SUBTASK 3.1E
EXPERIMENTAL AND NUMERICAL STUDIES OF HIGH INTENSITY COMBUSTION

Suppression of Knock Intensity by Metal Wire Installation in the End-gas Region for a Rapid Compression Machine

Mitsuhiro TSUE (University of Tokyo),
Yasushige UJIIE (Nihon University),
and
Michikata KONO (University of Tokyo)

Background

To suppress the knocking combustion:

・ Promotion of normal flame propagation by
Compactness of the combustion chamber, Central ignition, Induction of swirl and squish flows, Hydrogen addition, et al.

・ Suppression of auto-ignition in end-gas region by
Decrease in the intake air temperature with the inter cooler, Decrease in the wall temperature with the effective cooling technique, Reduction of the residual burned gas with the optimized valve timing, Decrease in the end gas temperature using the induction of the squish flow or piston speed control, et al.

Objective

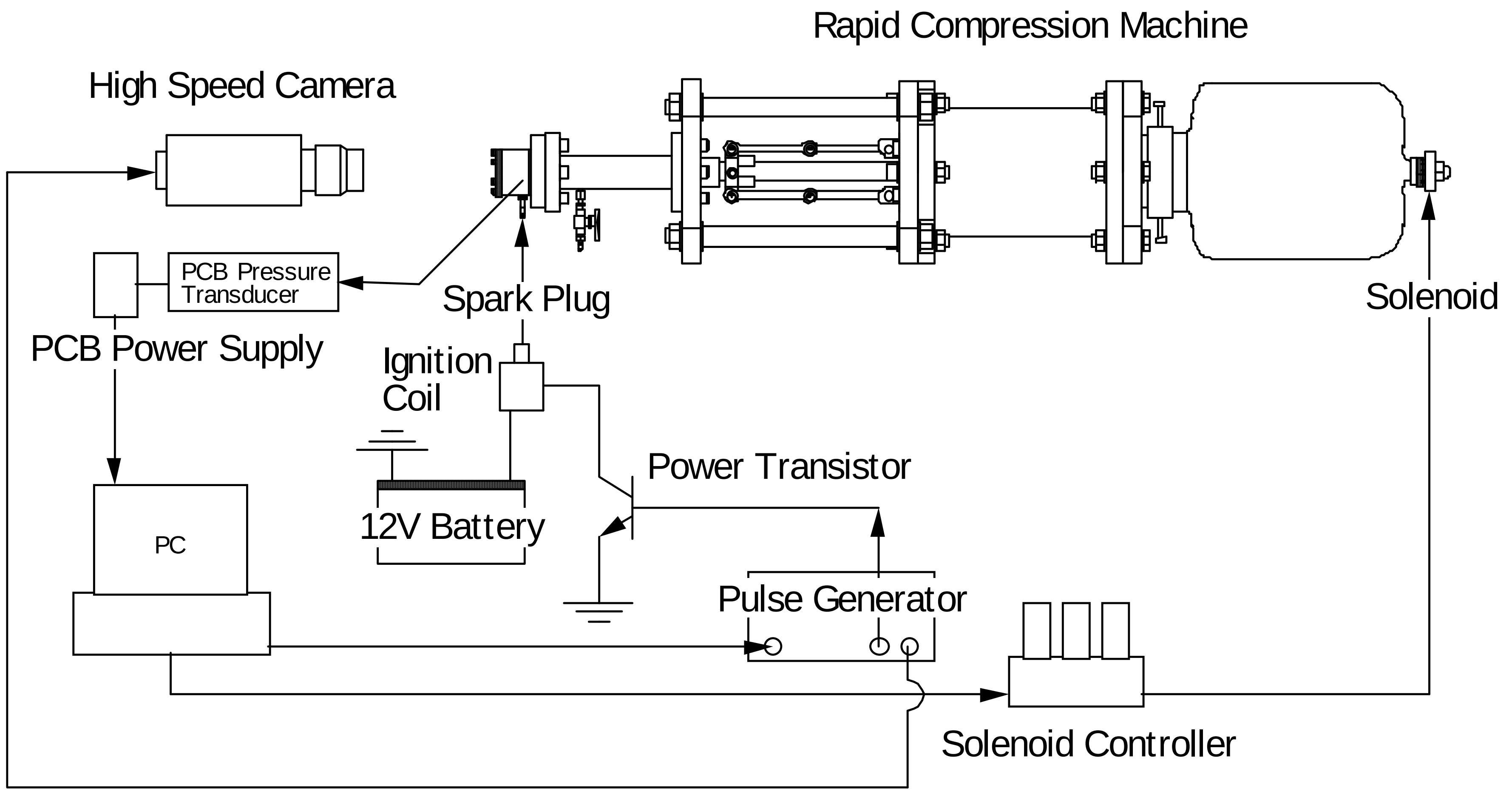
Our new concept for suppression of knocking combustion is metal wire installation in end-gas region.

Expectation:

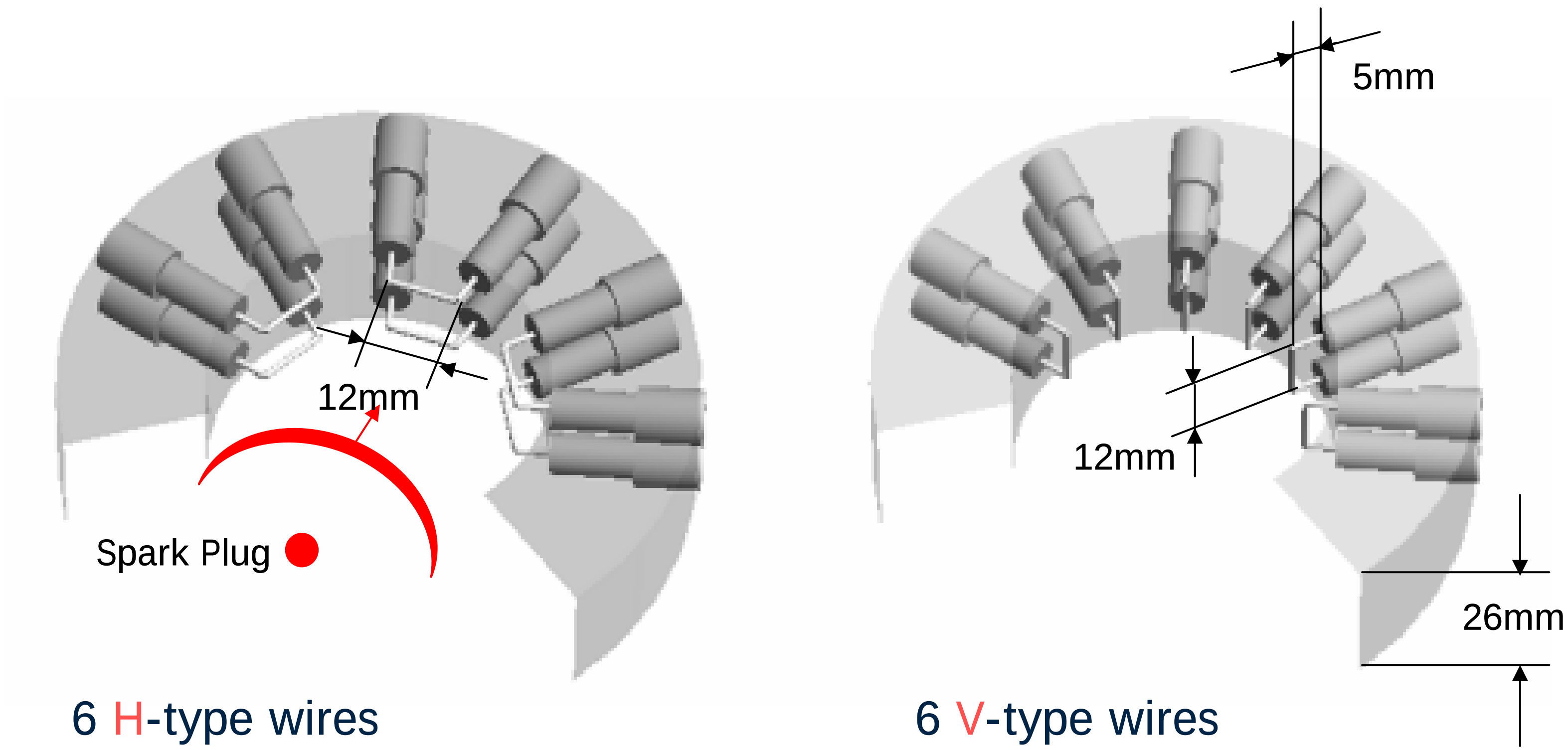
- Suppression of auto-ignition
  heat sink, consumption of radical species
- Suppression of pressure vibration (knock intensity)
  obstacle
- Others
  catalytic effect, et al.

The effect of wire installation on knocking combustion is verified experimentally using a rapid compression machine.

