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Effect of Laser Thermal Shock Test Parameters on the Temperature Field of Piston

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Abstract

Exploring experiments of laser thermal shock piston were conducted. The transient temperature of the piston was measured by high-resolution CCD cameras. Temperature of piston can be controlled by temperature-controlled method or time-controlled method. Results show the average temperature of thermal cycles can be improved by increasing heat duration time. There are different temperature response for piston with different preheat temperature in the same laser parameters.

Keywords

Laser; Thermal Shock; Piston; Temperature

Introduction

Pistons are subjected to severe thermal loads while in service, and the long-term transient internal stress may initiate cracks in the structure, a damage mechanism which is now known as "thermal shock". Thermal shock damage is a major failure mode of piston. With the development of high power density and compact diesel engine, the frequency of thermal shock damage is increased for piston. However, the piston is subjected to non-uniform thermal loading in operating condition, which causes heterogeneous distribution temperature of piston in time and spatial domain with the synthesis effect of coolant and structure design. Therefore, evaluation of cycles index of endurable thermal shock is very difficult by simulation test. At present, there are about three methods to study the thermal strength of piston, they are: experiments of the whole engine, experiments of the components and numerical simulation. Experiments of the whole engine experiments are expensive with consuming a great deal of time. Experiments of the components are economical with less time. Numerical simulation method needs abundance dates of thermal physical properties, which isn′t suitable for engine design stage. Experiment of the components is an effective method to evaluate thermal strength of piston. Current methods of the components for evaluate thermal strength of piston have laser thermal shock, localized intense flame, high frequency wire coil, thermal resistance heating, and quartz lamp heating, etc. However, it is difficult to simulate the thermal shock process due to non-uniform distribution of temperature for piston in time domain and spatial domain, which requires the heat source in an experimental simulation system can be designed in both spatial and temporal domains in a controllable manner.The localized intense flame methods have similar combustion circumstance of engine with uncontrolled variable heat source in spatial distribution. High frequency wire coil has high energy input with uncontrolled variable heat source in temporal distribution. Resistance heating, and quartz lamp have low energy input.

Lasers have high-power density. Meanwhile, energy of laser beam can be conveniently controlled in temporal and spatial domain with the aid of integration software. All these merits make laser an ideal heat source used in the thermal shock test.

Some researchers have employed laser to study thermal shock behavior of material specimens fromgas turbines, diesel engines and railroad steels.

R. Pulz conducted laser thermal shock experiments for advanced ceramics. O. Emoharel studied lase induced thermal stress and the heat shock response in neural cells. J. K. Kim studied thermal shock strengths for graphite materials by a laser irradiation method. S.Charles generalized laser shock processing and its effects on microstructure and properties of metal alloys. Z. J. Dai et al., investigated the thermal shock strength of tungsten by laser irradiation.

However, very few thermal shock experiments of piston have been conducted by laser. In this paper, temperature distribution and fluctuation are studied by variation laser thermal shock parameters on piston. The investigation results can supply parameters optimization for laser thermal shock on piston.

Experimental

Experimentation is carried out by Nd: YAG laser thermal shock equipment with standard power 3kW. The experimental set-up is illustrated in Fig. 1. Laser of rotundity was shaped concentric multi-circular beam for simulating the actual temperature distribution of piston in operating condition, as shown in Fig. 2. The transient temperature of the monitoring region is measured by infrared pyrometers. The transient images of the piston are captured by three high-resolution CCD cameras. Temperature of piston can be controlled by temperature-controlled method or time-controlled method. The temperature-controlled method is actualized by enactment maximum temperature and minimum of one thermal cycle.The time-controlled method is actualized by enactment heating duration time and cooling duration time.

