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APPLICATION OF VARIOUS SIGNAL PROCESSING METHODS IN COMBUSTION ENGINES

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RESEARCH ARTICLE

ABSTRACT: Study of combustion process in engines often rely on various diagnosis techniques which are based on acquisition of in cylinder pressure. In this work various tests were conducted to analyse the working of a gasoline engine by varying the load, speed and amount of fuel injected inside the cylinder. Effects of varying these operational parameters on in cylinder pressure, heat release rate and rate of rise of in cylinder pressure was analysed.

KEY WORDS: Combustion Engines, Signal processing

PRIMENA RAZLIČITIH METODA OBRADE SIGNALA U MOTORIMA SA SAGOREVANJEM

REZIME: Proučavanje procesa sagorevanja u motorima često se oslanja na različite tehnike dijagnostike, koje se zasnivaju na akviziciji pritiska u cilindru. U ovom radu sprovedeni su različiti testovi za analizu rada benzinskih motora promenom opterećenja, brzine i količine ubrizganog goriva u cilindar. Analizirani su efekti promene ovih radnih parametara na pritisak u cilindru, brzinu oslobađanja toplote i brzinu porasta pritiska u cilindru.

KLJUČNE REČI: motori sa sagorevanjem, obrada signala

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1. INTRODUCTION

Signals representing the in cylinder pressure form an important feedback for diagnosis of combustion process in combustion engines [1]. Use of various piezo-electric transducers has paved way for easy acquisition of pressure data [2, 3]. These sensors work on principle that charge is generated in them due to mechanical deformation.

These sensors are based on Quartz or Ceramic materials like Lithium Niobate &Lead Titinate [4]. However these sensors are sensitive towards temperature variations. The charge generated in these sensors is directly proportional to applied force as well as first pressure derivative [5]. Some other advantages of these sensors include high cycle life (109 cycles), low pressure hysteresis, high pressure as well as temperature stability [6]. Positioning of pressure transducer also effects signals acquired [7]. The charge output from transducer is applied to amplifier which converts signals to proportional voltage.

There are cyclic variations in acquired signals which can be eliminated by cyclic averaging. Previous works have taken into consideration 46 [8], 10 [9], 64 [10] and 100 [11] cycles. These variations occur due to varying amount of fuel injected, combustion conditions and different types of fuel-air mixtures formed inside combustion chamber [12]. There are several errors in signal acquisition process owing to resonance process as well as transmission and conversion errors [13]. Hence suitable filters are needed to smoothen the signals before further calculations can be done.

2. BACKGROUND

Due to high efficiency, diesel engines have been a favourite choice for heavy duty applications including trucks. However they suffer from drawbacks of high noise, weight and vibrations. These engines are of two types:

- Direct Injection (D.I.) engines
- In direct Injection engines.

In the D.I. engines, the fuel is directly injected inside combustion chamber and due to lesser time for mixing, a heterogamous mixture consisting of both rich and lean parts is formed in the chamber. Modern diesel injection systems use multiple injection process to control emissions like soot and Nitrous oxide (NOx) formation. These generally use three phases of injection. namely pre-injection period, Main –injection period & post injection period as seen from figure 1.

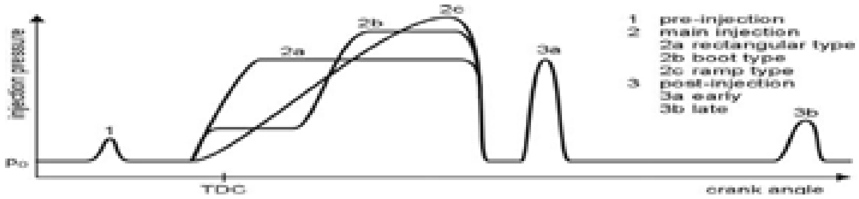

Figure 1. Multiple Injection process in diesel Engines

There is delay period between the start of ignition process and fuel injected inside diesel engine. More this ignition delay, more is the temperature during combustion and hence better condition for NOx formation. To shorten the delay period, small amount of fuel is pre-injection before main injection during the phase pre-Mixed combustion phase. The torque and power produced in engine depends upon main injection period. It is advantageous to vary injected fuel mass with time to reduce the specific fuel consumption. This method is known as rate shaping as depicted in figure 1. Rate shaping may be rectangular, step or boot in shape. Post-injection of fuel is done to reduce soot emissions and in some cases may be useful for exhaust gas recirculation treatment of gases [16]. It has been reported that post injection reduces soot by about 70% without increasing the fuel consumption [16].

