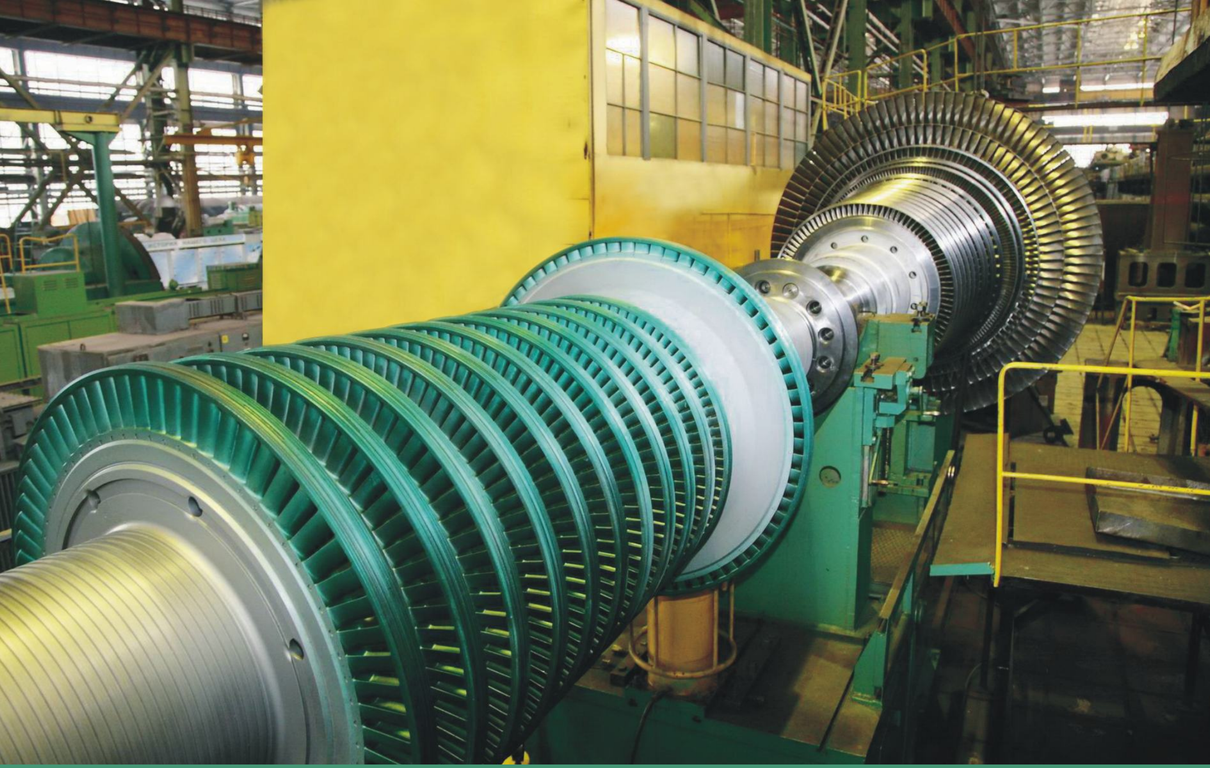

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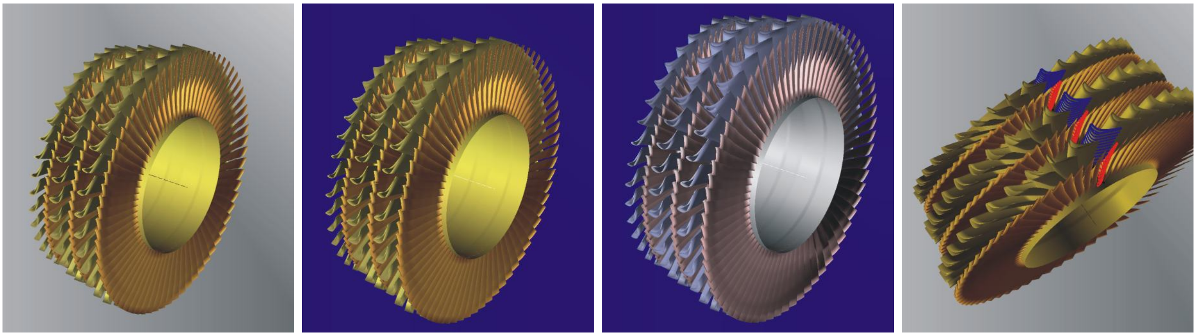

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Preface

The decades of the 1970s and 1980s of the last century were marked by the emergence and rapid development of a new scientific direction in turbine manufacturing – optimal design. A summary of the approaches, models, and optimization methods for axial turbine flow path is presented in the monographs [13–15 and 24].

