MACHINE CONFIGURATOR FOR BRAIDED COMPOSITE PROFILES WITH ARBITRARY CROSS SECTION

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Abstract

This work presents the algorithms and the software program, based on these algorithms, which support the definition of the machine configurations for braiding of profiles with arbitrary cross section form using may pole braiding technique. The composite profiles based on carbon, glass or natural fibers are becoming more widely used in the various applications, because of their lower weight compared to the metal profiles and the natural connection between the yarns in given form. In order to produce some cross section form, the engineers have to arrange large number of horn gears on the machine plate, to define the tracks and the arrangement of the carriers without collision. Experimental trials of such tasks are very time and resource expensive, trials on paper are not very effective. The presented original algorithms model the key machine parts and their interaction - horn gears with their sections hold the carriers which move along the tracks - so that the motion of the machine can be simulated and evaluated. The software can be used both for machine configuration and for calculation of the carrier path, required for further FEM simulation of the braiding process and product. It can be integrated as well on the TexMind simulation tools for the modelling of the geometry of the dry textile of the braided product..

1. Introduction

The most common uses of the braiding are for flat and tubular braiding, where the tubular braiding becomes very popular in the form of radial braiding for covering of mandrels of different form (overbraiding). The braiding of solid profiles, in the contrary, is less developed and used mainly for gaskets and only single reports and patents about production of larger solid braids are known in the literature [1]. A literature review of different braiding technologies for three dimensional braiding, including maypole braiding, two step rotary braiding [2], [3], Cartesian braiding, and lace braiding variation [4] are given in [5]. Some fundamental rules how to design a machine for maypole braiding for certain profile is actually not published until now. Some basic idea about the selection of the carrier arrangement and horn gear size is given in [1]. The current paper presents the some ideas about the realization of computational algorithms for design of classical braiding machines with the goal to be extendable for machines for more complex cross section. The basics of the programming algorithms are presented in [6], the current paper concentrates more on the technological issues aspects, which has to be considered using these algorithms.

2. State of the art

The design of the maypole braiding machines is a subject, for which almost no scientific data is available. The most books consists of information about the general configuration of the horn gears for tubular and flat braids [7], [8], [9], some of these as well the configurations for form braids [10] and their arrangement. The most of these presents the configurations on the base of figures with no more rules or equations. The basic rules about the relation between the braided structure, explained through the floating length of one yarn, the slots in the horn gear and the carrier arrangement is given in [11] and explained in more details in [1]. Contrary to the machine design, which know-how is kept safe by the machinery builders, about the design of the braided products there are significantly more investigations. These can be grouped into subgroups as

- analytical or numerical methods for topological description of the braid geometry or
- numerical methods for building of the braid geometry on the base of the carrier motion emulation.

The first group has very limited application, because is useful only for one certain type of fabrics and machine. These methods can help for improvement of product properties, but they cannot be used for development of new products with different geometry. The yarn path during overbraiding for instance can be computed for open structures using the methods given in [12] and [13]. After one of the first presentations of 3D geometry of the braids in [14] on 1998 now is the presentation of the 3D geometry of the classical braids standard procedure in the scientific papers like [15], [16] . Some of these methods are very well developed and allows even the consideration of the single yarns as multifilament structures [17].
The second group of methods is can be applied in the general case of maypole braiding machines – the yarn path is created on the basis of the information of the carrier motion. Very powerful method for the calculation of the yarn path over the mandrel during the overbraiding is presented in [18], the emulation of the process in connection with FEM software is used as well for 3D braiding machines as reported in [2], and some of the basic flat and tubular structures can be created using the software [19].
How to arrange the horn gears on a larger braiding machine with several tracks and if the arrangement would be free of collisions is still not covered topic and is performed until now mainly using the trials and errors [20]. The main programing and algorithmic aspects are presented in [6]. The idea of the software is, that each horn gear, carrier, and track and modelled as separated objects and the complete machine motion is modelled, considering the common work of the single objects. This allows numerical simulation of the motion of the carriers and checking if some of these are crashing or not. In this meaning, the machine configuration can be analyzed without building the machine. Additionally, the carrier motion paths can be used for simulation of the braiding process and generation of 3D models of the braids, used later for homogenization of the properties of the composite parts.

