

# 31st IAHR Symposium on Hydraulic Machinery and Systems

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**Abstract.** Hydropower is one of leading sources of energy used to meet the primary, secondary and territory ancillary services to balance the energy demand. Hydraulic turbine is essential component of a hydro power plant to generate electricity. The IAHR symposium on hydraulic machinery and systems provides unique opportunity to the academic and industrial research teams to exchange the state-of-the-art knowledge and ideas on the development of the next-generation of hydropower technology. 31<sup>st</sup> Symposium on Hydraulic Machinery and Systems was organized by Norwegian University of Science and Technology, Trondheim, Norway, during 26 June – 01 July 2022. This preface describes the overall summary of the symposium, including the parallel sessions, scientific and cultural tours. For more specific detail, please visit the symposium website [www.ntnu.edu/iahr2022](http://www.ntnu.edu/iahr2022). Scientific manuscripts reviewed by the experts, accepted and presented during the symposium are published in a proceeding at IOP Science EES conference series.

## 1. Introduction

The Symposium on Hydraulic Machinery and Systems, widely known as IAHR symposium within hydraulic machinery community, is organized every second year. It is organized under the framework of the International Association for Hydro-Environment Engineering and Research (IAHR), which is founded in 1935. IAHR comprises of several technical divisions, provides operational framework for the Committees. The present symposium is organized under IAHR Hydraulics — [Committee on Hydraulic Machinery and Systems](#). The earliest Symposium on Hydraulic Machinery and Systems was organized around 1960; since then, the tradition is continued. The symposium combines both academic and industrial researchers on common platform and provides unique opportunity to share state-of-the-art knowledge and ideas.

Hydropower and hydraulic machinery play essential role to reduce carbon footprint and provide green energy for the industrial and domestic use. Hydropower also helps to enhance the robustness of the power grid through energy storage and flexibility, which allows high penetration of wind and solar power. The main emphases are to stimulate the innovation-based research, to understand the technologies associated with hydraulic machinery, and to promote the interaction between the turbomachinery designers, users, the academic community, and the



**Figure 1.** Waterpower Laboratory, NTNU.

society at large. Scope of the symposium is hydro-mechanical equipment, including turbines, pump-turbines, pumps used as turbines, smart grid, digital twin, turbine intake system, and other hydro mechanical equipment.

## **2. Scope and scientific topics**

The symposium covered all topics pertaining to hydro-mechanical equipment of a hydropower. Following are the broad topics (highly in the context of hydropower) covered in the symposium.

### *2.1. Intake system*

This section covered the research topic pertaining to complete intake system from inlet of the penstock to the inlet of the spiral casing. Some examples are, intake gate, trace rake, conduit, penstock, main inlet valve, water hammer, surging, surge tank, head losses, fatigue loading in the penstock, hydraulic transients, bifurcation, trifurcation junctions, etc.

### *2.2. Hydraulic turbines*

This section was relatively broad and covered all components of hydraulic turbines, such as spiral casing, stay vane, guide vane, runner, blade, splitter, labyrinth seals, and draft tube. The section covers axial, radial, tangential and mixed flow turbines; high, medium, low and very low head (kinetic – ocean wave) turbines; Pelton, Francis, Kaplan, bulb, fluvial, propellor, etc. Topics such as turbine optimization, design, model tests, efficiency measurements are also included.

### *2.3. Pump-turbines*

This section covered all topics related to the pump-turbines, fast transition, phenomena occur in pump mode, turbine mode, etc. Many times, centrifugal pumps are used as turbine. This section also covered the topics of centrifugal pump, its design, optimization, performance, cavitation, suction circulation, blade design, vibration, NPSH, parallel/series operations, etc.

#### *2.4. Multiphase flow*

This section covered the broad topics, which involves two or more phases in the study (experimental and/ or numerical). Examples are cavitating flow, erosion, air injection, aeration, development of cavitation/erosion model, etc.

#### *2.5. Vortex breakdown*

This section covered the topics of vortex breakdown in hydraulic machinery that includes, trailing edge vortex, inter-blade vortex, draft tube vortex rope, leading edge vortex, etc.

#### *2.6. Measurement techniques and signal processing*

This section covered all topics which emphasizes new measurement techniques/ idea/ approaches in hydropower plant. It may be efficiency, pressure, strain, velocity and vibration. However, the focus is measurement technique and the instrumentation and not the flow phenomenon. Topic related to calibration and uncertainty quantification were covered here. This section also covers the topics of data collection and processing, new approach of data processing, data collection, development of analytical technique for large data, statistical analysis of data.

