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Analysis of ignition signal characteristics of a spark ignition engine under ethanol–gasoline blends

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ABSTRACT

This study aims to use a digital oscilloscope to analyze the ignition signal characteristics of a fuel-injection spark ignition engine operating with different gasoline–ethanol blends (E0, E20, E40, E60, and E80). Signal measurements were conducted under two engine speed conditions: idle and high speed. The evaluated signal parameters include frequency, period, duty cycle, peak voltage, peak-to-peak voltage, and effective (RMS) voltage. The results show that increasing the ethanol content generally increases the ignition signal frequency, even at high engine speeds, while reducing peak voltage and RMS voltage. The findings also indicate that a shorter coil dwell time reduces ignition power and suggest that the engine control unit (ECU) can adapt its settings for gasoline–ethanol combustion. Overall, the study provides useful insights for improving ignition system calibration and tuning in spark ignition engines operating on gasoline–ethanol fuel blends.

1. Introduction

The growing demand for sustainable energy sources and increasingly stringent emission regulations have encouraged the use of alternative fuels in internal combustion engines. Among these alternatives, ethanol has attracted significant attention due to its renewable nature, oxygenated molecular structure, and high octane number, which make it suitable for blending with gasoline in spark ignition (SI) engines. Numerous studies have reported that ethanol–gasoline blends can influence combustion characteristics, engine performance, and exhaust emissions, particularly under low- and medium-load operating conditions (Turner et al., 2011; Costa and Sodré, 2010; Kunwer et al., 2022).

In fuel-injected SI engines, combustion stability is strongly governed by the ignition system, which is actively controlled by the engine control unit (ECU). Ethanol-blended fuels typically exhibit a lower heating value and a higher latent heat of vaporization compared to gasoline. These properties can increase ignition energy demand, particularly at low engine speeds and during idle operation, where mixture preparation and flame initiation are more sensitive to fuel characteristics (Heywood, 2018; Kunwer et al., 2022). To maintain stable combustion, modern ignition systems rely on ECU-driven adaptation of ignition parameters, including coil dwell time, ignition timing, and the electrical excitation delivered to the ignition coil.

Although extensive research has been conducted on the effects of ethanol blending on engine performance, combustion behavior, and emissions, relatively limited attention has been devoted to the electrical characteristics of ignition control signals under varying ethanol concentrations. Recent studies have emphasized that ignition-related electrical parameters play a critical role in ensuring reliable flame initiation, particularly when alternative fuels with different physicochemical properties are employed (Nad et al., 2026). However, experimental investigations that directly measure ignition control signals using oscilloscope-based techniques in practical engine configurations remain scarce.

Direct analysis of ignition control signals enables detailed characterization of waveform shape, duty cycle, frequency, and effective root mean square voltage (VRMS), which collectively represent the electrical excitation supplied to the ignition coil. These parameters provide valuable insight into how the ignition system and ECU respond to changes in fuel composition, especially under operating conditions where combustion stability is critical (Heywood, 2018; Stone, 2017). Such measurements can therefore complement conventional combustion

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and performance analyses by revealing the electrical behavior underlying ignition system adaptation.

Therefore, this study investigates the ignition signal characteristics of a fuel-injected motorcycle SI engine operating with ethanol–gasoline blends ranging from E0 to E80. Measurements were conducted at idle speed and medium engine speed (4500 rpm) to examine the influence of ethanol concentration on ignition control signal waveforms and VRMS values. By focusing on direct electrical signal measurement, this work aims to complement existing studies on ethanol-fueled SI engines and to provide experimental insight into ignition system behavior and ECU control strategies under varying ethanol blending conditions.

2. Research methodology

This study used a quantitative experimental approach to investigate the ignition-signal characteristics of a single-cylinder spark-ignition (SI) engine operating with different ethanol–gasoline blends. Previous studies have shown that changes in ethanol concentration can affect combustion characteristics and the performance of SI engines. Therefore, ethanol–gasoline blends have been widely investigated under controlled experimental conditions (El-Faroug et al., 2016; Park et al., 2016).

