**DRAFT**

Description

SERVO TENSION CONTROL FOR MODULAR AFP FLOOD ASSEMBLY

Technical Field

1. This invention relates generally to automatic fiber replacement (AFP) machines and more specifically concerns a modular head assembly for AFP machines.

Background of the Invention

1. Automatic fiber replacement (AFP) machines currently have two primary mechanical configurations. One is the integral head design (IHD) and the other is the modular head design (MHD). Both designs use carbon fiber tow wound onto a bobbin or spool. In general operation, the fiber on the spools is unwound by a motor with a tensioning assembly and is directed to a placement tool which lays or places the fiber on a part, such as an aircraft part. Consistent tension on the fiber must be present during operation; otherwise tangling or breaking can occur, resulting in failure of the tape laying process.
2. Traditional IHD design requires electrical connections from the IHD head to the main CNC processor which controls the overall fiber replacement machine. The carbon fiber in the form of tow spools is threaded through a series of redirects to the tape laying tool. The long path of the fiber tool to the tool surface, which is referred to as the tow path, requires conventional servo motors to control tension in the system.
3. On the other hand, the MHD design has advantages of serviceability. In the MHD approach, the material spools are loaded on the head itself. Due to the relatively short tow path, tension is a less severe issue and pneumatic braking systems have been used in place of a servo motor system for tension control. The pneumatic braking system has the advantage of being lightweight and does not require the numerous electrical power supply, drive and wire connections that servo motor systems normally require. However, the tension, repeatability and reliability of present MDH systems with pneumatic braking to maintain tension on the tow is insufficient during high acceleration and high speed payouts. Although servo control has in the past been an effective solution to maintain tension in IHD systems, implementation has heretofore not been accomplished in MHD systems, due to size, power and inertia constraints on the tensioning system. Further, communication with the remote machine CNC would require communication with each servo motor individually, creating many more connections between the modular head and the remote CNC than the current MDH systems. The sheer number of connections which would have to be made quickly and reliably such as when spools are damaged, has prevented use of modular head based servo controlled spool motors in the past.

Summary of the Invention

1. .

Brief Description of the Drawings

1. Figure 1 is a functional diagram of the system of the present invention.
2. Figure 2 is a front elevational view of the modular head assembly of the present invention .
3. Figure 3 is a side elevational view of the modular head assembly.
4. Figure 4 is a front view of the creel assembly portion of the modular head assembly.
5. Figure 5 is a perspective view of the creel assembly portion of Figure 4.
6. Figure 6 is a rear elevational view of the modular head assembly.
7. Figure 7 is a schematic view of the servo motor/gearbox portion of the modular head assembly.
8. Figure 8 is a cross-section of one of the major components of the modular head assembly with other components of the modular head assembly. .
9. Figure 9 is a schematic view of the dancer tensioning assembly portion of the modular head assembly.
10. Figure 10 is an exploded view of the fiber breaker member of the modular head assembly.
11. Figure 11 is a block diagram of the control system of the modular head assembly of the present invention.

