PROJECT PROPOSAL

Date
2014-05-26

Version
Ver. 3

KME-707 IMPROVED STEAM TURBINE DESIGN FOR OPTIMUM EFFICIECNY AND REDUCED COST OF OWNERSHIP

1 MOTIVATION FOR THE PROJECT

The vision for the KME programme 2014-2018 is to improve the electrical and total efficiency by material technology development when utilizing climate neutral fuels in thermal energy conversion processes. The aim is to improve the efficiency by 3-5 percent. The current project is within the framework of KME 2014-2017 and addresses the increased cycle efficiency.

One way of further improving the utilization of CO_2-neutral production capacity is to maximize the efficiency of the turbine cycle. Increased turbine efficiency will increase the available production capacity (and revenues) for the same boiler duty. There are two available options namely; to increase the average temperature of heat addition (i.e. steam admission data and feed heating) and the turbine efficiency.

Most development efforts for industrial size steam turbines have been toward reduced first cost and not necessarily maximum efficiency. Most industrial steam turbines have fairly simple prismatic stages where the blade height is low, i.e. at most stages except for the last three. The reason for not implementing more advanced designs earlier in the turbine flow path is mainly driven by associated cost. An industrial turbine train typically lags several points behind larger utility size units [1]. The reasons are the lower volumetric flow and the higher cylinder pressure ratio – but on top of the size, there is a significant difference in technology between industrial and utility turbines [1]. The reason for having prismatic blades have historically been the difference in manufacturing costs between prismatic and milled blades. This situation has changed and today is five-axis flank milling very competitive with respect to manufacturing cost. The suggested project will focus on implementing more advance types of blades into the smaller industrial range of turbines.

1.1 Contribution to KME's goals

For the programme period 2014-2017, the overall goals are:

- Increased power production by improved efficiency, improved availability, improved heat and power production
- Increased fuel flexibility

- Improved operational flexibility

The overall aim is to improve todays BAT-level[1] efficiency by 3-4 points. This level is ambitious and requires a combination of process parameters such as steam temperature and pressure in concert with the direct component efficiency's. The aim of KME-707 is the latter and the work is focused on introducing more modern blading into the industrial frame size.

The aim of the project is to improve the turbine efficiency for increased production capacity and associate revenues – for potentially a reduced cost of ownership.

1.2 Energy and Industrial Relevance

The project contributes to the renewable energy system by a more efficient utilization of fuels. A more effective turbine will have higher production revenues, hence improved plant life-cycle economics and potentially a higher will to invest in renewable production.

Swedish turbine technology is today competitive and KME-707 will take the technology further by increasing the efficiency. The bulk of all world-wide thermal power is, today, produced with steam turbines and it is probably safe to assume that this situation will not change significantly in the future. The world-wide average efficiency of steam turbine plants is a low as 33 percent. Hence, there exists a significant potential of improving the production quality by more efficient turbines. Today, there is an impressive transition towards renewable production systems with high wind and solar penetration. The steam turbine will play also play a key role in power production with renewables such as forest residuals. Sweden has a district heating demand that is ideally suited for combined heat and power production. A more efficient turbine will produce a higher number of renewable MWs and therefore contribute to the 2020 goals.

2 PROBLEM AREA – STATE-OF-THE-ART

The attainable efficiency for a steam power plant is set by both process parameters and the turbine efficiency. The former is typically admission data (like flow, pressure and temperature), cooling media and final feed water temperature. The turbine efficiency is, to some extent, connected to the process parameters but the blading efficiency itself will also have an influence of the cycle efficiency.

During the last ten to fifteen years, the efficiency levels have increased significantly for large size utility type turbines. Published figures by Siemens (Boxberg in Germany) indicate levels exceeding 94 and 96 percent for high-pressure and intermediate-pressure turbines, respectively [1]. The drivers for the very high levels are: High volumetric flows, large cylinder pressure ratios and very high component efficiencies'. The latter is achieved by minimizing parasitic losses, minimizing

[1] Best Available Technology

leakages (and associated mixing etc.) and three-dimensional blading. Three-dimensional blading is certainly not novel - but the game-changer is to utilize the technology throughout the turbines (i.e. all stages) for maximum efficiency.

All industrial steam turbines lag several points behind the utility type of turbines because of the lower volumetric flows and more prismatic (i.e. straight and radially stacked) stages. The development of industrial size steam turbines has, to a great extent, traditionally been directed to reducing first cost rather than maximizing the efficiency. The gap can be reduced by introducing both improved blade profiles and three-dimensional stacking even for the industrial size.

3 INNOVATIVE CONTENT OF THE PROJECT

The innovative content is focused on increasing the turbine performance by introducing high-performing blading earlier in the turbine flow path.

