Advanced CAD/CAM System for Robotic Filament Winding

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Abstract - **In this paper CAD/CAM system for designing and manufacturing composite parts with robotic filament winding is presented. System provides automatic designing of mandrel shape, creating radial, helical and transition layers with great flexibility for changing winding angle, covering degree, and winding pattern with complete simulation of the winding process. Final result of the presented CAD/CAM system is complete G-code for controlling the individual axes of the industrial robot for filament winding.**

Keywords – **CAD/CAM, filament winding, simulation, G-code,**

I. INTRODUCTION

The filament winding process is efficient technique used commonly in the mass production of fibre-reinforced composite components such as pipes, pressure vessels, water tanks, rocket motor cases, lunch tubes, shafts, and other different axis and non-axisimetrical parts. The process is relatively simple involving the winding of continuous fibers, that are either impregnated or have been immersed into a epoxy resin bath onto a mandrel mould, to produce a polymeric composite component (Fig. 1.).
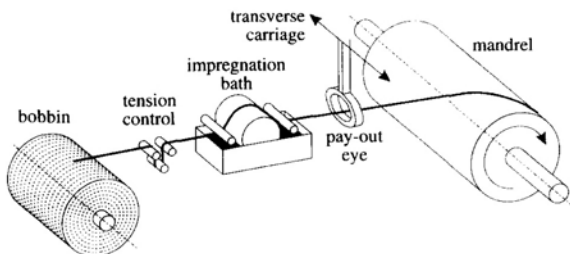

Fig. 1. Basic Filament Winding Process

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The shape of the final part is determined by the shape of the mandrel, and the thickness of the part is controlled by the number of circuits wound (number of layers). The reinforcement configuration is determined by controlling the winding angle which is the angle formed between the tangent to the filament end the tangent line to the intersection line of the surface to be wound with the plane parallel to the running axis of winding. For a body of revolution it will be the angle between the filament and the wind axis. By varying the angle of filament it is possible to control the reinforcement fiber angles within the same layer and through the thickness of the composite wall.

In the simplest filament winding machines with 2 to 3 axes, control of the movements and speed of the axes is done by rigid kinematical coupling (usually gears or chains). With modern winding machines up to 6 axes (with 3 rotational and 3 linear axes) different motions can be regulated individually with greater accuracy by computer control (Fig. 2.).
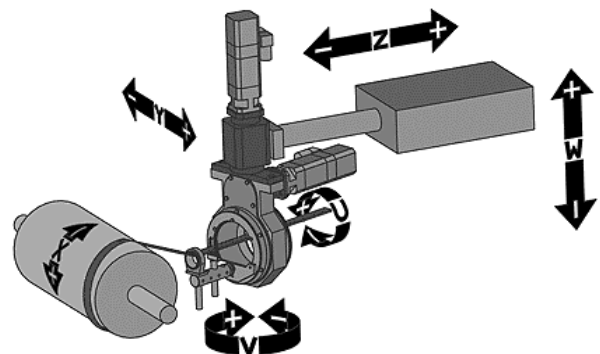

Fig. 2. Axis for Robotic Filament Winding: 1-mandrel X, 2-carriage Y, 3-cross-carriage Z, 4-vertical W, 5-Yaw Rotation V, 6-Eye Rotation U.

