VOL. 14, NO. 5, MARCH 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

COMBUSTION CHAMBER DESIGN FOR EFFICIENT HEAT TRANSFER

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ABSTRACT

A combustion chamber of an engine operating at really high temperature expels a hot stream of gas and thus, may be equipped with a cooling device. To achieve a lower temperature around the combustion chamber, a valve facing the combustion chamber in which engine oil is circulated with the help of valve stems which are equipped with oil introduction channels may be used or alternatively, the combustion chamber may have depressions formed in such a way that the stable outer layer of the stream of gas that that is formed around the inner wall of the combustion chamber is hydrodynamically destabilized in the area of the depressions during the operation of the engine.

Keywords: combustion chamber wall, cooling, threading, depressions, heat transfer.

1. INTRODUCTION

A cooling device located adjacent to a combustion chamber is usually required to keep the chamber wall that is heated by the burning gases, cool enough to ensure that the combustion chamber serves a satisfactory lifetime. However, in the case of regenerative cooled engines, it is necessary to enhance heat transfer to the cooling device so the heat absorbed from the combustion chamber by the cooling device can be used to increase the engine's operating efficiency usually by running fuel pumps. This means that enhanced heat transfer to the cooling device will result in increased efficiency of the engine.

One way of doing this is having a combustion chamber that has longitudinal ribs to accommodate a cooling channel containing a coolant. The heat transfer can be further enhanced by enlarging the inner surface of the combustion chamber. The disadvantages of this approach are the technical difficulties of producing the longitudinal ribs and the increased mass of the engine. However, another way of enlarging the inner surface of the combustion chamber is where the cooling pipes are formed by curving sections of the internal walls of the combustion chamber upwards. This method also involves considerable technical difficulty during production. Moreover, it also results in lower structural stability and capacity to withstand stress. The surface area can also be increased by increasing the length of the combustion chamber. However, since the total length of an engine is often fixed this method can lead to a shortening of the propulsion nozzle, which can result in a reduction in engine performance.

Another way is to reduce the temperature of the combustion chamber wall on the hot gas side. With the conventional cooling devices, however, it is only possible to achieve a slight increase in the difference between the gas temperature in the hot gas stream and the temperature of the combustion chamber wall. Moreover, this would also lead to a major loss of pressure in the coolant, which in regenerative cooled engine would also result in a reduction in combustion-chamber pressure.

2. THE NEED FOR DESIGN VARIATIONS

The objective is to provide a combustion chamber for an engine that will enable enhanced heat intake by a cooling device in a simple way.

The inner wall of the combustion chamber contains depressions formed in such a way that they cause hydrodynamic destabilization of the stable outer layer of the stream of gases that is formed around the combustion chamber wall during the operation of the engine.

In the conventional case, where there is a smooth inner combustion chamber wall, gas flow in the combustion chamber around the wall forms a smooth outer layer that develops a thermal insulation effect, which works against the combustion chamber wall absorbing heat from the stream of hot gases.

The new approach is configured to systematically disturb the formation of the thermally insulating outer layer, which will considerably increase heat transfer to the combustion chamber wall. Moreover, it has negligible effect on the characteristics of the combustion chamber as a whole because the depressions are formed such their effect is actually limited to the outer layer and without great expense, the disadvantages of the conventional technology can be eliminated.

To keep the effects of the depressions limited to the outer layer, the depth of the depression should not exceed half the thickness of the combustion chamber wall.

Different types of depressions can be made in order to achieve the desired effects. For example, depressions can be formed either by roughening the surface through the use of appropriate blast media or by threading. The technique of abrasive blasting involves a pressurized fluid, usually compressed air or a centrifugal wheel to propel the blast media. They can take the form of grooves with a maximum slant of 45° against the circumference direction of the combustion chamber. They may also take the form of closed grooves. Threading, which makes use of at least one spiral, is a particularly efficient and convenient way to make these depressions.

The form of depressions can be optimized according to different criteria in case they are not automatically determined by the production method. The cross-section of the depressions can take the form of a segment of a circle, the radius of which is greater than or equal to the depth of the depression. This facilitates a reduction in the notching-effect of the depressions, thus, enabling an increase in the lifetime of the combustion chamber.

It is essential to adjust local heat transfer for each area of the combustion chamber wall with respect to the altering conditions and requirements. This can be done by varying the density of the number of depressions.[3] In case of roughened surfaces, the number of depressions per unit of area is varied to localise the disturbing effect of the depressions on the outer layer. Else ways, the number of depressions per unit length is varied in case of the grooves to localise the disturbing effect of depressions experienced on the outer layer.

