GAS TURBINE AND WIND TURBINE ENGINES FOR MECHANICAL DRIVES

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Summary

Gas-turbine engines (GTE) are widely applied to drive compressors pumping natural gas and on main gas pipelines of many countries of the world. At the same time, about 10 per cent of all GTE, made in the world, are used on vessels, including large

hovercrafts and hydrofoils. In this sphere of application there is practically no alternative for GTE. GTE have found wide application also in various spheres of industry. An analysis of the features of GTE drives of various types is given and the basic parameters of GTE are specified. The state and prospects of development of each specified type of GTE are shown. The features of thermodynamic cycles and kinematic schemes of GTE drives, specially developed for gas pipelines, vessels, locomotives, automobiles, industrial enterprises, and GTE constructed on the basis of aviation engines are given. The approaches to transforming aviation GTE to stationary and transportation engines are shown. The technical and economic parameters of GTE drives are given. The approaches to the selection of kinematic schemes and parameters of specific GTE drives, which significantly differ from gas turbine units (GTU) meant power plants, are indicated. Possibilities of application of GTE for locomotives and for automobiles, which are not yet widespread, is given. At the same time, automobile GTE have great potential advantages in comparison with diesel engines, in particular, for their considerably smaller negative influence on an environment. It is shown that the prospects of development of automobile GTE are connected first of all with the development of ceramic materials for blades and disks of the gas turbine. Some attention is given to wind turbines, though their application as driving engines is rather limited in comparison with power wind turbines.

1. Introduction

Among the various fields of application of stationary gas turbine drive units one should mention gas pipelines. Superchargers and gas turbine units comprise the gas-pumping system. GTU are applied as drives not only in gas pipelines, but also in oil pipelines for transport of petroleum. Some of these systems are created on the basis of existing aircraft and marine gas turbine engines.

The division of GTU into drives and power units is conditional to some degree, as some GTU drives can be used as power units. Nevertheless they are projected as driving ones; that is why they should be considered separately.

Gas turbine installations are used as mechanical drives in various industries: in chemical plants and iron and steel industry, in the manufacture of nitric acid, in the synthesis of ammonia, in petrochemical industry, etc.

About 10 per cent of all GTU produced in the world are used in different kinds of ships: cargo vessels, warships, hydrofoils (vessels on underwater wings), hovercrafts (vessels on air cushion), etc. The marine gas turbine units could be competitive with diesel engines as far as their main economic characteristics are concerned. Both steam-gas and gas-steam units may be used as marine propulsion units. Also in use are combined marine propulsion systems consisting of a gas turbine engine and a Diesel engine, which are not combined by a common thermodynamic cycle.

In contrast, stationary drives and ship units, and locomotive GTE are considerably less applied. Nevertheless, experience during their development, design and research has shown prospects of application in cargo locomotives with GTE on a number of railway main roads of some countries of the world, and also prospects of application of passenger turbo-train on some main roads.

Automotive gas turbine engines are also considered as a good alternative to piston-type internal combustion engines. Their further progress is closely linked with the development of ceramic blades and disks.

2. Stationary Gas Turbine Drive Units

2.1. Features and Parameters of Gas Turbine Drive Units

Stationary GTU drives on main gas pipelines are popular among all areas of application. Such GTU serve as mechanical drives of centrifugal gas superchargers on gas-pumping compressor stations. Superchargers together with GTU make a gas-pumping unit (GPU).

