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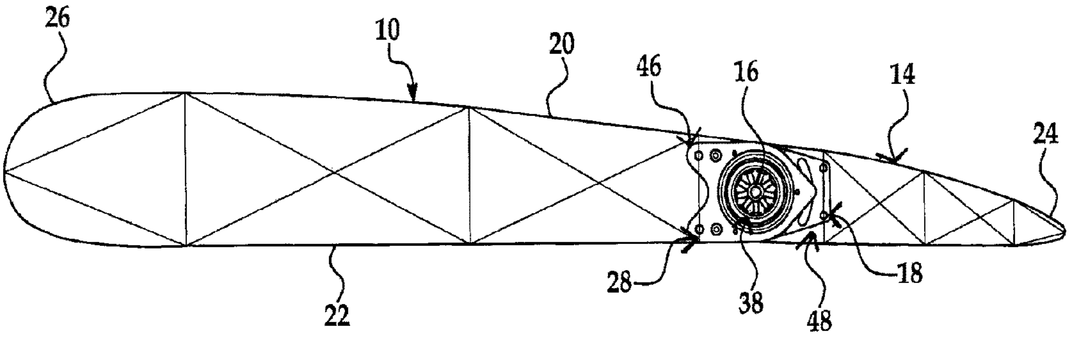


(57) **Abrégé/Abstract:**

An electromechanical hinge-line rotary actuator is provided. The actuator includes a drive member and a motor disposed inside and directly coupled to the drive member. The motor has a rotor configured toward an outside of the motor and directly coupled to an input of the drive member and a stator configured toward an inside of the motor and positioned inside the rotor. The drive member, rotor, and stator are arranged concentrically with each other.

ABSTRACT OF DISCLOSURE

An electromechanical hinge-line rotary actuator is provided. The actuator includes a drive member and a motor disposed inside and directly coupled to the drive member. The motor has a rotor configured toward an outside of the motor and directly coupled to an input of the drive member and a stator configured toward an inside of the motor and positioned inside the rotor. The drive member, rotor, and stator are arranged concentrically with each other.

ELECTROMECHANICAL HINGE-LINE ROTARY ACTUATOR

BACKGROUND OF INVENTION

[0001] This invention relates, generally, to an actuator and, more specifically, to an electromechanical hinge-line rotary actuator for use with a thin-wing aircraft in flight-control applications.

[0002] Many systems require actuators to manipulate various components. Rotary actuators rotate an element about an axis. In flight-control applications, there has been a trend toward a thinner wing such that size and space are limited at a point of attachment between the wing and an aileron (a wing-control surface) of an aircraft.

[0003] This trend has driven use of a rotary actuator of a "hinge-line" design, wherein a rotational axis of the actuator is aligned with that of the aileron and the actuator acts as a hinge (hence, the term "hinge-line"). This trend also raises a need for such an actuator with a tighter cross-section, which limits the diameter of a motor of the actuator, and higher power density.

[0004] In turn, torque of the motor is directly related to the motor diameter and current flowing through windings of the motor. However, with the limited motor diameter and an amount of the current being limited to useable amounts on a power bus of the aircraft, an amount of such torque is limited as well. And, since power of the motor equates to speed thereof times the torque amount and this amount is limited, the speed must be higher. Yet, use of the higher-speed motor at the limited torque amount is driving use of higher gear ratios, which makes inertia of the motor a sensitive design parameter.

[0005] More specifically, reflected inertia comes into play whenever the motor or a gear set of the aircraft is trying to be back-driven, which is a requirement for a surface of the aileron. And, reduction in the inertia prior to a gear affects the reflected inertia by a factor of a gear ratio squared (for example, a "10:1" gear ratio yields a reflected inertia of 100 times greater than the motor inertia while a "100:1" gear ratio yields a reflected inertia of 10,000 times greater). The inertia also affects responsiveness of the aircraft—i.e., a higher level of the inertia results in a lower responsiveness.

