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Robots in the Production of Polymer-Composite Components

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Abstract—Two robot systems for the shaping and machining of polymer-composite products are described. In the shaping system, an industrial robot lays out the fibers as prepreg tape. In the machining system, the boring and milling of polymer composites is improved. This system is adapted for the machining of sound-absorbing structures in airplane engines,

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Since the end of the 1990s, polymer composites have been increasing used in airplane production in Russia. By producing airplane components and assemblies from polymer composites based on high-strength carbon, boron, glass, organic, and other fibers, their mass may be minimized, with simultaneous increase in strength, rigidity, dimensional stability, and sound-insulating properties.

For such polymer composites, the unit strength in the reinforcement direction is 4–5 times that of structural steel, with increase also in the rigidity. In addition, polymer composites are generally characterized by low thermal and electrical conductivity, resistance to aggressive chemicals, and excellent technological and electrically insulating properties. The use of polymer-composite components is especially important in motors, antennas, and housing assemblies for the aerospace industry.

The production processes for specific polymer-composite components depend not only on the type of binder and filler but also on the overall configuration of the part. The orientation of the fibers in the part may be uniaxial, biaxial, laminar, or multiaxial, depending on the manufacturing method [1].

The production of polymer-composite components is focused largely on prepreg technology. A prepreg is an intermediate product (fabric or fiber) preliminarily impregnated with precatalytic resin at high temperature and pressure. The resin employed is in the semisolid state. Complete solidification occurs on shaping.

In steeping, the goal is maximum utilization of the physicochemical properties of the reinforcement and the assurance of specified electrical, mechanical, and other parameters.

The final prepreg usually takes the form of rolls or packets of tape, with a separating film between the layers. In that form, prepreg may be stored for several weeks. However, the storage time may be extended at low temperatures. The prepreg is eventually shaped into sheets or complex forms.

The prepreg obtained on special steeping equipment is characterized by satisfactory saturation of the filler with the binder; minimal mechanical damage to the filler; and uniform introduction of the binder in the filler, with optimal binder content. The lack of adhesion at normal temperatures permits automation of prepreg application by winding and layering; manual buildup of complex forms; and automated layout of prepreg on CNC machine tools (for example, on laser or ultrasonic layout machines).

Thus, the production of parts from polymer composites consists of two stages.

(1) Production of a blank of the specified configuration and its shaping to obtain high strength and rigidity. After heat treatment, the blank becomes solid.

(2) Machining and final shaping of the part.

Today, the following production methods are most common:

(1) contact shaping with the application of resin-steeped fibrous cloth on a form;

(2) application of fiber–polymer composite on the surface of a form;

(3) winding of resin-steeped fiber on a form;

(4) pultrusion or shaping of complex parts by passing fibers through a polymer bath with a calibrating die.

The characteristics of the product (such as its dimensions and shape) depend on the selection of the polymer composition and the methods of production and shaping. Therefore, the selection of the technology must take account of the structure of the product, its operating conditions, the scale of production, and the available production resources.

The expanded use of composites in aviation calls for automation of the application of fabric. The application of flexible and adhesive prepreg to a complex nonrigid second-order surface without gaps or creases (while ensuring the necessary direction of the fibers) is extremely complex. In addition, numerous requirements are imposed on this process: strict limits on the humidity and conditions in the workspace; the limited reaction time of the prepreg; and the specific adhesion and draping properties of the material.

Technology exists for the production of airplane structures from polymer composite, with automated layout of the cloth. Airplane structures are large, and their curvature is relatively small. Therefore, the prepreg may be laid out as broad sheets on large machines of gantry, column, or cantilever type. The main manufacturers of such equipment are MAG-Cincinnati, MTorres, Forest-Line, Ingersoll, and Microsam.

The next step in the development of automated layout of materials for more complex surfaces is fiber placement technology, protected by a United States patent [2]. In fiber placement technology, a set of narrow prepreg tapes (width 6.4 mm) is applied to the surface. This technology may be used in the manufacture of small and complex polymer-composite surfaces.

