



SERIES ON HYDRAULIC MACHINERY – VOL.1

# Cavitation of Hydraulic Machinery



Editor  
S. C. Li

Imperial College Press



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# Cavitation of Hydraulic Machinery

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## PREFACE

It is a privilege to be asked to write a prefatory note on this remarkable reference book, the latest in the Hydraulic Machinery book series. It is unusually wide in scope, ranging from basic research to engineering applications. Its publication marks the achievement of a large team of specialists in cavitation research and in the design and operation of hydro-turbines and storage pumps.

Although the problem of cavitation in machines is an old one, dating back at least to the time of Galileo (16th century), it has not yet been completely solved. This is because hydraulic machines are faced with increasingly severe performance requirements demanded by economic pressures. The need to provide cheaper designs involving smaller and more powerful machines rotating at higher speeds continues to heighten the danger of cavitation. Despite improved techniques that have been developed for detecting and measuring cavitation, and thereby assessing the damage capacity of cavitating flows, they do not necessarily solve the problem, but may nevertheless provide useful guidance for avoiding trouble.

The International Editorial Committee of the book series decided to initiate an up to date review of the state of the art of coping with practical cavitation problems in hydraulic machinery. An imposing team of twenty specialists was formed to cover topics ranging from basic cavitation research, machine design and performance, cavitation and abrasion damage and its repair, and also cavitation induced machine vibration and transient oscillations. A study of the chapter headings will show the particularly wide variety of topics covered in one volume; it is also a welcome trend that they range from basic science/applied physics to engineering operations. This has required a well conceived plan and efficient organisation by a patient and indefatigable Editor who has also written several of the sections. With exemplary co-operation he and the other authors have been engaged for twelve years in producing this comprehensive review of current knowledge.

Congratulations and thanks are therefore due to all concerned with launching and completing this monumental task. I am sure that all readers will be most grateful to the international team's outstanding achievement in assembling this treasure trove.

S.P. Hutton  
Emeritus Professor  
University of Southampton

## Foreword of the Editor

The present book *Cavitation of Hydraulic Machinery* is a volume in the Hydraulic Machinery book series. It covers cavitation related subjects from fundamental mechanisms to practical applications in turbines and pumps<sup>1</sup>.

Cavitation is one of the most unwanted phenomena in hydraulic machinery despite the fact that it does have some positive effects in other fields. Although a great advance in understanding this phenomenon has been achieved in the last 100 years, our knowledge about cavitation is not good enough to precisely predict and completely solve this problem. Nowadays, most of the cavitation related work in hydraulic machinery still, to a great extent, relies on previous experience, model test and prototype observation.

After introducing cavitation and its relationship to hydraulic machines, the rest of this book falls naturally into two parts. The first part, Chapters 2, 3 and 4, deals with the fundamental knowledge necessary for understanding the cavitation involved in hydraulic machines. It includes: cavitation types, scale effects, nucleation and inception, single bubble dynamics, multi-bubble dynamics (bubble-bubble, bubble-boundary and bubble-flow interactions), stochastic models of cavitation bubbles, noise spectra, cavitating flows of hydro-foil and cascade, cavitating characteristics of valves and other hydraulic elements. The second part, Chapters 5, 6, 7 and 8, deals with cavitation related themes in turbines and pumps such as cavitation features, similarities, cavitation detection techniques, cavitation damage mechanism and features, synergism of cavitation with silt erosion, material resistances to cavitation damage, cavitation-damage repair, cavitation-induced pressure-pulsations, cavitation resonance, cavitating transient flow and computer simulation. As it is impossible to include all relevant subjects in a single volume, careful selection has been necessary. Only those basic concepts and new developments which are not covered by existing books and review articles<sup>2</sup> are given in-depth treatment. Extensive lists of references and footnotes are thus included to support the presentation and assist readers who want to dig deeper.

A total of 17 authors from 7 countries, all experts in their chosen fields, have made contributions to the book. By drawing upon wide resources and

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<sup>1</sup>As agreed at the Inaugural Meeting of the International Editorial Committee, the Book Series would deal only with hydro-turbines and pumps.

