光学 精密工程
Optics and Precision Engineering

Vol. 20　No. 12
Dec. 2012

文章编号　1004-924X(2012)12-2571-28

用于清除水面污染物的移动式气动 CO_2 激光器

APOLLONOV V V
(俄罗斯科学院 普罗霍罗夫普通物理研究所,莫斯科 119991)

摘要:本文介绍的工程项目在于研发一种激光技术来清除大面积海域和其他水面存在的油膜污染物。针对海面严重污染问题,研究了基于喷气发动机的可移动气动 CO_2 激光器(100～250 kW)的设计方案及其在清除水面污染时的工程实现。提出的技术方案意在有效弥补传统的海面油膜处理方法只可处理块状油层而无法消除 100 μm 厚油膜的弊病。文中介绍了可移动气动 CO_2 激光器的设计机理,研究了可执行该项工作的不同类型的激光器,证明了选用可移动气动 CO_2 激光器执行该项工作的合理性。考虑了激光器系统的供气方案,选择了高质量的喷气发动机作气动 CO_2 激光器的动力设备并设置了该设备工作时需要的容量。最后,描述了该激光系统气动液压设备的设计方案,给出了相关设备、油箱、和操作控制单元的结构。目前,作者已经完成了用于处理水面油膜的气动 CO_2 激光器的概念设计,并制备了相应的激光系统。另外,研制了气动 CO_2 激光器系统的工作平台,通过用激光束扫描石油膜覆盖的水面,实验验证了利用该系统收集油膜和令油膜有效燃烧的可行性。

关　键　词:气动 CO_2 激光器;喷气发动机;水面污染;环境保护
中图分类号:TN248.2;X55　　**文献标识码**:A　　**doi**:10.3788/OPE.20122012.2571

Jet engine based mobile gas dynamic CO_2 laser for water surface cleaning

APOLLONOV V V

(*Prokhorov General Physics Institute of RAS*, *Moscow* 119991, *Russia*)
* *Corresponding author*, *E-mail*: *vapollo@kapella. gpi. rn*

Abstract: The purpose of the project presented in the paper is to develop a laser technology to clean large areas of seas and other water surfaces from oil film contamination. It mainly aims development of technological scheme and engineering design of jet engine based mobile Gas Dynamic Lasers (GDLs) (100 － 250 kW) intended to solve this important problem of environment protection. This method and laser system proposed are expected to complement other traditional methods, which usually more successfully treat bulk layer oil pollution but do not match to eliminate up to 100 μm oil films. In this paper, the basic design concept of a mobile gas dynamic CO_2 laser is introduced, and the possibility of using various types of lasers for solution of required tasks is considered and the selection of GDL is justified. Then, the possible schemes of organization of air supply in the laser installation are considered, and the jet engines are selected as the high quality power unit of GDL installation. The necessa-

收稿日期:2012-11-05;**修订日期**:2012-11-18.
基金项目:科技部国际合作资助项目(No. 2011DFA50590)

ry volume of the selected jet engine adaptation/modification experimental works is presented. Finally, the paper describes the design concept of GDL and the pneumohydraulic schematics, and gives structures of the related equipment, fuel tanks and operation control units. Now, the author has completed the conceptual analysis of GDL installation for disposal of petroleum films from a water surface, the basic capability of development of such installation is shown. The basic characteristics of the system are discussed and the schematic and design solutions of basic installation are presented. Furthermore, the GDL platform has been developed and some demonstration operations with scanning beam over water surface covered with petroleum film are carried out. The experiments confirm the effective gathering and burning of oil films on the water surfaces by proposed system.

Key words: gas dynamic CO_2 laser; jet engine; water surface pollution; environment protection

1 Introduction

What is the best to start our paper with? "Deep water Horizon" (BP's operation) case in the Mexican gulf is the best example of man made natural disasters. Today, the notion that "offshore drilling is safe" seems absurd. The Gulf spill harks back to drilling disasters from few decades past — including one off the coast of Santa Barbara, Calif. in 1969 that dumped three million gallons into coastal waters and led to the current moratorium. The "Deep water Horizon" disaster is a classic "low probability, high impact event" — the kind we've seen more than our share of recently, including space shuttle disasters, 9/11, Hurricane Katrina and earth quake in Japan. And if there's a single lesson from those disparate catastrophes, it's that predisaster assumptions tend to be dramatically offbase, and the worst-case scenarios downplayed or ignored. The Gulf spill is no exception. Fire boats battle the fire on the oil rig "Deep water Horizon" after the April 21 terrible explosion.

The post-mortem is only the beginning, so the precise causes of the initial explosion on the drilling platform and the failure of a "blowout preventer" to deploy on the sea floor probably won't be established for weeks or months. But the outlines of serious systemic problems have already emerged, indicating just how illusory the notion of risk-free drilling really was, while pointing to some possible areas for reform. A "blowout" on an oil rig occurs when some combination of pressurized natural gas, oil, mud, and water escapes from a well, shoots up the drill pipe to the surface, expands and ignites. Wells are equipped with structures called blowout preventers that sit on the wellhead and are supposed to shut off that flow and tamp the well. The blowout preventer for "Deep water Horizon" failed. Two switches — one manual and an automatic backup — failed to start it. When such catastrophic mechanical failures happen, they're almost always traced to flaws in the broader system: the workers on the platform, the corporate hierarchies they work for, and the government bureaucracies that oversee what they do. According to the study 600 major equipment failures in offshore drilling structures, 80 percent were due to "human and organizational factors," and 50 percent of those due to flaws in the engineering design of equipment or processes. With near-shore and shallow reserves of fossil fuels largely depleted, drilling has moved further off shore, into deeper waters and deeper underground. The technology for locating oil and gas reserves and for drilling has improved, but the conditions are extreme and the challenges more formidable. This is a pretty frigging complex system. You've got equipment and steel strung out over a long piece of geography starting at surface and terminating at 18,000 feet below the sea floor. So it has many potential weak points. Just as Katrina's storm surge found weaknesses in those piles of dirt — the levees — gas likes to find weakness in anything we connect to that source. It must be questioned, whether energy companies and government agencies have fully adapted to the new realities. The danger has escalated exponentially. We've pushed it to the bloody edge in this very unforgiving environment, and we don't have a lot of experience. Disaster has several possible insights for the oil spill: one was that BP and other corporations sometimes marginalize their health, safety, and environmental departments. BP and other companies tend to measure safety and environmental compliance on a day-to-day, checklist basis, to the point of basing executive bonuses on those metrics. But even if worker accident rates fall to zero, that may reveal nothing about the risk of a major disaster. These things we are talking about are risks that won't show up this year, next year — it may be 10 years down the road before you see one of these big blowouts or refinery accidents.

That assumption — that catastrophic risks were so unlikely they were unworthy of serious attention — appears to have driven a lot of the government decision-making on drilling as well. One, published in 2007, estimated the "most likely size" of an offshore spill at 4.6 K barrels. Current, conservative estimate of the Gulf spill put its total at more than 80 K barrels, increasing at a rate of 5 K per day.

Why we have paid in our paper such a detailed attention to the policy of BP's "Deep water Horizon"? The contamination of large water areas (oceans, seas, lakes, and rivers) with petroleum products as a result of accidents and not so smart industrial activity of similar companies and officials around them is one of major problems of protection of environment. Any other contaminant can not be compared with petroleum on a basis of universal utilization, number of contamination sources and degree of effect on all components of environment. Through penetration of petroleum products into water, there are deep, frequently irreversible changes of its chemical, physical and microbiological and even global (redirection of the ocean streams) properties.

The following methods for disposal of petroleum contamination of water: natural, mechanical, physical-chemical, chemical, biochemicals are widely used nowadays.

Natural method demands to leave the oil alone so that it breaks down by natural means. If there is no possibility of the oil polluting coastal regions or marine industries, the best method is to leave it to disperse by natural means. A combination of wind, sun, current, and wave action will rapidly disperse and evaporate most oils. Light oils will disperse more quickly than heavy oils.

The mechanical methods are such: collecting of petroleum from a surface manually or with different installations. All these methods are effective during limited time (from several hours to several days) only——time period during which the thickness of a petroleum film is great enough. Contain the spill with booms and collect it from the water surface using skimmer equipment. Spilt oil floats on water and initially forms a slick that is a few millimeters thick. There are various types of booms that can be used either to surround and isolate a slick, or to block the passage of a slick to vulnerable areas such as the intake of a desalination plant or fish-farm pens or other sensitive locations. Boom types vary from inflatable neoprene tubes to solid, but buoyant material. Most rise up about a meter above the water line. Some are designed to sit flush on tidal flats while others are applicable to deeper water and have skirts which hang down about a meter below the waterline. Skimmers float across the top of the slick contained within the boom and suck or scoop the oil into storage tanks on nearby vessels or on the shore. However, booms and skimmers are less effective when deployed in high winds and high seas.

Use dispersants to break up the oil and speed its natural biodegradation. Dispersants act by reducing the surface tension that stops oil and water from mixing. Small droplets of oil are then formed, which helps promote rapid dilution of the oil by water movements. The formation of droplets also increases the oil surface area, thus increasing the exposure to natural evaporation and bacterial action. Dispersants are most effective when used within an hour or two of the initial spill. However, they are not appropriate for all oils and all locations. Successful dispersion of oil through the water column can affect marine organisms like deep-water corals and sea grass. It can also cause oil to be temporarily accumulated by sub-tidal seafood. Decisions on whether or not to use dispersants to combat an oil spill must be made in each individual case. The decision will take into account the time since the spill, the weather conditions, the particular environment involved, and the type of oil that has been spilt and many other parameters involved into that hard consideration.

Introduce biological agents to the spill to hasten biodegradation. Most of the components of oil washed up along a shoreline can be broken down by bacteria and other microorganisms into harmless substances such as fatty acids and carbon dioxide. This action is called biodegradation. The natural process can be speeded up by the addition of fertilizing nutrients like nitrogen and phosphorous, which stimulate growth of the microorganisms concerned. However the effectiveness of this technique depends on factors such as whether the ground treated has sand or pebbles and whether the fertilizer is water soluble or applied in pellet or liquid form.

Besides of that the biological activity of microorganisms strongly depends on the temperature of water. As for physical-chemical methods it is necessary to mention, first of all, application of various adsorbing materials (polyurethane foam, coal dust, sawdust etc.), however all these methods are labor-consuming and low efficient. Besides they require secondary reprocessing of adsorbents.

Chemical method is the petroleum removal with the help of chemical substances. The basic disadvantages of this method are high price, and the fact that detergents frequently are more toxic for water microorganisms than petroleum.

