Robotic Filament Winding Technique (RFWT) in Industrial Application: A Review of State of the Art and Future Perspectives

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Abstract - *Filament winding technique gradually increases its the significance of fabrication process according to the modern automation technique development. Traditional filament winding machine is used to fabricate composite products, such as tubes, vessels, shafts and domes using lathe-type structure. However, filament winding machine with the lathe-type and multi-axis structure has its narrow limitations to produce non-symmetrical structure and novelty core-less filament wound composite products. Therefore, the aim of this paper is to review and compared traditional filament winding machine and robotic filament winding technique, which includes machine structure, machine axes, and machine performance. Moreover, robotic filament winding technique is mainly studied and reviewed in industrial development, which refers to technique characteristics, robotic performance and industrial application. Robotic filament winding technique (RFWT) can effectively solve the traditional lathe-type winding machine limitations according to its development and future perspective aspects.*

Key Words: Robotic filament winding technique (RFWT), Filament winding technique, Winding equipment, industrial winding robot

1. INTRODUCTION

Filament winding technique is an automated composite fabrication process, which is commonly used to fabricate filament wound composite tubes, pipes, vessels and shafts. It is gradually mature technique based on modern technique development. The previous research works of the filament winding machine mainly concentrated on the design and fabrication of low-cost machine structure. F.H.Abdalla et al. designed and developed a low-cost lathe-type filament winding machine using the wet winding method, which achieved regular winding and excellent surface finish of different circular specimens [1]. S Mutasher et.al developed the small-scale automated filament winding machine, which is controlled using a single PIC 18F452 microcontroller. Series of control algorithms were presented and tested in the entire winding process [2]. M.R.M.Rejab et al. presented the design of the filament winding machine with four axes of auto manual winding system, and some solutions were suggested to solve design concept problems [3]. Ma Quanjin et al. have developed a 3-axis laboratory scale filament winding machine, which has portable, low-cost, lightweight, inexpensive control system features [4]. ML Skinner reviewed several the latest advanced and innovated developments in filament winding equipment and applications [5].Apparently, the above-stated research works belong to filament winding technique development, and studies on machine development and control system are somewhat limited to advance filament winding technique using the modern technique method.

Robotic filament winding developed as a robotic filament winding cell of the PUMA-762, which can reduce investment costs and ultimately generate the collision-free robot program [6-8]. Since then, S.Chan et al. investigated the evaluation of a robot based filament winding cell consisting of an industrial robot (ASEA IRB 6/2), which was coordinated using a computer. The accuracy and speed relationships experimentally determined for three modes, and the results showed that the robotic winding cell was appropriate for very accurate winding of fibre strands [9] A typical robotic filament winding complex (RFWC) integrates design, analysis and manufacturing were discussed, and it had specialized CAD/CAM software for winding pattern generation and product analysis [10, 11]. However, limited research literature can be founded studying with robotic filament winding technique (RFWT) in recent years, which stagnates winding technique development. Based on traditional filament winding machines have several limitations to produce non-symmetrical structure or novelty core-less filament wound composite products, the review of the latest robotic filament winding technique will play an essential role in filament winding equipment development and novel filament wound composite structures. Finally, this review paper focuses on the current robotic filament winding technique for composite products in industrial application field, which has enormous potential to replace traditional filament winding technique.

The topology of this paper is organizsd as follows. Traditional filament winding technique is studied in section 1. The state of the art is presented in section 2, which provides an overview of robotic filament winding technique and future perspectives. Section 3 describes comparison results between filament winding technique and robotic filament winding technique. Conclusion is highlighted in section 4.

2. TRADITIONAL FILAMENT WINDING TECHNIQUE

Traditional filament winding technique is a highly automated process for advanced reinforced composite structural products. The fibre strands pass through the resin bath and wind on the mandrel with the impregnated condition. Then impregnated fibres take the shape of the mandrel in the curing process at an appropriate time and temperature condition. The wet fibre strands are controlled by the rotation speed of mandrel and horizontal carriage or delivery unit speed, which can provide different winding angles. The mandrel commonly removed after the curing process. However, it can remain as a part of product component in case of high-pressure composite vessels. Figure 1 presents the schematic of the traditional filament winding technique, which illustrates fibre rovings, resin bath, horizontal carriage and mandrel. As mandrel shape or winding patterns have become more flexible and sufficient, this technique can produce complex asymmetric products such as turbine blades, rocket motor cases, composite utility poles, aircraft fuselages, missile cases [12-14]. The main strength of this process is that it is highly automated and produce different fibre orientation respectively, which can provide different mechanical properties.

