# PECULIARITIES OF PROPERTIES OF THE PULSE PLASMA JET

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On the basis of the detonation of the fuel cycle it is considered the possibility of a flat pulsed plasma jet designed to feed into the optical resonator of the TEA laser to the heat pump. There is a schematic diagram of a device for the production of a flat plasma jet. It is shown that the using of detonation fuel cycle leads to greater population inversion of the upper levels. Because of that the possibility is achieved to perform the TEA laser, combining both the high average and peak power.

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## INTRODUCTION

When cutting by plasma jet, an arc burns between both the electrode and the forming tip of the plasma torch, and the object having been processed that is not included in an electric circuit [1]. This case is known to be called as an indirect arc. The cutting by plasma jet is used mainly for the treatment of non-metallic materials due to that are not needed be electrically conductive.

An arc flow is removed from the plasma torch as a high-speed plasma jet, and it is the jet energy is used for cutting. However, the direct using of a plasma-forming medium leads to its chemical interaction with the material. Having been created the plasma medium in the optical resonator, it enables accurate geometric processing of the material due to the focusing after extraction from it of infrared radiation. The chemical interaction with the material is absent.

From the energy point of view, the using of pulse mode is much better than continuous mode. It is the novel opportunities have been created for the treatment of the materials due to the transformation of the heat pump lasers with combustion products into the pulse mode and the following increase their efficiency at the maintaining or the increasing of the average power.

## 1. FEATURES A PULSED LASER MODE

If the pulse power density exceeds the threshold of ablation, the micro-explosion occurs with the formation of a crater on the surface of the sample and the luminous plasma together with the emitted particles. At this time, a similar process is implemented solid-state lasers with high peak power. They are used for micromachining surfaces, marking products, scribing, thermal cracking, pinholes drilling, laser-induced chemical etching. However, due to the low average power levels it can not be used for cutting designs. Typical powers do not exceed 100 W.

The ablation process of channel formation in steel is investigated in [2] by both the picosecond and nanosecond neodymium laser pulses (Fig. 1). It should be pointed that a large part of the incident radiation energy has been screened (up to 80…90 %) for sufficiently deep ablated channels. This is due to the breakdown of air containing ablated microparticles. It has been shown that even a slight negative pressure to a level of 300…400 mbar avoids the low-threshold and breakdown caused by shielding them. Experiments were carried out in air have shown that in the case of ablation with high pulse repetition frequency (about several kilohertz) in the ablated region it is realized the conditions that is similar to *that takes place at the so-called "vacuum" mode*, i.e. under the conditions shielding products is practically absent at the ablation process.

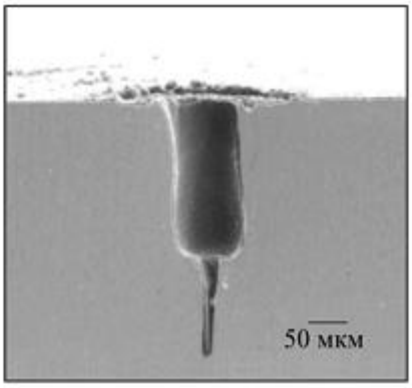


*Fig. 1. The cross section of the channel formed in the steel by the 300 ps pulses at an energy density of 75 J / cm$^2$ [2]*

To convert the TEA laser (here the acronym "TEA" is stands for Transversely Excited Atmospheric) in the pulse mode the Q-factor modulation techniques are known to involve the use of an optical resonator having active rear mirror or the self-injection of laser radiation due to the removal of radiation from cavity [3]. Both the temporal radiation structures and spatial ones are transformed by the disk modulator or an adaptive mirror. The diverted part of the infrared radiation comes back into the cavity. The power of the main laser beam is modulated and than that is acquired the desired phase distribution. It is designed thin layer bimorph adaptive mirrors based on silicon carbide. That is capable to operate at frequencies of tens of kHz.

However, they are limited in resource due to a combined mechanical-thermal load. In the case of disk modulator, the edges of the slit may be deformed and melted, when a necessary part of the IR radiation has been removed. In [4] it was proposed to create a pulsating laser active medium by means of high-frequency exhaust (up to 30 kHz) caused by a resonant pulse detonation engine (PDE) [5]. The high frequency is because of the lack of the intake and exhaust valves, and also of preliminary fuel decomposition into simple components which have explosive character of burning. The PDE is realized most economical fuel cycle close to the constant volume cycle. The supersonic velocity of the combustion products is necessary to maintain the stability of the active medium. That is provided without the using of the Laval nozzle. Carbon black and various other compounds which reduce the efficiency of the laser are absent in such exhaust.

