EUDP Bolt Robot – Final Report

August 2016

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1 Project Details

Project title	Robot for automated tightening of bolts in flange connections in wind turbines
Project identification (program abbrev. and file)	EUDP 2014-II, j.nr. 64014-0513
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Seagar ApS Hammerholmen 30 F 2650 Hvidovre
Project partners (Name and CVR)	Seagar Aps (CVR no. 17181856) Valcon Design A/S (CVR no. 30721101) Vestas Wind Systems A/S (CVR no. 10403782)
Date for submission	August 25, 2016

2 Project objective and results

2.1 In English

Goal: Tightening of bolts in flange connections when erecting wind turbines is a critical process that is today manual. The manual process is problematic: the process is time consuming, the labor environment at high altitudes is dangerous and difficult, and the quality of the operation cannot be standardized and documented.

The inventors, represented by the project applicant Seagar, have been granted a worldwide patent for a robotic device that enables bolts in wind turbine tower and blade connections to be tightened according to an automated process under Factory Acceptance Test (FAT) conditions.

Work Program: In an innovation phase is created a mechanical design of the robot, which can be used in various designs of wind turbines. Then is developed a control system, and the first prototype of the self-propelled robot is built. Next follows equipment of the robot with tools for tightening of the bolts, and finally a full prototype is being developed and tested in a field test.

Application of results: Seagar want to use advanced bolt robot technology commercially in the form of license sales, delivery of bolts robots and / or selling the service of bolt tightening in wind turbines. Vestas has a commercial interest in exploiting the new technology. Valcon Design is interested in being co-developers of an innovative robot design.

2.1.1 Purpose

Seagar aims to develop and demonstrate a device that enables bolts in wind turbine towers to be tightened automatically. The robot shall move from bolt to bolt, tighten each bolt, and document all relevant data. The innovation will reduce costs of energy from wind and decrease the number of frequent accidents, occurring today.

2.1.2 Results

The project has achieved all of its objectives. A robot platform has been developed that carries tools in the form of a bolt elongation tool and a hydraulic unit that generates the pressure that elongates the bolts. The robot is a self-propelled unit that travels along the flange via a gearwheel using the bolts as gears. The robot can position itself above any specified bolt and tighten it. A control system has been developed that enables both manual and automated control of the robot and which stores results about the bolt tightening process, including the bolt tightening pattern and the specific force-displacement curve of each bolt.

2.2 In Danish

Mål: Stramning af bolte i flangetilslutning ved opsætning af vindmøller er en kritisk proces, der i dag foregår manuelt. Den manuelle fremgangsmåde er problematisk, idet processen er tidskrævende, arbejdsmiljøet i store højder er farligt og vanskeligt, og kvaliteten af operationen kan ikke standardiseres og dokumenteres.

Opfinderne, repræsenteret ved projektansøgeren Seagar, har udviklet og fået tildelt et verdensomspændende patent på en robotenhed, der gør det muligt at spænde bolte i vindmølletårn og flangeforbindelser efter en automatiseret proces under Factory Acceptance Test (FAT) forhold, således at alle de nævnte problemer med den manuelle fremgangsmåde elimineres.

Arbejdsprogram: I en innovationsfase skabes et mekanisk design af robotten, der kan anvendes i forskellige design af vindmøller. Herefter udvikles kontrolsystem, og den første prototype af den selvkørende robot bygges. I næste fase forsynes robotten med værktøj til stramning af bolte, og endelig vil en færdig prototype blive udviklet og testet i en ”field test”.

Resultatanvendelse: Seagar ønsker at udnytte den udviklede bolterobot-teknologi kommercielt i form af salg af licenser, leverance af bolte-robotter og/eller udførsel af bolte-spænding i vindmøller. Vestas har en kommerciel interesse i at udnytte den ny teknologi. Valcon Design har en interesse i at være med-skaber af et nyt robot-design.

2.2.1 Formål

Seagar vil udvikle og demonstrere en robot, der gør det muligt at spænde bolte i vindmøller automatisk. Robotten skal bevæge sig fra bolt til bolt, spænde disse og dokumenterer alle relevante data. Innovationen vil reducere prisen på el fra vindmøller og reducere antallet af ulykker, der finder sted i dag.