Parameters	Coberra 6462	M5322 RB	LM2500	LM5000	GT-71
	Cooper-Royce (USA - UK)	General Electric (USA)			Ingersoll-Rand (USA)
Year of a beginning of the output	1983	1971	1979	1983	1978
Power, MW	25.3	23.8	21.6	33.3	34.0
Gas temperature at turbine inlet, K	1422	1205	1483	1497	1472
Air flow at compressor inlet, kg/s	90	113.5	67.6	124.4	130.8
Compressor pressure ratio	19.2	8.3	18.7	30.0	31.3
Number of shafts	3	2	2	3	2
Rated revolutions of output shaft,	4 800	4 670	3 600	3 600	4 000
Actual efficiency, %	36.3	36.0[*1]	35.9	37.8	37.7
Weight (without supercharger), t	26.33	116.70	23.60	40.20	12.26
External dimensions of GTU, m:					
length	6.4	15.25	8.48	17.7	11.3
width	3.05	3.36	2.81	3.14	3.36
height	3.05	3.66	3.51	3.66	3.36

PGT25	Spey*[3]	Avon-1535*[3]	211*[3]	Tornado	Mars	CW182RMB	10
Nuovo Pignone (Italy)	Rolls-Royce (UK)			Ruston (UK)	Solar (USA)	Westinghouse (USA)	Sulzer (Switzerland)
1981	1976	1975	1974	1982	1977	1982	1981
21.7	4.24	17.75	29.08	6.34	8.3	11.33	20.7
1066*[2]	260	1194	1423	1273	1269	1283	-
66.7	58.6	77.2	90.3	27.2	36.3	52.2	74.3
18.0	18.5	9.0	19.2	12.1	16	8.2	13.5
3	2	3	2	2	2	2	2
6500	-	-	-	10 000	9 500	7 250	7 700

36.4	39.7	33.8	41.7	31.0	32.8	36.8*[4]	33.1
26.80	1.48	1.62	2.59	19.07	27.24	52.5	28.0
7.93	2.75	3.5	3.05	7.32	10.4	10.7	8.0
3.05	1.22	0.92	1.53	2.44	2.44	3.36	3.15
3.36	1.53	0.92	1.53	2.90	2.75	3.97	3.4

*[1] With the generator. *[2] At inlet to the power turbine. *[3] Gas capacity behind gas-generator and parameters only gas-generator. *[4] With the generator.

Table 1. The characteristics some gas turbine units for gas pumping stations

The number of compressor stations is increased, as the production of gas grows; there are new deposits, which are on hundreds and even thousand kilometers far from places of consumption. Therefore GPU parks constantly expand; the total installed capacity and average individual capacity of GPU grow.Table 1 lists widely used GTU produced by leading firms and also GTU of other types and firms.

Leading engine-manufacturing companies Rolls-Royce (UK) and Pratt-Whitney (USA) have established special branches for development and manufacture and produced thousands of such GTU of total capacity more than million kW. General Electric Co. (USA) produced more than 800 GTU of industrial type ('heavy-duty' GTU with long service life) for gas- and oil-extracting and pumping installations by common capacity of more than 8 mln. kW. The common operating time of these GTU has exceeded 35 mln. h.

Ample opportunities for application of GPU are available; for example, in Russia large stocks of gas and petroleum are situated many thousands of kilometers from the major places of consumption. The largest Russian manufacturer of GPU is the Neva Machine-building Works (NMW) in St.-Petersburg: from the beginning with the release of the first units such as GT-700-4 in 1957 till 1999 the company produced almost 1700 units, with a total operating time exceeding 60 mln. h. GTU of series GTK-10 form a major part of the produced units (1030 units). Brnensky works (Czech Republic) under the license of NMW produces GTU of GT-750-6 series. GPU ‘Volga’ is one of the last delivered by the NMW. This unit includes the new gas turbine engine GTNR-16 type with power capacity of 16 MW and efficiency of 32.5 per cent. This GPU, as well as all units, which are newly launched by NMW, is intended to take the places of the old units GTK-10 type on gas pipelines. Therefore arranging the parts of the ‘Volga’ unit provides minimum capital expenses during installation and adjustment, and ‘Volga’ unit has the same joining sizes to external paths as GTK-10 unit and is mounted on an identical frame. The design of GPU is regularly improved, and this results in a reduction of the maintenance and repair time of the unit. The total operating time of GPU is large enough. So, in the case of some units of NMW it exceeds 120 thousand h., and a significant part of the units such as GTK-10, which were made and installed during 1970-1985 at Russian compressor stations (815 units common installed capacity 815 mln. kW), has worked more than 100 thousand hours. The main characteristics of the Russian GTU for GPU are given in Table 2.