3. Graphical interface for horn gear configuration

Figure 1 presents the main windows of the Braiding Machine Configurator. It allow to the user to define a set of horn gears, with arbitrary position, number of slots and starting angle. The example on the Figure 1 is a trial for design of a machine for production of double T profile. At that state only the horn gears are defined and it is not clear if this configuration would work or not.

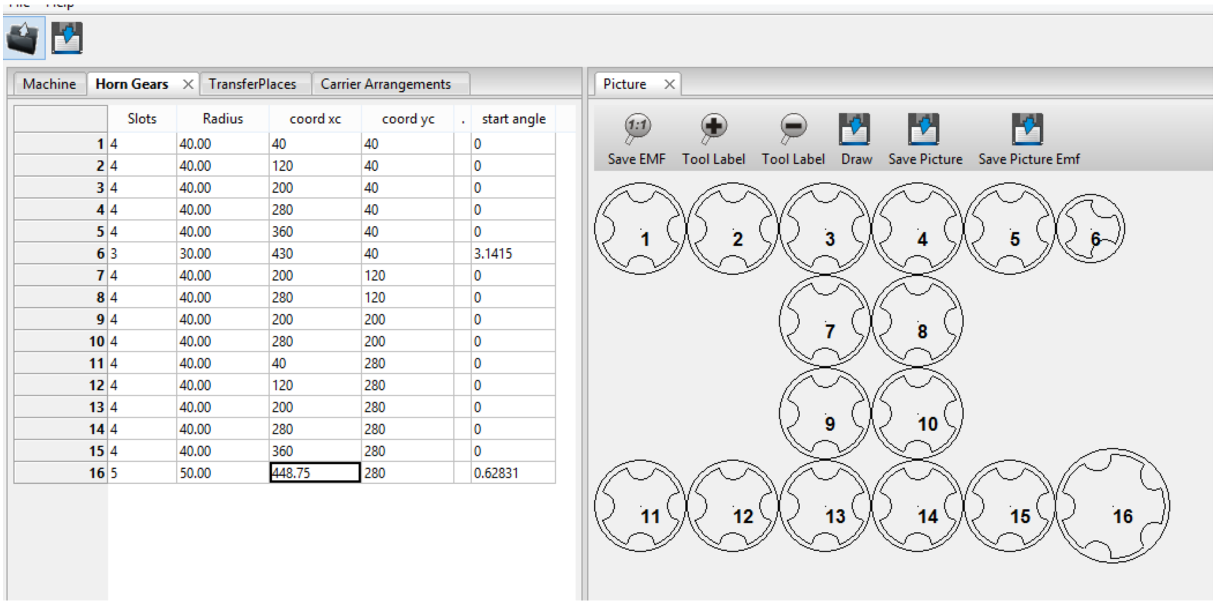

Figure 1. Main windows of the braiding machine configurator

The definition of the horn gears is the first step, after which the transfer places between the horn gear pairs have to be defined. The transfer places determine whether one carrier will be transferred to the next horn gear or will remains on the same horn gear after passing the contact area with the other horn gear. The answer of this question is normally given in the track of the machine, but the tracks are at that stage not defined, they have first to be created. In order to simplify the track definition, the horn gear pairs, which contact are defined as a pairs. Figure 2 shows the graphical user interface for the editing of the horn gear pairs and setting if they are transferring carriers or not.

