16 The DELTA knocking control – the necessary paradigm shift for engines with high power density

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Abstract

This article describes the necessity of introducing a new characteristic value for controlling the knocking intensity. The structure-borne sound information from the knocking sensor is used to determine the current knocking intensity in a quality that is comparable with that of pressure indication. The article describes an adaptation of a measurement chain required to guarantee absolute accuracy of the knocking intensity value. The definition of statistical parameters enables simplification in the evaluation of the knocking sensor signal and a pronounced enhancement in robustness, also toward interference noise. The continuity of the new parameter permits the application of a continuous controller to enable adjustment of the ignition timing as the needs dictate. This cuts adjustments of the ignition timing to a minimum. The article describes system properties that allow the control to implement early adjustment of ignition in the event that the cylinders have not been pre-set ideally.

1. Introduction / Motivation

The calls by the EU Commission to reduce CO2 emissions to 95 g CO2/km require substantial undertakings to increase the efficiency of combustion engines. One method is to shift the duty point toward high mean pressure with contemporaneous reduction in stroke volume – known as downsizing. With this in mind, current combustion methods permit compression ratios of 1:10 and more. But the knock threshold prevents operation at ideal ignition, especially at low speeds. Knocking control is used in order to guarantee the engine’s good working order. However, as the degree of downsizing increases, the weaknesses inherent to the standard version are becoming ever more apparent.

Firstly, the optimization of the combustion method reduces the combustion dispersion and hence also the dispersion of knocking events. This goes hand in hand with the reduction of the ratio between knocking and non-knocking events, which is important for the detection of knocking. This cuts the quality and stability of standard knocking detection and knocking control. It follows therefore that stabilizing the combustion processes in a gasoline engine as an objective in engine development run directly contrary to the requirements of standard knocking detection/knocking control (fig. 1).

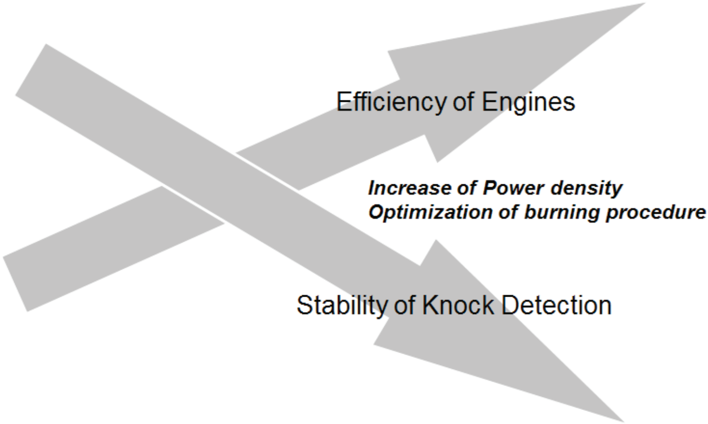

Figure 1: Conflicting objectives in current engine development

It must be stated furthermore that the rising number of systems designed to optimize combustion has also caused an increase in mechanical structure-borne sound emission. This also produces difficulties to compensate the reduction in the useable diference between structure-borne knocking signal and the basic engine noise.

Additionally, the ignition timing sequence which typically follows knocking detection prompts a disproportionate reduction in the engine torque. The later the ignition timing lies relative to the optimum knock threshold, the more the torque will fall in the subsequent positions. Engines with high power density in particular may therefore experience noticeable impact on drivability and fuel consumption.

The availability of high-octane fuels and the demands of the market for multiple fuel compatibilities present a further challenge to knocking control, as the knocking intensity exerts substantial influence on the knock distribution and hence on the difference between knocking and non-knocking.

Reasons of engine safety and engine efficiency necessitate a modification in the strategy of knock detection and the resulting ignition timing measures to suit current engine and market circumstances.

2. Repercussions of combustion optimization on knock detection

2.1. Knocking description through pressure indication

2.1.1. The standard counting method

The absolute maximum of band pass-filtered combustion pressure has become established in the determination of knocking intensity for individual combustions. The number of events above a defined pressure value is most commonly determined in order to describe knocking at a given duty point. In this example, there are 7 events of 1,000 that are located above a threshold of 3 bar (figure 2). For a long time this was deemed sufficiently precise.

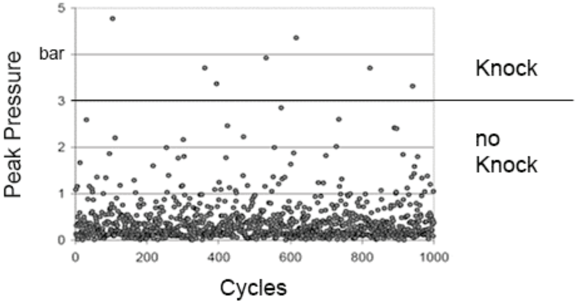

Figure 2: Knocking events in a standard engine

One primary objective in the development of combustion methods is to reduce the cyclic dispersion of the combustion process. This means that considerably more light knocking burnings appear. The strength of these individual events themself is uncritical. Figure 3 illustrates that an engine with an optimized burning procedure shows a considerably higher number of mean and small knocking events compared at an equal conventional numerator criterion (see figure 2).

