

2005 Asian Fluid Machinery

Edited by Xue Shengxiong Ph.D., Shu Pingling

合肥工业大学出版社
Hefei University of Technology Press

2005 Asian Fluid Machinery

THE 8TH ASIAN INTERNATIONAL CONFERENCE ON FLUID MACHINERY

Oct 12~15, 2005

Yichang • China

Edited by

Xue Shengxiong Ph. D., Shu Pingling



合肥工业大学出版社

Hefei University of Technology Press

内 容 提 要

本书集中了中国、日本、韩国、印度等亚洲国家相关学者近两年来在泵、阀门、压缩机、风机、流体密封喷射技术和水轮机等技术领域的最新科研与产品技术成果,从中反映出了亚洲国家流体机械的最新技术水平和专家队伍。

本书可供高等院校、科研院所、机械制造企业的流体机械技术人员和应用人员使用或参考。

图书在版编目(CIP)数据

2005 亚洲流体机械:第八届亚洲国际流体机械会议=2005 Asian Fluid Machinery; the 8th Asian International Conference on Fluid Machinery/薛胜雄,舒平玲主编. —合肥:合肥工业大学出版社,2005.9

ISBN 7-81093-264-0

I. 2... II. ①薛... ②舒... III. 流体机械—国际学术会议—文集 IV. TH3-53

中国版本图书馆 CIP 数据核字(2005)第 103761 号

2005 亚洲流体机械:第八届亚洲国际流体机械会议

主 编 薛胜雄 舒平玲

责任编辑 权 怡

出 版	合肥工业大学出版社	版 次	2005 年 9 月第 1 版
地 址	合肥市屯溪路 193 号	印 次	2005 年 9 月第 1 次印刷
邮 编	230009	开 本	889×1194 1/16
电 话	总编室:0551-2903038 发行部:0551-2903198	印 张	64 字 数 1720 千字
网 址	www.hfutpress.com.cn	发 行	全国新华书店
E-mail	press@hfutpress.com.cn	印 刷	合肥星光印务有限责任公司
		纸 张	山东光华纸业集团有限公司

ISBN 7-81093-264-0/TH·7

定价:300.00 元

如果有影响阅读的印装质量问题,请与出版社发行部联系调换

AICFM8—YICHANG

THE 8TH ASIAN INTERNATIONAL CONFERENCE ON FLUID MACHINERY

Organizing Committee

- Chairman:** Fan Gaoding, professor and director of Hefei General Machinery Research Institute, President of Chinese Fluid Engineering Institution
- Vice chairmen:**
- Gao Jinji, academician, professor of Beijing University of Chemical Technology
 - Wang Yuming, academician, chief engineer of Tianjin Dingming Seals Co., Ltd.
 - Cao Shuliang, professor of Tsinghua University
 - Li Liansheng, professor of Xi'an Jiaotong University
 - Jiang, Shanghong, professor of Wuxi Compressor Co., Ltd.
 - Yin Jian'an, professor and general manager of Shanxi Blower (Group) Co., Ltd.
 - Jia Xiaofeng, professor and vice director of Hefei General Machinery Research Institute
 - Bi Yaxiong, professor and general manager of China Yangtze Power Co., Ltd.
 - Xue Shengxiong, professor, general secretary of Chinese Fluid Engineering Institution
- General secretary:** Xue Shengxiong, professor, general secretary of Chinese Fluid Engineering Society
- Vice general secretary:** Shu Pingling, vice general secretary of Chinese Fluid Engineering Society
- secretary:**
- Song Donglan, chief editor, vice general secretary of Chinese Fluid Engineering Society
 - Fu Jianping, professor and vice president of the Three Gorges Hydropower Plant

International Advisory Committee

- | | |
|--------------------------------------|--------------------------------|
| Akinori Furukawa (Japan) | Cao Shuliang (China) |
| Charoon Kamolratana (Thailand) | Cho Kang-Rae (Korea) |
| Fan Gaoding (China) | Gao Jinji (China) |
| Han Fengqin (China) | Hiroshi Tsukamoto (Japan) |
| Jia Xiaofeng (China) | Junichi Kurokawa (Japan) |
| Kang Shin-Hyoung (Korea) | Kazumasa Kubota (Japan) |
| Kazuyoshi Yamamoto (Japan) | Kwang-Yong Kim (Korea) |
| Li Liansheng (China) | Masahiro Inoue (Japan) |
| Mohamad Afifi Abdul Mukti (Malaysia) | Noor Alias bin Mohd (Malaysia) |
| Sadrul Islam A. K. M. (Bangladesh) | Santhakumar, S. (India) |
| Wang Yuming (China) | Winoto S. H. (Singapore) |
| Xue Shengxiong (China) | Yoo Jung Yul (Korea) |
| Yoshinobu Tsujimoto (Japan) | Yutaka Kawata (Japan) |

PREFACE

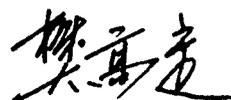
The Changjiang River flows east, the Three Gorges Dam towers up high and a high-level gorge and flat lake thus appears. The 8th Asian International Conference on Fluid Machinery (AICFM) will be held in Yichang, Hubei Province, China. Facing the great Changjiang River and seeing the bound volume of the conference papers thoughts flash across my mind and it makes me very excited. Since the 1st AICFM held in Beijing in 1984, the development of Asian fluid machinery technology looks like the scene on the Changjiang River that the powerful waves behind drive those before. The Asian countries gather here happily under the same roof, getting acquainted with new friends and keeping old friends in mind. Acquaintance, exchange, cooperation and development—AICFM has already become a forum and a bridge for the scholars of fluid machinery from Asian countries.

The 2005 AICFM conference proceedings have collected the latest scientific and technical achievements, assembled numerous advanced theories and aggregated strong professional teams. We seek differences while keeping union and seek common points while reserving differences. Here it shows us the breadth and depth of fluid machinery specialties -- pumps, valves and piping, compressors, fans and blowers, water turbines, jet technology and fluid sealing, and also presents us the commonness and characteristics of fluid machinery research: numerical simulation of flow fields, theory and experiments of vanes, inspection and analysis of fluid machinery, fluid machinery products and their applications; at the same time, this work makes the scholars of fluid machinery from Asian countries such as China, Japan, Korea, India, Singapore, etc. gather together more closely and jointly match to the future.

