Paweł Olszowiec, Mirosław Luft

Low Speed Pre Ignition – The problem of modern engines

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The article deals with the issue of knocking occurring in modern turbocharged internal combustion engines at low rotational speeds. The material describes the genesis of the phenomenon, its main causes and research results to prevent the above phenomenon.

Keywords: knocking combustion, turbocharged engine.

Wstęp

The rush for improving the efficiency of combustion units and optimizing the consumption of the power supply medium is a trend that we have known for over a dozen years, but rapid development in this area has only occurred recently. It was influenced by technologies used in propulsion units that changed the face of the power supply system. This technology has generally been called downsizing. The rapid development of this idea followed the popularization of solutions such as turbocharging and direct injection of gasoline in gasoline engines. Thanks to these technologies, it is possible to better use the potential of the power unit, despite its small displacement. Thus, a large motor can be replaced with a smaller one, just as dynamic and more economical. The downsizing effect is not only smaller engines that need less fuel to travel 100 km. These are also structures characterized by high flexibility, mainly due to turbocharging (Fig. 1). Even if the power is not higher than in the older and larger naturally aspirated engine, the new engine usually dominates over it with the torque available at lower revs. The consequence of such revolutionary activities is almost always the undesirable effects of the individual's work, which often appear only during operation. This is what happens in the case of low-knock knock combustion, which was observed during the operation of piston spark-ignition combustion units covered by downsizing technology.

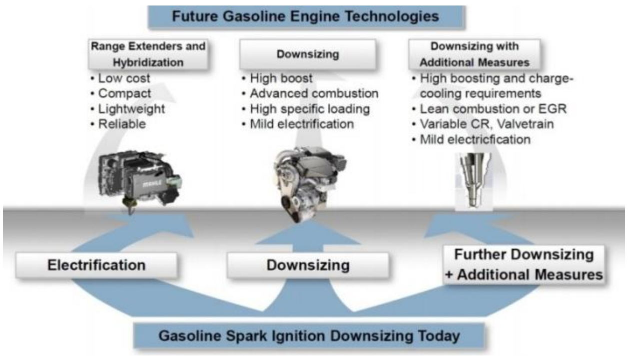


Fig. 1. Methods for improving the efficiency of an internal combustion engine

Many studies have been reported in literature to better understand the factors responsible for LSPI onset and frequency. Zahdeh et al.[7]evaluated an engine's LSPI frequency over extensive operating condition sweeps and varying hardware configurations (e.g. injector targeting, piston top ring geometry, etc.). The results of these experiments illustrated the sensitivities of LSPI to different operating conditions and even provided some strategies to greatly reduce the frequency of pre-ignition events. These strategies included the use of a high volatility fuel, targeting the piston top rather than the cylinder liner with the fuel injection spray, and using multiple fuel injections. However, the fundamental causes of LSPI still remain poorly understood, leading to a lack of firm consensus on the underlying mechanisms that promote LSPI. Zaccardi[8] describes many potential causes of LSPI such as auto-ignition in the gaseous phase and the ignition of fuel-air mixture due to either liquid droplets or solid particles. Furthermore, the presence of favorable thermodynamic conditions was observed to be necessary for all discussed mechanisms. Other re-searchers have also demonstrated the ability of appropriately-sized solid particulates, such as large soot particles or flaking deposits, in initiating LSPI events. Although deposits or soot cinders are possible sources of LSPI, Gupta et al. showed that these sources are highly improbable to persist over multiple cycles and thus are improbable as source for clustered LSPI events. Researchers have shown fuel/lubricant droplets to be a much more probable primary ignition source, and a significant amount of recent LSPI research has focused on understanding the effects of fuel and lubricant properties, as well as the interaction of fuel sprays and lubricating oil in the top crevice region. Piston ring motion and turbulence variations have also been proposed as possible transport-related causes of the apparently stochastic nature of LSPI