In this study, five ethanol concentrations were selected: E0, E20, E40, E60, and E80. These blends were used as the main fuel conditions for evaluating the effect of ethanol concentration on the ignition signal. The selection of different ethanol concentrations is consistent with previous experimental studies that have examined the effects of different ethanol–gasoline blend ratios on SI-engine combustion and performance (El-Faroug et al., 2016; Park et al., 2016).

Each fuel blend was tested at two engine-speed conditions: idle speed (1500 rpm) and 4500 rpm. These conditions were selected to represent different engine operating speeds. Previous research has shown that engine speed, fuel composition, ignition conditions, and engine load can influence the combustion behavior and performance of SI engines. Therefore, maintaining a consistent engine operating condition is important when comparing different fuel blends (El-Faroug et al., 2016).

The research variables were divided into independent, dependent, and control variables. The independent variable was the ethanol concentration in the fuel. The dependent variables were the ignition-signal parameters measured using a digital oscilloscope. These parameters included signal frequency (Hz), period (ms), duty cycle (%), peak voltage, peak-to-peak voltage, and effective voltage. These measurements were selected to provide quantitative information about the electrical characteristics of the ignition system and its response to changes in fuel composition.

Several control variables were also maintained throughout the experiments to improve the consistency and validity of the measurements. These included battery voltage, spark-plug condition, engine temperature, measurement conditions, and engine speed. The engine was operated after reaching a stable operating temperature, and the specified engine speeds of 1500 rpm and 4500 rpm were maintained during the respective tests. Controlling these conditions is important because fuel composition and engine operating conditions can both influence combustion behavior in SI engines (El-Faroug et al., 2016; Park et al., 2016).

Overall, this experimental design provides a consistent and measurable framework for examining how changes in ethanol concentration affect ignition-signal characteristics in a fuel-injected motorcycle SI engine. By keeping the main operating conditions constant and changing only the ethanol concentration, the study aims to identify differences in the measured ignition-signal parameters that can be associated with the fuel blend rather than with uncontrolled experimental conditions.

2.1. Research objects and tools

A 110-cc single cylinder with an Electronic Control Unit (ECU) and a controlled Transistor Controlled Ignition (TCI) system is the subject of the investigation. A two-channel digital oscilloscope with the following features was the primary tool utilized, as shown in Table 1.

Table 1: Specification of the oscilloscope used

No.	Oscilloscope specification	
1	Bandwidth	30 MHz
2	Sampling rate	250 MS/s (mega samples per second)
3	Channels	2 channel (CH1 and CH2)
4	Memory depth	10 Kpts up to 1 Mpts
5	Vertical resolution	8-bit ADC
6	Vertical sensitivity	2 mV/div to 5/div
7	Time-based range	5 ns/div-100 s/div
8	Trigger mode	Edge, Pulse, Video, Alternate, Slope
9	Auto measurement	Frequency, period, duty cycle, V-Max, V-Min, Vpp, Vtop, Vbase, rise time, fall time, VRMS, overshoot, undershoot
10	Display	8-inch TFT-LCD 800× 600 Resolution
11	Storage	USB Host, USB Device, supports saving wave from and screen capture to USB flash disk
12	Power	100-240 V AC, 25 W typical consumption

2.2. Data collection procedure

In order to ensure consistency between the theoretical calculation and the VRMS value reported by the oscilloscope, a manual calculation was performed after all waveform data had been collected. The ignition control signal observed in this study exhibits a square-pulse waveform characterized by a peak voltage (V_{peak}), an on-time (T_{on}) corresponding to the coil dwell period, and an off-time (T_{off}) during which the signal voltage approaches zero. For such a periodic square-pulse signal, the VRMS value can be expressed as Eq. 1:

$$V_{RMS} = \sqrt{D} V_{peak} \quad (1)$$

where D is the duty cycle expressed in decimal form (e.g., 50%=0.5) and V_{peak} is the peak voltage of the ignition control signal. This formulation is derived from the general definition of RMS voltage as the square root of the time-averaged squared voltage over one complete signal period. A schematic representation of the waveform used for the VRMS calculation is shown in Fig. 1, illustrating the relationship between V_{peak}, T_{on}, T_{off}, duty cycle, and signal period.