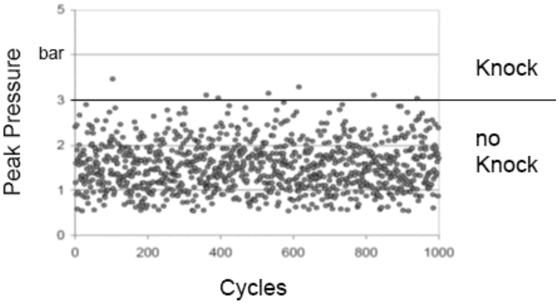

Figure 3: Knocking events in a modern engine

Accordingly, discrete description of knocking by using the standard counting method must be classified inadequate to cope even with the evaluation of the pressure gauge as a reference signal.

2.1.2. The statistical method

IAV tackled this problem as far back as the nineties, developing a statistical assessment of the knocking intensity. To do this, the relative accumulated distribution (figure 4, right) is determined for the example used in 2.1.1 (figure 4, left).

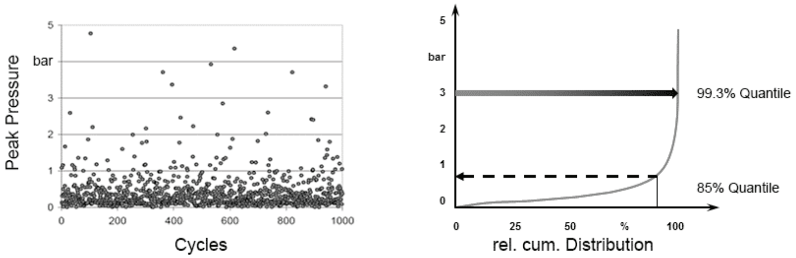

Figure 4: Statistical calculation of knocking intensity values

In this the sample is sorted according to the size of the elements, and the number of elements is standardized to 100 %. The strongest knocking incident describes the sample to 100 %. Hence this permits the consideration of any number of sample sections (quantiles).

At IAV, the 85 % quantile has proven most effective for assessing change knocking states like those found in test stand monitoring and automatic ignition timing optimization. It yields a stable value, even with a sample size of merely 240 cycles. Accordingly, the pressure value at the 85 % quantile in the sample selected is 0.8 bar.

If one applies the criterion found in 2.1.1 – threshold value of 3 bar – the quantile value for this distribution is 99.3 %. This means 0.7 % – in this case that seven events – are greater than 3 bar. 993 elements or 99.3 % are therefore equivalent to, or lower. Given that the pressure threshold remains constant, the quantile value in this method is variable. But this does not permit any statement on the mean knocking level.

Figure 5 presents the distribution for the example of an optimized combustion process, as seen in 2.1.1.

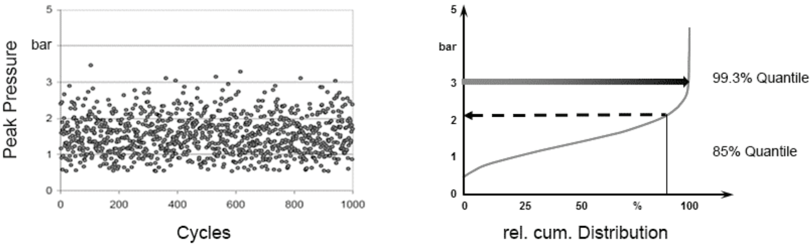

Figure 5: Statistical calculation of knocking intensity values

In this, the pressure value of the 85% quantile is 2.2 bar. This value reflects, to a far greater extent, the optical impression in the presentation of all cycles.

Given that the number of cycles with pressure vertex above 3 bar was held constant at 7 elements, the resulting quantile also remains constant at 99.3 %.

If one compares the position of the 85% quantile with the quantiles (constant here) determined at 3 bar, it is to observe a pronounced convergence between these two criteria in the optimized method. This reduced distance emphasizes the fact that a substantial reduction in difference between knocking and non-knocking can be ascertained in the reference signal already.

2.2. Impact of the altered distribution function on traditional knock detection and control

The problems associated with a reduced ratio between knocking and non-knocking are exacerbated once more in the evaluation of the structure-borne sound. The additive introduction of the engine's basic noise alone effects a linear, upward shift of the knocking signals, hence inducing a lower ratio between the two criteria.

This relevant distance is used, however, as a knock detection criterion at most control systems. A consequence for those systems is a strongly reduced selectivity between knocking and No knocking. The selectivity is also reduced considerably at control systems which evaluate the spread of the knocking events to themselves. As represented in 2.1.2, the distribution the knocking events approaches more and more the normal distribution. Therewith the difference between the standard deviations of knocking and No knocking also will sink.

The increasing effect of the firing angle on the mean knocking strength (e.g. 85% quantile at the pressure and reference level at the handling noise) also seems negative to the detection and control accuracy. Every intervention of the control – here the retarding of the firing angle – leads close to the knocking limit to a significant reduction of the knocking strength and therefore to a sinking noise. Due to the changed knock distribution the magnitude of hard knocking events does not drop much stronger then the reference any more, Therefore Signal- Noise Ratio does not drop clearly enough. Now also significantly lower knocking events are interpreted as knocking and responded by another firing angle retarding which in turn lets down the reference or noise drop again. The control is in a stable state of false detection (figure 6).

