DRAFT

Description

SERVO TENSION CONTROL FOR MODULAR AFP HEAD ASSEMBLY

Technical Field

[0001] 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

[0002] Automatic fiber replacement (AFP) machines currently have two primary mechanical configurations. One is the integral head or end effector design (IEE) and the other is the modular head or end effector design (MEE). 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.

[0003] Traditional IEE design requires electrical connections from the IEE to the main CNC processor which controls the overall fiber ~~replacement~~ placement machine. The carbon fiber in the form of tow spools is threaded through a series of redirects to the ~~tape laying tool~~add-cut-clamp module. 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.

Commented [OL1]: We should probably define the business end somewhere so we can refer to it.

Perhaps if we just called it something general like "material deposit system" or "tow deposit system" and say that it has add-cut-clamp and compaction rollers it would be useful to the reader.

[0004] On the other hand, the MEE design has advantages of serviceability. In the MEE 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~~supplies, drives and wires connections that servo motor systems normally require. However, the tension, repeatability and reliability of present MEE 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 IEE systems, implementation has heretofore not been accomplished in MEE 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

Commented [OL2]: I think this should be plural.

modular head and the remote CNC than in current MEE systems. The sheer number of connections which would have to be made quickly and reliably such as when spools are damaged or replaced, has prevented use of modular head based servo controlled spool motors in the past.

Summary of the Invention

[0005] .

Brief Description of the Drawings

[0006] Figure 1 is a functional diagram of the system of the present invention.

Commented [OL3]: I see in the PDF provided, business end is scratched out. I'll provide a new figure that I provided for Todd earlier.

[0007] Figure 2 is a front elevational view of the modular head assembly of the present invention .

[0008] Figure 3 is a perspective view of the modular head assembly.

[0009] Figure 4 is a front view of the creel assembly portion of the modular head assembly.

[00010] Figure 5 is a perspective view of the creel assembly portion of Figure 4.

[00011] Figure 6 is a rear elevational view of the modular head assembly.

[00012] Figure 7 is a schematic view of the servo motor/gearbox portion of the modular head assembly.

[00013] Figure 8 is a cross-section ~~of one of the major components~~of the servo-tension assembly of the modular head ~~assembly~~ with other components of the modular head assembly.~~–~~.

Commented [OL4]: I would call it a servo-tension assembly since that is what I meant to highlight here. Perhaps more precisely it is the servo/material spindle assembly.

[00014] Figure 9 is a schematic view of the dancer tensioning assembly portion of the modular head assembly.

[00015] Figure 10 is an exploded view of the fiber ~~breaker~~ backer film spindle~~member~~ of the modular head assembly.

[00016] 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

[00017] 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~~ 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 high level control of the individual servo motors.

Commented [OL5]: Duplicate numbers 16 for dancer and the carbon spool.

[00018] 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 clamp/add/cut portions of the system. 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 or not present for some material types.

[00019] 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.

[00020] 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 material. Each spool assembly, for example 30, comprises a servo motor/controller which rotates a spindle to let the carbon fiber 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~~ 34 which is used to control the tension of the carbon during the payout thereof. The dancer assembly includes a sliding assembly on which the dancer linearly moves. A linear displacement sensor, such as a linear encoder, 34 provides dancer position information back to the servo motor/controller.

Commented [OL6]: I'm not sure if you meant to label the linear encoder as 34. It is in fact part of the dancer assembly but perhaps you want to put another label and point to it directly.

[00021] Each spool assembly also typically includes a backing film removal assembly 36 which removes the plastic backing film, if present, 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 combined with the dancer 34 and backer 36 for the modular head is referred to as the creel.

Commented [OL7]: On this figure there is no ultrasonic sensor which was earlier labeled 32.

[00022] Figure 7 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 on ~~44~~46 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 gearbox 46 and mounts the complete assembly to the back plate of the modular head unit.

[00023] Gearbox 46 reduces the rotational speed of the spindle and hence the spool 40 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 inertial forces from head rotation and translation, 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 servo motor 48, in one embodiment, has analog and ~~a~~ digital I/O capabilit~~y~~ies, and receives spool diameter information and linear position of the dancer information to maintain tension in the tape/tow from the spool. The servo motor 48 is capable of forward and backward movement, again to maintain proper tension on the tape/tow. One example of a commercially available servo motor having such a capability is model SM23166MT by Moog, Inc.. In another embodiment, the servo motor receives drive and control information from a local PLC computer mounted on the modular head assembly. In the present embodiment, discussed above, the servo motor is completely self contained, capable itself of controlling the spindle with input from the diameter sensor and the linear displacement sensor. In both of these embodiments, the control of the servo motors is localized on the modular head. There are no wires or other connections for drive and control with the remote CNC. Both of these embodiments include a servo motor controller, which, as indicated above, has significant advantages over existing modular head/end effector arrangements with pneumatic braking, and eliminates the long wire connections necessary for control of the individual servo motors to the CNC computer.

