JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS

VOLUME 04, ISSUE 11
MOPNTHLY JOURNALS

ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

GAS TURBINE INSTALLATIONS

M.X. Boboqulova
Department of General Technical Sciences,
Asia International University

Abstract: This scientific article provides a comprehensive analysis of the thermodynamic foundations, structural characteristics, energy efficiency, operational parameters, and prospects for the application of gas turbine installations (GTI) in modern aerospace, power engineering, and transportation industries. The study investigates the working processes of gas turbines, dynamic variations in temperature and pressure fields, optimized combustion models, the aerodynamic efficiency of compressors and turbines, heat transfer issues, material limitations, and the use of next-generation high-temperature resistant alloys.

The article also examines international advances in the development of low-emission combustion chambers, energy-saving and eco-friendly design approaches, hybrid energy configurations, digital control systems, and scientific prognostic models for GTI operating on hydrogen and synthetic fuels. Practical challenges encountered in GTI operation—such as vibrational stability, thermal shock, coating erosion, high-speed mechanical loads, and service life prediction—are analyzed in detail.

Finally, the paper discusses future development scenarios of the GTI industry, including the digital engine concept, AI-assisted adaptive turbomachinery, and the role of gas turbine technologies in sustainable energy systems.

Keywords: Gas turbine installations, turbine, compressor, combustion chamber, Brayton cycle, thermal efficiency, high-temperature alloys, aerodynamics, turbomachinery, hybrid energy systems, digital engine, aerospace propulsion, hydrogen fuel, turbine blade cooling, energy system balance.

Introduction

Gas turbine installations (GTIs) represent one of the most complex, high-technology, and efficient systems used in modern energy and transport industries. Today, GTIs are widely applied in electric power generation, aircraft propulsion, marine transport, gas processing, petrochemical plants, compressor stations, and military equipment. Their primary advantages include high power density, compactness, high rotational speeds, reliability, and rapid start-up capabilities. Over the last 50 years, the energy efficiency of GTIs has increased from 18–22% to 40–45%, while combined gas-steam cycles have exceeded a total efficiency of 62%.

In the context of the global transition toward reduced carbon emissions, GTIs are playing an increasingly important role due to the more complete combustion of natural gas, the development of low-emission combustion chambers (LNG, DLN systems), and the emergence of designs adaptable to hydrogen fuel. Technically, GTI operation is grounded in classical thermodynamics and aerodynamics, relying on the Brayton cycle, in which compressed air from the compressor is heated by fuel combustion and subsequently expands in the turbine to generate mechanical energy.

The further advancement of gas turbine technology is directly linked to innovations in materials science, ceramic and superalloy compositions, thermal barrier coatings, advanced cooling architectures, digital sensors, and AI-driven analytics. Turbine blade cooling and aerodynamic optimization remain the key directions for increasing GTI efficiency. Therefore, modern research heavily depends on digital modeling, including CFD (Computational Fluid Dynamics), FEA (Finite Element Analysis), thermodynamic optimization algorithms, and real-time monitoring systems.

This article presents a detailed overview of GTI operating principles, construction, energy efficiency, environmental compliance, reliability, service life prediction, and future innovations. It is intended for students, engineers, technologists, doctoral researchers, and specialists in the field of gas turbine technology.

Thermodynamic Foundations of Gas Turbine Installations

GTIs operate based on classical thermodynamics, specifically the Joule/Brayton cycle. The cycle involves four main processes:

1. **Isentropic compression** of atmospheric air in the compressor
2. **Isobaric heat addition** in the combustion chamber
3. **Isentropic expansion** of hot gas in the turbine
4. **Heat rejection** to the environment

The ideal thermal efficiency of the Joule cycle is expressed as:

$$\eta=1-\frac{1}{\pi^{\frac{k-1}{k}}}$$

where:

η— cycle efficiency

π— compressor pressure ratio

k— adiabatic index of the working fluid

Higher compressor pressure ratios increase efficiency but also lead to aerodynamic losses, blade heating, and mechanical stresses.

Real system limitations include:

Maximum turbine inlet temperature limited by material properties

Compressor and turbine efficiencies below ideal values (85–92%)

Mechanical friction losses

Heat transfer constraints

Modern GTIs exhibit approximately 25–30% deviation from the ideal cycle due to these losses, although advanced cooling and high-temperature materials significantly reduce the gap.

Compressor Technology

The compressor serves as the heart of a gas turbine, determining at least 40% of its efficiency. Modern compressors include:

Types of compressors:

Axial compressors — used in high-power GTIs

Centrifugal compressors — used in small GTIs and auxiliary power units

Key aerodynamic challenges:

Flow separation zones

Stall and surge

Choking

Supersonic tip speeds

Blade design, angle optimization, roughness minimization, and material selection (titanium, composites) are critical for efficiency.