The opposite can happen in the equal operation point too. By advancing the firing angle the mean knocking strength and therefore the noise increases. Inevitably significantly higher knocking is not recognized anymore and no firing angle retarding is carried out. The control is in a state of NON-detection.

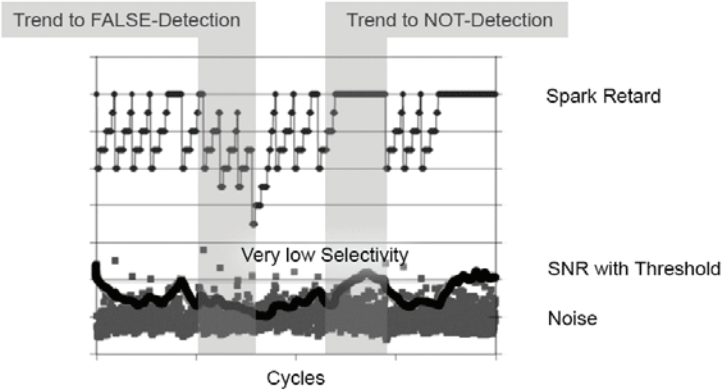

Figure 6: Weaknesses of standard knock detection/control

The stability and quality of knock detection and control continue to suffer if the combustion dispersion falls further. Hence, the goals of engine development run directly contrary to the requirements of the current knock detection and control strategy.

3. Parameterization for engine control

3.1. Ignition timing control at the IAV test stand using pressure gauging

The knocking intensity parameter described in 2.1.2 has been used successfully in test stand automation for many years at IAV. Firstly, it permits secure monitoring of the test sample on the basis of archived threshold values and response measures.

Secondly, the continuity and currency of the parameter permits control of the ignition timing.

The sequence of operations of an automatic firing angle adjustment represented is in the figure 7. Beginning with a sure firing angle the knocking strength target or limit is approached by linear advance of the firing angle (1).

A first estimation of the distance to the target value is carried out with the progress of 85% quantile (here dp85). By checking the distance to the target and boundary conditions an acceleration of the spark advancing can speed up the target achievement (2). In a safe distance to the target value the advancing of firing angle is reduced again (3). At transgression of the set point a retard is carried out on the last knocking free firing angle value (4). The optimum is reached and the measuring is executed (5).

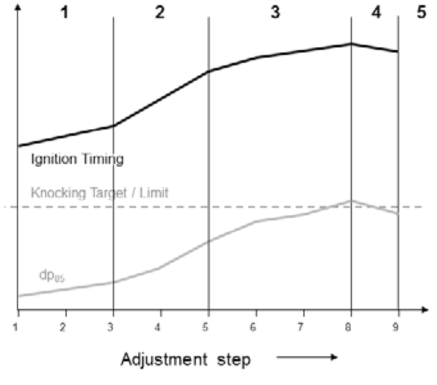

Figure 7: Automatic ignition timing control on the IAV test stand

This optimization can be combined with additional threshold and target values, for instance the location of the center of combustion.

Monitoring and optimizing the knocking intensity on the basis of a statistic knocking parameter has proven effective at IAV. The task at hand is now to transfer the principle to engine control.

3.2. Parameterization on the basis of structure-borne sound signals

3.2.1. Correlation between pressure and structure-borne sound signals

The principal requirement for the applicability of statistical evaluation is the proof of informational equivalence between pressure and structure-borne sound signals. This correspondence can be proven on the basis of an ignition graph presented in figure 8. It is clearly recognizable that the quantile value of pressure and also the level of structure-borne sound change exponentially with the ignition timing.

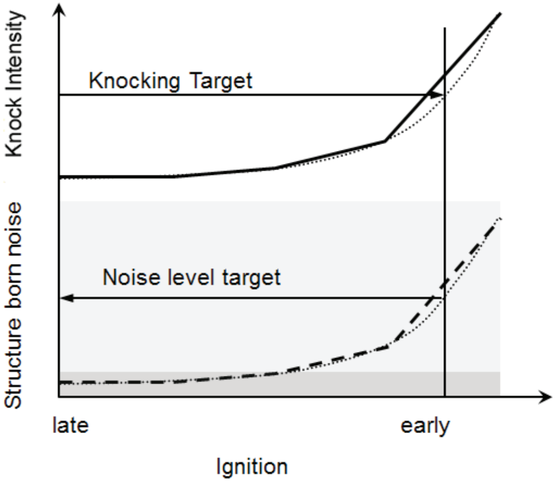

Figure 8: Statistical pressure and structure-borne sound criteria

In terms of the structure-borne sound, the explanation for this is that, up to a certain level, it consists solely of the normal noise emitted during engine operation. This includes mechanical noises, noises created by the electrical systems and the combustion itself.

But the structure-borne sound level rises sharply as soon as the early ignition creates knocking. This shows the separation of basic noise and the signal level generated by knocking. This furthermore proves that any knocking intensity identified by means of pressure indication can be assigned unambiguously to a structure-borne sound level. The demand for informational equivalence is satisfied in this 100 % correlation.

3.2.2. Optimization of signal recording by simplification

The better the structure-borne knocking information rises from the basic noise, the earlier and with greater the knocking intensity can be determined. This is achieved by optimizing the evaluation of the structure-born noise in a temporal and also spectral optimal form. Therefore signal filtering is simply reduced to a minimum.