3. EXPERIMENTAL SETUP

Experiments were conducted on single cylinder diesel engine. The engine test rig have Dytran Model Series 2300V LIVM pressure transducer for in cylinder pressure measurements and an optical crank angle encoder for detection of TDC position as well as engine speed. The given system can do maximum of 2 injections per cycle.

A Behringer ECM8000 type microphone was used to record the block noise. During the tests variations in injection timings and duration of injection was carried out. The data recorded during each test was under steady state conditions as seen in Table 1. All signals were acquired for a complete cycle of operation of engine.

Table 1. Injection parameters

CASE	Q_{pre} (mm^3/stroke)	Q_{main} (mm^3/stroke)	SOI_{pre} (Degree before TDC)	SOI_{main} (Degree before TDC)
B1	1	6.3	19.9°	5.09°
B2	1	13.9	14.6°	6.29°
B3	-	-	-	-
B4	1	6.6	22.5°	5.68°
B5	1	13.8	16.5°	6.29°
B6	-	-	-	-

Measurement installation is shown on Figure 2.

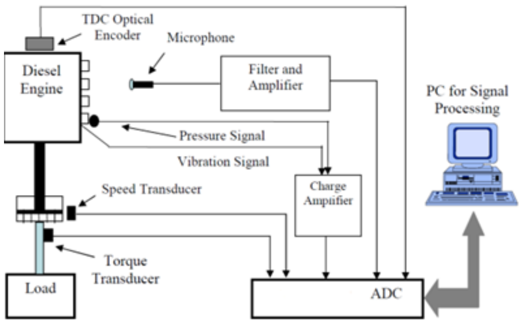

Figure 2. Measurement installation

4. RESULTS AND DISCUSION

Figures 3 and 4, show the variations of raw voltage signals obtained from amplifier for a single cycle of diesel engine with crank angles for various testing conditions.

