Applied Energy 92 (2012) 628–636

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The engine knock analysis – An overview

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ARTICLE INFO

Article history:
Received 25 August 2011
Received in revised form 28 November 2011
Accepted 28 November 2011
Available online 20 December 2011

Keywords:
Knock
Detection methods
Visualization researches
Simulations
Models
Suppressing methods

ABSTRACT

Knocking combustion in spark-ignition (SI) engines is an abnormal combustion phenomenon which can constrain the engine performance and thermal efficiency. It can also result in severe permanent engine damage under certain operating conditions. This paper systematically reviews the engine knock phenomenon, including the mechanisms, influencing factors, consequences and detection methods etc. It introduces the visualization researches, simulations and some judging indexes of engine knock. Three mathematical models which can predict the engine knock, and various kinds of methods of suppressing knock are summarized. Finally, this paper puts forward some new suggestions on the weakness in the researches of knocking combustion.

Contents

1. Introduction

Spark-ignition (SI) engine has achieved a high level of success since the invention of the first Otto cycle engine. During the early days, researchers and engine manufacturers mainly focused on the study of how to increase the engine power and how to improve the engine working reliability. However, in the recent years, due to the limited fossil fuel reserves and more and more stringent emission regulations, researchers have shifted their attentions towards the development of more advanced combustion systems

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doi:10.1016/j.apenergy.2011.11.079

[1]. Thus power generation with the lowest energy input from fossil resources has become more and more important since then.

Due to the steady rise in oil prices and the increasing concerns towards global environmental pollution, the optimization of engine performance and emission has become the most pressing factor. However, the optimization potential is not well utilized as there is a lack of knowledge about the detailed in-cylinder combustion process and emission formation mechanisms. Future stringent legislation on emissions in combination with an increase in engine efficiency poses a great challenge to the designers and researchers. However, engine design and operating parameters such as compression ratio, inlet pressure and temperature, spark timing, equivalence ratio and exhaust gas re-circulation must be optimized for the best performance and efficiency. The essential task in the development of SI engine today is to achieve a good balance between the reduction of fuel consumption and the improvement of torque [2,3].

In SI engines, the combustion can proceed as a normal or abnormal phenomenon depending on the certain operating conditions. The normal one, which is initiated solely by a timed spark, generates a flame front moving across the cylinder volume in a uniform manner at normal velocity. Depending mainly on the temperature and pressure history of the end-gas as well as on the rate of development of the flame, the abnormal combustion can cause an important phenomenon: Knock. Knock is well known as a major barrier obstructing further improvement of the SI engine thermal efficiency. If knock occurs over a long period of time, it will bring some unfavorable effects [4–6]:

- Breakage of piston rings.
- Cylinder head erosion.
- Piston crown and top land erosion.
- Piston melting.
- Limits engine compression ratio or vehicle acceleration performance.
- Increase air pollution.
- Decrease in engine efficiency.
- Considerable rise in engine specific fuel consumption (SFC).
- Possibility of structural harms to engine in a long-term period.
- Knock may cause damage and it is a source of noise in engines.

Thus this must to be avoided. For more than a century, researchers did many efforts to understand the causes of knock. There are two generally accepted theories of knock, auto-ignition and detonation. The theory of auto-ignition can be traced back to the ignition of so-called hot spots in the unburned end gas. These hot spots are formed due to non-uniformities in temperature or concentrations. After spark ignition the unburned gas is compressed by the expanding burned gas, compressed or expanded by the moving piston, heated by radiation from the flame front, and cooled or heated by the surrounding boundaries. At the point where the temperature and pressure of the end gas exceed its auto-ignition point, the end gas would ignite spontaneously, starting at one or more points (velocities higher than 2000 m/s) [7]. A violent explosion will occur in the end gas, causing pressure waves to oscillate in the combustion chamber, causing the pinging sound. Detonation theory, on the other hand, assumes that knock occurs due to the propagation of the flame front that accelerates from the spark plug to the other end of the detonation. The shock wave would then reflect from one cylinder wall to another at the combustion chamber. The impact pressures are short in duration but high in magnitude, causing the occurrence of knock [8].

It is generally accepted that engine knock is the result of auto-ignition in the end-gas before it is being reached by the flame front emanating from the spark plug [9–15]. Because reaction propagates depending on the compositional and thermal heterogeneity of the unburned end-gas, so auto-ignition is seldom homogeneous, it usually occurs randomly in localized centers. When it occurs, pressure waves are generated, which can cause the formation of detonation waves, which sounds like metallic ringing which is distinct from the mute sound of normal combustion. Sometimes auto-ignition does not necessarily give rise to knock. There are three basic modes of propagation from the auto-ignition centers, depending on the temperature gradients [16]. These are:

- When the end-gas has low temperature and steep temperature gradients, it will produce a weak pressure, which propagates from the center and is attenuated, combustion undergoes a gradual transition to knock. The cool flame, which travels with average speeds of v = 50–200 m/s. In this phase, combustion is non-knocking combustion.
- When the end-gas has high temperature and small temperature gradients, it will generate simultaneous chemical reaction follows the occurrence of the auto-ignition. As the onset of the main heat release, the average speed can be up to v = 500 m/s. There is a clear correlation between the propagation velocity and the knock intensity: the faster the reaction front of main heat release propagates, the higher the knock intensity.
- When the end-gas has intermediate temperatures and temperature gradients. When the gradient smaller than a critical value, it will generate enough intensity to initiate chemical reaction. Then the strong shock waves are created. Pressure waves are generated by the fast-propagating reaction front. When the pressure is strong and the end-gas is reactive enough, it will

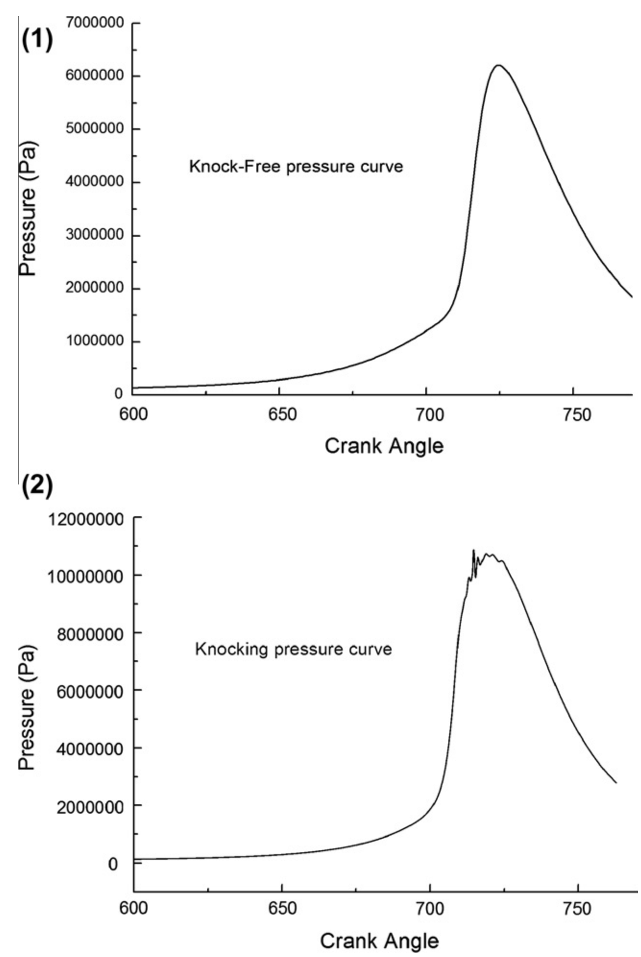

Fig. 1. Typical knocking and non-knocking cycles.