Best Mode for Carrying Out the Invention

1. Figure 1 is a simplified functional diagram of the tensioning system portion of the modular head assembly of the present invention, showing the progress of the tow from the spool to the tool which lays the fabric on a part, such as an aircraft wing. The system, as shown generally at 10 includes a servo motor and gear box assembly 12 which is controlled via inputs from a diameter sensor 14 which senses the diameter of a carbon fabric spool 16 and an input from a linear sensor 16 which senses the position of a dancer element 18 which controls the tension on the fabric. A PLC computer 19, in one embodiment is located on the modular head assembly for control of the individual servo motors.
2. In operation, the fabric backing is unwound from the carbon spool 16 under the control of the servo motor assembly 12. The fabric proceeds to a backing spool 17, which removes a backing film from the fabric which then proceeds to the dancer tensioning assembly 18 and from there to one or more redirects 22 and the business end of the system, the fiber placement tool 24. While the backing spool 17 will typically be present in the system, it is not necessary, as the backing film may be removed by other elements.
3. Figures 2 and 3 illustrate a carbon fiber modular head assembly. A typical modular head assembly will include a plurality of identical carbon fiber placement assemblies arranged in a circular fashion. The modular head assembly is attached to a fiber placement machine which is controlled by a CNC processor, typically located remotely from the modular head itself.
4. Figures 2-5 show various views of a modular head assembly, including a plurality of individual servo motor controlled carbon spool assemblies. Figure 2 shows a back plate 26 on which are mounted a plurality of spool assemblies including a spool containing the carbon fiber. Each spool assembly, for example 30, comprises a servo motor/controller which rotates a spindle to let the fiber carbon plus backing film off the spool portion of the spool assembly. The diameter of the spool as it is rotated is sensed by an ultrasonic sensor 32 which continuously measures the diameter of the spool for a proper speed command for the servo motor. Each spool assembly also includes a dancer assembly 32 which is used to control the tension of the carbon fabric during the payout thereof. The dancer assembly includes a sliding assembly on which the dancer member linearly moves. A linear displacement sensor 34 provides position information back to the servo motor/controller.
5. Each spool assembly also typically includes a backing film removal assembly 36 which removes the plastic backing film from the carbon fiber before the fiber is laid down on the part by a fiber placement tool. Figures 4 and 5 with more clarity show the arrangement of elements 30, 32 and 36 of one spool assembly. The plurality of spool assemblies for the modular head is referred to as the creel.
6. Figure ? is an exploded view of the material spindle assembly of the spool assembly. It includes a material spool 40 which contains the combination of carbon fiber material and polymer backing film. The polymer backing film is removed in the process of unwinding the material from the material spindle assembly 42 on which spool 40 is mounted and which in turn is mounted directly on the gear drive locking the carbon fiber spool 40 so that there is no relative motion. This ensures that gearbox output flange 44 rotates at the same speed as the carbon fiber spool 40. The spindle 42 must be able to support the load of the spool 40 during acceleration and loads due to gravity. Mounting flange 44 connects to the gearbox 46 and mounts the complete assembly to the back plate of the modular head unit.
7. Gearbox 46 reduces the rotational speed of the spindle and hence the spool and increases the torque of the motor which allows the motor to move the high inertia spool 40. It also is strong enough to handle the spool/fabric load due to the rapid acceleration of the spool as well as gravity. The servo motor and controller/amplifier shown at 48 in Figure 7 is an integrated unit with servo motor and amplifier into one package. The motor has communication in one embodiment, to a PLC computer on the modular head assembly. The servo motor 48 has a digital I/O capability, and receives the linear position of the dancer so as to close the control loop for fabric tension. The servo motor 48 is capable of forward and backward movement to maintain proper tension on the fabric. One example of a commercially available servo motor having such a capability is\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_. In the present embodiment, the servo motor receives drive and control information from a local PLC computer mounted on the modular head assembly. In another embodiment, the servo motor could be completely self contained, capable itself of controlling the spindle with input from the diameter sensor and the linear displacement sensor. In both of these embodiment, the control of the servo motors is localized on the modular head. There are no wires or other connections back to the remote CNC. Both of these embodiments include a servo motor controller, which, as indicated above, has significant advantages over existing modular head arrangements with pneumatic braking, and eliminates the long wire connections necessary for control of the individual servo motors to the CNC computer.
8. Figure 8 shows one spool assembly. It includes a spool of fiber 60, with a spring loaded support rod 64. In the nominal position, rod 64 is pulled downwardly toward the gearbox assembly, which locks the spool, which is typically cardboard, to the output flange. When the spool is to be unlocked, the rod64 is pulled upwards and rotated to bring it into a higher locked position. The spool 60 maybe then be changed. After loading a new spool, a switching motion of the rod relocks it in place.
9. When the locking rod is in its nominal position, it is pulled downwardly, as indicated above, wearing support pads 67 to expand due to a wedge action. The expansion of the pads applies a normal force to the spool which results in a friction hold on the spool. This ensures that the carbon spool rotates at the same rate as the gear box output flange.
10. A magnetic sensor 70 on the dancer assembly, discussed in more detail below, indicates the linear displacement of the individual dancer element. This information is fed to the servo motor directly and also to the PLC for error detection.
11. Gearbox 72 in the embodiment shown includes a 10-1 reducer element responsive to the shaft 73 input to produce a reduced output speed. This allows support of the bearing load in different orientations and during acceleration because of the cantilevered position of the spool.