Chinese Fluid Engineering Society (CFES) has already successfully held 4 sessions of AICFM in China. For twenty-one years, CFES has successfully made a close cooperation with the institutional organizations of Asian countries. The conference this time also received the energetic support from the academic organizations and scholars of such countries as China, Japan, Korea, India, etc., and Mr. Cao Shuliang, Mr. Yoshinobu Tsujimoto and Mr. Kwang-Yong Kim provided a lot of help for the organization of this work, CFES hereby expresses hearty thanks to all of them!

Wish the 8th AICFM a satisfactory success!

Wish AICFM carry forward and become better and better!



Fan, Gaoding, Professor
President of Chinese Fluid Engineering Society
Aug. 2005

8th Asian International Conference on Fluid Machinery
 October 12~15, 2005 • Yichang, China

Table of Contents

Session 1: B-Blower and fan

B01 PREDICTION OF FLOW CHARACTERISTICS IN MULTI-BLADE FAN <i>Hidechito Hayashi, Yoshio Kodama, Takahiro Yamasaki, Souichi Sasaki, Tohru Fukano</i>	1
B02 IDENTIFICATION AND EXPERIMENTAL DETERMINATION OF VARIOUS LOSSES IN A RADIAL TIPPED CENTRIFUGAL BLOWER/FAN <i>Balaganesan T, Channiwala S, Vibhakar N</i>	13
B03 THE UNBALANCED ROTOR RESPONSE ANALYSIS FOR FCC EXPANDER <i>Ji Jiang, Ding Qin</i>	27
B04 FLOW ANALYSISs OF THE VERTICAL AXIS CROSS-FLOW WIND TURBINE <i>Eiji Ejiri, Shunichi Shizawa, Shoji Yabe</i>	35
B05 EXPERIMENTAL INVESTIGATION ON FLOW IN GAP BETWEEN A ROTATING AND A STATIONARY DISK WITH LARGE FORCED THROUGH FLOW USING PIV <i>Wen Su-Ping, Hu Xiao-Wen, Wang Ke, Guo Yu-Long, Chu Yi</i>	42
B06 DESIGN OF AN AXIAL FLOW FAN WITH SHAPE OPTIMIZATION <i>Seoung-Jin Seo, Seung-Man Choi, Kwang-Yong Kim</i>	50
B07 DEVELOPMENT OF HIGH SPEED JET FAN BY CFD <i>Tomoki Kawakubo, Akihiro Yamagata, Kenji Oda</i>	64
B08 SLIP FACTOR ASSESSMENT AND EXPERIMENTAL ANALYSIS FOR RADIAL TIPPED CENTRIFUGAL BLOWER. <i>Deepakkumar.M.Sharma, Deepakkumar.M.Sharma</i>	76
B09 Numerical investigation for centrifugal impeller with load blade <i>Wen Su-ping, Hu Xiao-wen, Chu Yi, Guo Yu-long</i>	88
B10 DEVELOPMENT OF AN AIR-SEPARATOR FOR APPLICATION TO A PRIMARY AIR FAN USING IN A POWER PLANT <i>Takahiro Nishioka, Shuuji Kuroda, Tsukasa Nagano, Tadashi Kozu</i>	96
B11 TECHNICAL DEVELOPMENT AND APPLICATION OF FOUR MACHINE TRAIN IN CHINA <i>Zheng Xiuping</i>	107
B12 STUDY ON TIP LEAKAGE VORTEX IN A SMALL AXIAL FAN <i>Norimasa Shiomi, Kenji Kaneko, Kazuyuki Shimozono, Toshiaki Setoguchi</i>	115
B13 ON A NEW APPROACH TO PERFORMANCE ESTIMATION OF STRAIGHT-WING VERTICAL AXIS WIND TURBINES <i>Aika Shibuya and Akisato Mizuno</i>	126

Session 2: C-Compressor

C01 PROGRESS OF COMPRESSOR TECHNOLOGIES IN THE PAST DECADES AND THEIR DEVELOPMENT TREND IN NEAR FUTURE <i>Li Liansheng, Shu Pengcheng, Zhao Yuanyang</i>	138
C02 DEVELOPMENT AND APPLICATION OF AN ADVANCED CENTRIFUGAL COMPRESSOR DRIVE - VARIABLE SPEED PLANETARY GEAR - VORECON <i>Lu, Pengfei, Reimesch, Uwe</i>	147
C03 COMPARISON AND ASSESSMENT OF VARIOUS VARIABLE SPEED DRIVERS FOR CENTRIFUGAL COMPRESSOR <i>Lu, Pengfei</i>	156
C04 ENERGY SAVING TECHNOLOGY OF RESIDENTIAL AIR-CONDITIONERS	

AND ITS EFFECT

	<i>Eiichi Aikawa, Keiichi Morita, Makoto Sugiyama</i>	167
C05	RESEARCH AND DESIGN OF GAS COMPRESSORS FOR THE COMBINED CYCLE POWER PLANT(CCPP)	
	<i>Wang Yitian^{1,2}, Huang Shujuan¹, Jiang Guodong², Ye Changqing², Shi Xiaoyun², Zhang Limin</i>	175
C06	DESIGN AND PROTOTYPING OF MICRO CENTRIFUGAL COMPRESSOR FOR ULTRA MICRO GAS TURBINE	
	<i>Ronglei Gu, Shimpei Mizuki, Hoshio Tsujita, Toshiyuki Hirano, Yutaka Ohta, Eisuke Oota</i>	182
C07	AN INNOVATIVE IDEA OF ENERGY SAVING – FCC TOTAL PRESSURE ENERGY RECOVERY SYSTEM (TPERS)	
	<i>Lu, Pengfei</i>	191
C08	A JET INTERFERENCE OF A HIGH SPECIFIC SPEED PELTON TURBINE	
	<i>Tsuneaki Fujii, Tsukamoto Tadashi, Shigeki Matsuoka, Toshiaki Karaki</i>	197
C09	DISCUSSION ABOUT ‘SILENT’ HIGH-PRESSURE COMPRESSOR UNIT	
	<i>Hu Yiluo, Li Qi, Zhang Chengyan</i>	206
C10	PIPELINE BOOSTER COMPRESSOR FOR SAKHALIN-2 PROJECT	
	<i>Hideto Nogiwa, Keiji Ooyabu</i>	215
C11	DEVELOPMENT OF SHAFT SEALING TECHNOLOGY OF HIGH-SPEED TURBO-COMPRESSORS IN PROCESS INDUSTRIES	
	<i>Yuming Wang, Jianli Wang, Huixia Yang, Haining Wang, Yanmei Liu</i>	224
C12	AN EXPERIMENTAL STUDY ON THE SHUT-OFF OF THE FLOW IN A SIPHON PIPE BY AIR ADMISSION	
	<i>Michihiro NISHI, Tomoaki MARUMO, Kouichi YOSHIDA</i>	239
C13	DEVELOPMENT OF HIGH PERFORMANCE COMPRESSOR FOR TURBO HEAT PUMP	
	<i>Ryo Fukushima, Akihiro Nakaniwa, Wataru Seki, Kenji Ueda</i>	251