#### *2.7. Computational fluid dynamics and fluid structure interaction*

This section covered all phenomena occur in hydraulic machinery as well as solution using numerical techniques. Topics which emphasized the CFD techniques, high quality simulations (1D, 2D or 3D), 1D-3D coupling, development of numerical model, turbulence modelling, numerical verification and validation, detached eddy simulations, large eddy simulations, direct numerical simulations, etc. FSI analysis, one-way, coupled, FEA of turbine components, etc.

#### *2.8. Vibration and fatigue loading*

This section covered all topics relevant to vibration, resonance, damping, modal, strain and fatigue analysis. The section also covered estimation fatigue lifetime, crack development, stress-strain measurements, fatigue analysis.

#### *2.9. Sustainable hydropower*

This section somewhat overlaps the topic of *hydraulic turbines* however, this section focuses on sustainability and more towards development of sustainable hydraulic turbines of any head-power-discharge range. Some of the examples are fish friendly turbine design, very low head turbine with little infrastructure, easy to install, hybrid option (hydro-wind-solar) for rural applications, environment friendly design, green metals for turbine components, mini and micro hydro, innovative technology for sustainable hydro, energy efficient application, etc.

#### *2.10. Energy storage and flexibility*

This section covered the topic related to studies/research on energy storage in the context of hydropower, energy market, scheduling, energy management, transient operations such as load variation, start-top, load rejection, no-load, runaway. No-load and runaway are steady state operation however, both are results of transient operations and considered in this section.

Energy production and management with multiple turbines, load sharing, ancillary services, load ramping, etc. are part of this topic.

#### *2.11. Smart grid and digital twin*

Smart grid and digital twin are somewhat different topics however, those are grouped here to avoid a long description of scope. This section covered hybrid operation of hydraulic turbines, isolated grid operation with wind-solar-hydro, other topic of smart grid that involves hydraulic turbines. Topics of hydropower digitization, automation, signal processing, monitoring and conditioning as part of digital twin, use of digital twin for the prediction of maintenance, fatigue loading, damage calculations are part of this section.

#### *2.12. Selected topics*

This section covered the topics, which are not included in above sections. One such example is manufacturing techniques for hydraulic turbine and components, heat treatment, prototyping, scaling, surface roughness, blade material and metallurgy, topics related to refurbishment projects, etc.

### **3. Symposium organization and highlight**

The symposium was organized during 26 June – 1 July 2022 at Norwegian University of Science and Technology (NTNU), Trondheim, Norway. The last time, NTNU/NTH organized this symposium during 20 – 23 June 1988. It is an honor to organize the prestigious symposium again. The symposium included parallel sessions for the presentation of the research work, a concert, laboratory tour, scientific tour and cultural tour. The preparation of the symposium was started from the initial announcement in IAHR 2018 Kyoto, and after the formal approval from the Executive Committee. Formal invitation for IAHR 2022 Trondheim was sent out during IAHR 2020 Lausanne by the Chair of the organizing committee, [Ole Gunnar Dahlhaug](#). The organization of the symposium was led by [Chirag Trivedi](#).

The symposium comprised of three committees: (1) organizing committee, (2) executive committee (3) scientific committee. A total of 10, 18 and 37 members in the organizing, executive and scientific committees, respectively. The symposium was divided into 12 distinct topics of hydraulic machinery and systems: (1) Intake system, (2) Hydraulic turbines, (3) Pump-turbines, (4) Multiphase flow, (5) Vortex breakdown, (6) Measurement techniques and signal processing, (7) Computational fluid dynamics and fluid structure interactions (8) Vibration and fatigue loading (9) Sustainable hydropower (10) Energy storage and flexibility, (11) smart grid, digital twin and artificial intelligence, (12) Selected topics. A total of 170 abstracts received for the symposium, and 122 manuscripts accepted for the symposium presentations. The manuscripts accepted after two rounds of review, and the final submission deadline for the manuscripts was 15 May 2022. Experts (around 56) in the field of hydraulic machinery have contributed to carry out the review process. Total successful presentations of scientific work were 117, including physical and virtual participations. The organizing committee had made an additional arrangement for the virtual participant, who could not attend physically in Trondheim.

The symposium registration (welcome reception) was opened on 26 June (18:00 hrs) at Kafe To Tårn with beverages in Trondheim. There were around 45 delegates registered. The symposium was formally inaugurated by [Stefan Riedelbauch](#) on 27 June in Trondheim, NTNU Gløshaugen campus. The programme was streamed for the virtual participants. Stefan Riedelbauch has presented research related to hydraulic machinery and associated challenges in

experimentations and scaling for the prototype machines. Later, Ole Gunnar Dahlhaug welcome the participants as a Chair of the organizing committee and presented historical development of the [Waterpower Laboratory](#). Later, [Asgeir Tomasgaard](#) presented the research work related to energy transition in NTNU, and the main activities of FME center, [NTRANS](#). Another presentation on FME center, [HydroCen](#), was presented by [Liv Randi Hultgreen](#). Research and development activities under the hydropower center were presented, including the international collaborations with Europe, Asia, Africa and North America.

