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Design, Modelling, and Manufacturing of a Novel Composite Winding Machine for Producing Complex Shapes

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ABSTRACT

This paper aims to design, modeling and manufacturing a prototype composite winding machine used to produce corrugated composite tubes. Seven different types of tubes can be produced: Radial Corrugated Tube (RCT), Radial Corrugated Surrounded by Cylindrical Tube (RCSCT), Cylindrical Tube (CT), Tangential Corrugated Tube (TCT), Tangential Corrugated Surrounded by Cylindrical Tube (TCSCT), Combined Radial and Tangential Corrugated Tube (CRTCT), and Combined Radial and Tangential Corrugated Surrounded by Cylindrical Tube (CRTCSCT). All types can be produced with different size. Although it is designed mainly for composites, however, paper, and thin sheet of metallic materials can be used as raw material too. Different fiber forms can be used such as knitted, woven roving, continuous filament, or chopped mat of glass or carbon fiber. Corrugation profile can be changed to any required shape such as sinusoidal, triangular, square, rectangular, trapezoidal, or combination of any two or more profiles. The machine uses a special technique utilizing a mandrel that can be driven manually as well as automatically. A prototype of a designed machine have been manufactured, and tested. Two different samples of prospected products have been produced successfully.

Keywords
Composite Material.
Corrugation Profile.
Machine Design.
CAD/CAM System

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1 INTRODUCTION

Composites have already proven their worth as weight-saving materials. The use of composites rather than metals has in fact resulted in savings of both cost and weight. Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. Mazumdar, S K.[1] illustrated that among all materials, composite materials have the potential to replace widely used steel and aluminum, and many times with better performance. Replacing steel components with composite components can save 60 to 80% in component weight, and 20 to 50% weight by replacing aluminum parts. Thus the shift of composite applications from aircraft

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to other commercial uses has become prominent in recent years. It can be said that its applications and use are spread to almost in all fields of life.

While composites are applicable for wide range of different applications, and it is able to replace metallic materials for several uses, therefore, the current challenge is to make it able to produce any part of composite material with different shape, and geometry and make them cost effective. But as it well known there is a difference in nature of metallic, and composite materials. Metallic materials able to be machining, forming, casting, grinding, welding, and applying many other different processes. However, the nature of composite materials limiting applying of all these manufacturing processes. Composites are made of two or more different materials with multiple layers. This feature of composites make it difficult to produce components of complex shapes. The efforts to produce complex shapes and economically attractive composite components have resulted in limited innovative manufacturing techniques. Unfortunately the technology designed to produce such complex shapes has not kept up with the advances in composite material technologies. Hence, there is a lot of work need to be done to overcome the challenge in manufacturing processes of composite materials especially for products with complex shape.

For example, cylindrical shapes are widely used in engineering applications. High attention was given to produce composite cylinders. Filament winding machine has the ability to produce composite tubes, cones, and cylinders with different geometrical sizes. However, it is not able to produce tubes with different profile such as radial corrugated composite tubes. Such profile is never been produced automatically. That is because of the difficulty of using composite materials for producing such geometrical shape.

For this type of shape particularly, (composite tube with corrugated profile), limited number of researchers pay attention to inventing a method for producing such geometrical shape of composite tubes. Patz invented a method and apparatus for producing a honeycomb structure in a continuous production process includes five process stations. The invention generally pertains to honeycomb structures, and more particularly to a method and apparatus for corrugating and connecting deformable sheets to produce a honeycomb structure [2]. Donecker et al. presented a method for making a corrugated fiber

reinforced preform for a corrugated channel which involves the sequential application of fiber plies to a shaping tool, each of the plies individually formed to the contours of the shaping tool, using a corrugating tools, restraining means used to maintain the plies in conformance with the tool [3]. Hegler manufactured a composite pipe comprising a smooth internal pipe; an external pipe alternately provided with annular corrugation crests and annular corrugation troughs. The internal pipe and the external pipe being welded together at the bottom of the corrugation troughs, forming a pipe section; and a socket [4].