1.Knocking Ignision

Detonation combustion, commonly known as knocking, is characteristic of spark-ignition engines, which does not mean that it suddenly appears in the engine. Its main reason is too high a compression ratio in relation to the octane number of the fuel used. During normal combustion (Fig. 2), a portion of the flammable mixture (gasoline with air) lit in the immediate vicinity of the spark plug causes heating above its ignition temperature of its further parts and in this way the combustion spreads to the entire load at a speed called flame transfer rate of 20 to 40 m / s. On the other hand, when the compression ratio is too high, the burning part of the mixture does not manage to transfer the flame quite quickly, it increases its volume by rapidly compressing the remaining unlit part of the combustible mixture. As a result, it spontaneously ignites. It is accompanied by rapid combustion called detonation, several dozen times faster than during normal combustion. This speed may even exceed 1000 m / s, the temperature of the engine components and the pressure in the combustion space increases. The detonation wave hitting the cylinder walls, cylinder head and piston crown produces a metallic sound (a distinct knock is heard). Detonation is very harmful to the engine. May damage piston crowns, valve seats, local overheating and deformation. Fuel resistance to detonation (knocking) is determined by the octane number - LO. Available gasoline and low harmful ethyl alcohols and ethers acting as antidetonators are added to gasolines. Until the mid-1980s, leaded gasoline (ethyline) was produced. It contained a lead tetroethylene (anti-detonator), which caused gasoline's resistance to detonation but was very toxic and prevented the use of catalysts that it destroyed. For these reasons, the ethyl was discontinued.

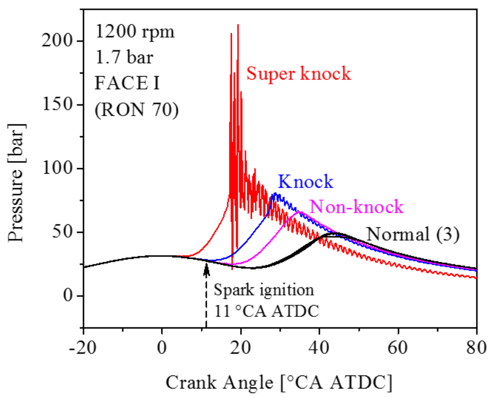


Fig. 2 Pressure diagram during knocking ignision

In the literature you can find many works devoted to knocking, describing issues such as: measurement and analysis of the knocking signal, the use of various knock detection detection algorithms, classification of effects related to combustion chemistry, computer simulation of knocking, and analysis of pressure waves accompanying this phenomenon. Modern spark-ignition engines, especially those in which stratified mixture combustion systems have been used, enabling a significant reduction in fuel consumption, are characterized by an increased compression ratio (H> 11). Large pressure gradients occurring after ignition of the mixture are associated with the need for reliable recognition of knocking combustion. Currently, the most commonly used methods to prevent knocking are: improving fuel quality, optimizing engine design and operating parameters, and delaying ignition timing after detection of knock by accelerometers. Engine block-mounted accelerometers are used in many mass-produced engines and are great at low speeds. However, the quality of the obtained signal deteriorates rapidly as the speed increases due to mechanical interference superimposed on the acceleration signal. As a result, the control system ignores this feedback signal and delayed ignition is used, which reduces engine efficiency and power.

The power of an internal combustion engine results directly from the amount of fuel-air mixture fed into it. While the amount of fuel can be easily increased, providing more air proves to be more troublesome. The obvious solution is to increase the engine displacement so that it can suck more air from the atmosphere. The second solution is to supply the engine with compressed air, which at the same volume provides much more oxygen needed for proper combustion. This idea is called engine boost. A larger amount of air and fuel in the cylinder releases more energy during combustion, resulting in higher engine power. Turbocharging is the most common solution affecting the power and efficiency of the engine
in diesel units. Today it is the basis for the implementation of the Downsizing assumption in spark-ignition vehicles. In modern ZI engines, several supercharging solutions are used. The first is a classic turbo compressor driven by engine exhaust gases, designed to increase the pressure in the intake manifold. This is one of the basic elements of the idea of "reducing internal combustion engines".