The first keynote speech of the symposium was focused on the historical development of high head hydraulic turbines and associated challenges with some open questions. The keynote speech was presented by Bjarne Børresen from Multiconsult. The challenges related to the turbine fatigue, need for the flexibility, and the open questions of rotor stator interactions, crack and fatigue loading were presented. Later part of the day, parallel sessions were organized for the authors to present their research work. The parallel sessions were organized in three auditoriums, and one of them was hybrid auditorium for the virtual participants. A special arrangement was made to the participants, who could not attend the symposium, because of flight cancellation or unable to travel at last minute. Those participants joined virtually via dedicated link and presented their work in real-time.

The second day was started with the keynote speech on industrial research and development of high head turbines by Thorbjørn Hellum-Reppen from Rainpower. The keynote focused on some of the challenges related to manufacturing of the turbines over the period of 50 years and how advancements in manufacturing are made. The keynote speech highlighted that manufacturing and refurbishment of high head turbine runner is complex due to very small blade passages, and not necessarily meet the ideal design idea of drawing board. Another keynote speech was delivered by Andrea Pirocca from [45 Engineering](#). This keynote was part of [Young Professional Network](#) of IAHR and aimed to encourage young researchers with innovative idea, and business opportunity. Later part of the day, parallel sessions were organized for the authors. During evening hours, a tour of the Waterpower Laboratory was scheduled followed by Choir concert at the Nidaros Cathedral and Gala dinner at Britannia Hotel. Choir concert at the Nidaros Cathedral was very good based on the feedback from the participants.

Third day of the symposium was started with keynote speech on digitization of hydropower by Joakim Gundersen from Hafslund Eco Vannkraft AS. The keynote speech focused on state-of-the-art of digitization and condition monitoring in the context of the hydropower plant. A considerable progress has been made in condition monitoring however the conclusion was that there is long way to go and transform the analogue system into the real-time condition monitoring. The speaker also emphasized that real-time monitoring helped to prevent the breakdown and the long downtime of the powerplant, which helped to minimize the production cost. Later part of the day, parallel sessions were organized for the authors. During evening hours, a tour of the Waterpower Laboratory was scheduled for another group. Participants had opportunity to see the research results from the different on-going research projects, they discussed with the PhD students and postdoctoral researchers in the laboratory. They also discussed the different challenges in the experimental numerical work, and possible cooperation to mitigate the challenges.

Fourth day of the symposium was started with keynote speech on challenges and research progress of the medium and low head turbines. The keynote speech was delivered by Carl-Maike Högström & Jens Österud combined from Vattanfall AB. The keynote speech was focused on state-of-the-art experimentations in the Vattanfall Research and Development laboratory under various projects, and challenges related to the need for the flexible energy, added mass, etc. The main challenge was the scaling of the research results in the laboratory environment to



**Figure 2.** Group picture with the symposium delegates.

the prototype environment, specifically the dynamic part of the results. The laboratories have certain limitations due to short intake and influence of feed pump to mimic the prototype environment. Later part of the day, parallel sessions were organized for the authors. Closing ceremony was organized after the parallel sessions. The closing ceremony was led by Stefan Riedelbauch as Chair of the executive committee. Stefan Riedelbauch has presented the summary of executive committee meeting, which was held on 27 June, and upcoming event of IAHR during 2023 and 2024. Chirag Trivedi presented the overall statistics of the symposium for the participants followed by the presentation from Arun Kumar to host 32nd Symposium on Hydraulic Machinery and Systems. The symposium was formally concluded by Stefan Riedelbauch and Ole Gunnar Dahlhaug around 1530 hrs.

Fifth day aimed for scientific and cultural tours depending on the interest of the participants. The scientific tour was planned to visit [Nea Hydropower plant](#) in Tydal, which is around two hours from Trondheim. The cultural tour was planned to visit [Røros](#) (UNESCO world heritage site), which is around two hours and thirty minutes travel time from Trondheim. Large part of the participants preferred to join the scientific tour. Overall, both tours were informative and enjoyable for the participants.