[0006] A typical electromechanical hinge-line rotary actuator designed for flight-control applications is arranged to use a conventional motor that is framed (i.e., encased, housed, or mounted) and includes a rotor. The rotor is disposed inside the frame and indirectly connected to an end of a planetary gearbox or gear set through a drive shaft or coupler. In this way, the motor is disposed exterior to and in alignment with the gear set, and there are bearings for the motor and gear set. Such alignment is accomplished by a precision-machined housing for the motor and gear set or compliant coupling on an output shaft of the motor to an input of the gear set. This arrangement has inefficiencies associated with packaging and is not optimized for typical requirements of such an actuator. More specifically, it is not optimized for power density, performance, and reliability.

[0007] Accordingly, it is desirable to provide an electromechanical hinge-line rotary actuator an arrangement of which does not have inefficiencies associated with packaging and is optimized for typical requirements of such an actuator in flight-control applications. More specifically, it is desirable to provide such an actuator that reduces inertia and is optimized for power density, performance, and reliability.

BRIEF DESCRIPTION OF INVENTION

[0008] According to a non-limiting exemplary embodiment of the invention, an electromechanical rotary actuator is provided. The actuator includes a drive member and a motor disposed inside and directly coupled to the drive member. The motor has a rotor configured toward an outside of the motor and directly coupled to an input of the drive member and a stator configured toward an inside of the motor and positioned inside the rotor. The drive member, rotor, and stator are arranged concentrically with each other.

[0009] The actuator is configured to be employed with a thin-wing aircraft. Toward that end, arrangement of the actuator does not have inefficiencies associated with packaging and is optimized for typical requirements of such an actuator in flight-control applications—power density, performance, and reliability. More specifically, the concentric packaging of components [i.e., the drive member and motor (stator and rotor)] of the actuator provides a higher power density. Also, a load path of the actuator is a direct drive such that a drive shaft is not required, resulting in a lower inertia and, in turn, higher performance. Furthermore, the actuator has few components (including removal of one set of bearings and no requirement as well for the compliant coupling or precision-machined housing), which lends itself to higher reliability and reduced cost. In addition, a total axial stack length of the actuator can be changed to accommodate a higher output load, making the actuator versatile for different applications. Moreover, the actuator can achieve higher forces while it maintains a same cross-section thereof, making the actuator versatile for the different applications.

BRIEF DESCRIPTION OF DRAWING

[0010] The subject matter that is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawing in which:

[0011] FIG. 1 is an end view of a non-limiting exemplary embodiment of a wing of an aircraft provided with an electromechanical hinge-line rotary actuator according to the invention.

[0012] FIG. 2 is a schematic top view of a non-limiting exemplary embodiment of the electromechanical hinge-line rotary actuator according to the invention.

[0013] FIG. 3 is a schematic side environmental view of the embodiment of the electromechanical hinge-line rotary actuator illustrated in FIG. 2.

[0014] FIG. 4 is a schematic sectional side view of the embodiment of the electromechanical hinge-line rotary actuator illustrated in FIG. 2.

DETAILED DESCRIPTION OF INVENTION

[0015] Referring now to FIG. 1, a non-limiting exemplary embodiment of a wing of an aircraft (not shown) is generally indicated at **10**. Although the wing **10** is disclosed herein as being implemented with a non-rotary-wing aircraft, such as an airplane, it should be appreciated that the wing **10** can be implemented with any suitable type of aircraft, in general, and non-rotary-wing or rotary-wing aircraft (such as a helicopter), in particular.

[0016] As shown in FIG. 1, the wing **10** is one of two substantially similar wings of a lift system of the aircraft (in contrast, a rotor blade would be one of a plurality of substantially similar rotor blades of a rotor system of a helicopter). The wing **10** defines a root portion (not shown) that extends to tip portion (not shown) through an aileron portion, generally indicated at **14**, which acts as a flight-control or an output-control surface (such as a wing flap). The aileron portion **14** also defines, in turn, an axis of motion or rotation **16** and includes a spar, generally indicated at **18**. The wing **10** defines further first and second opposing surfaces **20**, **22**, a trailing edge **24**, and an opposing, leading edge **26** and includes a rearward spar, generally indicated at **28**.