2.2.2 Resultater

Projektet har været meget succesfuldt og har opnået alle sine formal. En robot platform er blevet udviklet, der bærer værktøjer i form af et bolte-strækværktøj og en hydraulisk enhed, der genererer tryk til værktø-jet, hvorved bolte kan spændes. Robotten er selvkørende og driver sig selv frem og tilbage langs flangen ved hjælp af et tandhjul, der benytter boltene som tænder. Robotten kan positionere sig selv over enhver specificeret bolt og efterfølgende spænde denne bolt. Der er også blevet udviklet et kontrolsystem, der kan benyttes til både manuel og automatisk kontrol af robotten, og som gemmer data omkring bolte tilspæn-dings-processen herunder mønsteret og data omkring kraft-forlængelse af hver individuel bolt.

3 Executive summary

In the project, a functioning prototype of a bolt robot capable of tightening bolts in any pattern in L-flange connections in WTG towers has been developed. The functionality has been shown on a full-scale mockup of a typical flange connection in a Vestas V112-tower with 120 Ø48mm bolts on a flange connection with an approximate diameter of 4,000mm.

The robot can travel fully autonomously along the flange, position itself above any given bolt, catch and tighten the bolt (using an elongation tool), and document all data concerning the operation, including the bolt tightening pattern and the specific force-displacement curve achieved for each single bolt.

Compared to existing methods and technologies, the robot has significant advantages. This has been demonstrated in the project. Key advantages include: **(i)** faster erection process at reduced cost, **(ii)** less variance in achieved bolt pre-tension forces with possibility for significant material optimization, **(iii)** full documentation of achieved results, and **(iv)** significantly improved HSE aspects.

Following the current project, variants of the technology for other main WTG assemblies are planned, in-cluding solutions for: **(i)** foundation bolt assembly, **(ii)** assembly between nacelle and top tower section, **(iii)** blade assemblies, and **(iv)** vertical bolt connections in shell towers.

Currently, commercial negotiations are taking place between the project partners concerning commercial utilization of the technology.

The global value creation for the technology is estimated to be approximately 50-100 MEUR per large (>10-20% world market share) OEM. Assuming a 50% market penetration, this puts the value of the technology at between 100-300 MEUR annually for the OEM's. It is estimate that this can contribute to a 2-5% cost

reduction of WTG installations and thus be a major contribution to realize the Danish energy policy objectives.

4 Project objectives

The key objective of the project was to develop a working prototype of a robot that can tighten bolts in wind turbine tower segment connections in a fully automated way and to demonstrate the functionality.

The activities were divided into 4 Work Packages. Below follows a description of whether the objectives of each work package were achieved, whether development happened as foreseen, and whether the agreed upon milestones were achieved. Also, descriptions of the risks associated with the activities are described.

Work Package No.	WP1
Work Package Name	Basic mechanical module
Objective	Development, production, and testing of mechanical prototype able to move on predefined tower flanges. Sourcing and building of a full-scale tower connection mockup for test purposes.
How the work package evolved	The objectives of WP1 were achieved according to schedule
Milestones	**MS1**: Mechanical prototype able to move on predefined tower flange was achieved prior to the scheduled date
Risks associated with activities	None
Non-expected problems experienced?	None

Work Package No.	WP2
Work Package Name	Basic control system
Objective	Mechanical prototype able to move and position itself according to a defined procedure on the flange above the bolts/nuts.
How the work package evolved	The objectives of WP2 were achieved according to schedule
Milestones	None in WP2
Risks associated with activities	None
Non-expected problems experienced?	None

Work Package No.	WP3
Work Package Name	Advanced mechanical module
Objective	Full functionality of bolt robot, including bolt tightening tool, shown during a field test
How the work package evolved	Both MS2 and MS3 were achieved prior to schedule with fully successful results. MS4 was not achieved. The project partners agreed that testing was better done at the full-scale mockup which replicated fully the geometry and conditions in a real tower. Safety aspects concerning tests in a real tower was also a restriction.
Milestones	**MS2**: Mechanical prototype able to move and position itself above bolts/nuts **MS3**: Full functionality of bolt robot to be shown on mockup **MS4**: Full functionality of bolt robot to be shown in field tests
Risks associated with activities	None for activities leading up to MS2 and MS3. It was considered beneficial to focus test on the full-scale mockup and not in a real tower. It wouldn't have generated substantial value and would also have meant safety risks.
Non-expected problems experienced?	None