II. ROLE OF CAD/CAM SYSTEMS IN FILAMENT WINDING

Creation of the programs for the FW machines is not a simple task. The main problem in the control of the robotic filament winding is the synchronization of the axes. In the past the most common practice was using "trial and error" and teach method. Starting from 20 years ago a different algorithms were developed for off-line programming [2], [4], [6] and several software packages (CADWIND, CadFill, Composite Designer, FiberGrafix) are introduced and widely used in filament winding industry. All of these packages offers different level of flexibility, accuracy, adaptability and user friendly environment.
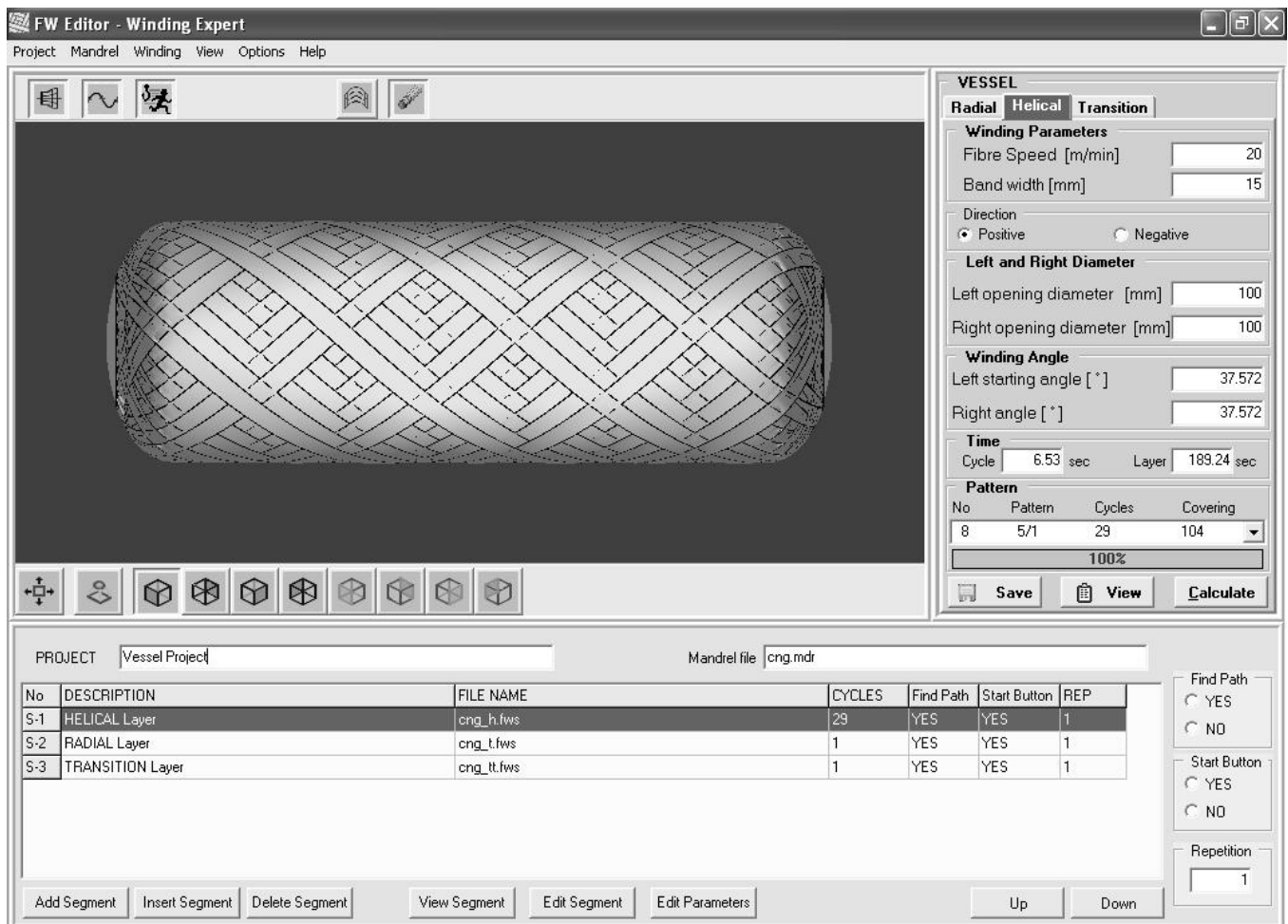
Fig. 3. Winding Expert Main Screen

The main features of the programs are: (i) the calculation of possible winding paths for rotationally-symmetric components; (ii) searches for covering patterns; (iii) updating of the geometry between successive layers; (iv) the performing of simple strength and stiffness analyses of the resulting laminate; (v) the transfer of laminate data to FEM-programs for detailed analysis; and (vi) the transfer of data for the generation of control files for filament-winding machines. All previous mentioned software packages provides main features on different level of implementation, but also there are gaps whish must be filled with the new generation of software. Improvements can be made in these fields:

- Real time simulation and rotation of mandrel instead of predefined views,
- Accurate calculation of winding path in the opening diameter regions,
- Integration of all patterns for the composite product into single file,
- Integration of smoothing algorithms directly in generation of axis movements,
- Maximum flexibility for different FW machines and motion controllers.
- Intuitive Human Machine Interface

III. ADVANCED CAD/CAM SYSTEM - WINDING EXPERT

Starting from 1999 a research group from Faculty of Technical Sciences and Mikrosam – Prilep began with development of new advanced CAD/CAM system, which will incorporate the latest achievements in filament winding technology, compatibility with PC Based controller for Robotic Filament Winding [3], maximum flexibility for use in different motion controllers and improved user friendly interface. In this paper is presented a new, advanced CAD/CAM system for Robotic Filament Winding – Winding Expert.

In Fig. 3 is shown the main screen of the Winding Expert (WE). The upper left part is Simulation window in which user can see in real time mandrel shape and created winding patterns. Upper right part is for winding parameters, which are used as input in calculation of patterns, and for showing the possible patterns and their characteristics. Depending of the winding mode this part can be different. In lower part (Project window) are all necessary information's and all patterns for specific composite part.

