OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

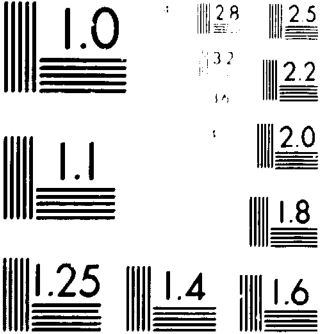
FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART

RESTRICTED

12399

DP/ID/SER.A/435
16 March 1983
English

ASSISTANCE TO MACHINE BUILDING INDUSTRY

DP/CPR/79/021

CHINA

Technical report: Design and testing of axial and mixed-flow pumps in the Chinese Academy of Agricultural Mechanization Sciences*

Prepared for the Government of China
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Ralph A. Nixon,
expert in pump engineering

United Nations Industrial Development Organization
Vienna

* This document has been reproduced without formal editing.

V.83-53530

Explanatory notes

CAAMS	The Chinese Academy of Agricultural Mechanization Sciences (Beijing, People's Republic of China)
NEL	The National Engineering Laboratory (Glasgow, Scotland)

ABSTRACT

Advice on design and testing of axial and mixed-flow pumps.

Post Key Code: DP/CPR/79/021/11-16/31.9.B

This report concerns a 3 month mission —25.11.82 to 19.2.83— to advise and assist the Irrigation and Drainage Machinery Research Division of the Chinese Academy of Agricultural Mechanization Sciences on the design and testing of Pumps used for irrigation and drainage in the People's Republic of China. The Academy is in Beijing, where the mission was spent, apart from a 5 day visit to Wuhan to advise on testing and operational problems of two large pumping stations for land drainage.

Technology transfer was effected in the form of comprehensive and detailed pump design and testing course notes from the National Engineering Laboratory, Scotland, from discussions and lectures, and a series of written reports, drawings, and mathematical analyses.

Modifications to improve testing methods for all the rigs were suggested, and one rig extensively redesigned. Some of the modifications have already been put into successful effect.

The work of the mission has provided a sound basis for the modernization and success of future design and testing at the Academy. Much must yet be done, particularly with regard to on-the-job training with computer-aided-design of pumps and use of data acquisition systems in hydraulic machinery research.

CONTENTS

INTRODUCTION

The Chinese Academy of Agricultural Mechanization Sciences (CAAMS) is an institution of the Ministry of Machine-Building Industry. Its Irrigation and Drainage Machinery Research Division has a pump and water-turbine testing laboratory. The purpose of this laboratory is principally for research and development of axial and mixed-flow pumps for irrigation and land drainage. There was a requirement for the improvement of pump design, the use of models, and of testing techniques. I had worked in a similar area in the Fluid Machinery Division of the National Engineering Laboratory (NEL) in Scotland for over 25 years, until November 1981. I had worked during that period for nearly 20 years on the drafting of British Standard and International Standard Organization (ISO) Pump Test Codes, in collaboration with experts from all the many countries who took part. In addition I was familiar with, and partly responsible for, some of the design and development of high specific speed pumps using computer aids. There was therefore a good possibility that a useful contribution could be made to the aims of the mission.

We agreed a programme of work shortly after arrival, and kept to it except for insignificant changes in order of execution.

It took two or three weeks to become thoroughly acquainted with all the problems of the laboratory, after which I was able to advise through the following channels:

i) Set discussions

a) in the office

b) on the job

ii) Informal discussions

iii) Technical notes written as a result of discussions

iv) Detailed pump design and testing information brought with me, or sent out to me during mission

v) Lectures

These activities took place at CAAMS, and occupied nearly all the time of the mission. I visited a pump factory in Beijing, another in Wuhan together with two pumping stations in the Wuhan area.

The report that follows describes these activities in some detail.