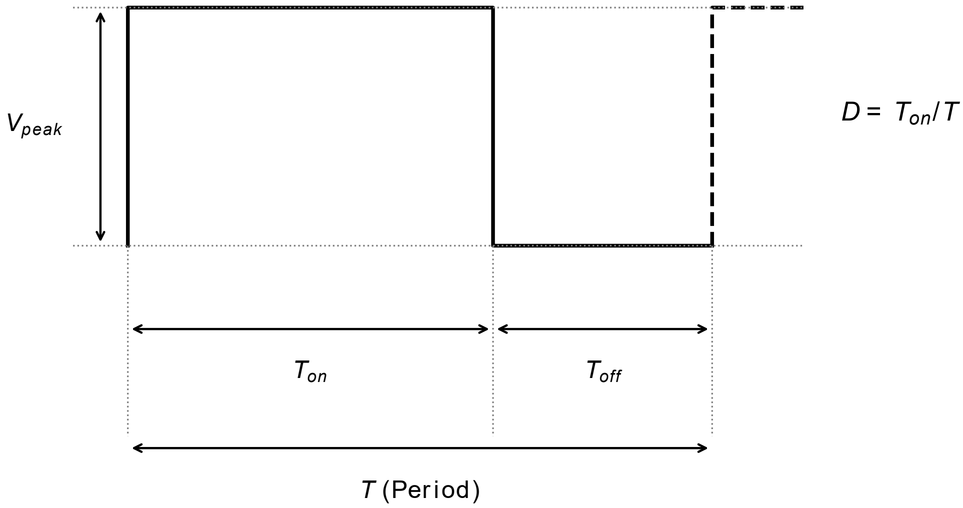

Fig. 1: Schematic representation of the ignition control signal waveform used for VRMS calculation, illustrating peak voltage (V_{peak}), on-time (T_{on}), off-time (T_{off}), duty cycle (D), and signal period (T)

The VRMS value calculated using Eq. 1 represents the effective electrical excitation level delivered to the ignition coil and does not correspond to mechanical vibration measurements. The calculated VRMS values were compared with the oscilloscope auto-measurement results to confirm consistency between analytical and instrument-based measurements. To assess measurement repeatability, each ignition signal recording was repeated three times for every ethanol blend and operating condition. The reported values were summarized as the mean of the repeated measurements, and variability was quantified using the standard deviation (SD). The “5% threshold” was applied as a quality-control criterion to screen for transient disturbances (e.g., unstable engine speed or waveform interference); when a deviation greater than 5% was observed among repeated captures for the same condition, the measurement was repeated under stabilized operating conditions. This approach ensured that the reported waveform parameters represent steady-state ignition signal behavior.

2.3. Research instruments and materials

The ignition signal parameters of fuel injection are measured with great precision in this study using a variety of instruments and test materials. An electronic oscilloscope is the principal tool for measuring waveforms. It has a 30 MHz bandwidth, 250 MS/s sampling rate, two input channels, a vertical sensitivity range of 2 mV/div to 5 V/div, and an auto-measurement function that shows signal parameters like frequency, period, duty cycle, peak-to-peak voltage, and effective voltage in real-time. Modern motorcycle TCI/ECU systems record ignition signal characteristics with voltage and coil charging time changes on the scale of milliseconds. This oscilloscope was chosen for its sampling capability and bandwidth, which are more than adequate for this task. Recorded signals are also guaranteed to be distortion-free due to measurement issues or bandwidth limitations, thanks to the instrument's reliability.

From the electronic control unit (ECU) to the ignition coil, the signal for ignition travels along the main ignition control line. Selecting the primary line was based on the fact that the waveform of a voltage pulse managed by the ECU clearly depicts the ignition process dynamics, including dwell time, frequency stability, and signal amplitude changes caused by fuel variances. By employing a controlled ground and DC coupling mode direct probing technique, the accuracy of the readings may be guaranteed from the oscilloscope. An unmodified 110 cc FI engine in its normal operating condition served as the test subject for this investigation. Details about the engine specifications are provided in Table 2.