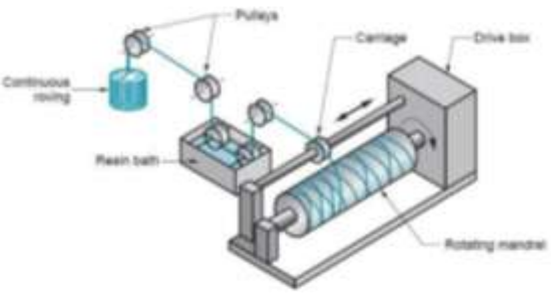


Fig -1: Schematic diagram of filament winding technique [15]

2.1 Machine Structure

Filament winding machine structure is developed with numerical control axes, and it defined in Figure 2, which presents X, Y and Z axes are linear motions and A, B and C axes are rotational motions. Axis X defines as the carriage or delivery linear motion, which provides precision movement using an AC brushless sevro motor. Axis Y is the cross carriage linear motion and it is supported from the X carriage frame, which is driven through toothed time belts. Axis Z is the vertical linear motion, which is fitted with a brake to provide position holding in power down conditions. Axis A is spindle or mandrel rotation, which can provide the initial winding requirements. Axis B is the pay-out eye or the feed-eye rotation, which is driven through gearing and shafting from servo motor with feedback mounted at the rear of the "Y" arm. It can allow fibres to pass through its centre of rotation hollow ring structure. The face of the rotation ring has combined comb device to separate fibre strands. The B axes head can be removable to allow the use of other fixed devices. Axis C is yaw with vertical rotation and designed at the end of the "Y" arm, which is in the horizontal plane. Machine numerical control axes definition is illustrated in Table 1, which presents a systematical axes definition to develop or upgrade the related filament winding machine according to machine axes.

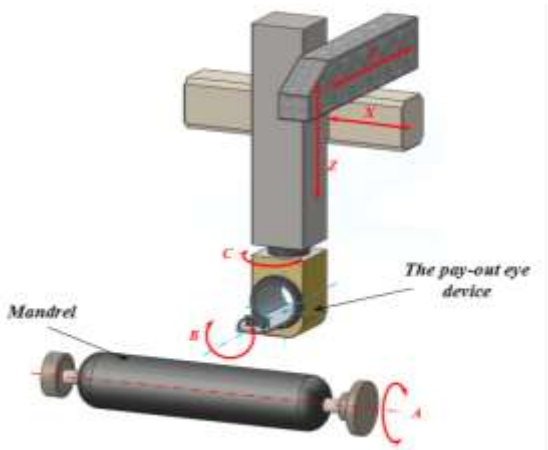


Fig -2: Filament winding numerically controlled axes configuration (Prototype design from Pultrex Modwind machine structure)

Table -1: Machine numerical controlled axes definition

NC AXES	X	Y	Z	A	B	C
2 NC	√			√		
3 NC	√	√		√		
4 NC	√	√		√	√	
5 NC	√	√		√	√	√
6 NC	√	√	√	√	√	√

Note: √ is defined as it provided

2.2 Technique Trend of Development

Filament winding technique is one of the traditional composite fabrication processes to produce composite products, which depends on filament winding machine capability. Through its development timeline, filament winding technique has evolved in recent decades ranging from 2-axis classic lathe-type to 6-axis bed-type or goal post-type, which develops filament winding using an increased number of degrees of freedom. Industrial robot embeds into the filament winding technique named robotic filament winding technique, which enhances filament winding machine development to the next revolution. Robotic filament winding technique has enabled complex shapes, winding patterns and novel winding approaches, and it breaks numerical controlled axes limitation. Filament winding technique development trend is presented in Figure 3, which provides technology development direction. Figure 3 shows that there has been a steep increase in the timeline, which developed based on technology development as well.

