Ignition: A Critical First Step For Combustion

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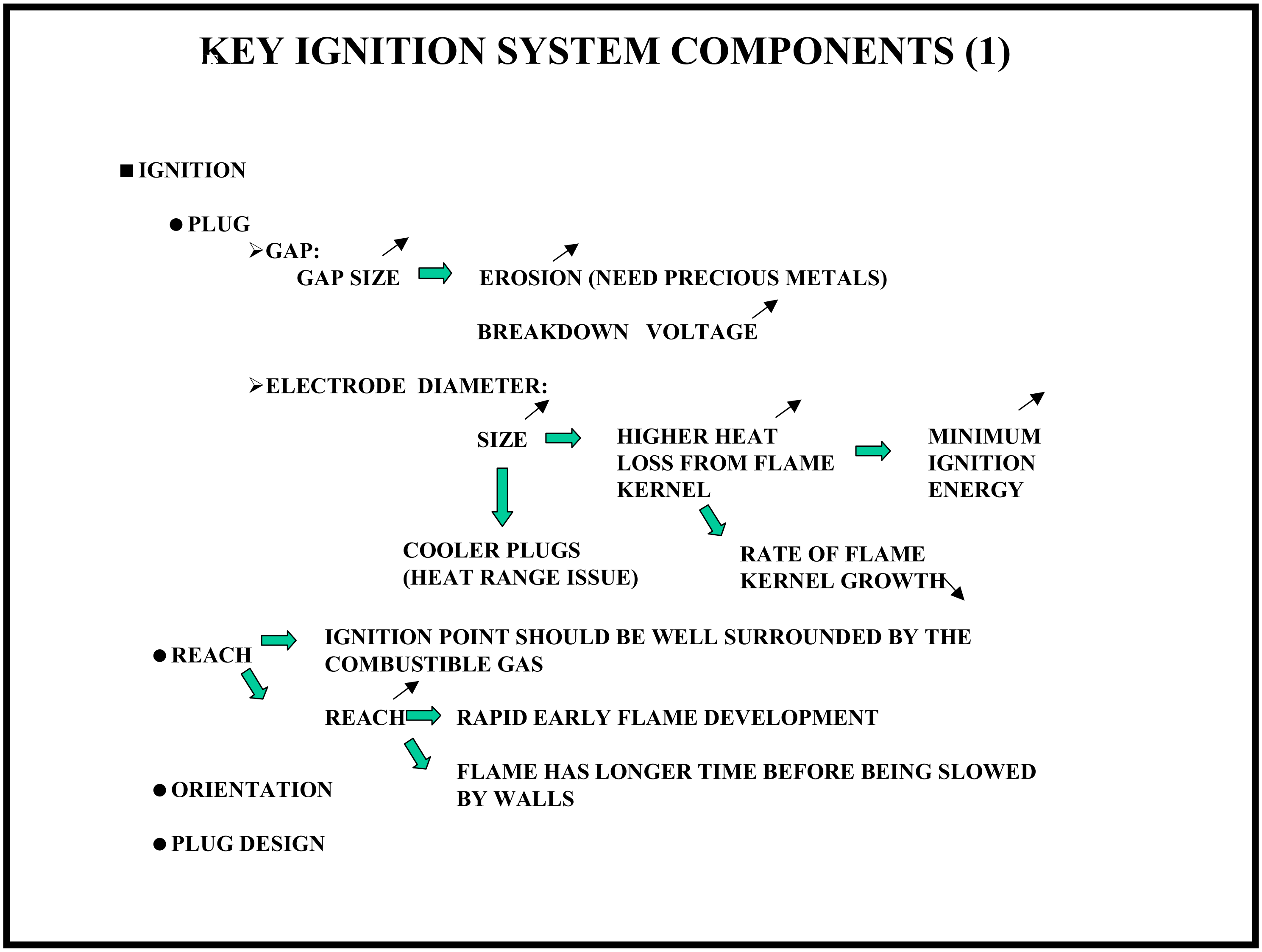
Combustion (or burning) is a fast self-sustaining chemical reaction that releases a large amount of heat. Burning candles, forest fires, log fires, the natural gas burning in home furnaces, and the burning of gasoline in internal combustion engines are all examples of common combustion processes. Many of critical technologies today employ combustion as the key element of their operation. The objective is to convert the stored chemical energy of the "fuels" into thermal energy. To achieve this, three things must normally be present: a fuel, an oxidizer, and an *ignition source*. Today, nearly 85% of the world's energy is produced through combustion and hence is vital to our way of life. Therefore, it poses great challenge to maintaining a healthy environment. Improved understanding and control of ignition and thereby combustion will assist us in dealing with the problems of pollutants formation, performance, and fuel economy. To this end, it is crucial for engine design engineers to be aware of basic knowledge and recent advances in combustion-initiation (ignition) issues to more intelligently evaluate and harness their potentials.

