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INTRODUCTION

In recent years, Electric Vehicles demand is growing so fast, which is imposed by few major drives, one is government regulations and next is environment attentions by customer to save world from air pollution due to fossil fuels. To aid those drives, recently many companies, corporate and associations are putting lot of efforts and investment to investigate every domain of EV components. For example, high energy density Batteries, high power density e-machines and inverters, compact E-drive system with less cost, light weight and more powerful. One of the main challenges for recent E-drives are space or size and cost. Angle position sensors are must for perfect dynamic control of E-drive under various conditions like Space vector control, direct torque control etc., To have smooth driving experience, these high accurate angle position sensors are almost mandatory in modern e-drive systems. Please refer below Fig 1 to understand the representation of Variable reluctant resolver used in recent E-drive system.

Fig 1: VR resolver used in Edrive system

To install these kind of sensors into e-drive system, additional space is required. Please refer Fig 2 below to understand the special design in Edrive system to accommodate those sensors. In many cases, these additional space create serious issue in package design. Due to space constraints, these sensors are located very close to Emotor's stator winding, which leads to malfunction of sensors. To avoid that, metal shielding was recommendedand used in many projects, which again need some more space. Major issue with existing sensor type, which is widely used in EV drives is Space.

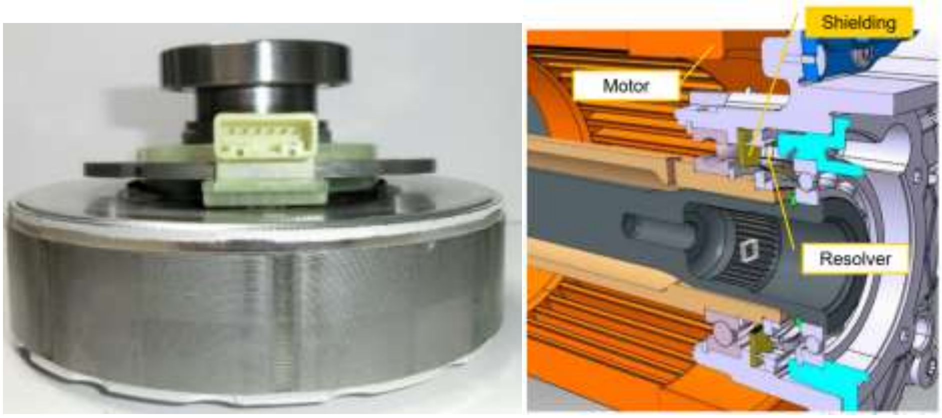

Fig 2: VR resolver installation in Edrive

The next issue is cost of sensor itself and its installation cost(production). Currently, cost of sensor and its installation cost is almost same. This is due to servicability and reliability also taken into account. Third issue is offset of complete system accumulation with respect to tolerance stackup, meaning stationary part and rotating part of sensor relative location during assembly(considering total tolerance stackup) and during operation at extreme condition. If this offset(in all directions) goes beyond certain limits, accuracy of angle prediction also compromised. To aviod this variation in stackup, tolearance limits to be reduced, which results in high machining cost and tools for machining, this in turn affects the total landed cost of E-drive. Majors challenges with existing sensor configuration are space, cost, accuracy. In this dissertion, 3 patents were described in brief manner to solve th above problem with innovative sensor solution to measure angle accuractly with less space and less cost compared to current solution.

In Chapter 2, Patent1 explains how the reliabiliy of moving part was monitered using some innovative sensor solution, which will give more reliable solution for automative market at extreme environmental conditions. In Chapter 3, Patent2 explains how the active angular sensor(200 deg spactial) was used to measure 360 degree angle position with same accuracy under extreme offset and environmental conditions. This reduces the space required for installation. Being active magnetic sensors, no need of shieldings, which solves the space required for metal shield and its installation cost along with raw material. Being only 200 deg stationary part(arc sensors), space for installation wont be a serious problem. In Chapter 4, Patent 3 explains similar concept like Patent 2, but much more smaller option for stationary part, which means, instead of 200 Deg, it will be 180 Deg arc sensor to measure 360 Deg angle, with same accuracy. Even this concept demonstrate less space, low cost, no shield, relative to the concept explained in Patent 2. So overall the final solution would have big advantage over existing concept

COMMENTARIES OF PATENT 1

Title: Circuit breaker position sensing and health monitoring system

Abstract: A circuit breaker includes a breaker housing, a stationary contact, a movable contact, an operating shaft, and a linear position sensor. The stationary contact is non-movable mounted within the breaker housing, and the movable contact is movably mounted within the breaker housing. The movable contact is coupled to receive an input force and is configured, upon receipt of the input force, to move between a closed position, in which the movable contact, and an open position, in which the movable contact is electrically isolated from the stationary contact. The operating shaft is coupled to the movable contact to supply the input force therto. The linear position sensor is connected to opearting shaft and is configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position.

Main topics:

- Using Linear Position sensors to ensure the circuit breaker operation and its reliability from remote location
- Health monitoring system of circuit breaker

Benefit1: Identifying fault-initiated circuit breaker:

Linear position sensor is used to sense the high-power circuit breaker's moving shaft position during every operation from remote location to record and maintain their health. In oil fields, windmills, solar farms etc., are spread across wide range of land, where human travelling in regular basis is not feasible. In these power farms, numerous circuit breaker is available, which can be monitored using current flowing through them. In case of multiple circuit breakers failed, it is very hard to identify which CB triggered first, which resulted to trigger the others. All these phenomena happen in millisecond time. These linear position sensor signals with time information will be useful to identify the exact CB, which triggered the fault and then remaining breakers are follows. All these can be done using both current behavior and linear sensor signals. Many farms or grids or substations doesn't have infra to measure every segment transient current, so this linear sensor signal are 100% useful at those locations to monitor the right CB and helpful for further root cause analysis for the fault.