<sup>2</sup>Such as *Cavitation* by Knapp/Daily/Hammit (1970), *Cavitation* by Young (1989), *Cavitation and Bubble Dynamics* by Brennen (1995) and 'Cavitation in Fluid Machinery and Hydraulic Structure' (*Ann. Rev. Fluid Mech*) by Arndt (1981) etc.

experiences from North America, Europe, China, Russia, Japan etc, the book aims to give a more balanced view of the various topics. The editor is greatly indebted to all the authors for their valuable contributions and effective cooperation over last 12 years. Without their great efforts, the book would not have been possible. In particular, I would like to say a few words in memory of Professor Pierre Henry who died on 26th April 1994 from cancer. We miss him very much, he was only 54 and had built up the Lausanne Laboratory and established a brilliant reputation in unsteady operating conditions due to cavitating vortices. The sections of §7.1.3, §7.3 and §7.4 he wrote were mainly based on that remarkable work.

The structure and content of this book was originally proposed by the editor in 1983 as a monograph to be written in collaboration with Professor Fredrick G. Hammitt (University of Michigan, USA) as an effort to bridge the existing gap between fundamental cavitation phenomena and cavitation-related subjects in hydraulic machines. This book, together with another proposed joint book on the topic of transients in hydraulic machines, subsequently provided the inspiration for the Hydraulic Machinery book series. The International Editorial Committee (IECBSHM) was established for this purpose in 1986 in Beijing. Unfortunately, a deterioration in his health denied Professor Hammitt the opportunity to participate in the book. Nevertheless, his enthusiastic response to the editor's initial motion was a vital support and encouragement. I would like to take this opportunity to say a special word of thanks in memory of Fred, who passed away in 1989.

In order to provide up-to-date information to our readers, authors were allowed to amend their contributions right up to the last minute, squeezing the editing and compilation into the last few months. This presented me with a very complicated and intensive job. The support of the following persons was invaluable in achieving this. Many experts were invited to review manuscripts. Their constructive criticism, comments, discussion and suggestions are highly valued by the authors and the editor. They are Professor Peter W Carpenter (Warwick University, UK), Professors Allan Acosta, Dr. M L Billet and Professor C E Brennen (California Institute of Technology, USA), Dr. R K Turton (Loughborough University, UK) and Mr. Harland Topham (Water Turbine and Pump Consultant, UK). Thanks also go to Professor Duan C G and Dr A P Boldy of IECBSHM for their support; to Professor H Murai for his assistance in coordinating with some authors in the early stage; to Dr. Tony Price and Dr. Wanda Lewis (Warwick University, UK) for their advice; to Mrs. Wendy Murray (IT Services, Warwick University) for her assistance in preparing computer-editable source files from some



manuscripts; and to Mr. Alan Hulme (the Engineering Computer Manager) and the secretaries for their effective support.

The constant support and encouragement received from Professor David Anderson (the Chairman, School of Engineering) and Professor Peter W Carpenter (the Head of the Division, Civil & Mechanical Engineering), and the advice given by Dr S P Hutton (Professor Emeritus, University of Southampton, UK), who also wrote the preface, were greatly appreciated.

During the publishing process, the advice received from the commissioning editors, Dr John Navas, Mr Anthony Doyle, and the desk editor, Mr Yeow Hwa Quek, was vital that made this volume eventually available to our readers.

My work on the book is supported in part by the National Research Grant No. 87022190 of Water and Power (China), the EPSRC (Engineering and Physic Science Research Council, UK) Grants (GR/F57977 and GR/L74729), and the internal funds of the School of Engineering, Warwick University (UK).

The figures in the book have come from a variety of sources. The acknowledgement appears in the caption as a parenthetical reference keyed by the name(s) of the original author(s) and a number to the list of references at the chapter end where the source is cited in full. A particular thank you goes to Mr. R Stahel (Sulzer Hydro Ltd, Switzerland) who kindly supplied me with the original photos of Figures 6.14, 6.23, 6.24, 6.26 and 6.27.

Finally, the editor is in great debt to his family members for their understanding, support and forbearance during the lengthy process of writing and editing this book.

LI S C, Editor  
University of Warwick

## Contributing Authors

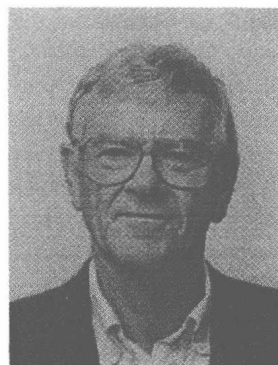
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Principal Research Fellow (Warwick University, UK). Founding member of IECBSHM. Distinction-graduation specialised in hydraulic machinery from the Beijing University of Hydraulic Engineering. PhD (self-guided) from Warwick University. Research Engineer, Ministry of Water Resources & Power, 1964-77. Since 1977, associated with the North China University of Water Resources. Visiting Scientist to the University of Michigan (USA) 1981-83. Research areas: cavitation in hydraulic machinery, stochastic behaviour of cavitation, transient flows of flow systems, developments of pioneering turbines and governors, turbine-test techniques.