Fig. 2 shows the strokes of PDE. The collision of radial supersonic jets of cold mixture entering into the fuel cavity causes the formation of a shock wave, which goes to the bottom of the cavity, and is reflected by it, and than focuses in the center of the cavity. In this area, the local increases in temperature and pressure take place due to the Hartmann-Sprenger effect, that are sufficient for self-ignition of air-fuel mixture. Thus, the detonation combustion occurs in system. Both the pressure and temperature rise sharply in combustion product mixture due to the fuel burning. The detonation wave is transformed into a reflected shock wave.

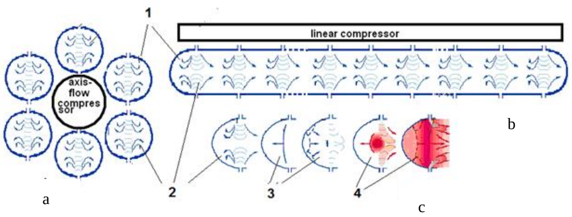


*Fig. 2. Scheme of the integration of thermal cavity with the compressor: a) axis; b) linear; c) beats knock fuel mixture: here 1 is the thermal cavity; 2 is the injection of the fuel mixture; 3 is the formation of a shock wave; 4 is the combustion and emissions*

The wave flows with high speed into the nozzle device. Along the way, the wave drags for combustion products. This effect makes it possible to create a rear in cavity that is needed condition for subsequent thermal cycles. The pulsation frequency is determined by the geometrical parameters of the thermal cavity. The cavity is usually made in the shape form of a hemisphere. In turn, the supercharging of PDE is carried out by a gas turbine engine (GTE) thrust minimized. It should be pointed that the compressor of an ordinary GTE causes a circular jet in the cross section. A part of the air is taken to heat the cavity. This geometry is useful if the cavity are considered as a source of thrust for the aircraft. The heat cavities are arranged circumferentially around the turbine engine (see Fig. 2,a). That is to minimize the drag of the aircraft.

However, to use the exhaust as an active medium of the laser source and to produce high average power, it should be take place a flat gas jet directed to the elongated optical cavity. That jet can be provided by a thermal cavity having a semicylindrical shape (see Fig. 2,b). It should be underlined, that the concept of the focus must be replaced by the definition of "a line focus" [7, 8]. The similar shape of heat cavity was proposed in [6]. Accordingly, in their turn, all other mechanisms must be made in a linear geometry. There are a compressor, a combustor, a nozzle, a chemical decomposition reactor fuel, and the fuel inlet channels of air mixture.

## 2. FROM A VACUUM PUMP TO THE BLOWER AND COMPRESSOR

On the base of the linear compressor a twin-rotor vacuum pump can be made which is like to the Roots pump having external compression. The working chambers of pump are created by housing and two profile synchronously counter-rotating rotors with a fixed clearance. The rotors, which have shaped in the form of eights (Fig. 3,a), are most widely used in the vacuum and compressor technology. On the other hand, the trilobal rotors and four lobe ones (Fig. 3,b) are used much less frequently. Contactless rotary pumps have high frequency rotating, high pumping parameters and low wear of parts. This pumps are widely used to provide pumping corrosive, explosive and expensive gases, steam and gas condensing mixtures, and fluids containing solids having a size no more than minimal clearance in the rotary mechanism.

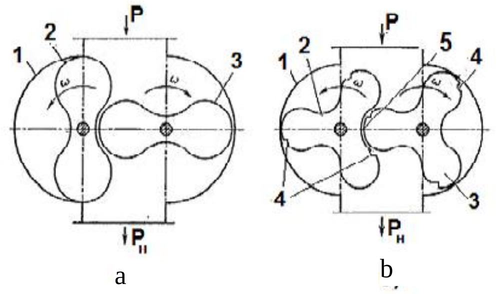


*Fig. 3. Scheme of two-rotor type vacuum Roots pump: Here 1 is the pump housing; 2, 3 is rotor; 4 is an aerodynamic seal threshold; 5 is the labyrinth sealing*

The main disadvantage of contactless pump are known to consider a low pressure ratio due to reverse flow through the gaps. If you change the input-output the pump can be operated in a blower mode. A series connection of several stages allows the increasing of the pressure ratio.