Parameters	GT-750-6*	GT-6-750**	GTK-10*	GTN-6	GTK-16**	GTK-16	GPA-Tz-6,3	GPA-10	GPA-Tz-16	GTN-25 (NMW)	GTN-25 (UTMW)	GTN--40
Year of a beginning of the output	1965	1966	1970	1975	1976	1981	1974	1978	1982	1982	Project	Project
Power, MW	6.0	6.0	10.0	6.3	16.0	16.0	6.3	10.0	16.0	25.0	25.0	40.0
Gas temperature at turbine inlet, K	1023	1033	1053	1033	1083	1173	1083	1103	1123	1163	1293	1223
Air flow at compressor inlet, kg/s	55.6	45.5	86	47	100	85	56	100	100	175	103	208
Compressor pressure ratio	4.6	6.5	4.6	6.2	7.5	11.5	7.8	11.5	11	12.5	13.2	15
Number of shafts	2	2	2	2	2	2	2	3	3	3	2	3
Number of stages (LPC/HPC)	12	12	10	12	13	15	14	7/9	4/6	7/7	17	7/7
Rated revolutions of turbo-compressor shaft	5 200	6 200	5 200	6 200	4 000	6 850	9 300	5 650/ /7 650	5 100/ /6 750	4 400/ /5 050	6 000	4 400/ /5 000
Rated revolution of power shaft	5 300	6 150	4 800	6 150	4 600	6 500	8 200	4 800	5 300	3 700	5 500	3 700
Actual efficiency, %	27	23.3	28	24	26	29	23	27	28.8	29.4	31	30.6
Overhaul life, thousand hours	8	9	12	12	8	25	8	20	10-15	20	25	30

* Unit with generator. ** Unit are not produced.

Table 2. The main characteristics of gas-pumping units produced by the Russian enterprises

Forepart from GPU made by Russian enterprises, units of leading firms of the world are installed on Russian gas pipelines; the basic types of such machines are shown in Table 3.

Parameters	Centaurus	GTK-25I	GTK-10I	Coberra 182
	Solar Turbines (USA)	Nuovo Pignone (Italy)	General Electric (USA), Nuovo Pignone (Italy), AEG-Kanis (Germany), John Brown (UK), Thomassen Int. (Netherland), Hitachi (Japan)	Rolls-Royce (UK), Cooper Bessemer (USA)
Power, kW	2 620	25 000	10 000	12 500
Gas temperature at turbine inlet, K	1113	1223	1198	1173
Air flow at compressor inlet, kg/s	14.7	117	52	78
Compressor pressure ratio	7	8.2	8.2	10
Number of shafts	2	2	2	2
Number of compressor stages	11	16	15	17
Rated revolutions, min^{-1} of gas-generator shaft	14 600	5 100	7 100	7 500
of power shaft	15 700	4 670	6 500	5 000
Actual efficiency of GPU, %	24	27.2	25.1	28
Specific weight of GTU, kg/kW	1.1	3.5	6.3	1.6
Overhaul life, thousand hours	30	24	24	24

Table 3. The main characteristics of gas-pumping units of various firms installed on gas pipelines of Russia

GPU for gas pipelines are designed not only as special stationary units and by specialized design bureaus: they also are converted from aircraft (turbojet, turboprop, turbofan) engines, and are designed on the structural base of engines for ships. Some examples of such GPU are GPA-Tz-6.3 with a capacity 6.3 MW, transformed from an aviation engine of NK-12 series, and GPA-Tz-16 with a capacity 16 MW (see Table 2), in which engine of NK-16ST series serves as a drive of gas supercharger; this engine is produced on the basis of the dual-flow turbojet engine (DFTE) NK-8, which is in operation on TU – 154 aircraft.