[0017] The wing **10** includes also a control system (not shown) that has an electromechanical hinge-line rotary actuator, generally indicated at **30**, and a controller (not shown). The actuator **30** defines the axis of rotation **16**. The controller may be mounted to or near the actuator **30** and is operatively linked to the actuator **30** and a control system (not shown).

[0018] A stationary attachment bracket or ground arm, generally indicated at **46**, of the actuator **30** is mounted to the wing rearward spar **28** and configured to be attached to interior structure of the wing **10**. A rotatable attachment bracket or an output arm, generally indicated at **48**, of the actuator **30** is mounted to a frame of or within an interior of the aileron portion **14**. The mounting is highly flexible as long as the axis of rotation **16** of the aileron portion **14** is aligned with an axis of rotation **16** of the actuator **30**. The actuator **30** allows wing flexing and, hence, does not put undue stress on the wing **10** at points of attachment when flex is encountered, such as during turbulence.

[0019] It should be appreciated that the control system can also define a plurality of control surfaces (not shown) arranged within the aileron portion **14** and selectively deployed between the first and second surfaces **20**, **22** to affect flight dynamics of the wing **10**. Each surface defines first and second surface portions. The actuator **30** is configured to rotate the surface from a first or neutral position, such that the surface is disposed within the wing **10**, to a second or deployed position, such that the surface extends out an outer periphery of the wing **10**. At this point, it should be appreciated that the above description is provided for the sake of completeness and to enable a better understanding of one non-limiting exemplary application of the actuator **30**.

[0020] Referring now to FIGS. 2 - 4, a non-limiting exemplary embodiment of the actuator **30** is shown. The actuator **30** is disclosed herein as being implemented with a control system for a flight-control application. However, it should be appreciated that the actuator **30** can be implemented in any suitable system capable of operating in multiple environments and should not be considered as being limited to non-rotary or rotary aircraft or aircraft of any kind.

[0021] The actuator **30** includes, in general, a drive member, generally indicated at **36**, a motor, generally indicated at **38** (FIG. 1), disposed inside and directly coupled to the drive member **36**. The motor **38** includes a rotor, generally indicated at **52**, configured toward an outside of the motor **38** and directly coupled to an input (not shown) of the drive member **36** and a stator, generally indicated at **42**, configured toward an inside of the motor **38** and positioned inside the rotor **52**. The drive member **36**, rotor **52**, and stator **42** are arranged substantially concentrically with each other.

[0022] More specifically, the rotor **52** and stator **42** combine with each other to make up the motor **38**. The actuator **30** defines a longitudinal axis and includes also the ground arm **46** that is configured to be connected to the wing rearward spar **28**. The actuator **30** includes also the output arm **48** that extends from the drive member **36**. In flight-control applications, the output arm **48** can define a hole **50** configured to receive a pin (not shown) that, in turn, is configured to be connected to an output-control surface (i.e., the aileron spar **18**) of the aircraft.

[0023] As shown in FIGS. 3 and 4, in a version of the exemplary embodiment, the drive member **36** takes the form of a harmonic drive that includes a wave generator **40**. In particular, the harmonic drive is a gear of a gear train or set having harmonic drive. However, it should be appreciated that the gearing can be other than harmonic. For example, the gear set can be conventional (compound, planetary, simple, etc.). In any event, the gear set acts as a speed-reduction device.

[0024] A reduction in number of components and, thereby, cost is achieved with design of the actuator **30**. More specifically, placement of the motor **38** within the gear or gear set removes the drive shaft and one set of bearings of the known actuator and reduces inertia and number of parts of the actuator **30**. Also, the coupling and precision-machined housing of the known actuator are not required in the actuator **30** since an axis of rotation of the motor **38** is controlled by the gear set itself.

[0025] "Reliability" analysis uses essentially a "reliability" factor for each component of a system multiplied by a number of components thereof. Thus, with fewer components of the same reliability with respect to each other, the system is more reliable. The actuator **30** has the fewest components for design of a motor/gear-set combination, leading to higher reliability of the actuator **30**.

