed.



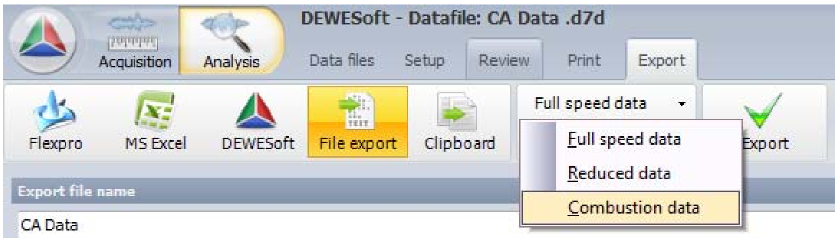
Various types of exports are available.
Direct export into Excel and Flexpro, as well as file export.

For file export various file formats are provided to export data into an appropriate format.

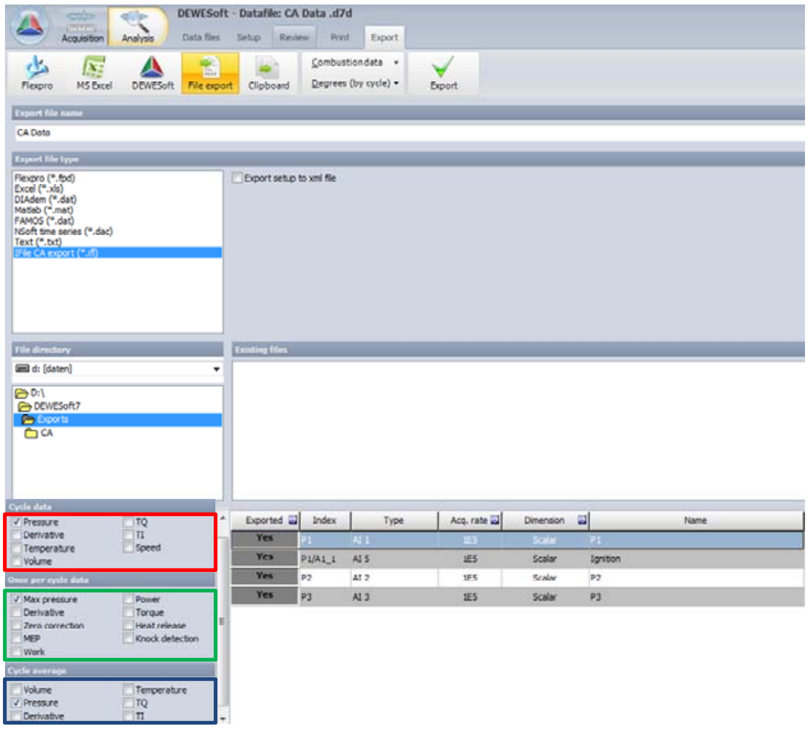
In the channel list, channels can be defined for export.

The default setting for export is full speed data.

In this mode the raw channels and the calculated cycle based channels, and also math channels are available for export. It does not provide an angle based result, such as corrected pressure curve, heat release, and all other angle based results.



To get the angle based result of CA calculations Combustion data must be selected for export.



Now angle based results are provided for each pressure channel, as well as for the additional channels.

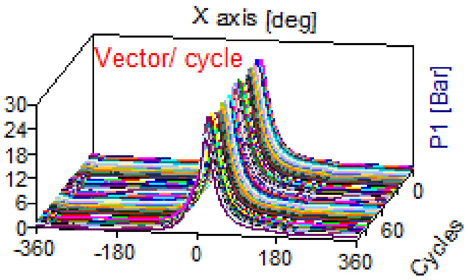
The results are provided in three categories.

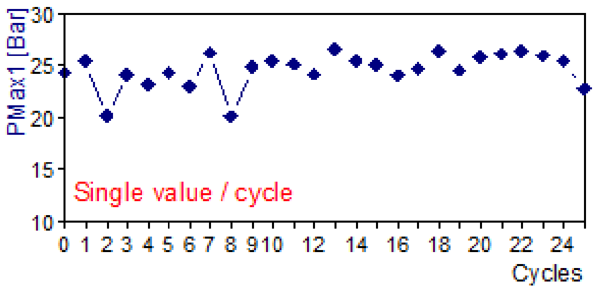
Cycle based data, will export angle based results. P1, P2, TQ, TI, …