During the 1990s the family of GPU constructed on the basis of aircraft engines was replenished by GTU of NK-14ST series (beginning of output is 1992, capacity 8 MW), NK-40ST (1995, 10 MW), NK-38ST (1995, 16 MW) and the most powerful GTU of this series NK-36ST (1993, 25 MW). The high efficiency units of this family – greatest with GTU NK-38ST and NK-36ST (38 per cent) – is achieved due to the large compressor pressure ratios (respectively 25.9% and 23.1%) and high inlet gas temperature (respectively 1475 and 1420 K).

The Aviadvigatel enterprise in 1994 on the basis of aviation engines besides power installations has adjusted release of driving units of series GTU-12P (1994, 12 MW, T_g = 1353 K, π = 15.8, η = 34.5 per cent); GTU-16P (1996, 16 MW, T_g = 1416 K, π = 19.8, η = 37 per cent); GTU-8P (1997, 8 MW, T_g = 1178 K, η = 14.7, η = 37 per cent); GTU-10P (1997, 10 MW, T_g = 1250 K, π = 14.7, η = 34 per cent); GTU-25P (1998, 25 MW, T_g = 1515 K, π = 28.7, η = 40 per cent). In 1977 a prototype model of unit of GPA-10 series (see Table 2) having a capacity 10 MW with marine GTE were made. The engines of this type were made in a block mode are intended for installation on the floor level in machine halls or individual shelters of the lightly built structure. The turbo-compressor part of the unit can be installed without shelter in the container. The volume of construction and assembly works at the site of the compressor station with eight units of GPA-10 series is less in 1.7 times, and the volume of human labor is less than two times relative to GTK-10 series by NMW.

Later forepart from units of GPA-10 series on the basis of marine engines the units of other types have begun to produce: GT15001 (1988, 17.8 MW, T_g = 1348 K, π = 19.6, η = 35 per cent); GT16001 (1989, 17.2 MW, T_g = 1138 K, π = 12.8, η = 32 per cent); GT25000 (1993, 27.9 MW, T_g = 1500 K, π = 21.8, η = 36 per cent).

Despite obvious successes in the creation of GPU, there are serious problems, which should be solved. The first problem is relatively large fuel consumption in GTU. Valuable natural gas itself as it is pumped, is used as fuel for GTU in compressor stations, and it is very important to make this consumption as small as possible, because in essence gas is spent for auxiliary purpose. The most rational approach to the problem is, certainly, replacement of units, which have practically served their term, with the GTU of new generation distinguished by higher efficiency. Sophistication of the thermodynamic cycle of gas pumping GTU is one of the promising directions towards improvement of its fuel efficiency. In this context higher efficiency could be obtained at rather moderate temperatures in the gas turbine and pressure ratios in compressor of GTU. GTU 'Nadezhda' ('Hope'), which is mentioned above (its capacity is 16.3 MW and efficiency is 42-43 per cent), is an example of such approach: thermodynamic cycle of this unit includes intermediate air cooling and heat regeneration.

GTU can be applied for mechanical drive not only on gas-, but also oil pipelines for pumping petroleum. One of the largest oil pipelines equipped with eleven pumping stations with GTU, is the oil pipeline in Saudi Arabia, by which every day about 4.10^5 m^3 of petroleum are pumped through all the Arabian peninsula. On each of the stations are installed three GTU of such series as GT4A-9 of capacity 20.4 MW each. Fuel for these units could be not only the pumped crude petroleum after some processing, but also natural gas. Stationary GTU drives find use in chemical and metallurgical industries, in which plenty of heat is dissipated. GTUs, which are included in these technological cycles, usually named as technological units.

