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An adaptive and automated bolt tensioning system for the pitch bearing assembly of wind turbines

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ABSTRACT

The assembly process of wind turbines is performed mainly manually and is characterized by unergonomic operations. In the case of the rotor blade bearing assembly three bearings, which have a diameter of several meters, are bolted to the rotor hub with hundreds of bolts. Although the introduced preload force on these bolts should be subjected to only minor deviations, the tightening process is performed manually despite its high labor intensity. Until now, low production numbers and a lack of automation concepts for large-variant components did not allow a cost-effective automation. By developing a robot guided bolt tensioning tool and adaptive tensioning process the tightening process can be automated for rotor blade bearings of wind turbines.

1. Introduction

Until the beginning of the 21st century wind energy turbines were assembled in accordance with the fixed position assembly [1]. Despite long cycle times and large product sizes, the production has changed to flow production similar to the automotive production since then. This enables standardized processes and lean manufacturing techniques [2,3]. Regardless of this organizational change, the assembly of the rotor hub is still characterized by manual assembly. A possible application for the introduction of an automated solution is the rotor bearing assembly. In the last step of the rotor hub assembly process, the preload force is applied to the pre-assembled bolts which join the bearings to the rotor hub. This is a recurring activity because several hundred bolts of three bearings have to be tensioned. In addition to the economic potential, this process offers possibilities to improve the ergonomics.

For this reason, this paper describes the development process of a flexible automated assembly system, so the tensioning process can be fully automated and used for different types of rotor hubs. Starting with an analysis of the product, the manual assembly process is analyzed and a tolerance chain is developed. Based on these analyses the adaptive assembly process is developed. Beside the process development, the development of the innovative tensioning tool and its components is described. First results of the test on an original 2.5 MW rotor hub are presented, before a summary is given.

2. Manual assembly process of rotor Hub bearings

In wind turbine assembly, three bearings are joined to the rotor hub in the wind turbine factory. These bearings are assembled between the rotor blade and the rotor hub. Due to the bearing, a rotation of the blades around their longitudinal axis to influence the rotor´s rotational speed is given which is shown in the left picture of Fig. 1 [4]. In modern offshore wind turbines, these bearings have an outer diameter of up to 4 m. The size of the bearing diameter depends on the loads and the length of the rotor blades. To ensure a reliable connection between bearing and the rotor hub, an exact preload force has to be applied by tensioning cylinders to over 120 bolts ranging in size from M30 up to M36.

The bolts of a pitch bearing ring require a particular equal and reproducible application of the preload force for all bolts because this has a significant effect on the stiffness of the connection and the service life of the bearing [5]. The preload force application via a torque wrench is relatively inexpensive and simple, but the calculated torques do not match the necessary torques, due to frictional influences, which cannot be determined exactly. Therefore, the preload force is subject to fluctuations. Moreover, it is difficult to support the torque on adjacent parts. Consequently, the torque-controlled method is an unsuitable tightening method for bolts of wind turbine pitch bearings [6,7]. Thus, hydraulic bolt tensioning cylinders are used at the pitch bearing assembly, which

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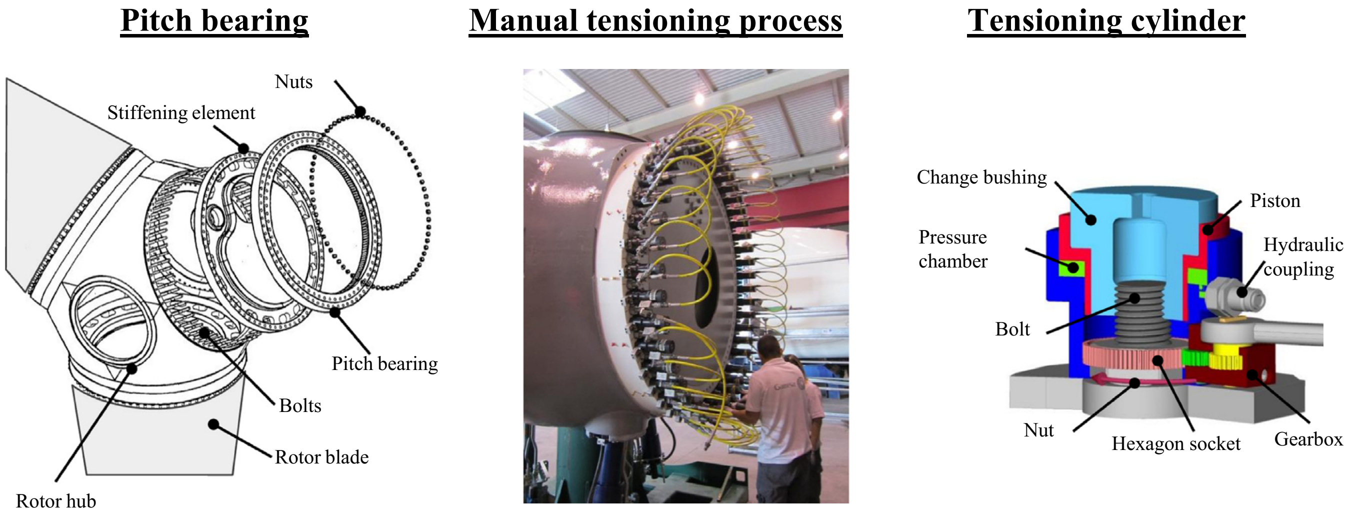