[0026] The motor **38** is electric and can take the form of a brushless motor having the rotor **52** and stator **42**. The motor **38** is also frameless and of a high-performance type (i.e., has a high power-to-weight or power-to-volume ratio or power density). It should be appreciated that the motor **38** can be any suitable type of motor **38** that has a rotor **52** positioned on the outside.

[0027] The stator **42** is fixed and includes a plurality of coils **54**. An exterior/outer surface **52** of the rotor **52** acts as the wave generator **40** of the harmonic drive. Alternatively, the wave generator **52** can be shaped to the exterior/outer surface. As shown in FIG. 3, an air gap **56** is defined between the rotor **52** and stator **42**.

[0028] The actuator **30** is configured to be employed with a thin-wing aircraft. Toward that end, arrangement of the actuator **30** does not have inefficiencies associated with packaging and is optimized for typical requirements of such an actuator in flight-control applications—power density, performance, and reliability. More specifically, the concentric packaging of the harmonic drive and motor **38** (stator **42** and rotor **52**) of the actuator **30** provides a higher power density. Also, a load path of the actuator **30** is a direct drive such that a drive shaft is not required, resulting in a lower inertia and, in turn, higher performance. Furthermore, the actuator **30** has few components (including removal of one set of bearings and no requirement as well for the compliant coupling or precision-machined housing), which lends itself to higher reliability and reduced cost. In addition, a total stack length of the actuator **30** can be changed to accommodate a higher output load, making the actuator **30** versatile for different applications. Moreover, the actuator **30** can achieve higher forces while it maintains a same cross-section thereof, making the actuator **30** versatile for the different applications.

[0029] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions, or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various non-limiting embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS:

1. An electromechanical hinge-line rotary actuator comprising:

a drive member; and

a motor disposed inside and directly coupled to the drive member and including a rotor configured toward an outside of the motor and directly coupled to an input of the drive member and a stator configured toward an inside of the motor and positioned inside the rotor, the drive member, rotor, and stator being arranged concentrically with each other.

2. The electromechanical hinge-line rotary actuator of claim 1, wherein the actuator comprises further at least one ground arm configured to be connected to a spar of a wing of an aircraft.

3. The electromechanical hinge-line rotary actuator of claim 1, wherein the actuator comprises further an output arm extending from the drive member and configured to receive a pin for connection of the actuator to an output-control surface of an aircraft.

4. The electromechanical hinge-line rotary actuator of claim 1, wherein the drive member is a harmonic drive including a wave generator.

5. The electromechanical hinge-line rotary actuator of claim 1, wherein the drive member is any of a harmonic gear and compound, planetary, and simple conventional gear.

6. The electromechanical hinge-line rotary actuator of claim 4, wherein an exterior surface of the rotor acts as the wave generator of the harmonic drive or the wave generator is shaped to the exterior surface.

7. A wing of an aircraft comprising:

an aileron portion defining an axis of rotation and including an aileron spar;

a wing spar; and

a control system including an electromechanical hinge-line rotary actuator connected to the wing spar and the aileron portion, and a controller operatively linked to the actuator; the actuator including:

a drive member; and

a motor disposed inside and directly coupled to the drive member and including a rotor configured toward an outside of the motor and directly coupled to an input of the drive member and a stator configured toward an inside of the motor and positioned inside the rotor, the drive member, rotor, and stator being arranged concentrically with each other.

8. The wing of claim 7, wherein the actuator comprises further at least one ground arm that is configured to be connected to the wing spar.

9. The wing of claim 8, wherein the actuator comprises further an output arm that extends from the drive member and is configured to receive a pin for connection of the actuator to an output-control surface of the aircraft.

10. The wing of claim 7, wherein the drive member is a harmonic drive including a wave generator.

11. The wing of claim 7, wherein the drive member is any of a harmonic gear and compound, planetary, and simple conventional gear.

12. The wing of claim 10, wherein an exterior surface of the rotor acts as the wave generator of the harmonic drive or the wave generator is shaped to the exterior surface.

13. The wing of claim 9, wherein an axis of rotation of the output-control surface of the aircraft is aligned with an axis of rotation of the actuator.