Experimental Setup



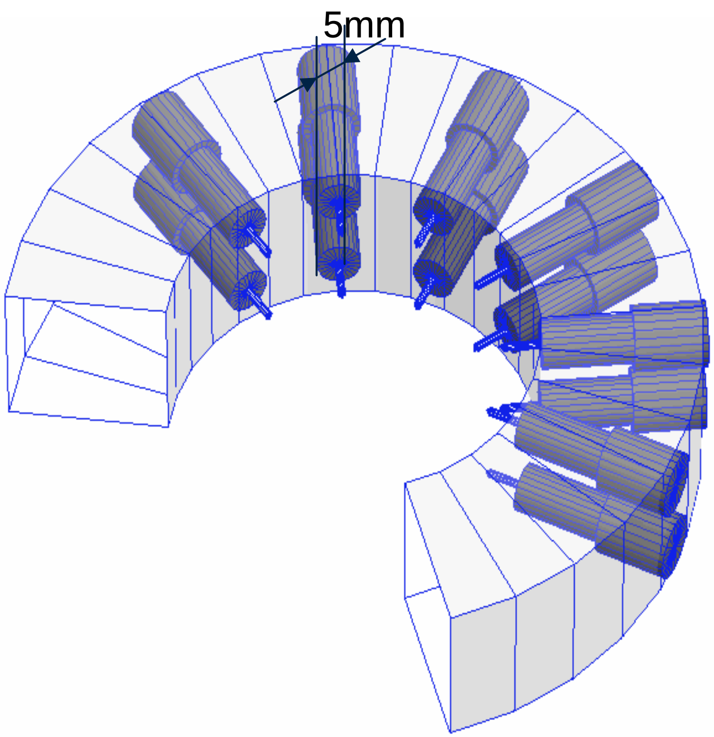
Combustion Chamber (Type-A)



Inner diameter of combustion chamber: 51 mm
Height of combustion chamber at TDC: 26 mm
Wire diameter: 0.9 mm (Ni-Cr)

Configuration of Wire Installation for Combustion (Type-A)

Compression Ratio : 7.5

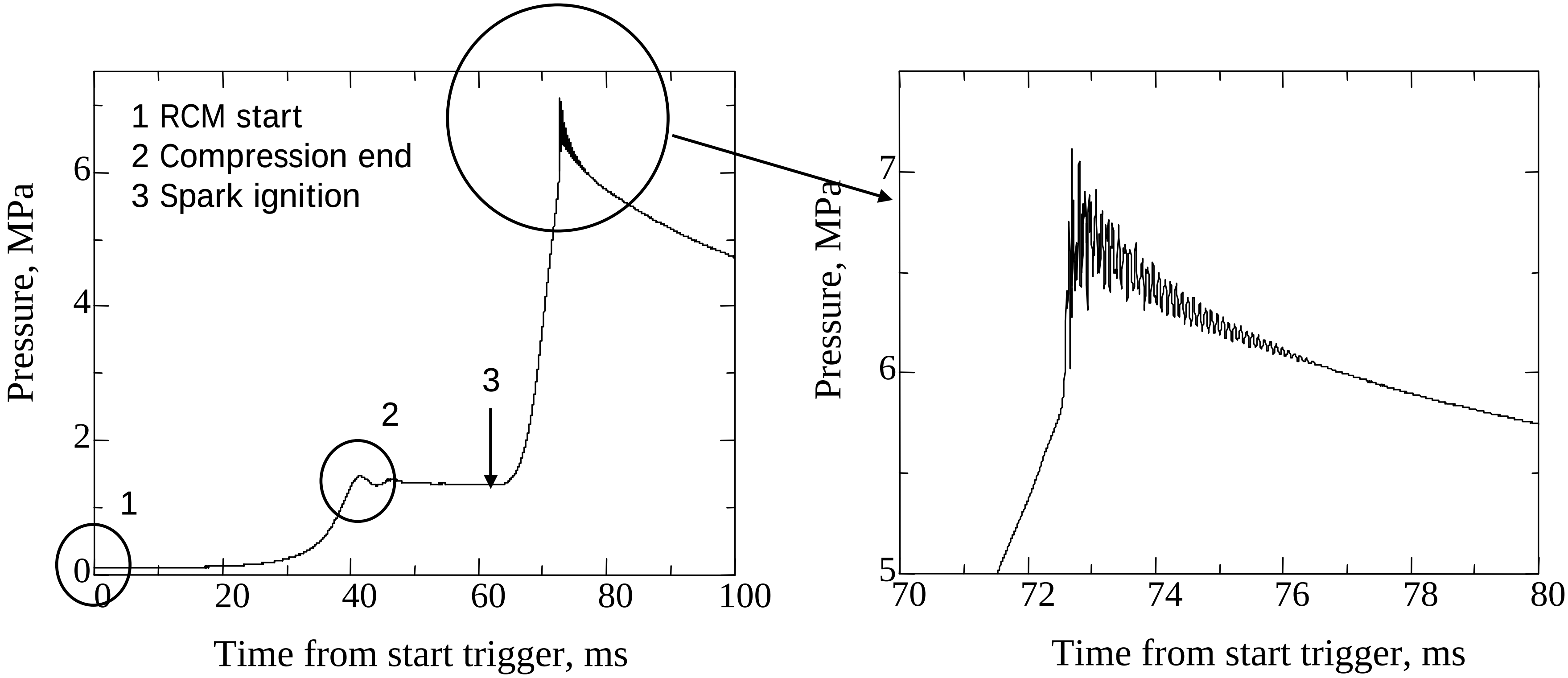


12N-type wires

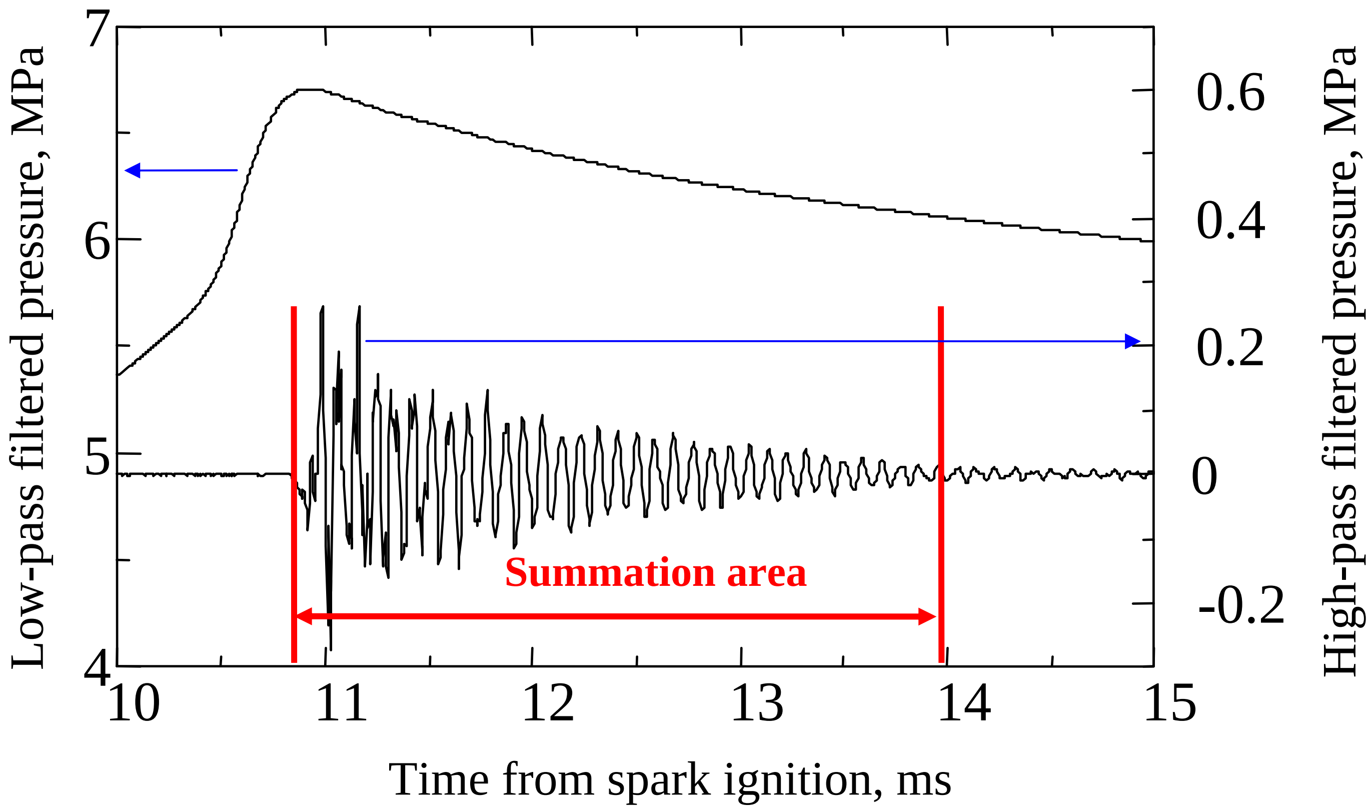
Experimental Condition

Mixture	n-butane - air
Equivalence ratio	1.0
Initial temperature	295K
Initial pressure	0.1 MPa
Compression ratio	5.0, 7.5, 8.5, 9.0