The laser method of cleaning of water surface from a thin petroleum film is one of physical-chemical methods. Some time later after penetration into water, the petroleum spreads on a surface of a water and forms very thin film (thickness several microns). This film cannot be forced to burn, since because of a good thermal contact to a surface of water the film cannot be heated to temperature ensuring steady combustion.

The principle idea of a laser method consists in following. The laser beam passes through a petroleum film and then is absorbed in thin layer of water. The water heats very fast up to the boiling temperature, and the forming vapor destroys a film, bursting it in small-sized fragments, which mixing up with the hot vapor, are decomposed quickly with formation of simple untoxic substances.

The main advantages of a laser method consist of the followings.

(a) This method is "fast-response" one, since does not require any special preparation; in emergency situations the time from the moment of obtaining of the alarm signal to the beginning of the laser installation operation is determined only by time necessary for arrival of the ship or the helicopter with the installation on board in given area.

(b) The method is contactless, i. e. does not require realization of preparatory or other activities in the oil spillage.

For realization of the proposed technology, it is possible to utilize different types of lasers, as continuous (power up to 250 kW), and high repetition rate pulse-periodical (average power of the same level with duration of pulses 100 ns and repetition rate up to 100 kHz).

Theoretical estimations and the experiments have shown, that as a result of a laser beam action on a surface of a water and land, covered with film of hydrocarbon contamination, following effects can be observed:

Evaporation and burning, and in a continuous mode the consumption of energy for 1 gram of vaporized liquid on the order of value surpasses energy necessary for heating up to boiling temperature and evaporation of a film, that is explained by a heat consumption for heating of water. In a pulse mode, the consumption of energy is per unit of vaporized mass of a liquid (film) approximately in 5 times less, thus the process of film ignition start more easily.

Knocking out the particles of polluting substance above a surface of water under action of pulse or powerful scanning laser radiation should be considered[1]. The physical mechanism of this effect is explained by sharp evaporation (boiling-up) of a thin layer of water under a layer of polluting substance. This process takes place where as hydrocarbon polluting thin film has an absorption coefficient less, than water. Knocked out particles of petroleum at a height up to 50 cm is possible. For this case, the energy consumption per unit mass of a raised liquid is sufficiently less than energy necessary for evaporation and ignition (mode number one) or for sucking up and saving for future efficient usage (mode number two).

The character of a task to be solved superimposes certain conditions on operating characteristics of the laser device concerning both parameters of laser source, and concerning auxiliary systems.

Technological lasers of 10—15 kW power range, which are widely used in production, will have the output completely insufficient for liquidation of large scale contamination presenting the greatest danger according to the above-stated estimations. Such lasers can be utilized, at the best, for improvement of a process engineering of cleaning under modeling conditions.

Besides, the character of this task dictates impossibility or extreme undesirability of use of the stationary civil engineering service line (electric power network, water pipe, main gas line etc.), in view of the requirement of a high self-sufficiency and mobility. The power unit should not limit mobility and thus provide totally energy needed of all installation, the necessary reserve of expendables and fuel on board a complex. A capability of a fast redeployment from one type of a vehicle on another is also desirable.

In the present technical paper, the basic design concept of the mobile laser installation on basis of gas dynamic CO_2-laser is developed. The activities were executed in accordance with the working plan of OOO “Energomashtechnika”.

In the first paragraph, the possibility of using of various types of lasers for solution of required tasks is considered and the selection of GDL is justified.

The second paragraph is devoted to selection and substantiation of basic performances of the laser installation and principal schematics of GDL.

In the third paragraph, the possible schemes of organization of air supply in the laser installation are considered. The selection of jet engines for high quality power unit of GDL installation has been provided. The necessary volume of the selected jet engine adaptation/modification experimental works is presented.

The fourth paragraph of the paper is devoted to the description of the design concept of GDL, and also laser installation as a whole. The pneumohydraulic schematics are described, the structure of the equipment, fuel tanks and operation control units are determined. The description of jet engine based CO_2 GDL and detailed analysis of the laser installation components is also presented.

2 The substantiation of selection of laser type according to specific parameters, operation autonomy, and mobility

There are few the most effective and scalable modern high power continuous/pulse-periodical operated gas lasers should be considered for realization of clamed in the title of that paper tasks: Electro Discharge Laser (EDL), as Dynamic Laser (GDL), Chemical Laser HF/DF (CL) and Chemical Oxygen-iodine Laser (COIL). We are not going here to detail of high power high repetition rate P-P laser systems operation. Main results of oil films elimination detailed consideration taken in the past can be summarized and reduced to the paper format and presented here as following:

2.1 Analysis of applicability of various types of lasers to the task

The laser with output power up to 250 kW of continuous operation (CW) or high repetition rate pulse-periodical operation (P-P) during few hours (minimum requirement) is required for realization of the mentioned above task. Besides of that, according to the physics of the process of destruction of a petroleum film, explained in introduction, laser radiation should be weakly absorbed by petroleum film and should be absorbed effectively by water. In the Tab. 1, the computational data for depth of radiation penetration for 4 types of mentioned above lasers in petroleum and in water are presented.

Tab. 1 Laser radiation penetration depth for petroleum and water (μm)

Laser type	Depth of penetration	
	Petroleum	Water
GDL, EDL	100—260	10
CL	26—200	0.8—40
COIL	50	2 000

The range of values of depth of penetration for petroleum is the sequence of the fact, that absorption coefficient of various grades of petroleum and water (for the CL case) in relation to wavelength in CL radiation spectral band is considered.

From the Tab. 1, it is obvious that the COIL radiation is rather weakly absorbed by water and is rather strongly absorbed by petroleum. However to heat a petroleum film by thickness ~ 100 microns through the absorption mechanism of COIL radiation practically is impossible because of strong heat transfer from a film into water through the heat conductivity. The conclusion is: the use of COIL to solve this task is impossible.

As the lengths of waves of radiation GDL and EDL are identical, the comparison of these two types of lasers is carried out on the basis of mass——dimension characteristics and other parameters that are listed in Tab. 2. The comparison is carried out for two real installations, which were developed and tested in the past to sufficient degree, precisely - GDL of rated power up to 250 kW, and EDL with 20 kW output power.

Tab. 2 Comparison of the parameters for GDL (250 kW) and EDL (20 kW)

#[1]	The name	GDL	EDL
1	Power laser (max)/kW	Up to 250	20
2	Overall dimensions of the laser installation/m	4 m×2.4 m×2.4 m	2.5 m×3 m×3.5 m+ 2 m×0.8 m×0.8 m
3	"Dry weight" (free of fuel)/t	5	18.6
4	Specific, 1 kW of laser power dry weight/$t \cdot kW^{-1}$	Up to 0.02	0.93
5	Specific, 1 kW of laser power, dry volume/$m^3 \cdot kW^{-3}$	0.1	1.5
6	Specific volume fuel consumption for 1 kW of laser power/ $m^3 \cdot (h^{-1} \cdot kW^{-1})$	0.02	0.01

The analysis of the data, presented in the Tab. 2 shows, that GDL has decisive advantages in comparison with EDL. It is necessary to be mentioned here, that EDL specific fuel consumption is 2 times less, than that of GDL. However, influence of this factor on the total complex weight will demonstrate a negative influence only for large operation time (5 h or more). At the arrangement of a laser complex on the board of helicopter, the operating time will not exceed 1 h, therefore in this case smaller EDL specific fuel consumption will not take decisive value.

Thus, GDL and CL are remaining the only competing systems. The comparative analysis of these two types of lasers with reference to the considered task is stated below.

2.1.1 Specific power of laser generation

GDL specific power, Wsp is about 20－35 J/g (C_2H_4 + toluene); this value for CL is much higher and reaches 150 J/g. From this point of view, CL has big advantage in comparison with GDL. But taking into account few other papemeters one can say it is not the final conclusion for this particular story. Very important parameters for our task to be solved should be considered as well: wavelength, scalability of the system, technical maturity of the technology, safety, life time of hardware and so on. Up to now GDL looks like the best system for the task under consideration——cleaning of water surface from petroleum films.

2.1.2 Wavelength of radiation

GDL radiation wavelength, $\lambda = 10.6$ microns and CL wavelength, $\lambda = 2.7－4.5$ microns. From this point of view, CL has one more potential advantage over GDL, as the diffraction limited angle of divergence of CL beam is 3－4 times less in comparison with GDL (at identical aperture). However this problem requires the further presize consideration.

(a) Radiation extraction from the resonator

In high-power lasers, extraction of laser beam from the resonator, where the pressure is much lower than atmospheric pressure, in external space through a rigid window is practically impossible for the reason of thermal destruction of such a window. For a extraction of such a beam out of installation, the aerodynamic window (AW) usually can be utilized. The supersonic gas stream cross-sectional to the beam direction fulfills the task of transparent boundary. As there are areas of various density gas sheaths limited by curvilinear surfaces in such flow, the beam transmission through this gas inuniformity introduces the distortions of a wave front resulting in increase of an angular divergence of a beam. These distortions do not depend on a wavelength, as the dispersion of an index of refraction of gas is extremely small and therefore these distortions have the same absolute value for GDL and CL. However relative values of these distortions of a wave front set (i.e. reduced to wavelength) are for CL 3－4 times higher than for GDL, therefore from the point of view of an angular divergence of radiation the advantage CL in comparison with GDL can be not so essential.

(b) External optical system

The optical systems GDL and CL for delivery beam energy to remote objects include necessarily external (in relation to the resonator) optical elements and systems, intended for expansion of a beam with the purpose of reduction of its divergence. A principal component of a telescope is the main mirror, which diameter can reach the value up to several meters (depending on required power density on the target). The one piece glass or metal mirror will be too heavy. For this reason the main mirror is usually considered as consisting from large number of small mirrors (facets), assembled in one unit. Every facet has the own adjusting device. The accuracy of relative positioning these facets should be not worse $\lambda/4$, otherwise distortions of a wave front after reflection of a laser beam from this mirror will cause the essential increase of an angular divergence in comparison with it diffraction limit. This is $\lambda/4 \cong 2.5$ microns for GDL, $\lambda/4 \cong 0.75$ microns for CL. Therefore in practice required accuracy is much more difficult to ensure for CL.

This brief discussion shows, that the efficiency of CL external optical system can be much below, than that of GDL and, hence, reduces advantage of shorter wavelength of CL radiation.

Besides that, for small delivery length of the beam energy down to the water surface, the angular divergence has no great importance, since density of power on a water surface appears sufficiently high without application of an additional external optical system.