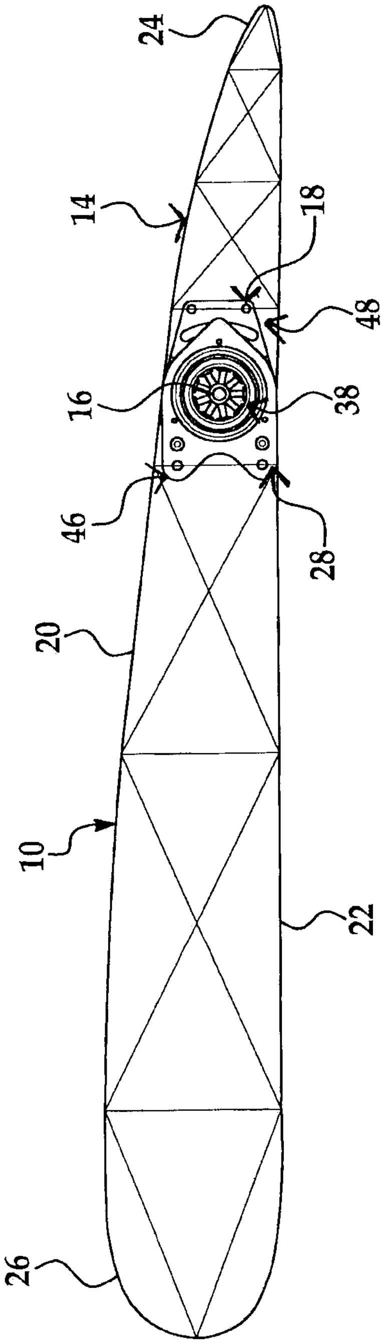


FIG. 1

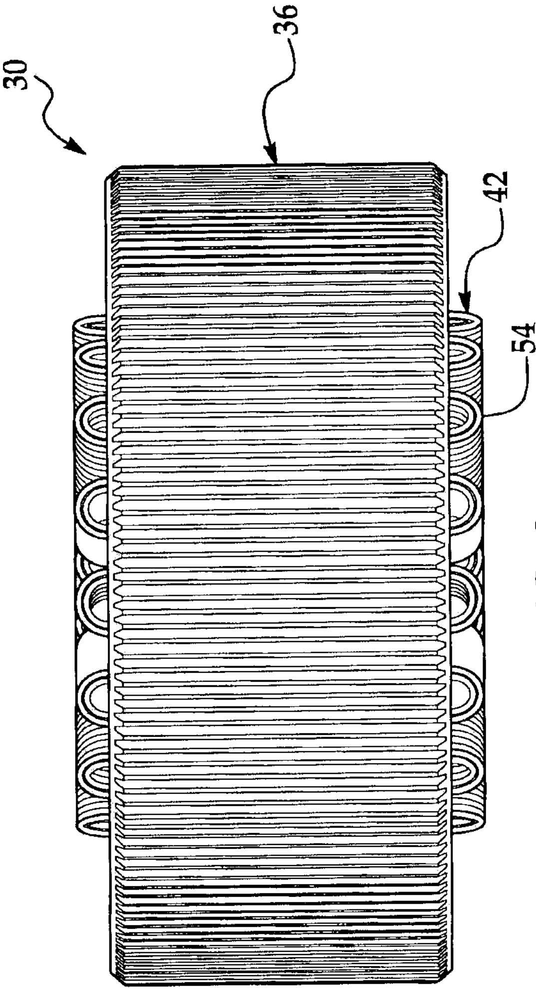


FIG. 2

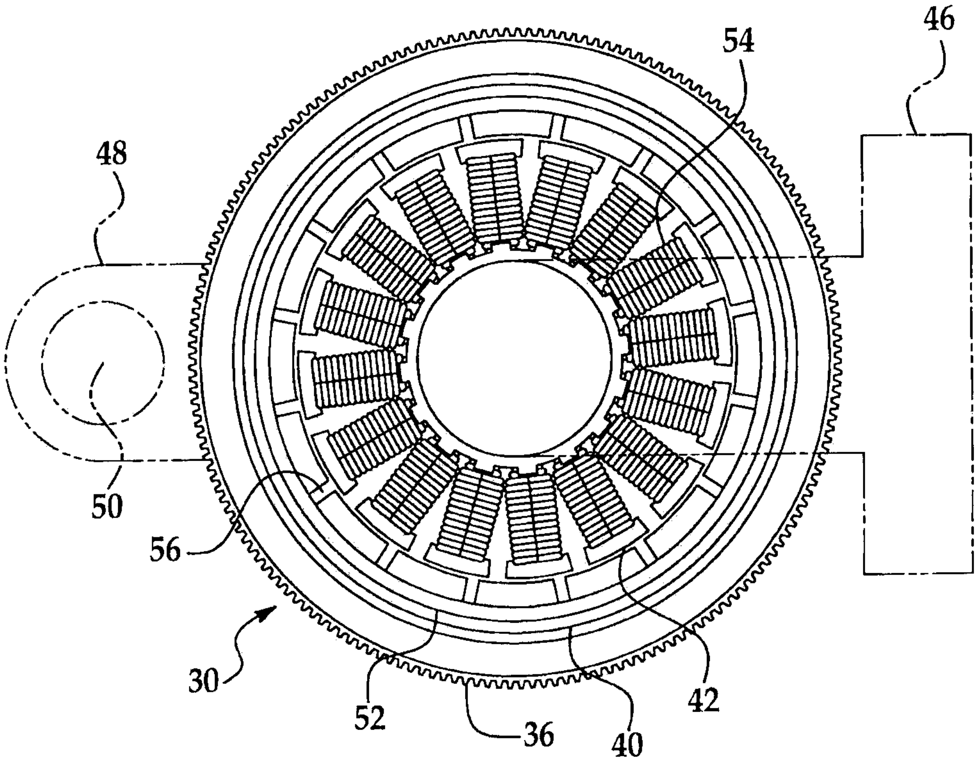