Table 2: Spark ignition engine specifications

No.	Motorcycle specifications	
1	Engine type	4 strokes, SOHC with air cooling, eSP
2	Engine capacity	108.2 cc
3	Fuel supply system: injection	(PGM-FI)
4	Bore × stroke	50 × 55.1 mm
5	Transmission type	Automatic (V-Matic)
6	Compression ratio	9.5:1
7	Maximum power	6.38 kW (8.68PS)/7.500 rpm
8	Maximum torque	9.01 N.m (0.92 kgf.m)/6.500 rpm
9	Starter type	ACG starter, Pedal and electric
10	Clutch type	Automatic, Centrifugal, Dry type

In order to replicate low and medium load conditions, the engine was tested at two different rotational speeds: Idle (1500 rpm) and 4500 rpm. The fuel utilized was a RON 92 blend of ethanol and petrol with five distinct compositions (E0, E20, E40, E60, and E80) that was prepared using a controlled volumetric mixing technique to meet the study requirements for alternative fuels. To prevent fuel evaporation and fluctuations in mixture fraction, all fuel is stored in containers with tight lids. Using this combination of materials and tools will ensure that other researchers can replicate the full test, in addition to yielding accurate signal data. Therefore, this section of the instruments and materials is crucial for understanding the impacts of ethanol variation on FI motorcycle ignition systems because it provides the ignition signal output that is genuine, exact, and useful.

2.4. Data processing procedure

This study's data processing technique was built to verify the accurate processing of all ignition signal measurement results prior to analysis. After receiving raw data from an oscilloscope in the form of signal parameters, the data was reprocessed through a series of steps, including numerical data extraction, recalculation of technical parameters, waveform reconstruction, and subsequent compilation of comparative data between variations of gasoline ethanol mixtures. Frequency, period, duty cycle, peak-to-peak voltage, effective voltage, and all other characteristics obtained by the auto-measurement feature were compiled and organized in a digital spreadsheet for methodical analysis. Two engine test settings, idle and high rpm, and five different gasoline ethanol composition levels were used for data classification. After that, we need to check the VRMS value analytically. Since the primary coil line's ignition signal is a digital pulse wave with a predetermined ON/OFF time ratio, the theoretical Eq. 1. The correctness of the calculations is crucial to the quality of the interpretation during analysis, so this validation procedure is essential for keeping the data intact. VRMS stands for the average energy supplied to the ignition coil. Once everything is in order, the signal data is transformed into waveform diagrams in Excel. Signal period, duty cycle, and voltage amplitude are the primary characteristics used for reconstruction. If we want to make it easier to evaluate different ethanol variants, we need a signal representation that is clean, devoid of visual noise. Additionally, unlike oscilloscope screen grabs, this reconstruction method allows for a more in-depth examination of signal patterns such as frequency fluctuations, dwell time shortening, and amplitude declines. The association between ethanol composition and variations in ignition signal characteristics at various engine speeds is demonstrated by putting the processed data into comparative tables and trend graphs. Prior to their examination in the following chapter, all measurement findings are meticulously prepared via this data processing procedure. In addition to being theoretically valid, the resulting argument will be representative of the physical phenomena seen in FI motorcycle ignition systems driven by gasoline ethanol blends and will be based on sound methodology.

3. Results

3.1. Ignition signal characteristics in E0 mixture variations

Under E0 (pure gasoline) operation, the ignition control signal waveform exhibits a stable square-pulse pattern at both tested engine speeds. At idle speed, the measured average voltage of the ignition control signal was approximately 2.51 V, with a corresponding VRMS value of about 3.54 V. When the engine speed increased to 4500 rpm, the VRMS value decreased to approximately 2.15 V, while the average voltage was reduced to around 1.37 V.

The ignition signal waveforms and associated voltage parameters for E0 fuel at idle and 4500 rpm are shown in Fig. 2.