2.1.3 Length of radiation generation zone

In GDL working section (the resonator region) the transfer of oscillation energy from N_2 to CO_2 has taken place. The characteristic time of this process is relatively large. Besides the relaxation time of oscillatory——exited molecules CO_2 at their collisions with other particles is also large. Therefore for full extraction of N_2 accumulated oscillatory energy, and transformation it in laser radiation, length of a working zone in flow down direction should be 10 — 15 cm. Such large length provides certain freedom of selection of the resonator scheme (one pass or multipass, symmetrical or asymmetrical, etc.). Thus the mirror operating surfaces are large enough, that results in a reduction of its thermal loading and distortion of a surface due to inhomogeneous heating.

In CL, the length of beam generation section is small, less then 2 cm. This circumstance causes difficulties in optimization of the laser resonator and leads to increase of thermal loading of mirrors, which results to significant thermal distortion of mirrors and distortion of a wave front, i. e. to significant increase of an angular divergence of laser radiation.

2.1.4. Direct exhaust of used gas to atmosphere

If GDL or CL are placed on ground or on the board of flying vehicle (plane or helicopter), there is a problem of exhaust of spent gas to atmosphere. In the case of GDL this problem can be solved rather simply by use of the diffuser, as the operating pressure in a zone of the resonator is rather high. For reaching a maximum degree of pressure recovery in the diffuser it should have a very special geometry.

In the CL case the operating pressure in the resonator is much lower in comparison with GDL, therefore the direct exhaust to atmosphere with the help of the diffuser is impossible, it is necessary to utilize additionally gas or water vapor ejector to ensure necessary pressure in output section of the diffuser. Such ejector requires large additional gas flow rate, that results in fundamental complexity of the laser installation design and significantly decrease specific power of generation, i. e. in this case one of main CL advantages is lost in comparison with GDL.

2.1.5 Toxic characteristics

The degree of danger CL from the point of view of toxic characteristics of working components and exhaust gases is much higher in comparison with GDL. In CL, for creation of a working mixture the extremely toxic substances containing fluorine should be utilized. Besides the exhaust CL contains a significant quantity of fluorine hydride HF, which is supertoxicant. In this connection with use CL in a system of laser cleaning of water areas it will be necessary to ensure special safety measures, that will cause the significant complication of the installation design and rise of its price.

In the case of GDL exhaust gas is ecologically clean ($N_2 + CO_2 + H_2O$). However, CO, carbon monoxide which is toxic gas can be used as a fuel for GDL. Hence, system of storage and supply of CO should ensure absence of its leakage. On the other hand, CO is lighter-than-air, therefore it floats in atmosphere and is fast blown away by wind. If as fuel in GDL will be used liquid hydrocarbon fuel (benzole, toluene), the system of its storage and supply does not require special measures to secure the ecological safety.

2.1.6 Absorption of laser radiation by atmosphere

The wavelengths of GDL and CL radiation are within of windows of atmosphere transparency. These windows are usually determined for vertical transmission of beam through atmosphere, and for this case power dissipation on track is ~ 20% for GDL and 25% for CL. For vertical tracks of length 50—150 m, which are of interest with reference to a considered problem, the radiation power dissipation can be neglected.

2.2 Substantiation of selection gas dynamic CO_2-laser

Proceeding from the comparison of various type lasers, explained in the previous paragraphs, it is concluded that the most suitable laser for development of the installation for disposal of petroleum films is GDL:

2.2.1 Simplicity of design

From design point of view GDL components are the most simple in comparison with the considered lasers. The combustion chamber operates on usual components, for example, kerosene + air. The design of such chambers is practically very much mature, there is a wide experience of their operation in various technical devices. The nozzle unit of GDL is made from heat resisting steel and can work long time without forced cooling. Wide zone of the media population inversion behind the nozzle unit (10—15 cm) stipulates simplicity of selection of the scheme of the resonator for obtaining laser generation with maximum efficiency. Thus the characteristic size of a mirror of the resonator is approximately equal to length of a zone of generation, i.e. 10—15 cm, therefore manufacturing of these mirrors does not call serious technological difficulties.

The capability of GDL activity at high pressure of gas in the resonator in front of the nozzle unit (up to 3 MPa and more) provides with a straight line an exhaust of spent gas in atmosphere with the help of the supersonic diffuser of a special design. Such capability all remaining considered lasers are deprived. The aft ejector is necessary for maintenance of a direct exhaust of these lasers which requires additional gas flow rate, that complicates the installation and reduces specific energy of radiation.

It is necessary to note that GDL output power rather weak varies at change over a wide range of parameters of gas (pressure, temperature, chemistry) in the combustion chamber, i.e. GDL is not critical to accuracy of a task and maintenance of an operational mode. One more virtue GDL is the small time (some seconds), necessary for start.

Thus, GDL is the rather simple, reliable and flexible tool ensuring high output power of laser radiation.

2.2.2 Mobility

From all considered types of lasers GDL for today has, apparently, least "weight" and "volume" of 1 kW of laser power. It allows rather simple to place GDL on any vehicle, whether it will be airplane or helicopter, ship or railway platform, etc. With the help of such GDL mobility, many tasks are sloved, including connected with disposal of petroleum films.

2.2.3 Selection of propellant components

One of specific singularities of working process of the CO_2-laser is, that the working mixture of gases should contain in a receiver rather small quantity of water vapor (no more than 5－6 volume %). On the other hand, the operation temperature of gas in a receiver should be enough high (1 300－1 600 K). It superimposes limitations on selection of propellant components (fuel and oxidizer). From the point of view of maximum specific energy of radiation (J/kg) optimum components are gaseous at standard conditions with damp (CO) and liquid nitrous oxide (N_2O), thus additional nitrogen (or air), necessary for working process, moves in a receiver from a separate source, and the water vapor in quantity 1.5%－2% is formed by burning small quantity of hydrogen or alcohol in air.

2.2.4 Wavelength of radiation

The analysis of the data presented in Tab. 1 show, that for the solution of a problem of disposal of petroleum films, the optimal wavelength of radiation is that of the CO_2-laser, as this radiation is weakly absorbed by the film and is strongly absorbed by water. From the point of view of a diffraction limited angular divergence of radiation, the CO_2-lasers (EDL and GDL) lose for CL. However with reference to a considered problem, the value of a divergence is not critically important. The estimations show, that at length of a beam from the laser source down to a surface of water ～ 50－100 m and power of radiation up to 250 kW, the precision focussing of laser beam is not required, for the reason of obtaining required density of power in a spot on water surface. It is possible to utilize unfocussed or partially focussed beam. Therefore with reference to a considered problem, the relatively large wavelength of GDL radiation is not the factor of insufficiency.

The explanations above allow to make a unequivocal conclusion for the selection GDL as the laser radiation generator for the mobile installation intended for disposal of a petroleum film on a surface of water. At the estimated power of radiation, GDL is preferable in weight and volume factors in comparison with EDL, HCL and COIL: it does not require the electric power, uses a low toxic fuels, provides the direct exhaust of utilized gas to atmosphere. GDL is very simple in control, it is not critical to changes of working parameters in a sufficiently broad range, and it is convenient in operation. The important circumstance is that we had in our hands a very reliably and operable GDL with output power 100 kW, which is a very effective tool for intensive research program to be carried out. In particular, the design of the aerodynamic window permitting to extract a laser beam from the resonator zone to atmosphere without application of transparent for the working wavelength materials has been effectively developed.

3 Selection and substantiation of basic performances of the laser installation and GDL principal diagram

In the previous chapter, the comparison of various types of high power lasers was carried out from the point of view of their application for the solution of this task, where was shown, that the most appropriate type of the laser is CO_2-GDL. There are different types of GDL, therefore it is necessary to choose the optimal version, and also to develop the general concept of the power installation for optimal supply of working components in GDL.

In the present chapter the analysis of the various GDL schemes, their advantages and disadvantages are given according to the application in the considered installation, the selection of propellant components for GDL is justified from the point of view of their power efficiency, production and toxic characteristics, and ecological safety.

Last part of the chapter is devoted to the substantiation of the GDL characteristics working on the chosen components. For this purpose the calculation results which have been carried out according to[2], are permitting to define specific power of laser radiation at the given initial parameters, such as fuel chemistry, temperature and pressure in front of the nozzle block, expansion ratio of the nozzle etc are used. The calculation results and computer analysis are shown.

For definition of the main dimensional characteristics of the laser and its flow organizing parts, it is necessary to define the basic level of laser radiation power, which, in turn determines the total fuel consumption and remaining geometrical characteristics of the laser.

3.1 Selection of optimal radiation power of GDL

3.1.1 Theoretical substantiation of power level

The basic capability of disposal of petroleum contaminations from water surface by means of irradiation of a petroleum film by a high flux of laser radiation has been proved experimentally and presented in our publications. However, the published data give only the general representation about basic possibility of using of such method. It is obvious, that the combustion is complex multiparameter process and, if we talk about operational use of the mentioned principles in the particular technical device intended for practical use, the optimization of parameters of the installation is necessary. The important value in this case is the efficiency, which it is possible to understand as the area of cleaned water surface divided to mean energy, used on clearing. For optimization of parameters of the installation it is necessary to conduct a cycle of research works on study of evaporation, ignition and combustion processes of petroleum used for the above mentioned method. The experimental research of the given problem even without qualitative understanding of involving processes represents a very difficult task in connection with vast quantity of optimization parameters and requires heavy material costs and time. In this connection the preliminary development of theoretical model representing process of disposal of petroleum film is desirable.

The second phase[3] of the process is presented, the various interaction mechanisms of a laser beam with a petroleum film on a water surface are theoretically considered. The following mechanisms are included:

——laser heating active absorbing, translucent and transparent films;

——an explosive boiling-up and conditions of process efficiency;

——evaporation and vaporization.

The basic conclusions of the technological approach are the following.

1. For reaching temperatures of evaporation of the film the necessary time of radiation action is about 100 nanoseconds at laser power 100 kW and diameter of an irradiated zone is about 30 cm. Temperature of water layer under the surface of film can essentially exceed boiling point. Such situation arises due to superior velocities of laser heating (up to several millions degrees of Celcius per one second) and inertial character of heat transfer process. At such temperatures the water passes in a metastable state with active outgassing. Under a surface of a film there will be microexplosions of air-steam bubbles. As result, there will be a separation of a film from the surface of water, after it's breaking the outflow of drops of petroleum take place to the open air.

2. The scanning velocity at power of the la-

ser of 100 kW and diameter of a spot 30 cm ought to be in range of 10－12 m/s. Thus the velocity of cleaning of a surface 18 000-24 000 m^2/h can be provided.

