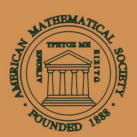
Mathematical Surveys and Monographs

Volume 92

Operators, Functions, and Systems: An Easy Reading

Volume 1: Hardy, Hankel, and Toeplitz

Nikolai K. Nikolski



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Volume 92

Operators, Functions, and Systems: An Easy Reading

Volume 1: Hardy, Hankel, and Toeplitz

Nikolai K. Nikolski

Translated by
Andreas Hartmann

American Mathematical Society

Based on a series of lecture notes, in French,
Université de Bordeaux, 1991–1995.
Translated by ANDREAS HARTMANN and greatly revised by the author

2000 *Mathematics Subject Classification.* Primary 47–02, 30–02, 93–02, 30D55, 47B35, 47A45, 93B05, 93C05.

ABSTRACT. The book joins four formally distant topics of analysis and its applications: Volume 1 contains 1) Hardy classes of holomorphic functions, 2) Spectral theory of Hankel and Toeplitz operators, and Volume 2 contains 3) Function models for linear operators on a Hilbert space and free interpolation, and 4) Infinite-dimensional system theory and signal processing. Beyond standard topics covered by these titles, it includes elements of maximal functions, Littlewood-Paley techniques, the Riemann zeta-function, Wiener filtering (all in Volume 1), as well as moment problems, reproducing kernel spaces, Schatten-von Neumann ideals, stationary processes, best rational approximations, similarity theory, and controllability with the least control operators (in Volume 2).

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A Few Words about the Book

WHAT THIS BOOK IS ABOUT

The book represents a mixture of harmonic and complex analysis with operator theory. The interplay between these disciplines is one of the most significant features of the second half of Twentieth century mathematics. It gave rise to several jewels of analysis, such as the theory of singular integral operators, Toeplitz operators, mathematical scattering theory, Sz.-Nagy-Foias model theory, the L. de Branges proof of the Bieberbach conjecture, as well as solving the principal interpolation problems in complex analysis and discovering the structural properties of function spaces (from Besov to Bergman).

The principal ingredients of the book are clear from the Contents and Subject Index, and indeed a simple list of key words tells more than long explanations. Without reproducing these lists nor the introductions to the four parts A, B, C, and D of the book, I would like give an abridged list of my favorite subjects, ordered by their appearance in the book:

Hardy classes
The Hilbert transformation
Weighted polynomial approximation
Cyclicity phenomena
Maximal and Littlewood-Paley functions
The Marcinkiewicz weak type interpolation
Wiener filtering theory
Riemann ζ function
Hankel operators: spectral theory, Peller's theory, moment problems
Reproducing kernel Hilbert spaces
Schatten-von Neumann operator ideals
Toeplitz operators
The operator corona problem
Spectral theory of normal operators
Sz.-Nagy-Foias function model
Von Neumann inequalities
Carleson and generalized free interpolations
Theory of spectral multiplicities
Elements of semigroup theory
Classical control theory of dynamical systems
Bases of exponentials on intervals of the real line
Elements of the H^∞ control theory

Style

I have tried to follow the logic of the above subjects as I understand it. As a consequence, this book is neither a function theory monograph, nor an operator theory manual. It is a treatise on operator-based function theory, or, if you prefer, function-based operator theory. As in my previous book "Treatise on the shift operator" (Springer, 1986) I have in mind a picture close to mathematical reality, where the most interesting and important facts take part of several disciplines simultaneously. This is why the way in which things proceed in this book is sometimes different from the appoved didactic style of presentation, when, first of all, background materials should be developed (even if you will need it 300 pages later...), then you go to the next preparatory level, and so on.

Here, new concepts and auxiliary materials appear when they are needed to continue the main theme. This theme is developed as theory of functions on the circle group and of operators acting on them, starting with the basic shift operator, then passing to stationary filtering, and Hankel and Toeplitz operators as compressions of the multiplication operators. Next, we arrive at the model theory for Hilbert space operators as (advanced) compressions of the same shift operator, and, finally, all this machinery is brought together to control dynamical systems. Therefore, taken as a style to telling mathematics, this is more a passion or a tale of mental intrigue than a rationally arranged catalog of facts.

It is also worth mentioning that this book has its origins in four courses I gave in 1992-1996 to graduate students in the University of Bordeaux, France. Although the courses were considerably extended when preparing this book, the text, perhaps, preserves the flavor of interaction with the audience: sometimes I repeat some notions or ideas already stated some tens (or hundreds...) of pages earlier to remind the reader of something what he may have forgotten from the last course.

