Termination Report

FLOW IN HYDRAULIC MACHINERY

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Hydrodynamics Laboratory
California Institute of Technology
Pasadena, California

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INTRODUCTION

This report concludes the work conducted by the Hydrodynamics Laboratory at the California Institute of Technology under Contract N6onr-244, Task II, in the general field of hydraulic machinery. This work was initiated in January 1947 under the initial guidance of Professors Knapp and Hollander. It has subsequently been continued by additional amendments to the original contract up to the present.

The over-all objectives of this program were to make detailed observations and measurements of the internal flow in rotating impellers and stationary diffusors to permit the establishment of accurate design procedures for hydraulic machinery, and to serve as a starting point for realistic mathematical analysis of such flows.

It is the intention of this report to indicate the scope of the work done under this contract and to describe the facilities built for its experimental end. A further aim is to outline, in brief, the reports and publications issued and some incidental benefits derived from this project.

SCOPE OF WORK AND FACILITIES

The basis of understanding and any analysis of the real fluid flows occurring in rotating turbo-machines rests on experimental work. For this reason it was decided at the very outset to emphasize the experimental approach.

Unlike the original Hydraulic Machinery Laboratory which used complete pumping units and measured as far as the impeller is concerned, only the in- and outflow velocities, pressures and torque, the purpose of this facility, as originally conceived, was mainly to investigate the complete flow picture through centrifugal and axial flow impellers, while permitting other research with only minor
changes. Thus the test facility had to be built for maximum flexibility within the limited space available.

Some unique features incorporated in it and some novel experimental techniques used with it are:

(a) Three test stands are located around a square central column. Two of these are provided with a metered flow in either direction.\textsuperscript{1,3} The third stand, originally made for central photography, is now replaced by the self-contained inducer facility.\textsuperscript{22} An additional self-contained test stand was also fabricated (with industrial sponsorship) for use with expensive working fluids.

(b) Specially designed, light weight, narrow line blind shut-off valves permit an easy change of the setup and compact arrangement of the piping.

(c) Special throttle valve with long travel for exact setting indicated by counter permit exact repetition of a test.

(d) Rotating water-manometer with up to 32 tubes directly connected by plastic tubing to the small brass tubes in the impeller hub leading to impeller blades. Thus the pressures along the impeller blades can be read very fast stroboscopically.

(e) Stereoscopic photography to observe three-dimensional flows.

(f) Lucite impeller shrouds for centrifugal impellers followed by lucite diffusors and similarly lucite blades and/or case for axial flow units for observation and photography.

The experimental work done falls roughly into three categories:

The first consists of over-all and internal flow observation and measurement in centrifugal pump impellers. Numerous different designs were employed all in the range of good efficiency as obtains in conventional pump practice. In the same category, two-dimensional impellers, with parallel shrouds, were also tested because the flows were the subject of comparison with potential flow theory. This project was one of the theses carried through at the laboratory.\textsuperscript{7,11,19}

Another thesis under this heading was the investigation of
different shroud boundaries by electrical analogy.\textsuperscript{20}

Using the modified test stand previously mentioned, a series of experiments was made on the effect of Reynolds number. A mixture of glycerine and water was used for this purpose and the work was carried out under industrial sponsorship. This work would not have been possible without the equipment and experience gained under the present contract.

The second category consists of experimental work on axial flow impellers suitable for operation in the pump rather than in the compressor field.\textsuperscript{8, 9, 10, 17}

Theoretical considerations led to a new design procedure for axial flow pumps and the experimental work was conducted to substantiate the theory.

The third category and the most recent area is an experimental investigation of cavitation. This work is being carried out with axial flow inducers. These are impellers designed to operate in the cavitating regime and their function is to supply the subsequent pumping stage with a pressurized stream of bubble-free liquid. The investigation of this problem is only in the preliminary stage, though some results are available.\textsuperscript{22} As with the other categories, some analytical studies have been, and are being, undertaken to interpret and clarify the experimental results.

The emphasis and direction of the work of the project as such has been described. However, the presence of this equipment and the project staff have provided opportunity and stimulus for additional research. As an example may be cited the complete pumping characteristic (Karman-Knapp) diagram for axial and mixed flow pumps\textsuperscript{18} previously only available for centrifugal machines.

Furthermore, as part of an educational institution with strong connections to Industry, this program made a real contribution by employing research engineers lent by industry, as well as graduate and undergraduate students, to make them familiar with experimental techniques and give scope to and develop their initiative to new
approaches. The five theses attest the effectiveness of this effort. Those graduated from this program are today heading or conducting research in these fields.

LIST OF PUBLICATIONS AND REPORTS

In this section the various technical reports and publications issued under this contract are listed. The titles usually are self-explanatory. Where they are not, a brief explanation is added. At the end of this list, various graduate theses done under the project, or with the use of the contract facilities, are reported.

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ACKNOWLEDGMENT

It is a real pleasure to express appreciation for the kind advice, criticism, encouragement and stimulation given by Professor Aladar Hollander.

The work reported herein has been made possible by the cooperation of other members of the Hydrodynamics Laboratory and Institute staff; among the latter, particularly Dr. Dino Morelli, who conducted the early tests, is prominent.

The writer would also like to acknowledge the support and interest of the Office of Naval Research in making this work possible.

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