It is also advisable that different areas of the inner combustion-chamber wall have different densities in the number of depressions. Combustion chambers with the fuel injection head on one end and a combustion chamber neck on the opposite end should more importantly be based on similar lines; the reason being significantly high heat flux values in the area of the combustion-chamber neck. A higher density in the number of depression in this region can contribute towards the reduction in these values, hence, facilitating smooth and steady heat transfer across the regions. The region of fuel injection head has a lower operating temperature than the neck region and thus, experience lower heat flux too.

Higher density in the number of depressions in this area of the combustion-chamber wall can increase heat transfer to the combustion-chamber wall, so that local heat transfer at this point can be aligned with local heat transfer in areas of the combustion-chamber wall located farther downstream. This makes it possible to achieve even heat transfer over the entire length of the combustion chamber. There can be alternate or cumulative increases in the density of the number of depressions in individual areas of the combustion-chamber wall.

3. METHODOLOGY

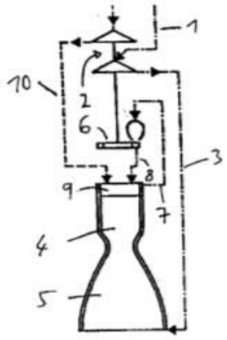

Figure-1. Illustration of the expander process. [4]

Figure-1 depicts a unique rocket engine that operates with accordance to the mainstream process, i.e., without pre-burning, also called the expander process. [3] The fuel line propagates the first propellant to a fuel pump. The fuel line branches off, bringing the first propellant to a cooling device, which serves to cool the wall of the combustion chamber and possibly also the exhaust nozzle of the rocket engine. While cooling, the first propellant absorbs heat from the combustion chamber and also from the exhaust nozzle. [4] Another fuel line takes the first propellant, along with the thermal energy it contains, away from the combustion chamber. The thermal energy is used to run a turbine that propels the fuel pump. Thereafter, the first propellant is brought via a fuel line to the injection head of the rocket engine and injected into the combustion chamber for burning. The second propellant is brought directly to the injection head after passing the fuel pump via the fuel line and also injected into the combustion chamber.

In order to achieve the highest possible combustion-chamber pressure, it is necessary that the first propellant absorbs as much heat as possible as it enters the cooling device, so that the propellant enters the turbine at the highest possible temperature. This improves the overall efficiency of the engine by producing a correspondingly high compression of the propellants in the fuel pumps.

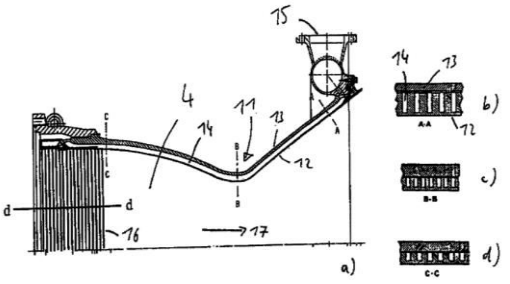

Figure-2(a). Cross-section of the most efficient engine. [4]

Figure-2(*a*) shows a cross-section of the structure of the highly efficient combustion chamber. A narrowing, commonly known as the combustion chamber neck can be observed from the figure illustrated above. The inner layer of the combustion-chamber wall contains cooling channels through which a coolant passes the first propellant. The cooling channels are covered by a second layer of the combustion chamber wall on the side facing away from the hot-gas side of the combustion-chamber wall. The coolant guides the cooling channels through a connecting channel that can be connected to the fuel line mentioned as shown in Figure-1. The coolant, thereafter, moves against (opposite) the flow of the hot gas stream that is passing through the cooling channels in the direction of the fuel injection head. The coolant absorbs heat from the inner layer of the combustion chamber during the course of its flow.