In recent decades many researches carried out on filament winding techniques in order to moving from classical lathe type towards modern automated machines with an increased number of degrees of freedom. Filament winding is a type of composite manufacturing process, where controlled amount of resin and oriented composite fibers are wound around a rotating mandrel and cured to produce the required composite part [5]. Minscha et al. made analysis and investigation of filament winding processes and potential equipment technologies regarding feasibility, operational and economic aspects, different filament winding equipment is established in an experimental environment. Thereby advantageous solutions can be assigned to particular winding methods and the selection of appropriate filament winding equipment is facilitated [6]. Wang et al. designed and simulated a S-elbow winding pattern. It is aimed at the S-elbow composed of two elbows with different radii. He proposes a winding pattern design method combined with patch winding method and traditional winding method. Results showed that combined winding pattern design method is a good solution to the S-elbow combined winding pattern design [7]. Xiaodong et al. made an analysis and control of the compaction force in the composite prepreg tape winding process for rocket motor nozzle. According to the experimental results, a winding nozzle with fewer voids and a smooth surface could be wounded by the invariable compaction force in the flexible winding system [8]. Many other researches in these aspects have been carried out [9–21] All were related to development of filament winding machine and techniques used for winding process. Although, there are a development in filament winding machine over the years, still there is a lag in producing composite products with complex shape and geometry. Composite tubes with

radial corrugated profile for example is not being able to be produced with a machine. Meanwhile, now days there is a need for offering composite products with complex shape and geometry. It has many applications and researches on such products running rabidly. This challenge was the main motivation behind the current work. The designed machine solved such problems completely. It is really has the ability to produce composite materials products having cylindrical shape with complex geometry automatically. Therefore it can be said that this work offering a novel machine which is a major contribution in the field of manufacturing processes and composite materials technology.

2 DESIGN PROCESS

Design process is the starting point of the research work. It includes translating the main research's idea to drafts leading to final design. Design process file will include engineering drawings of machine parts. Different machine parts with certain shape and dimension will be drawn using CAD system. Sold Work software is utilized to perform design process.

It is wise to refer that design process is focused only on mechanism of the machine rather than material of the machine parts, and other design requirements. Simple mechanism leads to successful working process is an achievement for design process. Preparing of an electronic file of the drawings of machine parts with specified dimensions and details is the end point of design process. Electronic drawings file will be forwarded automatically to next process (modeling).

3 MODELING PROCESS

Modeling process includes assembly of the machine parts and testing its movement. The process is generated automatically using CAD system. Solid Work software utilized for this purpose. The machine need to be designed consists of three stations as shown in Figure 1. The figure illustrated a side elevation view of a system for producing a corrugated structure from a raw material in accordance with the , generally designated as **100**. System **100** comprises a continuous production apparatus wherein elongated raw materials are automatically corrugated to form the corrugated structure.

System **100** has three Stations designated Station **1** through Station **3**. As shown in the embodiment, raw material is in a form of a roll **101** at Station **1**, in which

it surrounds a circular bar to allow smooth feeding into the apparatus. The raw material can be of any type of deformable or non-deformable materials, for example, glass or carbon fibre or a thin sheet of metal in the case of metal products.

The raw material is dispensed from Station **1** via first roller **102** to Station **2**. At Station **2**, raw material is fed via second roller **103** that is immersed in a bath of epoxy resin to create a rigid structure after curing. After impregnation at Station **2**, raw material is dispensed to Station **3** via third roller **104**, fourth roller **105**, fifth roller **106**, and sixth roller **107**. These rollers are tensioning rollers that maintain the tension of the raw material while being fed into Station **3**. Impregnation of raw materials in epoxy resin is omitted in case of producing non-composite structures.

At Station **3**, raw material is corrugated to form the final product of corrugated structure which is formed by layers of raw material. The number of layers of raw material being fed into Station **3** to undergo corrugation varies and depends on the desired thickness of the final product.

Station **3** is the main part of the machine that includes the mechanism used for producing the desired shape of products. Majority of the machine parts are fitted together consisting complete system of main mechanism. Driving system of the machine which is ether manually or automatically is directly engaged to the system of Station **3**.