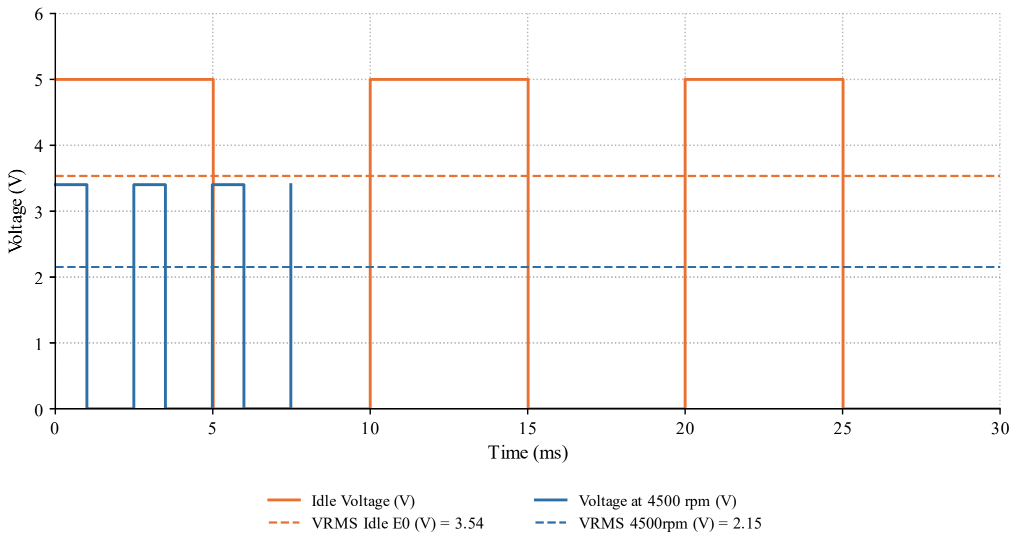

Fig. 2: Ignition signal E0 graph

3.2. Ignition signal characteristic in E20 (80% RON 92 and 20% ethanol)

For the E20 ethanol–gasoline blend, an increase in ignition signal magnitude was observed relative to E0 conditions. At idle speed, the VRMS value increased to approximately 4.45 V, accompanied by an average signal voltage of about 3.14 V. At 4500 rpm, the VRMS value decreased to approximately 2.40 V, with an average voltage of around 1.70 V.

The ignition control signal waveforms recorded for the E20 fuel blend at both engine speeds are presented in Fig. 3.

3.3. Ignition signal characteristic in E40 mixture (60% RON and 40% ethanol)

The ignition signal characteristics for the E40 fuel blend are illustrated in Fig. 4. At idle conditions, the VRMS value reached approximately 4.49 V, with an average signal voltage of about 3.20 V. At 4500 rpm, the VRMS value decreased to approximately 2.18 V, while the average voltage was approximately 1.38 V. These measurements indicate a gradual variation in ignition signal magnitude as ethanol concentration increased from E20 to E40.