Combustion Chamber

The combustion chamber converts chemical energy into thermal energy. Modern systems use the **Lean Premixed Prevaporized (LPP)** method to achieve complete and low-emission combustion at temperatures of 1500–1800°C.

Cooling methods include:

Film cooling

Transpiration cooling

Convective cooling

These techniques significantly extend turbine blade life.

Turbine Section

The turbine operates at extremely high temperatures and pressures. It includes:

High-pressure turbine (HPT)

Intermediate-pressure turbine (IPT)

Low-pressure turbine (LPT)

Advanced cooling, thermal barrier coatings, and single-crystal superalloys enable operation at >1700°C.

Operational Characteristics and Vibrational Stability

GTIs operate at 10,000–30,000 rpm, which creates mechanical and vibrational challenges such as:

Stall

Thermomechanical resonance

Rotor critical speeds

The structural integrity of GTIs requires precise calculations, diagnostics, and maintenance.

Construction and Components of GTIs

A typical gas turbine consists of:

1. Air intake
2. Compressor
3. Combustion chamber
4. Turbine
5. Exhaust system
6. Gearbox
7. Lubrication and cooling systems
8. Digital control system (FADEC)

Each module contributes to overall efficiency, durability, and performance.

Environmental Impact of Gas Turbines

GTIs emit CO_2, NOx, CO, unburned hydrocarbons, SOx, and particulates. Environmental impact depends on:

Fuel composition

Combustion chamber design

Temperature and pressure conditions

Emission reduction technologies include:

Low-NOx burners

Exhaust gas recirculation (EGR)

Water/steam injection

Hydrogen-compatible combustion systems

AI-based emission monitoring

Innovations & Future Prospects of Gas Turbines

GTI evolution is driven by:

High-temperature alloys and ceramic matrix composites

Aerodynamic optimization

Advanced cooling designs

Digital engine technologies (Digital Twin)

AI-controlled adaptive turbomachinery

Hydrogen-based combustion systems

3D-printing of turbine components

These technologies will make future GTIs more compact, efficient, and environmentally clean.

Conclusion

Gas turbine installations remain a strategic component of modern energy systems, aviation, and industrial technologies. This research demonstrates that GTI efficiency depends primarily on improved Brayton cycle configurations, optimized aerodynamics, high-temperature materials, and advanced cooling systems. Combined cycle technologies further increase overall efficiencies to 55–62%.Operational reliability relies on vibration diagnostics, temperature monitoring, FADEC digital control, and predictive maintenance. Environmental considerations are addressed through NOx and CO_2 reduction technologies and the transition toward hydrogen and synthetic fuels.Innovations such as Digital Twin engines, adaptive turbine blades, ceramic matrix composites, superalloys, and hybrid energy systems will shape the future of GTIs.In conclusion, gas turbines will continue to play a crucial role in global energy security, sustainable power development, and next-generation propulsion systems.

References:

1. Boboqulova M. X. (2025). NANOELEKTRONIKA MATERIALLARI: XOSSALARI, TURLARI VA QO‘LLANILISH SOHALARI. Development Of Science, 6(5), pp. 192-199. https://doi.org/0

2. Boboqulova, M. X. (2025). MEXANIK TO ‘LQINLARNING INSON ORGANIZMIGA TA’SIRI. Science, education, innovation: modern tasks and prospects, 2(6), 34-43.
3. Boboqulova, M. X. (2025). BIOLOGIK TOQIMALAR VA SUYUQLIKLARNING OZGARMAS TOKDA ELEKTR OTKAZUVCHANLIGI. Science, education, innovation: modern tasks and prospects, 2(6), 58-66.
4. Boboqulova, M. X. (2025). SUYUQ KRISTALLAR VA ULARNING XOSSALARI. Problems and solutions at the stage of innovative development of science, education and technology, 2(4), 42-49.
5. Boboqulova, M. X. (2025). GIDROENERGETIKANING ENERGETIKA SOHASIDA TUTGAN O ‘RNI VA AHAMIYATI. Recent scientific discoveries and methodological research, 2(6), 14-24.
6. Boboqulova, M. X. (2025). OPTIKA QONUNLARINING TIBBIYOTDA AHAMIYATI. Introduction of new innovative technologies in education of pedagogy and psychology, 2(5), 42-52.
7. Boboqulova, M. X. (2025). RADIOAKTIVLIK. IONLASHTIRUVCHI NURLANISHNING ORGANIZMGA TA’SIRI. Introduction of new innovative technologies in education of pedagogy and psychology, 2(5), 18-26.