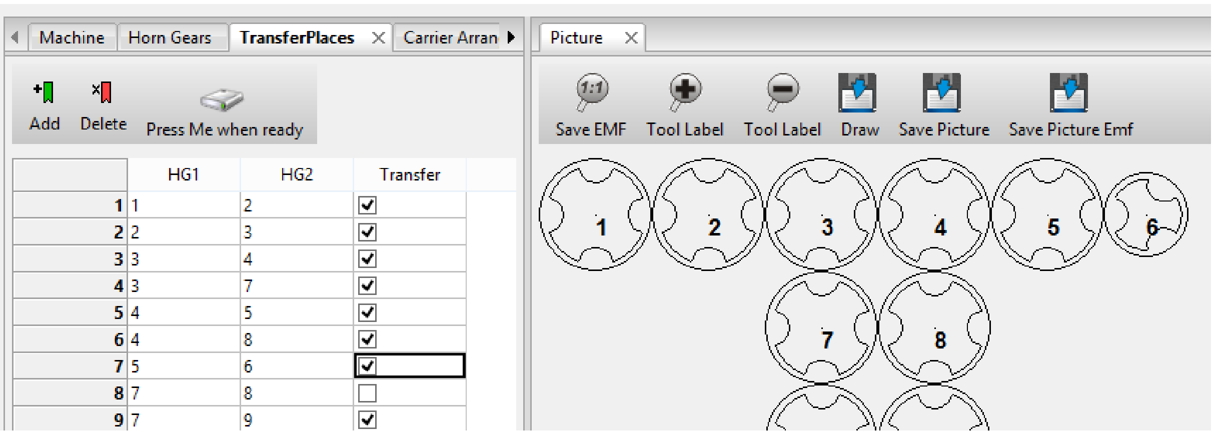

Figure 2. Definition of the horn gear pairs and the transfer places. The pair between horn gear 7 and 8 will not exchange carriers.

The definition of the pairs, where the carriers are not transferred simplify the algorithms for checking the carrier collision later, as mentioned in [6], because between the two horn gears can stay only one carrier in both of the cases, if it will be passed to the next horn gear or when it remains on the same horn gears. But if the common place is defined as “Transfer place” the program check if some carrier is already there is simple- and costs only one checking operation. In the contrary, if the common space between the two horn gears is not defined as “Transfer place”, then the checking of occupation of the slots of the both horn gears has to be done using the distance between the carriers, which is more computational intensive especially for larger machines where several carriers have to be checked.

With the information about the position and size of the horn gears and their pairs is available, it can be given to an automated algorithm, which check the pairs step by step and creates the tracks of the machine.

4. Automated track generation

The automated track generation is done in several steps. The first step reads the contacting (Transfer) pairs and calculate the position of the circles around the horn gears, where these have to be split in to arcs (Figure 3). As demonstrated on the figure 3, around the horn gear Nr. 16 only one curve will be created, around the horn gear 15 will be created two curves and around 14 – three curves, because it contacts with two another horn gears.

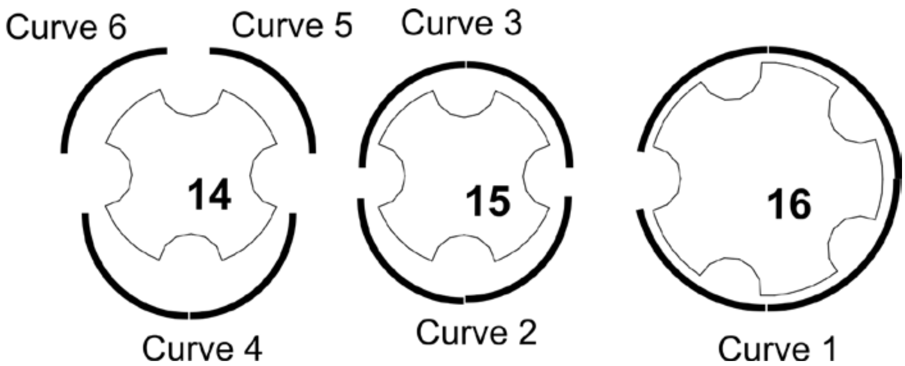

Figure 3. Example of automated separation of the circles around the horn gears to arc curves for building the track

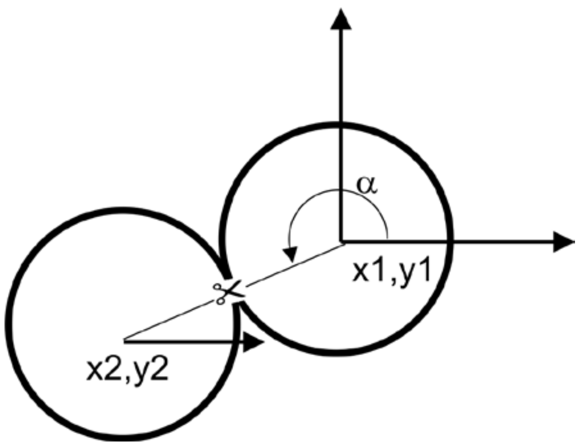

Figure 4. Calculation of the contact point – where the curves (circle or arc) will be interrupted.