Technological GTU are used in the manufacture of nitric acid and in blast-furnace process; there are possibilities in the synthesis of ammonia, in by-product coke plants, in the production of sulfuric acid, ethylene, methanol and other chemical products, and also in oil refining industries. The Russian plant 'Dalenergomash' (Khabarovsk) under the license of NMW makes the gas turbine units of two types: GTT-3 and GTT-12 for the process of manufacture of dilute nitric acid. NMW itself produced gas turbine units of GTT-12 and KMA-2 series on the basis of GTK-10 for the same purpose. These units work in corrosive media, therefore their life time is a little bit lower, than their prototypes, and in five-six years of service they require replacement. For this purpose the new technological unit KMA-4 series was developed. In it all the experience gained during the operation of the prototypes was taken into account and measures for improvement of ecological performance of GTU were stipulated.

Modern blast furnaces have an output gas equal 300-400 thousand m^3/h and work with excess gas pressure equal to 0.155-0.255 MPa. Most effectively this pressure can be used in the so-called utilization gas-turbine unit (UGTU) without compressors. Gas turbines working on blast-furnace gas are installed in several metallurgical works in Russia, Japan, Italy, and India. In a petrochemical industry there are many possibilities for increasing the efficiency of complete transformation of energy at application of GTU: up to 75% in oil refineries in comparison with 55% in application of steam-turbine units and up to 80% in gas-conversion plants. Fuel consumption, which is in technological processes, could be reduced with GTU by 6-8.5 per cent. In oil refineries, the compressor gives compressed air for burning of coke formed by passing petroleum vapor through reactor, and products of combustion which are obtained as a result of this process, are utilized by the gas turbine, which drives the compressor.

There are also other effective ways of application of GTU in gas- and oil refining plants. General Electric Co alone made and put in operation more than 500 similar GTU each of individual capacity up to 30–35 MW. Technological GTU can find application in combination with steam-turbine units in industrial enterprises requiring simultaneous production of heat and energy of various kinds. Such installations are widely applied. Solar Co. (USA) has been delivering GTU for industries consuming energy and heat, already for more than 25 years. More than 300 GTU of capacity from 800 up to 7 400 kW from this manufacturer have a common operating time of more than 8 mln. h. Some installations made up to 100 thousand h. The same company delivers steam-gas turbine units of capacity 14 MW, using the products of processing of waste of residential areas of large cities as fuel.

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article gives brief information about the state of business with application of wind turbines in the world, about the basic theory of wind turbines, about effect of wind turbines on environment].

Biographical Sketch

Eduard A. Manushin – Candidate of sciences (Ph.D.) (Technics) – 1964; Doctor of Sciences (Technics) – 1978; Professor – 1980; Full Member of the Russian Academy of Education (former – Academy of Pedagogical Sciences of the USSR) – 1989. Graduated from Moscow Higher Technical School (now Moscow State Technical University – MSTU) named after N. Bauman (1956), specialty – engineer-mechanic in turbine-building. Engineer, lecturer, professor of MSTU (1956-1986). First vice-rector of MSTU (1986-1991). First vice-rector of the Russian Academy of Administration (1991-1994). General Director of the International System Research Center for Higher Education and Science (1995-1999). Academician-Secretary of the Higher Education Department of the Russian Academy of Education (1997-2002). Editor-in-Chief of the MAGISTER-PRESS Publishing House (1999 till now). Professor of MHTS (till now). Research interests are concerned on energy-machine-building, specifically – in the sphere of construction and computing of gas turbine and combined units, in particular – in cooling systems of high temperature gas-turbine engines. Besides of this he is the specialist in the field of pedagogy of the higher school and in the sphere of informatization of education. He has 16 textbooks, more than 150 scientific articles. His recent publications include *Theory and designing of gas turbine and combined units* (textbook, 2000, with co-authors); *Heat-transfer apparatus and cooling systems of gas turbine and combined units* (textbook, 2003, with co-authors); *Education and 21st century: Information and communication technology* (with co-authors, 1999); *History of Humanity* (Russian edition of UNESCO Encyclopedia in 7 volumes – editor of 1-6 issued volumes).