I. RECOMMENDATIONS

The detailed recommendations for use of the staff of CAAMS are contained in the documents listed in Annex C. They may be summarized as follows:

i) Make exhaustive analyses of all possible sources of testing errors.

ii) Improve flow measurement and calibration accuracies along the lines suggested.

iii) Achieve stability of testing conditions by continuous pressure control, stable end conditions, and removal of sources of flow disturbance.

iv) Arrange for in-situ calibration or calibration checks for pressure transducers and torque-tubes.

v) Acquire transducers for the measurement of pressure, flow, torque, speed and temperature which are both reliable and compatible with an internationally approved standard data acquisition system

Longer term recommendations are:

vi) Staff should be provided with on-the-job training by experts in computer-aided pump design, using real computer facilities and the suites of programs which have been developed for this purpose.

vii) Similar training should be given using fully developed data acquisition systems for pump research and development.

viii) A design study should be made of the feasibility of providing a large weigh-tank facility which could serve the common needs of all test rigs at CAAMS.

ix) More effort should be spent on the design of high specific speed mixed flow pumps of stable characteristics to take over the role of axial flow pumps wherever possible.

x) Enquiries should be made about which organizations and countries could make available suitable training courses to visiting members of the staff of the laboratory.

II. LABORATORY WORK

The test laboratory of the Irrigation and Drainage Machinery Division of CAAMS contains the following rigs:

A. Energy

B. Submersible

C. Vertical

D. Horizontal

All these rigs are for pumps handling water, although the Energy and Vertical rigs have been designed for model water turbine work as well. With the exception of the vertical rig, still commissioning, all circuits are in regular operation. The main requirements for improvement are in respect of

a) Accuracy

b) Operational efficiency

A short account now follows of these rigs, and of the assistance given.

A. Energy test rig

Designed for testing axial flow pumps and water turbines. The largest operational rig in the laboratory.

General arrangement is similar to one illustrated in the ISO Class A ("Precision Class") draft pump test code. Designed to accommodate a complete model - intake bend, vertically mounted pump, and discharge pipe - of an axial flow pump as installed on site. As suggested in the ISO Code, such an arrangement, although not permitting highly accurate measurement, may nevertheless provide the most accurate indication of how the pump will perform on site.

The arrangement leads to the following problems.

Although intake bend is correctly modelled, and draws from a body of free water, as does prototype, flow pattern in channel upstream of prototype may be dissimilar from pattern in suction tank from which model draws.

Theory suggests that for flow similarity in water with free surface, model and prototype should run at same Froude number.

For similarity of flow patterns within the pump, similarity of Reynolds number should be the basis of comparison.

These two requirements are incompatible. In practice, model must run at too high a Froude number (causing risk of excessive turbulence in suction tank) and at too low Reynolds number (making accurate measurement and prediction more difficult).

Although it is customary to run pump models at same head (and therefore velocities) as prototypes, openlevel in head tank will not permit model head greater than height of tank. Thus most tests are conducted at Reynolds numbers lower than those recommended for accurate prediction.

Measurement of flow rate, using rectangular weir with long approach channel, takes up a great deal of floor space, compared with measurement of flowrate over same range in closed pipes. Flow cannot be measured very accurately with uncalibrated rectangular weir, and in turn, such a weir is difficult to calibrate accurately.

All of points above have been discussed during mission. Possibility of changing rectangular weir type discharge to one which could be calibrated more accurately has been suggested. Paper No. 8 analyses reasons for long time taken to set up each new test point, and using suggestion from the rig group leader, recommends ways in which testing time could be greatly speeded up.

Other advice has included estimation of suction bend losses, and the need and methods for flow surveys of water velocity entering bend from suction tank.

B. Submersible test rig

For evaluation of multistage centrifugal borehole pumps. Unlike other rigs, these pumps, although small in diameter, are full-size.

Because they are not models, there is no "scaling-up" problem.

Because they are high-head centrifugal machines there is less difficulty in measuring pump head accurately.

Because flow rates are comparatively low, there is better opportunity of calibrating flowmeters accurately.

Design, manufacture, operation and maintenance of weigh-tank for accurate flowmeter calibration has been main point of discussion with team for this rig, backed up by literature references 27, 28, 34, 36, 61, 62, 63, and 74 from the documents provided.