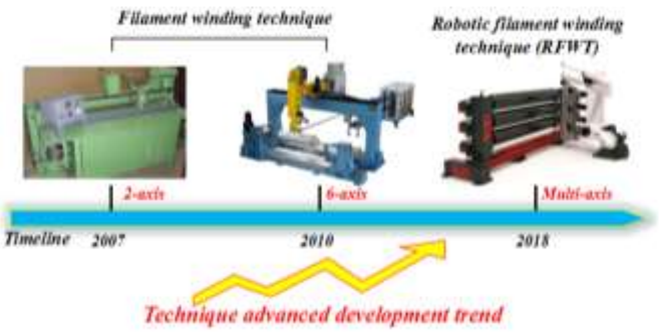


Fig -3: Filament winding structure development trend (Source: http://mikrosam.com; https://www.roth-composite-machinery.com) [1]

3. THE STATE OF THE ART

Robots provide a significant development platform for filament winding technique, which can make flexible and scalable winding equipment. Robotic filament winding technique (RFWT) consists of an industrial robot arm to handle the pay-out eye device or mandrel rotation, which can provide advanced winding pattern integrated design, analysis and manufacturing process. This new winding concept dates from the conceptual design of robotic filament winding complexes (RFWC), which provides off-line programming and coordinated control system of the industrial robot and related support equipment [10, 16-20]. However, none of the related studies has sufficiently offered robotic filament winding technique advantages over traditional lath-type filament winding machine.

3.1 Robotic Filament Winding Equipment Structure and Type

Robotic filament winding method is to adopt a classical industrial robot to rotate the mandrel unit or the pay-out eye unit and related devices using high degrees of freedom concept. Robotic filament winding technique has four major components, which consists of the mandrel unit, industrial robot unit, a specially-developed fibre delivery unit attached to robot unit, and supplementary equipment [21]. In this method the main advantage is to provide a less sophisticated, automated and flexible winding cell to produce complex shape composite products, which profoundly responds to market needs. Current industrial robotic equipment structure is necessary to study its degrees of freedom, which can understand the winding pattern concept. The industrial robot consists of many rigid links assembled by mechanical joints. The link joints, robot arm and robot head designed on a base. Figure 4 illustrates the robotic structure schematic diagram, which explains degrees of freedom differences between two current robotic prototypes. The typical robotic feature is a 6-axis motion as degrees of freedom, which is shown in Figure 4 a. The PA10 industrial robot model is a 7-DOF manipulator, which presents the rotation direction and joint name respectively in Figure 4 b.

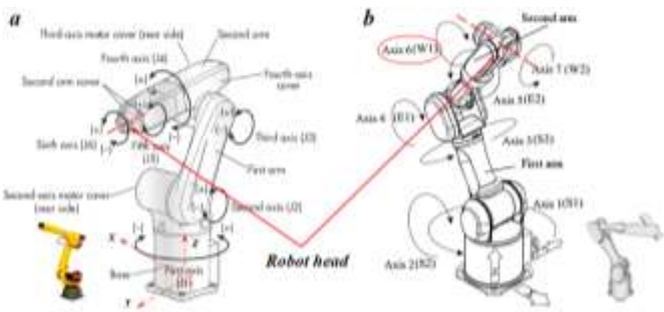


Fig -4: Schematic of industrial robotic structure: (a) 6-axis robot; (b) 7-axis robot [22]

In the recent industrial development stage, standard or customised industrial robots have been applied in filament winding technique as robotic filament winding equipment [23]. Worldwide suppliers are collected such as Kuka, Fanc, ABB and MF Tech companies, which advance robotic filament winding technique. Figure 5 presents the two primary modes in which the industrial robot can be developed, which is well defined robotic filament winding mode. Mode 1 is the robot head rotates the mandrel, and the pay-out eye unit is fixed at a static position, which is visible in Figure 5 a. Mode 2 is where the mandrel is held in lathe-type rotation equipment, and the robot head moves the pay-out eye unit, which is shown in Figure 5 b.