OAO Aviadvigatel (Perm), the developer of the PS-90A and PD-14 airplane engines, makes extensive use of polymer composites. We may note, in particular, their use in the engine pods of the PD-14 engine [3]. Therefore, OAO Aviadvigatel has pioneered the use of fiber placement technology in Russia

The Scientific and Educational Center for Composite Aviation Technology (Perm), which has been created at Perm Research Polytechnic University, is developing a department for the automated application of prepreg. This is a collaborative project of OAO Aviadvigatel, Perm Research Polytechnic University, and Coriolis Composites (France) [3].

This project forms part of the program for the introduction the PD-14 engine (within the scope of the Russian state program for the development of the aviation industry between 2013 and 2025) and also the development program for engines that may be used in the MS-21 airplane. At the Perm Center, a six-axle KUKA robot employs Coriolis Composites technology for automated prepreg application. The equipment permits the manufacture of parts of diameter 3500 mm and length 3000 mm [3]. The dimensions of the robot's applicator head (Fig. 1) permit the simultaneous application of up to eight prepreg tapes (width 6.35 mm), without any human intervention. Note the importance of the software employed. Correct laying of the material depends on how well the system is programmed in the specialized CADFiber software.

Fig. 1. Machining head of six-axle KUKA robot used in Coriolis Composites system.

The Coriolis Composites equipment has the following benefits over the available competitors: reliable supply of material; compatibility with all software packets; universality; and relatively low cost. Similar developments are underway at research centers in Europe and the United States.

However, even with the most up-to-date methods of shaping polymer composites, machining operations account for 25–40% of the total production cycle.

The machining of polymer-composite products differs from the machining of other structural materials, as considered for hole drilling and milling in [4–6].

In practice, the manufacture of polymer-composite products entails the following tasks.

(1) Design of a high-tech system for five-axle machining (hole perforation and milling) of complex polymer-composite parts.

(2) Development of technology for hole perforation and milling.

(3) Development of a method of tracking the fractures of compact cutting tools when sandwich panels with tubular polymer-composite filler strike barriers.

(4) Monitoring of the trajectories of the working elements and correction of tool positioning in coordinate machining.

(5) Design of equipment for the attachment of the parts.

(6) Development of control algorithms.

(7) Selection of the system components (high-speed spindle, tool, ventilation system, auxiliary adaptive monitoring components).

Within that framework, we propose a robot production system for the automated machining of polymer composites [4, 5].

This is a universal flexible system based on an industrial robot manipulator. Its benefits over CNC machine tools are as follows.

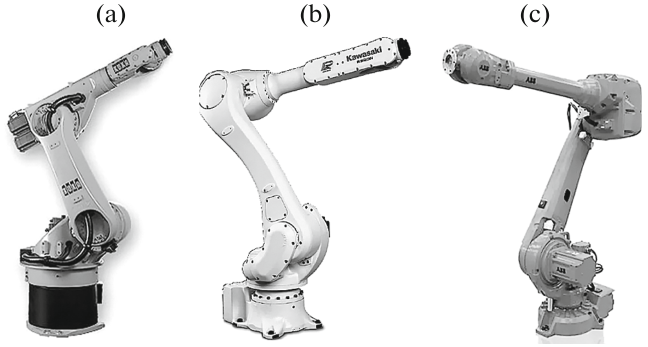

Fig. 2. Six-axle robots: (a) KUKA KR 60 HA (Germany); (b) Kawasaki RS060N (Japan); (c) ABB IRB 4600-60/2/05 (Sweden).

(1) The cost of the robot system is several times lower than that of a comparable CNC machine tool.

(2) Servicing of the robot system is much less expensive.

(3) The robot permits motion of the tool with respect to 12 synchronous mathematically conjugate degrees of freedom in the system. In other words, the tool may move over any complex trajectory in a three-dimensional coordinate system.

(4) The robot may be attached to the floor, a wall, or the ceiling, and its 3-m working zone permits the machining of large parts.

(5) The robot may be rapidly adapted for work with different models. That permits operation with a wide range of products and decreases the time to recoup capital investments.