In [9] the design of a single-stage double-rotor supercharger is considered. The supercharger has an original trilobal shape the rotors, which is used for piston engine. It should be pointed that the supercharger rotors have helical shape. The axes of symmetry of the cross sections of each rotor are rotated relative to each other and around the axis of rotation of each rotor. The rotation angles of different rotors lying in the one plane are equal in magnitude and opposite in sign. An air is transferred from suction area in the discharge region under condition that the synchronous rotation of the rotors 2, 3 (see Fig. 3,b) relative to their axes takes place in opposite directions.

The shape of helical trilobal rotor provides increased overlap of the following phases of process carried out by each of the rotors: the suction phase, transfer and injection phases. That improves the uniformity of flow and reduction of sound vibration load. In the experiment for a piston engine at frequency about 1000 the outlet pressure was 4 kPa, and at higher frequency about

3000 rpm/min that was increased up to 5.5 kPa by the reducing the return air current. To supercharge the PDE it needs the pressure about 30 kPa. The obtaining of aerodynamic seals 4 (see Fig. 2,b), which are formed on the rotor 2, allows to decrease reverse overflows and to increase outlet pressure to an acceptable level.

An aerodynamic seal provides the necessary counter-pressure by means of flow of the protrusion blow on the outer surface of the rotating rotor. The connection of additional steps to the compressor and the increasing of rotation frequency up to 12…15 thousand rpm/min allow to achieve the required degree of compression.

## 3. GTE WITH A COMPRESSOR ON THE BASIS OF TWO-ROTOR SUPERCHARGER

Fig. 3 shows a diagram of a powerful industrial laser based on the typical aviation GTE having an axial compressor. The engines overage are known to use in that lasers. In such way it is reduced the cost of laser. The combustion products formed in the chamber 4 at a temperature of 1500°C. In turn, after the exit of nozzle 7 the products fall into the optical cavity 9. Having been rapid cooled the products, there are free bottom quantum levels and the settling of upper quantum levels is maintained. The transition of electrons between them induces the infrared (IR) radiation having the power of several kW. It is a useful fuel mixture of benzene $C_6H_6$ and nitrous oxide $NO_2$. This allows to obtain the composition of active medium close to the optimum. It should be pointed that the nitrous oxide $NO_2$ are known to be useful for convenient storage in bottles due to that at 500 kPa it becomes liquid. Also, benzene and its homologues are known to form mixtures exploding easily with air and nitrous oxide.

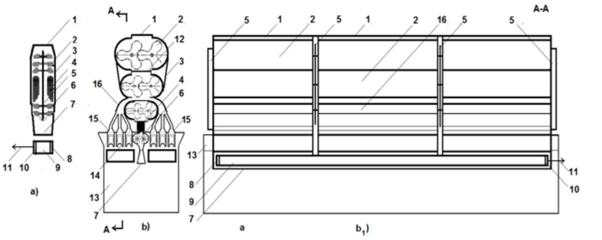

*Fig. 4. Schematic diagram of the infrared laser with an open gas-dynamic cycle: a) continuous wave laser; b) and b1) a pulse-periodic radiation laser. Here 1 is an air inlet, 2 is a compressor, 3 is the crankcase, 4 is the combustion chamber, 5 is the transmission, 6 is a gas turbine, 7 is a nozzle, 8 is a blind mirror, 9 is an optical cavity, 10 is a half mirror, 11 is IR-beam, 12 is stator vanes, 13 is ejector, 14 is a thermal cavity, 15 is the fuel decomposition reactor, 16 is the duct*

Figs .3,b and 3,b 1) – show schematic diagrams of pulse laser based on PDE with a flat exhaust jet. An ambient air enters through the inlet into the compressor 1, than after passing through the second stage that is compressed to 30…40 kPa, and, in turn, that is divided into two parts. One of them gets into the third stage of the compressor and provides further work of GTE. The second part enters the duct 16. In the reactor 15 an air is mixed with fuel which is decomposed into simpler components having explosive nature of combustion. As a result of oscillatory processes (see Fig. 2,c) the fuel mixture is compressed in a resonant mode up to about 120…150 units. Than, the mixture is burned in the thermal cavity 14. The ejector 13 together with the nozzle 7 enables to provide the efficient pumping of an active medium in the atmosphere.

Fig. 6 presents a comparative graph of temperature and pressure changes along the axis of combustion chamber for a typical GTE, which is usually used for both the TEA laser and the thermal cavity of PDE. The curve 1 is constant in time, and the curve 2 indicates both the maximum and minimum pressures occurred during the last stroke which is shown in Fig. 2,c. The combustion temperature in the thermal cavity 14 (Fig. 4) is substantially higher than that in a typical combustion chamber of GTE 4. Because of that a higher settling of upper quantum levels takes place.

