Рис 2. Гистограмма порошка после МА смеси «Hf + C» в течение 30 мин в атмосфере: а – ацетилен; б – пропан+бутан+изобутан; в – пропан; г – воздух

Механическая активация смеси порошков гафния и сажи в атмосферах ацетилена, смеси газов (пропан+бутан+изобутан), пропана и воздуха способствует механохимическому синтезу HfC. Максимальное количество карбида гафния при наименьшем намоле размоленных тел наблюдается при механоактивации смеси «Hf + C» в атмосфере пропана и составляет 91,6 % HfC и 8,4 % Fe. Порошок карбида гафния, полученный при МА смеси «Hf + C» с использованием пропана в качестве атмосферы при механоактивации, является высокодисперсным продуктом с приемлемым химическим составом для применения в традиционной и порошковой металлургии, а также для производства огнеупорных и абразивных материалов.

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Komlev G.V., Mitrofanova A.S.

Thrust measurement of liquid propulsion thruster

*Reshetnev Siberian State University of Science and Technology
(Russia, Krasnoyarsk)*

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Аннотация

Одной из важнейших характеристик любого реактивного двигателя, в том числе и жидкостного ракетного двигателя малой тяги является его удельная тяга. Измерение

этой характеристики – сложный и ответственный процесс. В этой статье рассматриваются методы измерения удельной тяги, а также применяемые типы датчиков.

Ключевые слова: жидкостный ракетный двигатель, удельная тяга, активный метод измерения, реактивный метод измерения.

Abstract

One of the most important characteristics of any jet engine, including a liquid propellant small thrust engine, is its specific thrust. Measuring this characteristic is a complex and responsible process. This article discusses methods for measuring specific thrust, as well as the types of sensors used.

Keywords: liquid rocket engine, specific thrust, active measurement method, reactive measurement method.

The main parameters of a liquid propulsion thruster, to be measured and recorded, include:

- thrust created by the engine;
- fuel component costs;
- gas pressure in the combustion chamber, pressure chamber, components in the lines at the engine inlet, in tanks, etc.;
- temperatures of fuel components, structure walls, etc.;
- engine operating time.

One of the most important characteristics of an engine is its specific thrust — a characteristic of a jet engine equal to the ratio of the thrust it creates to the mass fuel consumption. It is measured in meters per second and means, in a given dimension, how many seconds a given engine will be able to create a thrust of 1 N, while spending 1 kg of fuel. With a different interpretation, specific thrust is equal to the ratio of thrust to weighted fuel consumption; in this case, it is measured in seconds - this value can be considered as the time during which the engine can develop a thrust of 1 kgf using a mass of fuel of 1 kg. To transfer the weight specific gravity to mass it must be multiplied by the acceleration of gravity.

A complete list and technical characteristics of the measured and recorded parameters during the fire tests of liquid thruster rocket engines are given in table 1.

When testing liquid thruster rocket engines, measurements of low thrust and second fuel consumption rates and rapidly changing parameters in pulsed operation are typical. Means of measuring these parameters should provide reliable information about the operation of the engine in both continuous and pulsed modes [1].

When measuring slowly changing or stationary parameters, the accuracy of the measurement does not depend on the inertia of the measuring instruments, which greatly simplifies the task. The possibility of studying transient processes is provided by measuring devices with very high natural frequencies, for which in some cases it is necessary to create non-standard measuring instruments. Often, due to the lack of measuring instruments for the low level of parameters produced by the industry, original measuring systems for stationary processes are also developed in the practice of researching liquid thrusters of small thrust [2].

In this section, we consider only those methods and means of measurement that are inherent in liquid propulsion thrusters and, as a rule, are not standard. As noted, their peculiarity is caused, first of all, by the need to evaluate parameters in a pulsed mode of operation, in which the quality of transients significantly affects the characteristics of liquid propellant small thrust engines [3].

Table 1.