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Member of the National Academy of Engineers (USA).

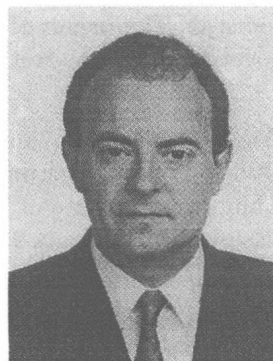
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Doctor of Technical Science. Graduated from the Moscow Aviation Institute in 1949. Author and co-author of 5 monographs, a branch reference book, a textbook, training aids, 90 scientific articles and 56 inventions. Scientific activities: improvement of cavitation characteristics for blade pumps with different working media; hydraulic improvement and cavitation erosion/tear prediction of large blade pumps; and, automation of technical process for land-reclamation stations.



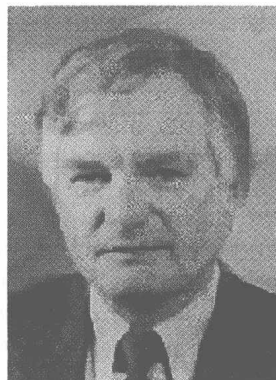
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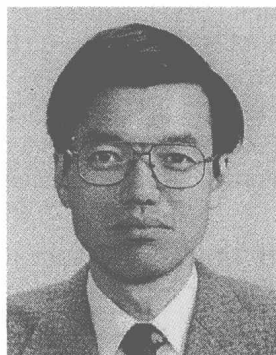
**Pierre Henry**, (Deceased) Professor,  
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Professor Henry died on the 26th April 1994 from cancer. The Sections, §7.1.3, §7.3 and §7.4, he prepared are included in this volume as a tribute to Pierre.



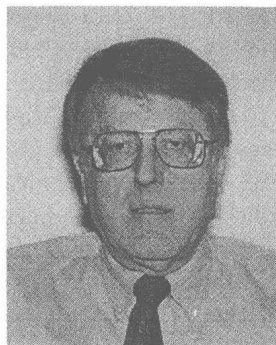
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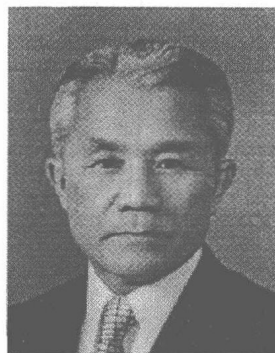
Born in USA in May 22, 1936. Ph.D (1964) and M.S. (1961) from Georgia Institute of Technology; B.S. (1958) from Virginia Polytechnic Institute and State University. Assistant (63-67), Associate (67-74) and full Professor (74-present) at Georgia Institute of Technology. Guest Professor (Technical University of Munich, West Germany, 1984-85; University of Karlsruhe, Germany, 1970-71). Ford Foundation Faculty Resident, Harza Engineering Company (1966-67).



Designer of Hydraulic Machinery, Newport News Shipbuilding and Dry Dock Company (1959-60). Professional Engineer, State of Georgia. Research experience: Cavitation characteristics of control valves using signal analysis, development of numerical methods for representing characteristics of hydraulic machinery (pump-turbines, Francis turbines and Kaplan turbines), hydraulic model testing (pump intakes, bifurcations and spillways). Honours: Alexander von Humboldt U.S. Senior Scientist Award (1984-85), American Society of Mechanical Engineers Fellow Election (1983), American Society of Civil Engineers J. C. Stevens Award (1977), American Society of Mechanical Engineers John R. Freeman Scholar (1970-71), Fulbright Travel Grantee (1970-71), Ford Foundation Faculty Fellow (1966-67) and Ford Foundation Fellowship (1961-62).

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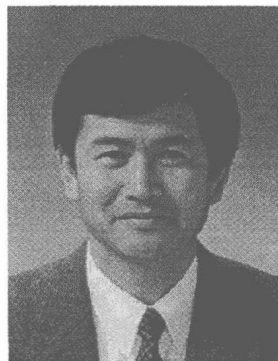
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