Design of composite structures and appropriate programs for manufacturing on FW machines requires 6 steps:

1. Creation of Mandrel
2. Designing of the composite layers by creating filament winding segments
3. Winding simulations

4. Export data for Finite Element Analyses
5. Creation of the Winding Project
6. Post processing and creating the executable G-code

Mandrel can be designed using standard forms with parameters for most frequent used shapes: pipe, vessel and cone. For the rotational bodies mandrel can be created by importing the profile from DXF file created with CAD program.

Composite layers are designed by creating different filament winding segments using a panel with winding parameters which appears in upper right part of the screen for chosen mandrel shape (Fig 4.), using different algorithms which ensure a large number of achievable patterns with avoidance of fiber slippage [6].
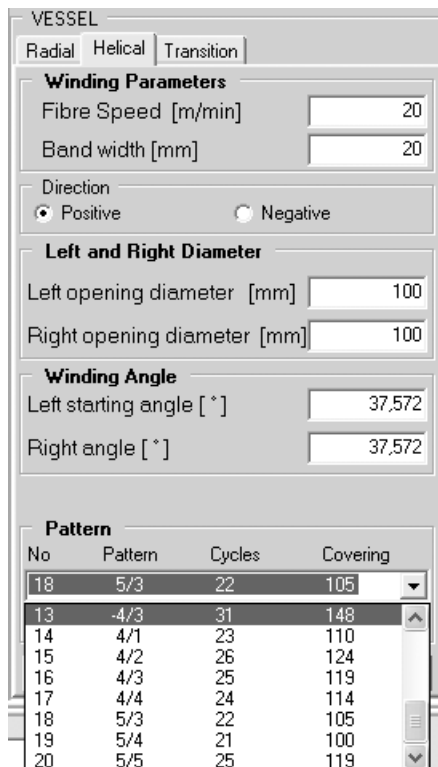

Fig. 4. Winding parameters for Vessel

For Vessel winding for example, user can choose radial, helical and transition layer, with different fiber width and speed, can vary opening diameters, and angles of the composite, and also can chose between different winding patterns with specific characteristics (number of cycles, degree of covering, etc.).

User has complete control of creating composite structure. Using the Simulation window he can create a lot of different patterns (Fig. 5), with different characteristics, and he can choose the most appropriate for his project.

The next step in creating the composite structure is Finite Element Analyses. Software will provide an export file with all data necessary for input in FEA software (NISA, NASTRAN, ANSIS etc.). If the structure does not satisfy the real conditions (resistance to strain, forces, pressure,

temperature) user can change (increase) the number of layers (thickness of the composite), angles and patterns, until the structure reaches the appropriate characteristics.
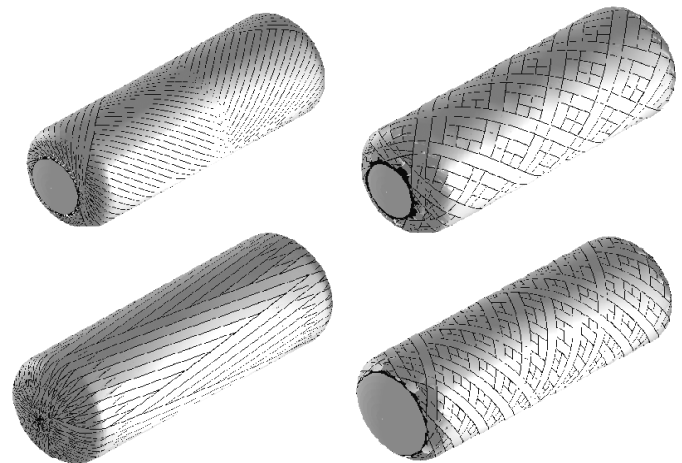

Fig. 5. Different helical patterns for vessel winding

Combination of different layers can be done in the Project Window, the lower part of the screen. User can use the following options:

- *Add Segment* – Add filament winding segment in project
- *Insert Segment* – Insert filament winding segment in project
- *Delete Segment* – Remove segment from project
- *View Segment* – View segment code
- *Edit Segment* – Edit segment code in Segment Form
- *Edit Parameters* – Edit parameters in segment window
- *Up* – Move the segment up in the grid
- *Down* – Move segment down in the grid

After creating the composite structure, thus means that Winding Project is created. This is very important in mass production of composite parts (for example CNG tanks) where the composite structure always is created with combination of different number of radial and helical layers connected with radial-to-helical and helical-to-radial transition layers. This concept ensures that the whole part will be manufactured at once without stopping the FW machine.