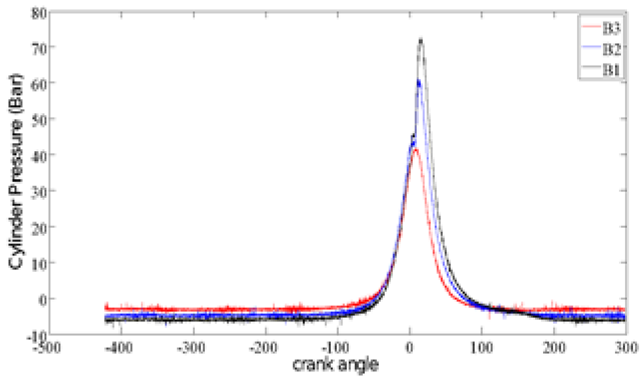

Figure 3. In cylinder pressure trace for various testing

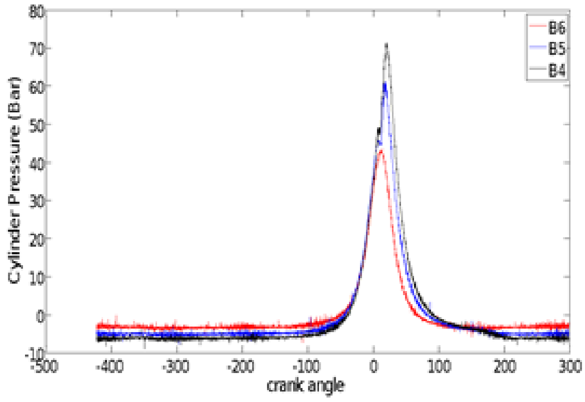

Figure 4. In cylinder pressure trace for various testing

It can be observed that depending upon engine speed/load condition, the intensity of maximum pressure and its location on crank angle domain changes. The data was converted from crank angle domain into time domain using relevant sampling rate & then pressure spectrum was plotted using FFT analysis. Figure 5 shows such plot. The signals acquired were filtered to avoid aliasing. The peak value of spectrum was observed to at a frequency of 316 KHz. The cylinder pressure spectrum was found to be load and speed dependent. In cylinder pressure provides most valuable information about combustion process occurring in engines. Piezo electric sensors have fast response time, small size and low sensitivity to surroundings, hence they are more suited to measure cylinder pressure in combustion chambers [17]. Several factors like noise due to pressure signal transmission and conversion, analog to digital conversion and variation in engine input parameters effect the pressure measurements. Oscillations are also caused by pressure waves in the cylinder which are picked up by the sensors.

