IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Calculation of Parameters of the Cryogenic Rotor-Blade Engine for the Drive of the Refrigeration Unit for Truck

To cite this article: D Uglanov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **692** 012015

Calculation of Parameters of the Cryogenic Rotor-Blade Engine for the Drive of the Refrigeration Unit for Truck

D Uglanov*, O Tereshchenko, S Zaika and I Neverov and R Panshin.

Department of Heat Engineering and Heat Engines, Samara University, 443086, Moskovskoye shosse, 34, Samara, Russia

*E-mail: dmitry.uglanov@mail.ru

ABSTRACT. Cars with internal combustion engines using hydrocarbon fuels occupy the main market share. The cost of these products is increasing, and this negatively affects the prosperity of the population and the cost of freight transportation. The growth in energy consumption and the rapid growth of cars deplete non-renewable natural oil and gas resources, leading to intense combustion of atmospheric oxygen.

One of the promising types of environmentally friendly engine is a cryogenic fuel engine. Such engines have higher energy performance and lower cost in comparison with electric vehicles, and their operating costs are comparable with traditional cars, taking into account the ecological aspect.

The study presents the development of methods for calculating the rotor-blade engine and its design. Since refrigeration plants consume 3% of the internal combustion engine power, it is advisable to replace them with autonomous units using a cryogenic working fluid, thereby reducing emissions of harmful substances into the atmosphere.

1. INTRODUCTION

Every year the number of trucks and cars in the world increases. Daily a large number of freight traffic around the world, logistics between countries is developing rapidly, requiring for this a large number of trucks.

The increase in energy consumption and the rapid growth of cars with internal combustion engines deplete the non-renewable natural resources of oil and gas, which leads to intense combustion of atmospheric oxygen. The processes that occur during fuel combustion create serious problems in the field of ecology and emissions of harmful substances into the atmosphere. A large concentration of carbon dioxide in the state is a barrier to the thermal radiation of the Earth's Sun, which leads to a greenhouse effect.

2. MODERN CONDITION OF ENGINES FOR CRYOGENIC FUEL

One of the promising types of environmentally friendly engine is a cryogenic fuel engine [1,2]. Such engines have higher energy characteristics and lower cost in comparison with electric vehicles, and their operating costs are comparable to traditional cars with engines, taking into account the ecological aspect [3].

3. MODERN CONDITION OF ENGINES FOR CRYOGENIC FUEL

In England the production company Dear has already begun serial production of the cryogenic engine

[1].

The Dearman engine works as follows:

1) the hot heat carrier (ethylene glycol) is fed into the cylinder;
2) then, liquid nitrogen is introduced into the cylinder, which enters into interaction with the high-temperature liquid, and due to this it begins to expand;
3) heat from the heat carrier is absorbed by the expanding gas, as a result of which isothermal expansion occurs;
4) the piston is urgently lowered, the exhaust valve is opened, and the mixture of gas and hot coolant is removed from the engine;
5) Then, the hot heat carrier is separated from the mixture in the separator and returned to the tank, while nitrogen or air is discharged into the atmosphere. In this research [3] the power plant operating on liquid nitrogen (LN2) is presented, it is intended for transformation of thermal energy of environment at gasification of liquid nitrogen into mechanical energy, which can be used, in particular, for working a cryogenic car.

The power plant ‘figure 1’, operating on liquid nitrogen, includes a special Dewar vessel 1, a heat exchanger 5 with shut-off regulating and measuring equipment that ensure the conversion of liquid nitrogen to high-pressure gaseous nitrogen with a temperature close to the environment, and an air motor.

The working process of this engine is carried out for one revolution of the crankshaft in three cycles: input under excess pressure of nitrogen gas, working stroke and exhaust gases. The nitrogen gas is introduced into the inlet cavity 20 by supplying liquid nitrogen from the Dewar 1 vessel under excess pressure with the valve 2 open through the gasifier 5 in which it passes from the liquid state to the gaseous due to heat inflow from the environment.

From the gasifier 5, through the pipeline 6, gas enters the common cavity 17 for the two cylinders of the air motor, which acts as a receiver from which the gas inlet to the cavity 20 occurs when the crankshaft 13 rotates. In this case, the push rod 15, screwed into the piston 11, moved by the connecting rod 14, The valve 18 opens and the inlet cavity 20 is filled with a high-pressure gas. In position B, the valve 18 is closed. With further rotation of the crankshaft from position B to position B, expansion of the gas takes place with the accomplishment of useful work (working stroke). When the crankshaft rotates to position B, openings 16 in the cylinder wall are opened, which allows release of not fully expanded gas (exhaust) into the atmosphere. The energy of the working stroke is perceived by the flywheel 9 and ensures the further rotation of the crankshaft and the cycle is repeated.

The schematic representation of the power plant is shown below in figure 1.

