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A NOVEL APPROACH FOR FIBER PLACEMENT TRAJECTORIES AND FABRIC DRAPING IN CAE

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ABSTRACT

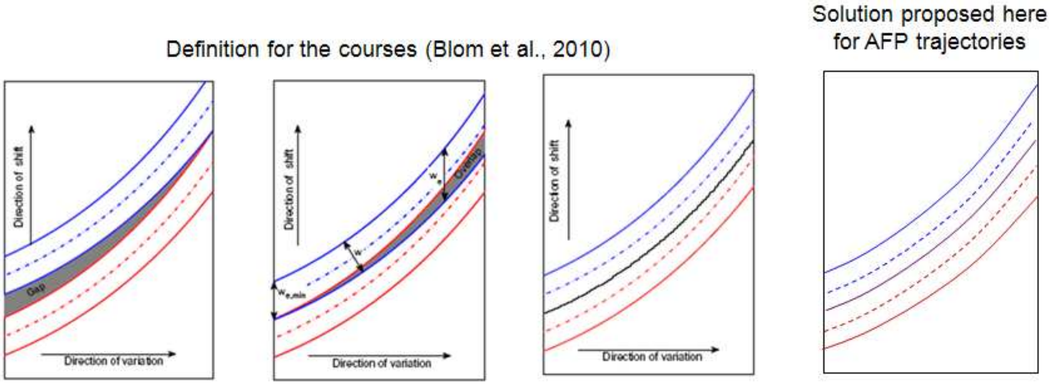
The definition of the fiber placement trajectories or the determination of the draped fabric configuration is an important step in the analysis of a composite part. In this paper, we study the efficiency of applying the numerical simulation of a moving interface to the problem of defining fiber placement trajectories for composite structures. This new approach is based on the Fast Marching Method. It has two main advantages: first, it simulates the mechanism of an Automated Fiber Placement machine by producing equidistant fiber courses, without undesirable gaps or overlaps between the successive courses; secondly, this method is very general and can be easily applied to complex surfaces, as it works directly on a mesh of the composite part and not on its representation by geometric equations. The method is extended here to deal with the draping of fabrics on surfaces which may be non-developable. The method is then able to identify zones with large shear due to the fabric deformation resulting from the draping process. This approach is illustrated through examples from real case studies for straight and curved fiber placement trajectories, and is compared to finite element solutions in the case of a fabric draping.

1. INTRODUCTION

In the Automated Fiber Placement (AFP) or Automated Tow Placement (ATP) technologies [1,2], the head of the machine lays down multiple pre-impregnated tows on shapes. AFP machines can place simultaneously several tows side by side during a course of the machine head, and a complete ply is obtained by laying down successive courses. Contrary to the Automated Tape Laying (ATL) process, AFP allows the definition of curved fiber paths using narrow individual tows. The AFP process can therefore be used to produce structures of complicated shape with possibly curved fiber courses.

The draping simulation of fabrics has been studied in [3–6]. In [4, 5] the weft and wrap directions are defined by computing the crossing points of the fibers. These points constitute a grid of points with a fixed spacing in each direction and belong to the draping surface, and the fibers are the broken lines connecting the crossing points. For AFP trajectories, Hyer and Gurdal, in [7–10], proposed a solution for variable stiffness laminates in flat panels. In [11], the fibers are placed on a flat surface and are assumed to be a set of Bezier curves or polynomial functions. In [2, 10, 12], the fibers are defined as a geodesic path, a constant angle path, a path with a linearly varying fiber angle, or a path with constant curvature. They have been applied on cones and cylinders. A third approach in [13–15] is to consider a reference curve over the draping surface and to compute the set of points over the surface which are at a constant distance from the reference curve. A fiber is the broken line that connects these equidistant points.

All of these approaches, for AFP trajectories and fabric draping, suffer from two major drawbacks. First, they are geometry methods requiring the parametric equations of the surfaces to be draped. Most of the time, these parametric equations are not available, especially for industrial applications on complex structures, for which one works with CAD surfaces and the corresponding mesh. Therefore, a method for defining the fibers using a mesh and not parametric equations is needed. Secondly, these approaches (except the third one) do not generate equidistant paths for the courses in the AFP process. If two consecutive course centerlines are not equidistant, undesired gaps and overlaps appear (see Figure 1). The gaps weaken the structure and the overlaps increase its weight. Such flaws are undesirable. In [2] it is mentioned that using the cut and restart capabilities of the AFP machine allows to avoid the undesired gaps and the overlaps, and consequently provides plies of constant thickness over the structure. However, this technique can be time consuming since the full capability of the machine to propose courses of constant (and maximum) width is not used.