A broad and rigid measurement window (figure 9) means that the location of combustion, and hence of knocking, is immaterial to the signal energy recorded. It follows that the measurement window does not have to move together with the ignition. Any and all interference is therefore recorded identically at all times, thus leading to stable basic noise, independent of ignition.

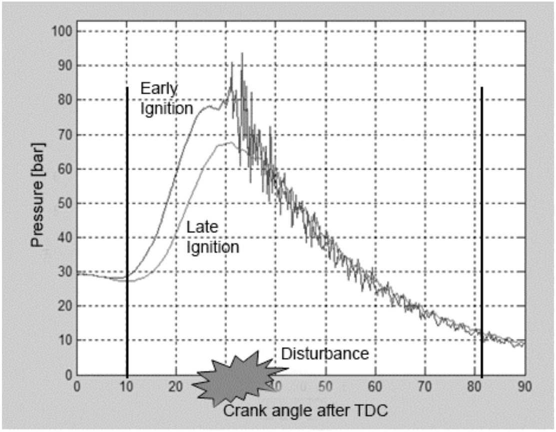

Figure 9: Broad, rigid measurement window

Filtering is expanded to include the entire spectrum of useful signals in the frequency range also (figure 10). This records the entire oscillation energy of the knocking events. Given that only the location of combustion will change in an ignition sweep with stable duty point, the basic noise remains constant, and only the knocking noise rises.

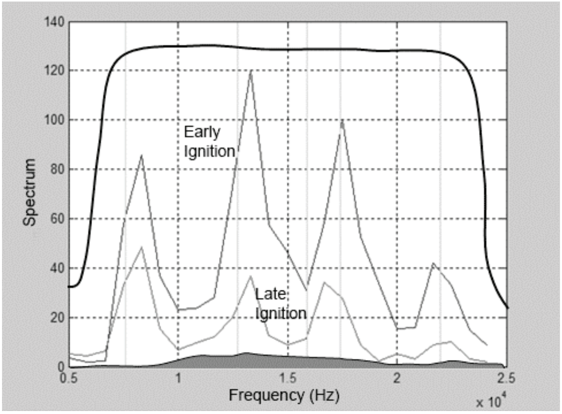

Figure 10: Broad signal filtering

A welcome side-effect of this simplification is the substantial reduction in effort involved in recording and evaluating the signals. The elaborate identification of filtering and windowing, dependent on the cylinder, speed, load, and fuel, are entirely unnecessary.

3.2.3. The TARGET value model

This context described in 3.2.1 applies to every duty point. The absolute value of target knocking level, however, is dependent on the duty point and must therefore be archived accordingly. This requires knowledge of the respective target knocking intensity, and it must be suitably set; for instance through the application of automatic ignition timing adjustment as defined under 3.1. This produces an engine map covering load and speed, in which the target level is archived (figure 11).

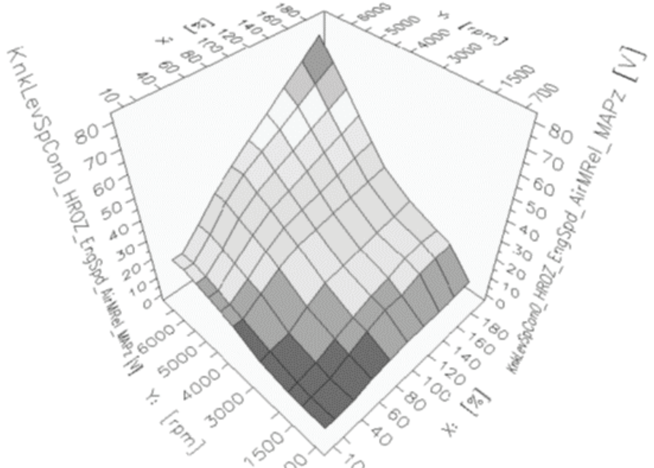

Figure 11: Target knocking level engine map

In modern engines, however, a speed-load point can be achieved by means of systems (camshaft adjustment, valve stroke, boost level, number of cylinders, injection strategy, air- fuel- ratio, etc.), activated or positioned in different ways. Furthermore, these systems are driven, which may lead to interfering signals.

The target value is also exposed to the ambient thermal conditions of the engine. As soon as a change in one of the system impacts on the basic noise, it will also influence the target knocking level. It follows therefore that the changes in parameter relevant to noise must be known and the reference target value requires correction equivalent to these changes. To do this, it is necessary to create a model, consisting of five modules.

Mechanical noise

This incorporates alterations in the noise emitted by all moving components.

However, it only relates to components that can be (de)activated or possess an adjustment range, where they leave from and return to the measurement window, for instance the noises of inlet and outlet valves closing.

Combustion noise

Combustion impacts very substantially on knocking distribution (see 2.1.2). Increasingly lean fuel, for instance, will raise knock dispersion, meaning that individual events will occur that should be classified as critical, even if the knocking level remains constant. Accordingly, modifications of carburetion must lead to an adjustment in the target level.