Benefit2: Health monitoring:

Every circuit breaker has to be operated within few milliseconds either "ON" or "OFF" based on medium of breaker (Air, SF6 etc.,), power level, heat dissipation capacity, size, altitude, Voltage level, AC or DC etc., Over a period of time, the response time of circuit breaker is becoming longer and longer, which makes them to fail very soon due to aging. It is very difficult to understand their performance during operation only by measuring the grid current transients, because there are many factors which affects the grid current time response (which is not scope of this topic). Linear position sensor data with respect to time during both operations would help to understand their health and condition. And this would be monitored and recorded every time for every circuit breakers to have a record of degradation, which will be helpful for maintenance of the same and even as input for new generation breakers designs to overcome the shortfalls and increase the life time of the same with tiniest design change

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(43) Pub. Date: Feb. 21, 2013
Venkitachalam et al.

(54) **CIRCUIT BREAKER POSITION SENSING AND HEALTH MONITORING SYSTEM**

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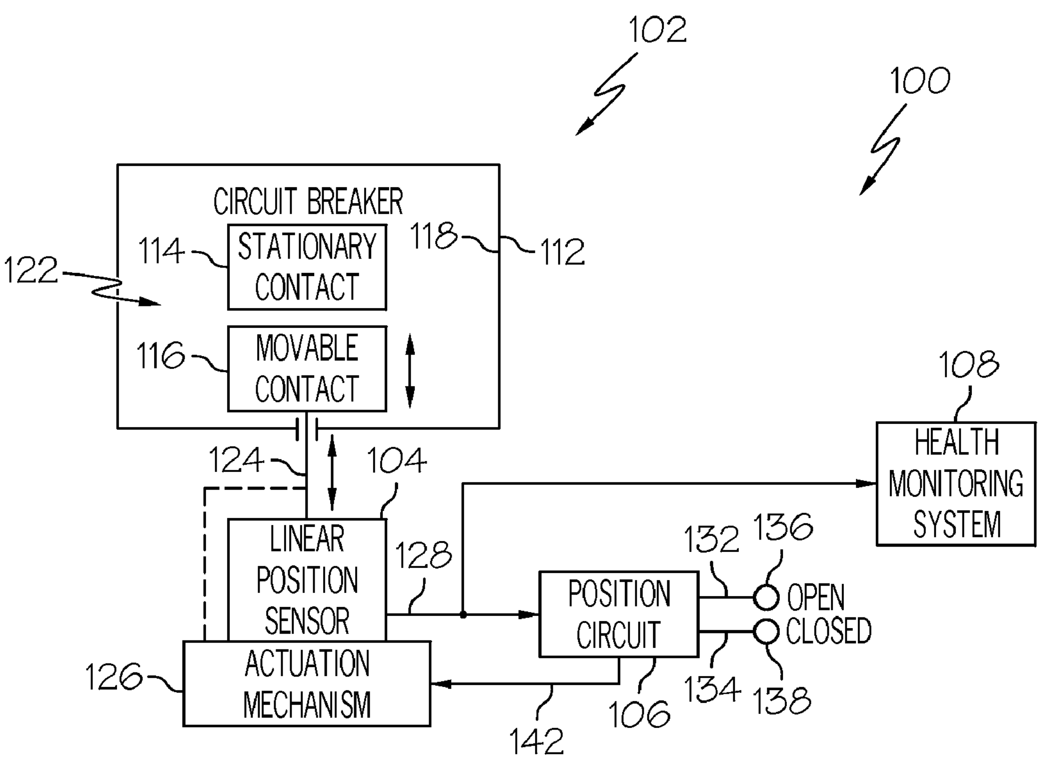
(52) **U.S. Cl.** **200/329**

(57) **ABSTRACT**

A circuit breaker includes a breaker housing, a stationary contact, a movable contact, an operating shaft, and a linear position sensor. The stationary contact is non-movably mounted within the breaker housing, and the movable contact is movably mounted within the breaker housing. The movable contact is coupled to receive an input force and is configured, upon receipt of the input force, to move between a closed position, in which the movable contact is electrically coupled to the stationary contact, and an open position, in which the movable contact is electrically isolated from the stationary contact. The operating shaft is coupled to the movable contact to supply the input force thereto. The linear position sensor is connected to the operating shaft and is configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position.