Session 3: H-Hydro-Turbine

H01	ANALYSIS OF PRESSURE FLUCTUATION IN THE DRAFT TUBE OF ALSTOM UNITS IN THE LEFT BANK OF THREE GORGES HYDROPOWER STATION	
	<i>Jianping Fu, Hao Xiong, Jianping Sun, Liyuan Zheng</i>	257
H02	IRREGULAR DEAD CORE AND VORTEX ROPE IN UNSTEADY FLOW IN DRAFT TUBE OF FRANCIS TURBINE	
	<i>Fan Chunxue¹, Gui Zhonghua¹, Han Fengqin¹, Kubota Takashi¹, Xiao Yexiang¹, Zhang Weiping²</i>	265
H03	COUNTER-ROTATING TYPE HYDROELECTRIC UNITS APPLICABLE TO VARIOUS HYDRO-CIRCUMSTANCES	
	<i>Daisuke Tanaka, Toshiaki Kanemoto, Makoto Ohkura, Masanori Osono, Hirohisa Takeda, Akira Inagaki</i>	273
H04	THE INFLUENCE OF GAS SUPPLY TO THE STABILITY OF THE LEFT BANK UNITS OF THREE GORGE HYDROPOWER PLANT OPERATING IN LOW HEAD	
	<i>Hao Xiong, Jianping Fu, Jianping Sun, Zheng Liyuan</i>	281
H05	EFFECTS OF CASING GEOMETRY ON INLET BACKFLOW OF TURBOPUMP INDUCERS	
	<i>XiangYu Qiao, Hironori Horiguchi, Yoshinobu Tsujimoto</i>	287
H06	UNSTEADY INTERFERENCE BETWEEN FREE WATER JET AND REAR SURFACE OF ROTATING BUCKETS IN PELTON TURBINE	
	<i>Zheng Ailing, Han Fengqin, Xiao Yexiang, Kubota Takashi</i>	302
H07	DESIGN OPTIMIZATION OF A HIGH SPECIFIC SPEED FRANCIS TURBINE USING MULT-OBJECTIVE GENETIC ALGORITHM	
	<i>Sadao Kurosawa, Kazuyuki Nakamura, Takanori Nakamura</i>	311
H08	HYDRAULIC GRADIENT IN FREE SURFACE FLOW ON ROTATING BUCKET OF PELTON TURBINE	
	<i>Xiao Yexiang, Han Fengqin, Kubota Takashi</i>	323
H09	THE ANALYSIS OF THE STABILITY FOR TURBINE HYDRAULIC SYSTEM IN A NUCLEAR POWER PLANT	

	<i>Tae-ha Son, Byung-heon Lee, Tae-han Chung</i>	331
H10	NUMERICAL SIMULATION OF SWIRLING FLOW AND PRESSURE PULSE IN HYDROTURBINE DRAFT TUBE	
	<i>Jiang Jin, Zhang Chen Bo, Dong Sheng Wen, Zhao Wen Sheng</i>	339
H11	100KW RADIAL STRAM TURBINE POWER GENERATION SYSTEM WITH SMALL FLOWING-THROUGH BOILER	
	<i>Masahiko Mitsuda, Toshiyuki Kobayashi, Hideaki Kuwabara, Atsushi Kakimoto, Hirohide Furutani</i>	346
H12	THE FLOW ANALYSIS OF THE UNIT IN THREE GORGES POWER STATION UNDER 4% OPENING	
	<i>Jianping Fu, Shuangquan Zhang, Hao Xiong</i>	355
H13	VORTICES WITHIN THE SEPARATION IN A DECELERATING CHANNEL FLOW (PROFILES OF THE TIME-AVERAGED VELOCITY AND TURBULENCE LEVEL)	
	<i>Yoichi Kinoue, Toshiaki Setoguchi, Mohammad Mamu, Norimasa Shiomi, Kenji Kaneko</i>	362
H14	ON-LINE MONITORING AND FAULT DIAGNOSIS OF AIR GAP AND STATOR BAR VIBRATION OF LARGE- SCALE HYDROGENERATOR BY USING RBF	
	<i>Jiang Jin, Liu Guanglin, Tang Shaohua, Tao Zhijian</i>	374
H15	NUMERICAL SIMULATION OF FLOW ON ROTATING FLAT PLATES BY A PARTICLE METHOD	
	<i>Yuji Nakanish</i>	384
H16	OPTIMUM PROFILE OF FLOATING TYPE TIDAL CURRENT POWER STATION	
	<i>Toshinori Kashiwabara, Toshiaki Kanemoto</i>	394
H17	GUIDE STRUCTURE ANALYSIS OF THROUGHFLOW-TYPE-TURBINE'S RUNNER	
	<i>Xuejun Zhou, Shifeng Huang</i>	404
H18	A HYBRID 3D VORTEX METHOD FOR FLOW OVER SHIP PROPELLER	
	<i>Lingjia ZHAO, Hiroshi TSUKAMOTO</i>	410
H19	DISCUSSION ON THE ALTERATION PROJECT OF THE TURBINE RUNNER SEAL OF GEZHOUBA HYDROPOWER STATION	
	<i>Lu Jinyu, Deng Jian, Huang Ming, Tu Yangwen</i>	421