Finally, the organizing committee of the 31st Symposium on Hydraulic Machinery and Systems is sincerely thankful to all participants for their contribution and participation to the symposium. The organizing committee hope the scientific work presented by the authors is useful to advance the research work. The organizing committee understand, travelling requires huge effort, time, finance, and meticulous planning, including backup plan. Without your presence, the symposium could have not been this much successful. It is our collective effort and contribution, and the organizing committee congratulates all. Once again, the organizing committee would like to extend my sincere thanks for the physical participation and travelling to Norway.



**Figure 3.** Delegates at Nea hydropower plant in Norway.

#### 4. Summary

The symposium was organized during 26 June – 1 July 2022 at Norwegian University of Science and Technology (NTNU), Trondheim, Norway. The symposium comprised of three committees, i.e., organizing committee, executive committee and scientific committee. A total of 170 abstracts were received for the symposium, and the final approved manuscripts were 122. The total number of scientific presentations were 117 comprising 30 parallel sessions spanned over four days. The symposium included four keynote speeches exclusively focused on research on hydraulic machinery. Historical development and challenges on research and development of hydraulic machinery were presented by the keynote speakers. Participants from more than 25 countries have attended the symposium physically, and the total number of participants were 178.

The laboratory tour was organized for the interested participants to see on-going research work, and they interacted with the researchers from the Waterpower Laboratory. On 28 June, Choir concert at the Nidaros Cathedral and Gala dinner at Britania Hotel were organized. Choir concert at the Nidaros Cathedral was very good based on the feedback from the participants. Closing ceremony was organized on 30 June after completing all parallel sessions, which was led by Stefan Riedelbauch as Chair of the executive committee. He presented the summary of executive committee, which was held 27 June, and upcoming events of IAHR during 2023 and 2024. Chirag Trivedi presented the overall statistics of the symposium for the participants. All presented research papers will be published in IOP Science as separate volume of EES. The symposium was formally concluded by Stefan Riedelbauch and Ole Gunnar Dahlhaug around 1530 hrs. Fifth day aimed for scientific (Nea hydropower plant) and cultural (Røros) tours depending on the interest of the participants. Large part of the participants preferred to join the scientific tour. Overall, both tours were informative and enjoyable for the participants. Finally, the organizing committee of the 31st Symposium on Hydraulic Machinery and Systems is sincerely thankful to all participants for their contribution and participation to the symposium.

## 5. Keynote speech

[1] Bjarne Børresen, 27 June 2022, *Norwegian development of high head Francis turbines – A brief historic review and some open questions*, 31<sup>st</sup> IAHR Symposium on Hydraulic Machinery and Systems, 26 June – 1 July 2022, NTNU, Trondheim, Norway.

[2] Thorbjørn Hellum-Reppen, 28 June 2022, *Historic perspective of high-head Francis runner development, manufacturing techniques and open challenges*, 31<sup>st</sup> IAHR Symposium on Hydraulic Machinery and Systems, 26 June – 1 July 2022, NTNU, Trondheim, Norway.

[3] Andrea Pirocca, 28 June 2022, *Hydropower business opportunities for young researchers*. This speech was part of IAHR Young Professional Network Scandinavia, 31<sup>st</sup> IAHR Symposium on Hydraulic Machinery and Systems, 26 June – 1 July 2022, NTNU, Trondheim, Norway.

[4] Joakim Gundersen, 29 June 2022, *Digitalization of the hydropower plants, and current state-of-the-art*, 31<sup>st</sup> IAHR Symposium on Hydraulic Machinery and Systems, 26 June – 1 July 2022, NTNU, Trondheim, Norway.

[5] Carl-Maikel Högström and Jens Österud, 30 June 2022, *Industrial experience and challenges associated with low and medium head hydropower machines in a new energy landscape*, 31<sup>st</sup> IAHR Symposium on Hydraulic Machinery and Systems, 26 June – 1 July 2022, NTNU, Trondheim, Norway.

## 6. Organizing committee

- Ole Gunnar Dahlhaug (Symposium chair)
- Chirag Trivedi (Head of organizing committee and Editor-in-chief)
- Torbjørn Nielsen
- Pål-Tore Selbo Storli
- Debbie Koreman van den Bergh
- Liv Randi Hultgreen
- Berit Hagen
- Einar Jones-Kobro

## Acknowledgement

The Organizing Committee acknowledges all delegates of the symposium and making effort to travel to Trondheim. The committee also acknowledges the executive committee and the scientific committee for their input during the symposium organization, including reviewing some of the manuscripts. Chirag Trivedi, Editor-in-chief, is sincerely thankful to all the reviewers for their time and effort to carry out the review process.



**IAHR 2022**

31<sup>st</sup> Symposium on  
Hydraulic Machinery  
and Systems

TRONDHEIM - NORWAY

26 June - 1 July 2022