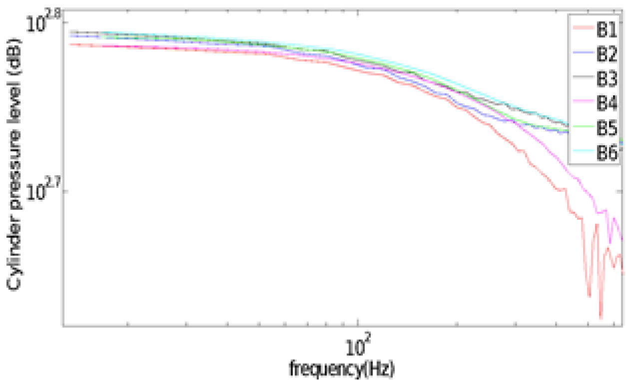

Figure 5. In cylinder pressure levels

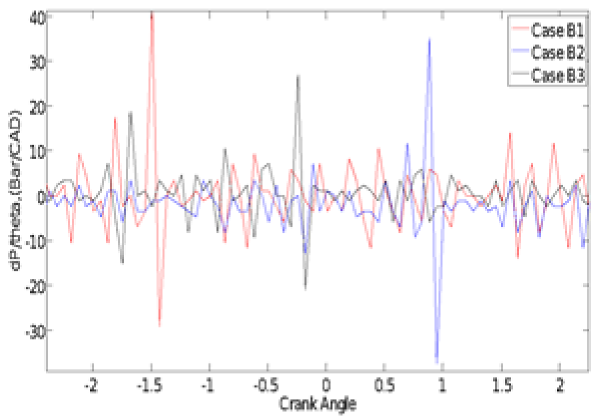

Figure 6. Rate of cylinder pressure rise

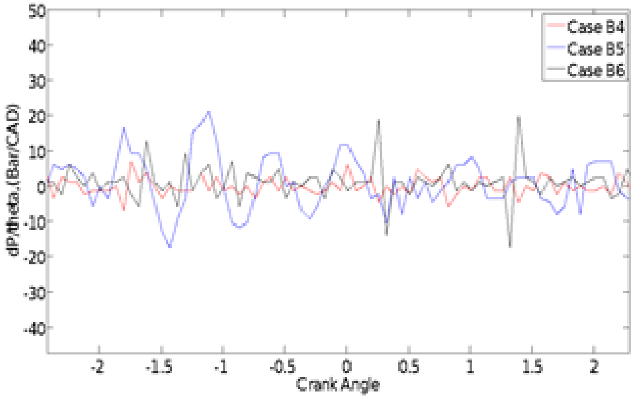

Figure 7. Rate of cylinder pressure rise

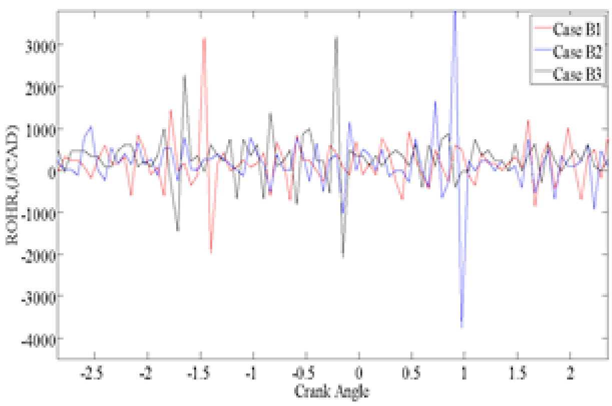

Figure 8. Rate of Heat Release Rate

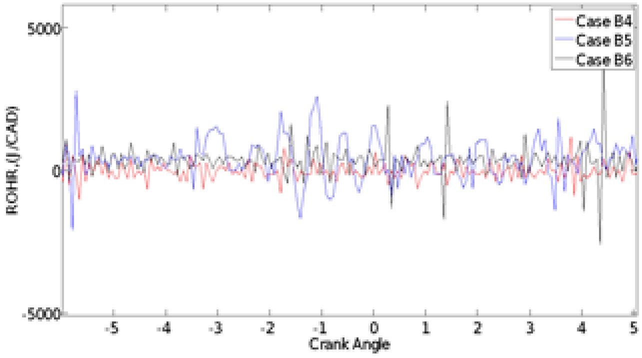

Figure 9. Rate of Heat Release Rate

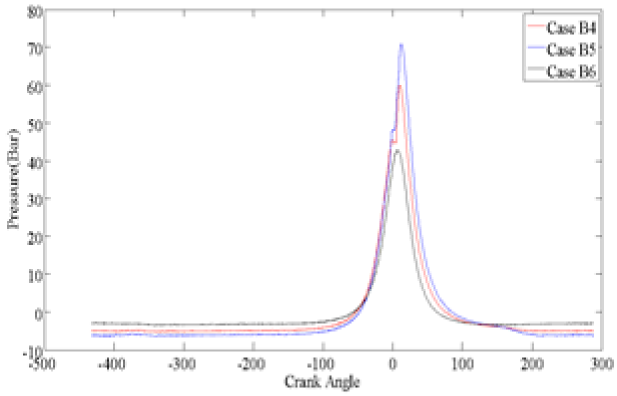

Figure 10. Filtered in cylinder pressure trace for various testing conditions

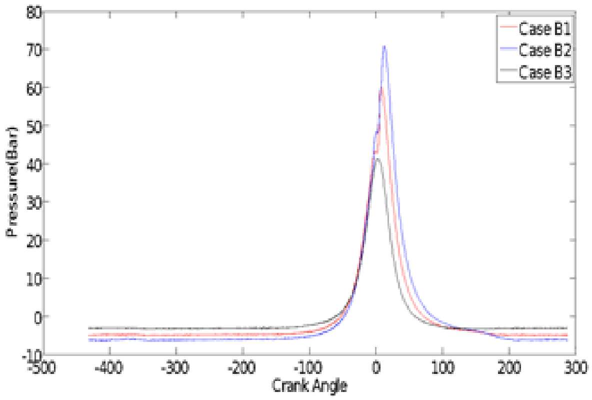

Figure 11. Filtered in cylinder pressure trace for various testing conditions

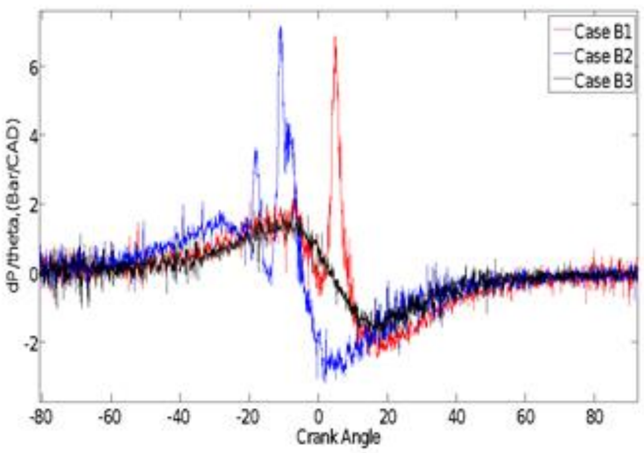

Figure 12. Filtered rate of cylinder pressure rise

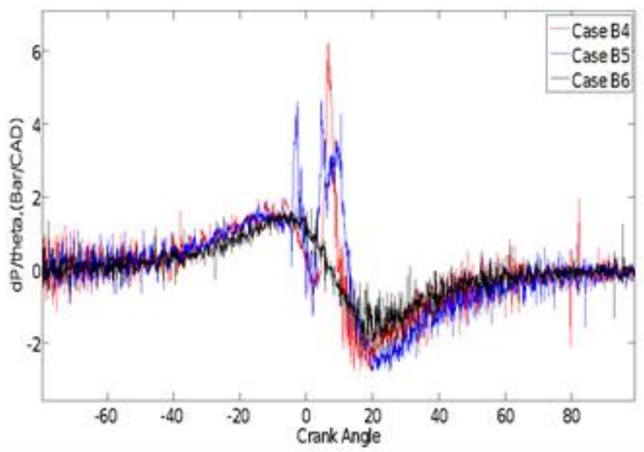

Figure 13. Filtered Rate of Cylinder Pressure Rise

The effects of noise are visible in pressure derivative curves. The oscillations in heat release rate curves are much more than pressure derivative curves. For correct visualization of combustion process it is necessary to filter the pressure data acquired. This was done by applying Savitzky-Golay filters. Figures 14 and 15 show the smoothened signals obtained by applying such a filter of third order. Since all the high frequency components are removed the remaining signals (having amplitude lesser than unfiltered signals) provide a useful information about combustion diagnosis. It can be seen from the curves that ROHR is almost zero outside combustion zone for case of filtered signals whereas for unfiltered one such values are high. It is needed that ROHR must be zero outside combustion zone as no fuel is burnt in this duration and hence no heat release rate is observed in combustion chamber.