Session 4: J-Jet Technology

J01	THREE-DIMENSIONAL NUMERICAL SIMULATION ON FLOW FIELD WITHIN A JET PUMP	
	<i>Jinmu Zhu, Han Ning, Xiping Long</i>	427
J02	STATISTICAL PREDICTION OF UNSTEADY WATER JET FLOW BY CFD	
	<i>Lin Zhiwen, Han Fenqin, Xiao Yexiang, Zheng Ailing, Kubota Takashi</i>	435
J03	EFFECT OF NON-EQUILIBRIUM CONDENSATION OF MOIST AIR ON SUPERSONIC CAVITY FLOW	
	<i>Shigeru Matsuo, Alam Miah MD, Ashraful, Toshihiro Nakano, Masanori Tanaka, Toshiaki Setoguchi, Kenji Kaneko</i>	443
J04	DUAL-JET NOZZLE STRUCTURE AND ROCK CUTTING EXPERIMENT	
	<i>Li Gensheng, SONG Jian, NIU Jilei, HUANG Zhongwei, Yi Can, HU Yongtan</i>	457
J05	DESIGN FOR HYDRAULIC HEAD ARRANGED AT SYMMETRICAL ANGLE	
	<i>Guangheng Liu, Yanli Zeng, Zheng Sun, Zhen Qin, Naibo Han</i>	465
J06	HIGH-PRESSURE WATER JET CLEANING DEVICE FOR SPENT FUEL ELEMENT TRANSPORTATION CONTAINER	
	<i>Chen Zhengwen, Wang Yongqiang, Sheng Yetao, Peng Haojun, Zhu Huaqing</i>	469
J07	EXPERIMENTS ON EROSION MECHANISMS OF CAVITATING WATER JETS	
	<i>Yiyu Lu, Xiaohong Li, Wenyong Xiang</i>	477
J08	NUMERIC SIMULATION OF ULTRA-HIGH PRESSURE ROTARY ATOMIZING WATERJET FLOW FIELD	
	<i>Xue Shengxiong, Li Jiangyun[*], Peng Haojun, Chen Zhengwen, Wang Yongqiang, Zhu Huaqing</i>	487
J09	NUMERICAL SIMULATION OF FLOW FIELD OF JET PUMPS MODEL BY USING MONTE CARLO METHOD	
	<i>Tongzhuo Li^{1,2}, Deng Shan², Junxian Lv³, Hongqi Lu³, Bangmin Zheng³</i>	499
J10	NUMERICAL SIMULATION FOR CONFINED JETS OF SMALL AREA RATIO	

	<i>Jinmu Zhu, Xinpeng Long, Weifeng Wu</i>	507
J11	THEORETICAL AND EXPERIMENTAL STUDY ON CORRELATION BETWEEN JET PUMP CAVITATION PARAMETERS	
	<i>Xinpeng Long, Biaohua Cai</i>	515
J12	MAXIMAL FLOW RATE OF GAS SUCTION BY WATER JET AIR EJECTOR	
	<i>Qingjiang Xiang, Hongqi Lu, Tinghao Li</i>	523
J13	NUMERIC SIMULATION AND MATHEMATIC MODEL ESTABLISHMENT OF HIGH-PRESSURE ROTARY JET FIELD	
	<i>Wang Yongqiang Zhu Huaqing Yan Xinru *Zeng Zhaohai</i>	535

Session 5: P I -Pump I

P I01	TENTATIVE STUDY ON REAL-TIME DATA PROCESSING FOR ADVANCE DETECTION OF CAVITATION SURGE IN PUMP INDUCER	
	<i>Takashi Atono, Akinori Furukawa, Satoshi Watanabe, Koichi Ishizaka</i>	541
P I02	DYNAMIC CHARACTERISTICS ANALYSIS OF HIGH SPEED IMPELLER SYSTEM CONSIDERING GYROSCOPIC EFFECT	
	<i>Qinghua Song, Weixiao Tang, Ning Lun</i>	549
P I03	PREDICTION OF UNSTEADY HYDRAULIC FORCE IN A MIXED-FLOW PUMP WITH VOLUTE CASING BY USING LARGE EDDY SIMULATION	
	<i>Katsutoshi Kobayashi, Hayato Shimizu, Yasushi Shigenaga, Ichirou Harada, Toshiyuki Satou</i>	556
P I04	CFD ANALYSIS OF AXIAL-FLOW PUMP USING MULTIPLE ROTATING FRAMES	
	<i>Fujun Wang, Yaojun Li, Guohui Cong, Haisong Wang, Haini Wei</i>	566
P I05	NUMERICAL SIMULATION OF INTERNAL FLOW WITHIN PUMP AND PUMP ARRANGEMENT	
	<i>Hongxun Chen, Fajia Shi, Bing Zhu, Xuelian Zou, Jiguang Zhang, Peiru Wei</i>	574
P I06	SUPPRESSION OF CAVITATION IN INDUCER BY J-GROOVE	
	<i>Junichi Kurokawa, Young-Do Choi, Masahiro Ito</i>	588
P I07	STUDY ON CLOUD CAVITATION AROUND HYDROFOIL	
	<i>Mindi Zhang, Guoyu Wang, Xiangbin Li, Junrui Lu</i>	603
P I08	INVESTIGATION OF VORTEX SHEDDING FROM A THIN CAMBERED BLADE	
	<i>Baoshan Zhu, Shuliang Cao, Wei Kang</i>	611
P I09	THE FRACTAL FEATURES OF SALT-OUT CRYSTAL SURFACE IN LIQUID-SOLID TWO-PHASE FLOW	
	<i>Minguan Yang, Weidong Jia, Bo Gao, Hongbin Zhou, Dong Liu</i>	619
P I10	CFD SIMULATION OF FLOW IN MODEL PUMP SUMPS FOR DETECTION OF VORTICES	
	<i>Okamura, Tomoyoshi Kamemoto, Kyoji</i>	625
P I11	STUDY ON NUMERICAL SIMULATION OF FLOW CHARACTERISTICS IN AN AXIAL-FLOW PUMP ASSEMBLY DISCHARGE PASSAGE	
	<i>Jiyan Huang, Baoyun Qiu</i>	639
P I12	NUMERICAL STUDY OF UNSTABLE CAVITATION PHENOMENA ARISING IN TANDEM CASCADE	
	<i>Yuka Iga, Makoto Hiranuma, Takashi Shimura, Toshiaki Ikehagi</i>	650
P I13	MIXTURE MODEL APPLIED TO THE NUMERICAL SIMULATION OF PUMP SELF-PRIMING PHENOMENA	
	<i>Fengjiao Zhao, Fujun Wang</i>	665

Session 6: P II -Pump II

P II01	INVESTIGATION ON NUMERICAL MODEL OF CENTRIFUGAL PUMP BLADE	
	<i>Renhui Zhang, Junhu Yang, Yi Liu</i>	671
P II02	SPECIAL DESIGN CONSIDERATIONS FOR ULTRA HIGH HEAD PUMP-TURBINES	
	<i>Hiroshi Tanaka, Shinsaku Sato, Kaneo Sugishita</i>	676
P II03	NUMERICAL SIMULATION OF FLOW FIELD IN THE IMPELLER OF HD PETROCHEMICAL PROCESS PUMP	
	<i>Yi Liu, Jiahui Zhang, Xiaoyan Wang</i>	688