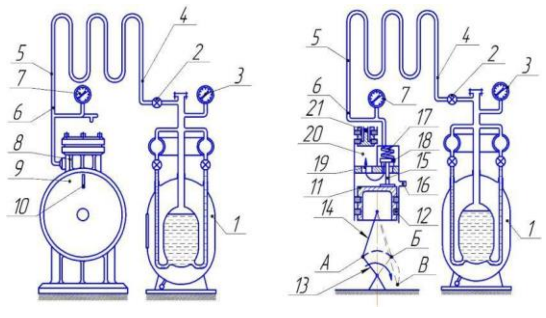

Figure 1. Schematic representation of the power plant.
1 - Dewar vessel, 2 - valve, 3.7 - manometers, 4, 6 - pipeline, 5 - gasifier, 8 - inlet cavity, 9 - flywheel, 10 - crankshaft position sensor, 11 - piston, 12 - O-ring, 13 - crankshaft, 14 - connecting rod, 15 - pusher, 16 - outlet, 17 - receiver, 18 - valve, 19 - bypass opening 20 - inlet cavity, 21- piston volume adjustment.

This installation has significant advantages:

A) complete ecological cleanliness;

IOP Conf. Series: Materials Science and Engineering **692** (2019) 012015 doi:10.1088/1757-899X/692/1/012015

B) inexpensive technology for the production and maintenance of CS;

C) the effective efficiency can reach 50 ... 60%, which significantly exceeds the maximum efficiency of internal combustion engines;

D) fire safety;

E) availability and relatively low cost of the working fluid (liquid nitrogen);

The main disadvantage of such installations is insufficiently effective use of low-temperature cryoproduct potential.

4. METHOD OF CALCULATING ROTARY-LOBE CRYOGENIC EXPANDER

Calculation procedure and a description of an installation contributing to reducing emissions of harmful substances by road transport are presented in this research.

As a result, the capacity for the refrigeration unit is calculated by the following formula:

$$Q\text{п}=Q\text{ст}+Q\text{пр}+Q\text{т} \qquad (1)$$

The plant scheme with a cryogenic cylinder and a rotor-blade expander is shown below in figure 2.

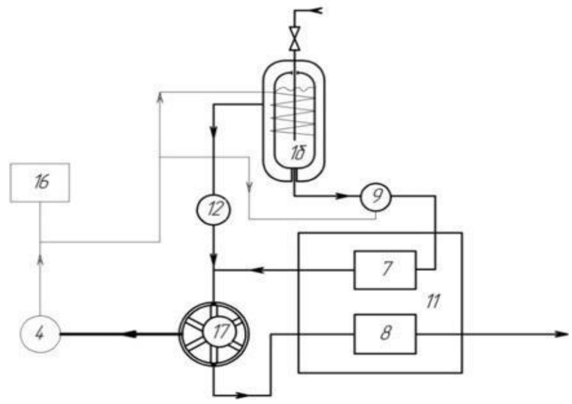

Figure 2. Diagram of the plant with a cryogenic cylinder and a rotary-blade expander. 1b - universal gas cylinder; 4 - electric generator; 7 - heat exchanger of the cryogenic working fluid; 6 - a thermal chamber; 7 - cryogenic pump; 8 - refrigerant evaporator; 11 - a thermal chamber; 12 - gas reducer; 16 - battery pack.

The cryogenic liquid from the balloon 1b, by means of a pump 9, enters the heat exchanger 7, where boiling occurs. Specific work (heat of vaporization, heating of single-phase flow) and fluid flow determine the cooling capacity of the proposed power plant. The refrigerant in the form of steam is supplied by the vtoronno-lopa expander17, the work received through the drive goes to the power generator 4, the flow, expanding in the inter-port channel, is stalled, which allows reusing steam in the heat exchanger 5.

The procedure for calculating the rotor-blade expander consists of the following steps:

1) Evaluation of the influence of the number of plates on the parameters of the expander.
2) Estimation of the influence of eccentricity on the speed of the expander.
3) Estimation of the influence of the width of the plate on the stability of work.
4) Estimation of the influence of the length of the rotor on the speed of the expander.
5) Selection of the angles of the location of the edges of the suction and discharge windows.
6) Choice of plate material. For the production of plates in expanders with lubrication, various materials are used: asbestos-textile, textolite, glass-textolite, steel 85 [4,5].
7) Determination of the main dimensions of the expander [6].
8) Finding the power of the expander [7].

The effective power on the expander shaft (W):

$$N_в = N_i + N_{fr} \qquad (2)$$

where N_{fr}— power used to overcome frictional forces.

Using the presented technique, we make the determination of the parameters of the rotor-blade expander.