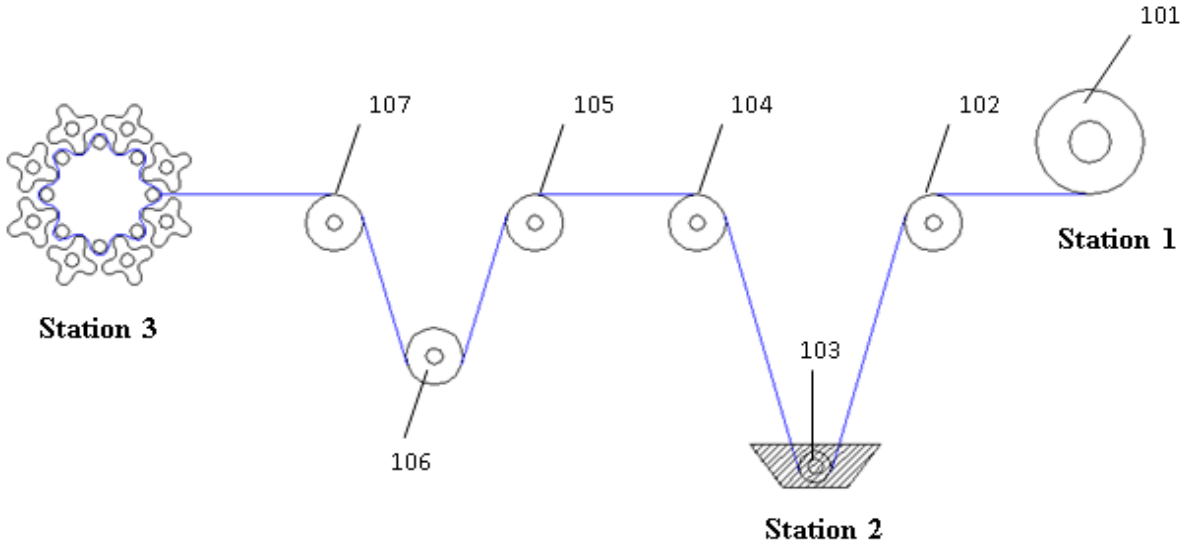


Figure 1. schematically diagram of side elevation view of designed machine

Smooth movement of mechanical parts following to designed mechanism is the main goal of modeling process. Successful and final test of working process leads to the next stage, that is manufacturing and fabrication of machine parts. Then assembly all the parts together forming the prospective machine as shown in Figure 2. Disassembly of machine parts for maintenance or other purpose is part of design and modeling processes.

4 MATERIAL

Material of the machine parts is not the issue for the current research. This research focusing on how the machine can work successfully rather than the type of material for machine parts. For this purpose it is planned to make a prototype which can be made of wood, plastic, metal, or combination of different materials. However, real prototype was made of Aluminum, except the main shaft which made of steel. For mass production, material of the machine parts is an important issue and should be studied carefully.

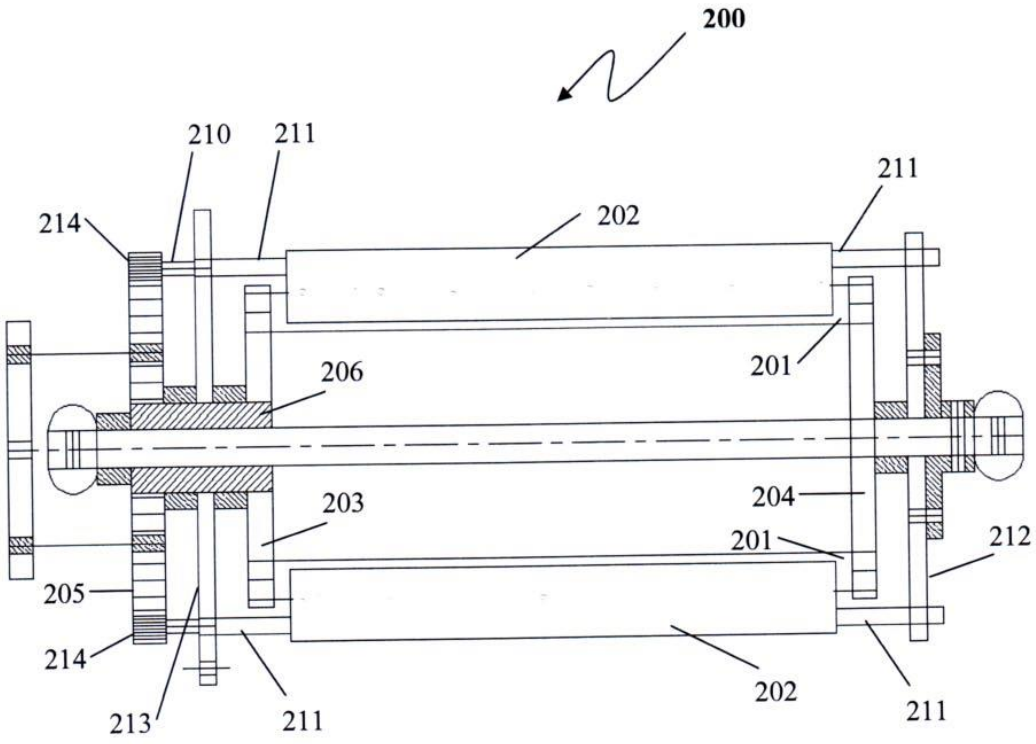


Figure 2. Cross-section view of the mandrel that shows the assembly parts in detail