PII04	NUMERICAL SIMULATION OF UNSTEADY CAVITATION IN A CENTRIFUGAL IMPELLER <i>Minguan Yang, Can Kang, Xiuhua He</i>	695
PII05	SUCCESSFUL PERFORMANCE OF THE PILOT TEST PLANT OF A SEAWATER PUMPED STORAGE POWER GENERATION AND TECHNICAL INVESTIGATION OF UNDERGROUND PUMPED STORAGE POWER GENERATION <i>Kuninori Tanaka</i>	701
PII06	ROTATING STALL BEHAVIOR IN RADIAL VANELESS DIFFUSER OF CENTRIFUGAL PUMP AND ITS SUPPRESSION <i>Hirokazu Yakushijin, Satoshi Watanabe, Hisasada Takahara, Akinori Furukawa</i>	717
PII07	INFLUENCE OF AXIAL-FLOW PUMP ROTATING SPEED ON THE INNER FLOW FIELD <i>Yanli Wang, Fujun Wang</i>	728
PII08	NOISE QUALITY CONTROL OF SMALL HIGH SPEED WATER PUMP BY REDUCING SEPARATED FLOW <i>Yoshiyuki Maruta, Hirofumi Nakaniwa, Gaku Minorikawa</i>	735
PII09	STUDY ON HIGH EFFICIENCY AND HIGHLY RELIABLE DESIGN OF SMALL SIZED PUMP WITH LOW SPECIFIC SPEED <i>Yinchun CAO, Hidetsugu KOBAYASHI, Akinori FURUKAWA, Cichang CHEN</i>	744
PII10	TRANSIENT HYDRAULIC PERFORMANCE OF A CENTRIFUGAL PUMP DURING RAPID STARTING PERIOD <i>Songying Chen, Rongjuan Sui, Yanpeng Qu, Chunfeng Li</i>	758
PII11	COMPUTATION OF UNSTEADY INCOMPRESSIBLE VISCOUS FLOWS AROUND A CASCADE BY USING AN IMPLICIT SMAC SCHEME* <i>Yongxue ZHANG, Baoshan ZHU, Shuliang CAO</i>	765
PII12	EFFECT OF PRE-WHIRL ON UNSTABLE FLOW INCEPTION IN A CENTRIFUGAL IMPELLER <i>Daisaku Sakaguchi, Masahiro Ishida, Hironobu Ueki</i>	773
PII13	SIMULATION FOR THE EFFECT OF WALL ROUGHNESS ON THE HYDRAULIC PERFORMANCE OF AXIAL-FLOW PUMPS <i>Honggen Zhu, Souqi Yuan, Houlin Liu, Weidong Shi</i>	784
PII14	MONITORING FOR CANNED MOTOR PUMP'S BEARING <i>Junpei Sakai, Akira Ogura, Masaaki Eguchi</i>	792

Session 7: PIII-PumpIII

PIII01	APPLICATION OF SCROLL EXPANDER FOR A CO2 HEAT PUMP WATER HEATER CYCLE <i>Hyun J. Kim*, Bo Y. Nam, Sung O. Cho, Kyung R. Cho</i>	799
PIII02	DEVELOPMENT AND APPLICATION OF NEW TYPE RUNNER WITH SPLITTER BLADES TO PUMPED STORAGE POWER PLANTS <i>Kotaro Tezuka, Yasuyuki Enomoto, Kazumasa Kubota, Narumi Umeda</i>	807
PIII03	THE RESEARCH ON A NEW DIGITAL-DISPLAY CONTROLLER APPLIED IN THE Metering -pumps <i>Hongying Deng, Shengchang Zhang, Jiegang Mou, Shuihua Zheng</i>	820
PIII04	A STUDY ON A NEW TYPE SEWAGE PUMP <i>Yasuyuki NISHI, Kouichi MAKITA, Junichiro FUKUTOMI</i>	826
PIII05	DESIGN AND ANALYSIS OF OUTLET VALVE FOR HIGH-PRESSURE RECIPROCATING PUMP <i>Li Qiang, Gong Enxiang, Shi Haixia, Liu Guangbing, Jiang Qing, Jianjun Xu</i>	839
PIII06	DEVELOPMENT OF THE DESIGN SYSTEM FOR A MIXED-FLOW AND CENTRIFUGAL PUMP IMPELLER <i>Hideki Ono, Tatsuro Yashiki, Sadashi Tanaka, Takahide Nagahara, Hideo Nishida</i>	846
PIII07	STUDY ON ECONOMICAL OPERATION OF LARGE PUMP STATION BY DJUSTING OPERATION DUTY <i>Baoyun Qiu, Xiaoli Feng, Jiyan Huang, Haijiang Lin, Shouqi Yuan</i>	856
PIII08	PUMP UNIT SELECTION IN EASTERN ROUTE OF SOUTH-TO-NORTH WATER DIVERSION PROJECT OF CHINA BASED ON RELIABILITY AND ECONOMY	

	<i>Baoyun Qiu, Haitian Huang, Zhengjun Tang, Shouqi Yuan, Xiaoli Feng, Haijiang Lin</i>	871
PIII09	ESTABLISHMENT OF IMPELLER DESIGN METHOD IN SCREW-TYPE CENTRIFUGAL PUMP	
	<i>Tatebayashi, Y., *¹ Tanaka, K., *¹ Kobayashi, T. *²</i>	885
PIII10	INTERNAL LEAKAGE AND FLOW PULSATION RESEARCH	
	<i>Ji Luo, Shenglin Wu, Zirong Yuan</i>	892
PIII11	DESIGN & TEST RESEARCH FOR MIDDLE AND HIGH SPECIFIC SPEED CENTRIFUGAL SELF-PRIMING PUMPS	
	<i>Zhipeng Li, Yanni Liu, Minglan Liu, Zongzhao Shen</i>	899
PIII12	THE PERFORMANCE ANALYSIS AND APPLICATION OF MONO PUMP*	
	<i>Wang Like, Zhu Shixing, Yang Yonghong, Tian Jing</i>	906
PIII13	REAL-TIME OPTIMUM DISPATCH SYSTEM OF MULTI-STAGE PUMP STATION	
	<i>Xiong XiaoMing, Liu guanglin, Long xinpeng</i>	913

