GAS TURBINE ENGINES FOR MARINE AND ROAD TRANSPORT

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Contents

Summary

The main demands for the transport gas turbine units were determined. Road transport and ship gas turbine engines development periods; the most rational fields of their application, their advantages and disadvantages in comparison with other engine types were discussed. Thermodynamic cycle analyses and principle schemes of gas turbine units were carried out. The construction examples of most typical gas turbine engines in different classes of ship, wheel and truck machines and railway transport power units

were given. The main problems under these engine operation and their probable solution ways were shown. The future transport gas turbine development was discussed.

1. Introduction

Presently available gas turbines (GT) find an ever-growing use in marine and land vehicle power plants due to many advantages they can offer over other thermal engines. The principal advantages of GT are: best specific mass and overall dimensions, abandonment of the liquid-cooling systems, simple maintenance, good cold starting characteristics, clean exhaust due to high air-fuel ratio etc.. Some advantages of GT are of critical importance in the selection of this engine for a certain type of vehicle. Thus, carrying capacity of some heavy dumpers may exceed 100 t. GT engines having output of 1000 kW and more are available and up to 1500 kW in the nearest future. Diesels of similar output level have excessive weight and overall dimensional data, worse torque and exhaust with toxic characteristics, more time-consuming maintenance than that for GT. The most important requirements for power plants of military vehicles are: space saving, good cold starting characteristics, simplicity of the operational control. Automotive engines must release minimum of the toxic components in exhaust gases and have simple maintenance. GT application to the heavy duty automotives and trucks having mass 25 – 50 t must have 350 – 400 kW power unit and it will promote driving, simplify maintenance, permit abandonment of the liquid-cooling systems, improve reliability of the power-unit [1].

The above-mentioned advantages stipulate application of GT in marine and traffic power plants. Turbine engines are used in ships, for which little specific weight and overall dimensions have essential significance, possibilities for any engine parts immediate replacement, maneuverability [2].

GT are extensively used in the navy and in dynamic support principal ships – hovercrafts and hydrofoils. GT have better specific data in comparison with steam-turbine unit due to the elimination of the feed water heating boiler, less number of auxiliary instruments. GT demonstrates low cost of service in operation, ease of automation. In comparison with reciprocating internal combustion engines marine GT is also profitable in size and weight, may use cheaper fuel (oil fuel for instance), is simpler in service.

However marine and transport GT are superior to diesel power plants in fuel economy when applied to the ships and heavy-duty automobiles. It also relates to the steam turbine marine power plants and gas internal combustion engines, which are the main type of low power engines for land transport.

2. Requirements of transport power plants

The term “power plant” must be understood as a combination of engines with systems providing its operation in different conditions of operation. Thos e combinations include: fuel and lubrication systems, starting device control and testing system, air delivery and cleaning system, cooling system, exhaust gas devices system etc.. Besides power generation for propulsion, as a general purpose, additional requirements imposed on the power plant are provisions with electricity, steam and compressed air for service aid. These requirements are achieved by the use of special-purpose equipment (electric generator, air compressor) driven by the shaft of the main engine or by the auxiliary power unit (APU). Application of the turbine or piston APU raises the overhaul period of the main engine and improves economy of the vehicle in operation. It can be achieved by disengaging of the main engine or by reducing its operation period when the ship or vehicle is inoperative. APU is also used to facilitate main engine starting.

Power plants may also contain additional devices providing characteristics of supplementary modes – for instance, for retardation or reverse (for ships). Engine purpose must be taken into account while developing the base engine models for transport or their modifications. These requirements depend principally on the load and operation modes. Mutual influence of the engine and environment must also be taken into account.

2.1. Requirements determined by load distinctions

The main engine of transport is connected with the propelling agent through a reduction gear which is used to match speeds of the engine shaft with that of the propelling shaft. Electrical transmission (having generator and motor) or hydraulic drives are used less often. Transmission must afford reverse of transport or possibility of a variety gear ratio (in land vehicles). Marine power plant transmission can be used for power summation of several engines or for power distribution to different propelling agents.

Fixed blade propeller characteristics are approximately proportionate to the squared torque at the given speed. Therefore, torque sharply decreases with propeller speed drop.

By contrast, characteristics of the load at an automotive engine shaft or at an adjustable propeller present a field of possible modes. Thus different amounts of automotive engine torque can correspond to each speed of the carrying wheel depending on ground characteristics, road slope, and other factors.

At straight-line traffic of the vehicle having mass G and speed V on the road with level or slope angle α, the torque at the carrying wheel is:

- overcoming slope force $P_1 = G \cdot \sin\alpha$, where angle α depends on the transport purpose
- overcoming ground resistant force $P_2 = G \cdot f_{gr} \cdot \cos\alpha$, where f_{gr} is the ground resistance coefficient (approximately 0.02 for asphalt, 0.03…0.05 for dry soil road, 0.08…0.1 for sand road),
- aerodynamic resistance force $P_3 = k \cdot F \cdot V^2$, where F – automotive cross section,
- k – air resistance coefficient, depending on the shape and surface quality.