Fig. 1. Analysis of the product, manual process and tool [9,10].

are threaded on the projecting thread of the bolts. When the tensioning cylinders have been attached to the bolt, a pressure is build up which stretches the bolt. While the bolt is stretched the nut is tightened with a torque wrench via a gearbox, shown in the right picture of Fig. 1. The applied torque in this stretched condition is much lower compared to the torque getting applied by tightening tools. Due to this technique, the preload force can be controlled and is applied directly and reproducibly. Another advantage is the absence of the additional stress on the bolt cross-section, due to torsion and bending. Thus, the bolt is free of shear stress and has only pure axial stress, so the bolt sustains a higher tensile stress [8].

2.1. *Analysis of the bolt tensioning process*

Wind turbine manufacturers attach tensioning cylinders to every second bolt which then apply a defined preload force to the bolts. During the manual tensioning process workers have to climb on ladders and work on high platforms and attach the tensioning cylinders with a weight of approximately 12 kg. Moreover, the workers stay in front of the tensioning cylinder to tighten the nuts when a pressure of over 1000 bar is applied to the tools and hoses. These facts show the potentials to improve the ergonomics and reduce the risk of the working environment.

To determine the product and process parameters, which have an effect on the preload force during the tensioning process, investigations have been undertaken. Therefore, the bolting process was simulated on a demonstrator which represents a bearing section with five M36 bolts. More components like a manual tensioning cylinder and measurement equipment are used for the tensioning process replication, as shown in Fig. 2. The applied preload forces are measured during the whole tightening process by strain gauges which are attached to the bolts and connected via an amplifier to a PC.

In the practical test two major effects were investigated which lead to a force loss during the tensioning process [9]. The first force loss occurs in the pressure decreasing step when the measured force of the bolt abruptly reduces, which is referred to as elastic re-suspension. This re-suspension increases with the applied pressure, but decreases with higher torques at the same pressure level. Thus, the force loss depends on the nut tightening torque and the pressure. This results in a force loss between 9% and 22% of the respective maximum nominal preload force value. This effect is caused by a change of the force flow which at the process beginning between the tool and the bearing ring and changes then to bolt connection, when the pressure is decreased. To compensate the preload force loss and to apply the target preload force, the applied pressure has to be higher than the pressure equivalent to the target preload force. A higher torque would reduce the force loss but an additional torsion stress would be applied.

Furthermore, the tensioning of the adjacent bolts leads to a force loss of bolts that have already been tensioned. Due to compression in the intermediate layer, the effect of directly adjacent bolts is bigger than the influence of the outermost bolts of the test bench. In the second tensioning cycle, the effect of the preload force loss due to adjacent bolt tensioning diminishes compared to the first cycle. Only the directly adjacent bolts have an effect on the preload force because the intermediate layer has already been compressed in the first tensioning cycle. Because of the compression effect of the intermediate layer and the resulting preload force loss, the bolts are repeatedly tightened in the real process at the wind turbine manufacturer to compensate for this effect. Instead of a repeated tensioning cycle, the multi tensioning is another method to compensate the force loss, where tensioning cylinders are attached to every second bolt.

2.2. *Analysis of the assembly tolerance chain and identification of assembly parameters*

Extremely large and heavy components, as found in wind turbines, are subject to both product and process tolerances. The tolerance chain analysis is a method to identify the influences and tolerances [10]. To analyze the tolerance chain, it is being assumed that the components to be joined are positioned in a robot cell in front of a robot. Within this cell the tensioning tool is guided by the robot to different bolt positions of the bearing ring. The tolerances result on the one hand from the pre-assembled components of the rotor hub and on the other hand from the robot-guided tensioning tool, which is shown in Fig. 3. The product tolerances include the relative position between the rotor hub and the robot. Due to a rotor hub weighing up to 30 t, it is impossible to position the rotor hub exactly reproducible. In addition the holes in the hub flange have both orientation and position tolerances, which are manufacturing-related. Furthermore, the bolt protrusion above hub flange varies because the bolts are threaded manually into the holes of the rotor hub. On the other side of the tolerance chain, at the tensioning tool, tolerances are caused by the robot accuracy as well as the attachment of the tensioning tool

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