Typical Pressure Trace with Knocking Combustion

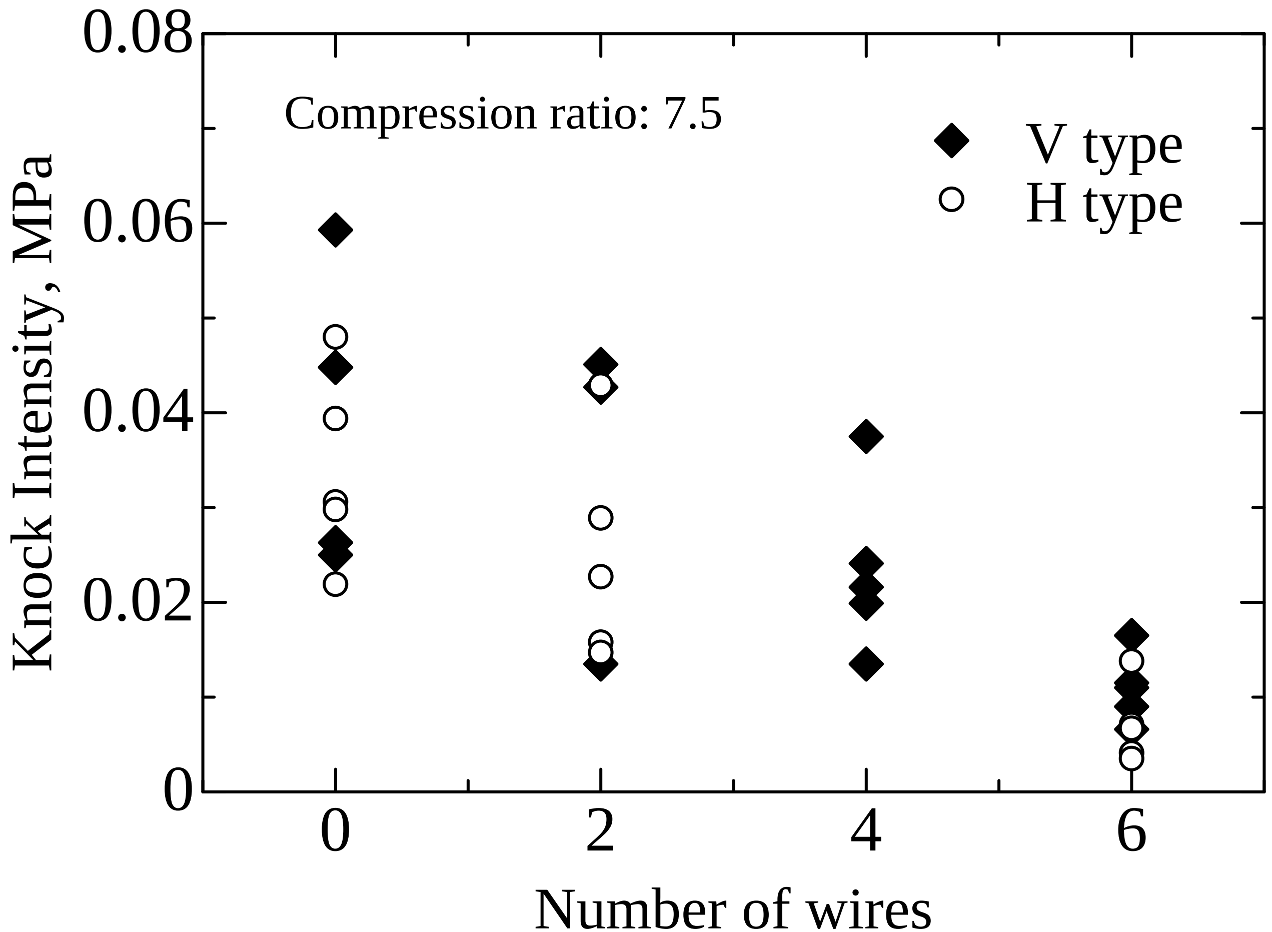


Definition of Knock Intensity

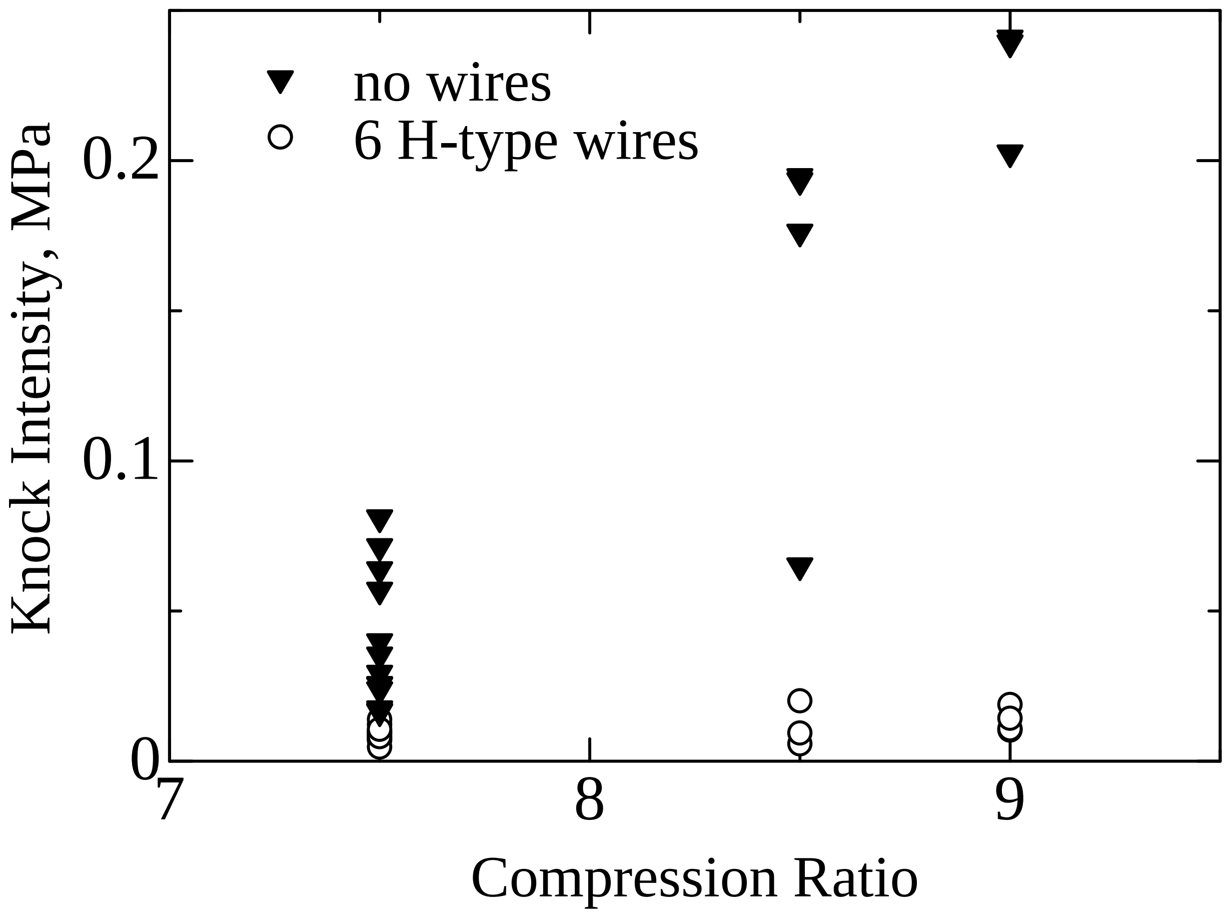


Knock intensity $$KI = \frac{1}{N}\sum abs\{p(i)\}$$

Effect of Configuration and Number of Wires on Knock Intensity

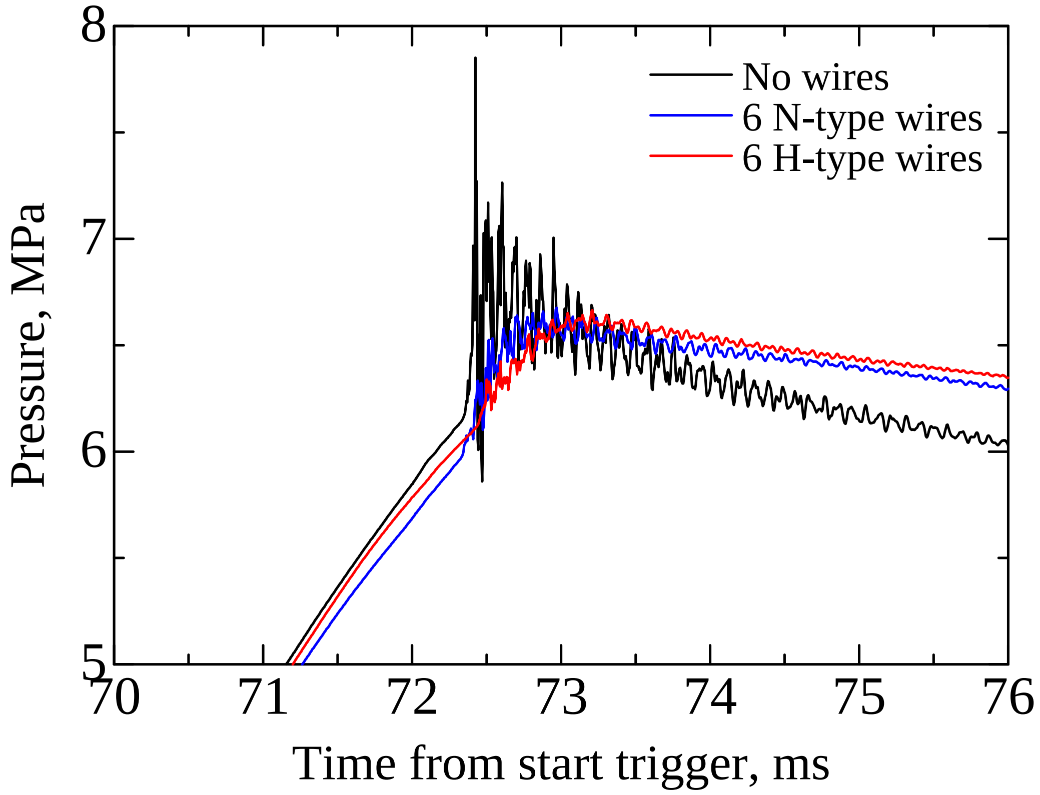


Effect of 6-H Type Wire Installation on Knock Intensity



Effect of N-type Installation on Knock Intensity

Compression Ratio : 7.5



Averaged Knock Intensity

