

RES

THE SCHOOL
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INVESTIGATION OF THE POTENTIAL FOR IMPROVING THE EFFICIENCY OF TURBINES OF HYDROELECTRIC POWER GENERATION STATIONS OF ALPIQ

Application of improvements in Polish hydroelectric power plants

Dariusz M. Loza

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UNIVERSITY OF ICELAND



University
of Akureyri



ABSTRACT

This thesis investigates the methodology for assessment of the potential for efficiency gain in hydroelectric power plants owned by Alpiq (Switzerland). Necessary introduction to Swiss electricity market, working principles of Pelton turbines and turbines' efficiency has been presented in the initial chapters. Thorough review of recent publications and scientific articles has been performed. The research is focused on turbines' efficiency gain and involves all components installed inside powerhouse. The studies on losses analysis in each component of turbine, reason for their occurrence and the methods of their minimization have been prepared. Gordon's efficiency prediction and theoretical power plant design are described as well as utilization of these tools for comparison with actual values. Basing on statistical data, experience from several power plants, state-of-the-art experiments and knowledge contained in many publications as well as done investigation, the methodology for efficiency gain estimation is precisely presented. Using this methodology as well as before-mentioned tools, selected Alpiq's hydropower schemes have been assessed and proper inferences have been drawn. In addition, following methodology has been presented as a computer's algorithm, which could be used to write the software in chosen computer language.

As the requirement of this thesis, the particular chapter is devoted to Polish issues. Application of investigated methodology and possibility of its usage in Polish hydropower plants is described and some recommendations and modifications are included. Finally, the conclusions from whole work are emphasized in the last chapter.

Due to limitation of available time for research, only selected Alpiq's power stations and their assessment is presented. Also, the methodology is not converted into computer program from the same reason. Nevertheless, general algorithm explains all processes and programmers may have choice of proffered computer language.

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REFERENCES

- [1] Anagnostopoulos, J & Papantonis, D 2006, 'Experimental and numerical studies on runner design of Pelton turbines', *Hydroenergia 2006*, 7-9 June, Crieff, Scotland, UK.
- [2] Angehrn, R, Rettich, J & Schärer, Ch 1999, 'Pelton runner design based on measured unsteady pressure distributions in the bucket', *Hydropower & Dams*, Issue 6.
- [3] Avellan, F, Dupont, Ph & Kvicinsky, S 1998, 'Flow calculations in Pelton turbines – Part 2: free surface flow', *19th IAHR Symposium on Hydraulic Machinery and Systems*, Singapore.
- [4] Bachmann, P, Schärer, Ch, Staubli, T & Vullioud, G 1990, 'Experimental flow studies on a 1-jet model Pelton turbine', *15th IAHR Symposium*, Belgrad, Serbia.
- [5] Bernsten, G, Brekke, H, Haugen, JO & Risberg, S 2001, 'Analysis of the free surface non-stationary flow in a Pelton turbine', *Hydropower and Dams*, Issue 6.
- [6] Bjerke, M, Brekke, H & Berg, KI 1990, 'Modern design and manufacturing of multijet Pelton turbines', *IAHR Symposium*, Belgrad, Serbia.
- [7] Blanco, MA 1999, *Rehabilitating and Upgrading Hydropower Plants*, A hydropower technology round-up report, vol. 2, EPRI, Palo Alto, California, USA.
- [8] Bøkko, E, Nilsen, E & Vinogg, L 2000, 'Thermodynamic efficiency measurement: The uncertainty of efficiency versus the hydraulic head', *IGHEM 2000*, Kempten, Germany.
- [9] Brekke, H 1984, 'A general study on the design of vertical Pelton turbines', *Turboinstitut*, vol. 3, nr 46, Ljubljana.
- [10] Catanese, A, Barglazan, M & Hora, C 2004, 'Numerical simulation of a free jet in Pelton turbine', *Proceedings of the 6th International Conference on Hydraulic Machinery and Hydrodynamics*, Timisoara, Romania.
- [11] Cengel, Y & Cimbala, J 2009, *Fluid Mechanics: Fundamentals and Applications*, 2nd edn, McGraw-Hill.
- [12] DeSiervo, F, DeLeva, F 1976, 'Modern trends in selecting and designing Francis turbines', *Water Power and Dam Construction*, August.
- [13] DeSiervo, F, Lugaresi, A 1978, 'Modern trends in selecting and designing Pelton turbines', *Water Power and Dam Construction*, December.
- [14] Fiereder, R, Riemann, S & Schilling, R 2010, 'Numerical and experimental investigation of the 3D free surface flow in a model Pelton turbine', *25th IAHR Symposium on Hydraulic Machinery and Systems*, IOP Publishing.
- [15] Finnemore, E & Franzini, J 2001, *Fluid Mechanics with Engineering Applications*, 10th edn, McGraw-Hill.
- [16] Gass, M 1998, 'Modernization and performance improvements of vertical Pelton turbines', *Hydropower and Dams*, Issue 2, pp. 25-29.
- [17] Gass, M 2002, 'Modification of nozzles for the improvement of efficiency of Pelton type turbines', *Proceedings of the HydroVision Conference*, Portland, Oregon, USA.
- [18] Gass, M 2003, 'Mechanical rehabilitation: Lesson learned at Moccasin Powerhouse', *HydroReview*, vol. 22, nr 1, pp. 10-12.