1. Theoretical action speed :

$$S_{\Gamma} = \frac{S}{\lambda} \tag{3}$$

2.The optimal number of plates:

$$Z_{opt} = \pi\left(\frac{R(\bar{\lambda}+1)}{3\delta}\right)^{1/3} \tag{4}$$

3. Angle between plates:

$$\beta = \frac{2\pi}{Z_{opt}} \tag{5}$$

4. Stator radius:

$$R = \left(\frac{2\pi S_{\Gamma}}{C\bar{\lambda}K_L u}\right)^{1/3} \tag{6}$$

5. Rotor length:

$$L = K_L R \tag{7}$$

6. Rotor eccentricity:

$$e = \bar{\lambda} r \tag{8}$$

7. Plate thickness:

$$\delta = \bar{\delta} R \tag{9}$$

8. Plate height:

$$h = 0.4R \tag{10}$$

9. Rotor radius:

$$r = R - e \tag{11}$$

10. Number of turns:

$$n = \frac{U}{2\pi R} \tag{12}$$

11. Angular velocity:

$$\omega = 2\pi n = 52 \tag{13}$$

12. Maximum angle of expansion:

$$\alpha_{\mathrm{p}} = \arccos\left[2\left(\frac{p_0}{p_k}\right)^{\frac{1}{n}} - 1\right] \tag{14}$$

13. Current gas pressure in the cell:

$$p_{\phi} = p_0\left(\frac{\beta+2\sin\frac{\beta}{2}+\frac{\bar{\lambda}}{2}\sin\beta-\frac{\bar{\lambda}}{2}\beta}{\beta+2\sin\frac{\beta}{2}\cos\varphi\ +\frac{\bar{\lambda}}{2}\sin\beta\cos 2\varphi\ -\frac{\bar{\lambda}}{2}\beta}\right)^{n} \tag{15}$$

14. The pressure drop between two adjacent cells, one of which is connected to the suction inlet:

$$\Delta p_{\phi} = p\left\{\left[\frac{\beta+2\sin\frac{\beta}{2}+\frac{\bar{\lambda}}{2}\sin\beta-\frac{\bar{\lambda}}{2}\beta}{\beta+2\sin\frac{\beta}{2}\cos(\varphi-\frac{\beta}{2})+\frac{\bar{\lambda}}{2}\sin\beta\cos 2(\varphi-\frac{\beta}{2})-\frac{\bar{\lambda}}{2}\beta}\right]^{n} - 1\right\} \tag{16}$$

15. The pressure drop between two adjacent cells, one of which is connected to the discharge pipe:

$$\Delta p_{\phi} = p_i - p\left[\frac{\beta+2\sin\frac{\beta}{2}+\frac{\bar{\lambda}}{2}\sin\beta-\frac{\bar{\lambda}}{2}\beta}{\beta+2\sin\frac{\beta}{2}\cos\left(\varphi\ -\frac{\beta}{2}\right)+\frac{\bar{\lambda}}{2}\sin\beta\cos 2\left(\varphi\ -\frac{\beta}{2}\right)-\frac{\bar{\lambda}}{2}\beta}\right]^{n} \tag{17}$$

16. Pressure drop between two adjacent cells:

$$\Delta p = p\left\{\begin{array}{l}\left[\dfrac{\beta+2\sin\frac{\beta}{2}+\frac{\bar{\lambda}}{2}\sin\beta-\frac{\bar{\lambda}}{2}\beta}{\beta+2\sin\frac{\beta}{2}\cos\left(\varphi+\frac{\beta}{2}\right)+\frac{\bar{\lambda}}{2}\sin\beta\cos 2\left(\varphi+\frac{\beta}{2}\right)-\frac{\bar{\lambda}}{2}\beta}\right]^{n}\\ -\left[\dfrac{\beta+2\sin\frac{\beta}{2}+\frac{\bar{\lambda}}{2}\sin\beta-\frac{\bar{\lambda}}{2}\beta}{\beta+2\sin\frac{\beta}{2}\cos\left(\varphi\ -\frac{\beta}{2}\right)+\frac{\bar{\lambda}}{2}\sin\beta\cos 2\left(\varphi\ -\frac{\beta}{2}\right)-\frac{\bar{\lambda}}{2}\beta}\right]^{n}\end{array}\right\} \tag{18}$$

17. Coefficient $\zeta_{сж}$:

$$\zeta_{сж} = 1 + 0{,}12\frac{\tau}{U} \tag{19}$$

18. Indicated horsepower:

$$N_i = N_T\zeta_{сж}\zeta \tag{20}$$

19. Power expended on overcoming the friction forces of the plates in the rotor slots from inertia forces:

$$N_i = \frac{4}{\pi}m\omega^3R^2\bar{\lambda}Z\mu_1\mu_2\frac{1+\bar{\lambda}}{1-\bar{\lambda}}\left[1-\frac{h}{2R}+2\bar{\lambda}^{2}\right] \tag{21}$$