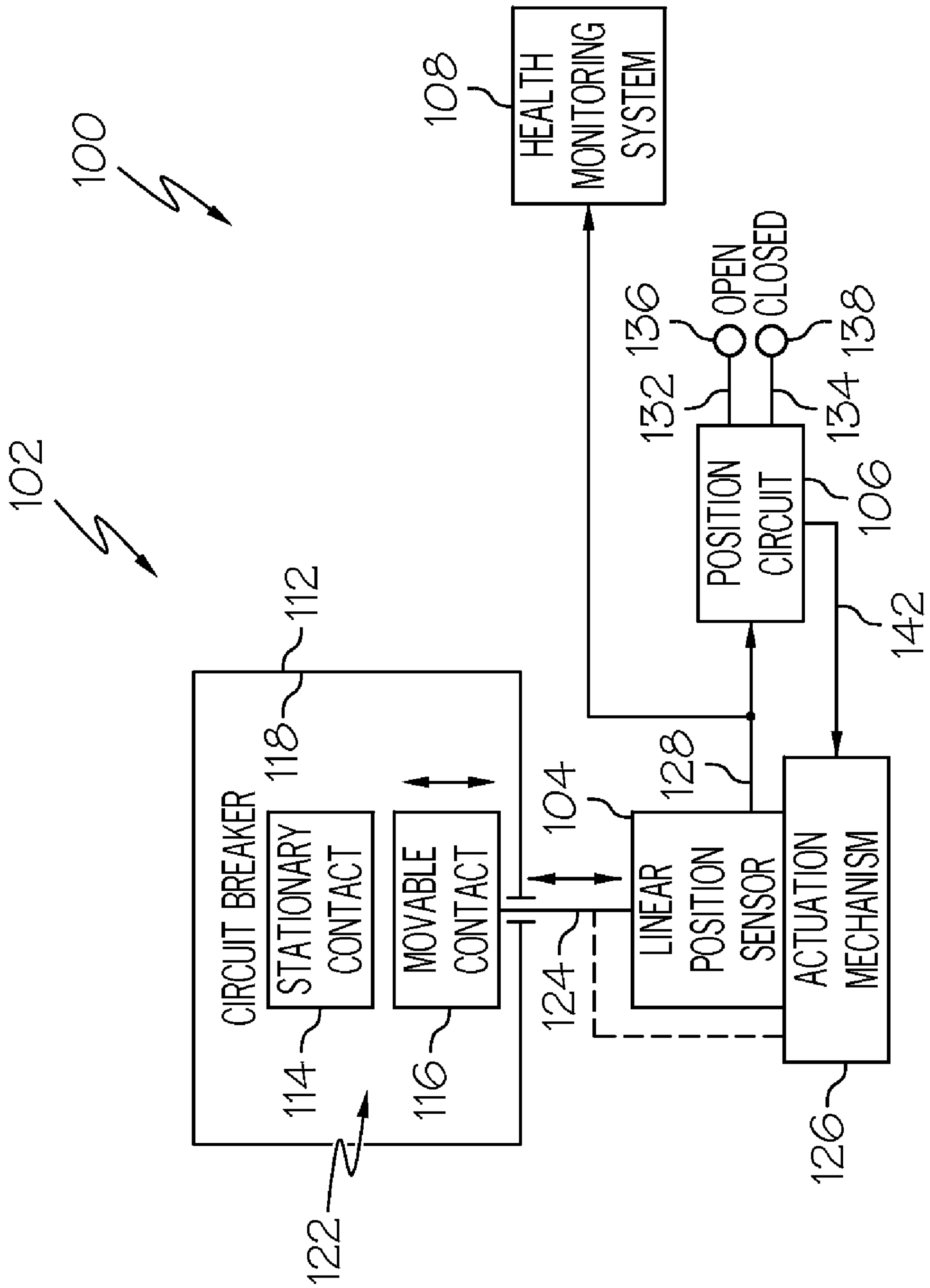

100
102
CIRCUIT BREAKER
STATIONARY CONTACT
MOVABLE CONTACT
LINEAR POSITION SENSOR
ACTUATION MECHANISM
POSITION CIRCUIT
HEALTH MONITORING SYSTEM
OPEN
CLOSED
104
106
108
112
114
116
118
122
124
126
128
132
134
136
138
142

FIG. 1

CIRCUIT BREAKER POSITION SENSING AND HEALTH MONITORING SYSTEM

TECHNICAL FIELD

[0001] The present invention generally relates to circuit breakers, and more particularly relates to a circuit breaker position sensing and health monitoring system.

BACKGROUND

[0002] Many electrical power distribution circuits include circuit breakers. The primary function of a circuit breaker is to interrupt the flow of electrical current in the unlikely occurrence of a fault or other event that may result in undesirably high current flow. Circuit breakers also provide a means for temporarily de-energizing portions of a circuit to allow maintenance or repairs to be conducted on the circuit.

[0003] Many circuit breakers include position sensing devices to provide an indication of the position of the circuit breaker. Many high power circuit breakers are configured with rotary angular position sensors. These rotary angular position sensors are configured to sense rotational movement and position of a link lever mechanism that is coupled to the breaker via other link mechanisms. These sensors thus exhibit relatively long response times, less accuracy, and less reliability due to the location of the sensing area and number of link mechanisms involved. These drawbacks can additionally inhibit accurate health monitoring of the circuit breaker.

[0004] Hence, there is a need for a circuit breaker position sensing configuration to more accurately and reliably sense circuit breaker position and/or control circuit breaker function and/or improve health monitoring of circuit breakers. The present invention addresses one or more of these needs.

BRIEF SUMMARY

[0005] In one embodiment, a circuit breaker system includes a breaker housing, a stationary contact, a movable contact, an operating shaft, and a linear position sensor. The stationary contact is non-movably mounted within the breaker housing, and the movable contact is movably mounted within the breaker housing. The movable contact is coupled to receive an input force and is configured, upon receipt of the input force, to move between a closed position, in which the movable contact is electrically coupled to the stationary contact, and an open position, in which the movable contact is electrically isolated from the stationary contact. The operating shaft is coupled to the movable contact to supply the input force thereto. The linear position sensor is connected to the operating shaft and is configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position.

[0006] In another embodiment, a circuit breaker system includes a breaker housing, a stationary contact, a movable contact, an operating shaft, a linear magnetic position sensor, a position circuit, and a health monitoring circuit. The stationary contact is non-movably mounted within the breaker housing, and the movable contact is movably mounted within the breaker housing. The movable contact is coupled to receive an input force and is configured, upon receipt of the input force, to move between a closed position, in which the movable contact is electrically coupled to the stationary contact, and an open position, in which the movable contact is electrically isolated from the stationary contact. The operating shaft is coupled to the movable contact to supply the input force thereto. The linear magnetic position sensor is connected to the operating shaft and is configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position. The position circuit is coupled to receive the position signal from the linear position sensor and is configured, upon receipt thereof, to determine at least when the movable contact is in the closed position and the open position and supply one or more breaker position signals representative of movable contact position. The health monitoring circuit is coupled to receive the position signal from the linear position sensor and is configured, upon receipt thereof, to determine circuit breaker health and generate data representative thereof.

[0007] Furthermore, other desirable features and characteristics of the circuit breaker position sensing system will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the preceding background.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

[0009] FIG. **1**, which is the sole FIGURE, depicts a functional block diagram of one example of an embodiment of a circuit breaker system.

DETAILED DESCRIPTION

[0010] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Thus, any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. All of the embodiments described herein are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary, or the following detailed description.

[0011] In this document, relational terms such as first and second, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. Numerical ordinals such as "first," "second," "third," etc. simply denote different singles of a plurality and do not imply any order or sequence unless specifically defined by the claim language. Furthermore, depending on the context, words such as "connect" or "coupled to" used in describing a relationship between different elements do not imply that a direct physical connection must be made between these elements. For example, two elements may be connected to each other physically, electronically, logically, or in any other manner, through one or more additional elements.