Measurement of electric motor efficiency to determine power input to pumps has been answered by reference to appropriate notes in reference 6½ (NEL Pump Test Course).

Problem left unanswered was measurement of axial thrust. Suggestion was made to design equipment based on oil pressure, and may be followed up in private correspondence after mission.

Other advice given concerned discharging, at end of test pipe, to below water surfaces, rather than to atmosphere as at present — this should improve stability and flow measurement accuracy.

Also to use more than one flow meter to cover range for each pump, rather than only one as at present.

C. Vertical test rig

Did not see this operating — still being commissioned — but is of fundamentally sound design — not basically dissimilar to vertical rigs running successfully elsewhere in world.

Discussions covered 4 quadrant testing, pressure control for cavitation tests, service and boost pumps, flow measurement, mounting of pump and driving motor to prevent vibration, torque measurement, instrumentation, and modern pump test data acquisition systems.

D. Horizontal test rig

For research and development of high specific speed mixed flow and axial flow pumps. The problems were as follows:

i) Stability

ii) Calibration of flow meter

iii) Measurement of pressure

iv) Cavitation testing

v) Circuit losses

vi) How to increase accuracy

vii) Future R + D programme

Discussing and advising on these matters has been a major activity of the mission, covered by reports 2, 4, 7, 11, 15, 16, and 22. Recommendations are already being put successfully into effect, though it will be several months, at least, before the redesigned circuit can be made, installed, and commissioned.

III. DESIGN

The main assistance given for pump design at the Academy was the provision of the comprehensive and detailed notes on the design of mixed-flow and axial-flow machines, using computer techniques, given in the NEL Pump Design Course book (Ref.39). During my stay, there was insufficient time for the staff concerned to study these notes in full, and ask questions. In fact, the best way to take advantage of this information is in conjunction with a computer with the suite of programmes referred to. This question will be referred to again in the conclusions to this report.

It was clear from the design discussions we had that the Pump Division designers have adequate sources of design know-how, and technical ability, to produce, by empirical means, pumps which will perform satisfactorily. These sources are in general the same as those available to designers in other parts of the world.

In the discussion on how prediction of large pumps can be made from experiments on models, reference No.39, which contains a fully worked example, was given. Also relevant are references 2, 6, 18, 21 and 63.

IV. DISCUSSIONS AND LECTURES

Well over half of the working days of the mission were takenup by set discussions and lectures. A set discussion was one formally prearranged, and took part between the working team involved, the interpreter, and the expert. For important summary discussions a senior staff member or Professor Mei might take part.

They were held either in the office, or "on the job" in the laboratory. Of the 6 lectures prepared, written out in full, and translated, only 3 were presented orally. A fourth was given on a paper which I had already written and brought with me.

LECTURES

DATE	PLACE	TITLE
6-12-82 a.m.	CAAMS	"INTRODUCTION TO PUMP TESTING"
6-12-82 p.m.	CAAMS	"FLUID MECHANICS DIVISION, NEL"
25-1-83 a.m.	HUAZHONG UNIVERSITY	"FLUID MECHANICS DIVISION, NEL"
7-2-83 a.m.	CAAMS	"SPECIFYING A PUMP TO MEET SYSTEM FLOW REQUIREMENTS"
7-2-83 p.m.	CAAMS	"ISO CLASS A DRAFT PUMP TEST CODE"

39% of the set talking time was spent on horizontal rig questions, 21% for energy rig, 17% for submersible rig, 7% on the vertical rig. Remaining time on lectures and work programme discussions.

In addition to set discussions, I was freely available at any time, not formally committed, to give technical advice to individual members of staff. These informal discussions bring the estimate of total "talking and listening" time up to 70% of the total working time available.

Results of all discussions are fully documented in the written reports listed.