(6) A single robot (with automatic tool replacement) may perform several different operations in sequence.

(7) The robots (made in Germany and Japan) are able to work around the clock for 12 years, with maintenance every 5000 h.

The basis of the system is a robot manipulator, such as those produced by Kawasaki (Japan), KUKA (Germany), and ABB (Sweden).

In Fig. 2, we show the KUKA KR 60 HA, Kawasaki RS060N, and ABB IRB 4600-60/2/05 industrial robots.

Table 1 presents the basic characteristics of some six-axle robot manipulators.

Comparing the characteristics in Table 1, we select the KUKA KR 60 HA robot, which has the highest precision.

After the design workup, the system has the following main components: (1) the. KUKA KR 60 HA industrial robot (load capacity 60 kg); (2) a sealed dust-protection casing for the robot; (3) a control desk with a controller; (4) a computer with software capable of working with CAM files; (5) a high-speed servo-drive spindle (power 8 kW, maximum speed 24000 rpm); (6) a single-axle positioning system (rotary table) with a vertical axis (load capacity at least 500 kg); (7) a system of scanning laser sensors tracking the tool trajectory relative to the workpiece surface; (8) a system monitoring the tool's null point; (9) a sensor system tracking fractures of the compact tool; (10) a ventilation system with local exhausts and vacuum filters; (11) a removable spindle chuck; (12) clamps for different tools (diameters 2, 4, 6, 8, 10, 12, and 16 mm); (13) an automated store for ten chucks; (14) the tool (drill, mill); (15) the attachment for the tool; (16) shields and safety equipment.

Table 1

Number of axle and engineering characteristic	Robot					
	KUKA KR 60 HA		Kawasaki RS060N		ABB IRB 4600-60/2/05	
	Angle of axle rotation α and maximum speed ω					
	α, deg	ω, rad/s	α, deg	ω, rad/s	α, deg	ω, rad/s
1	±185	2.23	±180	3.14	±180	3.05
2	+35, −135	1.78	+140, −105	3.14	+150, −90	3.05
3	+158, −120	2.23	+135, −155	3.22	+75, −180	3.05
4	±350	4.53	±360	4.53	±400	4.35
5	±119	4.27	±145	4.53	+120, −125	4.35
6	±350	5.61	±360	6.27	±400	6.27
Number of degrees of freedom	6		6		6	
Attainable radius, mm	2033		2100		2050	
Precision in linear positioning, mm	±0.05		±0.07		±0.05–0.06	
Load capacity, kg	60		50		60	
Maximum flange velocity of sixth axle, mm/s	No data		13400		No data	
Mass, kg	665		555		435	