Background

As it is clear from the preceding lines, the book can be read by anyone having a standard analysis background: Lebesgue measure, L^p spaces, elements of Fourier series and Fourier transforms (the Plancherel theorem), elementary holomorphic functions, Stone-Weierstrass theorem, Hilbert and Banach spaces, reflexivity, the Hahn-Banach theorem, compactness, and so on.

Formal structure

Parts A and B form the first volume of the book, and parts C and D form the second. Formally speaking, parts A, B, C and D are (reasonably) independent of each other in the sense that, for example, I may employ in part B some results of parts A, C, or D, but in the same way that I use (rarely) results from some exterior basic monographs.

The Parts are divided into chapters; there are 25 in the book. All chapters but one contain two special sections: *Exercises and Further Results*, and *Notes and Remarks*. These are important and inseparable parts of the book. To illustrate, the

book contains 1428 propositions conventionally called theorems, lemmas, corollaries, and exercises. For *Exercises and Further Results*, the proofs are called "hints", and while they are shorter they still contain all the principal ingredients to understand the proof. All exercises were tested by a team of volunteer readers whose names are listed below (there were no casualties...). Some (rare) facts included in exercises and not proved are marked by asterisk $*$.

Sections *Notes and Remarks* usually contain surveys of the rest of the theory presented in the main body of the corresponding chapter.

Reference $A.\alpha.\beta.\gamma$ means subsection $\alpha.\beta.\gamma$ of Part A; $\alpha.\beta$ means section β of chapter α of the Part where you are; $\alpha.\beta.\gamma(3)$ means point (3) of subsection $\alpha.\beta.\gamma$, etc. Sign $\square$ indicates the end of a proof or a reasoning.

The reader and the author

As it is clear from the subtitle of the book, I expect that some readers are novices, graduate or undergraduate students, possessing the needed knowledge indicated above. It is also supposed that some readers are experts. Well, I shall be rewarded if there is at least one. In this case, and also anticipating the inevitable reproaches as to why I selected such and such subjects and not others, I permit myself to quote (in my translation from Russian) a great philologist, an expert of texts as such.

"The answers books give us are to questions that are not exactly the same as the author set before himself, but to those that we are able to raise ourselves... The books encircle us like mirrors, in which we see only our own reflexion; the reason why it is, perhaps, not everywhere the same is because all these mirrors are curved, each in its own way."

M.L. Gasparov
"Philology as morality"

What is missed

Of course, I do not intend to list here the rest of mathematics but just to mention explicitly some border subjects that could have been included but were not. These are (without any ordering) *extremal problems* of complex analysis (starting from results of S.Ya. Khavinson and H. Shapiro in the 1960's); the *problems of harmonic analysis-synthesis* (from L. Schwartz and B. Malgrange of the 1950's); *invariant subspaces*, from the existence problem in a Hilbert space, up to (more important) classification problems for concrete operators (including descriptions of *closed ideals* in algebras of holomorphic functions); *singular integral models* for hypo- and semi-normal operators; *scattering*; *univalent functions* via quasi-orthogonal decompositions; *realization theory*; *operator valued constrained interpolation*, and some other themes. I have no better way to excuse these omissions than to follow E. Beckenbach and R. Bellman who quoted the following verses (for a similar purpose):

Oh, the little more, and how much it is!
And the little less, and what worlds away!

R. Browning (Saul.st.39)

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Several people read preliminary versions of the book and gave me their opinions, both mathematical and technical, especially by testing numerous exercises. For this I am greatly indebted to E. Abakumov, A. Aleksandrov, A. Baranov, A. Borichev, M. Gamal, V. Kapustin, S. Kislyakov, S. Shimorin, V. Vasyunin, P. Vitse. Also, I appreciate the time spent by my colleages A. Borichev, A. Hartmann and S. Kupin in helping me verify the reference list.

It has happened that a rather big part of this book, being lecture notes of my Bordeaux courses, was written in French, excepting some more recent additions. This part of the text was carefully translated into English by Andreas Hartmann, whose work essentially surpassed the simple translation including several constructive mathematical criticisms. I am very grateful to him for this work, as well as to Th.V. Pedersen for reading the translation and to D. Sherman for occasional advice.

My own function for completing preliminary lecture notes up to a self-contained book largely surpassed in time all predicted limits. During all these long months, my wife Ludmila steadily bore this somewhat rash enterprise, and all in all what is done bears the mark of her support.

I am also grateful to the publisher, the American Mathematical Society, for including the book in this series, and for having much patience during entire period of my work and enough flexibility at the moment when it became clear that the result would double the predicted size.

July 23, 2001
Gradignan

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