Session 8: V-Valve and Pipe

V01	A STUDY ON THE VISCOUS FLOW IN HELICAL ELIPTICAL PIPES	
	<i>Yin Jian'an^{1,2}, MA Jianfeng², Zhang Benzao²</i>	919
V02	RESEARCH AND DESIGN OF THE MULTIFUNCTION BUTTERFLY TYPE HYDRAULIC FORCE AUTOMATIC VALVES	
	<i>Zhipeng Li, Minglan Liu, Yanni Liu, Zongzhao Shen</i>	929
V03	FLUID-STRUCTURAL INTERACTIONS IN A BELLOWS-SEAL GATE VAVLE	
	<i>K.-S. Kim, Youn J. Kim</i>	935
V04	FINITE ELEMNETS STATE-VARIANT MODEL FOR ONE-DIMENSIONAL PNEUMATIC PIPE	
	<i>Yurong You, Weiliang Zeng</i>	944
V05	THE NUMERICAL ANALYSIS AND EXPERIMENTA INVESTIGATION OF AN AUTOMATIC FLUX COMPENSATION VALVE	
	<i>Xinrong Shen, Bing Lu, Jiangli Li, Zengzhen Li</i>	951
V06	EXPERIMENTAL RESEARCH AND UNIVERSAL HYDRAULIC CALCULATION OF PIPE FLOW	
	<i>Jiang Shizhang, Yong Qiwei, Jiang Ming, Chen Ming</i>	957
V07	NUMERICAL STUDY ON TRANSIENT FLOW IN PIPELINE WITH FLEXIBLE TUBE	
	<i>Young-Joon Kim, Koji Miyazaki, Hiroshi Tsukamoto</i>	964
V08	ANALYSES AND PROTECTION OF WATER HAMMER IN GAS-DISSOLVED LIQUID PIPELINE	
	<i>Yong Qiwei, Jiang Shizhang, Jiang Ming</i>	975
V09	The Tentative Study on the Frictional Loos of Unsteady Flow of Pipe	
	<i>Xinfeng Zhang, Xinpeng Long</i>	982
V10	NUMERICAL SIMULATION OF FLOW FIELD IN QUENCH OIL TOWER	
	<i>Shuihua Zheng, Shengchang Zhang, Jiegang Mu, Huajun Zhang, Hongying Deng</i>	987
V11	RESEARCH ON THE DYNAMIC CHARACTERISTICS OF THE PILOT- SOLENOID VALVE	
	<i>Wang Xinglu, Li Xiaoming</i>	994
V12	STUDY OF THREE-DIMENSION NUMERICAL SIMULATION OF FLOW FIELD WITHIN A TRUSSED TYPE BUTTERFLY VALVE	
	<i>Weimin Feng, Han Ning, Fang Hong</i>	1002
V13	CALCULATION METHOD FOR WATER HAMMER WAVE SPEED IN COUPLED PETROLEUM PIPELINE	
	<i>Jiang Ming, Yong Qiwei, Jiang Shizhang</i>	1009

PREDICTION OF FLOW CHARACTERISTICS
IN MULTI-BLADE FAN

Hidechito Hayashi, Yoshio Kodama
Nagasaki University
Nagasaki, Japan

Takahiro Yamasaki
Daikin Air-Conditioning R&D Laboratory LTD
Sakai, Japan

Souichi Sasaki
Nagasaki University
Nagasaki, Japan

Tohru Fukano
Kurume Institute of Technology
Kurume, Japan

ABSTRACT

In the multi-blade fan, there is the large re-circulation region near the front shroud. Then the flow in the impeller is fairly varied in span direction. We proposed the prediction method for the flow characteristics of the multi-blade fan, in which it is considered the re-circulation region and the flow variation in span-direction. The two-step procedure is proposed. The first step is the potential flow procedure that is included the vortex ring and the source. It can be roughly estimated the meridian flow distribution in span direction and the scale of the re-circulation region. The next step is the correction of the first step. It is proposed the criterion that the static pressure is kept constant in span direction. The blade load, which is estimated with the quasi-one dimensional empirical method, makes the span-wise width modified at the outlet of the impeller. The flow characteristics out of the blade passage were estimated. The predicted results were examined with the experiments and the references. The scale of the re-circulation region is predicted well. The flow characteristics of the impeller are roughly predicted.

1. INTRODUCTION

A multi-blade fan has the large advantage. It can be obtained the high pressure and large flow rate with a small scale. The cost to manufacture it is rather lower than the other type fans because of the simple geometry. But the efficiency of it is fairly low and the noise level is relatively large with the large rotating speed. It is consumed the large power. Then it is required that the fluid characteristics are improved and the performance of the fan is progressed.

The multi blade fan has the special geometry that the ratio of the inlet area to the outlet of the impeller is fairly small. The span length of the impeller is large. The chord length of the blade is short. And the deflection angle is very large. It is known that the flow of the multi-blade fan has the particular characteristics. There exists the large re-circulation region near the front shroud, where the air flows from the outlet of the impeller to the inlet ⁽¹⁾. And The main flow is biased toward to the hub-side. This re-circulation flow makes the flow varied in span direction. The separation on the suction surface of the blade is occurred ⁽²⁾⁻⁽⁴⁾ and makes the main flow being complicated ⁽¹⁾⁻⁽⁵⁾. The total pressure rise of the multi-blade fan is mainly produced with the dynamic pressure rather than the static pressure. So it is large the dynamic pressure loss compared to the other type fans. These characteristics increase the loss and decrease the performances of the multi-blade fan. It is required the improvement of this type fan and it is important for predicting the performances of the multi-blade fan to be modeled the re-circulation flow in the shroud region. It is difficult to understand these characteristics of this type fan.

There are researched for the multi-blade fan to improve these flow characteristics ⁽⁵⁾⁻⁽⁷⁾. But it has not succeeded now. It is needed the consideration of the re-circulation flow near the front shroud to improve the performances.

We propose the simple method to estimate the flow characteristics in the multi-blade fan. The method is able to estimate the re-circulation flow. The characteristics of the fan are evaluated in considering this re-circulation region. The method is consisted of the two-steps. First step is based on the potential flow theorem. The vortex ring, which is symmetry to the rotating axis of the impeller, is put the inflow to the impeller from the bell-mouth. The second step is the correction of the potential flow conditions. The criterion is proposed for it. The span-wise length of the passage at the outlet of the impeller is varied by this correction.