It is necessary to note, that all calculations are fulfilled for thickness of a petroleum film about 100 microns, which is rather large value and is observed only in the initial moments of formation of oil spillages. For much thinner films, the velocity of cleaning will be increased proportionally.

3.1.2 Experimental researches

For experimental confirmation of basic physical principles included in the basis of the Project, the participants carried out preliminary experimental research of interaction of laser radiation with films of various petroleum types on a surface of water. The research works were conducted within the framework of financing of activities.

During our experimental research works the GDL developed by our team, and prepared for this particular task to be solved had been used. The optical scheme of realization of experiments is presented in Fig. 1.

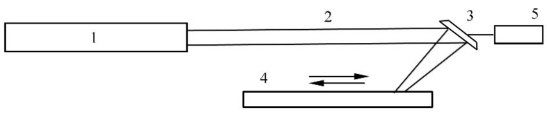

Fig. 1 Optical scheme of oil film interaction with laser beam

The GDL 1 generates radiation 2 with a wavelength 10.6 microns. The radiation is directed on a concave focusing mirror 3 and, being reflected, impacts on a surface of test heterogeneous structure in a cuveta 4. The mirror realizes periodic oscillations with the help of the mechanical device 5, thus the laser beam scans on a surface of a dish. Diameter of laser beam cross section on a surface of a dish changed from 15 cm to 30 cm. The laser radiation power was within the limits of 100 kW.

In Fig. 2－Fig. 4, the results of experimental research works are presented, on which it is possible to make following preliminary conclusions.

1. The carried out experiments testify the possibility of using of the laser installations for cleaning of an aqueous medium from contaminations of petroleum and of it processing products.

2. For definition of optimal parameters of the laser installation and operation modes in practical conditions it is necessary to select experimental conditions of the working regime according to the special program approved by a potential customer.

3. For necessary reserve, the radiation power of GDL of 100 kW for the installation to be developed according to the present consideration is chosen.

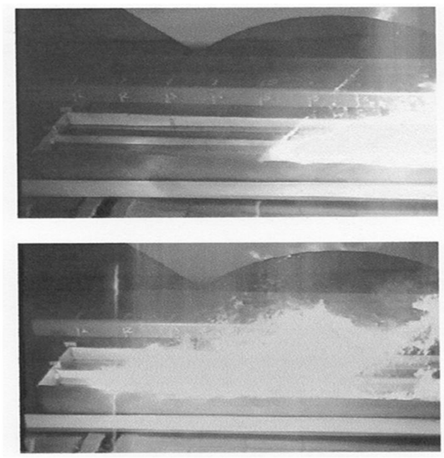

Fig. 2 Intensive combustion of petroleum contamination under laser radiation

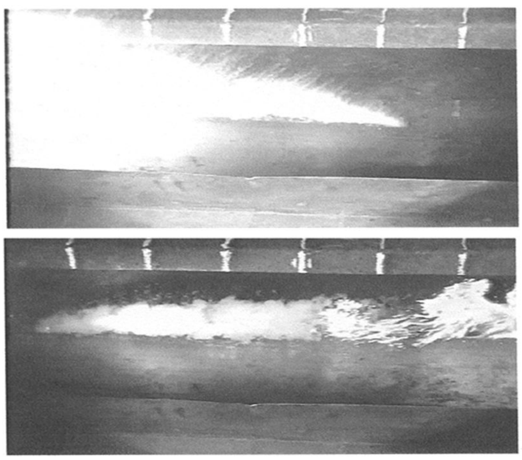

Fig. 3 Combustion of kerosene under laser radiation.

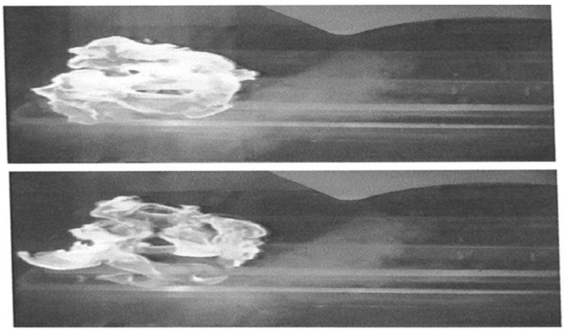

Fig. 4　Combustion of engine oil under laser radiation

3.2　Selection of the GDL scheme and its substantiation

3.2.1　Conventional scheme of GDL

The principle of GDL operation[4] is based on non-equilibrium fast expansion of the heated up working gas in the supersonic nozzle, at which there is a partial freezing population of oscillatory levels of molecules CO_2 and N_2 and formation of population inversion of upper and low laser levels. The heating of gas to an operation temperature 1 300－1 700 K at pressure 2－3 MPa is conducted in the combustion chamber through of combustion of chosen fuel——oxidizer components. The transformation of the accumulated oscillatory energy of gas to laser radiation has taken place in the optical resonator located down the nozzle. After the resonator the working gas passes through the supersonic diffuser and will be exhausted in atmosphere.

The most fast gas expansion take place near the critical zone of the nozzle at the length equal to the value of one order of magnitude of the critical cross-section size. Therefore for fast freezing of oscillatory energy it is necessary to use the nozzles with a small size of critical cross-section (< 1 mm). On the other hand, the pressure of gas after the nozzle (i. e. in the resonator region) should be small enough (< 100 mm Hg) to reduce to a minimum the losses of oscillatory energy due to collision relaxation. It has been solved by use of nozzles with large expansion ratio (area ratio of output to critical cross-sections $A/A^* \geqslant 20$, that corresponds to the value of a Mach number M4).

For effective transformation of the accumulated oscillatory energy to laser radiation the amplification of a small signal during the pass the length of an active zone should be large enough to compensate optical losses (removal of radiation, absorption in mirrors, dissipation in medium) and to ensure a high enough radiation power in the resonator. In GDL of very low powers (tens W) is possible to use the so-called mononozzle, which represents the flat (rectangular) nozzle with critical cross-section as a narrow slot. However for high-power GDL implementation of the mononozzle is practically impossible because of its large length (1 m and more); arising thermal deformations result in essential to nonuniform width of critical cross-section, h^*, down to full blocking of critical cross-section in some zones. Besides the mononozzle does not allow to receive enough large transversal size of an active zone, that causes certain problems at resonator selection. Therefore in high power GDL the so-called nozzle unit representing set of a many relatively short (～100 mm) slot-type nozzles is used. These nozzles were formed by contoured nozzle blades, made from thermal resisting metal. Such design of the nozzle unit allows changing in a wide range width and height of an active zone. Besides the nozzle unit provides a uniform enough density field of gas in an active zone, that allows realising a small angular divergence of GDL radiation.

In view of such advantages of nozzle blocks, this technology now is widely used for GDL, and therefore it is possible now to name such GDL systems as the " GDL of traditional scheme ". The radiation power of such a GDL is in our days up to 250 kW and more for continuous and P-P radiation modes of operation[5-6].

3.2.2　GDL with a set of axisymmetrical nozzles

The nozzle unit of the conventional scheme has the disadvantage that it is complex in manufacturing, and also is subject to influence of thermal deformations. There is an alternative approach to the development of nozzle units, which consists of the following. Instead of two-dimensional nozzles the axisymmetrical nozzles with small diameter of critical cross-section are used. The supersonic part of such nozzle can be made as a conical or contoured. In this case nozzle unit looks like a plate, where the numerous small-sized nozzles located close as possible to each other are made. The manufacturing of such a nozzles is possible, they are not subject of thermal deformations, by the appropriate arrangement of these nozzles on a holding plate (quantity of rows and quantity of nozzles in a row) it is possible to give output cross-section of the nozzle unit with required configuration.

However such nozzle unit has at least two disadvantages caused by presence of "empty" zones between nozzles, since complete filling of output cross-section by round nozzles basically is impossible.

The first disadvantage consists of the empty zones, which are the sources of shock waves in a supersonic flow. That wave results in density inhomogeneous structure of gas in a zone of the resonator and, hence, leads to increase of an angular divergence of laser radiation.

The second disadvantage consists of the effect, which creats in empty zones the viscous vortices flows, which results in reduction of total pressure of a main flow. In turn, the reduction of total pressure has negative consequences on the supersonic diffuser operation, which can be appreciated as reduction a pressure recovery coefficient. In this case for realization of direct exhaust of working gas to atmosphere it is necessary to raise combustion-chamber pressure, which results in the decrease of output power of laser radiation.

For these two reasons GDL with the nozzle unit as a set of axisymmetrical nozzles is not widely used at the noticeable production scale.

3.2.3 GDL with mixing of working gases in a supersonic flow

In the case of traditional GDL the simultaneous heating of all components of a working mixture-N_2, CO_2, H_2O has taken place in the combustion chamber. However initial reserve of laser energy contains, primarily in oscillatory-exited molecules N_2, which part in gas mixture makes ~90%. The role CO_2 and H_2O consists only of transforming accumulated in N_2 oscillatory energy to laser radiation.

The pure nitrogen has extremely large time of an oscillatory relaxation stipulated by collisions of molecules N_2 among themselves. As the result, the oscillatory levels N_2 are easily frozen at fast expansion of the working mixture in the nozzle. However other components of a mixture (CO_2 and H_2O) considerably accelerate a collision relaxation N_2 and by this reduce a reserve of oscillatory energy.

For increase of a reserve of oscillatory energy it is desirable to raise temperature in the combustion chamber. However in the traditional GDL temperature is limited by value about 2 300 K; the dissociation CO_2 begins at higher temperatures, and the efficiency of conversion of the accumulated oscillatory energy in laser radiation decreases. In contrast to CO_2 the molecular dissociation N_2 begins at temperature ~ 4 000 K.

The presented ideas have resulted in the new GDL scheme, which consists in following: the pure nitrogen, heated up in a prechamber, expandes in the supersonic nozzle, and at the exit of the nozzle to it are mixed cold CO_2 and H_2O. Such scheme has three basic advantages for the usual scheme GDL: a) temperature of nitrogen in a prechamber can be essentially increased, b) more effective freezing of oscillatory energy of nitrogen is reached, c) energy loss for CO_2 and H_2O heating is not necessary.

In view of the indicated advantages mixing GDL can basically ensure the increase of specific power of radiation many times in comparison with the GDL conventional scheme. A main problem arising at realization mixing GDL-necessity to ensure fast intermixing hot N_2 with cold CO_2, but the disturbances of a supersonic flow N_2 should be kept at minimum.