[0012] Referring now to FIG. **1**, a functional block diagram of one exemplary embodiment of a circuit breaker system **100** is depicted, and includes a circuit breaker **102**, a linear position sensor **104**, a position circuit **106**, and a health monitoring system **108**. The circuit breaker **102**, which may be implemented using any one of numerous types of circuit breakers, includes a breaker housing **112**, a stationary contact **114**, and a movable contact **116**. The breaker housing **112** includes an inner surface **118** that defines an inner volume **122**, within which the stationary and movable contacts **114**, **116** are disposed.

[0013] The stationary contact **114** is non-movably mounted within the breaker housing **112**, and the movable contact **116** is movably mounted within the breaker housing **112**. The movable contact **116** is configured, upon receipt of an input force, to move between a closed position and an open position. In the closed position, the movable contact **116** is electrically coupled to the stationary contact **104**. Conversely, when the movable contact **116** is in the open position, which is the position depicted in FIG. **1**, the movable contact **116** is electrically isolated from the stationary contact **114**.

[0014] The movable contact **106**, as was noted above, is moved between the closed and open positions upon receipt of an input force. The input force is supplied to the movable contact **106** via an operating shaft **124** that is coupled to the movable contact **116**. More specifically, at least in the depicted embodiment, the operating shaft **124** is also coupled to an actuation mechanism **126**, which is configured to selectively supply the input force to the movable contact **116** via the operating shaft **124**. The actuation mechanism **126** may be variously implemented, and may be coupled to the operating shaft **124** using any one of numerous techniques. In FIG. **1**, the coupling of the actuation mechanism **126** to the operating shaft **124** is depicted using dotted lines. This is to indicate that the actuation mechanism **126** may be coupled to the operating shaft **124** either directly or via various numbers of intervening linkage mechanisms.

[0015] Typically, the circuit breaker **102** is configured such that the non-movable contact **116** is in the closed position. However, should an abnormality occur in the system in which the circuit breaker **102** is installed, resulting in an undesirably high current flow, the actuation mechanism **126** will be actuated and supply an input force to the operating rod **124** to cause the movable contact **116** to move to the open position. As a result, the movable contact **116** is electrically isolated from the stationary contact **114**.

[0016] The linear position sensor **104** is connected to the operating shaft **124** and is configured, upon movement of the operating shaft **123**, to supply a position signal **128** representative of the position of the movable contact **116**. Unlike presently known circuit breaker position sensors, the linear position sensor **104** directly senses the position of the operating shaft **124**, and thus the movable contact **116**, rather than indirectly via rotation or translation of one or more linkage mechanisms or components that may be coupled between the actuation mechanism **126** and the operating shaft **124**. It will be appreciated that the linear position sensor **104** may be implemented using any one of numerous types of suitable sensors. Preferably, however, it is implemented using a non-contact magnetic sensor, non-limiting examples of which include non-contact anisotropic magnetic resistance (AMR) sensors, giant magnetic resistance (GMR) sensors, tunneling magnetic resistance (TMR) sensors, and Hall-effect sensors.

[0017] No matter the particular type of sensor that is used to implement the linear position sensor **104**, the position signal **128** is supplied to the position circuit **106** and to the health monitoring circuit **108**. The position circuit **106** is coupled to receive the position signal **128** and is configured, upon receipt thereof, to determine at least when the movable contact **116** is in the closed position and the open position. That is, it could be configured to determine only when the movable contact **116** is in the closed and open positions, or it could be configured to continuously sense the position of the movable contact **116**. In either case, the position circuit **106**, at least in the depicted embodiment, is additionally configured to supply one or more breaker position signals representative of movable contact position. In the depicted embodiment, the position circuit **106** is configured to selectively supply an open signal **132** and a closed signal **134** to an open indicator **136** and a closed indicator **138**, respectively. The open and closed indicators **136**, **138**, in response to the open and close signals **132**, **134**, supply indicia representative of movable contact position.

[0018] As FIG. **1** further depicts, and depending upon the configuration of the actuation mechanism **126**, the position circuit **106** may additionally be configured to supply a position signal **142** to the actuation mechanism **126**. The actuation mechanism **126** may additionally be configured, in response to the position signal **142**, to selectively supply the input force to and remove the input force from the operating shaft **124** and thus the movable contact **116**.

[0019] The health monitoring system **108** may be implemented using any one of numerous known devices, systems, and/or components for monitoring system/component health. In the depicted embodiment, the health monitoring circuit **108** is coupled to receive the position signal **128** from the linear position sensor **104** and is configured, upon receipt thereof, to determine circuit breaker health and generate data representative thereof. The health monitoring circuit **108** may be used to monitor, for example, the response times of the circuit breaker **102**, and the total number of open-close cycles of the circuit breaker **102**, just to name a few characteristics.

[0020] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. A circuit breaker system, comprising:

a breaker housing;

a stationary contact non-movably mounted within the breaker housing;

a movable contact movably mounted within the breaker housing, the movable contact coupled to receive an input force and configured, upon receipt of the input force, to move between a closed position, in which the movable contact is electrically coupled to the stationary contact, and an open position, in which the movable contact is electrically isolated from the stationary contact;

an operating shaft coupled to the movable contact to supply the input force thereto; and

a linear position sensor connected to the operating shaft and configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position.

2. The circuit breaker system of claim **1**, wherein the linear position sensor comprises a non-contact magnetic sensor.

3. The circuit breaker system of claim **2**, wherein the non-contact magnetic sensor comprises a magnetic resistance (MR) sensor.

4. The circuit breaker system of claim **3**, wherein the MR sensor is selected from the group consisting of an anisotropic magnetic resistance (AMR) sensor, a giant magnetic resistance (GMR) sensor, and a tunneling magnetic resistance (TMR) sensor.