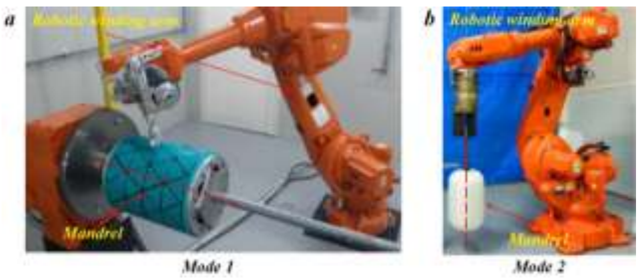


Fig -5: Robotic filament winding mode definition: (a) mode 1; (b) mode 2 (Source: https://composites bizblog.wordpress.com) [24]

3.2 Robotic Filament Winding Machine

Industrial robotic filament winding machines using mode 1 are presented in Figure 6, which highlights its design concept and characteristics. Mode 1 is better to choose when the mandrel is a long size or large inertia because it provides a lower power supply of the robot. The pay-out eye unit is designed in robot head, which has the potential to add more parallel the pay-out eye units to advance machine capability. This Mode 1 is applied a simple winding pattern for a sophisticated or asymmetric mandrel structure compared to Mode 2. Many industrial suppliers have advanced multiple mandrels and the pay-out eye units according to Mode 1 concept.

Industrial robotic filament winding machines using mode 2 are presented in Figure 7, which summarises winding robots such as Cadfil, ABB, Harbin KPS and MF Tech companies. Schematic motion of robotic filament winding equipment is marked in Figure 7 (a) (b) (c) (d) respectively. Robotic winding motion is discussed and follows, Z motion is the winding machine linear movement toward robot head. X motion is the transverse (radial) movement, and A motion is the mandrel rotation. The pay-out eye unit can be replicated by an external rotation axis or provided the static station, which is labelled E1. The mandrel is orientated to the static pay-out eye unit, which is entirely using of available the robot axes. Mode 2 needs a set of additional complex and integrated robotic control system, which is substantially much complex motion and programming compared to Mode 1.

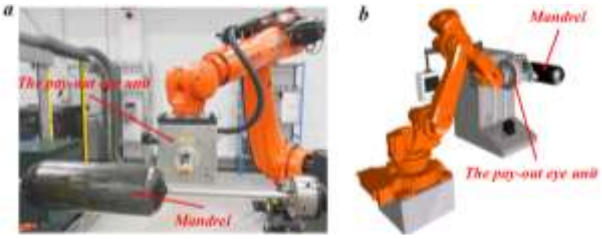


Fig -6: Robotic filament winding machine using mode 1: (a) MFTech FW robot; (b) Comec robot (Source: amrc.co.uk;http://www.comecinnovative.it/products/filament-winding-robot)

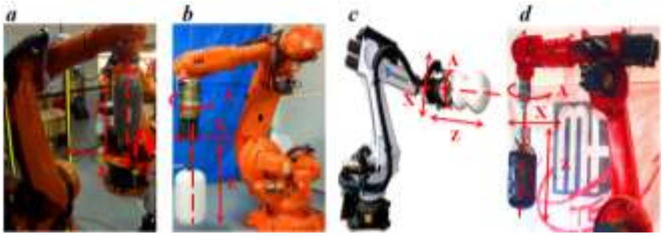


Fig -7: Robotic filament winding machine using mode 2: (a) Cadfil robot; (b) ABB robot; (c) Harbin KPS robot; (d) MF Tech robot (Source: http://www.cadfil.com /filamentwinding;https://compositesbizblog.wordpress.com; http://www.hrgfrp.com; http://www.mftech.fr/en/)

3.3 Robotic Multiple Filament Winding Machine

Robotic winding equipment is commonly provided the limited winding efficiency based on the single pay-out eye unit. The theory of a multiple pay-out eye unit is motivated to overcome the low winding efficient limitation. Figure 8 presents the numerous the pay-out eye units' schematic, which adopts mode 1 with 8 movable roving guides. The winding equipment with multiple pay-out eye units should meet the two requirements, which are constant free filament length and symmetry design of the pay-out eye unit is perpendicular to the mandrel rotation axis. The impregnated units are designed on 8 movable devices for guiding the fibre strands to the mandrel. The concept of multiple pay-out eye units is sufficient method to reduce winding cycle time, which advances winding technique to another higher aspect.