2.Low Speed Pre Ignition

LSPI typically occurs during very-high-load operation at engine speeds around 2000 r/min or below wherein, the flame initiates before the spark is fired and leads to flame propagation at a significantly advanced combustion phasing. The increased pressure rise due to theadvanced combustion phasing often causes violent end-gas knock or even‘superknock’for events that transition to developing detonation. While the LSPI event and the resulting super-knock event are related, they are distinct phenomena, and not all LSPI cycles exhibit super-knock. LSPI is apparently a stochastic phenomenon and under appropriate operating conditions, will typically occur within every 10,000 cycles. However, LSPI can also manifest as a cluster of many events that occur in an alternating pattern; wherein, every other cycle exhibits LSPI behavior. Additionally, though extremely rare, the occurrence of consecutive LSPI cycles has also been reported in literature

In a spark-ignition engine, the air-fuel mixture must ignite at a specific point in the 4-stroke cycle for the engine to function properly. The LSPI phenomenon is precisely that the air-fuel mixture ignites too early, causing huge, unplanned pressure in the cylinders. When the mixture ignites at the wrong time or explodes unexpectedly, instead of burning normally, there are knocks or a characteristic sound of detonation. The phenomenon has a very negative effect on the engine and may result in its complete failure. The most vulnerable to damage are: pistons, spark plugs, rings, connecting rods (Fig. 3). Research on this process was not easy due to the destructive nature of LSPI and the randomness and unpredictability of the phenomenon. Today, it can be said that there are many factors causing LSPI. In addition to the engine design, it is influenced by high pressure in the cylinder with increased engine power, the use of low-quality gasoline and poor air-fuel mixtures, as well as poor-quality engine oils. Unlike the "normal" knocking LSPI, it is impossible to predict and correct the ignition timing, which is why the engine control unit (ECU) is useless in this situation.

Fig. 3 Example of piston damage due to LSPI

Service practice observed in recent years, in which the need for mechanical intervention in units of the so-called "Reduced" indicates a very significant problem, which is the low durability and quality of materials from which the above units are made. An attempt to improve the efficiency of a piston combustion unit is, among others, an attempt to reduce its weight. This process did not bypass the crank-piston system, by reducing (shortening) the piston. The lower piston has become more susceptible to lateral effects due to the movement transmitted to the connecting rod relative to the cylinder liner. Such a solution drastically affected the life span of modern combustion units and oversized engine oil consumption. This problem has become a worldwide bane of drivers operating vehicles of many brands. Leakage in the crank-piston system also translated into the possibility of engine oil entering the combustion chamber, which, when exposed to high pressure and temperature, explodes in an uncontrolled manner, contributing to LSPI. That low-speed knocking combustion is partly related to engine oil, has led to in-depth analysis and research that found some lubricant composition ingredients, such as zinc dithiophosphate (ZDDP) and molybdenum, reduce the risk of LSPI, while others based on excessive amounts of calcium sulfonate (Fig. 4), act as its promoters. In addition, some results suggest that the use of synthetic base oils also reduces the risk of LSPI.

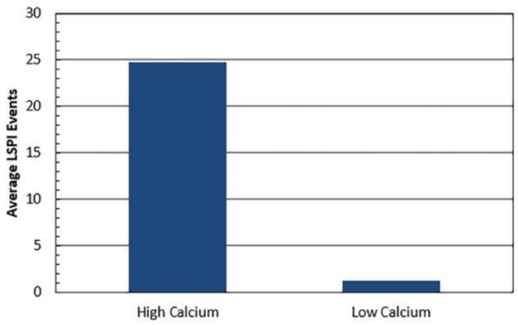


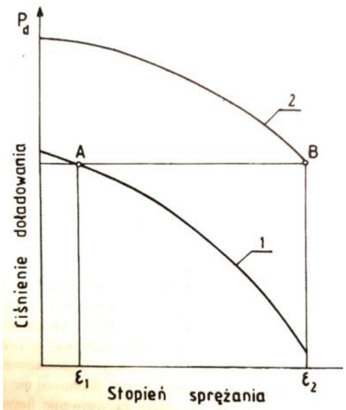
Fig.4 Graph of dependence of calcium content in oil on knock

Observations on the behavior of lubricants allow observation of the correlation between the self-ignition propensity of various base oils and the LSPI frequency, indicating the opposite direction: the risk of self-ignition seems to increase from API I to API IV. This shows the complexity of the problem, but it should be remembered that all the properties of the engine, fuel and engine oil play an important role. However, solving the LSPI problem by developing a lubricant formula is not so easy. Each component has many functions and it is not enough to replace one component with another, because each change causes the lubricant to change in many areas.