V. PAPERS

Two lists of documents are given in Annexes B + C. The first itemises those initially brought to Beijing to assist with the project, together with those sent out later during the mission as the need for them became apparent, in response to my requests to NEL by Telex (items 60, 61, 62, 64, 65, 67, 68, 69, 70, 74, 75, 76, 77, 78, 79, and 80). Particular mention must be made of items 26, 27, 28, 29, 35, and 38 which are substantial volumes giving very detailed information on all aspects of pump design and testing, including computer-aided pump design and data acquisition systems.

The second list identifies notes and reports written during the mission. These provide a record for CAAMS of the detailed recommendations for design, procedure, instrumentation and analyses discussed and explained at the time.

VI. VISITS

A. BEIJING

Beijing Pump Factory 8-1-83

Tour of factory — test bed, tool making shop, main machine shop, heat treatment plant, new products test bed, foundry, assembly shop. Product — small and medium sized centrifugal pumps.

Discussions on pump design, noise measurement, electromagnetic flowmeters, flow traversing, plans for new test facility.

They would like:

i) Details of any pump design courses planned during coming year.

ii) Details of 5 hole probes for traversing.

iii) British pump manufacturers catalogues.

Items i) and iii) will be attended to on my return.

Item ii) information is with CAAMS, who already use 5-hole probes.

B. WUHAN

i) Wuhan Pump Factory 22-1-83

Tour of factory — similar but larger than Beijing, with bigger range of pumps — centrifugal, also large mixed and axial flow pumps.

ii) Fankou Pump Station 23-1-83

This station is used to drain a large area of land during the flood season, pumping the excess water into the Yangtze River. This opens up fertile land for productive farming. Has now run for 3 years, and has performed its intended function. The 4.5 metre diameter pumps, four in number, are amongst the largest axial flow pumps in service in the world. There is access to the fixed guide vanes and to the impellers for maintenance. This was being carried out at the time of our visit, during the dry season.

However, the intake and discharge branches of the pump are an integral part of the massive concrete dam housing the pumps, and holding back Yangtze flood water. So there is virtually no possibility of the modifications other than in the impeller, and these would have to be completed during the dry season.

ii) Wuhan Hotel Discussions 24-1-83

These were attended by all those parties concerned with design, model testing and development, manufacture, site testing, and operation of the Fankou Station Pumps.

Main problems discussed were:

a) Unexpectedly high force required to change blade setting angles while running.

b) Noise.

c) Instability.

d) Testing.

e) Range of heads required.

Item a) was discussed at length. The designers had used a formula originating from Czechoslovakia to estimate the force required, applying a value drawn from their own experience for the empirical coefficient required to apply it.

They did not know whether this formula had any logical theoretical basis, but it had been used successfully in the past.

It was therefore impossible for me to answer the question of why the use of this formula had underestimated the force that would be needed to move the blades.

There was some discussion about how one might tackle the problem from first principles in the design and development stage, but of course this question is irrelevant to the existing operational problems.

Moreover, there is an element of doubt about the accuracy of casting and machining of the blades -- no proof of this, one way or the other, was forthcoming.

The effects of this problem are that the blade actuating mechanisms are being overstressed, but that even so only a very limited range of blade settings can be achieved, and therefore the pumps cannot operate over the entire range of duties for which they were designed.

Item b) was answered by handing over a paper by P. McNulty of NEL on the subject of causes of noise in pumps. Since then excessive noise persists for the whole range of operational duties, I suggested that it emanated from mechanical, rather than hydraulic, sources.

Item c) is a common one for axial-flow pumps, especially in starting conditions. I mentioned that although inevitable for axial pumps, mixed flow pumps of high specific speed could be designed with stable characteristics.

Item d) We discussed in some detail alternative methods of measuring flow. At present this is done by fitting current meters in the pump intake. Unfortunately, because of blade setting limitations, it has not been possible to produce any site test data which can be compared with corresponding model test data.