The associated cost for introducing more advanced blading has been prohibitive in the past. Recent development in five-axis flank milling technology offers the possibility produce more advanced geometries than conventional prismatic at leveled costs.

The innovative content is focused on increasing the turbine performance by introducing high-performing blading earlier in the turbine flow path.

The project has two parts:

A: Optimized blade profiles and turbine design philosophies

B: Optimized stackings (like variants of compound lean and flow path contours)

Optimized blade profiles

Most state-of-the-art short industrial turbine blades are prismatic (or constant section) and will have losses associated with poor span-wise matching (or incidence) with the incoming steam. The innovative part is to develop blading technology for a wide range of designs with maximum efficiency for the industrial range of steam turbines. This work is typically aimed at finding the best profiling philosophe (i.e. front- or aft loading).

The work will serve as base for the optimized twist and stacking (see next section).

Optimized twist and stacking

There are several available options related to twisting and stacking of turbine vanes and blades. Stacking could be explained as the process where the vane or blade is created from individual two-dimensional sections. A vane offers several levels of freedom since there are no requirements related to centrifugal stress and it is current practice to have variants of compound lean, or similar. A compound lean blade has either both pressure or both suction sides locally leaned towards the casing and hub, respectively. It is indeed controversial to describe both in a single sentence – since the rationale behind each of them is in direct conflict with the other. Both cases provide – potentially – higher efficiency by reducing the secondary loss [2] [3]. It is common gas turbine practice to introduce this kind of blades where it is allowed by the cooling system. There is even an example of a 600 kW gas turbine that has compound lean in both turbine stages for maximum efficiency.

Siemens [1] reports very high efficiency potential by introducing unconventional stacking. It is also important to recognize that all design features may not be applicable to the industrial size range – but some features may be attractive for smaller sizes.

4 GOALS

The project will evaluate the maximum cost effective efficiency potential of industrial steam turbines, by introducing improved blade profiles and advanced blade stacking technologies. An increased level of efficiency will increase the level of produced power per unit of fuel input, hence contributing to the 2020 environmental goals. In an end-user perspective, the increased efficiency will have a positive impact on the life-cycle cost because of the increased production revenues.

The overall goal of the project is to optimize the efficiency of the industrial frame size steam turbines. One approach is to introduce certain elements from the utility size into the smaller industrial range. *The goal is to increase the stage efficiency by two percent and thereby increase the turbine efficiency*. The mentioned level is estimated based on what can be expected from introducing a more advanced technology.

Beyond the pure technical dimension, the results will be published at conferences and in journals, according to the normal publishing within a Ph.D. student project. One goal is also to have M.Sc. thesis project(s) within KME-707.

The work is based on numerical tools for turbomachinery design (1D to 3D viscous CFD). The results will be based on quantitative results for efficiency and losses, where applicable for assessing the goals. There may be a need for reverting to qualitative results when the modelling tools cannot give the right levels. One such example, may be to minimize “helicity” rather than pure row efficiency, when optimizing e.g. compound lean and other measures for reducing end-wall loss.

5 PROJECT PLAN 2014-2017

The 2014-2017 project plan is a continuation of the previous project KME-607 (2012-2013) where the work with optimizing the turbine has started.

Task 1. Optimized Blade Profiles

Inventory and evaluation of different turbine design strategies for maximized turbine efficiency. The design of a steam turbine is to a great extent controlled by strategies for minimization of the swirl after each stage [4] [5]. There are other strategies at the hand for the designer but most of the philosophies are directed towards limitations in certain stage families and turbine types.

This sub-task will create the boundaries with respect to design criteria's for the next sub-task.

Performers: Lund University and SIT

Task 2. Optimized stacking

The second phase of the project is a continuation of blade profile phase. The aim is to introduce another level of freedom when designing a turbine stage – namely three-dimensional stacking. Different types of three-dimensional stacking have been suggested and applied since the late 60s. The common understanding and rationale behind introducing this technology is to reduce secondary flow loss and pressure drops over seals within the flow path. The associated manufacturing costs have in the past prohibited this technology to find its way into industrial size of turbines. There are examples of intuitive cost effective alternatives like pressure-side lean in concert with casing contouring (in operation since the mid-90s). This technology could be incorporated into a low-reaction design without significantly changing the manufacturing process. The next level of sophistication could be to introduce "compound lean" or similar earlier in the turbine. Such a blade requires more advanced manufacturing like five-axis milling, but the trade-off in efficiency versus cost could prove to be beneficial. Larger utility turbines have taken this even one step further by introducing three-dimensional short rotor blades.