No wires

KI = 0.0438MPa

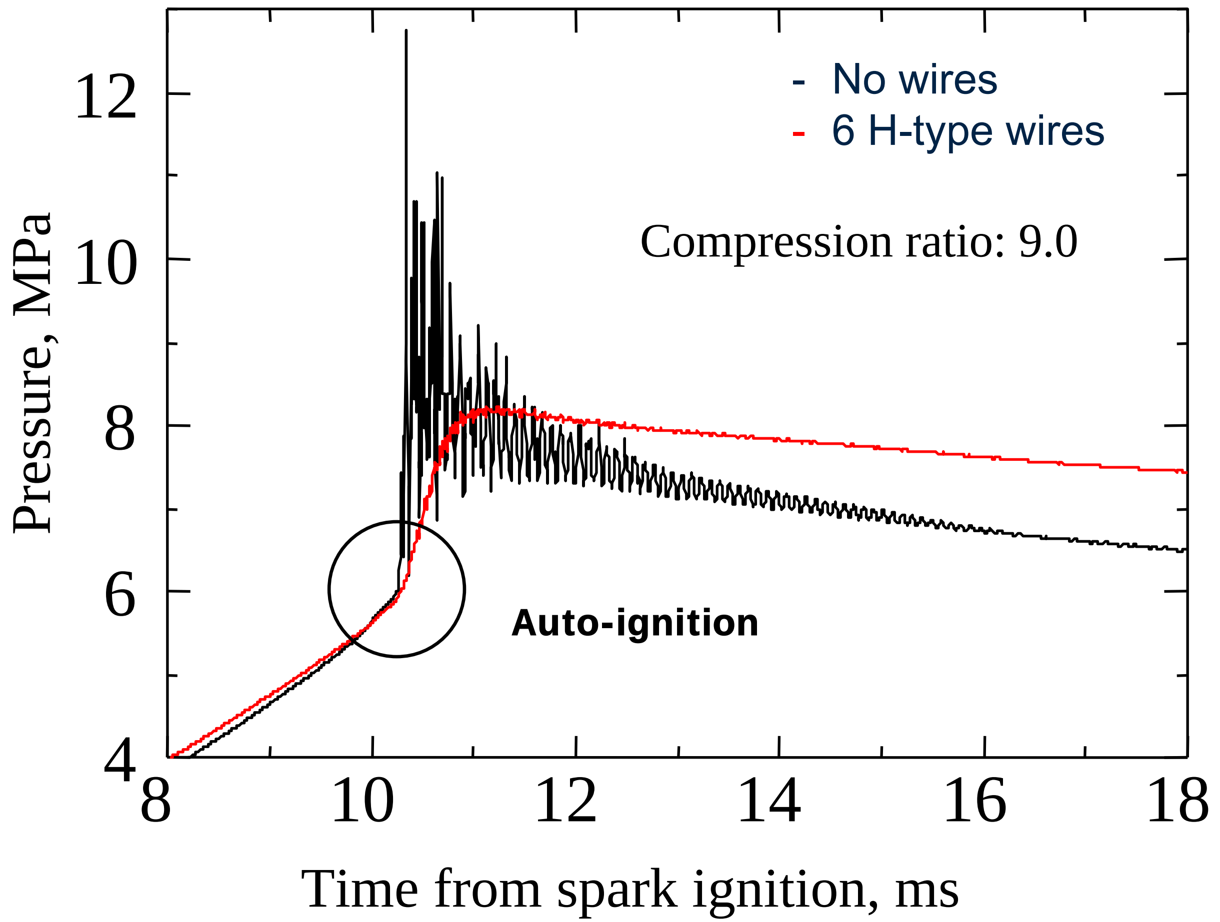
6 N-type wires

KI = 0.0139MPa

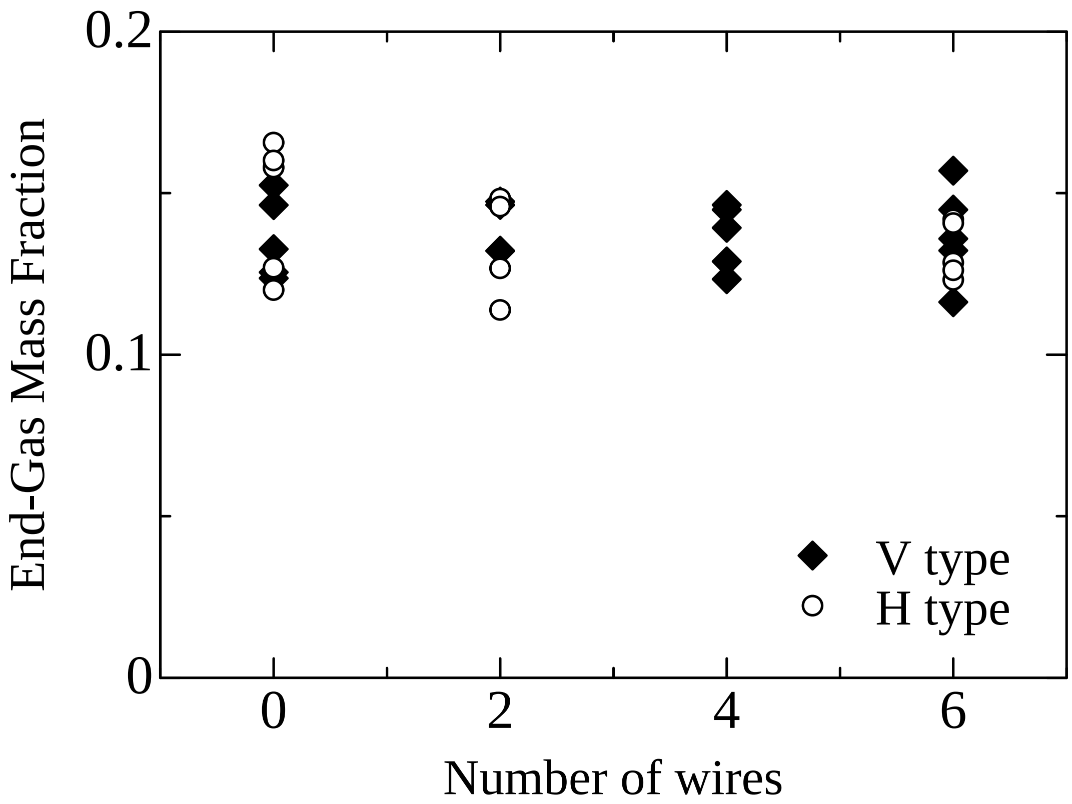
6H-type wires

KI = 0.0078MPa

Pressure Traces in the Vicinity of Onset Time of Knocking Combustion



Effect of Wire Installation on End-gas Mass Fraction



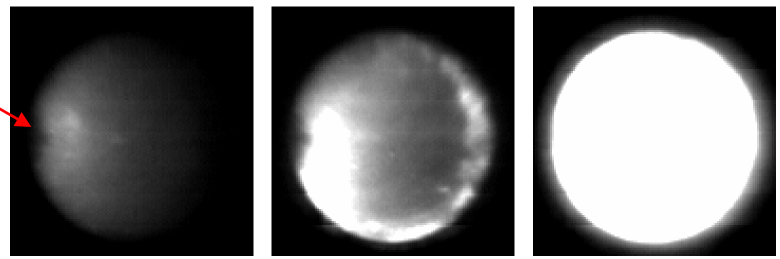
$$EMF = \frac{P_e - P_k}{P_e - P_{ig}}$$

P_e: pressure at combustion end
P_k: pressure at onset of auto-ignition
P_{ig}: pressure at spark ignition