If the charge movement is variable, its activation will lead to an improved mix preparation and hence to a reduction in knocking dispersion. At the same time, the rise in charge cycle work increases the final compression temperature, which in itself prompts an increase in knocking susceptibility. The accumulating effect on the knocking sound must be available for target correction.

The individual values are monitored at the same time as defining the knocking level. Any extremely distinct, individual events that occur, indicate an anomaly compared with the known/archived statistical distribution of knocking and hence in the process of combustion. Given that the incidence of these extreme knocks is a response to changes in the ignition, the target level for the relevant engine map range is reduced significantly. Nevertheless, this system is not in the position to fulfill an independent pre-ignition detection.

Electronic noise

The principle here is the same as with the mechanics. The systems that can enter and depart the measurement window with their electrical disturbance must be identified. Significant repercussions on the basic noise are archived in a corrective value.

Octane number

The anti-knock properties of the fuel used have a very strong influence on the knock distribution. Accordingly, determining the octane number is a correct element of modeling the target value. Details will be presented in 3.2.4.

Measurement chain

The knocking signal is exposed to a wide range of damping and conversion on its way from the oscillating gas in the combustion chamber. Via the engine structure, the knock sensor, the jack connection, the cable, and the input circuit of the control device until it finally reaches into the analogue/digital converter. All elements in this chain are subject to exemplary dispersion and thermal influence, and some are also susceptible to ageing.

The thermal effects are summarized in the knocking sensor temperature model.

The exemplary dispersion of the individual elements and their ageing can only be assessed in their current assembly. Details are described in 3.2.4.

3.2.4. Noise adaptation

The target knocking level determined in 3.2.3 only applies to this specific engine used. Any stable control on the basis of the absolute target value requires an absolutely accurate target value for each individual engine in operation under all prevalent circumstances. This adaptation of the exemplary dispersion takes place by means of noise adaptation. It is conducted selectively for each cylinder and is virtually unaffected by driving behavior. Evaluation and classification of the measuring chain requiring adaptation is possible after merely one successful sequence. Approximately 5 successful adaptations are necessary in order to obtain sufficient precision for each cylinder.

As described in 3.2.1, the knocking intensity or the knocking level changes exponentially by advancing the ignition timing. The knocking intensity is often extraordinarily sensitive to any adjustment in the ignition timing, especially when approaching the target knocking intensity. This effect can be represented mathematically in the first derivative of the level curve through determination of the alteration gradient. Given that the level curve is a polynomial of at least the 3rd degree, the gradient produced will be a polynomial of at least the 2nd degree. Accordingly, one single level gradient can be assigned to each ACTUAL level. A target gradient belongs to the target level (figure 12).

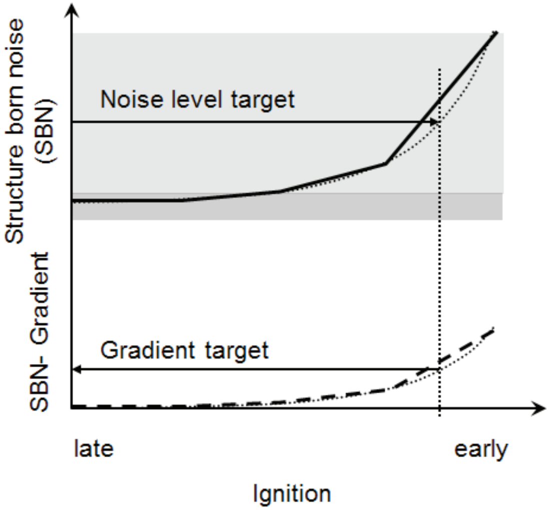

Figure 12: Level and gradient curve

The aim is to align the target value of the current measurement chain to the reference value by the application of linearization formula, in which

$$y = ax + b \qquad (1).$$

By applying the first derivative a curve shift towards the zero point was produced.

If the gradient curve of the system requiring adaptation (y) is equal to the reference system (x) applied in 3.2.3, the difference in level curves shall be equivalent to the displacement in zero point or the offset (b).

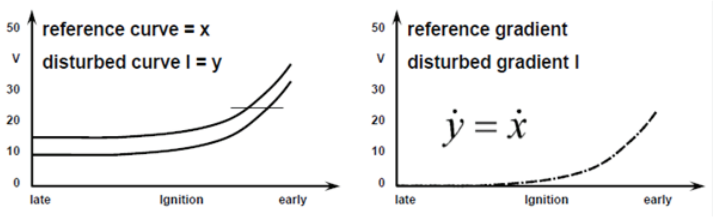

Figure 13: Impact of signal offset in measuring chain

The sensitivity of a measurement chain, that is the ratio between the potential created with given acceleration, is substantially influenced by the knocking sensor itself and the impact of applied impedance. It corresponds with the linear part.

If the comparison of the reference and actual gradient reveals a proportionate change, this represents the gain between the two level curves (a), i.e. the difference in sensitivity between the measurement chains.

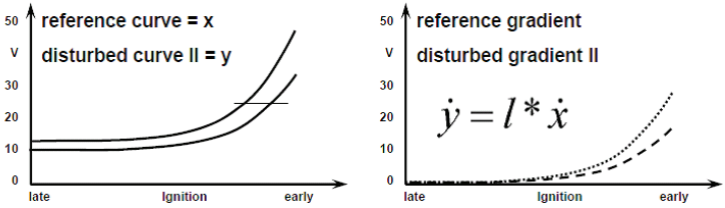

Figure 14: Impact of signal gain in measuring chain

Use of a low-octane fuel will produce a substantially steeper level and therefore gradient curve. Dependence between the current curve and the reference would be cubic. We shall now precede to the TARGET model for this gradient curve/this octane number using a switch threshold.