Taking into consideration $f_r = f_{gr} \cdot \cos\alpha + \sin\alpha$, where f_r - resistance coefficient for the automobile steady-state traffic, carrying wheel torque is $M_{cw} = R_{cw} \bullet (G \bullet f_r + k \cdot F \cdot V^2)$, where R_{cw} – radius of the carrying wheel. Torque at the aft shaft $M_a = M_{cw} \bullet (i_{tr} \cdot \eta_{tr} \cdot \eta_{ch})$, where i_{tr} – transmission gear ratio; η_{tr}, η_{ch} – transmission and chassis efficiency.

Wide load range for automobile include: starting, level and slope traffic in different road conditions. It becomes necessary to use the gearbox, i.e. increment transmission application dependents on the automobile traffic speed. This requirement cannot be satisfied by the application of a single shaft GT, combined with constant gear ratio transmission whose characteristics relate to 60 – 100 % of the aft shaft speed range (at n < 60% the inadmissible rise of gas temperature begins). It also leads to the rapid drop of torque with the reduction of rotation speed.

Two or three-shaft GT with free power turbine (load turbine) in this respect have acceptable propulsion torque characteristics in full speed range. Practically, it rises proportionally to the drop of the shaft speed, up to shut-down without engine off.

In project stage of the GT transient mode, conditions must be taken into consideration when necessary to provide acceleration or deceleration, start or stop of the engine. These modes are of first-rate importance, because transient modes in operation often define the dynamics of the vehicle concerned with the rate of acceleration or deceleration. Important and evident requirement of an engine is maneuverability of vehicle or ship, including propulsion stop and reverse. Introducing special devices can attain retarding modes of the transport power plants (for instance: retarder in automobile, reverse turbine in ship power plant). The other way is to apply special devices such as variable nozzle and shaft lock-up clutch. Note should be taken that GT provides greater moment of inertia to the shaft than piston engine in spite of the lower moment of inertia of the power turbine wheel. Therefore the equivalent retardation dynamics of the vehicle can be attained when GT power plant at similar moment can afford as twice torque as power plant with diesel.

2.2. Requirements determined by operational conditions

The main operational requirements of transport power units are as follows: economical operation, reliability, long service live before the overhaul, simplicity of service and low cost of operation. The dimensional value and the mass of a power installation as well as the possibility of using various types of fuels (including cheap ones), the oil consumption quantity and the necessity of utilizing other special fluids, the possibility of putting the engine into operation easily under different conditions, including negative air temperature, the simplicity of controlling and other factors are of great importance nowadays.

The engine with its systems has to be located under design limitations attributed to its application in the particular vehicle. It should have a good access to places of maintenance and regulations as well (fuel instrumentation, filters).

The run distance of transport vehicle and the floating of the vessel are defined by the quantity of fuel, by the unit power and the specific fuel consumption of an engine (or by effective efficiency). The efficiency is of primary importance while defining the operational traveling fuel consumption, which in its turn depends on both the profitability of the engine under different operation working conditions and on the time span of these conditions. Depending on the type and purpose of the vehicle (vessel) and on its operation conditions, the engine operational schedules are essentially different.

For example, a city bus on a line or a car in the urban cycle, a tanker on a long distance line or a boat at coast guard appear to have absolutely different operating conditions and time span for engine load operation. The traveling fuel consumption is greatly influenced by the idle engine duration and by the idle fuel consumption.

The engine has to meet the requirements of the customers in its reliability. This integrated concept is composed of both long service life and the original life before the capital repair, of a non-stop as the accessible number of failures during a certain interval of operational time. It should also include the concept of maintainability, the ability of control and keeping quality.

The engine design should be calculated for the effect of transport loading, rolls and trims taking place while the vehicle is traveling. The air feeding system should prevent water or abrasive particles (dust) to get into the engine in order to avoid erosion or contamination of the compressor and the turbine blades.

In order to decrease the engine designing and production cost the possibility of their multipurpose application as aviation, transport and ship engines are often discussed.

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Biographical Sketch

Nick I. Troitsky - Candidate of sciences (Ph.D. Technical) – 1977; Full Member of the Russian Academy of Quality Problems - 1994. Graduated from Moscow Higher Technical School (now Moscow State Technical University – MSTU) named after N. Bauman (1961), specialty – engineer-mechanic in turbine building.

Engineer-designer, Chief-engineer, Deputy Director of Gas Turbine Division of Engine Research Institute - NIID (1961-1988). First vice-director of NIID (1988-1991), Director of NIID (1991 till now). Lecturer of MSTU (1979 till now). Research interests are concerned on energy-machine-building, concretely – in sphere of gas turbine for vehicles, in particular – in constructions and characteristics of engines.

His recent publications include *Engines for Armored Vehicles:* Military Parade, nov.-dec.1996 (with co-author); *Which shout be the Tanks Engines at 21st century:* Dvigatel, Yule, 1999 (with co-authors).