Task:

- Investigate the feasibility of different stacking schemes
    - Stacking philosophies:
        - Damped forced vortex blading
        - parabolic forced vortex blading
        - Combining the previous mentioned angle distributions with variants of compound lean
    - Where in the turbine?

The vehicle for the work in phase I was a rather tall stage in the low-pressure part of the turbine. The work in KME phase II will include also short stages where the relative importance of end-wall (and clearance) is higher.

Performers: Lund University and SIT

Deliverables		**Månad**
D1	Report ”Optimum 2D blade profiles ” – 2D coordinates	6
D2	Status report #1	6
D3	Status report #2	12
D4	**Licentiat thesis** – **Srikanth Deshpande**	**12**
D5	Status rapport #3	18
D6	Report ”Blading twist philosophies and three-dimensional stacking”	24
D7	Status report #4	24
D8	Rapport ”Industrial turbine design philosophy”	30
D9	Status report #5	30
D10	**PhD thesis** – **Srikanth Deshpande**	**36**
D11	Final rapport	36

Milestones		**Månad**
M1	Projekt start/kick-off	1
M2	Optimum blade profile(s)	4
M3	Licentiat thesis – Srikanth Deshpande	12
M4	Blade twist philosophies och optimum three-dimensionell stacking	24
M5	Design philosophy for an optimum industry steam turbine	30
M6	Doctoral thesis – Srikanth Deshpande	36

6 INDUSTRIAL CONTRIBUTIONS AND FINANCING

Siemens AB, Research and development

- Contribution from R&D project "Improved Efficiency"

In-kind contribution 4342 kSEK

7 RESEARCHERS RECEIVING FINANCING AND ACTIVITIES

Lund University – Magnus Genrup

- Lund University, Department of Energy Sciences, Division of Thermal Power Engineering.
    - PhD-student 28,600*2.15*12 = 738 kkr/annum (full 12 months)
    - Supervision 0.18*49,500*2.15*12 = 227 kkr/annum (Associate Professors Magnus Genrup and Marcus Thern)

8 FINANCING AND COSTS

The project consists of two parts:

- Task 1 is performed throughout the duration of the project since there will be a need to iterate with Task 2.
- Task 2 starts in the first quarter of year two

	More efficient power production (kSEK)	
	In-kind 2014-2016	Cash
SIT AB	4343	
Total industrial	4343	
STEM contribution (40 %)		2895

Total amount available for academic research = 2895 kSEK

Costs = Lund University 2895 kSEK

9 TIME PLAN

The project will start on September 2014 with a duration of three years. The project is a continuation of the KME-607 with all staff at Lund University in place.

The project will start with task1 (work package 1 – WP1) in September 2014 and the task is running along with the sub-sequent task 2 (WP2). The two tasks cannot be performed in insulation since there is a strong inter-connection. The developed blade profiles will be used in WP2 and the whole approach is therefore iterative.

The second part – WP2 will start during the first quarter of 2015. The aim is to take the optimum two-dimensional section from WP1 and stack the individual section to form three-dimensional blades. This part will be the bulk of the project.

	2014											
Task	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Month									**1**	**2**	**3**	**4**
Project start									M1			
Kick-off									M1			
Status report												
Work package 1												
Work package 2												
Academic's												
Final reporting1												
Project end												

	2015											
Task	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Month	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Project start												
Kick-off												
Status report		#1						#2				
Work package 1	D1	D2						D3				
Work package 2								M3				
Academic's								D4				
Final reporting1												
Project end												

	2016											
Task	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**

Month	17	18	19	20	21	22	23	24	25	26	27	28
Project start												
Kick-off												
Status report		#3						#4				
Work package 1												
Work package 2		D5						D7				
Academic's												
Final reporting1												
Project end												

	2017											
Task	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Month	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**				
Project start												
Kick-off												
Status report												
Work package 1		D9										
Work package 2		D8						M6				
Academic's								D10				
Final reporting1								D11				
Project end								X				

10 REFERENCES

[1] A. Schaarschmidt et al.,"Performance Increase Through World Class Technology and Implementation"

[2] J. P. Longley, "Introduction to 3D Flows", Lecture notes Cambridge Turbomachinery Course, 2004 and 2008.

[3] T-Z Shieh, "Untersuchung von Axialturbinen-Beschaufelungen mit dreidimensionalen Gestaltnungselementen" PhD-thesis U. Hannover 2003

[4] S. Havakechian, R Greim, "Aerodynamic Design of 50 Per Cent Reaction Steam Turbines", In Denton "Developments in Turbomachinery Design, ISBN 1860582370

[5] P Walker, J Hesketh, "Design of Low-Reaction Steam Turbines Blades", In Denton "Developments in Turbomachinery Design, ISBN 1860582370