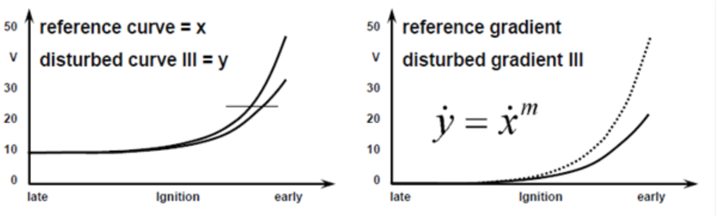

Figure 15: Impact of octane number

This evaluation of the gradient – the Δ (delta) – in knocking intensity provided the name of this control strategy.

3.2.5. Updating the knocking level

The statistical reliability is dependent on the dispersion within the sample and the number of elements considered. This applies to calculating the mean and also the quantile. A trend is apparent, however: the statistical parameter becomes increasingly stable or robust as the number of elements rises. In control, this is equivalent to high damping or a low filter factor.

When the working point is stable, the ambient conditions of very many events are identical. This is why a large number of elements can be evaluated here. The description of the state is extremely precise.

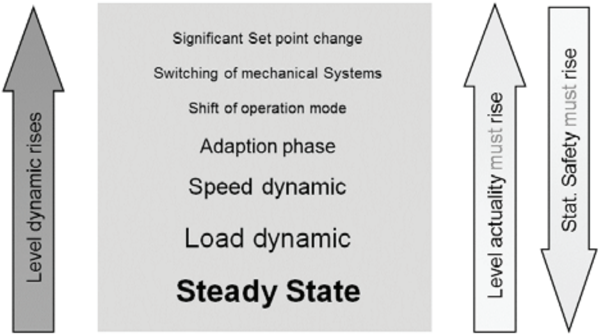

Figure 16: Dynamism-dependent compromise between currency and statistical security

The change in any parameter described in 3.2.3 produces signal dynamism. And currency comes increasingly to the forefront as the signal dynamism rises. To do this, the sample size, i.e. the level damping, is reduced in dependence on the signal dynamism. This reduction takes place in a compromise with the consequent decrease in statistical security of the knocking level. This decrease is permissible, as the dynamism case is limited in time and hence possesses barely any statistical relevance. Further, the gain in quality due to enhanced updating speed more compensates than the quality drops for sample reduction.

4. Knocking control with the engine control

4.1. Control structure

The structure of the DELTA knocking control is equivalent to the standard structure. In it, the actual level described under 3.2.5 replaces the controlled variable "ratio between knocking and non-knocking".

The standard common control factor "threshold for ratio between knocking and non-knocking" is replaced by the TARGET level as defined under 3.2.3 and 3.2.4.

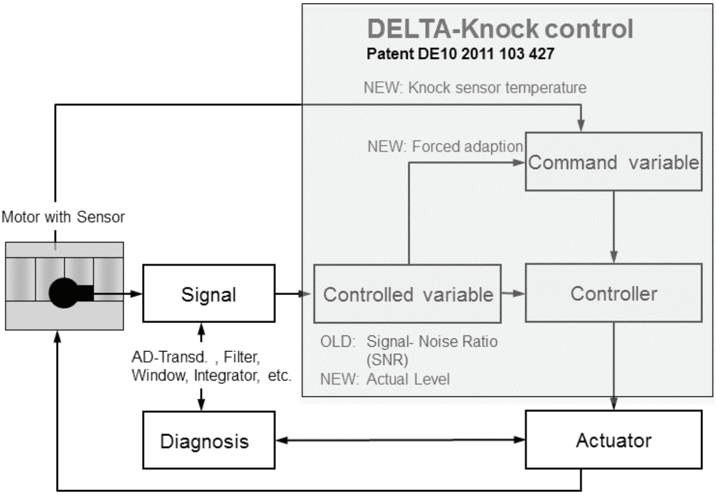

Figure 17: Comparison of standard versus DELTA control structure

A PID controller is used instead of the standard offset in ignition timing with following advance sequence. This is described in greater detail in 4.2.

4.2. Control strategy

The provision of a continuous control factor (current knocking level, see 3.2.5) and the derivation of controlled variable (target knocking level, see 3.2.3) permit the use of a continuous controller. Application of a PID controller means that the quasi predictive properties of the D part and the precise short and long-term reactions of the P and I parts can now also be exploited in knocking control.

This permits an extremely high increase of control quality.

Figure 18 uses a real measurement to provide an example of control with gradual, stage by stage increase in the target knocking level in volts and therefore the actual knocking intensity as dp85 in bar.