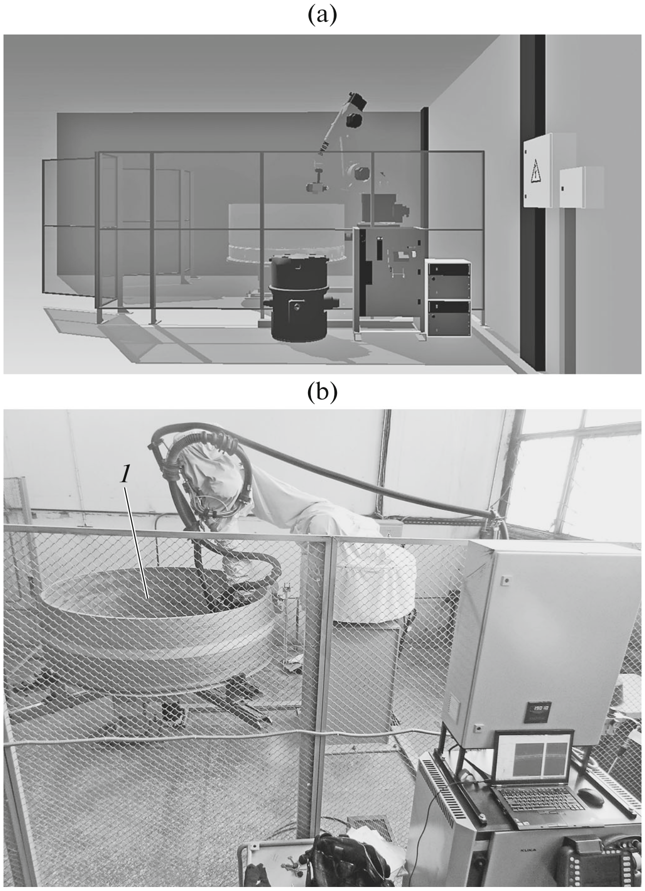

Fig. 3. Configuration (a) and overall view (b) of robot machining system: (*1*) nozzle housing of sound-absorbing structure, made of ST-ENFB glass fiber.

The basic configuration of the robot system for machining, with all its components and the workpiece, is modeled on a computer (Fig. 3).

This robot system is universal and may perform various machining operations (hole perforation and milling in multilayer shells), within the working zone of the robot. The workpieces may be made of polymer composites or other nonmetallic materials. The possible workpiece dimensions are as follows: diameter 2500 mm; height 1500 mm. Its mass may be as much as 1000 kg.

Standard products machined by the robot system include sound-absorbing structures for the PS-90A and PS-90A2 airplane engines (developed by OAO Aviadvigatel and produced by OAO Permskii Zavod Mashinostroitel). The sound-absorbing structures in these engines are used in Tu–204–100, Tu–204S, Tu–214, Tu–234, Il–96–400, Il–96–300, and Il–76MF airplanes. The department of the aviation industry at the Russian Ministry of Industry and Trade has specified the production of the promising PD-14 engine with polymer-composite sound-absorbing structures. The sound-absorbing panels *1* (Fig. 3b) consist of complex shells.

The sound-absorbing panels (made of ST-ENFB fiberglass) include numerous holes, which serve various purposes (for example, holes of 1.6–2.0 mm diameter for sound absorption and holes of 6.5 mm for attachment purposes). In one sound-absorbing structure, the number of small holes for sound absorption is 200000. The sound-absorbing panel has a perforated surface on the inside; the outer layer is unperforated.

A modular system is used for automatic tool replacement. The system includes several such systems with corresponding components. Both active and passive safety measures are built into the robot system, so as to keep service personnel away from hazard areas. The new robot system for the machining of polymer-composite parts is a high-technology production platform.

CONCLUSIONS

(1) The consequences of introducing the new robot system are as follows: (1) decrease in the high manufacturing costs of polymer-composite products thanks to the transfer of monotonous manual tasks to machines; (2) improved working conditions in the manufacturing shop by reducing exposure to noxious factors; (3) increase in output of sound-absorbing panels to meet rising demand.

(2) No Russian counterparts of the robot system exist. The Coriolis Composites system for automated application of polymer composites and the KUKA robot system for machining provide the basis for a new production cycle capable of supplying polymer-composite products to the aviation industry without human intervention.

REFERENCES

1. Anoshkin, A.N., *Teoriya i tekhnologiya namotki konstruktsii iz polimernykh kompozitsionnykh materialov: uchebnoe posobie* (Theory and Technology of Winding Structures from Polymeric Composites), Perm: Permsk. Gos. Tekh. Univ., 2003.
2. Vaniglia, M.M., US Patent 5110395, 1989.
3. Grinev, M.A., New robot used by Perm engineers, *Permsk. Aviats. Dvigateli*, 2013, no. 27, pp. 56–58.
4. Dudarev, A.S., Automated punching of apertures in noise-proof panels of aircraft engines from polymeric composite materials, *Probl. Mashinostr. Avtom.*, 2012, no. 3, pp. 63–68.
5. Dudarev, A.S., Svirshchev, V.I., and Bayandin, M.A., Robotic complex for hole punching and milling of noise-proof panels of aircraft engines from polymer composite materials, *Avtom. Sovrem. Tekhnol.*, 2013, no. 1, pp. 9–14.
6. Lomaev, V.I. and Dudarev, A.S., Machining of holes in the manufacture of products from fibrous composite materials for civil aircrafts, *Tekhnol. Mashinostr.*, 2006, no. 7, pp. 18–22.

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