Direct Images just before and after Onset of Auto-ignition

Time

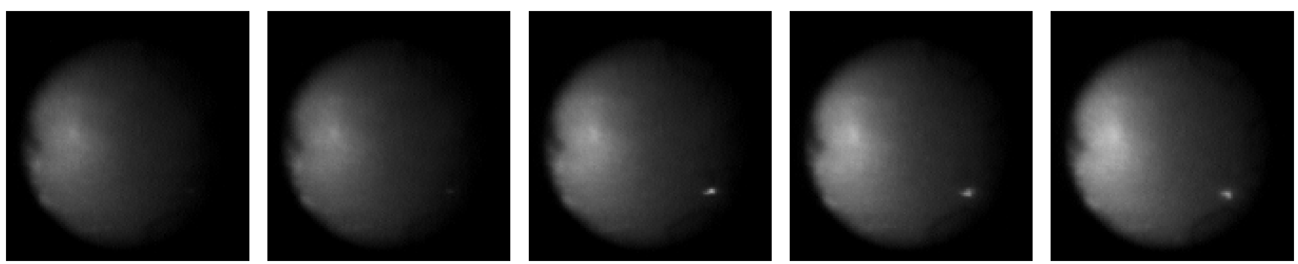
Spark plug



Compression ratio: 8.5
13,500 frame/sec

No wires

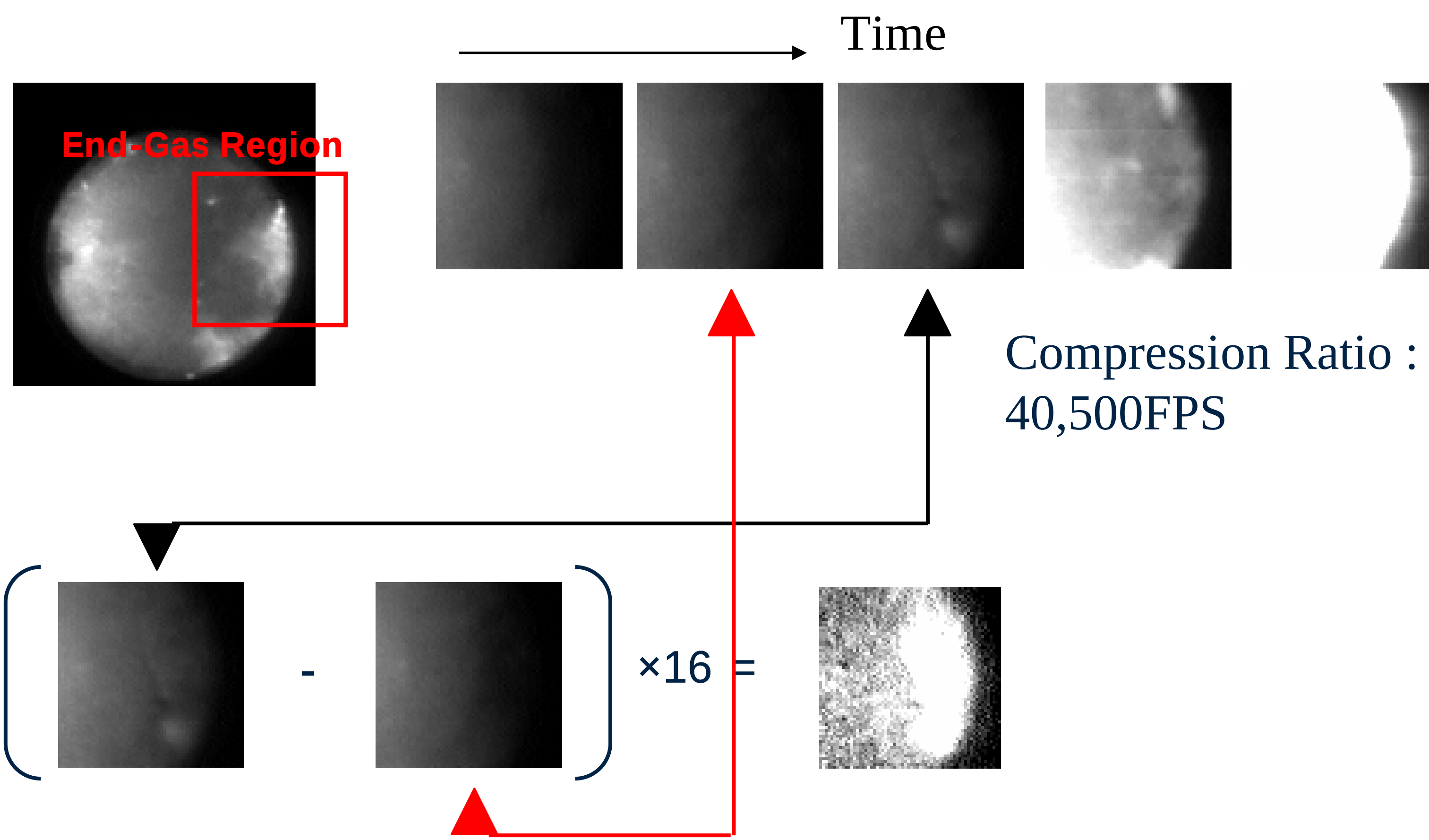
Time



6 H-type wires

onset of auto-ignition

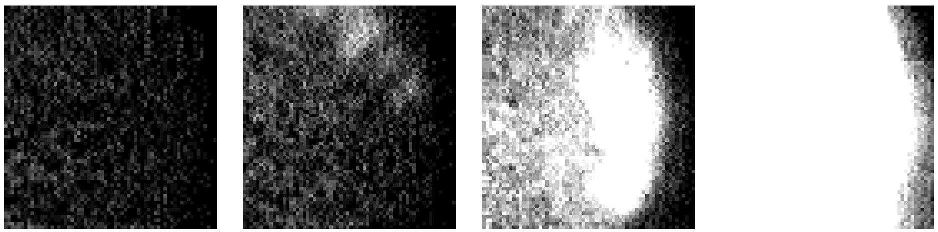
Estimation of Increment of Light Emission Intensity During Time Interval between Two Successive Frames



Compression Ratio : 9.0
40,500FPS

Time histories of Increment of Light Emission Intensity in End-gas Region

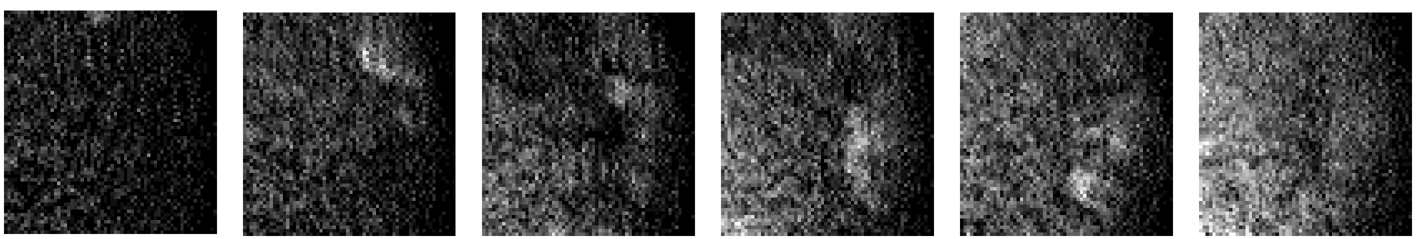
Time



Compression Ratio : 9.0
40,500FPS

No wires

Time

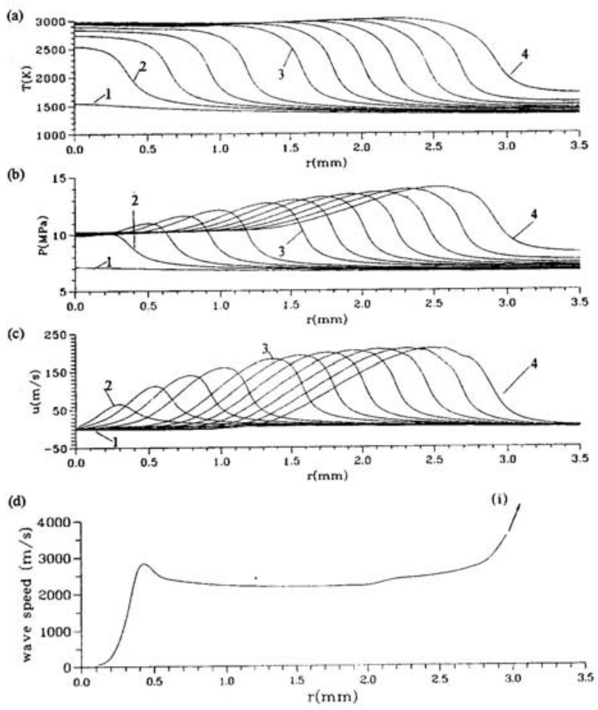


6 H-type wires

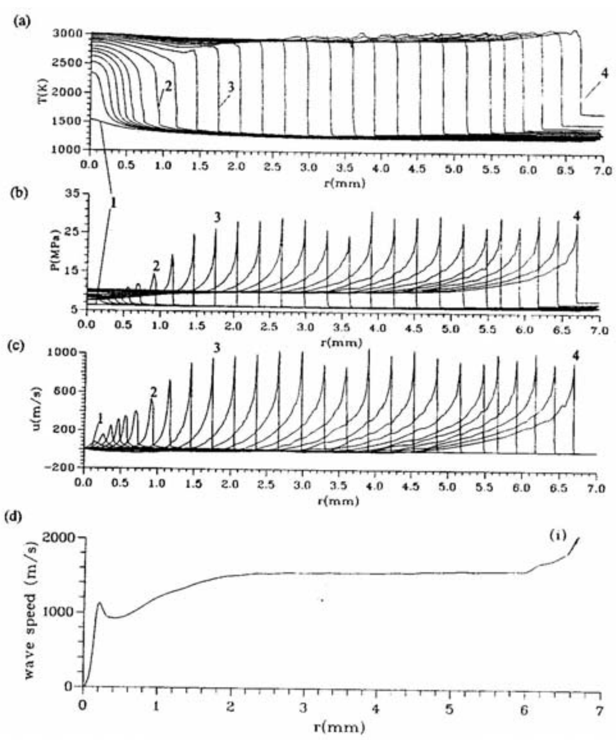
The combustion after auto-ignition becomes ‘moderate’ with wire installation.

Modes of reaction front propagation
(Bradley et al.)

1. Thermal explosion.
2. Supersonic autoignitive deflagration.
3. Developing, developed detonation.
4. Subsonic autoignitive deflagration.
5. Laminar burning deflagration.