Some solutions of this problem are possible. Technically it is much simply to organize mixing of CO_2 and N_2 in wakes. In this case flow CO_2 moves in parallel to flow N_2, in this case two sets of supersonic nozzles-one set for N_2, second for CO_2 are used. A advantage of such scheme of supply is that arising at interaction of wakes disturbances are minimum in comparison with other schemes of intermixing.

The basic disadvantage of this scheme is that the mixing of wakes is rather slowly, therefore for effective work of the laser the working section (from nozzle exit down to the diffuser inlet) should have sufficient length, which results in large relaxation losses and reduction of a pressure recovery coefficient of the diffuser. For these reasons the scheme GDL with intermixing of supersonic wakes, apparently, is not effective.

The theoretical analysis and the experimental data show that the GDL schemes are more effective, in which the injection of cold CO_2 is made near to critical cross-section of the nozzle in its transonic part. In experiments with heating N_2 in electric arc plasma generating device and supply of CO_2 under the scheme, was received record for GDL value of a gain equal 3 % cm^{-1}, that exceeds maximum value of a gain for usual GDL almost to an order of magnitude. However specific power of radiation was insignificant, that is connected to a small scale of the installation.

Despite of basic promising character of mixing GDL, there is a lot of problems connected with their practical realization.

One of the most important problems is obtaining hot nitrogen at temperature 3 000－4 000 K. Application of electric arc plasma generating device for high-power mixing GDL is unreal, since at the consumption of nitrogen 10 kg/s and more required electrical power exceeds 100 MW. It is possible to use for obtaining hot nitrogen special fuels, however all of them are strong toxicants.

As a source of hot nitrogen, the devices can also be considered, in which a combustion of metal in air has taken place. As a result of this strong exothermal reaction hot nitrogen and oxide of metal as particles are formed, which are extracted from the formed flow with the help of a cyclone separator. However, necessity of a very high degree of a nitrogen stream cleaning from particles makes this way problematic.

Other important technical problem is the development of the nozzle (selection of a material, development of a robust design), which would maintain without destruction large heat flows in the region of critical cross-section.

The supersonic diffuser causes one more important problem. For an effective work of the laser translation temperature of working gas in an active zone should be sufficiently low, whereas temperature in a prechamber should be relatively high. For the coordination of these two conditions, it is necessary to use supersonic nozzle with large Mach numbers ($M=5$ and more). However, the higher Mach number is the lower is pressure recovery coefficient for the diffuser. Therefore for a direct exhaust of gas in atmosphere it is necessary to develop special diffusers, thus can appear, that such task basically is impracticable without use of a fodder ejector. However consumption of inducing gas in some times exceeds the consumption of induced gas, and in this case specific laser power designed on summarized gas flow rate, considerably decreases.

From explained above it is possible to make a unequivocal conclusion: taking into account problems connected to development of the high power mixing laser, and also absence of the prototypes of such lasers, for the solution of a task of disposal of petroleum film on water surface it is necessary to choose GDL of conventional scheme.

3.3 Selection of fuel for mobile GDL

In the present part the analysis of possibility of using various fuels for support of operation of the mobile CO_2-GDL, intended for disposal of petroleum film on a surface of water is carried out.

CO_2-GDL provides the laser radiation generation in a continuous/P-P modes of operation with radiation wavelength 10.6 microns. A basic physical principle of operation gas dynamic of the CO_2-laser is the fast expansion in the supersonic nozzle of a mixture of gases (CO_2, N_2, H_2O) preheated up to temperature 1 500－2 000 K. In a supersonic flow with Mach number M= 4－5 temperature of gases down to values 300－350 K, necessary for population inversion of laser levels obtaining of a molecule CO_2. For nozzle operation at direct exhaust in atmosophere after pressure recovery in the diffuser (the static pressure in a zone of generation is equal 5×10^3－1×10^4 Pa) the nozzle inlet pressure (stagnation pressure of a flow), equal 2－3 MPa is necessary. At small transversal and longitudinal sizes of the supersonic nozzle (the height of critical cross-section is equal 0.3－0.5 mm, and length of the nozzle 20－40 mm) characteristic time of the gas flowing through the nozzle appears small and comparable with time of oscillating relaxation of molecules of a mixture of gases, i.e. oscillating-oscillating exchange (V-V process) and oscillating-translation relaxation (V-T process) has taken place in nonequilibrium mode. As a result of non-equilibrium processes in oscillating exited molecules at certain gas mixture ratio and flow parameters in the supersonic nozzles the inversion population of the upper laser level of molecules CO_2(0001) is formed. The molecules CO_2, are light generating molecules (laser radiation is realized on transition 0001－1000), N_2 molecules are donors molecules transmitting oscillating energy to the upper laser level of molecules CO_2(0001), the molecules H_2O are intended for population of the lower laser level of molecules CO_2(1000). The optimal ratio of mixture of gases for an effective work of gas dynamic CO_2-laser should contain CO_2=0.1, N_2=0.89, H_2O = 0.01 (volumetric fraction). It is necessary to note, that the increase of a volumetric vapor fraction of (H_2O) results in decrease of the laser radiation power with other things being equal.

For mobile GDL, laser radiation, ensuring high power in CW/P-P modes, a basic method of thermal excitation is the combustion of such fuel components, which as final products give necessary components of a laser mixture at relatively high temperature. The optimal mixture ratio of gases at high temperature of mixture can be obtained, for example, at burning of carbon oxide (CO) and hydrogen (H_2) in air or other oxidizer (N_2O, N_2O_4) with subsequent use of ballast nitrogen.

The specific requirements to the analyzed mobile installation impose some limitations on use this or that fuel, oxidizer and ballast gas. The main difference of this installation from existing lasers is the requirement of large duration of operation.

For processing of the greatest possible area of the polluted basin, the laser installation should have an operating time appropriate to operation capabilities of a vehicle, on which it is secured. For the helicopter this time makes t～30 min. The carried estimations of interaction of a beam with a water surface covered with thin petroleum film, have shown, that the power losses by heating water can be reduces through fast scanning of a surface by a beam of power W～100 kW. These requirements allow estimating total of fuel and ballasting gas necessary for mobile GDL operation. The specific power (W_{out}) existing homogeneous CO_2-GDL, as a rule, does not exceed 10 kJ/kg. Thus weight of fuel and ballast gas for such GDL operation should be not less than $m = W_t/W_{out} = 18\ 000$ kg. This value essentially will increase at the account of weight of the equipment for storage of working components. Apparently, that such large weight is unacceptable for laser arrangement on a flight vehicle.

At the same time, the main part (80% − 95%) of weight of design components used for creation of a propulsive mass GDL, is the weight of an oxidizer and ballast gas. Thus, use of free air as an oxidizer and a ballast gas is a unique opportunity to guaranty this installation operation. As CO_2-GDL fuel usually carbon monoxide is used with the hydrogen addition. Carbon monoxide allows receiving high values of specific power of radiation in comparison with liquid fuels, such as toluene, benzole, kerosene, but weight this fuel together with a system of storage is rather high. Weight CO is 13% − 15% from total mass of spent components, i. e. in our case of 2 000 − 3 000 kg. Weight of a storage system of such quantity gaseous carbon monoxide is ≈7 000 kg, and summarized weight fuel and system of storage $m_\Sigma = 9\ 000 - 10\ 000$ kg. In case of use cryogenic state carbon monoxide summarized weight m_z can be reduced approximately twofold, but nevertheless it considerably surpasses appropriate weight for liquid hydrocarbon. Weight of liquid hydrocarbon is 45% from total mass of spent components, and the tanks for storage are much lighter than for carbon monoxide, as the hydrocarbon are stored at atmospheric pressure. In our case weight of liquid hydrocarbon is 700 − 900 kg, and summarized weight fuel and system of storage $m_\Sigma = 1\ 000 - 1\ 500$kg.

Taking the above reasons into account, in the present operation as possible fuel are considered benzole, toluene and kerosene, and as an oxidizer and a ballast gas (instead of nitrogen) free air compressed by the compressor.

As it was mentioned above, for normal operation of supersonic nozzles of the laser it is necessary to ensure high total pressure of a stream ($P_0 = 2-3$ MPa). The aviation compressors can ensure a compression ratio up to $P_0/P_a = 20$. Here P_0 stagnation pressure of a working mixture in a GDL channel, P_a atmospheric pressure. In all further calculations the value of stagnation pressure of a flow $P_0 = 2$ MPa and maximum values, appropriate Mach number of the nozzle $M = 4.7$ with the area ratio of an exit of the nozzle to the critical cross-section $F/F^* \approx 25$ was accepted.

At comparison various fuels, basic parameter is the power efficiency, namely specific power of laser radiation W_{out} (power of laser radiation referred to summarized mass flow of laser components), achievable at use of the given fuel. In this connection the analytical-theoretical research of influence of various parameters on value W_{out} was carried out.

Temperature and chemistry of a working mixture formed at combustion various fuels in air, were determined by thermodynamic calculation. The necessary for calculation enthalpy of initial components was taken from[4]. For the reason of uncertainty of efficiency of the compressor (approximately it is 0.75 − 0.83) in a main part of executed calculations temperature of inlet air in the combustion chamber was assumed to equal appropriate temperature at adiabatic compression up to value $P_0/P_a = 20$. This temperature calculated according to the following formula $T = T_a\left(\frac{P_0}{P_a}\right)^{(\gamma-1)/\gamma}$, where T_a-temperature of free air, γ-isentropic exponent. At adopted values $T_a = 298$ K, $\gamma = 1.4$ temperatures of inlet air in the combustion chamber is $T \sim 700$ K. The enthalpy, appropriate to this temperature of air is equal $I = 400$ kJ/kg.

At thermodynamic calculation the thermal losses which depend on a design of the combustion chamber and beforehand are not known were not taken into account. In this connection in the subsequent calculations of flow of a working mixture in the nozzle block inlet temperature (K) was taken equal to 0.95 of temperature obtained in thermodynamic calculation.

The thermodynamic calculations have shown, that the working mixture contains in the investigated temperature range (or oxidizer-to-fuel ratios) only necessary for operation CO_2-GDL components (CO_2, N_2, H_2O) and oxygen (O_2), as the content of remaining components is insignificant. Therefore in the further researches it was supposed, that the working mixture consists only of carbon dioxide, nitrogen, water and oxygen. In the paper the calculations of non-equilibrium flow of a mixture CO_2-N_2-H_2O-O_2 in the supersonic nozzle are carried out as well. The kinetic model describing population change of separate oscillating levels of molecules CO_2 and N_2 at processes of VT- and VV- of exchange was used. All oscillating levels of a molecule CO_2 with characteristic temperatures $\theta < 5\ 000$ K were taken into account. It was supposed that the velocity of exchange of oscillating energy to a Fermi-resonance considerably surpasses a velocity of all remaining VT- and VV- processes. Thereof, the modeling system of levels was introduced, some of which have a large degree of degeneration and correspond to several levels in a full system of levels of a molecule CO_2. As a result of calculations the population inversion and gain coefficient of the nozzle unit outlet was determined. The calculations of specific output power of laser radiation were conducted at following input data.