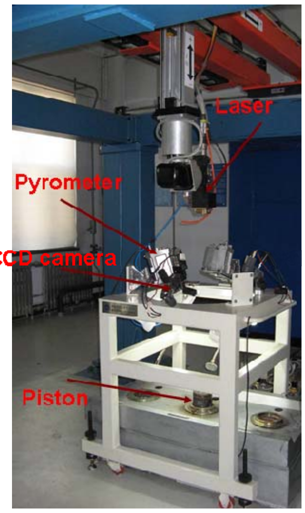

FIG. 1 EXPERIMENTAL SYSTEM

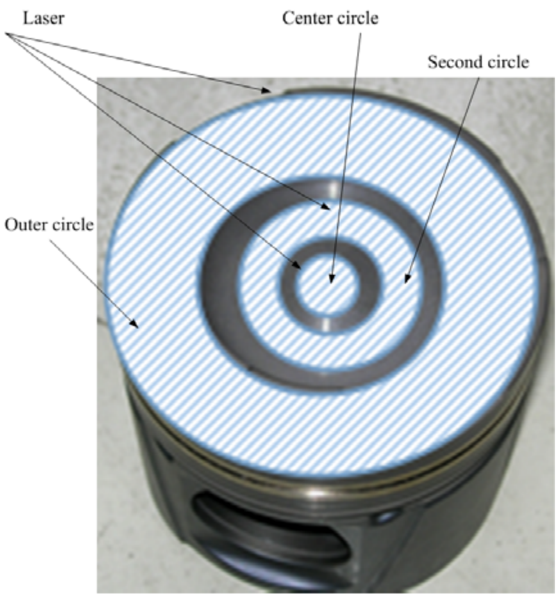

FIG. 2 SCHEMATICS OF LASER IRRADIATION ON PISTON

Results and Discussion

When piston is heated or cooled, its bulk is changed. The stress of tension or compression forms if the heat expansion or contraction is restricted. The restriction is formed due to nonuniform temperature distribution, structural design and external constraints. Therefore, thermal damage can be induced by temperature fluctuation, the periodic tension and compression stress result in an incremental damage, which is called thermal shock.Thermal shock of piston is directly related to the temperature gradients and temperature fluctuation. When diesel engine operates in steady working condition, the temperatures maintain the fluctuation of 10~20℃ range on the piston crown, which is called high thermal cycles of thermal shock. When diesel engine is operated in change working condition, the temperature maintain the fluctutaion of exceeding 50℃. The fluctutaion range of temperature is relation to operating parameters. The temperature field and temperature fluctuations are similar to those of a piston in normal service for laser thermal shock on piston. Piston is heated to an enactment temperature by constant laser power. The periodicity heat and cooling are loading on firepowe surface with piston preheated to constant temperature. The time of thermal cycle is heating time t_h, cooling time t_l and laser power P.

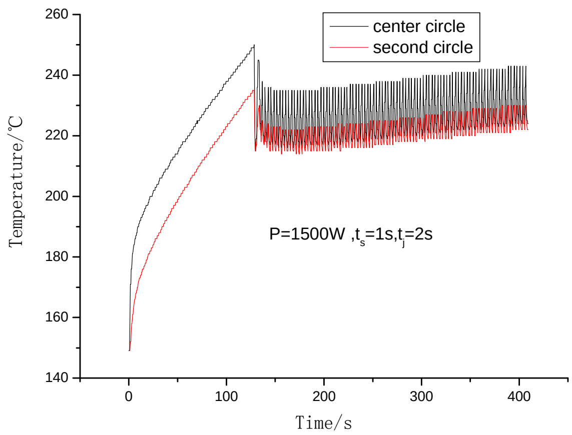

FIG. 3 TEMPERATURE FLUCTUATION OF THE TIME-CONTROLLED METHOD (T_S=1S AND T_L=2S)

Fig. 3 shows the temperature responses with thermal cycle parameters p=1500w, t_s=1s, t_l=2s. The average temperature of thermal cycles is gradually reduced, then increased. The average temperature is related with laser power, heating duration time, cooling duration time, convective and thermal conduction. When piston is preheated to constant temperature, heat input is lower the diffusing energy, which leads to the average temperature of thermal cycle reduced at the beginning. When the average temperature is low a constant value, heat input is higer the diffusing energy, which leads to the average temperature increased.