The angular coordinate of the contact point between two horn gears can be calculated using simple geometrical relations, as presented on the Figure 4. The angle α can be calculated from the centers of the horn gears (x1,y1) and (x2,y2), using for instance the function atan2 which is implemented into the most programming languages and which preserve the sign of the both y and x components:

$$\alpha = \operatorname{atan} 2(y2 - y1, x2 - x1) \tag{1}$$

The definition of the atan2 for the current case (where is not possible, that x and y are equal to 0 simultaneously) is like:

$$\alpha = atan2(x, y) = \begin{cases} \arctan\left(x / y \right) & x > 0 \\ \arctan\left(x / y \right) + \pi / 2 & x < 0, y \geq 0 \\ \arctan\left(x / y \right) - \pi / 2 & x < 0, y < 0 \\ +\pi / 2 & x = 0, y > 0 \\ -\pi / 2 & x = 0, y < 0 \end{cases} \tag{2}$$

Actually in this form atan2 returns angle between –π/2 and π/2. For the proper calculation the angle has to be returned in the range between 0 and 2π, for which the calculated value from (2) has changed to

$$\alpha = \begin{cases} \operatorname{atan} 2(y2 - y1, x2 - x1) & y2 - y1 > 0 \\ 2\pi + \operatorname{atan} 2(y2 - y1, x2 - x1) & y2 - y1 < 0 \end{cases} \tag{3}$$

After splitting the curves to arcs, they have to be connected into list of curves depending on the type of the connection points. For the curves at the figure 3 this list will consists of:

Curve 4
Curve 3
Curve 1
Curve 2
Curve 5

Once one carrier is mounted on a slot of the horn gear, depending on the angular coordinate of the carrier, the affiliation of the carrier to some of the curves in the list will be identified. From that point the carrier will be moved with the slot together with the horn gear until it arrive the end of the current curve. To which horn gear will be transferred later depends from the information stored in the next curve in the list. In this meaning, the curves do not take only the graphical information about the center, radius and end points, they keep reserved as well the information about their affiliation to the given horn gear.

5. Horn gear size and carrier occupation

Not all configurations of horn gears are useful for real braiding. Figure 5a demonstrate configuration of eight horn gears, based on a flat braiding machine and prepared for braiding of U profile or part of double-T profile, which cannot be implemented in a real machine because the carriers will crash with the other carriers after turning the moving direction around the horn gears 1 or 8. In order to solve this problem the end horn gears need to have one more section, so they have to be in the case with five slots (Figure 5b). For the extension of such machine for thicker profiles or more complex forms this problem appears at every place, where the single track behave as a track of flat braiding machine, at several places larger horn gears are required. If the profile can be created with tracks, where the carriers do not change the general moving direction, like these of the tubular braiding machines, then such profiles can be produced on a machine with same horn gears, for instance with four slots each. In this issue the configurator cannot really help currently, because the only information which can be received from the simulation of the motion is that one configuration is possible and the carriers do not crash during the simulation or the configuration is not possible.