[00024] Figure 8 shows one spool assembly in cross section. 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 rod 64 is pulled upwardly and rotated to bring it into a higher locked position. The spool 60 may then be changed if desired. After loading a new spool, a switching motion of the rod relocks it in place.

[00025] Also when the locking rod is in its nominal position, pulled downwardly, support pads 67 are expanded due to a wedge action. The expansion of the pads 67~~0~~ 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.

[00026] A linear displacement sensor 70 or linear encoder, such as a magnetic encoder, on the dancer assembly, discussed in more detail below, indicates the linear displacement of the dancer element. This information is fed to the servo motor directly and also to the PLC, depending on the embodiment, for error detection.

[00027] 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 induced by machine motion because of the cantilevered position of the spool.

[00028] 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 in one embodiment as well as inputs from encoders and analog sensors, such as the encoder on the dancer assembly.

[00029] Figure 9 shows the dancer assembly. The dancer tube is shown at 77. The tube is made from carbon, metal or other 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 dancer adequately to maintain contact with the carbon fiber from the spool, maintaining tension. 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.

[00030] The dancer tube and all the dancer assembly elements are mounted on a back plate 83. Plate 83 is mounted to the back plate of the modular head/end effector. The dancer tube is mounted on a bearing assembly 84 which allows for linear motion of the dancer assembly along rail 85. The dancer tube is bolted directly to the top of the bearing assembly. A linear displacement sensor/linear encoder in the embodiment shown -is mounted on the bearing elements, moving with the carbon fiber dancer to indicate linear displacement as the dancer assembly moves to maintain tension.

[00031] 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.

[00032] Figure 10 shows the backing film sleeve/remover, if present. 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 in place. 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.

Commented [OL8]: Doesn't seem to be labelled as 102 on the Figure 10

[00033] 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~~has diameter information updated by the PLC and directly receives the linear displacement sensor information 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

Commented [OL9]: Currently the PLC gives diameter to the motor. One implementation could be that the diameter goes through the motor.

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 and acceleration of payout of the tape while maintaining desired tension.

[00034] Figure 6 shows a rear view of the modular head. The embodiment shown includes a PLC computer controller positioned in the head. In one embodiment, 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. Both of the described embodiments make the modular head using servo motors feasible in a practical environment.

[00035] Figure 11 shows a basic schematic for the embodiment using a PLC on the modular head/end effector. The fiber replacement machine includes 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. A conventional ATI tool charger assembly 111 is also included. Each modular head will include a PLC computer 112. Communicating with the PLC computer 112 are the plurality of individual

spool assemblies 114-114 via individual communication lines 115. 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.

[00036] In the embodiment of Figure 11, 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 of Figure 11 uses a PLC computer, with connections to each of the servo motor drives units, each servo drive unit can be sufficiently smart and capable that it can itself produce the required ~~drive~~ motion with diameter and dancer displacement information, without a PLC computer. In some applications, this arrangement is

Commented [OL10]: This is a mistake on my end. The lines labelled 115 and 120 represent a daisy chain of Profinet communications, the second line 115 is not present. I have updated it in a new figure.

Commented [OL11]: The assemblies do not communicate with one another. They only communicate with the main PLC.

Commented [OL12]: Required drive? I'm not really sure what this means.

Perhaps required motion?

preferred. 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.

[00037] 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 or end effector 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 and 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 carbon 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 combination controls the movement of the spool so that the carbon fiber 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 to the machine controller.

4. The assembly of claim 1, including a tool charger connecting the modular head assembly to the machine controller.

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

6. 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 combinations.

7. The assembly of claim 2, wherein the spool assemblies, the dancer assemblies and the backing member assemblies are all connected to the back plate.

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

9. 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.

10. 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.

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

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

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

14. In a modular head assembly or end effector for a fiber placement machine having a machine controller, wherein the modular head assembly or end effector includes a support back plate, a plurality of one or more carbon fiber spool assemblies, each spool assembly including a spindle for a carbon fiber spool and a dancer assembly for tensioning the carbon fiber as it moves from the spool to a tool assembly which applies the carbon fiber to a part, wherein each spool

assembly includes a linear displacement sensor for the dancer assembly and a sensor for determining diameter of the carbon spool, the improvement comprising:

a servo motor and gearbox combination associated with each carbon fiber spool assembly for controlling the movement of the spool so that the carbon fiber is payed out at a controlled rate.

15. The improvement of claim 14 wherein the servo motor and gearbox combination operates directly in response to the information from the dancer assembly and the diameter of the carbon spool.

16. The improvement of claim 14, wherein the servo motor and gearbox combination is responsive to control information from a PLC computer located on the modular head assembly.

Abstract

A modular head assembly or end effector 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 include a linear displacement sensor for the dancer assembly and a sensor for determining the diameter of the carbon spool, the outputs of which are used to control the action of the servo motors.