The thermodynamic and fluid mechanical states of the unburned charge near and at the time of the spark strongly affect the quality of the combustion and therefore the emission of the pollutants from the engine. The engine performance and drivability are also strongly affected by a weak ignition. The so-called cyclic variability, which affects and bounds the lean and knock limits of an engine design, is to a great degree influenced by the ignition system.

Ignition is defined as the transformation of a combustible material from an unreactive state to a self-reacting state where the ignition source can be removed without the combustion process be extinguished. A “minimum ignition energy” is needed for initiation. If a lower than this quantity of energy in a form of heat and/or radicals (chemically active atoms or molecules) is injected into a combustible mixture, the resulting flame kernel decays rapidly because heat and radicals are conducted away from the surface of the kernel and dissociated species recombine faster than they are regenerated by chemical reactions in the volume of the kernel. The kernel extinguishes after consuming a small quantity of reactant. But if ignition energy exceeds the minimum ignition energy at the time when the peak temperature decays to so-called adiabatic flame temperature, the gradient in the kernel is sufficiently shallow that heat is generated in the kernel faster than it is lost due to conduction to the unburned gases. This then leads to the development of a steady flame that burns all the available fuel/air mixture. The minimum ignition energy for an stagnant stoichiometric methane-air and hydrogen-air mixture is 0.4 mJ and 0.02 mJ respectively. In a flowing mixture, the minimum ignition energy is higher and becomes dependent on both the mean flow velocity and turbulence level of the charge.

The function of the ignition system is to initiate the flame, provide excellent repeatability, and offer reliable operation over a full load and speed range of the engine operation. Fundamental requirements of a high-voltage ignition system are: (1), to provide sufficiently high voltage to break down the gas in the gap; (2), To have a low source impedance or steep voltage rise; (3), to have a high energy storage capacity in order to generate a spark kernel of a sufficient size; and (4), to provide a long enough duration of voltage pulse to ensure ignition. The discharge of the energy in a spark ignition is divided into four phases: prebreakdown, breakdown, arc, and glow phases. Approximately, they last about ~1 ns, 20-50 ns, order of µs , and order of ms, respectively. By far the most efficient phase in terms of energy transfer efficiency to the mixture is the breakdown phase followed by the arc and glow phases. The two figures in this writing, summarize the key components and effects of some major variables on the performance of the ignition system. In these figures, the black inclined up and down arrows indicate increasing and decreasing trends of the variables. For example, if the size of the electrode is increased it leads to higher heat lossws from the flame kernel to the electrode and can cause decreased rate of flame kernel growth, being an unfavorable effect.

Recently, the ignition system has been modified and used to provide in-cylinder information on local air-fuel ratio, misfire, knock, and mass fraction burned in each individual cylinder. Hence, great potential exists for applications of this information to attain a more fuel efficient and environmentally compatible engine.

