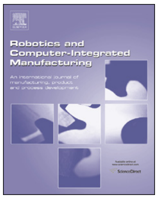
Robotics and Computer-Integrated Manufacturing 30 (2014) 577–588

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim



A cable feeder tool for robotized cable winding

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ARTICLE INFO

Article history:
Received 6 December 2013
Received in revised form
14 April 2014
Accepted 29 April 2014

Keywords:
Cable feeder
Cable winding
Stator assembly
Powerformer
Wave Energy Converter

ABSTRACT

Cable winding is an alternative technology to create stator windings in large electrical machines. Today such cable winding is performed manually, which is very repetitive, time-consuming and therefore also expensive. This paper presents the design, function and control system of a developed cable feeder tool for robotized stator cable winding. The presented tool was able to catch a cable inside a cable guiding system and to grab the cable between two wheels. One of these wheels was used to feed cable through the feeder. A control system was integrated in the tool to detect feeding slippage and to supervise the feeding force on the cable. Functions to calculate the cable feed length, to release the cable from the tool and for positional calibration of the stator to be wound were also integrated in the tool. In validating the function of the cable feeder tool, the stator of the linear generator used in the Wave Energy Converter generator developed at Uppsala University was used as an example. Through these experiments, it was shown that the developed robot tool design could be used to achieve automated robotized cable winding. These results also complied with the cycle time assumptions for automated cable winding from earlier research. Hence, it was theoretically indicated that the total winding cycle time for one Uppsala University Wave Energy Converter stator could be reduced from about 80 h for manual winding with four personnel to less than 20 h in a fully developed cable winding robot cell. The same robot tool and winding automation could also be used, with minor adjustments, for other stator designs.

1. Introduction

Energy conversion to and from electric energy through electric motors and generators is an essential component of modern society. With the introduction of electric energy conversion from new energy sources, such as wave energy, and increased use of electric motors in the industry, it is likely that the development of such large and medium size electrical machines will continue. An alternative generator design, which will be explored in this article, is the Very High Voltage machine, also known as the Powerformer or Motorformer concept, developed at ABB. The main mechanical difference between this technology and conventional large electrical machines is the cable winding in the stator. Traditionally, the stator winding is made from copper bars or strands of induction wire. Cable wound machines have some significant advantages compared to other technologies, including higher operating voltage level, reduced system losses and fewer winding production steps [1–5]. The design might also be more suitable for harsh off-shore environments where maintenance is complicated and expensive [6]. Some interesting application areas for cable wound machines are in high-voltage motors [7], wind power [8], hydropower [9] and wave power [10].

Manufacturing automation is an important tool in large scale production, especially to be competitive on a global market and to create and keep new industries in countries with higher personnel costs [11–13]. Electric machine assembly has historically become highly automated and efforts are continuously put into find more effective and flexible assembly methods [14–19]. However, an automation method for the stator winding of cable wound generators has not been developed yet. Today, cable winding of electrical machines is done manually in very small series, sometimes with the help of cable feeder tools [20]. This manual assembly is very repetitive, time-consuming and therefore also expensive. Developing a flexible cable winding automation is hence an important step towards wider use of cable wound machines. Within manufacturing automation, industrial robots are rapidly growing in numbers. Less expensive robots with higher performance, easier programming and improved offline simulation software, together with smaller product series, enable automation of complex tasks. Some of these tasks have clear similarities to cable winding [21–23].

An example of a device where cable wound generators are used is the WEC[1] concept developed at UU[2] [10,24], see Fig. 1. The UU WEC uses a direct-drive linear cable wound generator, connected

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http://dx.doi.org/10.1016/j.rcim.2014.04.003

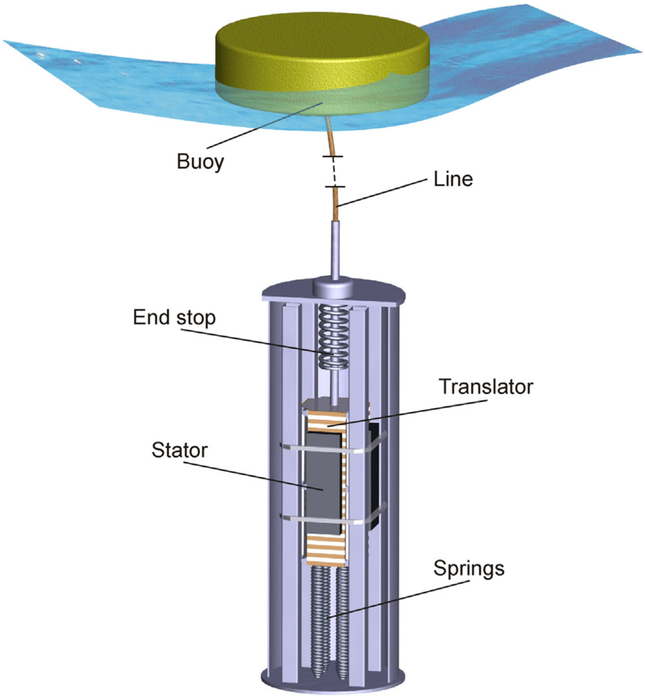

Fig. 1. A simplified model of the UU WEC unit design.