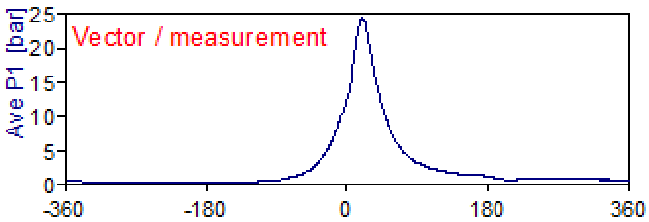
Once per cycle data, will export the cycle based results. P1MaxP, I50,…

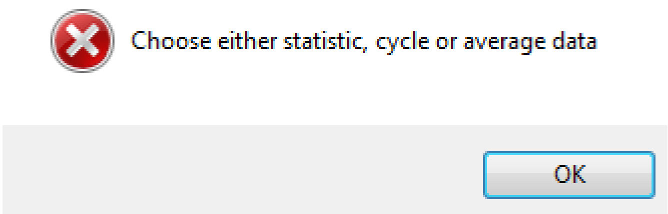
Cycle average, will export the averaged angle based results.
AVE P1, AVE P2, AVE P1 TI,…

Angle based, and cycle based data, have various x channels and various data types. For angle based results, the x channel runs from -360deg up to + 360deg (4Stroke),so we get a Vector for every cycle. where with cycle based results a single value is calculated for every cycle.
At cycle average we get one vector for the whole measurements.





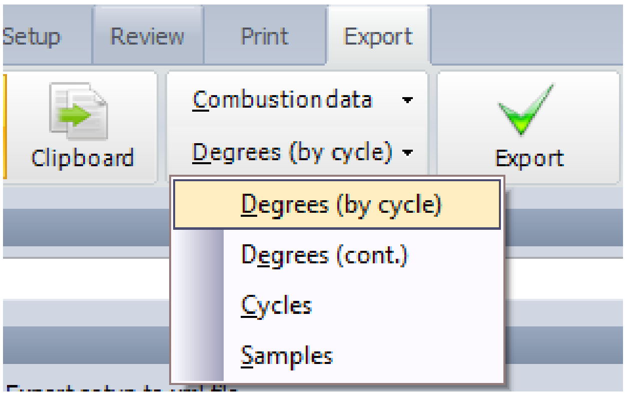




Some file formats do not support multiple data formats. That's why DEWESoft reports a massage to select only one result type.

➔ Combustion data, only exports channels which are calculated in the CA-Plugin. It cannot export any other channels such as basic math, statistic values calculated out of a statistic function.
If this is required, data must be additionally exported with “Full speed data”.

For the x base various formats are available at export.



Degrees (by cycle) :

Vector: -360 to +360 , -360 to +360,….
Cycle: 0, 720, 1440, …

Degrees (cont.):

Vector: -360 to +360, 360 to 1080, 1080 to 1800, …
Cycle: 0, 720, 1440, …

Cycles:

Vector: 0 to 1, 1 to 2, 2 to 3, …
Cycle: 1, 2, 3, …

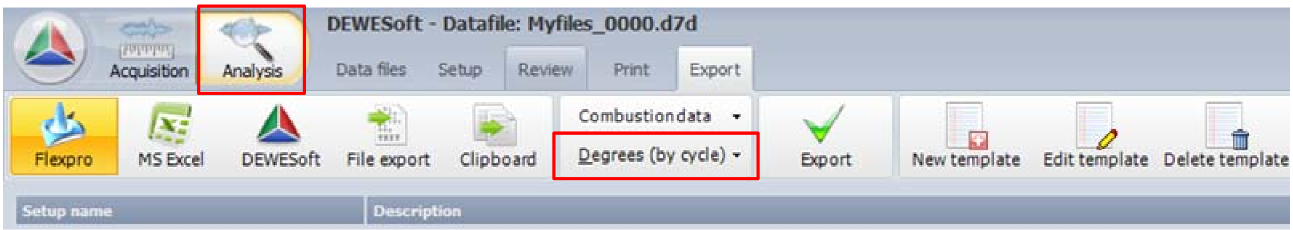
Samples:

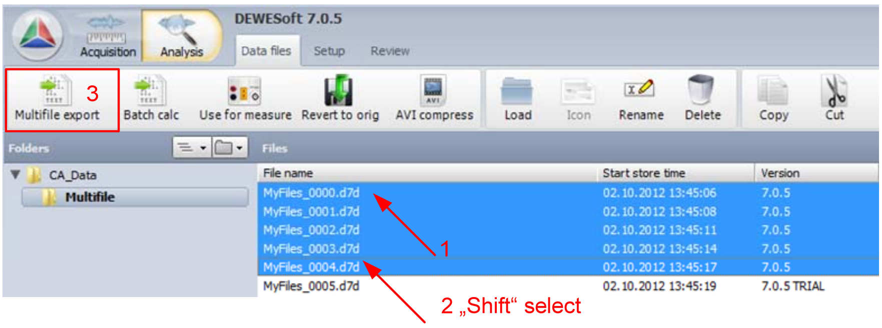
@0,5deg (720p/rev)

Vector: 0 to 1440, 1440 to 2880, 2880 to 4320, …
Cycle: 0, 1440, 2880, 4320, …

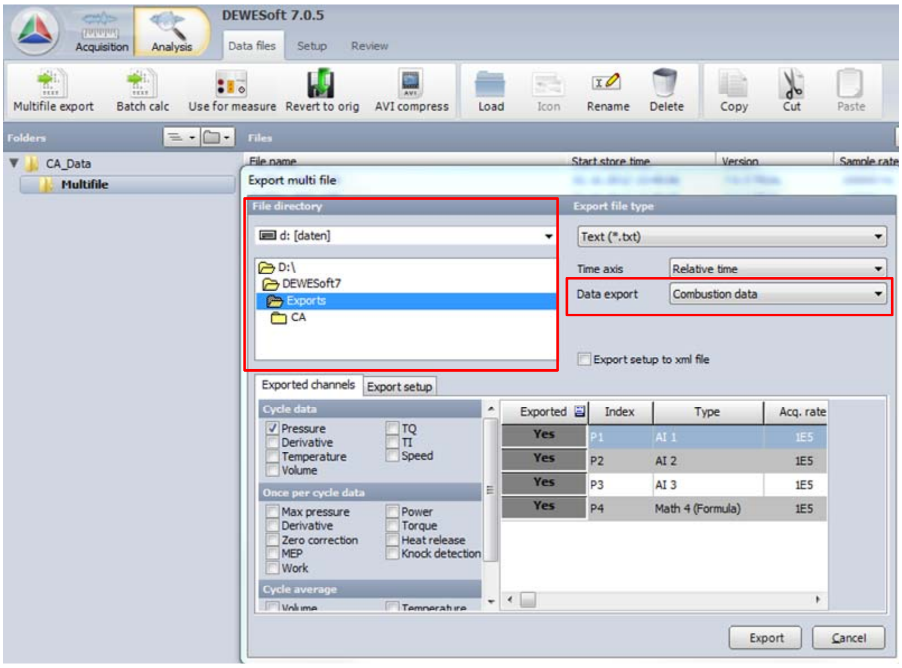
8.1 Multifile Export

Another option is to export several files at the same time. For this set the x base according to point 8. Samples, Cycles, Degrees by cycle, and change to Analysis.





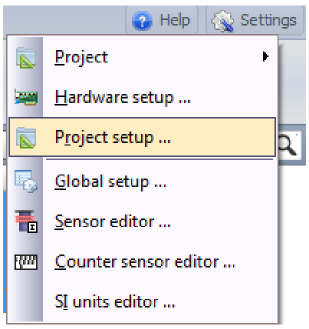
In the analysis screen, Data files, select the first file, and the last with SHIFT button pressed. Files to export are now marked, and can be exported with the multi file export function.

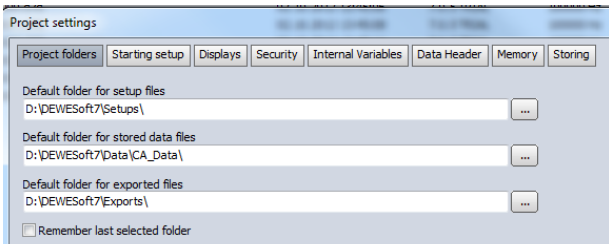


The export Combustion data must be selected, to get CA based results at export.

The export location, can be set up in the file directory section. The default directory is the Exports folder in the DEWESoft7 directory.

For the x-time base (Degrees by cycle,..) in multi file export, the actual settings in export are used.





The default folder for export can be changed in the project setup, project folders. Also standard folders for the setup files and data files can be defined here in this section.

9 Calculation Background, Formulas

This chapter should give a quick reference how the major calculations are performed.