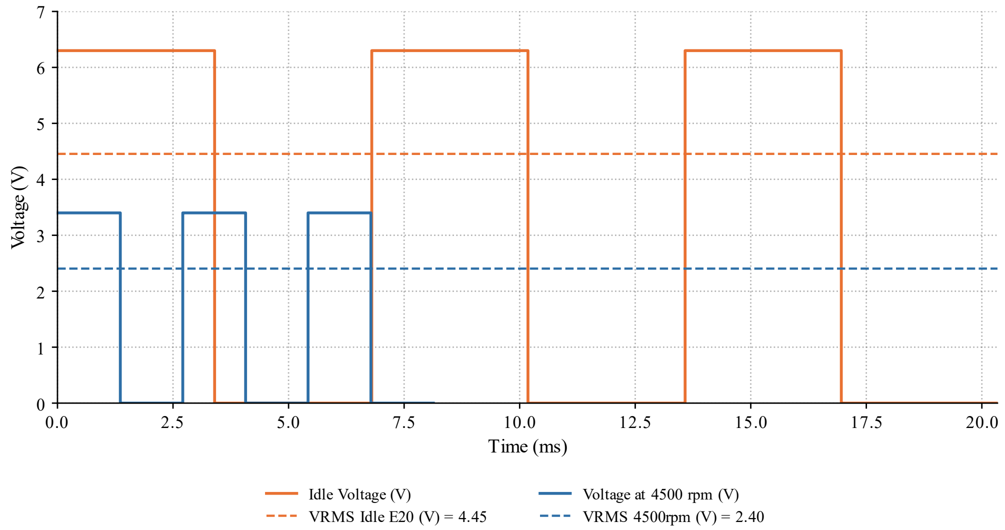

Fig. 3: E20 ignition signal graph

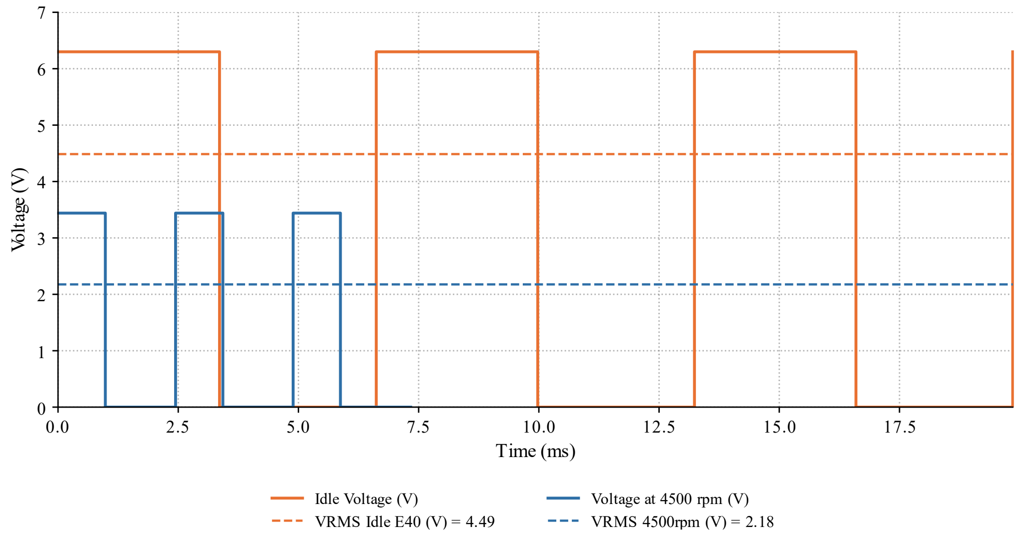

Fig. 4: E40 mixture ignition signal graph

3.4. Ignition signal characteristic in E60 mixtures (40% RON 92 and 60% ethanol)

For the E60 fuel blend, the ignition control signal VRMS at idle was approximately 4.45 V, with an average voltage of about 3.14 V. At 4500 rpm, the VRMS value decreased to approximately 2.40 V, accompanied by an average voltage of around 1.71 V.

The corresponding ignition signal waveforms and voltage characteristics for E60 fuel are shown in Fig. 5.

3.5. Ignition signal characteristic in E80 mixture (20% RON 92 and 80% ethanol)

The ignition signal characteristics for the E80 fuel blend are presented in Fig. 6.

At idle speed, the measured VRMS value remained at approximately 4.45 V, with an average voltage of about 3.14 V. At 4500 rpm, the VRMS value decreased to approximately 2.40 V, with an average voltage of around 1.71 V.

The ignition signal magnitudes observed for E80 are comparable to those measured for the E60 fuel blend under the same operating conditions.

4. Discussion

The experimental results clearly demonstrate that ethanol–gasoline blending exerts a measurable influence on the electrical characteristics of the ignition control signal in a fuel-injected spark-ignition engine, with the most pronounced effects observed under idle operating conditions. In comparison with pure gasoline (E0), ethanol-blended fuels ranging from E20 to E80 produce higher ignition signal VRMS values at idle. This increase in VRMS indicates that a greater level of electrical excitation is supplied to the ignition coil to ensure adequate spark energy delivery. Such behavior is consistent with the inherent physicochemical properties of ethanol, including its lower heating value relative to gasoline and its significantly higher latent heat of vaporization. These properties tend to reduce the in-cylinder mixture temperature during fuel vaporization, particularly at low engine speeds, thereby increasing the ignition energy requirement to initiate and sustain stable combustion. Furthermore, the observation that VRMS values remain relatively similar for higher ethanol fractions, particularly for E60 and E80, suggests that the ignition control system enters a stabilized operating regime at elevated ethanol contents. Within this regime, further increases in ethanol concentration do not lead to proportional increases in the ignition signal VRMS. This response indicates that the engine control unit (ECU) applies an adaptive control strategy that limits the electrical excitation within a predefined operating envelope.