5. The circuit breaker system of claim **2**, wherein the non-contact magnetic sensor comprises a Hall-effect sensor.

6. The circuit breaker system of claim **1**, further comprising:

a position circuit coupled to receive the position signal from the linear position sensor and configured, upon receipt thereof, to (i) determine at least when the movable contact is in the closed position and the open position and (ii) supply one or more breaker position signals representative of movable contact position.

7. The circuit breaker system of claim **6**, further comprising:

an indicator coupled to receive the one or more breaker position signals and supply indicia representative of movable contact position.

8. The circuit breaker system of claim **6**, further comprising:

an actuation mechanism coupled to the operating shaft and configured to selectively supply the input force to the movable contact via the operating shaft.

9. The circuit breaker system of claim **8**, wherein the actuation mechanism is further coupled to receive the one or more breaker position signals and is further configured, in response thereto, to selectively supply the input force to and remove the input force from the movable contact.

10. The circuit breaker system of claim **1**, further comprising:

a health monitoring circuit coupled to receive the position signal from the linear position sensor and configured, upon receipt thereof, to determine circuit breaker health and generate data representative thereof.

11. A circuit breaker system, comprising:

a breaker housing;

a stationary contact non-movably mounted within the breaker housing;

a movable contact movably mounted within the breaker housing, the movable contact coupled to receive an input force and configured, upon receipt of the input force, to move between a closed position, in which the movable contact is electrically coupled to the stationary contact, and an open position, in which the movable contact is electrically isolated from the stationary contact;

an operating shaft coupled to the movable contact to supply the input force thereto;

a linear magnetic position sensor connected to the operating shaft and configured, upon movement of the operating shaft, to supply a position signal representative of movable contact position;

a position circuit coupled to receive the position signal from the linear position sensor and configured, upon receipt thereof, to (i) determine at least when the movable contact is in the closed position and the open position and (ii) supply one or more breaker position signals representative of movable contact position; and

a health monitoring circuit coupled to receive the position signal from the linear position sensor and configured, upon receipt thereof, to determine circuit breaker health and generate data representative thereof.

12. The circuit breaker system of claim **11**, wherein linear magnetic position sensor comprises a non-contact magnetic sensor.

13. The circuit breaker system of claim **12**, wherein the non-contact magnetic sensor comprises a magnetic resistance (MR) sensor.

14. The circuit breaker system of claim **13**, wherein the MR sensor is selected from the group consisting of an anisotropic magnetic resistance (AMR) sensor, a giant magnetic resistance (GMR) sensor, and a tunneling magnetic resistance (TMR) sensor.

15. The circuit breaker system of claim **12**, wherein the non-contact magnetic sensor comprises a Hall-effect sensor.

16. The circuit breaker system of claim **11**, further comprising:

an indicator coupled to receive the one or more breaker position signals and supply indicia representative of movable contact position.

17. The circuit breaker system of claim **11**, further comprising:

an actuation mechanism coupled to the operating shaft and configured to selectively supply the input force to the movable contact via the operating shaft.

18. The circuit breaker system of claim **17**, wherein the actuation mechanism is further coupled to receive the one or more breaker position signals and is further configured, in response thereto, to selectively supply the input force to and remove the input force from the movable contact.

* * * * *

COMMENTARIES OF PATENT 2

Title: Arc position encoder with an extended angular position sensing range

Abstract: Disclosed are techniques for sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 200-degree angular position sensing range. The encoder may include a base defined by first and second ends, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of first and second base extension disposed on the first and second ends, and one or more polarity transition sensors disposed within the one or more of the first and second base extensions. The encoders may further include a magnetic target having first and second magnetic poles disposed on opposite ends as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base.

Main topics:

- Angular position sensor extension technique
- 200 Deg angular position sensor can be used for 360-degree angle position sensing using this new technique

Concept:

Arc position sensor built with AMR sensing elements into base, along with rotating target coupled with rotating object. 200 Deg Arc position sensor is used to measure 360 Deg of rotating part with virtual extended sensing range. This patent explains how this extension is possible by using same elements (Base) along with target opposite polarity signal to measure greater than 180 deg to 360 Deg.

Benefit1: Space for angle position sensor reduction by half (50%) wrt current practice

Under current scenario in Electric vehicles, rotor position is mandatory to be measured online to operated PM based traction motor to control as precious as possible to give confront driving experience to driven customer under various driving worst case condition. This mandatory part occupies good amount of space in both pure electric drivetrain (BEV) and hybrid electric drivetrain (HPEV). To avoid the complexity in space this patent proposed to use, 200 Deg arc position sensor as a base (Stator) along with PM targets spread across 360 Deg which is attached with rotating component. Being less than 360 deg arc component, it is easy for mounting or assembly into the drivetrain, and shield cost also reduced due to this elimination.

Benefit2: Flexibility in assembly

With current 360 arc position sensors, assembly is not flexible. Complete 360 deg, mounting or space is required. So, drivetrain must be designed along with bearing and other clamping plates according to those different parts and their assembly sequence. Using this reduced arc position sensor base (stator), based on the space availability around 360 Deg, mounting with respect to rotating part can be planned along with individual parts tolerance and total assembly tolerance. Usually front and rear drivetrain’s concept and package sizes are different, to accommodate same Emachine and position sensor, this kind of flexibility in rotor position sensor is great gift for drivetrain designers.

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(19) **United States**

(12) **Patent Application Publication**

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(43) **Pub. Date: Oct. 24, 2013**

Kunjappan et al.