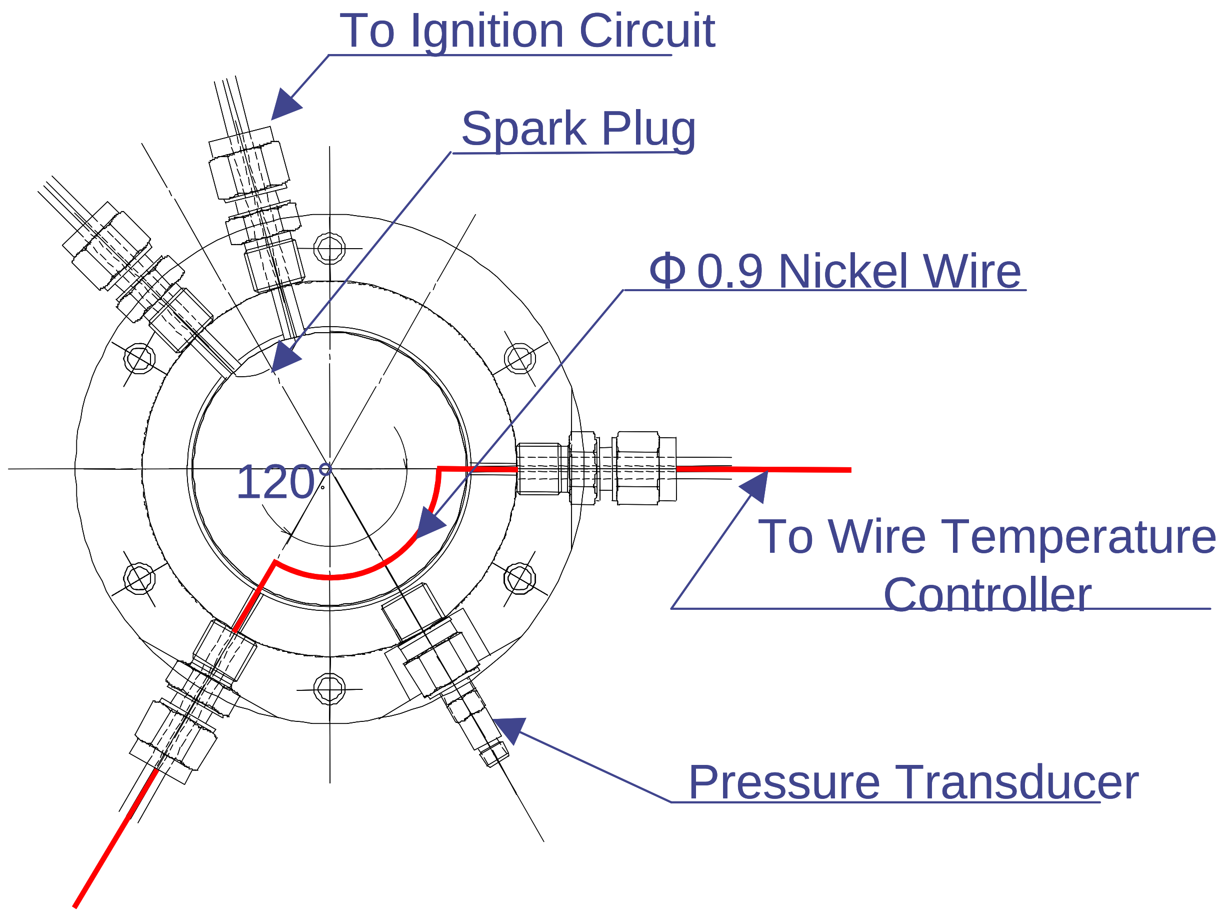


Supersonic autoignitive deflagration



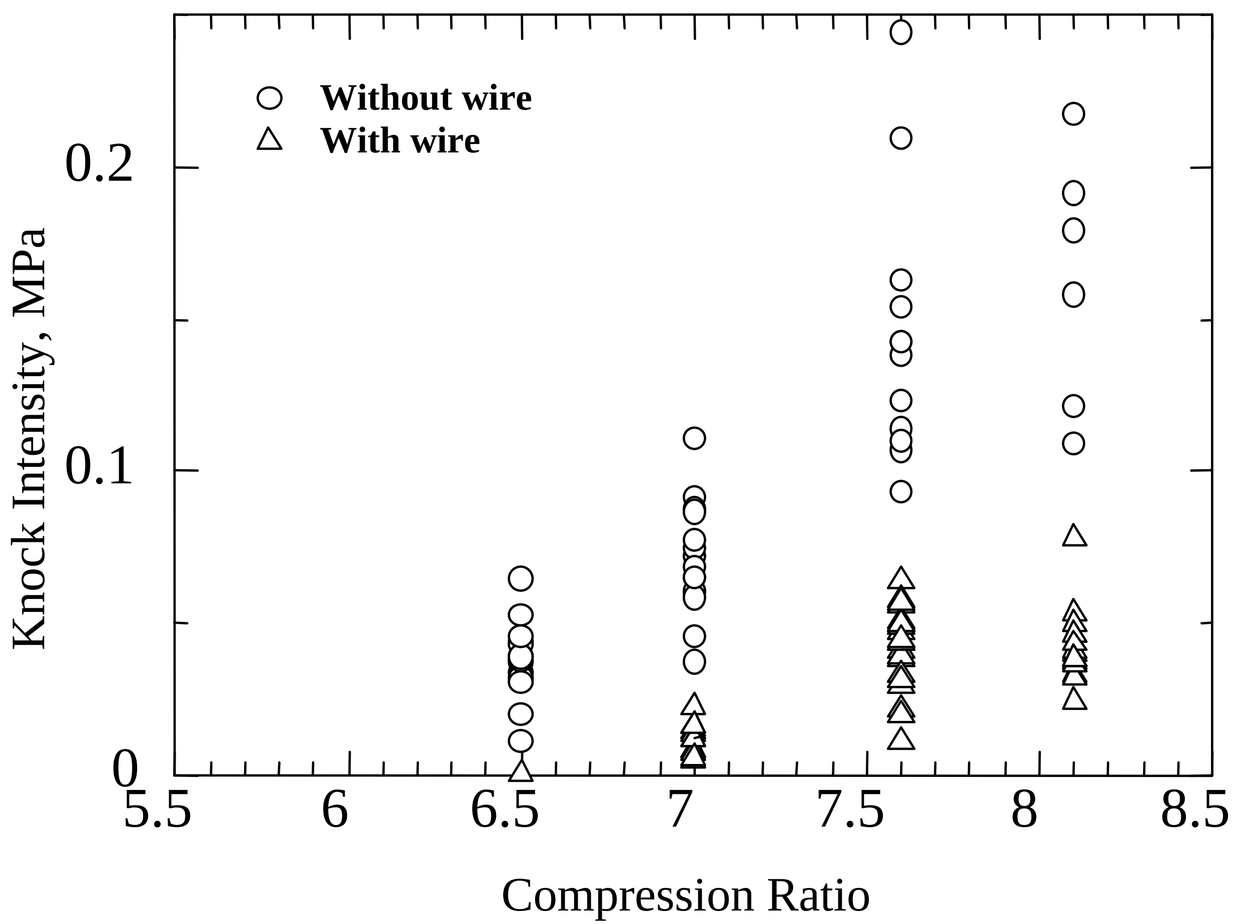
Developing, developed detonation

Combustion Chamber (Type-B)



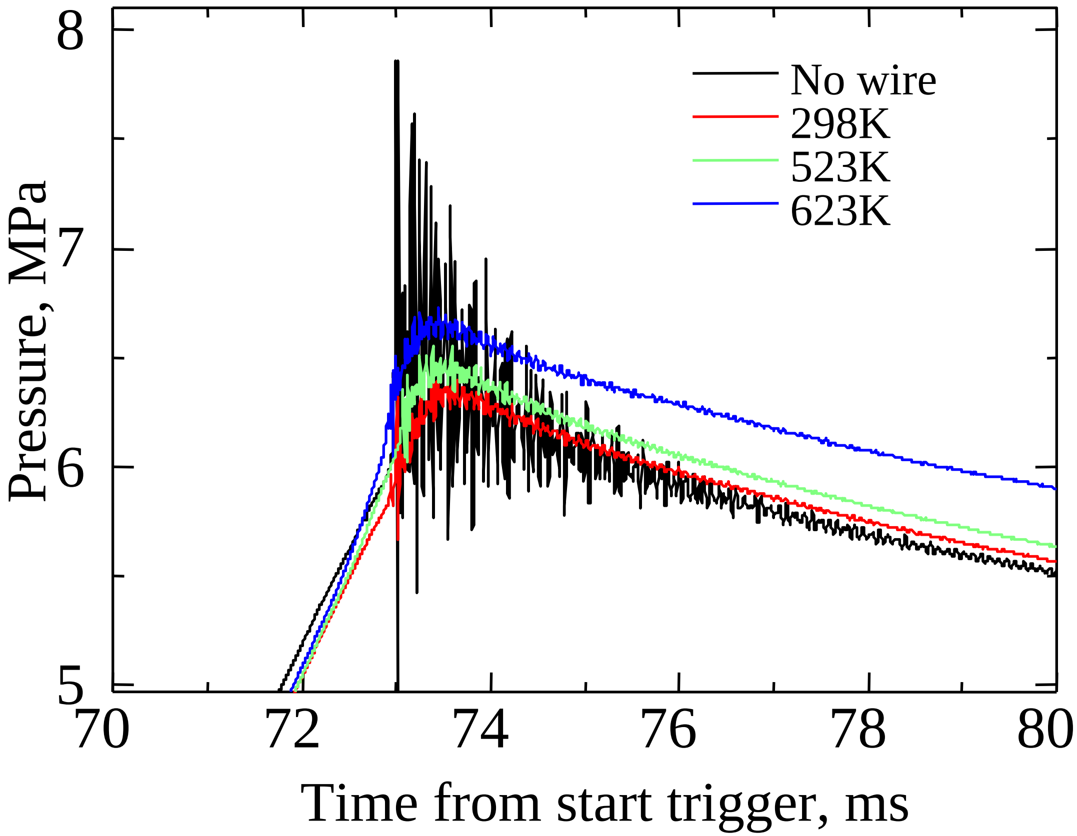
Wire is strung along 1/3 of the circumference of the cylinder.
Wire temperature can be varied from 298K to 623K

Effect of Wire Installation on Knock Intensity (Type-B, 298 K)



Effect of Wire Temperature on Knock Intensity

Compression ratio: 7.6



Averaged Knock Intensity

No wires:

KI = 0.1280MPa

298K:

KI = 0.0157MPa

523K:

KI = 0.0109MPa

623K:

KI = 0.0133MPa

Conclusions

The significant reduction of the knock intensity is achieved by the wire installation. The knock intensity decreases as the number of the wire increases.