Item e) is again bound up with item a). The problem is that the range of heads imposed by the rise and fall of the Yangtze water level is much greater than that for which axial flow pumps are usually designed. The maximum head of 10 meters is certainly well within the range for which mixed flow pumps are commonly used. I took note of all questions asked, and there may be further correspondence if useful answers can be found.

iii) Huazhong University 25-1-83

I was taken round their large hydraulic machinery laboratory. There are two main rigs. A vertical one not dissimilar from the CAAMS vertical test rig, used for water turbine research, and a horizontal test rig for pumps. It is also possible to set up smaller experiments.

I gave a talk on the work of Fluid Mechanics Division, NEL, similar to that given previously to CAAMS, followed by discussions and advice on test rig stability, pressure control, and cavitation testing.

17) Thompson Pumping Station 26-1-83

This station performs a similar function to that of Fankou, but in the Thompson Lake area. By contract with Fankou, which uses 4 very large axial flow pumps, this station is equipped with 15 medium sized axial pumps. There are virtually no operational problems. However, advice was sought on methods of flow measurement, which was given in some detail, and on operational control and monitoring. Here I suggested the use of index measurements, established during pump tests, rather than absolute measurements of flow power and head for control purposes. For example pressure in pump suction bend, relative to inlet water level, may be correlated to flow rate.

VII. FINDINGS

The laboratory test rigs are capable, with modifications and additions as recommended, of obtaining good experimental conditions. The energy rig by the nature of its design cannot be expected to provide such accurate measurement as will be possible in the other rigs, which can be developed to "Precision Class" standards or better.

The decision to provide the submersible rig with a weightank for accurate calibration of flowmeters is commended. In the long term, a larger weightank to provide a common calibration service for the other 3 rigs is worth consideration. In the meanwhile, much can be done to improve the accuracy of flow measurement with the existing volumetric facility, by improving the diverter systems at present in use, and the stability of operation of the rigs themselves.

Transducers for the measurement of power, pressure, flow, and temperature should be specified not only for their reliability and precision, but also for their compatibility with modern data acquisition systems. Such systems, using a minicomputer to process data monitor test conditions, and partly to control experiments, will enhance both the value of the experimental work and efficiency of its operation.

At present the design of rotodynamic (axial-, mixed-flow, and centrifugal) pumps at this station is made without computer aids. This makes it almost impossible to apply the complex 3-dimensional flow and geometry analyses in a thorough and systematic way. So both design and experimental development must be on an empirical basis. At the very least, computer-aided-design of pumps gives the designer the chance to examine a much greater range of options before deciding on which one to choose.

The computerisation of design and experimental work are obviously linked, if both are to be properly effective. Training by experts with appropriate computer facilities and software directly to hand is strongly recommended. Building up all the necessary programs and becoming proficient in computer aided design entirely by ones own efforts would take many years, and is not the only way to "catch up" with developments elsewhere. Approaches should be made to organizations abroad who may be able to provide on-the-job training.

There was little time, and very little firm evidence, on which to draw conclusions and make recommendations about the Fankou Pumping Station. The main problem here was stated to be the unexpectedly large force required to change the impeller blade angles. I am not able to suggest an immediate remedy -- other than the obvious one of modifying the existing actuating mechanism to provide a large enough force -- nor indeed a long term one. There may, however, be some private correspondence about this after the mission.

It might be worth considering, for future stations, a greater number of high specific speed mixed-flow pumps, rather than the minimum possible number of very large axial flow pumps, to cope with the same duties as those provided at Fankou.

Very detailed recommendations about equipment, procedures, etc., are given in my papers left with the Academy. This includes matters on computer-aided pump design in the NEL Pump Design Course notes.

The detailed modifications and developments suggested will probably take several months to put into effect and become operational, after which time it is recommended that the Academy produce a report on their effectiveness, and on any further work that needs to be done.

ANNEX A.

PERSONNEL

Lists follow of the personnel involved, giving their duties insofar as they affected the work of the mission. Their other duties and responsibilities have not been included. A special acknowledgement must be made to my principal interpreter Engineer Dong Mu-lan from the Tianjin Power Equipment Manufactury. She not only interpreted efficiently, but also dedicated her own free time to translation and typing work, and was responsible for the good relations which grew up between those working on the project.