Referring to Figure 2, illustrated a cross-section view of Station **3**, which is a mandrel, generally designated as **200**. Mandrel **200** generally consists of an inner rotating assembly and an outer rotating assembly that corresponds together in an opposite or counter rotating relationship during operation. Figures 3-4, shows the main parts of the mandrel.

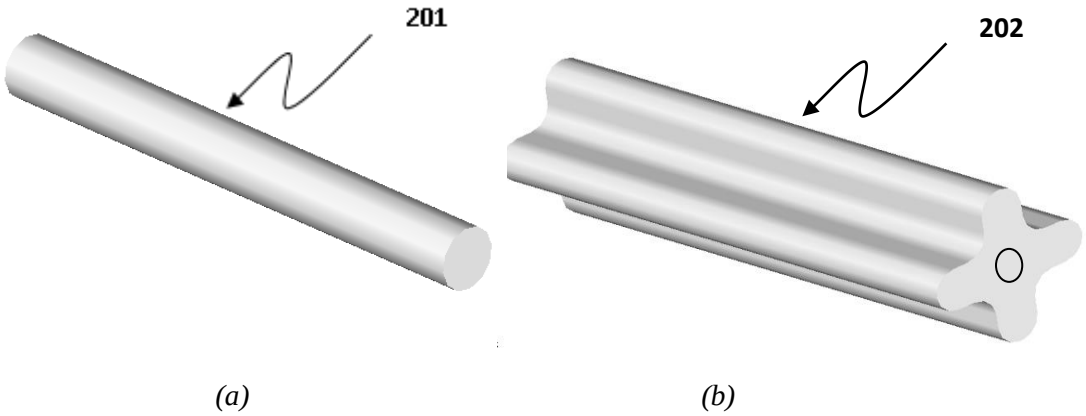


Figure 3. (a) Perspective view of an inner shaft, (b) Perspective view of an outer shaft

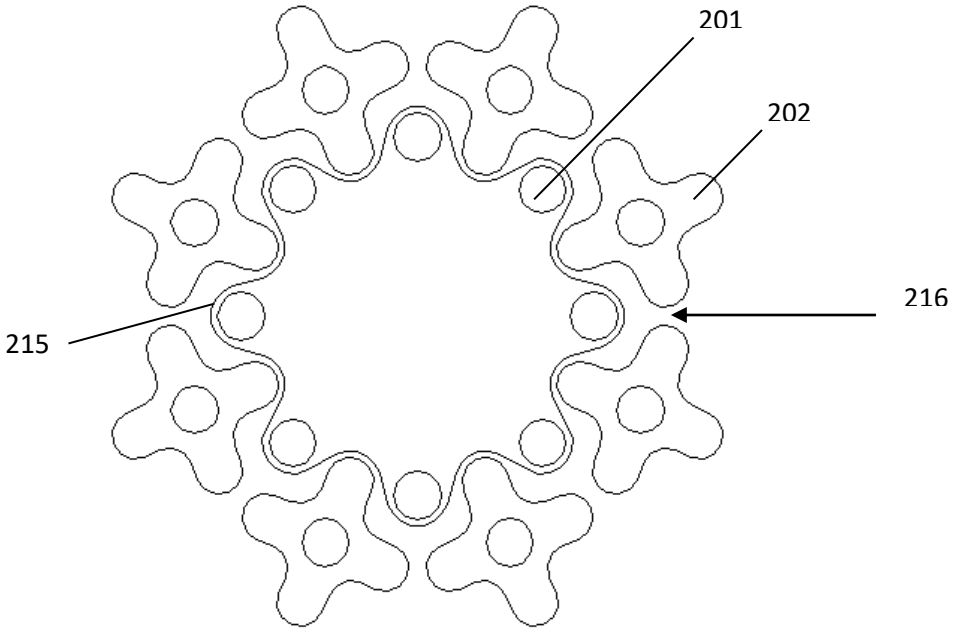


Figure 4. Arrangement of a set of inner shafts and outer shafts in the mandrel with a raw material being fed along a corrugation channel

5 FABRICATION PROCESS

Successful modelling of the machine and ensure it is working properly means that it is time for producing a prototype of the machine. Machine parts can be made using ordinary lathe/milling machine or CNC machine utilizing CAD/CAM system. For this work, CAD/CAM system was utilized for fabrication process.