- [19] Giesecke, J & Mosonyi, E 2009, *Wasserkraftanlagen: Planung, Bau und Betrieb*, 5th edn, Springer Verlag, Berlin
- [20] Gordon, JL 2001, 'Hydraulic turbine efficiency', *Canadian Journal of Civil Engineering*, vol. 28, pp. 238-253.
- [21] Grein, H 1988, 'Efficiency prediction for Pelton turbines', *Turboinstitut – Conference on hydraulic machinery*, Ljubljana, Slovenia, 3-15 September.
- [22] Grein, H & Keck, H 1988, 'Advanced technology in lay-out, design and manufacturing of Pelton turbines', *14th IAHR Symposium*, Trondheim, Norway.
- [23] Grein, H, Meier, J & Klicov, P 1986, 'Efficiency scale effects on Pelton turbines', *IAHR Symposium*, Montreal, Canada.
- [24] Gujan, H & Hauser H 1994, 'New Pelton runners for the Küblis hydroelectric power plant', *Water Power & Dam Construction*, pp. 26-28.
- [25] Hassler, P & Schnablegger, W 2006, 'Pelton runner maintenance and its results at Verbund-Austrian Hydro Power AG', *14th International Seminar on Hydropower Plants*, Wien, Austria.
- [26] Jošt, D, Mežnar, P & Lipej, A 2010, 'Numerical prediction of Pelton turbine efficiency', *IOP Conference Series: Earth and Environmental Science*, vol. 12, nr 1.
- [27] Karakolcu, A, Geppert, L & Marongiu, J-C 2010, 'Performance prediction in Pelton rehabilitation projects', *16th International Seminar on Hydropower Plants*, Vienna, Austria.
- [28] Keck, H, Scharer, Ch, Geppert, L, Vullioud, G & Chapuis, L 2000, 'Upgrading of Pelton turbines: Additional benefits compared with runner replacement', *Hydropower and Dams*, Issue 5, pp.86-89.
- [29] Kjølle, A 2001, *Hydropower in Norway: Mechanical Equipment*, Trondheim, Norway.
- [30] Kubota, T, Xia, J, Takeuchi, H, Saito, T, Masuda, J & Nakanishi, Y 1998, 'Numerical analysis of free water sheet flow on Pelton buckets', *Proceedings of the 19th IAHR Symposium*, Singapore, pp. 316-329.
- [31] Ligaard, P 1994, 'Modern technology successfully applied in Pelton turbine upgrades', *Proceedings of the HydroVision Conference*, HCI Publications, Phoenix, Arizona, USA.
- [32] List, B, Weiss, T, Parkinson, E & Geppert, L 2006, 'Hydraulic developments for the Pelton runner of Kopswerk II', *14th International Seminar on Hydropower Plants*, Wien, Austria.
- [33] Mack, R 2006, 'Pelton turbine design of Gilgel Gibe II', *HyPower – Voith Siemens customer magazine*, May 2006, pp. 14-21.
- [34] Matthias, HB & Promper, O 2004, 'Numerical simulation of the free surface flow in Pelton turbines', *Proceedings of the 6th International Conference on Hydraulic Machinery and Hydrodynamics*, Timisoara, Romania.
- [35] Muciaccia, FF 1998, 'Efficiency measurements on Pelton turbines with thermodynamic and acoustic methods; troubleshooting and comparison with model test results', *IGHEM 1998*, Reno, Nevada, USA.
- [36] Muggli, F, Zhang, Zh, Schärer, C & Geppert, L 2000, 'Numerical and experimental analysis of Pelton turbine flow. Part 2: the free surface jet flow', *20th IAHR Symposium*, Charlotte, North Carolina, USA.