- **Derivative [dp/dCA]**

Derivative is the first derivation of the cylinder pressure of cylinder X.

$$Derivative_i = \frac{P_{i+1} - P_{i-1}}{2 * Rs}$$

i …measuring point
Rs …measurement resolution [deg]

- **IMEPg [bar]**

IMEPg(ross) is the indicated mean effective pressure over 360 degrees crank angle of the power stroke. It is defined as the work produced during the power stroke divided by the displaced volume.

$$IMEPg = \frac{\sum_{i=k}^{n} P_i \cdot \left(V_{i+1} - V_{i-1}\right)/2}{V_S}$$

k … TDC pos. minus 180°
n … TDC pos. plus 180°
V_S … engine swept volume

- **PMEP [bar]**

PMEP is the pump mean effective pressure over 360 degrees crank angle of the exhaust and intake pumping strokes of cylinder X. It is defined as the work produced during the pumping strokes divided by the displaced volume. It is defined only for 4-stroke engines

$$PMEP = \frac{\sum_{i=k}^{n} P_i \cdot \left(V_{i+1} - V_{i-1}\right)/2}{V_S}$$

k … TDC pos. plus 180°
n … TDC pos. minus 180°
V_S … engine swept volume

In general this is negative, except for turbo charged engines!

- **IMEPg [bar]**

IMEPn is the net mean effective pressure. It is the sum of IMEPg and PMEP

$$IMEPn = IMEPg + PMEP$$

- **Thermodynamic zero point correction [bar]**

Pcorr is the result of zero point correction. Three different types of correction are possible:

- this method uses the ideal adiabatic compression assumption between to crank angles with a constant polytropic exponent. Therefore the absolute pressure value can be calculated from the pressure difference between two crank angles. Both crank angle points and the polytrophic exponent can be defined in the measurement settings. -100° for first crank angle (*CA*_1) and -65° for second crank angle (*CA*_2), $\kappa = 1.37$ for diesel engines respectively $\kappa = 1.32$ for gasoline engines are recommended.

$$Pcorr\_X = \frac{P_{CA\_2} - P_{CA\_1}}{\left(\frac{V_{CA\_1}}{V_{CA\_2}}\right)^{\kappa} - 1}$$

- **Heat Release TQ [kJ/m³/°CA]**

TQ shows the heating progress over the crank angle of cylinder X. For the calculation, the simplified procedure of the first law of thermodynamics is used. It yields the released energy per crank angle, disregarding the wall heat and blow-by losses. Start and stop crank angle position for the calculation can be defined in the *Measurement settings* setup.

$$TQ_i = \frac{1}{\kappa - 1}\left[\kappa \cdot P_i \cdot \left(V_{i+1} - V_{i-1}\right) + V_i \cdot \left(P_{i+1} - P_{i-1}\right)\right]$$

i … measuring point
κ … polytropic exponent
V … volume

- ## Integrated Heat Release TI [kJ/m³]

TI is the integrated heating progress of cylinder X. It shows the summed value of TQ.
Start and stop crank angle are the same as for TQ.

$$TI_i = TQ_i + TI_{i-1}$$

i … measuring point

- ## Work [J]

Work yields the theoretical work of the engine.

$$Work = IMEPn \cdot V_S$$

V_S ……swept volume

- ## Power [kW]

Power yields the theoretical power of the engine.

$$Power = \frac{Work \cdot 2 \cdot N}{60}$$ … 4-stroke engine

$$Power = \frac{Work \cdot 1 \cdot N}{60}$$ … 2-stroke engine

N … engine speed in Rpm

- ## Torque [Nm]

Torque yields the theoretical torque of the engine.

$$Torque = \frac{Work \cdot \pi}{4}$$ … 4-stroke engine

$$Torque = \frac{Work \cdot \pi}{2}$$ … 2-stroke engine

- **Temperature [K]**

Temperature shows the temperature inside the cylinder during combustions.

T = 273.15 + InputTemperature   // Input temperature converted to kelvins
VE = VolEfficiency   // volumetric efficiency 0..1, due to some loses in cylinder
IntakePressure = Pressure[180]   // intake pressure at 180 deg

$$GassMass = IntakePressure * 10000 + \frac{TotalVolume}{1000} / (R * T) * VE * 1000$$

$$Temperature = \frac{Volume}{1000} * \frac{Pressure}{100000} / \frac{\frac{R}{1000}}{GassMass}$$

The Temperature value is only valid around TDC.

- **Compression ratio [-]**

$$r_c = \frac{V_s + V_c}{V_c}$$

V_S ……swept volume
V_c ……clearance volume
r_c ……compression ratio