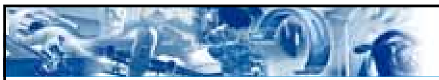

Filament winding with increased efficiency

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Content

Motivation to increase the winding efficiency

- **Increasing demand for pressure vessels in the automotive sector**
- **Traditional pressure vessels (~ 350 bar, ~ 5,000 psi)**
  - Natural gas vehicles (already in use)
  - Hydrogen vessels used in car prototypes
- **Requirements regarding high pressure tanks for hydrogen storage**
  - Pressure level 700 bar (10,000 psi) working pressure
  - Bursting pressure ~ 2,100 bar (35,000 psi)
- **Pressure level and acceptable weight can only be achieved by use of carbon fiber reinforcements**
- **Demand on new and advanced manufacturing technologies:**
  - Polymer or steel liners with carbon fiber reinforcement
  - High production rate, reduction of cycle time

Compressed hydrogen storage: Examples

High pressure vessels with carbon fiber reinforcements:

Dynetek Europe GmbH (steel liner)

Quantum Technologies Ltd. (polymer liner)

Motivation to increase efficiency: Winding machines and equipment

Conventional production with standard winding machines:

- **One filament guide per mandrel**
- **Limited production rate (material feed per time unit)**
- **Too long cycle time**
- **Low automation level (particularly replacement of the mandrel)**

Motivation to increase efficiency: Increasing the lay-down rate

Measures to increase the lay-down rate:

1. **Increasing of the winding speed:**
   - **Usual winding speed:** 60 up to 90 m/min
   - **Further increasing:** Insufficient impregnation of the fiber rovings
2. **Increasing of the number of rovings laid down with one payout eye:**
   - **Traditional machines:** Up to 10 rovings side by side
   - **Limitation:** Band width limits the free choice of winding angles
3. **Several payout eyes arranged circumferential:**
   - **Seldom used nowadays**
   - **Profitability:** Mass production and constant diameter of the mandrel (e.g. tubes)

Motivation to increase efficiency - Theory of a multiple payout eye

A winding machine with several payout eyes must meet the following requirements:

Demand I: Free filament length is constant at any time ! (distance between payout eye and mandrel)

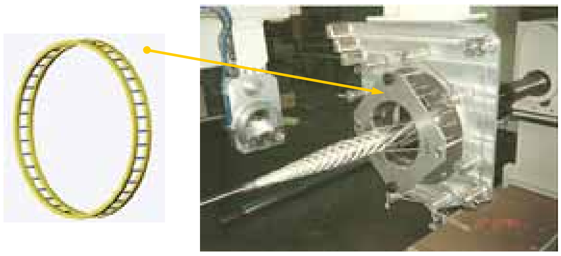
Demand II: Symmetry axis of the payout is perpendicular to the surface of the mandrel !

The following demands are advantageous for the realization of a multiple payout eye:

- Modular and compact construction of the impregnation units
- Process automation, especially the starting sequence

Multiple Payout eye: Traditional ring payout eyes

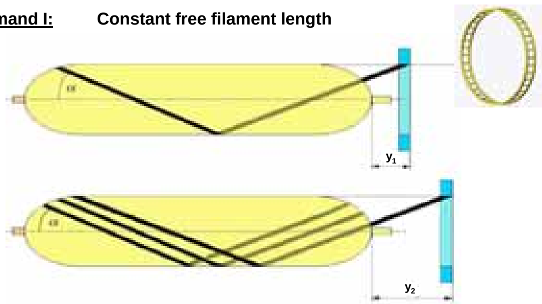
Demand I: **Constant free filament length can not be realized with traditional ring payout eyes**



Source: EHA - Bolenz&Schäfer GmbH

Multiple payout eye: Actual situation

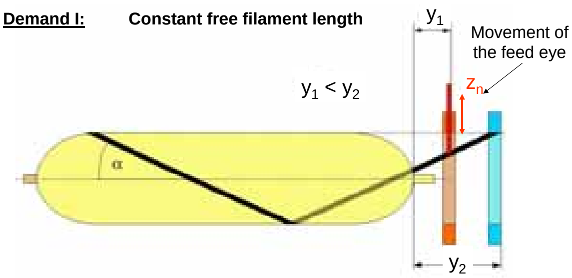
Demand I: **Constant free filament length**



The traverse path must vary according to the diameter of the polar port (y_1 respectively y_2).

