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Developments in filament winding software

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Filament winding is one of the few Automated Processes for composites manufacture and can produce highly repeatable, high quality components at reduced labour content. A big advantage of filament winding is that it used continuous fibres which leads to very good material properties for both strength and stiffness. There is also the ability to orientate the fibre directions for 'optimised' composites. High Fibre volume fractions are possible, and it can use materials in the simplest (lowest cost) form - Fibre Roving & Resin Winding is accurate, repeatable and gives a high-quality internal surface.

The background of the Cadfil company is software tools for the filament winding process. We started the Cadfil back in the early 1980s and were the first software system for filament winding that was not exclusively linked to a machine manufacturer. During the last 30+ years software and hardware capabilities have changed beyond all recognition. Today winding is a mature process and users are increasingly expecting the winding process to seamlessly integrate into their digital processes for design and development.

Some history

Filament winding is far from being a new process the first commercial winding machines started to appear in the 1960s. These machines were cumbersome, mechanical systems requiring changes to gears, and belts/chains in order to alter a wind angle or wind length. These were mainly used for making tubes. Special machines were developed for pressure vessels, including 'tumble' winders & polar (spherical) winders and in the late 1970s the first computer controlled winding machines started to appear. At first these were not the most reliable of machines and were quite difficult to program. Programming methods were a mixture of calculations, trial & error and teach-in where the machine is manually controlled, for example using a joystick, and the machine positions recorded. It would take some skill and numerous attempts before something close to a good result was achieved. In the early 1980s the first

Modern cnc winder with siemens control, photo courtesy of cnc technics ltd

CNC winding machines started to appear. Control technology was developing rapidly from companies like Bosch, Fanuc, NUM & Siemens.

These control systems were focused on metal cutting (Milling and Turning) but being general purpose could be used for filament winding.

The need for improved programming methods to take advantage of the new technology was clear.

In 1983 The CADFIL® company (Crescent Consultants Ltd.) was formed by two Professors at University of Nottingham in the UK.

During the late 70s and early 80s there were numerous research projects into many aspects of filament winding at the University which acquired a 5 axis Pultrex CNC winding machine. Considerable focus was put on exploring the capabilities of winding and developing programming techniques and one of the results was the CADFIL software system (Computer Aided Design for Filament winding).

In 1984 the first CADFIL software was sold, this was the first independently available off-line programming system for filament winding and ran on the new IBM PC with MS-DOS, it featured a graphical user interface.

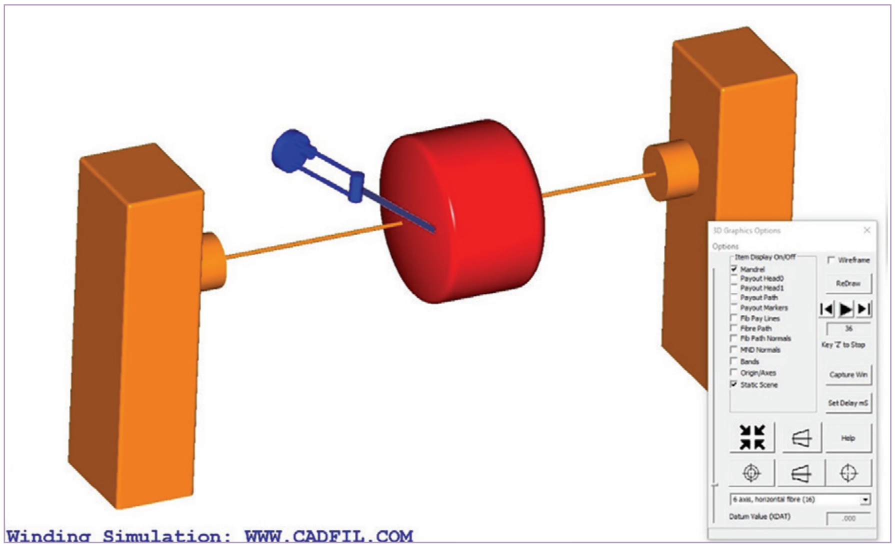
Why do we need filament winding software?

The simplest of CNC winding machines, those with two axes making pipes can be programmed by means of hand calculations or spreadsheets calculations and use of formulae. To do this you firstly need considerable knowledge coupled to some mathematical skills and practical experience in the chosen control system.

Even then, you will make some short cuts to simplify the programming process.

It will undoubtedly take a lot more time to get right (if you ever get it quite right) and you will take time on your winding equipment in the process that could be profitably be being used to manufacture product.

Worse, you may make sub-optimal programs that consume more material in the turning zones that are often not part of the final product and you may not minimise the winding time.