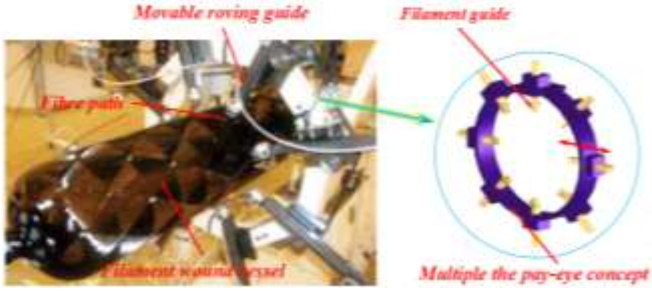


Fig -8: Multiple the pay-out eye units with movable feed device [25]

Cygnet Texkimp Ltd (Northwich, Cheshire, UK) has launched the world's first robotic 3D winding machine capable of producing complex curved composite parts such as cant rails, aircraft wing spars and wind blades. This 3D winder is a robot-mounted winding machine with a non-linear axis and cross-sections, which develops a new manufacturing composite method cost-effectively. Figure 9 presents the robotic 3D winding machine, which is successfully launched from the Northwest Composites Centre. Machine equipment schematic is shown in Figure 9 a, which refers to multiple pay-out device and an industrial robot. Meanwhile, Figure 9 b exhibits winding equipment performance using dry winding method for the single-aisle aircraft spar. Dry fibre strands are wound on a static mandrel with different high-speed ranges and infused with resin subsequently. Robotic 3D winding machine is targeted to produce a wide range of components from composite pipes to aircraft parts for automotive, aerospace, wind energy, and infrastructure sectors [26].

Fig -9: Robotic 3D winding machine: (a) machine equipment schematic; (b) machine winding performance using dry winding method (Source: https:// www. compositesworld.com/products/cygnet-texkimp-launches -robotic-3d-winding- machine)

3.4 Robotic Filament Winding Technique Application Development

The automated manufacturing line for composite CNG tanks has been launched in the city of Graz (Austria), which is the most advanced integrated production line. The production cycle line is fully integrated, automated and controlled the production cell unit and overall manufacturing process is carried out at the same working place based on the top level control system. Mikrosam develops an integrated composite manufacturing solution, which presents multi-spindle equipment, automated process with numerous equipment units and linear track system in Figure 10. The highlighted characteristic of this method is to fabricate various LPG and CNG tanks of different sizes, which are adjusted production parameters automatically. A wide range of fully-automated filament winding lines with the industrial robot is future technique development trend to sufficiently enhance the productivity of the overall cell units.

Fig -10: Filament winding machine with ind (Source: http://mikrosam.com)

The new lightweight suitable joining method is developed, which is based on the robotic filament winding technique. To require the repeatable winding nodes, robotic winding equipment is launched at the wbk Institute for Production Science. Therefore, the winding equipment provides a constant fibre tension and flexible kinematics winding patterns. Using this new joining method, it can wind a T-joint within a closed frame structure with the pay-out eye unit. The industrial robot winding path is highly flexible, which presents equipment details in Figure 11. A robotic winding technique is applied in the joining process, which enlarges the winding technique development field as well.

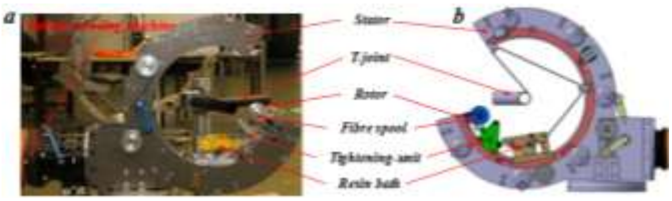


Fig -11: Robotic joining winding machine: (a) realised prototype; (b) C-shaped device for T-joint winding condition (Source: https://www.kit-technology) [27]

The robotic winding technique also opens up new possibilities for novel core-less strategies in architectural design and construction, which allows for a higher degree in lightweight structures [28, 29]. Industrial robot plays a vital role in development and implementation in novel prefabricated composite building components. Robotic filament winding technique is applied in a coherent design framework with a core-less novel method, which is illustrated robotic setup with 3D design and realised design prototypes in Figure 12. One robot is designed as the master, and one is controlled as the slave, which are effectively synchronised with a 12-axis kinematic system. This novel fabrication process expands the possibilities in architectural applications and lightweight structures using robotic core-less filament winding technique.