- [37] MWH 2010, *Assessment of Potential Capacity Increases at Existing Hydropower Plants*, Hydropower Modernization Initiative Report, Denver, Colorado, USA.
- [38] Patel, K, Patel, B, Yadav, M & Foggia, T 2010, 'Development of Pelton turbine using numerical simulation', *25th IAHR Symposium on Hydraulic Machinery and Systems*, IOP Publishing.
- [39] Parkinson, E 2008, 'Hydraulic Machines Engineering. Pelton turbines', *Lecture at EPFL, Laboratory for Hydraulic Machines*, Lausanne, Switzerland.
- [40] Parkinson, E, Angehrn, R & Weiss, Th 2007, 'Modern design engineering applied to Pelton runners', *Hydropower & Dams*, Issue 4.
- [41] Parkinson, E, Garcin, H, Vullioud, G, Zhang, Zh, Muggli, F & Casartelli, E 2002, 'Experimental and numerical investigation of the free jet flow at a model nozzle of a Pelton turbine', *21st IAHR Symposium on Hydraulic Machinery and Systems*, Lausanne, Switzerland.
- [42] Parkinson, E, Lestriez, R & Chapuis, L 1998, 'Flow calculations in Pelton turbines. Part 1: Repartitor and injector numerical analysis', *Proceedings of the 19th IAHR Symposium*, Singapore.
- [43] Parkinson, E, Neury, C, Garcin, H, Vullioud, G & Weiss, T 2005, 'Unsteady analysis of a Pelton runner with flow and mechanical simulations', *Hydro 2005*, Beljak, Austria.
- [44] Parkinson, E, Vullioud, G, Geppert, L & Keck, H 2002, 'Analysis of Pelton turbine flow patterns for improved runner-component interaction', *Hydropower and Dams*, Issue 5, pp. 100-103.
- [45] Parkinson, E, Vullioud, G, Richard, P, Heimann, A, Keck, H, Hauser, HP, Keiser, W & Rothenfluh, M 2008, 'Systematic approach of Pelton rehabilitation projects. Practical experience from case studies', *Proceedings of HydroVision 2008*, HCI Publications.
- [46] Peron, M, Parkinson, E, Geppert, L & Staubli, T 2008, 'Importance of jet quality on Pelton efficiency and cavitation', *IGHEM2008*, Milan, Italy.
- [47] Perrig, A 2007, 'Hydrodynamics of the free surface flow in Pelton turbine buckets', PhD thesis, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland.
- [48] Perrig, A, Avellan, F, Kueny, J-L, Farhat, M & Parkinson, E 2006, 'Flow in a Pelton turbine bucket: Numerical and Experimental Investigations', *Journal of Fluid Engineering*, ASME, vol. 128, pp. 350-358.
- [49] Perrig, A, Farhat, M & Avellan, F 2007, 'High speed visualization of an impinging jet on a Pelton turbine bucket', Proceedings of 5th Joint ASME/JSME Conference, 30 July – 2 August, San Diego, California, USA.
- [50] Sick, M, Keck, H, Vullioud, G & Parkinson, E 2000, 'New challenges in Pelton research', *Proceedings of Hydro 2000 Conference*, Bern, Switzerland.
- [51] Staubli, T, Abgottspion, A, Weibel, P, Bissel, C, Parkinson, E, Leduc, J & Leboeuf, F 2009, 'Jet quality and Pelton efficiency', *Proceedings of Hydro 2009 Progress – Potential – Plans*, Lyon, France.
- [52] Staubli, T, Abgottspion, A, Weibel, P, Bissel, C, Parkinson, E & Leduc, J 2009, 'Die Auswirkung der Strahlqualität auf den Wirkungsgrad von Peltonturbinen', *Wasser Energie Luft*, vol. 101, pp. 181-187.