Cadfil winding simulation/animation with clash detection

Considering the costs of fibres and resins such losses can be come considerable over a long production run.

With 4 axis machines in the production of parts such as pressure vessels, storage tanks or more complex axisymmetric shapes the manual programming activity becomes much harder and the problems of coordinating the simultaneous motion of 4 machine axes becomes very difficult.

In this case, the use of professional software systems becomes essential as huge amounts of time will be wasted on programming and poor results will be achieved.

There is also a benefit making the program offline away from the production equipment. When it comes to coordinating 6-axis machines or multi-axis robots for winding, the case for advanced programming software with simulation becomes overwhelming.

3D animated simulation and clash detections to ensure the winding machine head does not crash with the mandrel or other parts of the machine become ever more useful.

Inbuilt machine simulation

It is possible to do machine simulations in several high-end CAD and automation packages, but such systems seem to come with a very high price ticket that is not compatible with most industrial users of the filament winding process. For this reason, we chose to include full 3D motion simulation within the CADFIL packages.

A pragmatic approach was taken with this, the machine head that dispenses the fibres is modelled as a series of simple solid primitives which according to the machine control strategy selected can have three linear (XYZ) degrees of freedom and two rotational freedoms which equate to the layout roll and yaw axes (BC). The machine head needs defining only one time and several standard definitions are available to choose from.

The general environment of the winding machine can be solid modelled in any of the standard CAD package such as Solidworks or Catia and then exported as a simple STL file (STL is normally used for input to rapid prototype machines).

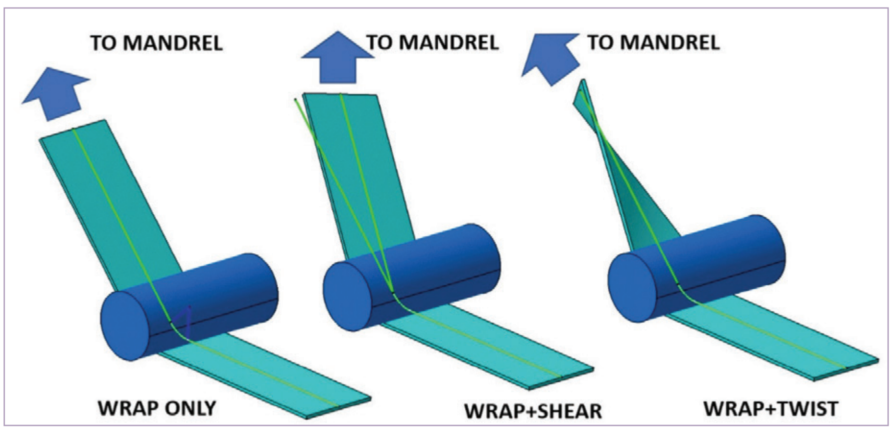
As can be seen in the screen image some of the machine hardware has been modelled in CAD (orange parts) the mandrel (red) and machine dynamic head (blue) is modelled in Cadfil.

A live simulation of the machine motion can be run and saved as a movie if required and clash detection can be performed and viewed if required.

Whilst nothing here is new technology it is presented to winders in a practical, accessible and most importantly affordable way in Cadfil.

Often these days designers are not in the same locations as the manufacturing so the requirement to be able to simulate and visualise to detect and correct any issues without the need to waste valuable time on the productions facilities is increasingly useful.

Woven tape used on a 90 degrees bended elbow



Accurate control of twist & shear is very important with wide fabric tapes

Winding machine control and configuration

There is a huge diversity of Control systems used on winding machine, most are as G-code type controllers that also find use in CNC Milling and turning machines. As well as the CNC style controllers are as many motion systems with their own proprietary languages, for example Kuka Robots is KRL (Kuka Robot Language) and ABB Robots use the RAPID language.

Coupled to this, there is also are range of mechanical configurations with between 2 and 6 degrees of motion freedom, standard lathe type configurations, Articulated Robot arms and machines with swinging arm axes. To cope with this diversity and other practical considerations such as the materials being wound, Cadfil has several user selectable control strategies. The control output generated for the machine is a combination of the chosen control strategy and a user configuration file. For maximum flexibility in Cadfil we created out own configuration language this allows a user to be able to configure and output style and format for pretty much any type of winding machine and controller.

A big advantaged of this system is that customers can have several totally different winding machines but can just by the selection of the appropriate machine configuration can make programs for the same set of wining patterns on any of the machines. Some users take full advantage of the huge flexibility and possibilities of this configuration by making the winding programs highly integrated into the manufacturing quality system so that things such as materials types and batches, tooling selected for the winding machine, label printing, oven settings etc. are all tied together with the winding program itself via a high end controller. This can eliminate all manner of failure possibilities die to user errors and is highly attractive in quality lead industries such as automotive, aerospace and defence.