1. The working mixture of gas dynamic laser is formed at combustion hydrocarbon fuel in air. The stagnation pressure of a flow is equal 2 MPa, total temperature is equal 1 600 K.

2. The nozzle unit of the installation consists of flat contoured nozzles with the height of critical cross-section 0.8 mm and expansion ratio 25.

3. The sizes of exit cross-section of the nozzle unit: length-1600 mm, height-130 mm.

4. The size of a cavity of the resonator along the flow direction-200 mm.

5. The three pass unstable resonator with a multiplication factor $M=1.4$. A reflection coefficient of mirrors $r=0.98$, the losses on dissipation make $\beta=0.03\ m^{-1}$.

The contour of a supersonic part of the nozzle was obtained as follows. The flow of gas with an isentropic exponent equal 1.35 in the contoured nozzle with an angular point was calculated and as a contour of a supersonic parts of the nozzle the form of a streamline $\psi=0.9$ was used.

Tab. 3 Values of specific output power of laser, based on different fuels

Fuel	k_V/m^{-1}	$w_{max}/(kJ \cdot kg^{-1})$	$w_{out}/(kJ \cdot kg^{-1})$
Benzole	0.41	23.6	9.6
Toluene	0.39	23.1	9.2
Kerosene	0.32	20.8	7.4

Thus, value of specific output power of laser radiation, which it is possible to expect at use as fuel benzole and toluene, and as an oxidizer and ballast gas-dry air, is ≈99.5 kJ/kg. are presented in Tab. 3. At use of kerosene this value is approximately 2 kJ/kg less.

By selection of fuel, except for power efficiency, it is necessary to take into account production and toxic characteristics, and cost of components.

The application of benzole is inconvenient at low environment temperature. The freezing temperature is 5.5 ℃. For toluene this value is equal −80 ℃, and for kerosene −38 ℃.

The limit for a room vapor concentration of researched fuel has following values: 5 mg/m^3 for benzole, 50 mg/m^3 for toluene, 300 mg/m^3 for kerosene.

From said it is concluded that the application of benzole is unwise, as it a little surpasses toluene according to power efficiency, but is significantly worse for toxic than toluene and is less convenient in operation.

As to selection between toluene and kerosene, the application of toluene provides specific power increase approximately 25%. However use of kerosene has a number of advantages. At first, kerosene is approximately 3 times cheaper than toluene. Secondly, kerosene is fuel for airplane and engines. Therefore at the arrangement of the laser installation working on kerosene on a flight vehicle, the additional system for fuel storage is not required.

As conclusion for this chapter, it is possible to note the following.

The homogeneous laser working on combustion hydrocarbon fuel products is most reasonable for development of the mobile installation.

The specific requirements to the mobile laser installation, impose the limitations on use this or that fuel, oxidizer and ballast gas. The main limiting factor is the required long duration of continuous operation. The carried out estimations have shown, that summarized weight of fuel, oxidizer and ballast gas necessary for GDL operation, is very hight and is unacceptable for arrangement on a flight vehicle. At the same time, the main part of weight of fuel components used for GDL operation mass, is weight of an oxidizer and a ballast gas. In this connection, use of free air compressed by the aviation compressor, as an oxidizer and a ballast gas is the only way to organized operation of this installation.

The carried out comparative analysis of various fuel has shown, that most reasonable among them are toluene and kerosene. The application of toluene provides specific power of the installation approximately 25% higher than that of kerosene. However, use of kerosene has a number of the advantages. At first, kerosene is approximately 3 times cheaper than toluene. Secondly, kerosene is the fuel for airplane and helicopter. Therefore at arrangement of the kerosene operating installation, on a flight vehicle the additional system for storage fuel is not required.

4 Selection of the power installation for GDL

4.1 Selection of a schematic of the power installation

4.1.1 Special conditions

In the previous chapter devoted to the computational substantiation of the basic power characteristics, the capability of development of the mobile CO_2-GDL with use of kerosene as fuel, and as an oxidizer and a ballast gas-atmospheric air supplied by the compressor is shown.

Besides, some GDL parameters, permitting to determine the required characteristics of the compressor are added.

The calculations have shown, that in case of GDL the condition $P_o/P_n=20$ should be realized Where: P_o—stagnation pressure of a working mix(mixture) in GDL channel; P_n—atmospheric pressure.

In view of channel losses from the compressor to GDL inlet of the chosen compressor should have the pressure ratio not less than 22—23.

Temperature of inlet air in GDL combustion chamber chosen at calculations is 720 K, which corresponds to the temperature range of compressed air for compressors with $P_к > 22 \div 23$.

For an estimation of necessary value of airflow rate through GDL it is rational to set specific energy extraction at known accepted power range of 100 kW. As was shown in the previous chapter, the GDL specific power with combustion of kerosene in air is 7.5 kJ/kg. However this value can be reached at dry air only. At increase of humidity of atmospheric air the specific power begins to decrease and at humidity value

100% (T=25 ℃) it is 5.4 kJ/kg.

To achieve the higher specific power it is possible in principle to include air dryer in an air flow path, however it large overall dimensions and power consumption can result in technical and operational problems and, besides the automatic control of dryer operation is necessary if air humidity and fuel have changed. It will be more conveniently to have certain losses of specific power at humid air, having compensated losses by increased air flow.

Therefore, having accepted average specific power of 6 kJ/kg, instead of 7.5 kJ/kg we shall receive an estimated value of an air flow —16.25 kg/s.

Thus, for an operation of the laser installation in power range of 100 kW it is necessary to have the compressor with an air flow rate ≈ 16 kg / s and $P_к > 22 \div 23$.

In essence task of air compression at flow rate of 16.25 kg /s and pressure in access of 20 atm does not contain unsolved technological problems, since compressor engineering is widely applied in industry. The task consists to find the optimal solution ensuring the reasonable cost of the installation, reliability of its activity and convenience in operation. Let′s consider three possible schematics of power installation.

4.1.2 Development special power installation for the above mentioned parameters of the compressor

In this case the installation will consist (Fig. 5) of the compressor itself, turbine for driving, gasgenerator for rotation the turbine, and also fuel supply system, control and regulation units.

As there is no installation for the mentioned parameters in industry, it is necessary to develop such installation from very beginning, to conduct preproduction activity and to find a producer. For all reason, the price of the produced installation will be high, and development-time consuming.

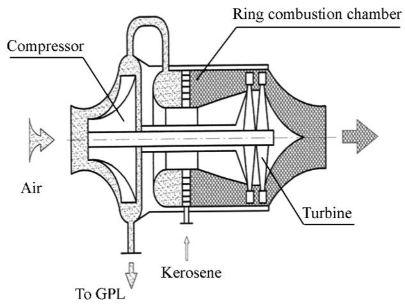

Fig. 5　New developing installation

Besides, short order book for such installations (single production) will lead initially to unprofitable operation for any producer.

4.1.3 The installation of air compressor on aviation engine shaft

In general approach, the task can be decided rather simple. On the shaft of the aviation gas-turbine engine the compressor with the required characteristics is installed instead of the propeller.

The calculations show, that the shaft horsepower about 5.5—8 MW is necessary for compressor driving with the flow rate of 16 kg/s and $P_к$ of 23 kg/cm^2. It is power of the aviation gas-turbine engine of middle power class, a lot of which is in series production. However, as engineering realization the task has a number of serious problems. The nominal speed of the propeller shaft of existing aviation engines is in the range of 5-8 thousand rpm, and all high efficiency centrifugal compressors require operation speed of the order above. For example, industry compressor TB7-117 being far from the best in efficiency already requires 30 000 rpm.

The installation between the gas-turbine engine and compressor of the high-speed gear reducer (multiplicator) because of complexity in operation and large overall dimensions excludes such solution as acceptable.

Technically task is solved by the installation on the shaft of the engine of an axial multistage compressor (Fig. 6). But even the principal diagram general view demonstrates the technical irrationality of such solution, it practically two aero-engines, one of which a production one, and the second requires large design and manufacturing costs connected refurbishment for realization of rigidity of the shaft, organization of turbine side exhaust etc. Besides of that, the overall dimensions and accordingly the weight of the installation are considerably increased.

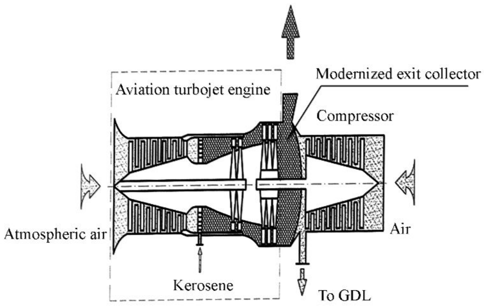

Fig. 6　Addition of air compressor to jet engine

4.1.4　Air bleed from aero-engine compressor final stage

It is visible from the scheme Fig. 7, if it is decided to take an air bleed for GDL after a final stage of the engine compressor, practically there is no necessity redesign the power installation with installing new aggregates. Moreover, the dismantling from the engine of the free running turbine operating for driving the propeller shaft for the reason of propeller nonuse, considerably simplifies a design of the installation as a whole.

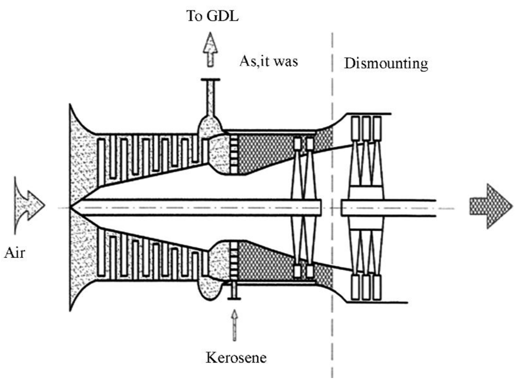

Fig. 7　Air bleed after the last stage

This solution bribes by the simplicity, since the engines not only will be used with minimum modification, but also all control systems are kept, including the use of the control panel which is taken off from a flight vehicle.

Besides, from point of view of the power, dismantling of the free running turbine together with nozzle block allows to lower required power of the turbine of system of the compressor-free running turbine.