2. CALCULATION MODEL

2.1 Potential Flow Model

We proposed the method to reveal the re-circulation flow in the shroud region. The vortex ring in the bell-mouth and the source at a far field, which are based on the potential flow theorem, produces the flow around the impeller (see Fig.1), which includes the re-circulation flow and the span-wise flow distributions.

The static pressure rise in the impeller is not large and the chord length of the blade is short. So it can be considered that the centrifugal effect is not enough influenced to the variation of the flow in span direction. The static pressure does not much varied in the impeller. Then it is supposed that the flow in the impeller is governed with the inflow conditions.

The flow of the fan is predicted with two steps procedure. The first step is the roughly estimation of the meridian flow in the impeller that is obtained with adopting the potential flow theorem at the inlet of the blade and the passage flow. The image method is applied to simulate the flow of impeller, that is, the hub surface of the impeller is considered. The second

step is the correction of the 1st step. It is set the criterion to correct it. The criterion is that the static pressure at the outlet of the impeller is put constant in span-direction. It makes the meridian flow being a little varied to keep the uniform static pressure at the outlet in span-direction.

In fig.1 the source q is located at 10 times apart of the radius from the bell-mouth in the rotating axis, which is presented as vector $\mathbf{R}q=(0,0,Zq)^T$. The vortex ring is located in the bell-mouth, which is presented as vector $\mathbf{R}v=(Rvx, Rvy, Zv)^T$. The center of the vortex is coincided to the rotating axis. The strength of it is Γ . The position and the strength of the vortex ring are decided from the condition at the bell-mouth. The image method is applied to make the radial flow at the hub side.

Then the velocity vector $\mathbf{V}(\mathbf{R})$ at position \mathbf{R} is obtained with the equation (1);

$$\begin{aligned} \mathbf{V}(\mathbf{R}) = & \frac{q}{4\pi} \cdot \frac{\mathbf{R} - \mathbf{R}q}{|\mathbf{R} - \mathbf{R}q|^3} + \frac{q}{4\pi} \cdot \frac{\mathbf{R} - \overline{\mathbf{R}q}}{|\mathbf{R} - \overline{\mathbf{R}q}|^3} \\ & + \frac{-G}{4\pi} \int_c \frac{(\mathbf{R} - \mathbf{R}v)}{|\mathbf{R} - \mathbf{R}v|^3} \cdot d\mathbf{S} + \frac{G}{4\pi} \int_c \frac{(\mathbf{R} - \overline{\mathbf{R}v})}{|\mathbf{R} - \overline{\mathbf{R}v}|^3} \cdot d\mathbf{S} \end{aligned} \quad (1)$$

where $\overline{\quad}$ is the image vector. The vector $\mathbf{R}v$ is the position of the vortex ring and $d\mathbf{S}$ is the small vector on the vortex ring, which directs to the circumference.

$$\mathbf{R}v = \begin{pmatrix} Rv \cdot \cos \theta \\ Rv \cdot \sin \theta \\ Zv \end{pmatrix} \quad d\mathbf{S} = \begin{pmatrix} -Rv \cdot \sin \theta \\ Rv \cdot \cos \theta \\ 0 \end{pmatrix} d\theta \quad (2)$$

When the parameters, the source strength q and the strength Γ and the position of the vortex ring are known, the velocity vector at the any location can be calculated by the equation (1).

2.2 Estimation of Source and Vortex Ring

It is required to estimate the source strength and the strength and the position of the vortex ring for calculating the flow characteristics in the impeller. These parameters are estimated with considering the potential flow condition. The potential flow is contacted to the wall of the bell-mouth, that the flow is attached on the bell-mouth surface. The condition is applied at the bell-mouth inlet, the 45-degree position and the throat of it. The vectors of these position are presented as $\mathbf{R}n_1$, $\mathbf{R}n_2$ and \mathbf{R}_s . The normal vectors at these positions are presented as Nn_1 , Nn_2 and N_s . Then the conditions of the flow along the bell-mouth wall are shown as follows.

$$\frac{\mathbf{V}(\mathbf{R}n_1) \cdot Nn_1}{|\mathbf{V}(\mathbf{R}n_1)|} = a_1 \quad \frac{\mathbf{V}(\mathbf{R}n_2) \cdot Nn_2}{|\mathbf{V}(\mathbf{R}n_2)|} = a_2 \quad \frac{\mathbf{V}(\mathbf{R}_s) \cdot N_s}{|\mathbf{V}(\mathbf{R}_s)|} = a_s \quad (3)$$

where the parameters of right side hand should be zero for fitting the bell-mouth.

The flow rate at the throat of the bell-mouth is given by the following equation.

$$Q = \int_0^{d_1/2} V_z(\mathbf{R}) \cdot 2\pi R dR \quad (4)$$

where the vector V_z is the axial component of the velocity. The flow rate estimated by this equation has to be equal to the operating flow rate Q_0 .

The source strength q and the strength Γ and the position Rv of the vortex ring are estimated from these equations (3) and (4). It was applied the RMS method to estimate them. That is, the following function f was introduced and the function f becomes minimum at optimum values of the source strength and the strength and the position of the vortex ring.

$$f(q, \Gamma, Rv, Zv) = a_s^2 + k_0 \left(\frac{Q - Q_0}{Q_0} \right)^2 + k_1 a_1^2 + k_2 a_2^2 \quad (5)$$

where the k_0 , k_1 and k_2 are the weight coefficients for the influence of the each parameter. These coefficients are set in 100, 0.1, 0.03, respectably. The RMS method is presented as follows.

$$\frac{\partial f}{\partial q} = 0 \quad , \quad \frac{\partial f}{\partial \Gamma} = 0 \quad , \quad \frac{\partial f}{\partial Rv} = 0 \quad , \quad \frac{\partial f}{\partial Zv} = 0 \quad (6)$$

These equations are the nonlinear equations and they are solved by the Newton iteration.