- [53] Staubli, T & Hausner, HP 2004, 'Flow visualization – a diagnosis tool for Pelton turbines', *IGHEM 2004*, Lucerne, Switzerland.
- [54] Staubli, T, Weibel, P, Bissel, C, Karakolcu, A & Bleiker, U 2010, 'Efficiency increase by jet quality improvement and reduction of splashing water in the casing of Pelton turbine', *16th International Seminar on Hydropower Plants*, Vienna, Austria.
- [55] Unterbeger, P, Bauer, C, Gaschl, J & Mack, R 2010, 'Studies on the free jet of Pelton nozzles', *16th International Seminar on Hydropower Plants*, Vienna, Austria.
- [56] Veselý, J & Lhotáková, L 2001, 'Optimization of Pelton turbine bucket, straight flow nozzle and distributor pipe using numerical simulations', *WaterPower XII*, Salt Lake City, Utah, USA.
- [57] Veselý, J & Varner, M 2001, 'A case study of upgrading 62.5 MW Pelton turbine', *Proceedings of International Conference: IAHR 2001*, Praha, Czech Republic.
- [58] Vulliod, G & Michon, M 1995, 'Capacity increase of multi-jet Pelton turbines', *Proceedings of the international conference on hydropower*, The American Society of Civil Engineers, San Francisco, California, 25-28 July.
- [59] Werderits, J 1990, 'Design calculation of the distributing pipe for a six-jet Pelton turbine', *IAHR Symposium*, Belgrad, Serbia.
- [60] Zhang, Zh 2007, 'Flow friction theorem of Pelton turbine hydraulics', *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, pp. 1173-1180.
- [61] Zhang, Zh 2007, 'Flow interactions in Pelton turbines and the hydraulic efficiency of the turbine system', *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, pp. 343-357.
- [62] Zhang, Zh 2009, *Freistrahl turbinen: Hydromechanik und Auslegung*, Springer Verlag, Berlin.
- [63] Zhang, Zh 2006, 'Improvement of scale-up method for efficiency conversion of Pelton turbines', *14th International Seminar on Hydropower Plants*, Wien, Austria.
- [64] Zhang, Zh & Casey, M 2007, 'Experimental studies of the jet of a Pelton turbine', *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, pp. 1181-1192.
- [65] Zhang, Zh & Müller, J 2005, 'On the flow interchanges between the jet and the bucket of Pelton turbines', *In Hydro 2005*, Villach, Austria.

INTERNAL DOCUMENTATION

- [66] Arrangements of Alpiq's power stations
- [67] Dozias, L 2006, 'Mesures de rendement de la turbine 1A, roue N°19, de Fionnay. Effectuées le 21 Octobre 2006', *Report of efficiency measurement at Fionnay powerhouse, Grande Dixence*, Hydro Exploitation, Sion, Switzerland.
- [68] Dozias, L 2006, 'Mesures de rendement de la turbine 2A, roue N°20, de Nendaz. Effectuées le 21 Octobre 2006', *Report of efficiency measurement at Nendaz powerhouse, Grande Dixence*, Hydro Exploitation, Sion, Switzerland.
- [69] 'Forces Motrices de la Gougra SA' – *leaflet about Gougra scheme*, Sierra 2008.