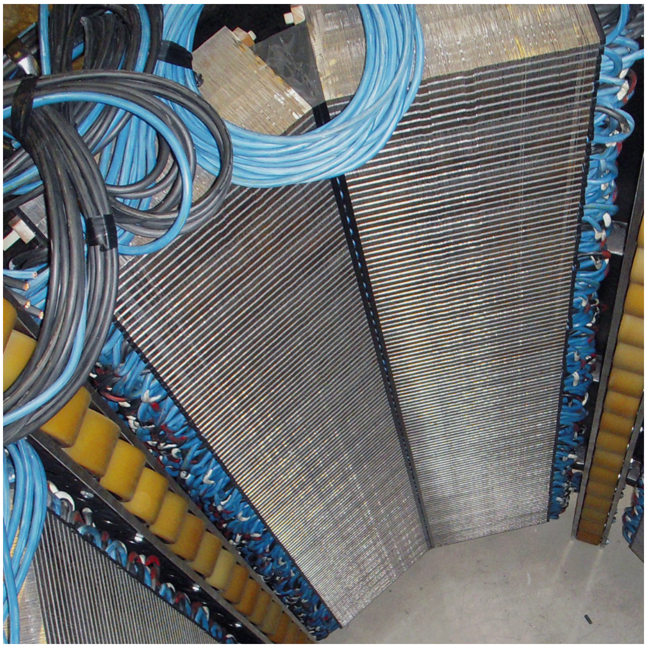

Fig. 2. A cable wound UU WEC stator section mounted inside an UU WEC.

to a point absorbing buoy. The stator of the generator is split in four 2 m long and 0.5 m wide stator sections. Each stator section has a 15 degree angle in the middle, so the full stator has eight sides towards the translator. The stator is wound with 16 mm^2 PVC-insulated multi-thread standard installation cables. Fig. 2 shows a UU WEC cable wound stator section which is mounted inside the generator housing, before the translator is mounted. Fig. 3 defines some key parts of the UU WEC stator section design.

For the UU WEC concept to be competitive on the global energy market, automated large scale production is required to keep down the cost per WEC unit. A bottleneck in assembling the generator is the stator winding. So far, all UU WEC generator prototypes have all been wound by hand. Such manual winding with four personnel require 20 h work per stator section. However, a fully automated stator cable winding method for the UU WEC generator stator has been suggested in previous research [5]. This method uses four industrial robots equipped with cable feeder tools, (see Fig. 4). The robots work in pairs, positioning against the stator sides to push and pull the cable back and forth through the slot holes of the stator according to a defined winding pattern. As the first robot has grabbed the cable, it positions against the first stator slot hole to be wound. The second robot is simultaneously positioned at the corresponding slot hole on the opposite side of the stator. Thus, the cable can be fed between the robots through the stator. Subsequently, the second robot positions against the next slot hole while the first robot drops the cable and positions on the opposite stator side. This procedure is repeated until the whole stator is wound. For one stator section, 24 cables, each about 25 m long, are used. The total cable feed length per robot pair and stator section is about 2500 m. A procedure for measuring the exact position of the stator to be wound using a proximity sensor on the robot-held tool has also been developed in previous research [25].

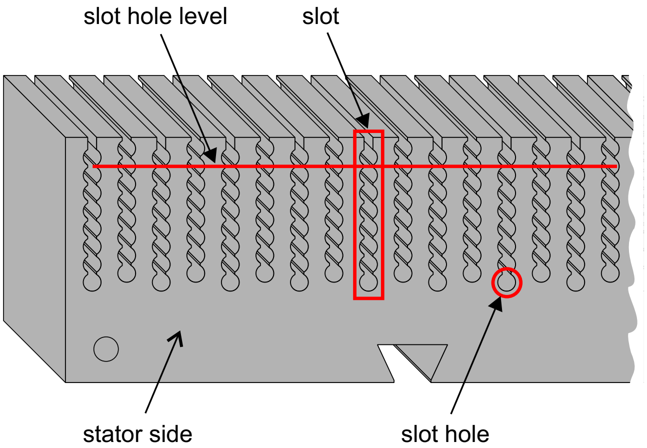

Fig. 3. Definitions of some key parts of the UU WEC stator section design.

The aim of this paper is to describe and evaluate the design and implementation of a robot held cable feeder tool, designed for robotized cable winding. This tool has been designed specifically for robotized cable winding and is, besides the robot itself, the heart of the cable winding automation. A cable feeder prototype tool has been designed and experimentally validated using the UU WEC generator as an example. However, the same tool principal design can be used for different stator designs, including rotating machines and other cable dimensions.

In the following, Section 2 presents the methods used to design and evaluate the cable feeder tool. Section 3 then describes the design of the final tool design and Section 4 describes the final experimental results. The results are discussed in Section 5, along with suggestions for future work. Finally, a conclusion is given in Section 6.

2. Method

In designing the cable feeder tool, an iterative work method was used. First, the demands on the tool were decided from manual winding experience and experiments. These demands were then translated to mechanical properties. A 3D CAD software was used to create an initial tool design, which was then validated together with the robot cell in an industrial robot offline