Fig -12: Schematic diagram of 12-axis robotic machine setup: (a) 3D design prototype; (b) realized design prototype [29]

3.5 Future Perspectives

Filament winding technique is gradually increased due to the widespread application using modern automation technique. Robotic filament winding technique advances filament winding process using the numerical controlled industrial robot, which is developed as automated robotic filament winding cell units. This technique mainly focuses on two aspects, which are industrial cell unit and automated filament winding line in the future development. The industrial robotic filament winding equipment is illustrated in Figure 13 a, which is presented in Scorpo™ robotics. The eight main components are manufactured on the setup to robotic filament winding cell unit. The industrial robot is setup and added the pay-out eye unit on the robot head position. The product is produced on the inner mandrel that rotates with mandrel rotator. The automated robotic controlled unit is surrounded by fibre winding tool, fibre tension device and safety fence. A laboratory-scale robotised filament winding equipment is developed using a kit, which consists of drive unit, mobile unit and the robot unit. The lab scale customised robotic winding equipment is designed and presented in Figure 13 b. Industrial cell unit work range can be extended, which applied the robot base on a track system or added an industrial unit line.

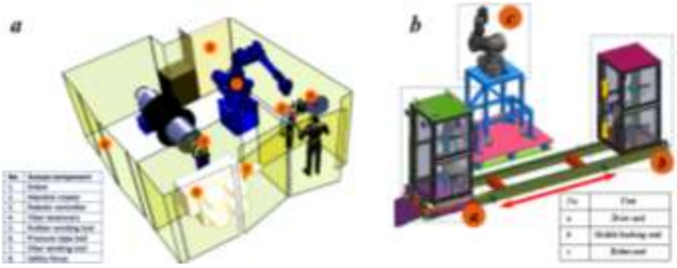


Fig -13: Robotic filament winding cell unit: (a) industrial setup; (2) laboratory setup (Source: http://www.taniq.com) [30]

Mikrosam provides automated winding lines for LPG, CNG and other types of high-pressure vessels, which can meet the higher output production demands of composite products. An automated complete product line is presented in Figure

14, which is shown the automated plant design procedure and function. The industrial robot moves the initial parts into the automated filament winding unit, and then five initial parts are inserted, which are ready to wind using glass or carbon fibre spools. After the wet winding process is completed, the industrial robot places the set of five wound parts into an automated monorail conveyor system. The parts are moved into the curing process, and the parts are placed in painting and coating procedure, which is applied to protect against ultraviolet radiation. This line is automated controlled between the loading station, filament winding unit and curing oven, which is shown the state of the art industry 4.0 revolution.

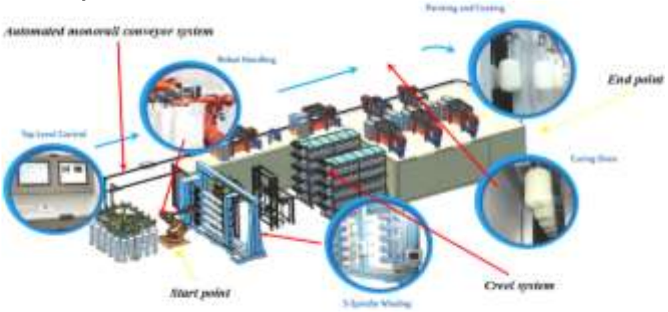


Fig -14: The automated filament winding line with industrial robot unit (Source: http://mikrosam.com)

Related filament winding device also determines future developments in the field of robotic filament winding technique. Instead of mandrel rotation concept, an open ring component is designed to rotate around the mandrel. The lotus ring component consists of three part, which is race, driver and shuttle [31]. The concept of new multiple pay-out eye system is combined with lotus ring concept and multiple pay-out eye concept, which innovates the new method to insert mandrel following radial direction. Robotic filament winding technique is developed based on robotised winding system and winding strategy. The new ring multiple pay-out device can have possibilities to embed more than one following x or y-direction on beam, which is connected with robot head directly. The advanced various winding device development is presented in Figure 15, which predicts and enhances robotic filament winding technique with higher efficiency. Robotized winding technique will become gradually significant in the future since composite product demands and automated, robotised and integrate method.