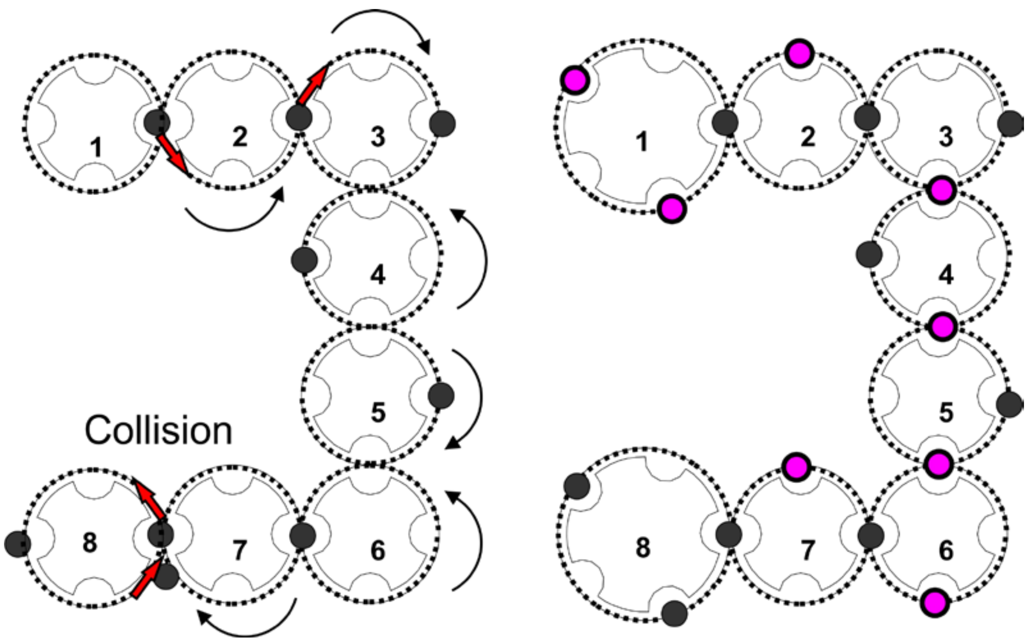

Figure 5. Not possible a) and possible b) configurations of horn gears for production of U profile

6. Example geometry generated on the basis of the emulation of the carrier motion

Based on the carrier motion emulation the idealized braid geometry can be created. Examples for braids with one and two tracks, which are created automatically, are presented on the figure 6. These 3D objects can be exported as FEM mesh and used as initial state for calculations, but their geometry do not represent the exact geometry of the braids, so some more iteration step, with consideration of the deformation of the cross section and the forces are required for more accurate results.

7. Open issues for multiple tracks

During the implementation of automated track generation of braiding machines for arbitrary cross section two issues were observed.

The algorithm cannot finish successfully, if the combination and arrangement of the contacting horn gears and transfer position between these leads to not closed paths for the carriers. In this case the algorithm does not reach the starting point of the track and any simulation of the carrier motion and respective braided structure is not possible.

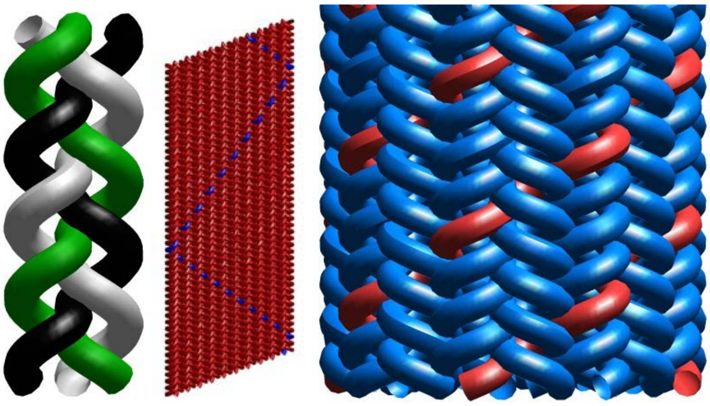

Figure 6. Example of 3D geometry, created on the basis of emulation of the carrier motion [19]

The second problem is in the definition of the starting point for the setting of the carriers in each track. For machines with one track, it is not a problem to start with the first carrier at any place. For machines with two tracks (tubular) the starting slot for the first carrier of the second track has to be carefully selected – it has to be empty at the time when the carrier is inserted and it has to remain empty until it care one carrier.
For machines with more tracks the starting slot for each track has to be checked against collision with all other tracks, which are already filled with carriers. This procedure is still based on trials and errors, which has to be done currently manually from the user. For this reason the generation of 3D geometry of more complex structures is currently automatic possible only for these configurations, which are suitable and have no errors.
Implementing some intelligence in the algorithm, so that it checks all possible configurations configurations for the starting place of the carriers will solve the problem with the manual trial and error and will allow faster design and arrangement of custom braiding machine configurations. This will allow checking of several configurations for maypole braiding machines and selecting of optimal one, which could be adjustable and usefully for more profiles.

8. Conclusions

The discussed algorithm and software can speed up the process of the design of custom braiding machines for production of profiles with various cross sections, but at the current state requires manual restarting with different and adjustment of the track and carrier occupation parameters if the configuration is not successful. If these steps are automated too, the design of complex maypole braiding machines will be speeded up and will allow checking of several configurations in short time.

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