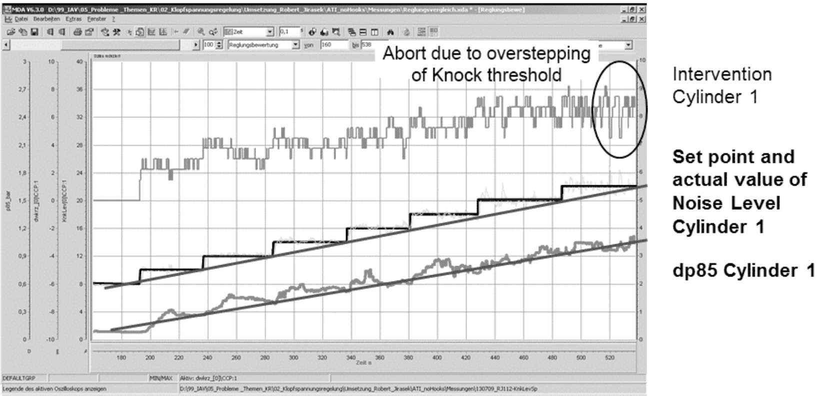

Figure 18: Gradual increase in the target knocking intensity

The control sets a very low deviation between TARGET and ACTUAL level with barely substantial alteration of ignition timing.

Progress of the target level now appears linear due to the temporal variation. This sequence in knocking intensity identified by pressure indication after the 85 % quantile (dp85) also progresses quasi linear and hence proportional to the target resp. the actual noise level.

The mean correction of ignition timing falls each noise set point increase as the knocking intensity increases. The curve of ignition correction is hyperbolic.

Presentation of the correlation between the ignition timing and knocking level or knocking intensity over time confirms the illustrations using the ignition timing variation as in figure 19, for example.

4.3. Control security

Use of a PID controller means that the ignition timing is set to early when values fall below the target. Two functions ensure that this early adjustment does not produce any hazardous knocking intensity.

Limitation in the adjustment factor range

During adaptation (see 3.2.4), more than just the target level is determined. Polynomial calculation permits extrapolation of level and gradient curve beyond the target value, hence enabling identification of the ignition timing at which the control parameters no longer guarantee the requisite security and quality (see “Limitation in ignition timing dynamism”). When the controller is in operation, this ignition timing serves as early limitation.

Limitation in ignition timing dynamism

In the case that the optimum control range – in other words, the target level – is exceeded, the pronounced non-linearity of the controlled variable (significant change in the rise of knocking level by early adjustment of the ignition angle) provokes substantial controller activity, that is ignition timing fluctuation (see top right in figure 15). This is a secure indication that the target knocking threshold has been exceeded.

The controller activity resp. the ignition timing dynamism is determined and monitored. In case of transgressing of the target knocking intensity caused by premature ignition timing the controller activity exceeds its limit. As necessary consequence the target level is reduced to a secure target value.

4.4. Control stability and quality

As presented in figure 19, the steep gradient of the controlled variable has markedly stabilizing effects. A deviation of ± 1° KW from the optimum ignition timing is equivalent in this example to a change of approximately ± 25 % from the target level.

The extended signal registration (see 3.2.2) and the adaptation (see 3.2.4) prevent any such fault. It is therefore fair to assume a control stability and precision of less than ± 1° KW.

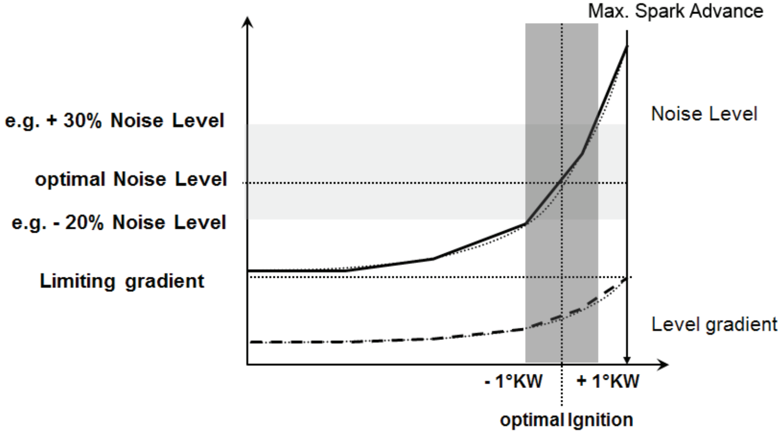

Figure 19: Control precision and maximum early adjustment

4.5. Robustness towards interference

Sporadic interference

Interference signals that do not follow any systematic pattern may be introduced sporadically into the structure of the engine. Provided the energy is sufficient, standard knocking control will detect these signals as knocking events and will respond by retarding the ignition timing. Statistical evaluation incorporates them in the overall sample, and their significance is thereafter extremely subordinate. Their impact on the control deviation and hence on changes in ignition timing is negligibly slight.

Constant interference

The control will set the target level by late adjustment of the ignition timing if the knocking level rises due to continuous interference, caused, for example, by a defect component. If this falls below an archived threshold, the control stroke is classified implausible and a noise adaptation is initiated.

If the mechanical defect is repaired, the limitation in ignition timing dynamism according to 4.3 shall remain in force until the next cyclic adaptation.

5. Summary and Outlook

The statistical approach to calculate the actual knocking level delivers a reliable criterion to establish secure controls, especially in engines with reduced knocking stochastic.

The DELTA knocking control enables for the first time the definition of an actual target knocking level to control knocking.

The level adaptation introduced guarantees a high degree of signal quality and the simple and secure adjustment of units within an engine series, along with a broad spread in octane number and across the entire life cycle.