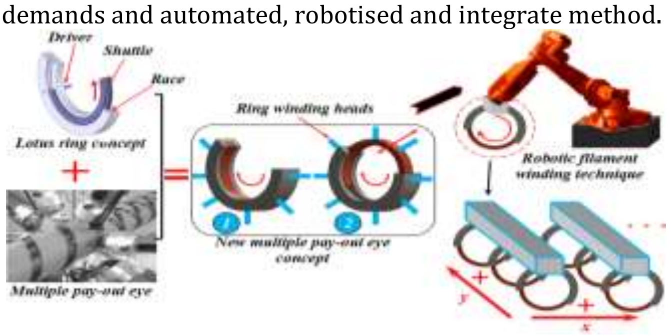


Fig -15: The new multiple pay-out eye concept in robotic filament winding technique development

4. RESULTS AND DISCUSSION

The result presents comparison and technique assessment of filament winding technique and robotic filament winding technique, which are mature manufacturing process in the composite material industry. Robotic filament winding technique is next innovation based on filament winding technique, which is lack of its characteristics. Comparison and evaluation of two methods are useful to study its weaknesses and strengths, which also provides a strong basement to analyse robotic filament winding technique. Table 2 demonstrates technique assessment between FWT and RFWT, which refers to technique capability in comparison criteria. Filament winding technique provides maximum 6 axes and several typical software types, which is commonly controlled using CNC control system. Robotic filament winding technique has more than 6 axes and several robotic machine systems such as Kuka, ABB and Fanuc, which has space to develop equipment type and software types respectively.

Table -2: Evaluation of techniques' result between FWT and RFWT

Comparison criteria	FWT	RFWT
Equipment type	Lathe-type, bed-type, goal post-type	Cartesian coordinate gantry-type, parallelogram-type
Mandrel range	500mm×1000-4000mm/ 2400mm×12000mm/300mm× 1000-2000mm	4200mm×11000mm /Customized
Machine system	IMS, Siemens CNC control system and servos, CNC system	Kuka/ABB/Fanuc robot system, TCON
Electrical power	380/440V 3 Phase 50/60Hz	400/480V 3 Phase 50/60Hz
Winding pattern	Hoop, helical, polar winding	Hoop, helical, polar winding
Motor type	AC digital servo motor	AC stepper motor
Axes aspect	2-6 axis	≥ 6 axis
Winding angle range	0-90°	0-90°
Control method	Manual/semi-automatic/automatic	Manual/semi-automatic/automatic

Software type	*Winding Expert™, Cadwind, ComposicaD, Cadfil, FiberGraphix*	*Cadfil*, several professional software

Notes: IMS: Pultrex integrated manufacturing system (Source: pultrex.com); TCON: top-level control system (Source: mikrosam.com); FWT: filament winding technique; RFWT: robotic filament winding technique

Table 3 indicates the evaluation of equipment result between FWT and RFWT, which compares related filament winding devices such as the pay-out eye device, tension device, and comb device. FWT and RFWT adopt same associated device to perform filament winding process using dry and wet winding methods, which follows the filament winding process procedure. Based on different technique capabilities, the suitable device type is selected to design and use in two techniques respectively.

Table -3: Evaluation of equipment result between FWT and RFWT

Comparison criteria	FWT	RFWT
The pay-out eye structure	Straight bar/ring or curved bar +	Straight bar
Tension device	Electronically/ mechanical controlled	Electronically controlled
Resin bath device	Dip-type/drum-type	Dip-type/drum-type
Comb device	Separated comb	Separated/collected comb
Creel device	Floor mounted/ carriage mounted type	Floor mounted

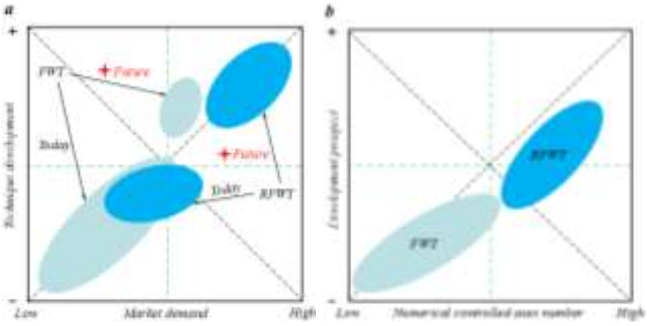
An overall technique evaluation between FWT and RFWT is illustrated in Table 4, which provides the technique development assessment respectively. It is highlighted that RFWT has higher equipment investment, cost-effective, degree of automation, development prospect, productivity and application area compared to FWT. Robotic filament winding technique is used to perform complex winding pattern strategies and product shape, which is hard to apply using FWT.