- [70] 'Gebidem – Ausflüge rund um die Wasserkraft', *Alpiq's leaflet about Electra-Massa scheme*, Lausanne 2010.
- [71] 'Grande Dixence – Ausflüge rund um die Wasserkraft', *Alpiq's leaflet about Grande Dixence scheme*, Lausanne 2010.
- [72] Lattion, C 2001, 'Mesures de rendement effectuées le 2 février 2001 sur la turbine n°3', *Report of efficiency measurement at Miéville powerhouse, Grande Dixence*, Hydro Exploitation, Sion, Switzerland.
- [73] Lattion, C 2002, 'Mesures de rendement effectuées le 17 avril 2002 sur la turbine n°2', *Report of efficiency measurement at Miéville powerhouse, Grande Dixence*, Hydro Exploitation, Sion, Switzerland.
- [74] Lattion, C 2003, 'Mesures des performances de la turbine 3A', *Report of efficiency measurement at Nendaz powerhouse, Grande Dixence*, Hydro Exploitation, Sion, Switzerland.
- [75] 'Salanfe – Ausflüge rund um die Wasserkraft', *Alpiq's leaflet about Salanfe*, Lausanne 2010.
- [76] Staubli, T 2004, 'KW Fionnay, Grande Dixence SA – Strahlbeobachtung. Im Auftrag von VA Tech Hydro', *Report of flow visualization test carried out at Fionnay powerhouse*, HTA Luzern, Horw, Switzerland.

Internal reports and technical drawings are Alpiq's ownership and external access to these documents is restricted.

WEB PAGES

- [77] en.wikipedia.org – free internet encyclopedia – pictures and figures, viewed November 30th, 2010.
- [78] <http://geni.org> – Global Energy Network Institute, viewed November 22nd, 2010.
- [79] <https://www.cia.gov/library/publications/the-world-factbook/geos/sz.html> - CIA The World Factbook – Switzerland, viewed November 22nd, 2010.
- [80] www.alpiq.com – Alpiq's company official website, viewed November 22nd, 2010.
- [81] www.bfe.admin.ch/index.html?lang=en – Swiss Federal Office of Energy SFOE, viewed November 22nd, 2010.
- [82] www.emosson-lac.ch – Website about Emosson site, viewed November 15th, 2010.
- [83] www.energiethun.ch – Energie Thun (pictures), viewed November 30th, 2010.
- [84] http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_pl_en.pdf - European Commission website, viewed January 28th, 2011.
- [85] <http://elektrowniewodne.freehost.pl/elektrownie.html> - Elektrownie wodne w Polsce, Hydropower plants in Poland, viewed January 28th, 2011.
- [86] www.grande-dixence.ch – Grande Dixence website, viewed November 30th, 2010.
- [87] http://www.indexmundi.com/poland/electricity_production_by_source.html - Index Mundi, Poland Electricity – Production by source, viewed January 28th, 2011.

- [88] www.nant-de-drance.ch – official website of Nant-de-Drance project, viewed November 25th, 2010.
- [89] <http://www.pigeo.org.pl> – The Polish Economic Chamber of Renewable Energy website, viewed January 28th, 2011.
- [90] <http://www.ptpiree.pl> – Polskie Towarzystwo Przesyłu i Rozdziału Energii Elektrycznej, viewed January 28th, 2011.
- [91] www.strath.ac.uk/esru - Energy Systems Research Unit at University of Strathclyde in Glasgow, viewed November 26th, 2010.
- [92] www.swissgrid.ch – Swiss national grid company, viewed November 22nd, 2010.
- [93] www.swissworld.org – general data about Switzerland, viewed November 22nd, 2010.
- [94] www.voithhydro.com – Voith Hydro website – turbine manufacturer, viewed November 26th, 2010.