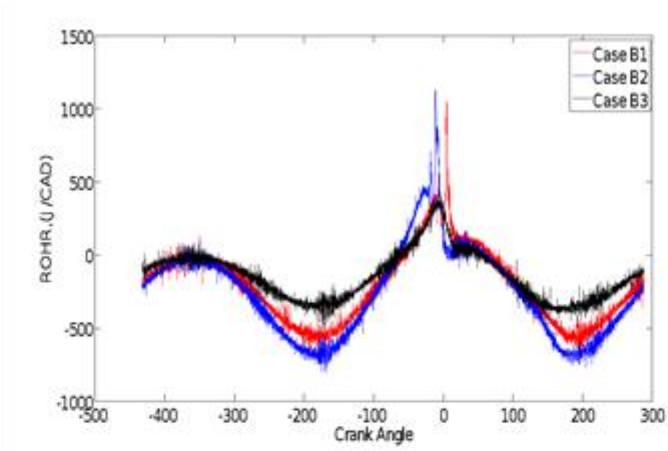

Figure 14. Filtered Rate of heat release rate

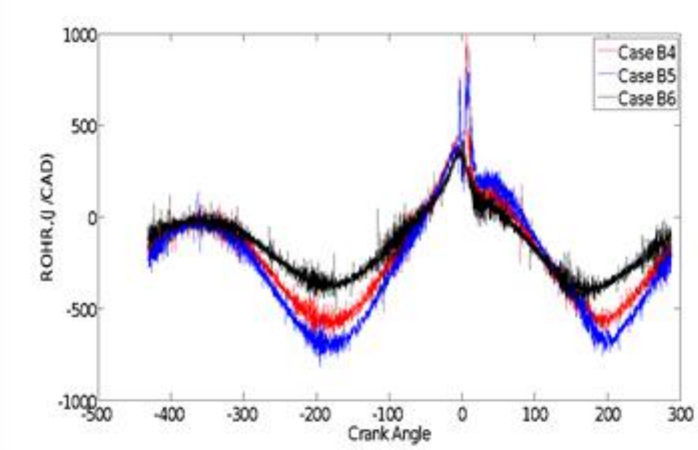

Figure 15. Filtered Rate of heat release rate

Several filters are available to filter digital signals which include butter worthy filter, zero phase & Savitzky-Golay etc. Figure 16 shows the effects of various filters applied on power spectrum of in cylinder pressure for case of test case B1. It is evident from this figure that Golay filters remove high frequency components more compared with other filters. In order to reduce the effects of cyclic variations optimum number of cycles are to be determined which depend upon engine type & operating conditions [18]. Using standard deviation of cylinder pressure signals. Figure 17 shows the standard deviation evolution for 20 cycles for the test condition B1.

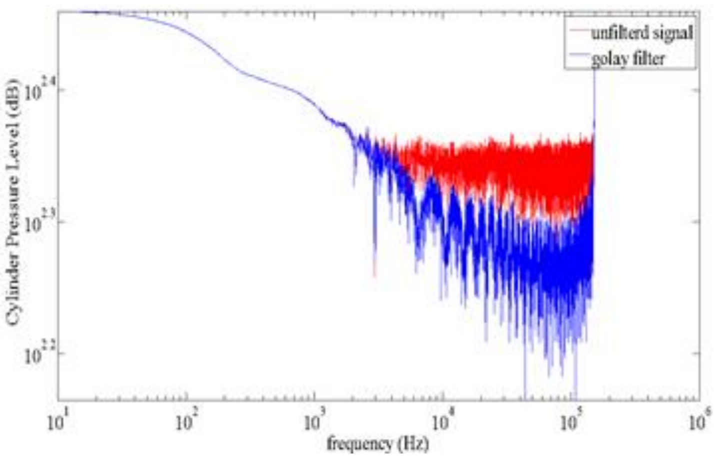

Figure 16. Effect of filtering on signals

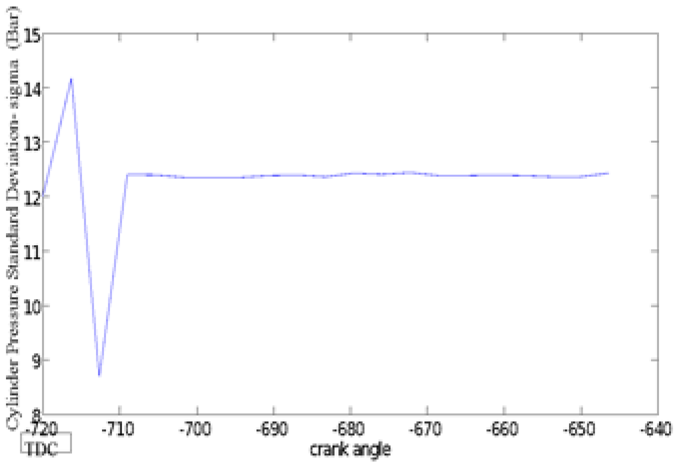

Figure 17. Standard deviation for pressure data

As it is evident from this graph, the standard deviation of pressure strongly depends upon the crank angle with large variations found near TDC position. This is because of combustion process occurring itself has large variations owing to no control over auto ignition of charge, combustion conditions and variations. In physical as well as chemical properties of charge formed in the combustion chamber. Hence filtered pressure data depicts the actual standard deviation as seen from figure 18.

