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Robot needle-punching for manufacturing composite preforms

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ABSTRACT

The advent of three-dimensional (3D) needle-punched preforms has presented the composites community with some novel options in materials' selection. 3D flat fabrics and fully special shaped preforms have been trialed with considerable success for engineering applications. This paper presents and evaluates the design and implementation of a six joints robot needle-punching system integrated for producing high performance fiber preforms for advanced composites. The system has been validated through robotized needle-punching experiments on a conical preform. It has been demonstrated that automated needle-punching using industrial robots can be achieved. Apart from the key points of interfacing and programming of the robot arm and the needle-punching apparatus, the major practical challenges are in ensuring the surface smooth and even of the needle-punched preform. Possible solutions to critical and potentially problematic aspects have been suggested. It is noteworthy that the presented robot needle-punching system can easily be adjusted to different preforms with different shapes, dimensions and needling distribution.

1. Introduction

The textile industry has developed the ability to produce net-shape/near-net-shape preforms by the use of three-dimensional (3D) forming techniques [1], such as 3D weaving [2], 3D braiding [3], 3D knitting [4], and 3D needle-punching [5]. Compared with other 3D forming technology which mainly uses manual operation, 3D needle-punching technology is a highly automated preform fabrication technology with higher production efficiency and lower cost [6]. Now the 3D needle-punching technology has been used to produce various preform for composite components, such as divergent section [7] of nozzle, exit cone [8,9], chamber, gas vane [10], airplane brake [11], throat [12], and other carbon/carbon(or carbon/ceramic) [13,14] composite components.

In order to meet the needs of the above-mentioned different shapes of composite components, different needle-punching machines have been developed and successfully adapted to use various types of high-performance fibers (glass, silica, carbon, aramid et.al) to produce both flat and net-shape/near-net-shape preforms. For instance, U.S. Pat. No. 4790052 to Olry [15] has disclosed a process for manufacturing homogeneously 3D needle-punched structures of fibrous material, layers of fibrous material are added to a stack of needled layers, the needling needles are moved away from the stack so as to maintain a uniform depth of needling over the entire stack, and to achieve a uniformly needled result; Lawton and Smith [16] patented a method and apparatus for producing a shaped filamentary structure and, more particularly, to filamentary structures which can be subjected to further processing, in order to produce a C/C composite. The raw material is cut to a certain shape, so there's a waste of some material. Olry et al. [17] developed an annular needle-punching device for producing annular preform for composite. Preforms are made by winding superposed layers of a strip of cloth of spiral or helical shape comprising substantially helical warp threads and substantially radial weft threads. The layers of the strip of cloth are needled so as to be bonded together by fibers pulled from the yarn of the cloth.

In parallel to the use of flat needle-punching machines, different forms of special shaped needle-punching devices have been developed for manufacturing 3D complex preforms. Olry [18] patented "Novoltex" needle-punching technology which is related to an apparatus (Fig. 1) and a process for manufacturing an axi-symmetrical and non-cylindrical 3D structure formed by superposed layers of fibrous material bonded together. The application of the invention is the production of 3D reinforced structures intended for manufacturing composite material components, particularly for nozzle exit cones. And in 1993, Olry and Dupont [19] invented a more advanced installation for making complex needle-punched fiber preforms by use of two-dimensional fiber fabric, an arm carried the needling head and possessing a plurality of degrees of freedom, and a control device for automatically adjusted the displacement of the arm to move the needling head within the range of the arm along predetermined trajectories and with predetermined orienta-

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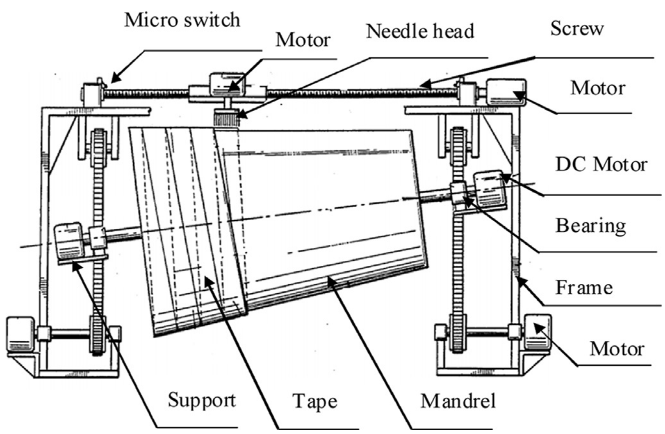

Fig. 1. A very schematic view in elevation of an apparatus for preparing non-cylindrical axi-symmetrical preforms [18].