12. The integrated servo motor and drive is shown at 74 in Figure 8. The motor has the ability to receive operational commands from the PLC computer on the head as well as inputs from encoders and analog sensors, such as the spring on the dancer assembly.
13. Figure 9 shows the dancer assembly. The dancer tube is shown at 77. The tube is made from \_\_\_\_ material. The tube in operation has the carbon fiber wrapped around it from the carbon fiber spool, 180 degrees during operation. The carbon fiber slides up and down the tube 77 and rolls around the rotational axis of the tube. The dancer tube is mounted on a linear rail 85, with a spring 78 tending to maintain the dancer assembly in its nominal zero position along the rail. Spring 78 generally should have the lowest spring rating as possible, while maintaining the ability to accelerate the dance adequately to maintain contact with the carbon fiber from the spool. Spring 78 is anchored by a bolt 80 to a dancer block element 82. The block 82 contains both the spring anchor and a small spacer to adjust the nominal position of the dancer tube when it is fully retracted. This ensures that the dancer will always be within the linear sensor measurement range.
14. The dancer tube and all the dancer assembly elements are mounted on a back plate 83. Back plate 83 is mounted to the back plate of the modular head. The dancer tube is mounted on a bearing assembly 84 which allows for linear motion of the dancer tube assembly along rail 85. The dancer tube is bolted directly to the top of the bearing assembly. A magnet 85 in the embodiment shown is mounted on the bearing elements, moving with the carbon fiber dancer on the assembly to indicate linear displacement as the dancer assembly moves to maintain tension.
15. Mounted at one end of the plate 83, is a pin stop 88 which prevents the dancer tube from leaving the linear rail in the event of a malfunction. The pin stop includes a small urethane bumper element. A magnetic linear displacement sensor 90 feeds a signal back to the integrated motor controller in order to maintain tension control over the tape as it moves from the spool.
16. Figure 10 shows the backing film sleeve/remover. The assembly shown generally at 94 is injection molded plastic and in operation sandwiches the backing film between a sleeve 96 and spindle 97. When the carbon fiber is payed out, friction rotates the spindle 97 and the backing film is wrapped around the outside of the sleeve, separating the backing film from the fiber. Spring loaded member 98 is compressed when the film sleeve is moved onto spindle 97. When the sleeve is in the down position, the spring member moves outwardly preventing the film sleeve from sliding off. The film sleeve in operation slides on to the spindle and locks into place. In operation, the backing film is sandwiched between the spindle 97 and the sleeve 94. The overall assembly is press fitted into the spindle and retained by rings 100. The assembly is bolted to a spindle mount 102, which is bolted to the back plate of the modular head assembly.
17. In operation of the spool assembly, the servo motor/controller rotates the fiber spindle at a controlled speed. The motor has inputs from the diameter sensor and the linear displacement sensor for the dancer. The fiber as it is payed out moves around the backing assembly and the dancer before it extends around one or more redirects to the placement tool which applies the tape to the part. The dancer assembly moves linearly along the dancer rail in order to maintain the proper tension of the fabric tape. The use of a servo motor controller for each separate spool assembly is advantageous as it allows significantly increased speed of payout of the tape while maintaining desired tension. This arrangement provided reliable control of tension for high acceleration and for high speed pay out.
18. Figure 6 shows a rear view of the modular head. The embodiment shown includes a PLC computer controller positioned in the head. All of the control lines and driver lines for each of the individual servo motors are provided to and from the PLC, thus eliminating the large number of contrail lines which would have to extend back to the main (remote) CNC computer. The present arrangement thus makes the modular head using the servo motors feasible in a practical environment.
19. Figure 11 shows a basic schematic for the overall system. The fiber replacement machine as a whole include a CNC computer 108 located remotely from the modular head. Connecting the CNC computer in the embodiment shown to the modular head, which includes a plurality of spool assemblies, is a conventional slip ring arrangement 110. Each modular head will include a PLC computer 112. Communicating with the PLC computer 112 are the plurality of individual spool assemblies 114-114. The embodiment shown includes a total of 16 spool assemblies arranged around the modular head, although it should be understood that a different number of spool assemblies can be used. Each spool assembly includes a spool 116 containing fiber tape and an integrated servo motor/controller with gearbox, shown generally at 118. There is a serial communication between each of the spool assemblies via a communication line generally at 120. Each spool assembly will include a dancer linear displacement sensor 122, and a fiber spool diameter sensor 124. The output of the linear displacement sensor on the dancer will be applied directly to the motor drive unit, while the diameter sensor output for each spool assembly will be applied to the PLC computer. This arrangement provides the required tensioning control over a wide variety of acceleration rates, and results in a significantly increased payout rate under good tension control. While the embodiment shown uses a PLC computer, with connections to each of the servo motor drives units, it is possible that each servo drive unit is sufficiently smart that it can itself produce the required drive with diameter and dancer displacement information. Further, it is also possible that at least some of the wiring connections can be provided through a specialized slip ring arrangement back to the CNC computer permitting the use of what can be characterized as a dumb servo motor.
20. Although a preferred embodiment of the invention has been disclosed for purposes of illustration, it should be understood that various changes, modifications and substitutions may be incorporated in the embodiment without departing from the spirit of the invention, which is defined by the claims which follow.