FIG. 3

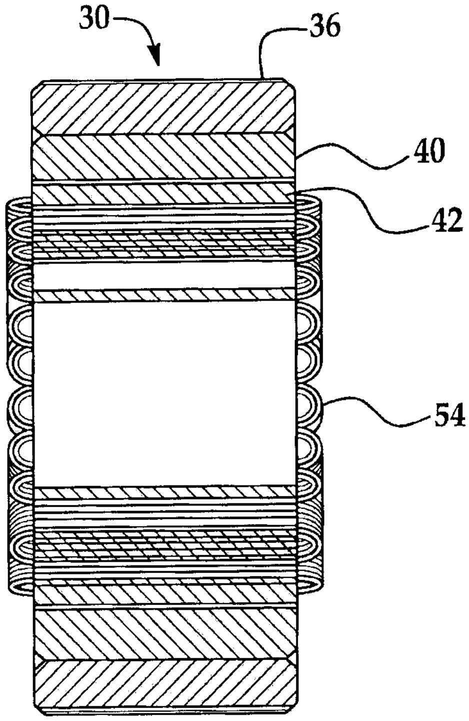
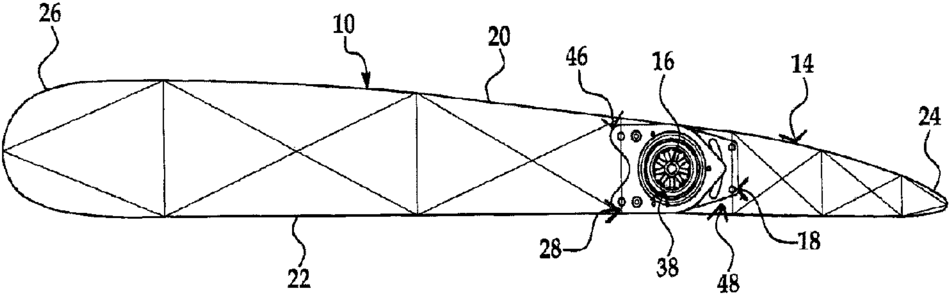


FIG. 4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