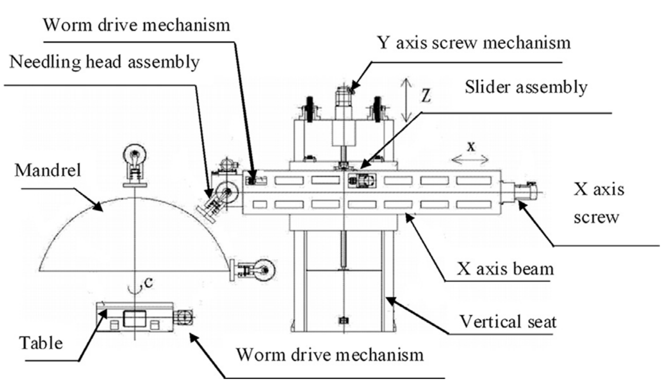

Fig. 2. Schematic view of a CNC needle-punching machine [20].

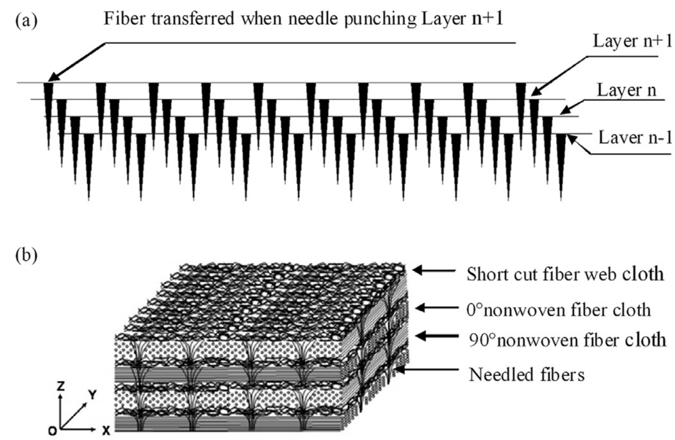

Fig. 3. (a) Generation of 3D needle-punching process [21]; (b) schematic of 3D needle-punching preform [22].

tions. More recently, patent document CN102828348B [20] disclosed a shaped CNC needle-punching machine (Fig. 2), needle-punching head components can swing in the range of 0–90°, but cannot achieve spatial arbitrary pose. The workbench is driven by worm gear, while the precision needs to be improved.

Even though these devices show certain extent flexibility for needle-punching for some shaped complex preforms. However, complex surface characteristics of parts (special for aerospace components) require needle-punching devices have much more degree of freedom to achieve high-quality needle-punched shape and adapt to different process features easily. In addition, the production efficiency and intelligent manufacturing are also vital, under the background of industry 4.0, it is noteworthy that using highly flexible multi-joint (such as 6 joints or more) industrial robots combined with side auxiliary equipment to prepare complex preform components should be an important development direction of intelligent manufacturing.

The aim of this paper is to describe and evaluate the design and implementation of a six joints robot needle-punching system integrated for producing high performance fiber preforms for advanced composites. Within this objective, the paper first introduces the needle-punching process and outlines the requirements on robot needle-punching system, and then presents the method for design the robot needle-punching system. Finally, a robot needle-punching system has been designed and experimentally validated using the conical preform as an example. However, it is noteworthy that the robot needle-punching system designed can also be used for different complex preforms with different shapes and dimensions.

2. The robot needle-punching system integrated

In this section, the needle-punching process, the demands on the robot needle-punching system and the resulting design choice for the system prototype are presented.

2.1. The needle-punching process

Needle-punching refers to a technique for producing textile preforms consists of attaching fabric layers to each other with fibers carried by hook fitted needles (hooks are designed so that fibers stay where they have been carried when the needles leave the preform). Needle-punching is carried out after each layer so that, at the end, each part of the preform, through the thickness, has received the same amount of transferred fibers as shown in Fig. 3(a), this provides good through the thickness homogeneity and the 3D needle-punched preform is shown in Fig. 3(b).

2.2. Requirements on robot needle-punching system

The most important demands on a robot needle-punching system for automated needle-punching for the composite preforms are summarized in Table 1. These demands originate from flat preform needle-punched experience and the early curved prefrom needle-punched experiments. The needle-punching experiments show that the reaction force of needling-punching could be very large if too many needles were assembled. That would affect the position accuracy of the robot end. Since single needle requires about 1 kg feeding force, and 20 pins is a reasonable choice according to experimental tests.

2.3. The robot needle-punching system design

2.3.1. The composition of the system

The needle-punching unit consists of a needle-punching end-effector interfaced to articulated robot arms (STSrobotics), typically with six rotary joints. The degrees of freedom of the set-up can be increased further by adding rotary table side auxiliary equipment. The robot needle-punching system is composed of robot body, needle-punching head, rotary table, and of course the control system. The composition of the robot needle-punching system is shown in Fig. 4.

2.3.2. The needle-punching head and rotary table side auxiliary equipment

Traditional needle-punching head is mechanically driven by a motor, linked by belt or eccentric wheel to crank mechanism which controls the reciprocation translation motion of the needle plate and the