6 TESTING AND VERIFICATION OF MACHINE'S MECHANISM

Once prototype is manufactured, it is wise to test the mechanism of the designed machine. This stage is very essential since it gives thrust that the machine is working properly, and it is able to produce the desired products.

Although the designed composite winding machine supposed to has the ability to produce at least seven different types of products, testing process was limited for radial corrugated tube only. The reason is, radial corrugated profile is the more complex one, and if it can be produced successfully it will be a strong indication that all other types of tubes can be produced successfully. Figure 5, shows side, and top view of products.

Regarding driving system, the machine is designed to be driven manually as well as automatically. For testing purpose, manual driving system was used, because of many reasons such as cost and speed control. Regarding raw materials, the machine is designed to produce products with different raw materials such as: composite materials with different kinds of fiber, thin metallic sheet, and paper. However, for testing purpose, radial corrugated composite tubes made of thin sheet of metals or woven roving composite materials will be produced. The main objective is verification of working mechanism regardless used raw materials.

Final shape of designed machine with its accessories is shown in Figure 6. However, Figure 7 shows the mandrel of designed machine in final form after modelling process and manufacturing.

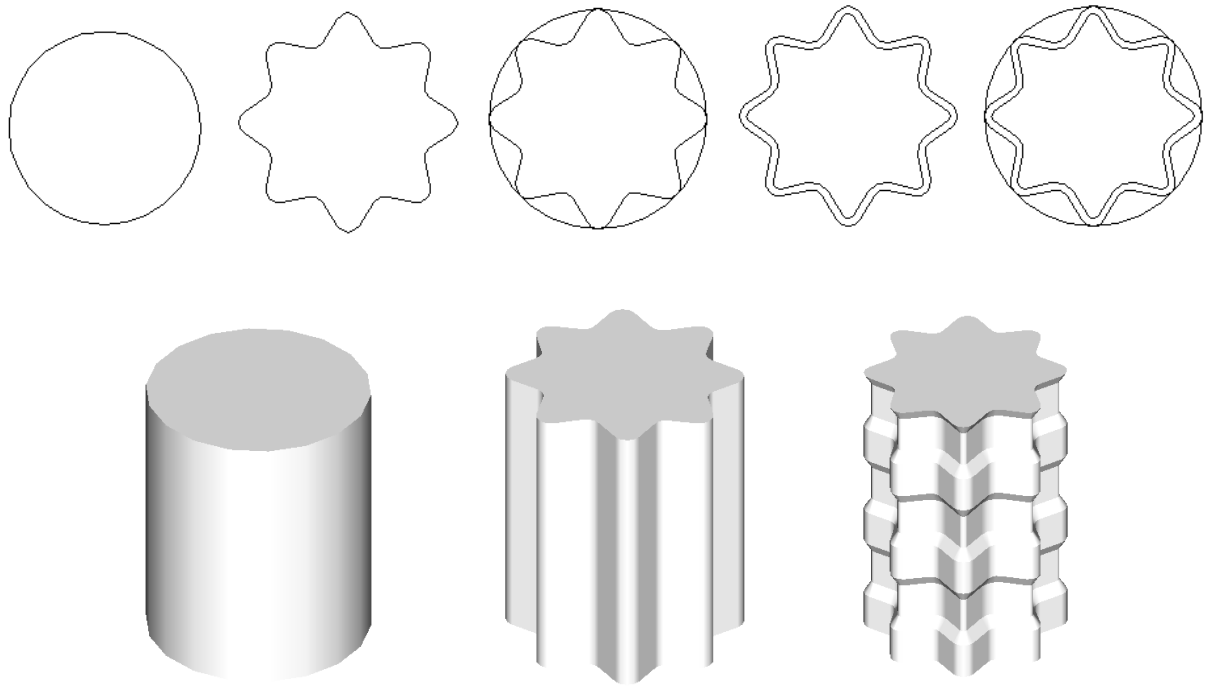


Figure 5. View of the structures produced by the designed machine

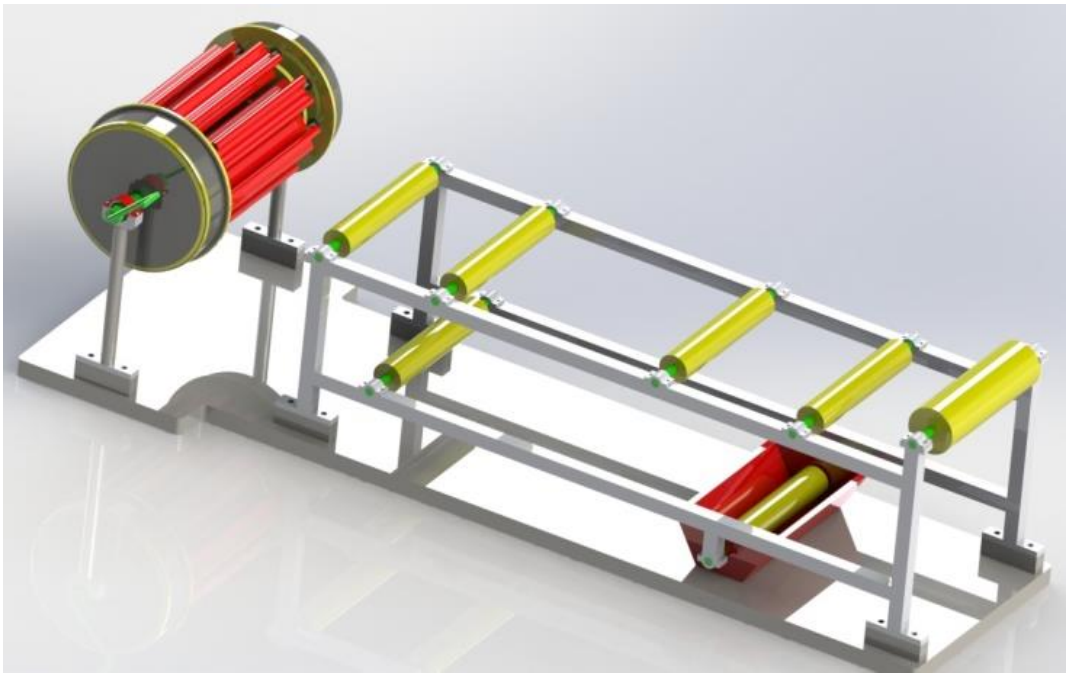
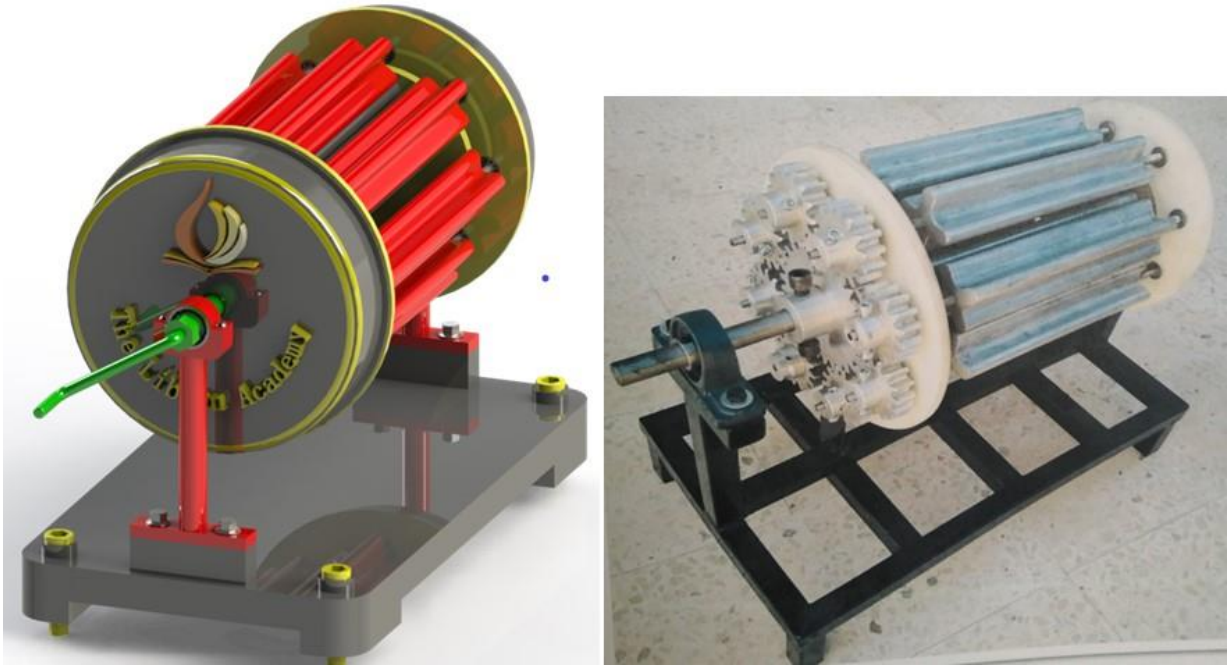