LIST I BEIJING

Name	Sex	Duty or Title
Hua Guo-zhu	male	President of the Academy
Wang Wan-jun	male	Vice-President, Chief Engineer
Feng Bing-yuan	male	Vice-Chief Engineer
Zhang Guang-fu	male	Director of the Irrigation and Drainage Machinery Research Division, Engineer
Zheng Xiao-ying	male	Vice-Director, Engineer
Duan Gui-fang	male	Group leader of the Test Laboratory, Engineer
Yao Huan-yuan	male	Vice-group leader, Engineer
Zhang Wen-zhu	male	Vice-group leader, Engineer
Cai Qi-ying	female	Engineer
Xial Chong-ren	female	Engineer
Han Wen-jun	male	Engineer
Yue Wen-fa	male	Engineer
Yuan Xiu-wen	female	Engineer
Dong Mu-lan	female	Engineer, Interpreter
Yin Guang-fu	male	Lecturer
Wang Hong-yu	female	Assistant Engineer
Li Hong-li	female	Assistant Engineer
Yuan Zheng	male	Assistant Engineer
Yao Jun	male	Assistant Engineer, Interpreter
Jin Zi-qing	male	Engineer
Zhang Qing-fan	male	Engineer
Sheng Wen-lin	male	Engineer
Mei Zu-yan	male	Professor of Hydraulic Machinery Qinghua University, Technical Adviser to CAAMS

LIST 2 WUHAN

Di Wen-cai
Chief of Science and Technical Managing Department
The Hubei Provincial Bureau of Agricultural Machine Building Industry
Hanko Yiyuan Road, Wuhan, China

Fang Du-wen
Engineer
The Hubei Provincial Bureau of Agricultural Machine Building Industry
Hanko Yiyuan Road, Wuhan, China

Yuan Huei-min
Engineer

Song Da-guang
Chief

The Hubei Provincial Bureau of Water Conservation
Wuchang Zhongnan Road, Wuhan, China

Li Ke-zeng
Head

Zhu Wenji
Engineer

Fankou Pumping Station
Yecheng County, Hubei Province, China

Lui Zhi-lin
Engineer
Wuhan Bureau of Water Conservation
Hangkongche Road, Wuhan, China

Yi Jun-jie
Engineer
Tang Xunhu Pumping Station
Wuchang, Wuhan, China

Zhang Li
Engineer

Yu Chuan-da
Engineer

Wuhan Pump Factory
Hanyang, Wuhan China

Jia Zong-me
Asst. Professor
Luo Nan-yi
Lecturer

Tan Yue-cai
Asst. Professor
Zou Chun-rong
Asst. Professor

Zhu Jian-hua
Lecturer
Liu Xiping
Head of Hydraulic Laboratory

Huazhong Technical Institute
Yu Jiashan, Wuchang
Wuhan, China

ANNEX B.

PREPUBLISHED PAPERS

1. S.I. Unit Conversion Factors
2. Scaling Up Head, Flow and Power Curves for Water Turbines and Pumps
3. Pump Research Development Needs in the Water Supply Industry
4. Studies on the Characteristics of Axial Flow Pumps
5. Hydraulic Design of Pump Sumps and Intakes
6. Installation and Scale Effects in Pumps
7. Eliminating Rotation Errors from Pump Head Measurements
8. Flow Measurement in Swirling or Asymmetric Flow
9. The Effects of Turbulence and Transverse Velocity Gradients on Pitot Tube Observations
10. A Simplified Integration Technique for Pipe-Flow Measurement
11. Pressure Tapping Analysis
12. The MERL Gas Content Apparatus
13. The NEL Universal Apparatus for Measuring the Gas Content of Liquids and Semi-liquids
14. Problems of Pump Head Measurement
15. Effects of Installation on the Performance of a Mixed Flow Pump
16. Comparison of the Wall Static Pressure and the Mean Free-stream Static Pressure at the Discharge of an Axial Flow Fan
17. The Interpretation of Pressure Readings taken on a Rotating Body
18. Examination of the Problem of Pump Scale Laws
19. Model Testing of High Head Pumps