Table -4: Overall technique evaluation between FWT and RFWT

Comparison	FWT	RFWT
Equipment investment	+→++	++→+++
Machine size	++→+++	++
Winding pattern strategy	++	++→+++
Product complexity	+→++	++→+++
Productivity	++	+++
Work space	++→+++	++
Cost-effective	+→++	++→+++
Degree of automation	+→++	++→+++
Control system complexity	++	+++
Development prospect	+→++	++→+++
Application area	+→++	++→+++

Note: +: low/small; ++: medium; +++: high/big

Based on two techniques assessment, market demand, technique development and technological capability are plotted in Figure 16, which is more intuitive to compare FWT and RFWT regarding product-process-market feature [32]. Figure 16 a presents FWT and RFWT characteristics based on technique development and market demand, which is recommended that RFWT has a higher development space. Figure 16 b is illustrated technique development prospect and equipment numerical controlled axes numbers. It is concluded that RFWT has more than 6 axes numbers with a higher development prospect respectively. Figure 16 c shows technique equipment capability in regards to winding speed and product shape, which concludes that RFWT aims at complex asymmetric product shape. FWT and RFWT can have a sizeable winding speed range, which depends on technique equipment capability. Figure 16 d shows the technique cost-effective parameter and equipment complex complexity trend, which indicates that RFWT has a higher cost-effective value.



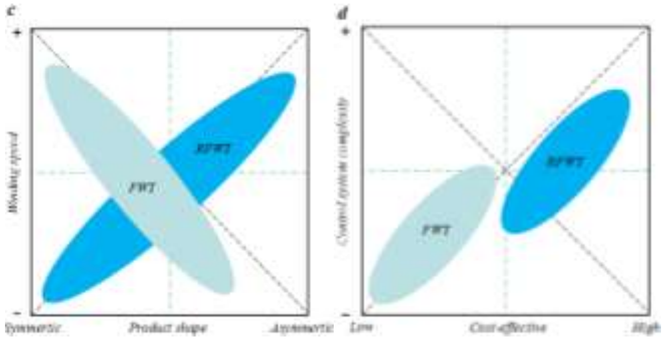


Fig -16: Technique comparison results between FWT and RFWT concerning product-process-market feature

Characteristics analysis of robotic filament winding technique is discussed as following general comparison and conclusion. Robotic filament winding technique is utilised Cartesian coordinate gantry-type or parallelogram-type as following kinematic structures. The gantry-type provides a higher accuracy (consistent resolutions), and parallelogram-type is considered to be more flexible. Robotic filament winding technique performs several kinds of tasks such as mandrel loading and unloading, trimming, painting and inspection procedures according to its high flexibility and complicated programmability. Since the industrial robot is mass produced, robotic filament winder is fewercosts compared to a traditional winder with similar equipment capabilities, which is integrally more reliable the conventional winders.

However, robotic filament winding technique has several drawbacks, which are discussed as well. The main disadvantages of robotic filament winding technique are as follows: (1) Depending on industrial robotic system flexibility, the pattern accuracy of the robotic winding cell may be lower than traditional winding machine because synchronisation between the robot and the mandrel drive is not assured. (2) The size of the mandrel is constrained by the limits of industrial robot work cell space.

5. CONCLUSIONS

The present paper shows the introduction of an automated winding technology, named robotic filament winding technique, which is playing a significant role in advancing the traditional filament winding technique in market demand. This technique is used to combine the filament winding method with industrial robot equipment, which enhances development prospects and the degree of automation of traditional filament winding technique. In order to study robotic filament winding technique development, the main result is analysed, evaluated and compared with conventional filament winding technique, which refers to equipment technology, machine capability and other aspects.

Robotic filament winding technique is analysed in technical application aspect, which provides several strengths accordingly. Robotic filament winding technique has higher equipment investment, cost-effective, the degree of automation, development prospect, productivity and application area characteristics respectively, which improves winding strategies, winding patterns and complex product shape according to market needs. However, RFWT also has its limitation, which may affect its development or application. The possible disadvantages are mentioned, which refer to winding pattern accuracy and limited mandrel size. Based on this technique development, it has been widely used in many fields such as the CNG tanks automated manufacturing line, joining process, architectural design and construction. This applied-based winding technique opens up the way for many potential applications, which enables the technology to advance rapidly.

Therefore, it is essential to forecast technique development trend, which advances the filament winding process in composite materials. This technique is mainly developed in two aspects, which are industrial cell unit and automated filament winding line. Related robotic filament winding devices are designed to overcome its possible limitations, which can gradually complete robotic filament winding technique procedure.

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