(54) **ARC POSITION ENCODER WITH AN EXTENDED ANGULAR POSITION SENSING RANGE**

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(21) Appl. No.: **13/449,874**

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Publication Classification

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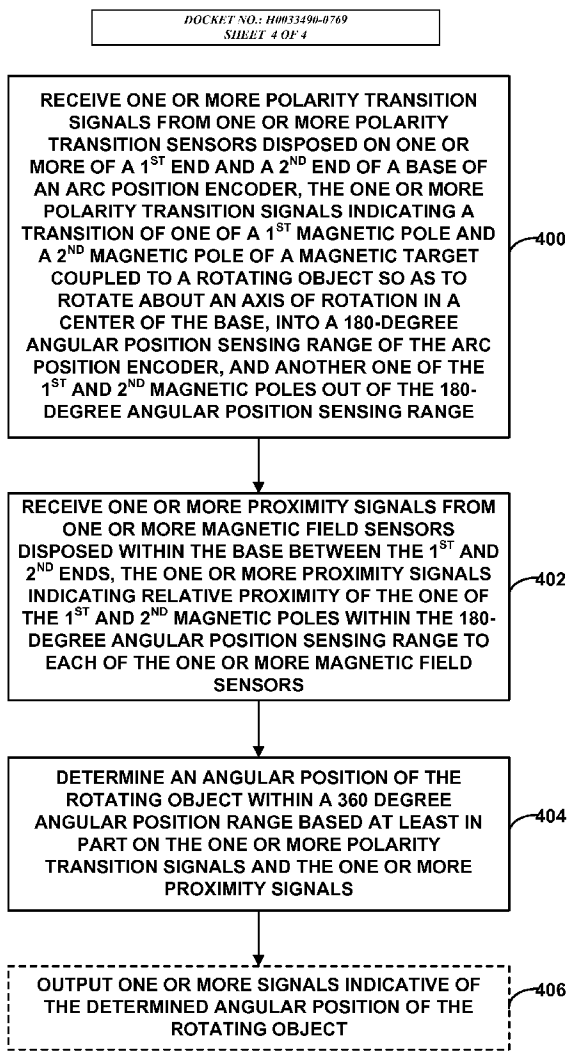
G01R 33/07	(2006.01)
G01R 33/09	(2006.01)

(52) **U.S. Cl.**

USPC **324/207.14**; 324/207.25; 324/207.21; 324/207.2

(57) **ABSTRACT**

Disclosed are techniques for sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range. The encoder may include a base defined by first and second ends, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of first and second base extensions disposed on the first and second ends, and one or more polarity transition sensors disposed within the one or more of the first and second base extensions. The encoder may further include a magnetic target having first and second magnetic poles disposed on opposite ends so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base.



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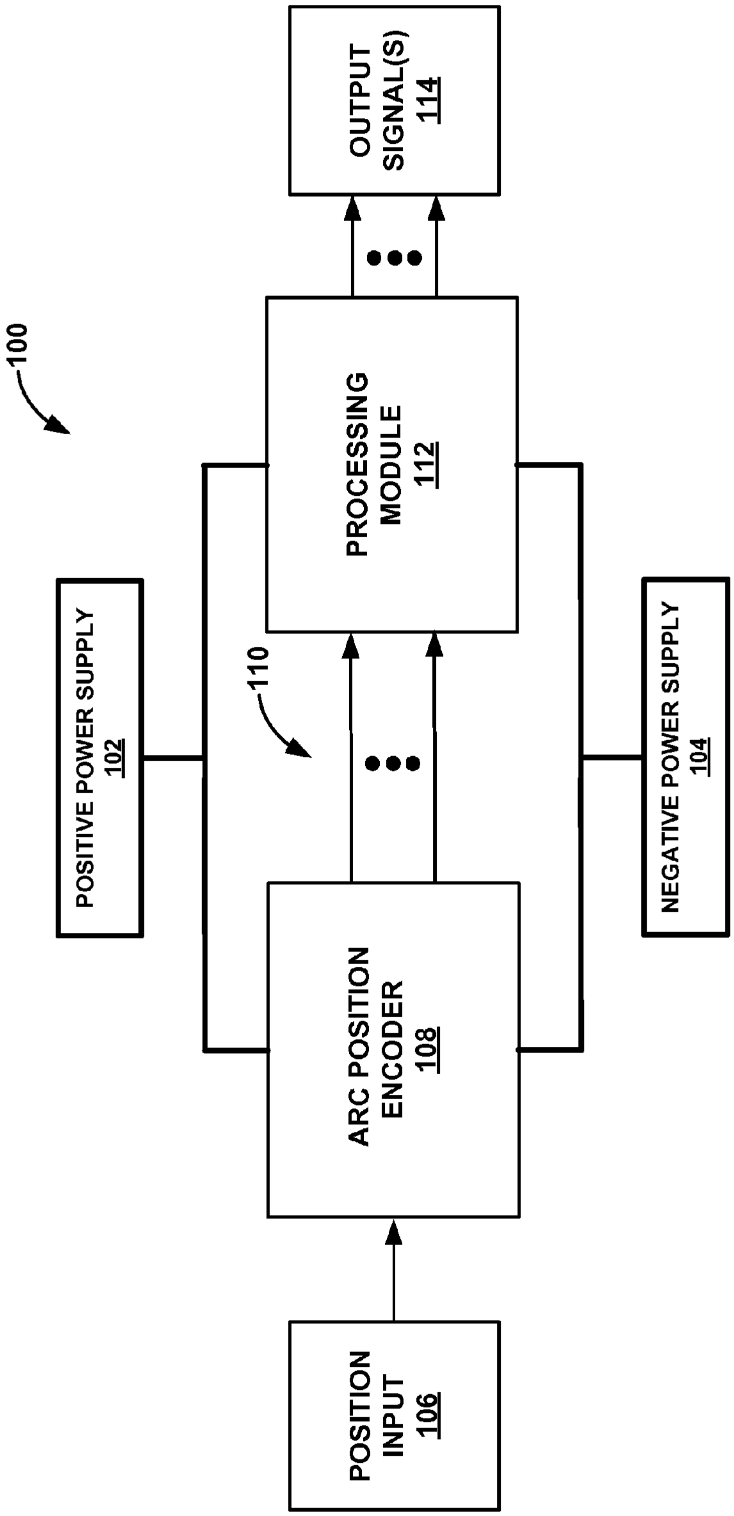