2.3 Calculation of Outlet Flow of Impeller

The flow conditions at the inlet of the blade are calculated from the equation (1) by using the source and vortex ring characteristics, which are obtained above. The effects of the blade load are considered with the modification of the span-wise length of the passage. The flow characteristics in the impeller are governed by the inlet condition of the impeller. Then they are varied in span-direction very much. The span-wise distribution is treated with dividing the span-wise small region to n . And the flow conditions are calculated for each divided region. In the 1st step, the meridian flow condition is roughly estimated by the potential flow condition. The streamlines in meridian direction are calculated by the equation (7) by increasing the time step t .

$$\mathbf{R}(t+1)^n = \mathbf{R}(t)^n + \mathbf{V}(\mathbf{R}(t)^n) * dt \quad (7)$$

The flow characteristics at the n^{th} position at the outlet of the impeller are calculated for each region, where the span-wise scale dz^n is estimated from the equation (7), $dz^n = |\mathbf{R}^{n+1} - \mathbf{R}^n|$. The experimental equations by Kind⁽⁸⁾ are adopted to calculate the flow characteristics at the outlet of the impeller. The flow angle at the outlet β_2 and the deviation angle σ is calculated by the following equations.

$$\begin{aligned} \beta_2 &= \beta_{2b} - \sigma \\ \sigma &= 15 \left(2 \frac{s}{c} \right)^{0.6} - 0.13i + 0.0007i^2 \end{aligned} \quad (8)$$

where s and c are the pitch and chord length respectively. The β_2 and β_{2b} are the flow out angle

and the outlet angle of blade. The incident angle i is estimated from the no pre-whirl condition and is used in degree unit.

The velocity vectors at the outlet of the impeller are estimated.

$$\begin{aligned}
 Vr_n &= \frac{dz_{in}}{dz_n} \cdot \frac{d_1}{d_2} Vr_1 \\
 Wu_n &= Vr_n / \tan \beta_2 \\
 Vu_n &= U_2 - Wu_n \\
 Vz_n &= \frac{dz_n}{dR_n}
 \end{aligned} \tag{9}$$

where dz_{in} is the span-wise scale at the inlet of the blade and is set as $dz_{in} = h/n_s$.

The pressure loss dP_l in the impeller is calculated by the following empirical equations⁽⁸⁾

$$\begin{aligned}
 k_d &= 1 - \left(\frac{Wu_2}{Wu_1} \right)^2 \\
 k_t &= \left(\frac{k_d}{4} + 0.5 \right)^{1.7} \left(\frac{c}{s} \right)^{0.7} + 0.35(0.01i)^2 \left\{ 1 + 12 \left(\frac{s}{c} - 0.85 \right)^2 \right\} + 0.01 \frac{c}{s} \\
 dP_l &= k_t \frac{\rho}{2} Wru_1^2
 \end{aligned} \tag{10}$$

where Wu_1 and Wu_2 are the relative velocity at the outlet of the impeller that are not considered the span-wise velocity.

The total pressure rise P_{02} is calculated as follows.

$$\begin{aligned}
 P_{th} &= \rho \cdot Vu_2 \cdot U_2 \\
 P_{02} &= P_{th} - dP_l
 \end{aligned} \tag{11}$$

2.4 Correction of Pressure Condition (2nd Step)

The flow in the passage between the blades is influenced by the blade load distributions. In this method, it is assumed that the deviation from the potential condition is a little. Because the chord length of the blade is very small and the geometry of the blade is two-dimensional. It can be considered that the blade load is mainly influenced the radial and circumferential distributions and not much to deviate the flow to span-direction. As the flow variation in span direction caused by the blade load is considered by the correction of the pressure condition.

The each n^{th} span-wise position evaluated from the equation (7), which is based on the potential theorem, is not considered the pressure variation with the blade load. When the pressure variation by the blade load exists in span direction, the span-wise flow is varied in span direction. It is assumed that the pressure at the outlet is seemed to be constant in span direction. That is, when the pressure is varied in span-position, the flow will be varied in span position for diminishing the span-wise pressure deferential.

Then it was set the criterion for the second step. The criterion is that the static pressure is constant in span-direction at the outlet of the impeller. The correction of the static pressure is caused the variation of the span-wise length of the small segment, so the flow characteristics at

the outlet of the impeller are varied with the corrected pressure. The averaged pressure in span at the outlet of impeller is used for the criterion.

It is shown the flow chart to calculate the separation region and the flow characteristics in figure 2. At the first step, the source strength and the strength and the positions of the vortex ring with potential theorem are estimated with RMS method. The flow region at the inlet of the impeller is divided to n_z and the streamline is calculated for finding the outlet height of each divided region. The Euler's pressure rise and the flow characteristics is estimated at the outlet of the impeller. The pressure criterion is applied to the outlet regions. The static pressure at each span location is set the averaged one. The span-wise height is corrected by adopting the static pressure criterion. The other flow characteristics are calculated again for the modified height.

3. RESULTS AND CONSIDERRATION

The validity of this method is examined in relating to the flow characteristics with the experimental results by Yamasaki and Satoh⁽²⁾. And the experiments are made for examining the performance. Four fans were used, which are different in outlet diameter, but the other dimensions of geometry are same each other. The ratio of inlet and outlet diameter is 0.84 and the number of blade is 42⁽⁹⁾.

3.1 Separation Region and Flow Characteristics

Fig.3 shows the velocity characteristics at the outlet of the impeller. The experimental data in reference (2) are shown with the black lines. The symbols \times are the calculated results with this method. The positions D, E and F in the figure show the circumferential positions. It is noticed that the absolute velocity ratio C_2/U_2 is low about at unity near the shroud. It is indicated that the velocity of the fluid is same to the rotating speed. The region of the low velocity near the shroud is corresponding to the re-circulation region. The flow in the re-circulation region does not have the net flow. The velocity increases near the middle of span-position. At the case of the calculated results, the red line and the symbols \times do not varied so smooth compared to the experimental results. The absolute velocity up to $x/b_2=0.4$ is unity, then the velocity is increased rapidly becomes about 2.0, where the net flow from the bell-mouth goes through downstream. The difference of the velocity distributions between the experiments and the calculated ones is caused by the diffusion and the mixing between the net flow and the re-circulation region. But the calculated velocity is well coincided with the experimental ones in the net flow region.

In the figure of the outlet angle α_2 , the distribution of it is well represented the difference between the re-circulation and the net flow regions. The separated flow is shown at the level of α_2 equal to zero (circle symbol in figure). At the middle span, the flow angle is increased to about 10 degree where the flow is relatively attached to the blade. The estimated distribution is well coincided to the experimental distribution.

It is more cleared the difference between the re-circulation and the net flow region in the meridian velocity distributions. The velocity under the $x/b_2=0.4$ is almost equal to zero, so the flow toward to the downstream from the impeller does not occurred in this region. The net flow is fairly deviated to the hub side. It is cleared that the calculation with this method can be presented the actual flow characteristics.

Figure 4 is the variation of the blockage factor with the span/diameter ratio. The line is the empirical equation from reference (2). The blockage factor presents the non-dimensional scale of re-circulated region. The circle symbols are the results of the calculation. It can be seen that