It should be noted that work on the optimal design of the flow path of axial turbines and the results obtained not only have not lost their relevance, but are now widely developing. Evidence of this is the large number of publications on the topic and their steady growth. Optimization of the turbomachine flow path is a priority area of research and development of leading companies and universities. Without the use of optimization, it is impossible nowadays to talk about progress made in the creation of high efficiency flow paths of turbomachines.

It is worth noting that the widespread use in power engineering of modern achievements of hydro-aerodynamics, the theory of thermal processes, dynamics and strength of machines, materials science, and automatic control theory, is significantly expanding the range of tasks confronting the designer and greatly complicating them.

The proposed book comprehensively addresses the problem of turbomachine optimization, starting with the fundamentals of the optimization theory of the axial turbine flow paths, its development, and ending with specific examples of the optimal design of cylinder axial turbines.

It should be noted that the mutual influence of designed objects of turbine installations and the many design parameters of each object, which the product's effectiveness depends on, is putting the task of multiparameter optimization on the agenda.

For turbines with extractions of working media for various needs, efficiency ceases to be the sole criterion of optimality. It is necessary to enable in the optimization process such important parameters as power supply. The task of optimal design of turbine has become multifaceted.

It should also be stressed that often the turbo installation mode of operation is far from nominal. So taking into account the operating mode in the optimization can significantly improve the efficiency of the turbine.

In the book, along with the widely used methods of nonlinear programming, taking into account the complexity of the task and the many varied parameters, the use of the theory of planning the experiment coupled with the LP sequence to find the optimal solution is discussed.

The first chapter of the book deals with general issues of the optimal design of complex technical systems and, in particular, the problem of optimization of turbomachines, using one of the approaches to the design of turbo installations – a block-hierarchical view of the design process. With this priority is given to flow path optimization of axial turbines. The task of object design and using mathematical models is formulated. A brief overview of optimization techniques, including the optimization method for turbines considering mode of operation is given.

The second chapter is devoted to the mathematical modeling of flow path elements of turbomachines. Special attention is paid to aerodynamic models of flow through the flow path, including flow through axial cascades of turbine profiles, one-dimensional and axial-symmetric flow through the turbine stage and multistage turbomachine cylinders; geometric and strength models; a model for creating a thermal scheme for a gas turbines and the computation of system equations is set out.

The results of the numerous calculations are compared with experimental data.

Chapter 3 examines one of the most important tasks in designing turbines – determination of the optimal number of stages and distribution between them of the heat drop.

The problem of parameter optimization of the axial turbine stage along the radius considering the slope and curvature of the working medium stream lines is the subject of the fourth chapter of the book. It assesses the impact of leaks on the optimal spin laws of the guides and working wheels of the axial turbine stages in a wide range of changes of bushing ratios, and the results of the effect of tangential slope on characteristics of axial turbine stage are presented.

Chapter 5 is devoted to optimal profile creation, starting from the choice of the main parameters and the consideration of their formation methods. The methods for optimal profile creation using geometrical quality criteria and minimum profile losses are described, and the results of experimental research of initial and optimal profiles are given.

The important problem of turbine blade shape optimization, using aerodynamic computation is covered in Chapter 6 of the book. The presentation of blade geometry, file formats for storage blades and grids, building up the lateral surfaces of blades and the three-dimensional parametric model of turbine cascades are discussed, an algorithm of spatial aerodynamic optimization of axial turbine cascades and the influence of simple and complex slopes on the flow in the ring cascade is described, and the reasons for increasing the efficiency of the optimized turbine cascade are analyzed.

The seventh chapter sums up the results of the developed optimization theory by applying it to the optimum design of flow parts of powerful modern steam turbine cylinders at nominal mode of operation and flow path of gas turbine installations, taking into account their operational mode.

It should be noted that in the book attention is paid to the verification of developed mathematical models of flow path elements of axial turbines as well as to the results offered by methods and algorithms for optimization. A comparison of the results of calculations and optimization with experimental data of the modeling stages and with two stage air turbines as well as with the results of full-scale experimental research of powerful steam turbine in a wide range of modes of operation in a thermal power plant is performed.

The comparison of the results of experimental and calculated research data have convincingly confirmed that optimization calculations and designed and programmatically implemented mathematical models have a high degree of accuracy and adequately simulate the physical processes flow of the working medium in an axial turbine flow path.

The book convincingly shows that at the present stage of design and manufacturing of turbines (characterized by decades of accumulated positive experiences of creating high-performance flow paths) their further improvement is possible only using the most modern methods and software systems, capable of solving tasks of a multilevel object-oriented multicriterion and multiparameter optimization of the flow paths of axial turbines, taking into account their operational mode.

The book is intended for researchers and experts in design, calculation and research on turbomachines. It is useful for University faculty members, post-graduate students and senior undergraduate students of Technical Universities.