FIG. 1

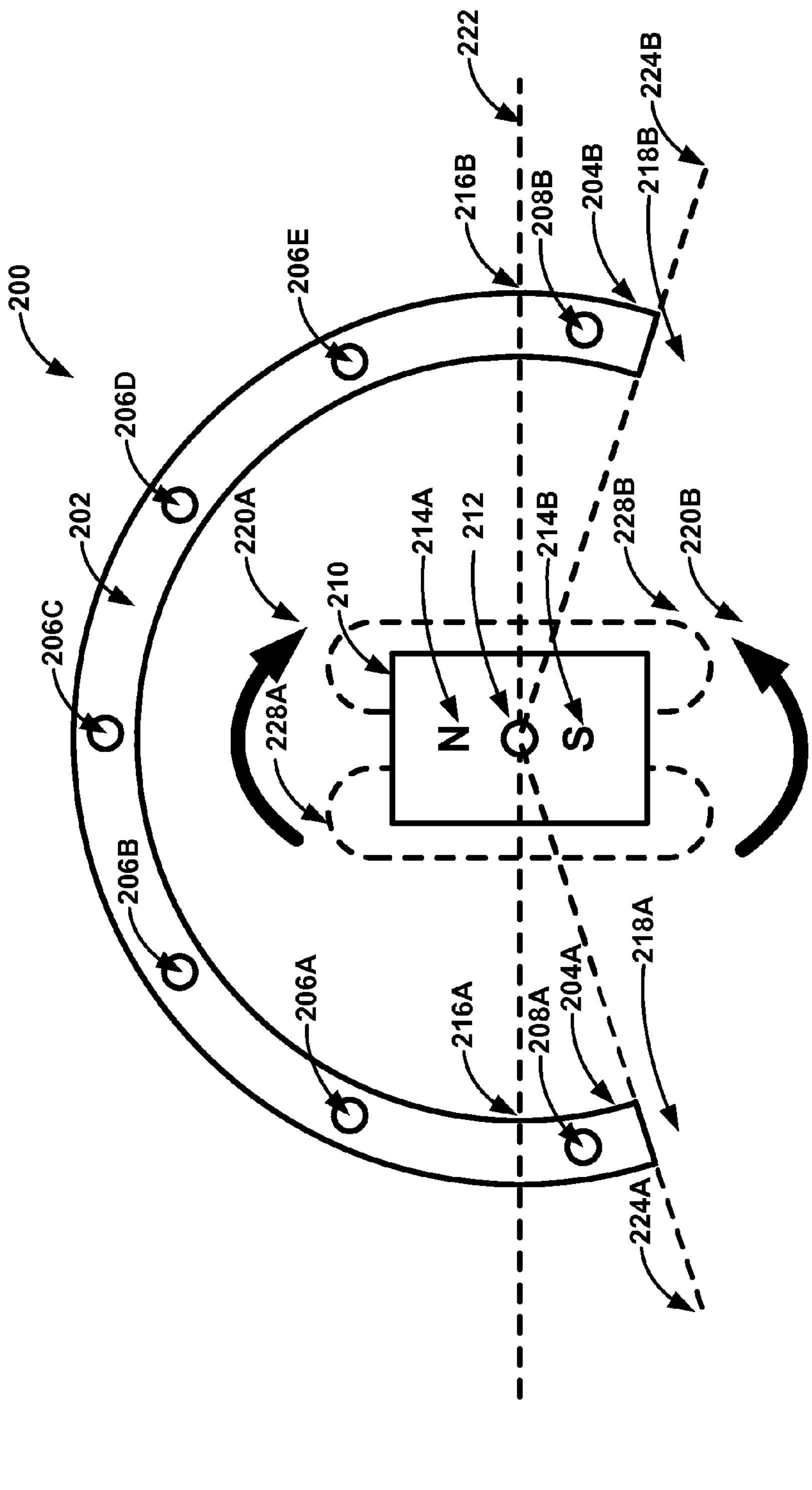
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FIG. 2

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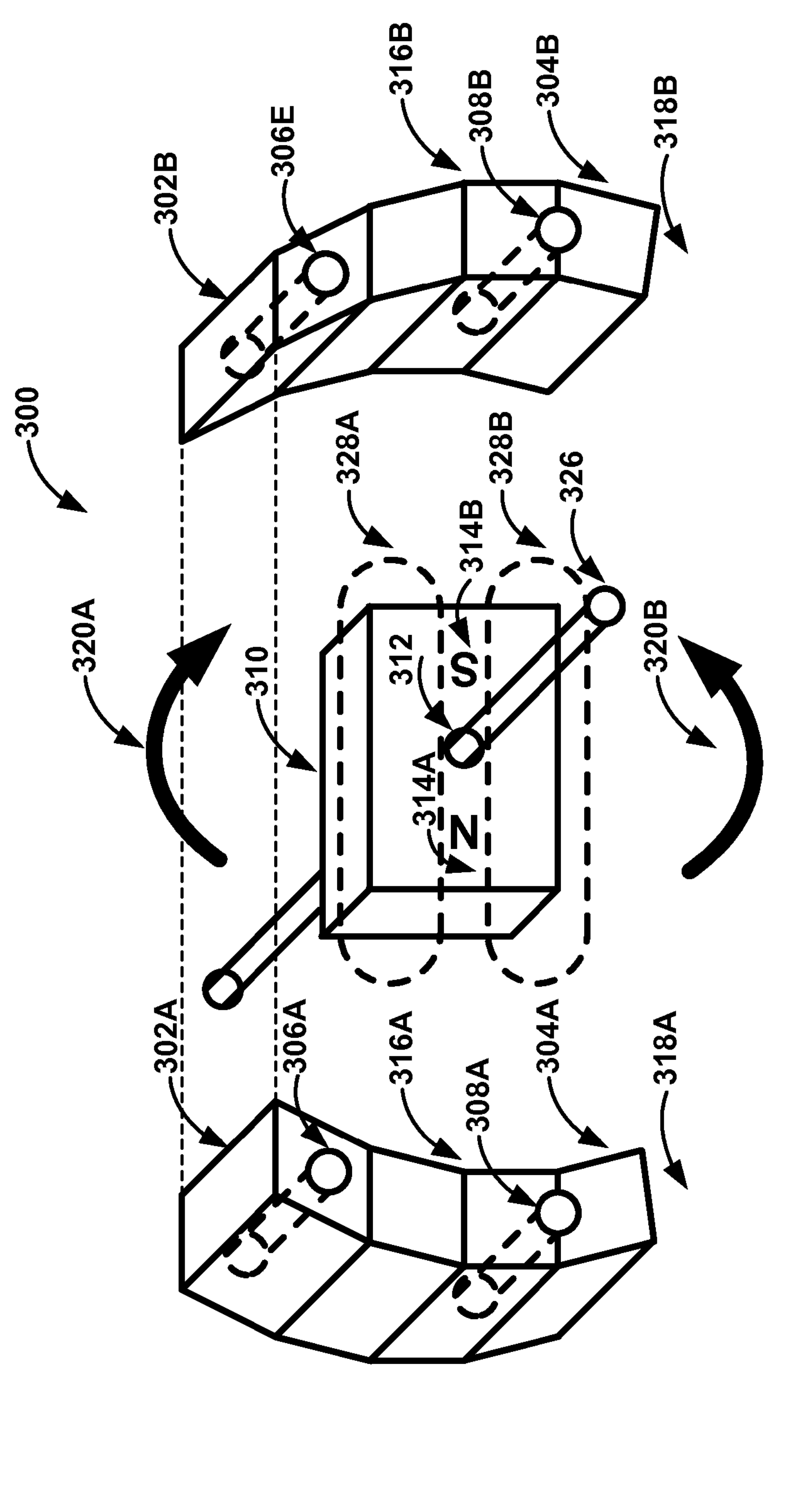