Measured and recorded parameters during fire tests of liquid rocket engines

№ p/p	Name of parameter, its dimension	Measuring range	Measurement error	Registration frequency, Hz
1	Engine thrust, N	0,1 – 1600	$\pm 1 \%$	10 – 200
2	Pressure in the combustion chamber, MPa	0,1 – 2,5	$\pm 3 \%$	≥ 1000
3	The pressure of the fuel components at the engine inlet, MPa	0,1 – 3,0	$\pm 0,4 \%$	1 – 10
			$\pm 2 \%$	1000
4	Boost pressure of tanks, level gauges of fuel components, MPa	0,5 – 3,0	$\pm 0,4 \%$	1 – 10
5	Temperature of fuel components at the engine inlet, °C	-50...+50	$\pm 2 \%$	1 – 10
6	The average mass consumption of fuel components, g/s	0,1 – 400	$\pm 2,5 \%$	1 – 500
7	Construction temperature, °C	-50...+1500	$\pm 2 \%$	1 – 10
8	Current through electrovalves, A	0 – 0,5	$\pm 2 \%$	1000
9	Supply voltage of electrovalves, V	0 – 36	$\pm 1 \%$	1000
10	Environmental pressure, mm Hg. Art.	$10^{-2} - 1$	$\pm 50 \%$	1 – 10
		1 – 800	$\pm 5 \%$	-
11	Ambient temperature, °C	-50...+50	$\pm 2 \%$	1 – 10
12	Time, s	0,01 – 1	$\pm 1 \%$	1000
		$\geq (1 - 150)$	$\pm 1 \%$	1 – 10

The thrust generated by the liquid propellant rocket engine is measured either by measuring the reaction force exerted by the engine mounts located on the testing machine, preventing it from moving when working in the direction of the thrust, or by measuring the force impulse generated by the gaseous combustion products flowing out of the nozzle per unit time. These two methods, which are the basis for measuring thrust of liquid propellant rocket engines, are named reactive and active, respectively, and are embodied in devices that are diverse in design [4]. Let's consider some of them.

Among the load-measuring devices operating on the reactive principle, the device is widely used in the form of an elastic beam cantilever mounted on a massive support, onto which the LREMT is usually mounted in an upright position, with the nozzle facing down (Figure 1).

Figure 1 – Diagram of thrust measurement of liquid propellant rocket engine reactive method.

1 – strain transducer, 2 – elastic beam, 3 – hydraulic damper, 4 – rocket engine, 5 – pressure measurement sensor in the combustion chamber.

During operation of the liquid propellant rocket engine, the beam bends and the value of the current engine thrust can be determined by the value of elastic deformation. The stresses arising in the beam are recorded, for example, by means of two strain gauges glued to increase the output electrical signal on the opposite upper and lower sides of the beam. To quickly dampen the vibrations of the elastic system that appear at the beginning and end of

the operation of the liquid propellant rocket engine, as well as during the transition from one mode to another, a hydraulic damper is used.

This traction device provides high accuracy (up to $\pm 1.0\%$) of traction measurement in continuous operation of a rocket engine. However, with a short pulse duration, the measurement accuracy is significantly reduced. This is due to the fact that in a reactive traction measuring device the engine is mounted directly on a sensitive element - a beam, which leads to an increase in the total mass of the element and, ultimately, does not allow to obtain the high natural frequency of oscillations of the measuring system necessary for registering rapidly changing traction. The natural frequency of oscillations of the system in question can be determined by the formula:

$$f_{\text{собств}} = \frac{1}{2\pi} \sqrt{\frac{P}{(m_{\text{ДВ}} + \varepsilon m_{\text{б}})\Delta}},$$

where P – is the engine thrust; $m_{\text{ДВ}}$ and $\varepsilon m_{\text{б}}$ – respectively, the mass of the engine and the elastic beam participating in the oscillatory process; ε – coefficient depending on the relative position of the liquid propellant rocket engine and the beam; Δ – is the displacement of the center of mass of the liquid propellant rocket engine under the action of engine P .

The analysis shows that the natural vibration frequencies of the mechanical part of the reactive traction measuring device do not exceed 200 Hz. Therefore, this system is suitable only for measuring thrust in stationary (continuous) and quasi-stationary modes of operation of a liquid rocket engine.