Developments in pipe fitting winding

A good case study in the interaction of machine design and flexible software control strategy can be demonstrated by looking at the winding of Pipe elbow fittings. Figure3 shows a 600mm Diameter pipe elbow with a 90 degrees bend. One of the challenges of winding such parts is achieving good axial strength. It is very easy with high angle (hoop) winding to achieve a very high radial burst pressure. However, if pressure tested with enclosed endcaps, we have significant bending forces trying to 'snap' the elbow and to counter this efficiently we need some low angle winding. Low angle winding is not physically possible as the fibres just bridge across the inside of the bend. One good solution is to use woven (0/90) fabric tapes. With the part in the picture is very practical to wind high angles with 200mm wide tapes and this gives optimal fibre directions for the principle stresses whist maintaining continuous filaments in the hoop direction and very long fibre filaments in the axial direction. A further benefit is that we also get a high rate of material application for a shorter production time. There is however a technical challenge: Wide woven tapes are quite difficult to handle on the rapidly changing double curvature of a pipe bend. The tape needs to be precisely controlled on the payout roller. It is very easy to get shear in the tape which grossly distorts the transverse fibres and causes both ripples, gaps and large angle variations.

A second problem is if the tape needs to be kept central to the rollers as deviation to the edges can make the tape fold over on itself and also decreases the accuracy and consistency of application to the mandrel. Tape twisting can also lead to a similar set of problems.

An illustration Twist and shear can be seen in the TSW diagram, Cadfil can analyse and output this information on a position by position basis for any chosen control strategy. When this was compared with the working parameters of using the tapes it leads to the conclusion that a five or six axes machine is required for the task, a machine that has two rotational degrees of freedom (roll and yaw) on the payout head in addition to the mandrel rotation and the normal axial and radial linear axes. The aspiration was to make this winding with no more than a 4-axis machine as this gives a better machine costs and ultimately a simpler machine gives better long-term reliability and maintenance costs over the long terms within a 24/7 production environment. Working with the established winding machine builder CNC Technics Ltd (Hyderabad India) it was concluded that by using a novel axis configuration it is possible to make these parts using only 4 axes of control whilst keeping precise control over the woven tape. The solution involved the use of a rotating arm on which the tape reel resin bath any eye/head roll axis is mounted. This also has the benefit of keep the tape path very simple with no bends or twists between guide rolls, an important consideration as this reduces friction and the possibility of fibre damage. Because of the modular software design of the Cadfil system is was a relatively simple matter to create a robust control strategy for this mechanical payout and then configure this within out post-processor.

Integration of winding process into the design system

One of the areas where there has been much recent and ongoing development is integration of the filament winding process into the overall design process. For example, on the domes of the pressure vessel the angle and thickness of an individual laminate is continuously varying. A high-performance pressure vessel can be made of many layers and trying to model the fibre architecture by manual processes is very time consuming. For this reason, an ability interface the winding program generation with the analysis system is very important for an efficient design process. There are currently three routes to interface axisymmetric winding data from Cadfil with FEA modellers. The first is via the Nastran bulk data format where a shell model is created complete with full laminate stack data for each element. This format is something of an industry standard and can be read directly into many analysis systems such as MSc Patran/Nastran. A second options is to output a laminate table that consists of grid points in the surface of the mandrel and an angle thickness/material/records data for each layer at each grid point. Systems such as ANSYS composite modeller can import such a table and then map it via interpolation to and existing mesh in that system. ABAQUS has similar capabilities. This is a better methodology because the mesh can be defined and refined in a software system specifically designed for that purpose rather than using a mesh defined in a system specifically made for designing winding programs. It is also possible (for example in Patran) to make macros that export co-ordinates with an element ID to a file, import that into Cadfil where is can be automatically associated with a design and thus a table of laminate data associated with each element ID in the original FEA model can be created. This is quite a powerful method for components that have significant parts that are not wound such as flanges and side ports on a storage / pressure tank because the laminate data becomes associated with only the appropriate parts of the analysis model without the user having to make lots of manual interventions. Current developments will soon include axisymmetric type output where the material property varies through the thickness element via element rather than being based on laminate shells.

The future...

The last 30 years have seen a great deal of change and particularly so in the area of development of our Cadfil filament Winding software, however, this work is never complete are always areas where we can improve integration with designs systems and advances and with advanced in machine technology. We are looking forward to the next 30 years. □

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