20. Power expended to overcome the forces of the pressure difference in the neighboring cells:

$$N_r = \frac{1}{2\pi}L\bar{\lambda}^{2}\mu_1R^2\omega p \times 10^{1.175(e/h)+1.325}k^{0.291} \times lg\frac{p_i}{p} \tag{22}$$

21. Power expended on overcoming the friction forces of the plates along the cylinder from inertia forces:

$$N_{ic} = m\omega^3R^2Z\mu_2\left[1-\frac{h}{2R}+2\bar{\lambda}^{2}\right] \tag{23}$$

22. Power expended to overcome the friction forces of the plates on the cylinder from the pressure difference in the neighboring cells:

$$N = \frac{1}{2\pi}L\bar{\lambda}^{2}\mu_1\mu_2R^2\omega p \times 10^{1.24(e/h)(\frac{1+[e/(2h)\sin\psi]}{\cos\psi})+1.4}k^{0.528} \times lg\frac{p_i}{p} \tag{24}$$

23. Total power:

$$N_e = N_i + N \tag{25}$$

24. Mechanical efficiency

$$\eta_m = \frac{N_i}{N_e} \tag{26}$$

The results of calculation of parameters of the rotor-blade expander are shown below in the table 1.

Table 1. The results of calculation of the main parameters

$S_г$, m^3/s	Z_{opt}	β	C	R (m)	L(m)	e	δ (m)	h (m)	h_I (m)
0.0625	10	45°	12.44	0.22	0.88	0.022	0.0044	0.088	0.089
r, m	F_h (m^2)	m (kg)	n (s^{-1})	Ω	Φ	γ_0	δ_1	δ_2	δ_3
0.198	0.006	2.6	5	34	112	4	21.6	134	18
δ_4	α_p	$p_ф$ (Pa)	$\Delta p_ф$ (Pa)	Δp (Pa)	q_{12} (Nm^{-1})	q_{22}, (Nm^{-1})	q_{23} (Nm^{-1})	q_1 (Nm^{-1})	$N_т$ (Watt)
18	128	125080	66670	11240	112.8	573.4	3400	33.1	102
$\zeta_{сж}$	N_i (Watt)	P_i (MPa)	T_0 (kH)	N_3 (kWatt)	μ_2	Ni (Watt)	Nr (kWatt)	N_{ic} (kWatt)	N, (kWatt)
1.07	136000	1.74	600.491	77	0.05	419.1	9.7	4.5	1.9

5. CONCLUSION

In the course of the research, a technique was developed for calculating the rotor-blade expander. The efficiency is 44%, so there is no need for variation in parameters to ensure a higher efficiency. The need to change a number of specified parameters arises, only with an efficiency of less than 40%.

It was found that the main source of pollution are cars running on hydrocarbon fuels, the proportion of which falls on cars with a refrigerated chamber.

IOP Conf. Series: Materials Science and Engineering **692** (2019) 012015 doi:10.1088/1757-899X/692/1/012015

Since refrigeration plants consume 3% of the ICE power, it is advisable to replace them with autonomous units using a cryogenic working fluid, thereby reducing emissions of harmful substances into the atmosphere.

REFERENCES

[1] Novotelnov, V.N. Cryogenic machines [Text]: textbook for high schools / VN. Novotelnov, A.D. Suslov, V.B. Poltaraus - St. Petersburg: Politechnica, 1991. 335 p.
[2] Bogdanova, SN / Refrigeration equipment. Air conditioning. Properties of substances [Text]: reference book / Bogdanova SN - St. Petersburg: SPbGAKHPT, 199. - 320 p http://dearman.co.uk/dearman-technologies/dearman-engine/
[3] http://www.holodcatalog.ru/entsiklopedii/promyshlennoe-oborudovanie/dvigatel- dearman-na-zhidkom-azote/
[4] S.I. Bondarenko, I.N. Kudryavtsev, A.Ya.Levin, N.M. Levchenko, B.N.Murinets-Markevich, A.I.Pyatak, Development of a cryogenic power plant for an environmentally friendly car, ISSUES OF ATOMIC SCIENCE AND TECHNIQUES, Series: Vacuum, pure materials, superconductors No. 14, 2004, P.152-157.
[5] Chumak, I.G. Refrigerating plants. Designing [Text]: a tutorial for universities / IG. Chumak, D.G. Nikulshina. - Moscow: Higher School, 1988. - 280 p.
[6] Blagin E.V., Dovgyallo A.I., Nekrasova S.O. и др. Estimation of the energy efficiency of cryogenic filled tank use in different systems and devices // Applied Thermal Engineering. 2016. Vol. 101. Pp. 537-544
[7] Blagin E.V., Uglanov D.A., Dovgyallo A.I. About LNG Energy Utilization Efficiency Estimation // Procedia Engineering, 2016. Vol. 152. Pp. 209-218)