Simplification of signal recording and modeling of the engine noise represent a significant reduction in the effort related to adaptation of knocking control for the stage of build, i.e. engine derivatives.

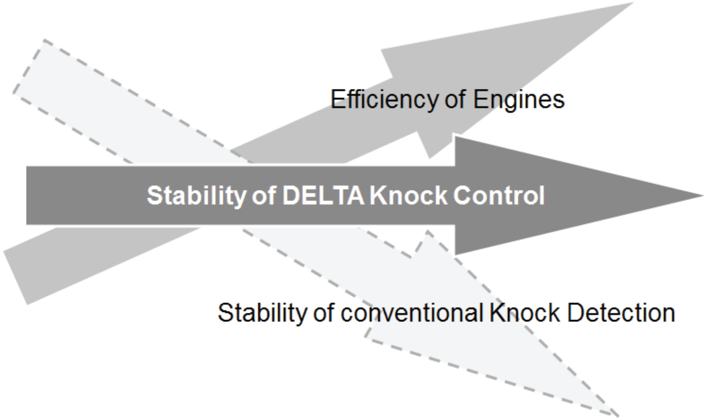

Figure 20: Solution of the target conflict

The PID controller and the correct target level cut the ignition timing reduction to a minimum. Level adaptation in cylinders with substantial potential in pre-control of the ignition timing permits its optimization. The consequent ignition timing effectiveness with DELTA knocking control is therefore improved, which may in turn have positive repercussions on fuel consumption.

The minimized impact range of ignition timing reduces the stress of following acting systems e.g. boost pressure control or drive ability.

The DELTA control method solves the conflicting targets between the ongoing optimization of combustion procedure and the demands of current knocking detection. This shall permit secure exploitation of additional benefits in terms of further downsizing and combustion stabilization.

17 Artificial Intelligence for knock detection

Matthias Biehl, Elvira Perless, Robert Sloboda

Abstract

This article deals with the identification of abnormal combustion phenomena in gasoline engines by reconstructing physical values, which cannot be detected directly or only at high costs. Therefore methods from the field of Artificial Intelligence, Pattern Recognition and Statistics are combined in this approach to create a basis for important Electrical Control Unit (ECU) algorithms. The influence of databases with an extremely uneven data distribution and data spectrums of high-variance is investigated. Standard measurements from various engines are processed to ensure a high generalizability of the model and the comparability to the results of the ECU. A noticeable increase of robustness against interferences resulting in an improved quality and a reduced parameterization effort is achieved by using this model.

Kurzfassung

Diese Veröffentlichung beschäftigt sich mit der Identifikation anormaler Verbrennungsphänomenen in Ottomotoren mit Hilfe der Nachbildung physikalischer Größen, die nicht direkt oder nur unter hohem Kostenaufwand bestimmt werden können. Daher werden Methoden aus dem Bereich der Künstlichen Intelligenz, der Mustererkennung und der Statistik in diesem Ansatz kombiniert, um eine Grundlage für wichtige Steuergeräte Algorithmen zu bilden. Der Einfluss von Datenbasen mit extrem ungleich verteilten Daten und Datenspektren mit hoher Streuung wird dabei untersucht. Um eine hohe Generalisierungsfähigkeit des Models und die Vergleichbarkeit zu den Steuergerätergebnissen zu gewährleisten werden Standardmessungen verschiedener Motoren verarbeitet. Eine deutlich verbesserte Robustheit bezogen auf Störungen, was weiterhin zu einer erhöhten Güte und einem verringerten Parametrisierungsaufwand führt, wird durch das Model erreicht.

1. Introduction

The ever-growing economical and ecological demands made on modern combustion engines, in particular with regard to the improvement in efficiency and emission performance standards, require permanent new and further development of components, methods, and functions. A vast number of these developments results in increased complexity and in side effects amongst each other, which necessitates adequate continued processing of the calibration.

For the knock detection that is based on a structure-borne noise sensor this adds up to a negative influence due to a rising number of mechanical and electrical interferences on the sensor or on the sensor signal. The cause for these disturbances is usually a result of the growing diversity of engine components and new strategies for the mixture formation and combustion process. The current reference value method for the knock detection, in particular when based on a multiple-filter strategy, provides a solution for this, although the calibration effort compared to the single-filter strategy is distinctly increased and can hardly be implemented without the support of a tool chain.

1.1. State of technology

The maximum value of the bandpass-filtered cylinder pressure signal (Peak) has proven to be the most representative value for the evaluation of the knock intensity. This value is used to verify the knock detection quality of different knock detection strategies. To date, the pressure sensor was not able to establish itself for the series production application, due to the comparatively high costs and the short service life.

The reference value method currently used in series production for the detection of knocking, calculates cylinder-individually the knock integral (IKR) on the basis of the structure-borne noise signal that has been processed with one or several adjustable bandpass filters. For this, the sensor signal is recorded in a limited time period after the ignition, which is specified by the adjustable measurement window (beginning and length). This integral is divided by a permanently updated mean value that is referred to as reference level (RKR) and that is based on the IKR. The result (RKI) is compared with an adjustable knock detection threshold (KEK), and when the threshold is reached a knock occurrence is detected.