Definition for the courses (Blom et al., 2010)

Solution proposed here for AFP trajectories

Figure 1. Possible trajectories for AFP machines.

In this paper, we use the Fast Marching Method (FMM, [16]) to define equidistant courses over surfaces of general (and possibly complex) geometry. The approach developed here relies on the definition on the structure of a reference curve, which represents the initial position of the interface, and which can be seen as an initial fiber trajectory represented by a course centerline. This reference curve is called ”reference fiber” from now on. This reference fiber is propagated over the whole surface in such a way that (possibly) curved fibers trajectories are generated without the drawbacks of gaps and overlaps, while exploiting the full capacity of the AFP machine, i.e. laying down courses of constant (and maximum) width. Moreover, this approach works with a mesh of the surface rather than using parametric equations to define the geometry of the structure. This feature makes possible the definition of fiber trajectories for structures of complex geometry. When two perpendicular reference fibers are considered, the method can be used as a tool for simulating the draping of woven fabrics: the fibers are perpendicular at the seed point, but may be not perpendicular anymore at other locations and therefore represent the shearing effect when non developable surfaces are considered. The two sets of generated fibers remain equidistant, as are the tows in the fabric. Since the method provides the local fiber orientation in each element of a mesh, it is a natural input for the finite element method [17] when a structural analysis of the composite component must be conducted. This method is then made available in a CAE environment, based here on the SAMCEF finite element code.

2. THE FAST MARCHING METHOD FOR AFP TRAJECTORIES

The definition of the set of equidistant fibers is based on the solution of the Eikonal equation. This equation predicts the travel time of a moving interface over a domain. Starting from an initial front defined on the meshed domain, the iso-values of the calculated times provide a network of equidistant curves. As described in Figure 2, the idea here is to use a reference fiber, defined on the meshed structure, and to apply the Fast Marching Method to solve the Eikonal equation. The information of the reference fiber is then propagated over the whole domain, and the resulting fiber network is made of equidistant curves. Since a mesh is used, the result provides a level-set representation of the fiber network. In each finite element, it is then possible to determine the gradient of that level-set, which is perpendicular to the local iso-value. The local fiber direction can then be computed with a vector product (Figure 2).

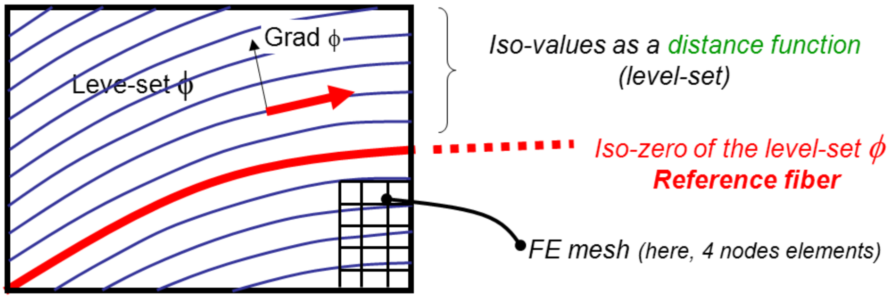


Figure 2. Possible trajectories for AFP machines.

In Figure 3, we consider the case of a non-developable panel. Two plies with curved fibers are defined on it. The AFP trajectories are also provided. It is observed that the courses are equidistant, avoiding undesirable gaps and overlaps.