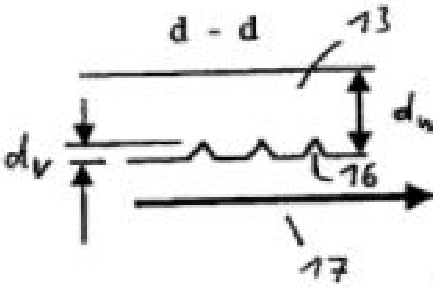

Figure-3. Depressions of the inner layer of the combustion chamber wall. [4]

In order to ensure that sufficient heat is absorbed by the coolant, the chamber provides diagonal grooves in the inner layer of the combustion chamber. [6] These grooves essentially run across the circumferential periphery of the combustion chamber, thus, vitally extending across the flow direction. The grooves can either take the form of closed circular grooves, which can be engraved or otherwise form individually as independent entities. This stage involving groove formation can be declared as the final stage in production. However, the grooves can also be slanted against the circumference direction, for example, in the form of threading slanted at a maximum of 45° relative to the circumference direction. The threading can also have single or multiple spirals. [7]
Figure-3 illustrates an example of the dimensions of the inner layer of the combustion chamber wall and the depressions in the form of diagonal grooves. The thickness of the inner layer of the combustion-chamber wall (d_w) varies from a few tenths of a millimeter to several millimeters. For example, it may range between 0.5-1 mm over a cooling channel. The typical thickness of a thermally insulating outer layer would be less than 1 mm. It is sufficient to have depressions with a depth (d_w) in the area of a few tenths of a millimeter, for example, a depth of 0.1-0.2 millimeters in order to achieve flow destabilization of the outer layer.

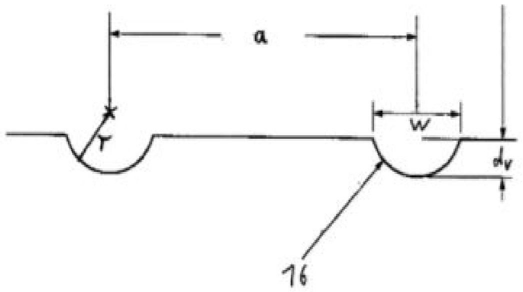

Figure-4. Dimensions of the slanted grooves. [4]

Figure-4 is a detailed showing of the dimensions of the slanted grooves, which have a depth (d_w), width (w), radius (r) and gap (a) between grooves. The depth of the diagonal grooves (d_w) is also in the area of a few tenths of a millimeter, for example a range of 0.1-0.2 mm. Because of the notching effect, the radius (r) of the grooves should be a large as possible, in the present instance, for example, about 1.5-2 times the depth (d_w) of the grooves. A groove-width (w), which in the case of Figure-4 is about 2-3 times the depth (d_w) of the grooves, produces grooves that largely take the form of circular segments, except for effects on groove form that are dependent on the production process.

The distance between the grooves can be adjusted according to local requirements for the strength of heat transfer to the combustion-chamber wall. The local density of the number of depressions can be adjusted using the gaps between them. In the embodiment of Figure-4, the distance is about 1 mm, which is approximately ten times the groove depth (d_w), so that here, 10 grooves per centimeter of length are intended. However, this density can be varied and the values can range between 0 grooves per centimeter and 50 grooves per centimeter. As mentioned earlier, it can be advantageous to have higher value of localized groove density in an area near the fuel injection head or in an area downstream from the combustion chamber neck, as compared to the inner walls of the combustion chamber.

4. CONCLUSIONS

- The incorporation of grooves along the combustion wall improves the overall thermal and mechanical efficiency.

- Enhanced flow and flame propagation could be observed on modification ion of the combustion chamber. As a result, the combustion chamber region will be less susceptible to volatility.

- Grooves and depressions along the chamber allow the gases to expand and compress with ease, thereby, improving the fuel efficiency, heat transfer rate, power and torque characteristics considerably. Higher values of maximum power and torque could be achieved. In addition, the idle speed will lead to significant reductions.

REFERENCES

[1] H. Immich. 1997. Cryogenic Liquid Rocket Engine Technology Developments within the German National Technology Programme. Joint Propulsion Conference & Exhibit, July 6-9, Seattle, Wash.

[2] Abrasive Blasting Operations, Engineering Control and Work Practices Manual. National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, Cincinnati, Ohio.

[3] Peter Bichler, Hans Immich, Joachim Kretschmer. Gunther Schmidt, US 20020092291 A1.

[4] Peter Bichler, Hans Immich, Joachim Kretschmer. Gunther Schmidt, US 6,637,188 B2.

[5] Monograph, Liquid Rocket Engine Fluid-Cooled Combustion Chambers (National Aeronautics and Space Administration).

[6] S.R. Shinen, S. Shri Nidhi. 2018. Review on film cooling of liquid rocket engines. Propulsion and Power Research. 7(1): 1-18.

[7] Robert Levy. Diana Brehob. US 2013 0036999A1.

[8] Thomas J. Drozda. Tool and Manufacturing Engineers Handbook: Machining.

[9] Somender Singh. US 6237579.