Authors express their sincere thanks to Director Engineering Institute Prof. Serbin S. I. for the kindly offered possibility of carrying out of CFD-calculations with usage ANSYS CFX at National Shipbuilding University named after Makarov. The authors also express gratitude to the junior scientist of National Technical University “Kharkiv Politecnical Institute” Naumenko Svetlana P. for her assistance on the final stage of work on the manuscript.

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Key Symbols

a – local sound velocity, m/g; inter-blade channel throat, mm;

B – blade's profile axial chord, mm;

b – blade's profile chord, mm;

c, c_r, c_u, c_z – absolute velocity and its components in the cylindrical coordinate system, m/s;

C_0 – velocity, equivalent to stage or module heat drop, m/s;

C_p – specific heat capacity at constant pressure, J/(kg·grad); pressure coefficient;

C_v – specific heat capacity at constant volume, J/(kg·grad);

D (or d) – stage (or annular cascade) diameter, mm;

F – stage (or channel) cross-section area, m^2;

G – mass flow rate, kg/s;

H – specific rothalpy (Bernoully constant) in the relative frame; turbine heat drop, J/kg;

L_u – specific peripheral work, J/kg;

Δh – specific kinetic energy loss, J/kg;

i– specific enthalpy, J/kg; incidence angle, grad;

k – isentropic factor;

ℓ – blade height, mm;

M – Mach number;

N – stage power, W;

N_{it} – a predetermined number of iterations;

n– number of stages in the module; rotation speed, rev/min;

P – pressure, MPa;

R (or ρ') – reaction degree by static stage input parameters;

$\bar{R}$ (or ρ) – reaction degree by total stage input parameters;

Re – Reynolds number;

r – stage radius, mm; profile's edge radius, mm;

r, φ, z – cylindrical coordinate system's axes;

S – specific entropy, J/(kg·grad); axial distance, m;

s – length (along a streamline), mm;

T – temperature, K;

t – cascade's pitch, mm;

u – rotor annular velocity, m/s;

w – fluid velocity in the relative frame, m/s;

z– number of blades; last turbine's stage;

α_n – heat recovery factor of the n-stage module;

α, β – angles between c, w and rotation direction u; $\tilde{\beta} = 180^\circ - \beta$, grad;

β_{r} – profile's metal angle, grad;

β_s – profile's stagger angle, grad;β_b = 90 °– β_s;

γ – angle in the meridional plane, grad;

ε (or θ) – flow turning angle in the cascade, grad;

ζ – loss factor, relative to dynamic head at the cascade outlet;

η_i – stage's internal efficiency;

η_u – stage's peripheral efficiency;

Λ – penalty coefficient; Lagrange’s coefficient;

μ – crown mass exchange coefficient; exit velocity utilization factor;

ν – velocities ratio, u/C_0;

ξ – relative (to stage’s heat drop) losses;

ρ – density, kg/m^3;

σ – entropy factor;

φ, ψ – velocity coefficients of stator and rotor blades;

χ – blockage factor;

Ψ – stream function;

Ψ^* – stream function at the tip;

ω – angular rotation speed, s^{-1};

$\aleph$ – stream line curvature, 1/м.

Indexes and Other Signs

0, 1, 2 – sections numbers at stage inlet, between vanes and at outlet;

abs – absolute;

add – additional;

as – additional stream;

bh – balance boles;

cons – constructive;

cr – critical;

cyl – cylinder;

def – defined;

e (or *eff*) – effective;

g (or *s*) – guide (stator) blade;

h (or *r*) – hub (root) radius;

i – stage number;

in – input;

j – section number;

l (or leak) – leakage;

ll – local losses;

m – module; at mean radius;

max – maximal;

min – minimal;

mix – mixture;

mod – module’s;

ms – main stream;

n – nominal;

nom – nominal;

opt – optimal;

out – rotor output;

p (or *t*) – peripheral (tip) radius;

r – rotor;

r.c. – radial clearance;

s – stream;

spec – specified;

T – corresponding to isentropic (theoretic) fluid expansion;

t – tip;

u – circumferential direction projection.

Abbreviations

C	– Compressor
CAD	– Computer aided design system
CC	– Combustion chamber
CU	– Gas compressor unit
EFF	– Efficiency
FMM	– Formal mathematical model
FP	– Flow path
GT	– Gas turbine
GTU	– Gas turbine unit
GV	– Guide vane
HPC	– High pressure cylinder
HPT	– High pressure turbine
IPC	– Intermediate pressure cylinder
LPC	– Low pressure cylinder
LPT	– Low pressure turbine
OMM	– Original mathematical model
R	– Regenerator
RH	– Reheating
RTE	– Recycling turbine expanders
RV	– Rotor vane
S	– Stator

SC – Natural gas supercharger

TC – Thermal cycle

TE – Turbine expanders