The last step is post processing and creating the executable code for different FW machines with different motion controllers and CNC control systems. For the post processing module it is necessary to provide a lot of machine parameters:

- Number of active axes (max 6)
- Reference coordinates (or angles) for each axis
- Dimensions of each axis
- Maximum velocities for each axis
- Maximum acceleration for each axis
- Resolutions of each axis

One of the main features in Winding Expert is jerk elimination algorithms incorporated in post processing module, which ensures smooth movement without strokes at high speeds (up to 1.7 m/s for carriage). As a default option post processing module is creating standard ISO G-Code for 6 axes, which can be viewed, edited and corrected (Fig. 6.) if it is necessary to make some adjustments in real conditions.
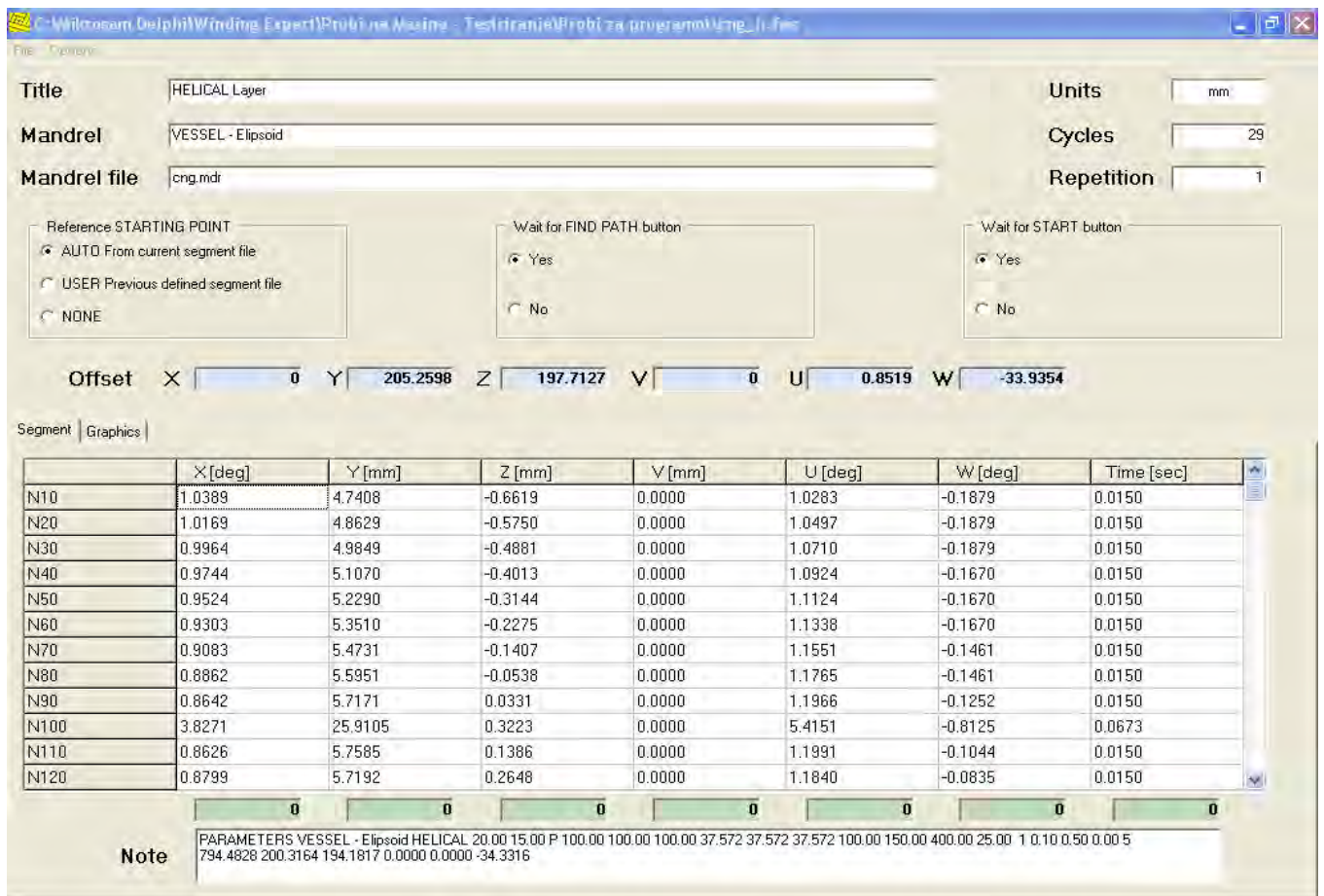
Fig. 6. Editing of G-Code

Also if it is necessary to ensure pause or break between segments (for applying reinforcement or different material between layers) user can chose the appropriate options for different pushbuttons supported by the control system. These settings can be different for the development phase and for the manufacturing phase of the composite production.

IV. CONCLUSION

Advanced CAD/CAM system for designing and manufacturing of composite parts with robotic filament winding is presented. System provides automatic design of mandrel shape, radial, helical and transition layers and offers great flexibility for changing of all winding parameters: winding angle, covering degree, opening diameters and winding patterns with complete simulation of the winding process. Smoothing algorithm ensures smooth movements of the machine without strokes at high speed. Final result of the presented CAD/CAM system is complete G-code for the industrial filament winding robot.

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