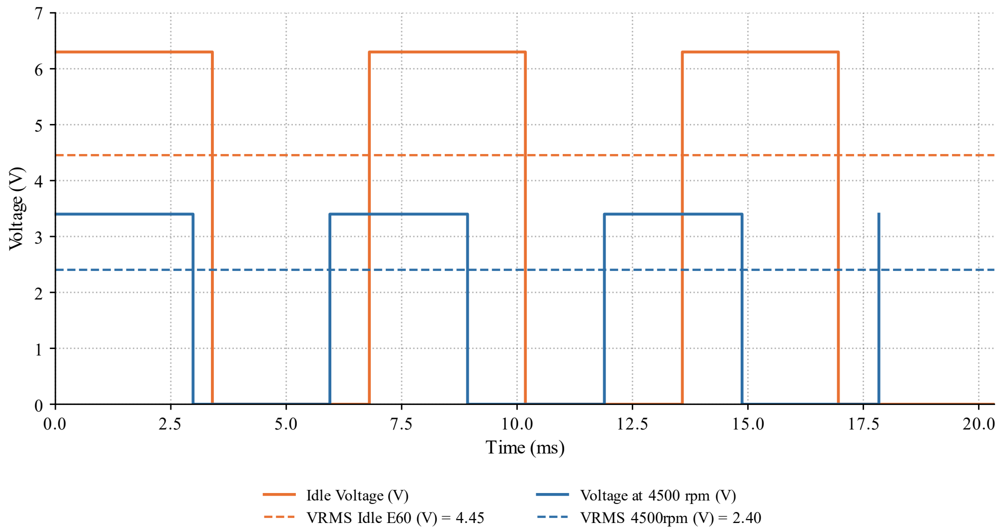

Fig. 5: E60 mixture ignition signal graph

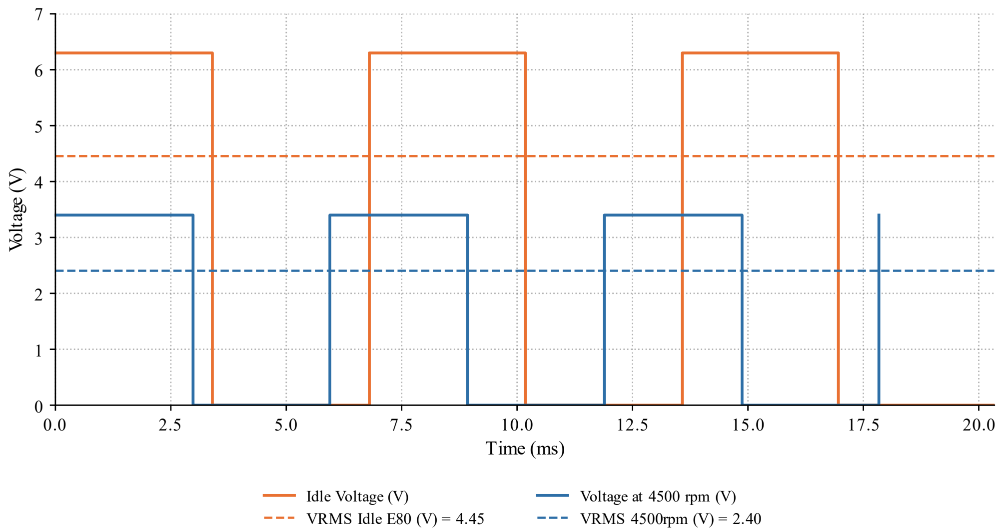

Fig. 6: E80 mixture ignition signal graph

By doing so, the ECU ensures reliable ignition performance while simultaneously preventing excessive electrical loading on the ignition coil and associated electronic components. This bounded control behavior reflects a deliberate balance between meeting increased ignition energy demands and preserving the durability and thermal integrity of the ignition system.

At higher engine speeds, specifically at 4500 rpm, a reduction in ignition signal VRMS is observed across all tested fuel types, including both pure gasoline and ethanol-blended fuels. This reduction can primarily be attributed to the decreasing dwell time available for each ignition event as engine speed increases. Shorter dwell times limit the duration over which the ignition coil can store electrical energy, resulting in lower RMS voltage levels. Nevertheless, despite this overall reduction, ethanol-blended fuels continue to exhibit VRMS values that are comparable to, or slightly higher than, those of pure gasoline under identical operating conditions. This indicates that the ignition control system remains capable of delivering sufficient electrical excitation to maintain stable combustion even under high-speed operating constraints.