The decrease of required power of the system offers the possibility to reduce quantity of required air and kerosene in the combustion chamber of the gas-turbine engine. With constant power rate of the turbine for the drive of the compressor and of the compressor flow rate, probably, it exist the possibility to take off a part of the air and to direct it to the combustion chamber of gas dynamic laser. At the same time, utilizing the characteristics of the combustion products down the main turbine (ρ, m, T), it is possible to organize an ejection of GDL gases down the supersonic diffuser for improvement of the gas dynamic laser overall performance, especially at start.

4.2　Selection of the aviation gas-turbine engine

With the purpose of optimal selection of an aviation-engine for this task it is necessary to formulate the initial requirements.

1. For obtaining air pressure in GDL inlet not less than 20 atm and in view of losses in a flow channel the compressor of the engine $P_к$ should be in the range of 22—25, not less.

2. The GDL inlet air flow rate is 16.25 kg/s.

As for elimination of extreme engine power reduction the air bleeding from the compressor should not exceed 15%—18%, the total air flow rate through the engine should be not less than 100 kg/s.

3. The chosen aviation engine should widely be used by standard aviation operation, that enables to utilize engines which are decommissioned from flight vehicles, having passed prescribed operational life limit, but still are operable for

ground installation. To buy them is much cheaper, than to buy new engines.

4. It is desirable to make a choice of domestic (Russian made) engines that enables in case of realization of the project to connect to activities, both engine developing company and manufacturer.

The table data of some Russian engines characteristics: Π_{κ} and G of airflow rate (kg/s) are given below.

Engine	P_{κ}	$G/(kg \cdot s^{-1})$
НК-12СТ	8.8	56.0
НК-14СТ	9.5	37.1
НК-14Э	9.5	39.0
НК-16СТ	9.68	102.0
НК-17	9.68	102.0
НК-36СТ	23.12	101.4
ПС-90А	19.6	56.0
РД-33	22.0	80.0

The analysis of the table results in a conclusion, that most reasonable for the laser installation could become the engine НК-36СТ serially produced by Samara plant 《Motorostroitel》, which satisfies to all requirements presented above. It is obvious, this is not the single engine, which can be put to use for this task, but in advantage of it would be desirable to note the following.

Fig. 8 Gas-turbine engine NK-368T

The high performance engine НК-36СТ of the Samara technological complex《Motorostroitel》, is developed in 1990 on the basis of an aero-engine НК-321 and is designed for the drive of the centrifugal supercharger in a structure gas pipeline pumping aggregate. The modular design

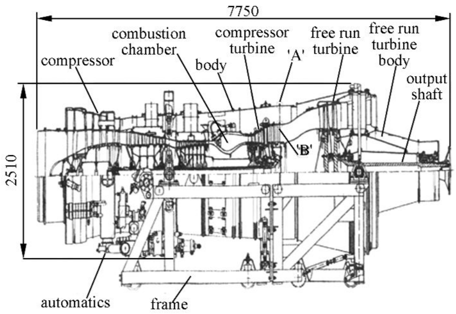

Fig. 9 Design schematic of NK-36ST engine

of the engine facilitates transport and assembly. The engine has the remote control panel and record of long life ground operation. The general view of the engine is shown in Fig. 8. and the design concept is shown in Fig. 9.

4.3 Gas dynamic assesment of the chosen aero-engine as the power unit for mobile GDL

In the previous chapter the task of GDL supply with oxidizer (air) by use of the НК-36СТ engine compressor was considered.

However, one more function-use of the engine exhaust gas as working medium for ejection of a GDL exhaust system is planed to the chosen engine.

The practice of development GDL with direct exhaust of combustion products in atmosphere has shown, that the aft diffuser of the laser produced the pressure recovery of gases up to atmospheric pressure requires for start significant the combustion chamber pressure increase (more than 30 atm), or decrease of exit pressure below atmospheric one. It is possible to ensure the last requirement, through installation of an ejector, for which the exhaust gases down the engine turbine are the working medium.

Gas dynamic estimation of the capability of the НК-36СТ engine of GDL diffuser start support is shown below.

As it was already indicated, the basic adaptation of the НК-36СТ gas-turbine engine is the elimination of design structure of the free running turbine, that allows to improve characteristics from the point of view of possible application in the laser installation, for which it is necessary to bleed air with the consumption $m_в = 16.25$ kg/s by pressure $P \approx 22$ kg/cm^2 and temperature $T = 720$ K.

Reasonable temperature for a GDL gas flow channel is $T = 1\ 600$ K at combustion-chamber pressure of 20 kg/cm^2.

The given temperature is realized in the combustion chamber for fuel kerosene-air at mass ratio $K_к = 38,5$, that is at kerosene flow rate $m_n = 0.422$ kg / s.

In GDL working section it is necessary to ensure static temperature of combustion products $T_a = 370$ K, that is realized velocity exhaust of combustion products through supersonic nozzles with velocity $W_{\hat{a}} = 1\ 700$ m/s at a Mach number $M_a = 4.46$, isoentropy index $\kappa = 1.333$, pressure $P_a = 0.057$ kg/cm^2.

For realization in GDL flat working section shock wave free flow of the combustion products in atmosphere is necessary to utilize the flat aft supersonic diffuser. One of major parameters of functioning of the diffuser in GDL operation conditions is the start pressure.

The start pressure (P_{st}) is determined on intensity of a direct shock wave relation:

$$\frac{P_{st}}{P_n} = \frac{g(\frac{1}{\lambda_a})}{g(\lambda_a)} \ ,$$

Where: P_n—pressure behind the diffuser; $\lambda_a = \frac{W_a}{a_*}$—velocity factor equal to the ratio of exhaust velocity in working section of GDL (W_a) to the critical velocity of sound (a_*).

The value of a velocity factor λ_a is connected to a Mach number by a ratio:

$$\lambda_a = \sqrt{\frac{X+1}{2} \cdot \frac{M_a}{\sqrt{1 + \frac{X-1}{2} M_a^2}}} \ ,$$

and then to a Mach number $M_a = 4.46$ corresponds $\lambda_a = 2.32$.

The function $g = \frac{Fkr}{Fa}$ determines the ratio of the geometrical area of critical cross-section of the diffuser to the area of gases exhaust and is according to expression:

$$g(\lambda_a) = (\frac{X+1}{2})\frac{1}{X-1} \cdot \lambda_a (1 - \frac{X-1}{X+1}\lambda_a)\frac{1}{X-1} \ .$$

For direct shock wave the following ratio is valid

$$\lambda_a \cdot \lambda_{nc} = 1 \ ,$$

Where: λ_{nc}—dimensionless velocity factor after front of a direct shock wave.

Thus, the ratio of pressure of start to pressure behind the diffuser is equal

$$\frac{P_{stor}}{P_n} = 13.7 \ .$$

The wind tunnel pressure of start is usually above their steady state operating pressure up to 10%—30%.

At the same time, in GDL laser conditions, when there is a gas volume involved in a working section (region of resonator mirrors) pressure of start of the diffuser can is still increasing to the value, at which the diffuser could not started.

Hence, it is necessary to lower exhaust pressure from the diffuser, that is possible to realized through an ejection of a gas jet, flowing out from the diffuser, by a gas jet flowing out after the turbine of the engine (Fig. 10).

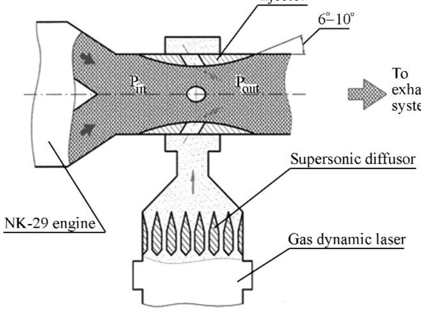

Fig. 10 GDL exit gas flow ejection

The designs of similar ejectors with maximum pressure recovery are known at high speeds of flow of gas in minimum cross-section. Such ejectors designs are characterized by smooth profile of an inlet part and with small cone angles (L) on an exit, which make value $L = 6—10°$.

The pressure recovery coefficient for such ejectors can reach value $\frac{P_{exit}}{P_{inlet}}=0.955 \div 0.965$ and even higher.

Thus the velocity factor value in minimum cross-section should be

$$\lambda=0.75-0.85.$$

Thus, such ejector inlet pressure should be $P_{inlet}=1.076\ kg/cm^2$, which can be provided with the gas-turbine engine without free running turbine. ($P_{exit}=1.033\ kg/cm^2$).

At a velocity factor in minimum cross-section and ejector inlet pressure $P_{inlet}=1.076\ kg/cm^2$ the static pressure in minimum cross-section becomes equal $P_{min}=0.73\ kg/cm^2$, that allows to organize introduction of flowing out from the GDL diffuser gas in area of minimum cross-section of the exhaust device of the gas-turbine engine and by that to lower pressure behind the diffuser GDL at least down to $P_{exit}=0.8$ instead of 1.033.

Such reduction of pressure will allow to lower start pressure of the GDL down, to a reasonable level of 18—20 atm.

4.4 Design solution for GDL power unit on the basis of the gas-turbine engine.

In view of the technical plan generated by the authors of the present technical proposal, experts of the Samara complex Motorostroitel has developed on the basis of the HK-36CT gas-turbine engine the engine for a laser complex under index HK-29.

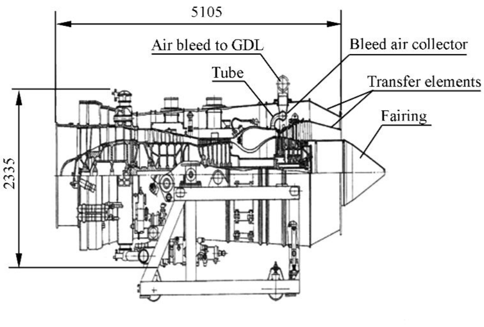

Fig. 11　NK-29 engine

The HK-29 engine (Fig. 11) represents the gas-turbine engine obtained as a result of adaptation of the engine HK-36CT, which consists of the following:

4.4.1　Dismantling of the free running turbine with the output shaft

The dismantling is made through the joint "A" flange of a engine body, through the joint "B" of the hot gas pipe down to the turbine of the compressor and finally the free running turbine together with a turbine casing is removed from the engine. As the frame, on which the engine is mounted, consists of two not connected permanently sections, the removal of the second turbine side section does not represent any complexity.

For organization of the smooth gas flow from the modified engine, and also for a fixing of the exhaust system to the engine, two conical adapters (casing) and internal fairing made of a stainless steel are added.

The external adapter is terminated by a flange to be fixed with the engine ejector. The adapters and fairing were designed by *Motorostroitel*, supplier in accordance to the aerodynamic characteristics of a gas stream and the strength requirements.