20. Correlation of Tolerances Used in Acceptance Testing of Fluid Machinery

21. The Assessment and Analysis of Errors in Pump Tests

22. Pumps for Low Suction Pressures

23. A Design Method for Mixed Flow Fans and Pumps

24. The Testing of Axial Flow Fans

25. Review of Present and Future Work on Pumps at NEL

26. Flow Measurement in Closed Conduits (volume one)

27. Flow Measurement in Closed Conduits (volume two)

28. NEL Fluid Mechanics Silver Jubilee Conference

29. Pump Design, Testing and Operation

30. Note on Temperature Rises caused by Energy Losses in Components of Water Handling Systems

31. Introducing NEL

32. A Resource for Industry and Government

33. Technical Literature:

    Engineering Measurement

    Flow Measurement

    Materials Technology

    Pump and Fan Technology

    Component Strength Evaluation

34. High Power Pump Testing

35. The Principles and Practice of Flow Measurement

36. Introductory Course to Pump Testing

37. Pump Design Course (four day course)

38. Scale Effects in Centrifugal Cooling Water Pumps for Thermal Power Stations

39. Weir Pumps Ltd.

    Research and Development

    Testing Facilities

    Pumping System Investigations

    Machinery Protection

    Bowl Type Pumps

    Canister Pumps

    Spyrobowl Pumps

    Pumps for the Water Industry

    Sewage Pumps

    Pumps for Dock Services

    Large Capacity Centrifugal Pumps

    Weir Product Brochure

    Performance Prediction of Centrifugal Pumps and Compressors

    Operating Problems of Pump Stations and Power Plants

    Scaling for Performance Prediction in Rotodynamic Machines

40. Control Engineering Applications

41. IC Engine and Vehicle Testing Component Design and Development at NEL

42. Engineering Measurement Technology

43. Metrology of Gearing

44. Ferrography

45. Metrology Services

46. Investment Casting

47. Plastics Engineering

48. Physical Properties of Liquids and Gases

49. Physical Properties Software and Data Banks

50. On-site Appraisal of Heat Transfer Equipment

51. Industrial Heat Exchangers and Heat Transfer

52. Heat Flux Meter Calibration Service

53. Burner Test Service

54. Cadcam at NEL

55. Vision for Industry

56. Workshop Estimating by Microcomputer

57. Automation for Industry

58. Fluid Power Engineering

59. Pump Testing

60. Flow Measurement Facilities at NEL on 1 October 1979

61. The Use and Maintenance of Weighing Machines

62. Some Model Experiments on Special Control Valves

63. TEHACHAPI Crossing Design Studies

64. Centrifugal Mixed Flow and Axial Pumps Code for Hydraulic Performance Tests Class A

65. The NEL Variable Pressure Water Tummel

66. Note on Temperature Rise caused by Energy Losses in Components of Water Handling Systems

67. Tiger - Tooth Control Valves

68. Drag Valves for Liquid Service

69. The Use of Cascades at Sharp Elbows in Water Pipes

70. Cascade Bends

71. Some notes on the Calibration of Swinging Frame Dynamometers

72. Density of Pure Water in Kilograms/Cubicmetre at A Pressure of One Atmosphere and Temperatures from 0-40 Degrees Celcius

73. Simplified Water Density Equation

74. VALTEX Tiger-Tooth Control Valves

75. VALTEX Mark One System 80 Control Valves

76. A Alence ME Stainless Steel High Pressure Metric Tube Fittings

77. Simplifix

78. A-LOK Stainless Steel Double Ferrule Tube Fittings

79. ERMETO-ALENCO Products

80. Metric High Pressure Tube Fittings

81. Review of Pump Testing at NEL Site Tests, Standards, and Contractual Aspects of Test Codes

82. Standards for Pump Makers and Users

ANNEX C.

REPORTS AND LECTURES WRITTEN DURING MISSION