Also, the temperature on the edge of cavity has a sufficient low value and that is about room one. That is due to the larger expansion of a working gas. In that way a small settling of bottom quantum levels is reached. It should be noted the two features. At the first, the increasing of cooling rate causes the decreasing of probability of relaxation of upper levels. At the second, the higher pressure in the cavity provides a large pumping rate of ionized gas through the optical cavity, because of that an average power of the laser is increased. Thus, these considerations suggest increasing the efficiency of laser.

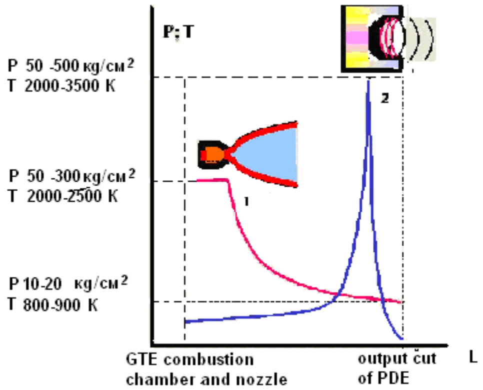


*Fig. 5. Pressure and temperature in the combustion chamber of a typical GTE (1) and in the thermal cavity of PDE (2) [10]*

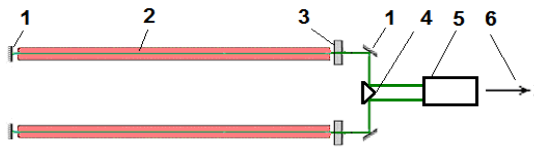

*Fig. 6. Schematic diagram of supersonic pulsed $CO_2$ laser with a heat pump: Here 1 is a dull mirror; 2 is an optical cavity; 3 is a semitransparent mirror; 4 is a rotating prism; 5 is focusing system; 6 is IR beam*

Anderson [11] pointed the possibility to achieve the stored energy about 120 kJ/kg in an active medium of TEA laser with the temperature about 3000 K. Under this conditions the problems of thermal resistance of laser parts are arisen. For PDE the temperature of the cycle "stroke" is ordinary (Fig. 5). In this case, the combustion products do not reach the chamber wall due to focusing at the time while the temperature has a maximum value. In TEA lasers the stored energy are known to be about 120 kJ/kg. It becomes possible to significantly reduce the optical cavity length. Also, the placement of laser system with higher average and peak power may be provided on standard transport base. Fig. 6 shows the hypothetical scheme of laser based on the PDE in transportable version.

An average laser power is determined by the capacity of the compressor, the number of thermal cavities, the cooling efficiency of focusing system. That power can reach values of 700…1000 kW.

## CONCLUSIONS

Thus, an application of the detonation fuel cycle for the pulsed pumping TEA laser allows to significantly increase its average power. That provides a possibility to perform cutting metal samples having a large thickness in the condition of both the large value of reflectance coefficient and the high thermal conductivity. The replacing of gas-laser cutting process [12] by the ablation cutting process will significantly simplify the technology and it improves the economic efficiency.

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## ОСОБЕННОСТИ СВОЙСТВ ИМПУЛЬСНОЙ ПЛАЗМЕННОЙ СТРУИ

***Ю.С. Подзирей, П.В. Порицкий***

На основе детонационного топливного цикла рассмотрена возможность получения плоской пульсирующей плазменной струи, предназначенной для подачи в оптический резонатор газодинамического лазера (ГДЛ) с тепловой накачкой. Представлена принципиальная схема устройства для получения плоской плазменной струи. Показано, что использование детонационного топливного цикла приводит к большей инверсионной заселённости верхних уровней, что позволяет выполнить ГДЛ, совмещающий высокую среднюю и пиковую мощности.

## ОСОБЛИВОСТІ ВЛАСТИВОСТЕЙ ІМПУЛЬСНОГО ПЛАЗМОВОГО СТРУМЕНЯ

***Ю.С. Подзірей, П.В. Порицький***

На основі детонаційного паливного циклу розглянута можливість одержання плаского пульсуючого плазмового струменя, призначеного для постачання до оптичного резонатору газодинамічного лазера (ГДЛ) з тепловою накачкою. Представлена принципова схема пристрою для отримання плаского плазмового струменя. Показано, що використання детонаційного паливного циклу призводить до більшої інверсної заселеності верхніх рівнів, що дозволяє виконати ГДЛ, який містить високу середню та пікову потужності.