Ejector, which scheme is shown in Fig. 10, is not the engine item. The ejector design is calculated and finally developed on the basis of engine, and laser complex exhaust system parameters and GDL exit characteristics (down the supersonic diffuser). Ejector design represents a pipe from high-temperature steel having symmetrical narrowing in the middle part ahead of critical cross-section. The pipe can be manufactured from three parts with flange or welded connections.

The middle narrowing part can be turned from a thick-walled billet or from a rolled ring and has mating collars for different side collector for convenience of assembly for welding. The orifices connecting cavities of exhausts of the engine and GDL are located around the perimeter of critical cross-section. The collector is manufactured by stamping of a sheet, has the welded branch pipe and serves for uniform distribution of gas after GDL on all cross-section of an ejector. The adaptation of the engine with removal of the free running turbine considerably reduces overall dimensions and weight of the installation. For clarity of estimation of advantage in overall dimension reduction of the modified engine the presentations of Fig. 9 and Fig. 11 are made in the same scale.

4.4.2　Air bleeding to GDL

The next considered problem is the air bleeding after the compressor to GDL.

During our long searching of the engineering solution for the engine adaptation the aviation specialists have offered to realize the air bleeding from the exit of the combustion chamber second contour, not from the compressor final stage exit, i. e. from a channel of a cooling flow of the combustion chamber. This solution is connected to the fact, that combustion chamber of the gas-turbine engine is one of the most thermal stressed items of the engine, and the cooling parameters are results of long development stage. Therefore the air bleed behind the compressor, reducing the air flow of the combustion chamber cooling flow, will change steady state thermal status, which can result in undesirable consequences for engine operation.

The collector ring for air bleeding with a branch pipe to GDL supply was recommended to position in a zone of the exit of cooling flow of the combustion chamber, and for that the chamber and collector are connected by angular branch pipes (Fig. 12). The angular branch pipes, 8 pieces in quantity, can be manufactured of a pipe or stamped sheet from two halves and have leak tight flanges to cooperate with the envelope of chamber cooling flow channel. The angular branch pipes are fixed by welding to the collector ring, which has the terminal flanged tap. To this tap the branch pipe to supply air to GDL is fixed. This branch pipe passes through an outer shell of a engine body and has "floating" attachment to it excluding deformation of designs at a thermal expansion of contacting elements.

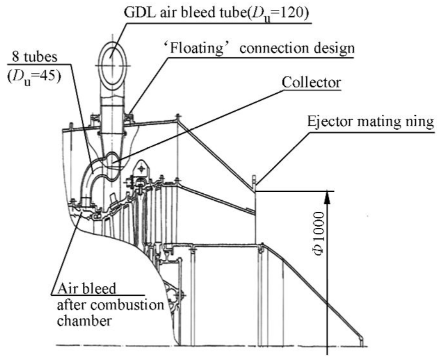

Fig. 12　GDL air bleed block design

It exists from the experience of such bleed scheme, however particular design should pass a number of development tests with the purpose of experimental selection of channel pressure reduction to ensure calculated bleed air flow rate. All other elements of the engine remain without change, including all start and cutoff automatics and operation control. Thus engine HK-29, obtained as a result of adaptation of the engine HK-36CT will require minimum development, and manufacturing costs.

The basic performances of the engine HK-29. All parameters of the engine are indicated for a nominal mode.

Fuel	Kerosene TC-1
Power/MW	−25
Air flow/(kg·s^{-1})	−107.2
Compressor pressure ratio/Pk	−23.12
CC gas temperature/K	−1 420
Gas exit temperature/K	−698
Propellant consumption/(kg·s^{-1})	−1.434
Engine weight, with frames/kg	−5 000

The engine HK-29 is single mode, as by activity of the laser installation is required neither decrease, nor increase of the power, that provides reliability and life value growth.

The engine HK-29 should be manufactured by aviation plant irrespective of, whether it is refurbished through adaptation of the engine HK-36CT or again assembled with use of furnished engine parts from production engines.

Thus, as a result of the carried out research work not only the optimistic results for possibility of adaptation of the gas-turbine engine for GDL gas dynamic complex were obtained, but also design activities by definition of general realization of such engine are executed in practice. And, what is very valuable, this activity is executed by the experts of aero-engines developing-producing company.

5 Mobile laser installation

In view of all computational investigations, design studies and engineering estimations within the present paper the provisional structure of the autonomous laser installation for clearing of surfaces of reservoirs of petroleum recordings is produced. The general view of laser installation is shown in Fig. 13. As it can be seen from the figure, the installation represents modular assembly. The engine has an own fixing frame, autonomous subsystems and producer-supplier. GDL also represents the complete aggregate, the developer and manufacturer of which is not connected to other suppliers. The same concerns are valid for the fuel storage system (is not shown in figure). Task of the installation developer as a whole is the coordination of these units both on arrangement on a vehicle, and organization of interaction during operation. For example, relative arrangement of the engine and laser can be arbitrarily, depending on overall dimensions and device of a vehicle, however in any case the fulfillment of following conditions is necessary:

* The engine and GDL should not have of rigid connection on the frame, the GDL frame should have vibration absorption plates.

* The engine and GDL should be placed as close as possible, as the unreasonable elongation of gas lines connecting them, will result in to additional losses because of pressure reduction.

* On fire protection control requirement fuel storage container should ne placed on distance from the engine and GDL, and is separated from them by a fire-prevention wall.

* For protection of the attendants the remote control panel should be born for limits of the installation, and input part of the engine and line of a beam are protected by special fences. The control of a scanning mirror also is carried out for limits of the installation.

* The direction of exhaust gases should not intersect structural items of the installation.

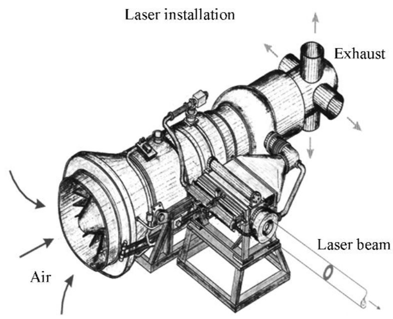

Fig. 13 Laser installation

As the development of the laser installation does not assume development of testing site for development testing, prior to deliveries the development installation should be assembled, on which all dezigner and operational problem solutions will be found.

6 Conclusion

The purpose of presented in the paper project is to develop a laser technology of cleaning of large areas of seas and other water surfaces from oil film contamination. This paper also aims development of composition scheme, technological requirements and engineering design solution of aggregates and units of vehicle, vessel or aircraft compatible mobile GDL (100－250 kW) intended to solve this important problem of environment protection. This method proposed for development is expected to complement other traditional methods, which usually more successfully treat bulk layer oil pollution but do not match to eliminate up to 100 μm oil films, the latter usually being spread over numerous square kilometers of sea and kilometers of seacoasts. Note about one million tons of such films drift now in the World Ocean, as consequence of such disasters.

Thus, this promising approach has a fundamental science basis, from one hand, and skill and experience of missile jet specialists and their laser prototypes, from another hand. The investigations are planned to be accomplished in three basic directions:

1) Theoretical and experimental research of the laser radiation action on thin oil and it's derivatives films over water surface, evaporation in three basic directions;

2) Experimental optimization of laser optical scheme and operation modes in order to achieve the maximum optical and gas-dynamic efficiency;

3) Engineering design, composition scheme and accompanied problems solution in order to adapt the laser module for vehicle, ship or aircraft transportation.

Results expected are as following:

-Certain recommendations on oil films elimination from large water areas, including conditions of real tanker and pipeline disaster, by means of laser radiation; development of technologies of oil and it's derivatives films burning out (mode number one) and oil films sucking up and saving of oil products for future efficient usage (mode number two) by means of high power mobile CO_2-GDL.

- Development of self-contained mobile CO_2 GDL tailored for these environmental problems solution.

These investigations may result in significant progress in the following branches of science:

a) Physics of liquid inhomogeneous films, phenomena on the boundary of water-carbohydrate composition, phase transitions and chemical processes in two-phase or multi-phase compositions under high power CO_2 laser radiation and related phenomena;

b) Problem of active resonators for high power GDL, different methods of laser efficiency calculation and simulation, control of temporal radiation modulation and optimization of performance, with respect to the problem of beam quality.

The author has completed the conceptual analysis of GDL installation development for disposal of petroleum films from a water surface. The basic capability of development of such installation is shown. The basic characteristic calculations of the system are made, the schematic and design solutions of basic installation are presented.

Besides of that, the GDL bench has been restituted by the author of the paper and his colleahues on their own costs and some demonstration operaions with scanning the beam over water surface covered with petroleum film were carried out. The experimental confirmation of film effective burning mode and mode of oil film gathering was obtained. The next part of realization phase can be the development of the installation preliminary design, in case of the customer objective and specific technical tasks, formulated by him. The preliminary design will include complete study of a design of all elements for the installation, technological works, will define all suppliers of the developing systems and sub suppliers from obtaining from them of the consent on terms and conditions. In the preliminary design, schedules of all phases of installation development will be worked out: issue of the working documentation, technology modification, manufacturing of a prototype, prototype development and beginning of installations deliveries.

Thus, according to the estimation, the experimental mobile CO_2 GDL installation for water surface cleaning can be designed, manufactured and tested for not longer than two-two and half years.

References:

[1] APOLLONOV V V, PROKHOROV A M. Universal laser for industrial, scientific and ecological use [C]. *Proceedings of GCL/HPL Conference, St. Petersburg*, 1998:140.

[2] APOLLONOV V V. Ecologically safe High power Lasers[C]. *Proceedings of Lasers-2001 Conference*, 2001:3.

[3] APOLLONOV V V. High power autonomous CO_2 GDL (100 kW, CW/P-P modes) for new technologies development and environment protection[C]. *Proceedings of GCL/HPL Conference, Lisbon*, 2008:35.

[4] APOLLONOV V V. New application for high power high repetition rate pulse-periodic lasers[C]. *Laser pulse Phenomena and Applications*, 2010:19.

[5] APOLLONOV V V. Oil films elimination by laser [J]. Oboronzakaz, 2007, 17(12):33.

[6] APOLLONOV V V. High rep. rate P-P lasers, Patent RF, 2175159[P].

Author biography:

Apollonov Victor Victorovich (1945—), male, Head of Dept. of A. M. Prokhorov General Physics Institute RAS, doctor of physics and mathematics, professor, academician of Russian Academy of Natural Sciences and Academy of Engineering Sciences, laureate of State prize of USSR (1982) and Russia (2001). E-mail: vapollo@kapella. gpi. ru