Figure 6. Final shape designed machine with its accessories after modelling process



(a) *(b)*

Figure 7. (a) Final shape of designed machine's mandrel after modelling process, (b) Photo of real machine's mandrel after manufacturing process

7 CONCLUSIONS

The main objective of the paper has been achieved. The idea for making a machine able for producing cylindrical complex shapes has been performed successfully. The process passed through a steps of design, modeling, manufacturing, and testing of the machine. Based on the work done and results obtained, the main conclusion points can be summarized as following:

- A novel and unique winding machine used for producing complex cylindrical shapes has been made.
- The designed machine proved that it has the ability to produce at least seven complex cylindrical shapes as mentioned.
- The designed machine can be used for producing complex cylindrical shapes made of composites, paper, and thin sheet of metallic materials. Different fiber forms can be used such as knitted, woven roving, continuous filament, or chopped mat of glass or carbon fiber.

- The designed machine has the ability to produce corrugated tubes with different corrugation profile, such as sinusoidal, triangular, rectangular, trapezoidal, or combination of any two or more profiles.
- A prototype of a novel machine has been made and tested successfully.
- A designed machine can be made of different size, depends on demand and applications.
- An electronic file for machine's specification including drawings, dimensions, type of material, and layout of assembly / disassembly of machine parts has been documented.
- Finally, presence of this machine is a valuable contribution in the field of industry and manufacturing processes, since its products with cylindrical complex shape is never been produced before.

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تصميم وأنمذجة وتصنيع آلة لف مركبة جديدة لإنتاج أشكال معقدة

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الملخص

تهدف هذه الورقة إلى تصميم وأنمذجة وتصنيع نموذج أولي لآلة لف المواد المركبة تستخدم لإنتاج الأنابيب المركبة المموجة. يمكن إنتاج سبعة أنواع مختلفة من الأنابيب: أنبوب مموج شعاعي (RCT) ، أنبوب مموج شعاعي محاط بأنبوب أسطواني (RCSCT)، أنبوب أسطواني (CT) ، أنبوب مموج مماسي (TCT) ،أنبوب مموج مماسي محاط بأنبوب أسطواني (TCSCT) ،أنبوب مدمج الأنبوب المموج الشعاعي والماسي (CRTCT) ، والأنابيب المموجة الشعاعية والماسية المُحاطة بأنبوب أسطواني .(CRTCSCT) يمكن إنتاج جميع الأنواع بأحجام مختلفة. على الرغم من أن الآلة مصممة بشكل أساسي للمواد المركبة ، إلا أنه يمكن استخدام الورق والصفائح الرقيقة من المواد المعدنية كمواد خام أيضًا. يمكن استخدام أشكال مختلفة من الألياف مثل الألياف المنسوجة أو الخيوط المستمرة أو الحصيرة المقطعة من ألياف الزجاج أو ألياف الكربون. يمكن تغيير ملف تعريف التموج إلى أي شكل مطلوب مثل شكل جيبي أو مثلث أو مربع أو مستطيل أو شبه منحرف أو مزيج من أي شكلين أو أكثر. تستخدم الآلة تقنية خاصة باستخدام مغزل يمكن تحريكه يدويًا وآلياً. تم تصنيع واختبار نموذج أولي للآلة المصممة. تم إنتاج عينتين مختلفتين من المنتجات المتوقعة بنجاح.

الكلمات الدالة:
مادة مركبة.
التموج.
تصميم آلة.
نظام CAD / CAM.

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