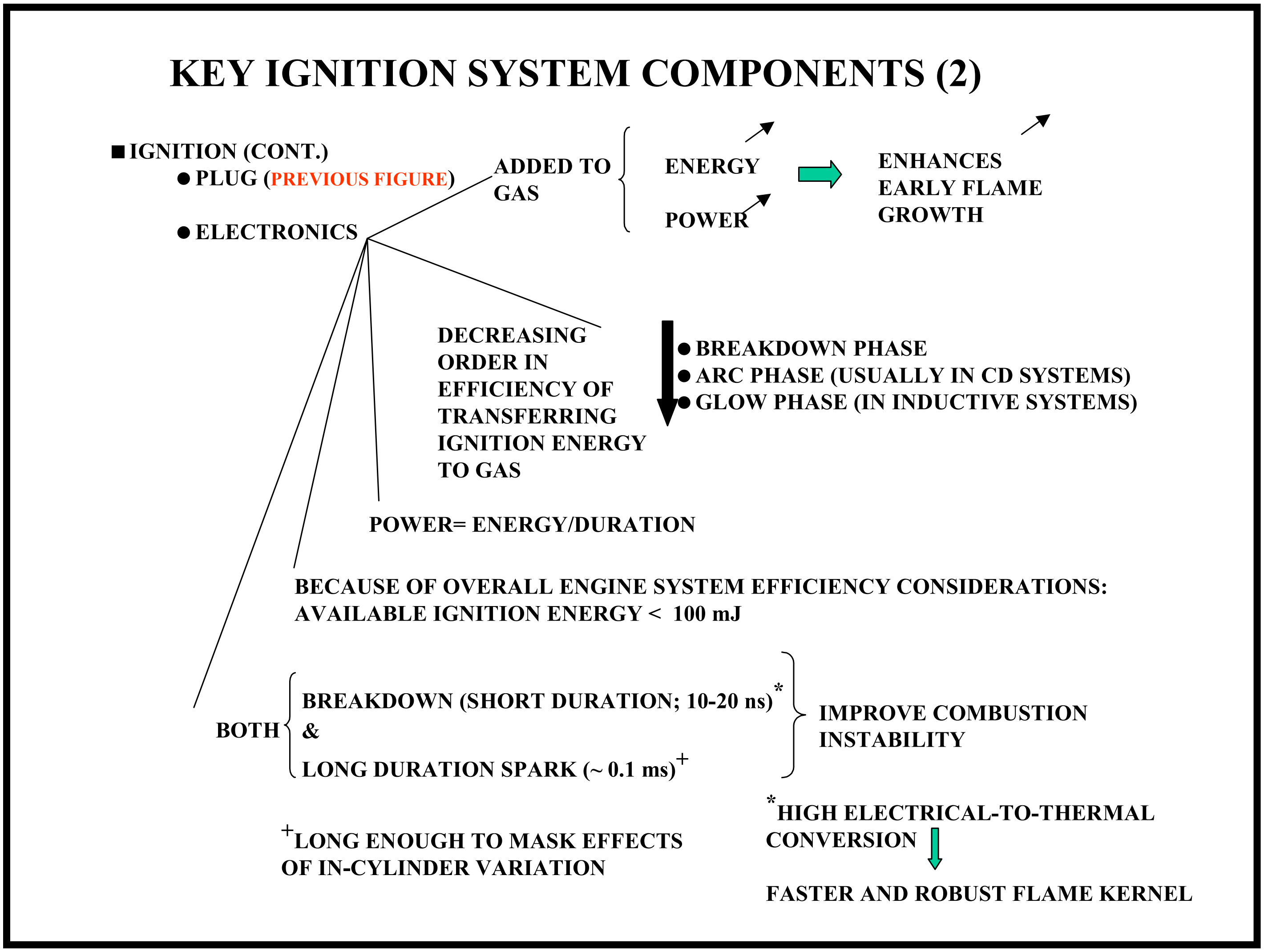


KEY IGNITION SYSTEM COMPONENTS (1)

■ IGNITION

- ● PLUG
  - ➢ GAP:
    - GAP SIZE ↗ ⇨ EROSION ↗ (NEED PRECIOUS METALS)
    - BREAKDOWN VOLTAGE ↗
  - ➢ ELECTRODE DIAMETER:
    - SIZE ↗ ⇨ HIGHER HEAT LOSS FROM FLAME KERNEL ↗ ⇨ MINIMUM IGNITION ENERGY ↗
    - ⇩ COOLER PLUGS (HEAT RANGE ISSUE)
    - ⇘ RATE OF FLAME KERNEL GROWTH ↘
- ● REACH ⇨ IGNITION POINT SHOULD BE WELL SURROUNDED BY THE COMBUSTIBLE GAS
  - ⇘ REACH ↗ ⇨ RAPID EARLY FLAME DEVELOPMENT
  - ⇘ FLAME HAS LONGER TIME BEFORE BEING SLOWED BY WALLS
- ● ORIENTATION
- ● PLUG DESIGN

Figure 1. Key ignition system components. The black inclined up and down arrows indicate increasing and decreasing trends of the variables.



KEY IGNITION SYSTEM COMPONENTS (2)

- IGNITION (CONT.)
  - PLUG (PREVIOUS FIGURE)
  - ELECTRONICS

ADDED TO GAS { ENERGY ↗, POWER ↗ } ⇒ ENHANCES ↗ EARLY FLAME GROWTH

DECREASING ORDER IN EFFICIENCY OF TRANSFERRING IGNITION ENERGY TO GAS ↓
- BREAKDOWN PHASE
- ARC PHASE (USUALLY IN CD SYSTEMS)
- GLOW PHASE (IN INDUCTIVE SYSTEMS)

POWER= ENERGY/DURATION

BECAUSE OF OVERALL ENGINE SYSTEM EFFICIENCY CONSIDERATIONS:
AVAILABLE IGNITION ENERGY < 100 mJ

BOTH { BREAKDOWN (SHORT DURATION; 10-20 ns)* & LONG DURATION SPARK (~ 0.1 ms)+ } IMPROVE COMBUSTION INSTABILITY

+LONG ENOUGH TO MASK EFFECTS OF IN-CYLINDER VARIATION

*HIGH ELECTRICAL-TO-THERMAL CONVERSION ↓

FASTER AND ROBUST FLAME KERNEL

Figure 2. Key ignition system components. The black inclined up and down arrows indicate increasing and decreasing trends of the variables.

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