Multiple payout eye: Demands

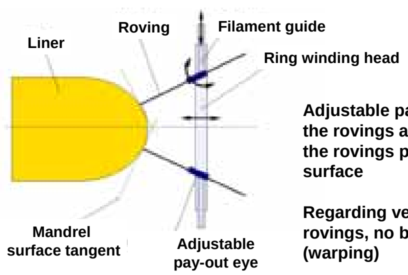
Demand I: **Constant free filament length**



A multiple payout eye with an additional axis (z_{1-n}) for each payout eye (radial motion) shortens the length of the traverse path significantly (reduced width of the winder)

Multiple pay-out eye: Demands

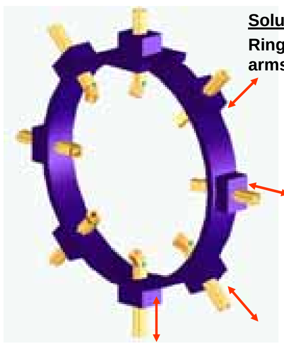
Demand II: **Symmetry axis of the payout eye is perpendicular to the surface of the mandrel !**



Adjustable payout eyes deflect the rovings and enable to locate the rovings precisely on the surface

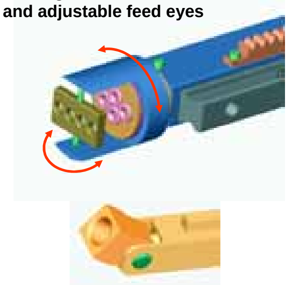
Regarding very wide spread rovings, no buckling occurs (warping)

New Multiple payout eye: Concept



Solution:

Ring winding head with movable arms and adjustable feed eyes



Achieved results - Ring winding head: Construction

Construction of the winding head is completed, all major mechanical parts are installed

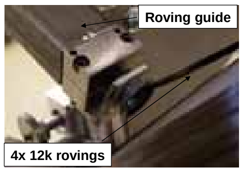
Impregnation units are mounted on the 8 movable arms for guiding the rovings to the mandrel

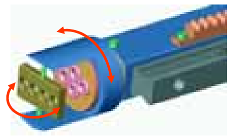
The bobbin support will be standard industrial parts (creel)

Achieved results - Ring winding head: Payout eyes

Construction and implementation of fiber lay-on devices (ring eyes)

For optimized fiber placement a new movable ring eye was designed and will be tested

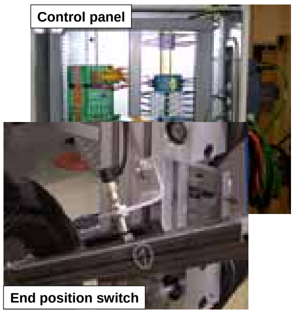




Achieved results - Ring winding head: Electronic control

Configuration of the electric motor control unit

Motor drive completely cabled and linked to the computer system and the CNC of the winding machine

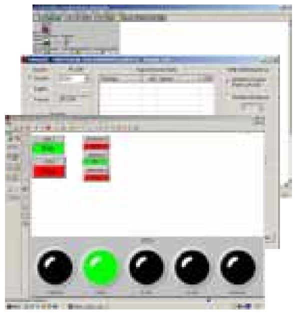


Achieved results - Ring winding head: Control software

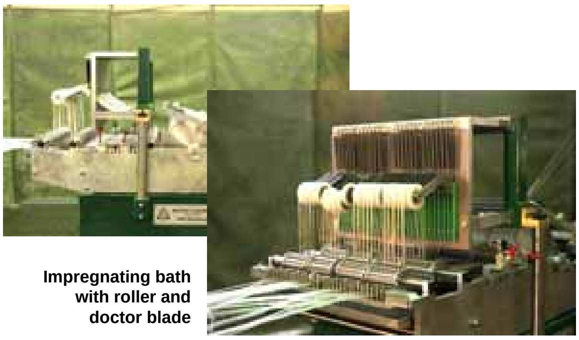
Visualization of the winding head referencing and startup routine integrated into the control software

Realization of winding path data import into the machine software

DIADEM, SYSTEM WORX, PROGRAM WORX, MOVITOOLS



Wet winding – Fiber impregnation: State-of-the-art resin bath

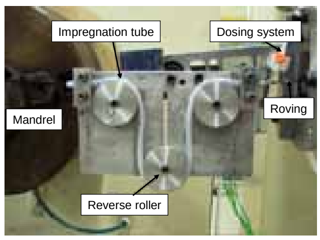


Impregnating bath with roller and doctor blade

Source: EHA - Bolenz&Schäfer GmbH

New tube syphon impregnation unit: Advantages

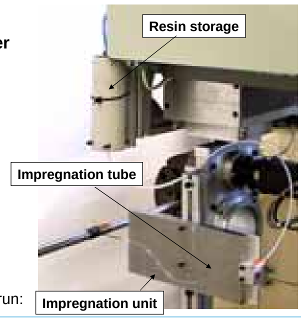
- Compact and modular construction
- Variable filament guide towards the mandrel
- No limitation due to pot life, resin is fed continuously
- Clean impregnation near the winder, minimized resin leakage
- Easy cleaning of the impregnation device



Prototype of the impregnation unit (test assembly):

New tube syphon impregnation unit: Test run

The tube syphon impregnation unit proved that it can work for a complete 8 hour shift without fiber rupture or extensive wear