The comparative trends observed between idle and higher engine speed conditions highlight that the influence of ethanol blending on ignition signal characteristics is most significant at low engine speeds, where combustion stability is more sensitive to fuel properties, mixture preparation, and ignition energy availability. Under higher-speed operation, the effect of ethanol concentration on VRMS becomes less pronounced, suggesting that the ignition system operates within a relatively stable electrical control regime. In this regime, ignition timing and energy delivery are dominated more by engine speed and control strategy than by variations in fuel composition.

Overall, these findings indicate that the fuel-injected ignition system exhibits adaptive electrical control behavior in response to ethanol–gasoline blending. Through the regulation of ignition signal VRMS across varying operating conditions, the ECU is able to maintain consistent and reliable ignition performance for ethanol contents up to E80 without exceeding the normal electrical operating limits of the ignition system. This adaptive capability underscores the robustness of modern ignition control strategies and supports the feasibility of using high-ethanol fuel blends in spark-ignition engines without compromising ignition system reliability.

5. Conclusion

This research shows that FI spark ignition signal parameters are significantly affected by changes to ethanol blends. At idle, the *VRMS* value increased dramatically between gasoline E0 and E20, then remained relatively constant until E80. Because it is thermally more difficult to ignite the ethanol-gasoline mixture than pure petrol, the ECU's compensatory response is this first rise, which keeps the ignition energy beyond the threshold. When the ignition frequency is increased, the coil charging time lowers, but the VRMS change pattern remains linear at 4500 rpm. This adaptive reaction ensures that spark energy remains within a safe range. This feature proves that the FI ignition system can adjust the main pulse's length and amplitude to keep ignition quality consistent across a range of ethanol concentrations. With the ignition system maintaining reliable performance under both test speeds, the results of this study indicate that the FI engine is tolerant to ethanol gasoline up to an 80% proportion. The ECU control method appears to be able to maintain the spark energy within the optimal range regardless of changes in the fuel's thermophysical properties, as indicated by the stable primary signal, consistent VRMS measurements, and adaptive tendency at high speeds. Research into ignition energy optimization, ignition timing analysis, and the overall influence of ethanol on the combustion system can be enhanced by building on this study, which also offers a solid technical foundation for using ethanol gasoline as an alternative fuel in an FI engine. This study was limited to a single fuel-injected motorcycle spark ignition engine and ethanol–gasoline blends up to E80 under steady-state operating conditions. Therefore, the findings may not be directly generalizable to other engine configurations or higher ethanol concentrations, and further studies are recommended to extend the analysis to different engine platforms and operating regimes.

List of abbreviations

AC	Alternating current
ACG	Alternator current generator
ADC	Analog-to-digital converter
cc	Cubic centimetres
CH	Channel
D	Duty cycle
DC	Direct current
E0	0% ethanol and 100% gasoline
E20	20% ethanol and 80% RON 92 gasoline
E40	40% ethanol and 60% RON 92 gasoline
E60	60% ethanol and 40% RON 92 gasoline
E80	80% ethanol and 20% RON 92 gasoline
ECU	Engine control unit
FI	Fuel injection
Hz	Hertz
kgf·m	Kilogram-force metre
Kpts	Kilopoints
kW	Kilowatt
MHz	Megahertz
mm	Millimetre
Mpts	Megapoints
ms	Millisecond
MS/s	Megasamples per second
mV/div	Millivolts per division
ns/div	Nanoseconds per division
N·m	Newton meter
PGM-FI	Programed fuel injection
PS	Pferdestärke (metric horsepower)
RMS	Root mean square
RON	Research octane number
rpm	Revolutions per minute
s/div	Seconds per division
SD	Standard deviation
SI	Spark ignition
SOHC	Single overhead camshaft
T	Signal period
TCI	Transistor-controlled ignition

TFT-LCD	Thin-film transistor liquid-crystal display
Toff	Off-time
Ton	On-time
USB	Universal serial bus
V	Volt
V-Max	Maximum voltage
V-Min	Minimum voltage
V/div	Volts per division
Vbase	Base voltage
Vpeak	Peak voltage
Vpp	Peak-to-peak voltage
VRMS	Root mean square voltage
Vtop	Top voltage
W	Watt

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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