What is claimed is:

# Claims

1.  A modular head assembly for a fiber placement machine having a machine controller, comprising:

a support back plate;

a plurality of carbon fiber spool assemblies, each including a spindle for a carbon fiber spool, servo motor/gear box combination and a dancer assembly for tensioning the carbon fiber as it moves from the spool to a tool assembly which applies the fiber to a part, wherein the spool assemblies include a linear displacement sensor for the dancer assembly and a sensor for determining the diameter of the carbon spool; and

wherein the servo motor assembly controls the movement of the tape spool so that it is payed out in a controlled rate.

2.  The assembly of claim 1, including a backing assembly for removing backing film material from the carbon fiber.

3.  The assembly of claim 1, including a slip ring assembly connecting the modular head assembly and the individual spool assemblies to the machine controller.

4.  The assembly of claim 1, including a PLC controller mounted on the head assembly with control connections extending between the servo motors and the PLC for control of the individual servo motors.

5.  The assembly of claim 4, wherein the spool diameter information is provided to the PLC and the linear displacement information is provided to the servo motor.

6.  The assembly of claim 1, wherein the spool tape assemblies, the dance assemblies and the backing member assemblies are all connected to the back plate.

7.  The assembly of claim 1, wherein the spool assemblies are mounted to and removable from the back plate assembly for replacement thereof.

8.  The assembly of claim 1, wherein each of the spool assemblies are individually connected to the PLC computer and wherein the plurality of spool assemblies are connected to each other in series.

9.  The assembly of claim 1, wherein the dancer assembly is mounted on a rail and positioned therealong by a spring assembly such that the dancer moves along the rail to maintain correct tension on the fabric as the fabric proceeds from the spool.

10.  The assembly of claim 1, wherein the spring assembly moves over a length of approximately 1-3 inches.

11.  The assembly of claim 1, wherein the servo motor controller moves the spindle in both directions, forward and reverse.

12.  The assembly of claim 1, including control/drive connections for the servo motors through the slip ring back to the CNC machine controller.

# Abstract

A modular head assembly for a fiber placement machine having a machine controller includes a back plate and a plurality of carbon fabric spool assemblies, each assembly including a servo motor combination and a dancer assembly for maintaining tension of the fabric as it is payed out. The spool assemblies further include a linear displacement sensor for the dancer assembly and a sensor for determining the diameter of the carbon spool, the outputs of which help control the action of the servo motors.