3.Classic methods of prevention

Other ways to avoid boosted engine knocking are by switching to higher speed, cooling the supercharged air, delaying ignition and to a small extent, work of the unit on a rich mixture. The effect of charge air cooling and compression ratio on acceptable due to knocking - the boost pressure is shown in diagram No. 1. It follows that the same boost pressure Pd = idem can be obtained without air cooling at low allowable $\varepsilon = \varepsilon 1$ and with air cooling at higher $\varepsilon = \varepsilon 2 > \varepsilon 1$. Influence of air temperature, mixture composition and octane number of fuel on the border - due to the occurrence of knocking.

Many factors have been demonstrated to impact LSPI, including: engine designs, fuel composition, and lubricant composition. On the lubricant side, the most noticeable impact has been from the detergent chemistry. Oils with higher concentrations of calcium, found in many detergent systems, have been shown to increase the frequency of LSPI. The exact chemistry of the detergent is less important to LSPI than the calcium content. Conversely, magnesium-based detergents do not seem to promote LSPI.



Diag 1. Graphic presentation of the impact of the degree of compression and cooling of supercharged air on the occurrence of knocking combustion [1]

Aside from the detergent system in the lubricant, there are many other additive and lubricant compositions that can influence LSPI. Molybdenum compounds, for example, not only provide frictional benefits, but also have been shown to decrease LSPI when used at high levels. Base oils also affect LSPI events. Both the quality of the base stock (i.e. Group II versus Group III) and the viscosity can have secondary effects on LSPI. The effect on LSPI from these other lubricant aspects are not as significant as the detergent system, but can shift the LSPI frequency in oils that are more prone to LSPI.

New and upcoming engine oil specifications include LSPI prevention. The ILSAC GF-5 oil specification was established in October, 2010. The proposed ILSAC GF-6 is under development and is expected to include a Ford engine test to discriminate oils based on LSPI event prevention (reduction). Thus, all oils that will make GF-6 claims will need to be formulated to address LSPI. GM's dexos1™ specification now includes a GM stochastic pre-ignition test.

In addition to the development of the ILSAC GF-6 oil specification, in mid-January 2018, the American Petroleum Institute (API) adopted plans to establish "SN Plus", a new interim category intended to tide over automakers until the much-delayed GF-6 oil specification can be implemented. The new "SN Plus" category will only be displayed in API donut symbols. The date for first licensing of SN Plus oils has not been announced.

The modern lineup of gasoline automotive engine oils are formulated to meet and exceed the latest API SN and ILSAC GF-5 oil specifications, and Syn-extreme oils are also licensed and approved in the GM dexos1™ oil certification program. Nemco will continue to develop oil formulations that meet the latest industry and OEM specifications, including ILSACGF-6 and API SN Plus, where licensed oils will have the formulation and properties required to combat LSPI.

Conclusion

It can be argued that the occurrence of uncontrolled detonation problems in modern internal combustion engines is the result of too early implementation of new solutions in which the user is a beta tester. Too short test period of modern drive units translates into the formation of very complex and expensive service damages, whose removal often takes several years. In the case of LSPI, the complexity of the issue concerns both structural problems - durability of the crank-piston system as well as operational - the quality of fuel and lubricants. The solution to the above problem is impossible without the cooperation of various automotive industries.

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Spalanie detonacyjne wolnych obrotów – problem współczesnych silników spalinowych

Artykuł porusza zagadnienie spalania stukowego występującego w nowoczesnych turbodoładowanych silnikach spalinowych przy niskich prędkościach obrotowych. W materiale opisano genezę zjawiska, jego główne przyczyny oraz wyniki badań pozwalające zapobiegać powyższemu zjawisku.

Słowa Kluczowe: spalanie stukowe, Silnik turbodoładowany,

Autorzy:

dr inż. **Paweł Olszowiec**– Uniwersytet Technologiczno Humanistyczny im. Kazimierza Pułaskiego w Radomiu, Wydział Transportu, Elektrotechniki i Informatyki p.olszowiec@uthrad.pl

prof. dr hab. inż. **Mirosław Luft** – Uniwersytet Technologiczno Humanistyczny im. Kazimierza Pułaskiego w Radomiu, Wydział Transportu, Elektrotechniki i Informatyki m.luft@uthrad.pl