Work Package No.	WP4
Work Package Name	Project management and dissemination
Objective	Key objectives included project management, documentation, test, and QA
How the work package evolved	The objectives of WP4 were achieved according to schedule
Milestones	None in WP4
Risks associated with activities	None
Non-expected problems experienced?	None

5 Project results and dissemination of results

The main activities in the project were to develop: **(i)** a robot that can travel along a tower flange and position itself over any given bolt, **(ii)** to have a bolt tightening device tighten a bolt, and **(iii)** to document all

data concerning the flange bolt tightening process, including the specific pre-tension force applied to each bolt.

The technical results for all of the above main activities were achieved in the project.

The commercial results have also been very successful. Demonstration of the functioning prototype on a full-scale tower mockup has made several leading companies within the WTG business interested in commercial exploitation of the technology and commercial negotiations concerning this is currently taking place. Commercial rollout for the technology is expected during 2017.

In general, the project has to a high degree succeeded in realising its objectives. All planned activities except filed testing were carried out and particularly the data collection exceeded the ambitions. The problem did thus answer specifically the problems stated in the project proposal with results as expected.

The project has for all three partners resulted in the expected increased turnover, exports, and employment.

The project results have been presented in several powerpoint-presentations and live demonstrations at the mock-up to most of the leading players in the global WTG industry. Relevant presentations are included as attachments to this report.

6 Utilization of project results

The project has produced a functioning prototype of a bolt robot that can travel autonomously along a tower flange, catch and tighten any specified bolt, and document data concerning the operation.

The results are expected to be utilized by selling the rights to the technology to a leading WTG OEM (one of the project participants) who will then finalize industrialization and implement globally.

Since the technology is expected to be sold, the business plan for the Seagar has not been updated. Should the technology not at the current stage be sold, the business plan will be updated to accommodate for obtaining further financing for industrializing the technology internally and starting up production/supply of bolt robots.

The project participants are planning to take out 3 more patents. The original patent gives a good protection against possible competitors.

The global value creation for the technology is estimated to be approx. 50-100 MEUR per large (>10-20% world market share) OEM. Assuming a 50% market penetration, this puts the value of the technology at between 100-300 MEUR annually for the OEM's. It is estimated that this can contribute to a 2-5% cost reduction of WTG installations and thus be a major contribution to realize the Danish energy policy objectives.

If the technology is not sold within the coming period, the intention of Seagar is be to manufacture and service bolt robots. Each major OEM would be expected to need 200-400 robots/year, corresponding to 1,000-2,000 robots/year. Selling price will be 20-25,000 EUR/pcs meaning a revenue of 20-50 MEUR when the technology is fully rolled out.

Results have not been transferred to other institutions but the technology has been presented quite broadly in the industry.

7 Project conclusions and perspective

The key conclusions of the project are that: **(i)** it has been demonstrated that the goals of the bolt robot can be successfully achieved in WTG installations and that **(ii)** there is a significant commercial interest for this technology.

In the current project, the technology has been developed specifically for L-flange WTG tower connections. The future planned development includes development of bolt robot variants for many other WTG assemblies, including: **(i)** foundation bolts, **(ii)** connection between nacelle and top tower section, **(iii)** blade assemblies, **(iv)** vertical bolt connections in shell towers, and others.

Development of such a range of robots will ensure that all main assemblies in WTG will be made: **(i)** at increased speed, **(ii)** at a lower cost, **(iii)** with a significant reduced variance in achieved bolt pre-tensioning forces, **(iv)** with full documentation of the assemblies, and **(v)** under much improved HSE conditions.

8 Annex

Title	**Description**
Bolt Robot Presentation	General description of the bolt robot technology
Technical Description	Specific technical details of the bolt robot technology
Industrial Design	Drawings of industrial design of bolt robot
Data Collection	Example of data collection in the form of force-displacement curves