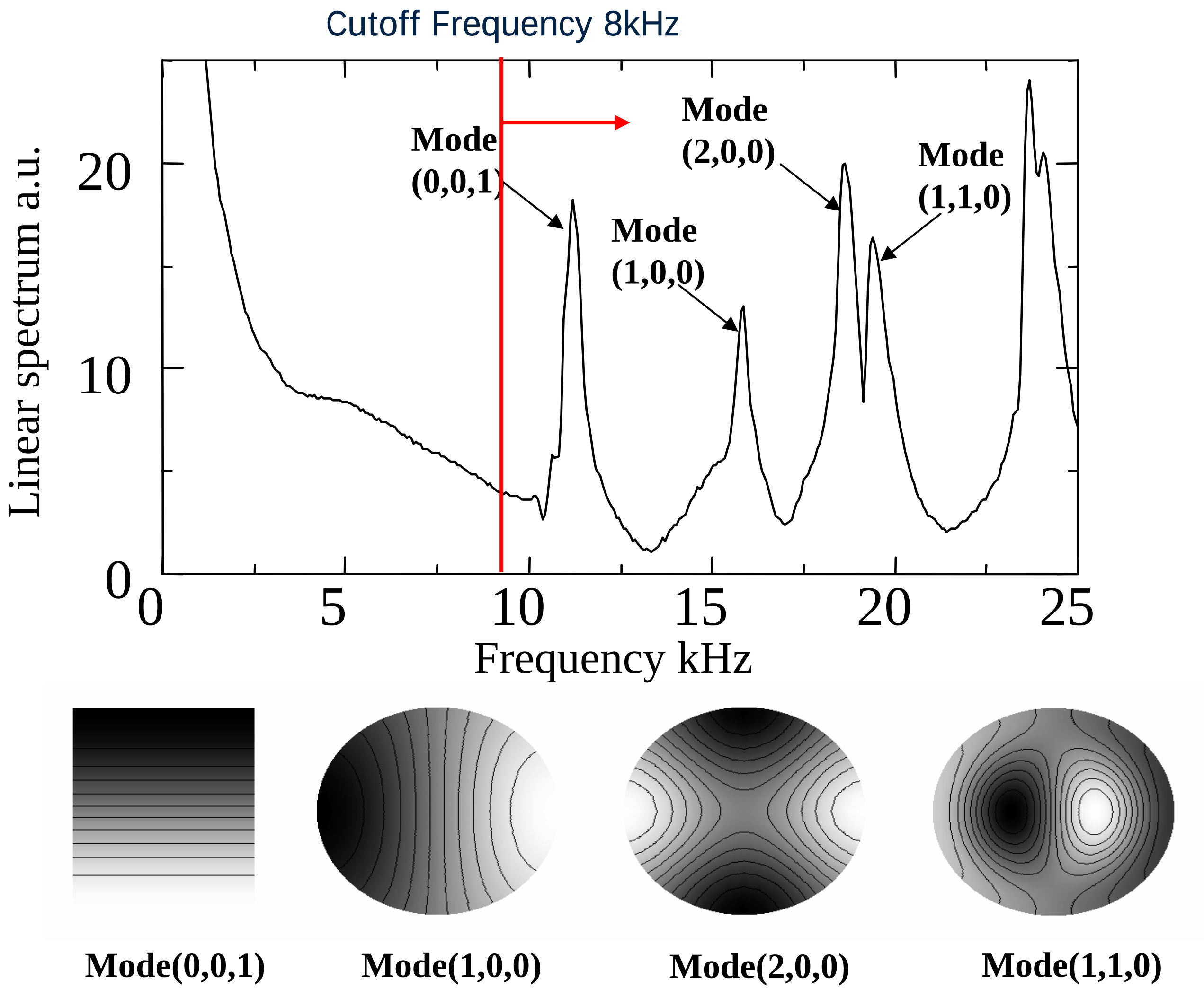
The auto-ignition occurs with and without wire installation.

The existence of the wire in the end-gas region has little effect on the normal flame propagation induced by the spark ignition. There is little change in the end gas mass fraction by the wire installation.

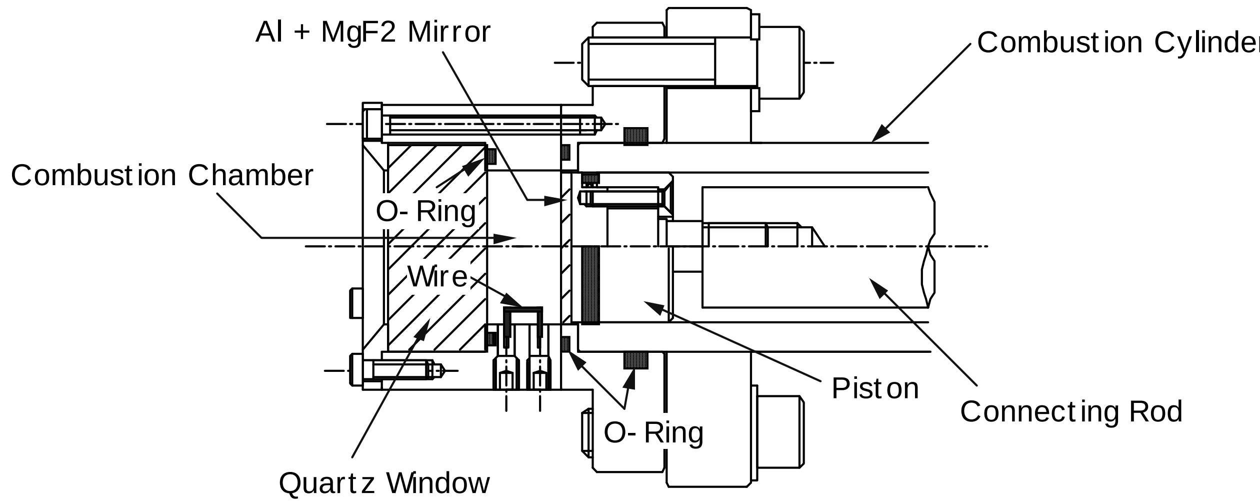
The knocking combustion behavior after the auto-ignition becomes moderate with wire installation, which may result in the reduction of the knock intensity.

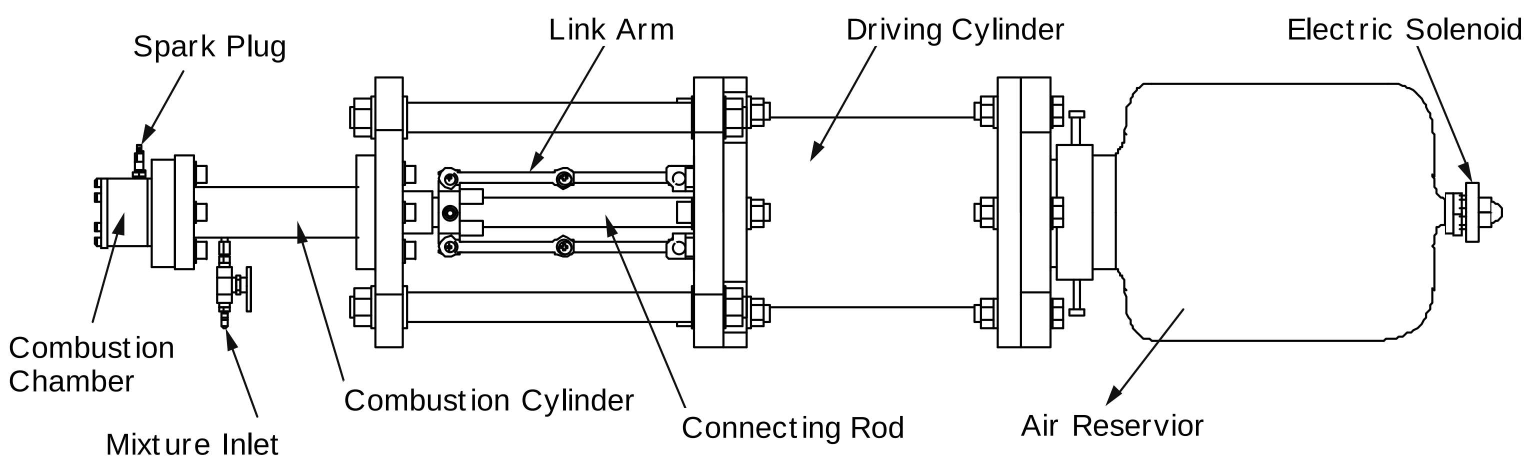
The installation of the wire heated electrically up to 623 K leads to the reduction of the knock intensity.