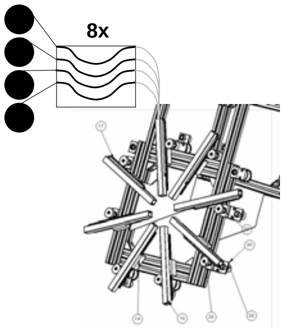
Prototype test run:

New tube syphon impregnation unit: Achieved results

All 8 arms of the ring winding unit were mounted with impregnation units

Designed to feed and lay down simultaneously 32 (8x4) 12k carbon fiber rovings

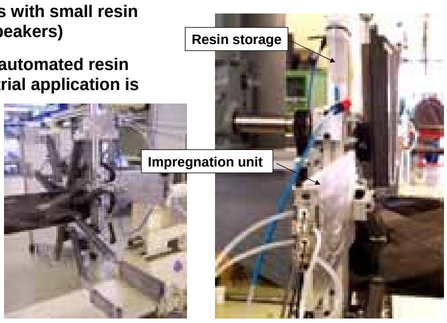
For industrial applications the processing of 24k rovings is necessary



New tube syphon impregnation unit: Resin dosing system

Successful tests with small resin storage tanks (beakers)

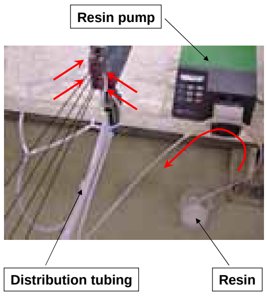
Selection of an automated resin mixer for industrial application is still pending



New tube syphon impregnation unit – Resin dosing system

Suitable resin dosing pump chosen and tested

For industrial applications a computer controlled resin pump (well known from RTM processes) is necessary



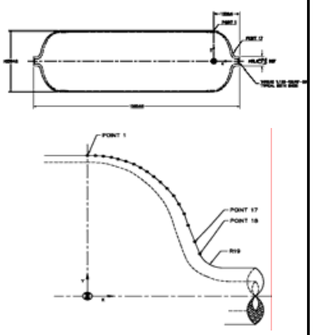
Achieved results - Ring winding head: Winding trials with aluminum liners

Simulation of the winding operation (CAD WIND) according the liner geometry and the predefined pattern

Generation of the CNC program (winder) and the contour program (winding head)

Adaptation of the liner onto the drive shaft of the winding machine

Winding trials to examine the accurate fiber placement



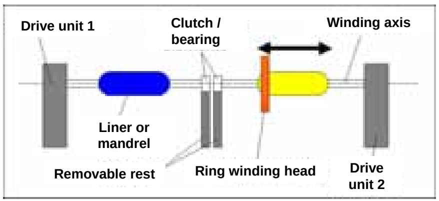
Video clip ring winding head – Commissioning of the prototype

Forecast within the research project

- Investigation of a flexible tubing in combination with a resin pump for a steady resin flow and distribution
- Construction and implementation of a new movable feed eye.
- Processing of 24k rovings (necessary for industrial applications)
- Optimization (control system, implementation of MATERIAL's CADWIND)
- Winding trials
- Production of vessel prototypes

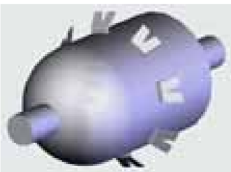
Automated double spindle winding Machine – Description of the functions

- While the first structure is wound, set-up routine on the opposite side of the winding machine
- When the last layer is completed, the impregnated fibers are pulled over the middle to the other side of the removable rest
- Continuous winding of the second structure without interruption



Double spindle winding machine: Start-up mandrel - Operating cycle

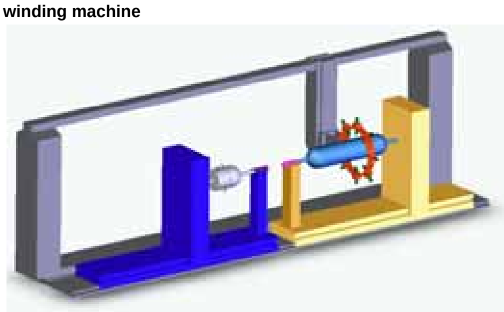
- The fastening of the huge number of rovings to the mandrel is very time consuming without any auxiliary tool
- The impregnated fibers are fixed by hand onto the start-up mandrel (special clamps)
- Advantage: Continuous winding operation



Design principle start-up mandrel

Double spindle winding machine: Possible construction

- The "Change-Over Winder" can be mounted to a conventional winding machine



Conclusions

Motivation to increase the efficiency:

- Increasing demand for pressure vessels in the automotive sector

More rational and cheaper production (cycle time):

- Automated double spindle winding machine ("Change-Over Winder")
- Separately driven spindles
- Ring winding head with small impregnation units
- Start-up mandrel

Acknowledgment

The authors like to thank the European Union for their financial support within the scope of the research project „StorHy"
(Contract No.: SES6-CT-2004-502667)

Thank You for Your Attention.