The frequency of natural vibrations of the mechanical part of the traction measuring device can be significantly increased (up to several kilohertz) with the active method of measuring traction (Figure 2), when it is measured not the reaction of gases flowing from the nozzle, but the direct force action of a supersonic jet.

With this method, the engine is fixed, and behind the engine nozzle a light gas trap of a closed type is installed, which ensures the rotation of gases strictly by 90 degrees with respect to the axis of the engine and their removal in the radial direction. The trap is rigidly connected to the membrane, which is an elastic force element of the traction device [5].

Figure 2 – Scheme of the active traction device.

1 – a primary converter for measuring pressure in the combustion chamber; 2 – rocket engine; 3 – trap; 4 – ferrite; 5 – inductive or capacitive primary converter; 6 – connector; 7 – nozzle; 8 – membrane

The membrane is calculated for a given force, and its deflection is determined by the capabilities of the primary transducer 5. To increase the natural frequency of oscillations of the mechanical part of the load-measuring device, possibly smaller movements are advisable. To record small movements, serial equipment designed for measuring pressure can be adapted. For example, in the design of one of the active traction measuring devices, an inductive type DD-10 converter with a cut-off membrane was used, while the natural frequency of oscillations of the mechanical part of the traction measuring device was 1450 Hz.

Figure 3 shows a fragment of the waveform for the start-up mode with traction recording ($P_{nom} = 25$ N), measured simultaneously by reactive ($f_{собртв} = 55$ Hz) and active ($f_{собртв} = 1450$ Hz) traction measuring devices [6]. It also shows the pressure changes at the inlet of the liquid propellant rocket engine along the lines of the fuel p_f , oxidizer p_o , in the combustion chamber p_k , current I and voltage U on the windings of the electromagnetic fuel valves, as well as the time stamp τ .

Having analyzed these methods, we can conclude that the reactive thrust measurement method is more suitable for stationary and quasi-stationary operating modes. Due to the small natural frequency of oscillations of the measuring device in pulsed modes of the engine, the measurement accuracy drops significantly. An active measurement method is more suitable for measuring engine thrust in pulsed modes.

Also, the results of thrust measurement by an active traction measuring device more adequately reflect the change in pressure in the combustion chamber. Determination of traction during transient modes by a reactive traction measuring device is difficult due to the influence of inertial and damping forces. Inertial forces are significant due to the significant mass of liquid propellant rocket engines and beams.

Figure 3 - Fragment of an oscillogram with recording of thrust of a liquid rocket engine by active and reactive traction measuring devices

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Насиров И.З., Раимджанов Б.Н.

Плазменный реактор для транспортных средств

*Андижанский машиностроительный институт
(Узбекистан, Андижан)*

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В Андижанском машиностроительном институте разработан способ получения дешевого и качественного топлива из сельскохозяйственных и бытовых отходов. Для чего в качестве сырья можно использовать: иль, нагары, лигнин, навоз, зола, канализационные выбросы, сорняки, отходы деревьев, листья, сельскохозяйственные отходы, бумага, ткань и тому подобные [1].

Готовится топливо следующим образом:

К отходам добавляется вода по объему 1:1 и доводится до кипения.

Смесь охлаждается до температуры окружающей среды.

Смесь разливается в контейнеры объемом 3...5 литров (в зависимости от объема двигателя транспортного средства) и добавляется дрожжи.

На крышке контейнера проделывается 4 отверстия, через два отверстия которых устанавливаются катодные, одно (в середине катодов) отверстие анодные электроды и одно отверстие шланг посредством штуцера.

Реактор состоит из следующих частей: 1- диэлектрический корпус; 2- центральный положительный электрод; 3- отрицательные электроды, расположенные по кругу; 4- крышка; 5- фильтр; 6- угольная среда; 7- водная среда; 8- газовая среда.

Отверстия, шланг и крышка плотно закрываются и загерметизируются. Контейнеры сохраняются 5-10 дней в теплом месте, после чего контейнер устанавливается на транспортное средство. Его шланг соединяется с воздухозаборным шлангом через миксер (используемый на сжатый газ), а электроды с электрическим током с напряжением 220 В, преобразованным посредством инвертора бортового напряжения 12 В [2].