Spectral Power for Pressure Vibration



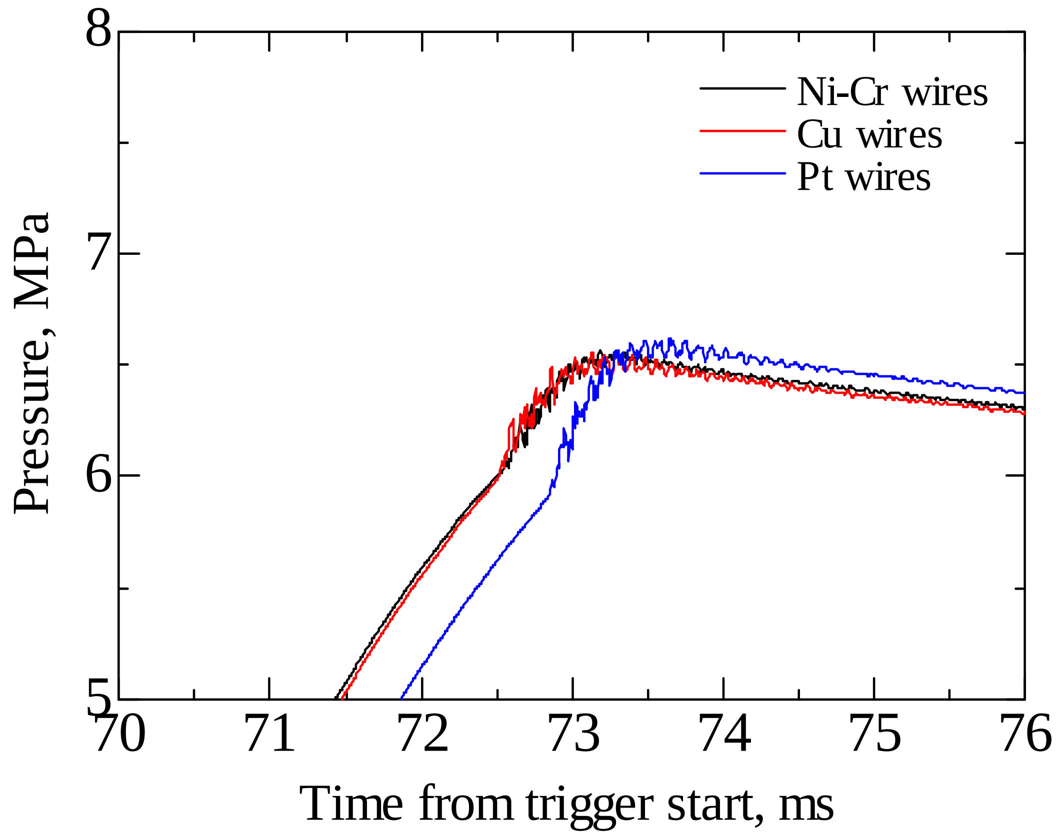
Detailed Configuration of R.C.M.





Effect of Kind of Metal on Knock Intensity

Compression Ratio : 7.5



Averaged knock intensity

- Ni-Cr wires
  KI = 0.064MPa
- Cu wires
  KI = 0.082MPa
- Pt wires (φ=0.7)
  KI = 0.078MPa

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EXPERIMENTAL AND NUMERICAL STUDIES OF HIGH INTENSITY COMBUSTION

Contributor: Japan National Committee for IEA/CRD Implementing Agreement on Energy Conservation in Combustion (JECC), Tokyo, Japan.

Tatsuya HASEGAWA
EcoTopia Science Institute, Nagoya University
Mitsuhiro TSUE
Dep. of Aeronautics and Astronautics, University of Tokyo

Description

The objective of this task is to obtain fundamental information, which can be useful for designing a high intensity compact industrial combustion system. For this purpose, the turbulence-combustion interaction in extremely strong turbulent flow and combustion behavior in the combustion chamber of internal combustion engines have been studied experimentally and numerically.

Two topics on high intensity combustion have been conducted in this subtask. One is the knocking combustion behavior in spark ignition engines, and the other is modeling of turbulent premixed combustion by DNS database.

Simulation of Turbulent Premixed Flames by a Hybrid Turbulence Model

A new turbulence model called hybrid model was proposed to simulate turbulent premixed combustion with flame-generated turbulence and counter-gradient diffusion. The model constants were evaluated by DNS database, and these models were in good agreement with DNS.

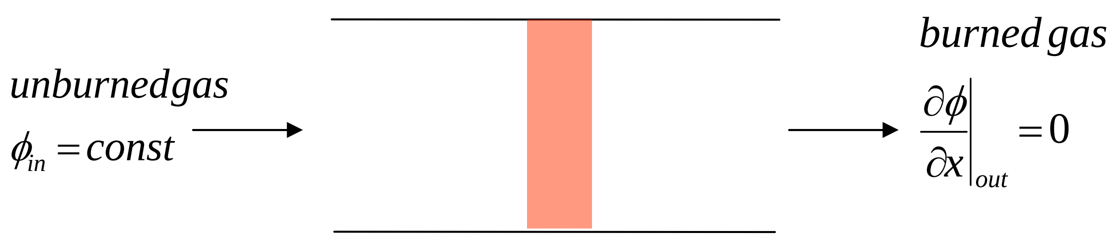

Fig. 1 Simulation model

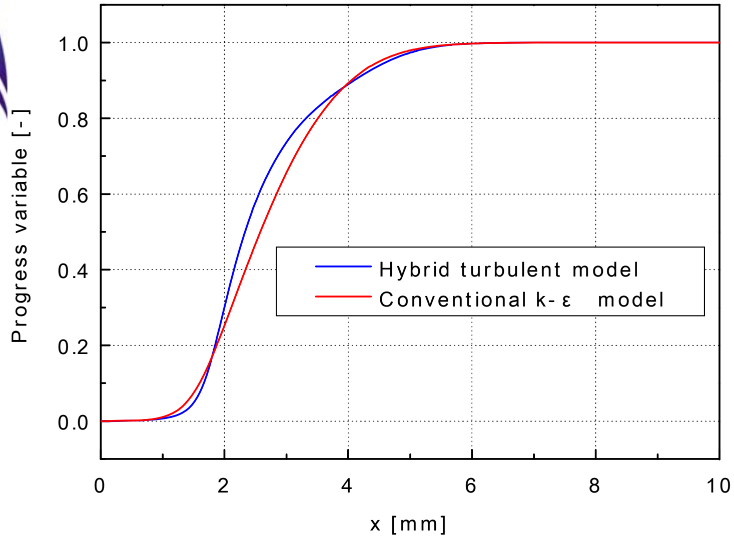

Fig. 2 Distribution of progress variable

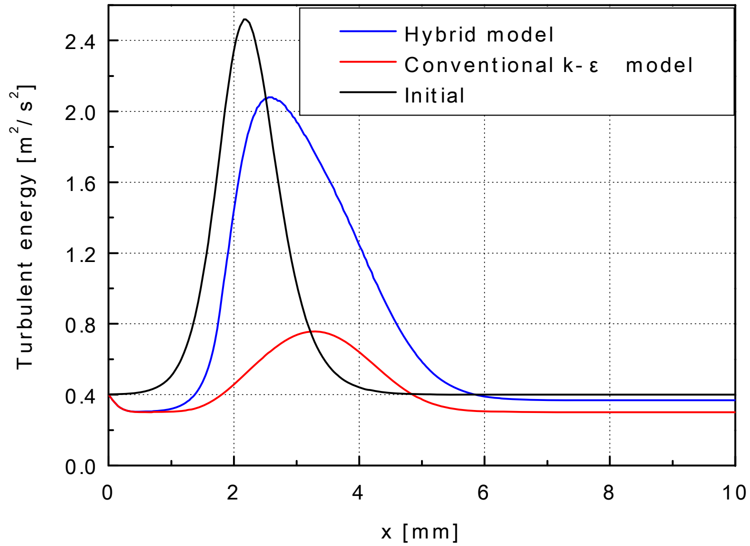

Fig. 3 Distribution of turbulent energy

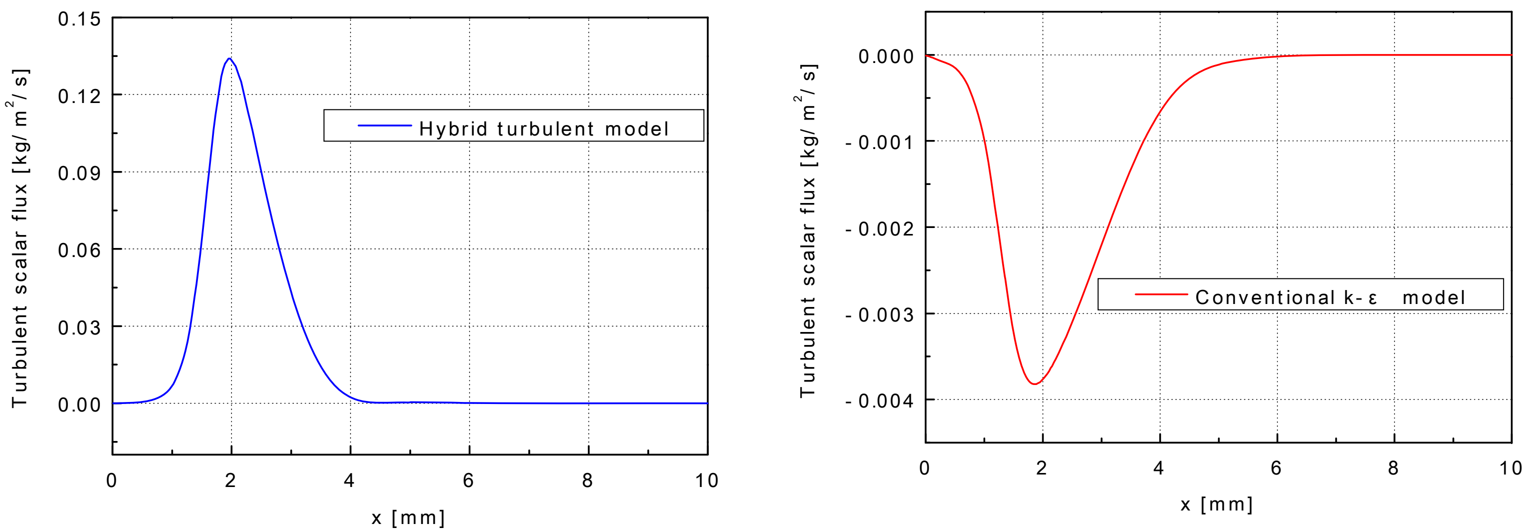

Fig. 4 Distribution of turbulent scalar flux