The increasing rate of average temperature is reduced with improving t_l time, as shown in Fig. 3, Fig. 4 and Fig. 5. The temperature of piston is reduced by increasing cooling duration time, which leads to the fall of the averge temperature. There are the same to thermal cycle parameters with different piston preheated temperature from Fig. 6 to Fig. 7. The average temperature of thermal cycle is increased with piston second circle temperature preheated to 250℃. The average temperature of thermal cycle is reduced or increased with piston second circle temperature preheated to 330℃ and 200℃, respectively.Average temperature status is directly related to the piston preheated to temperature.

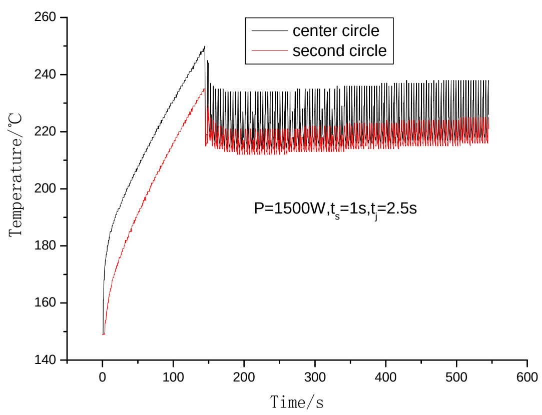

FIG. 4 TEMPERATURE FLUCTUATION OF THE TIME-CONTROLLED METHOD (T_S=1S AND T_L=2.5S)

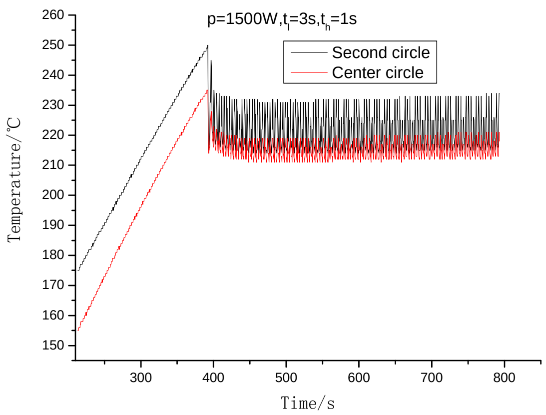

FIG. 5 TEMPERATURE FLUCTUATION OF THE TIME-CONTROLLED METHOD (T_S=1S AND T_L=3S)

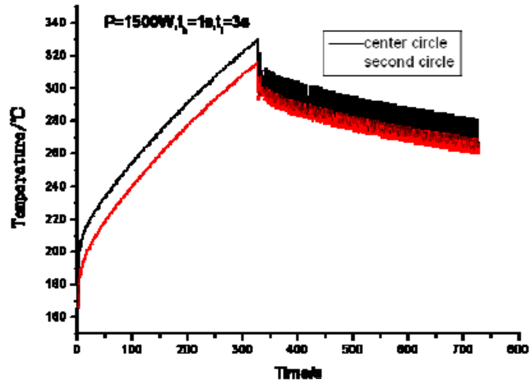

FIG. 6 TEMPERATURE FLUCTUATION OF THE TIME-CONTROLLED METHOD (T_S=1S AND T_L=3S)

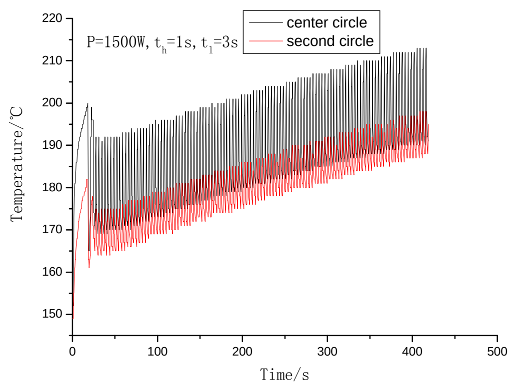

FIG. 7 TEMPERATURE FLUCTUATION OF THE TIME-CONTROLLED METHOD (T_S=1S AND T_L=3S)

Conlusions

The influence of laser thermal shock parameters on temperature of piston is investigated. Results show the temperature response of piston is related with thermal loading duration time and cooling time, laser power and piston preheated to temperature. The average temperature of thermal cycle can be improved by increasing heat loading duration time.

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