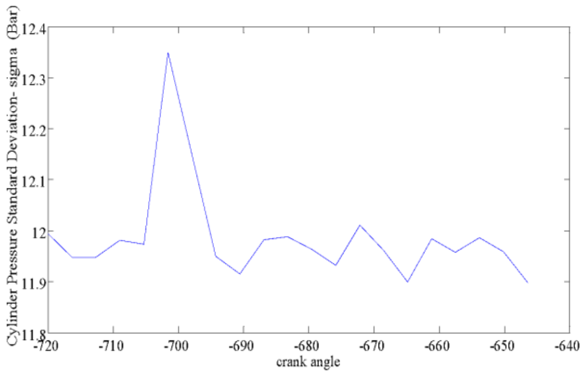

Figure 18. Standard deviation for filtered pressure data

The difference between maximum and minimum values of standard deviation data was found to decrease with an increase in number of cycles used. A point has been reported in [13] wherein increase in the number of cycles used does not change this difference. Hence after this point increasing the number of cycles does not improve the precision of results. Hence it can be concluded that optimum number of cycles are dependent upon engine operating conditions & smoothing methods used. ROHR provides an insight of how chemical energy of fuel is converted into thermal energy, hence an important tool in combustion diagnosis. So correct calculation of this curve is essential. Figure no 18 shows standard deviation of ROHR curves for the test condition B1 using data from 5 engine cycles. Reduction in these values was found when filtered signal data was applied in calculations as seen from figure no 19.

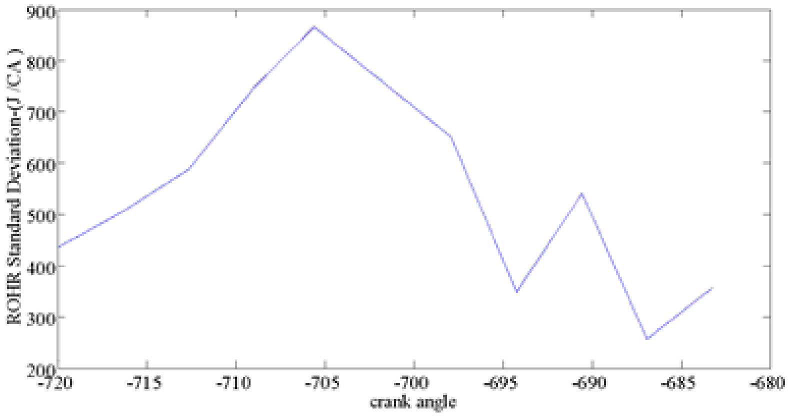

Figure 19. Standard deviation for ROHR data

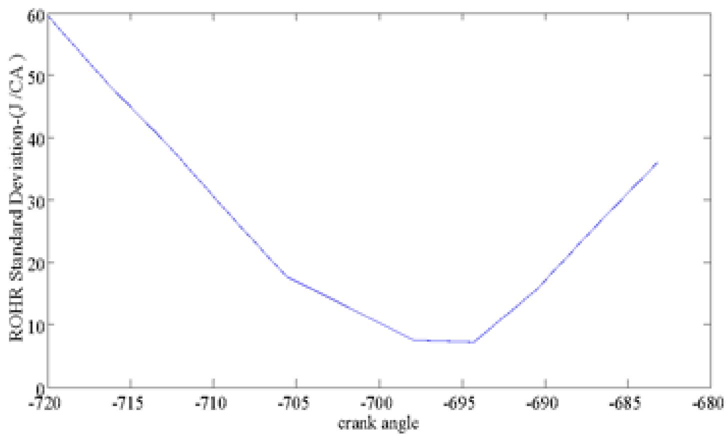

Figure 20. Filtered standard deviation for ROHR data

5. CONCLUSIONS

Experiments were done on a diesel engine operating at different engine conditions. The cylinder pressure data was measured for 20 consecutive engine cycles for analysis using piezoelectric pressure sensor. The cylinder pressure signals shows cyclic variations therefore signals were to smoothen to remove high frequency noise arising from various sources. This smoothened data was then used for calculating of ROHR and analyzing engine combustion. Variations in pressure signals increase with mixture enrichment. Oscillations in pressure traces during compression stroke are fairly small as compared to those originating from the combustion process. Averaging several cycles of pressure signals reduces the point-to-point variation due to signal noise. Optimum number of cycles to be used for combustion analysis is decided based on cycle-to-cycle standard deviation of pressure, rate of pressure rise and rate of heat release curves.

In the tested operating conditions of engine used for the study, optimal number is found to be 5 cycles while using Savitzky–Golay filter for smoothening the pressure signals. Savitzky–Golay filter is superior in performance compared to zero phase filter and Butterworth filter, while analyzing the signals.

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