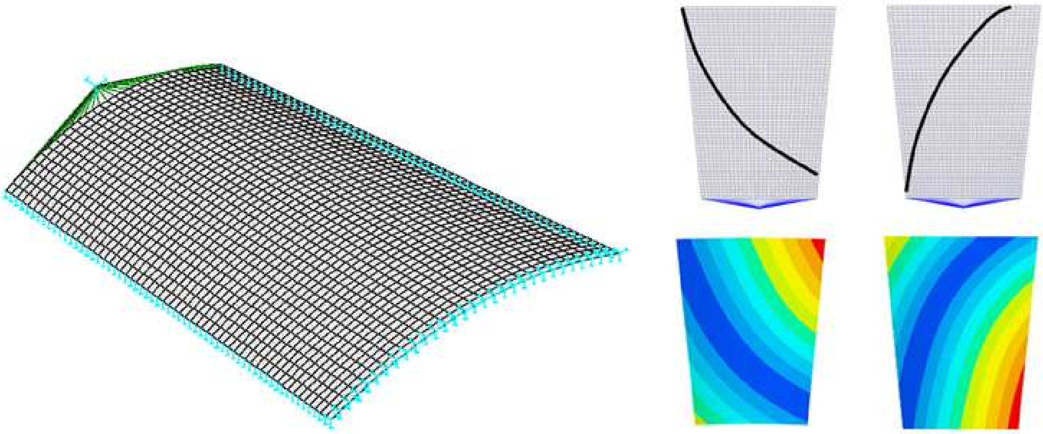


Figure 3. Applying the FMM method for AFP trajectories on a non-developable panel

3. THE FAST MARCHING METHOD FOR DRAPING DEFINITION

When this idea is used with two reference fibers perpendicular at one point, this point being called the seed point, the draping of fabrics can be addressed. It is illustrated in Figure 4, for the case of straight fibers, and for the case of curved fibers on a flat plate or straight fibers that present shear when the fabric is draped on a non-developable surface.

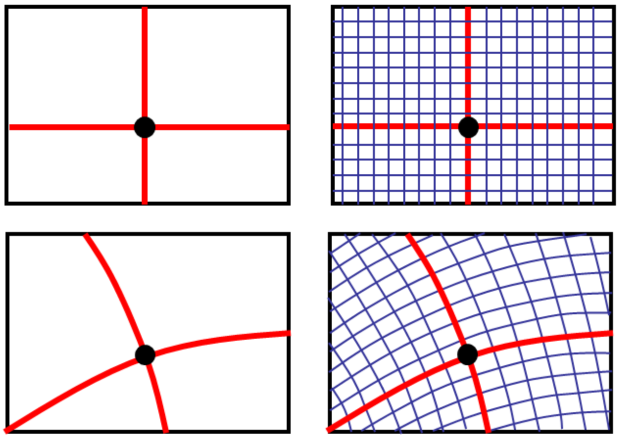
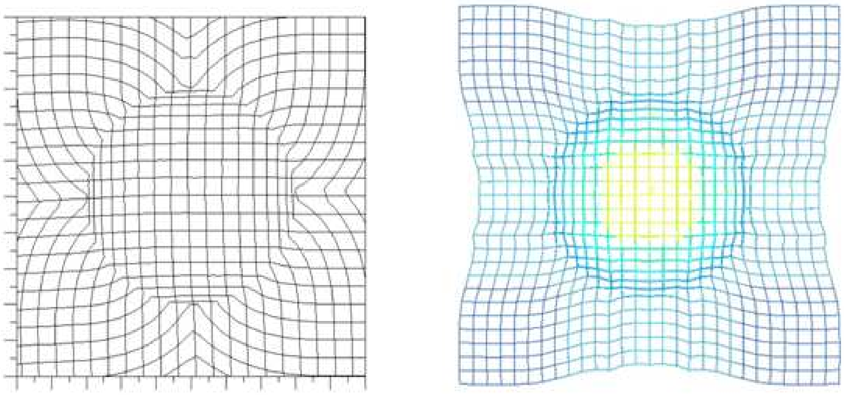


Figure 4. Possible draping of fabrics

In Figure 5, the approach is used on a hemisphere. The distance between the curves is constant, and a shearing effect occurs. The solution obtained with the FMM method is compared to a finite element solution (obtained with the SAMCEF finite element code).



FMM solution

FE solution

Figure 5. Possible draping of fabrics on a non-developable surface

4. CONCLUSIONS

In this paper, we have presented a new approach based on the FMM, which can be used for the definition of AFP trajectories and for the draping of fabrics. This method allows the definition of a set of equidistant curves. When applied to AFP, equidistant courses can be defined, avoiding undesirable gaps and overlaps. This property of equidistance is used to create a network of two equidistant curves, initially perpendicular at the seed point. The method is then used for the draping of fabrics. For the AFP trajectories definition, more details can be found in [18].

5. ACKNOWLEDGEMENTS

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