FIG. 3

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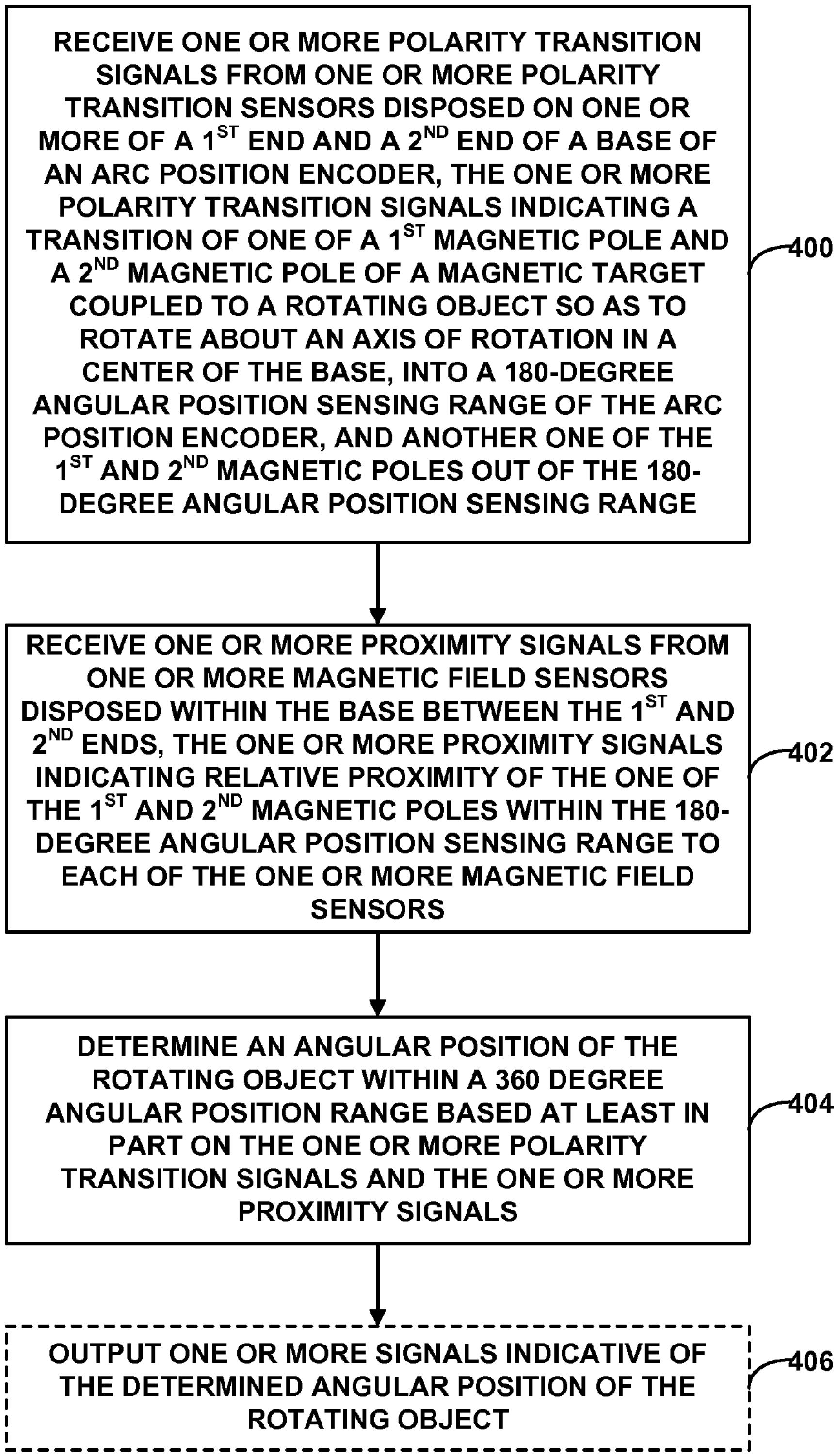

FIG. 4

ARC POSITION ENCODER WITH AN EXTENDED ANGULAR POSITION SENSING RANGE

TECHNICAL FIELD

[0001] This disclosure relates to position encoders, and more particularly, to techniques for using a position encoder to sense an angular position of a rotating object.

BACKGROUND

[0002] Position encoders are among a number of electromechanical transducers that may be used to sense a position of an object. Position encoders may be configured to sense an actual, or "absolute," position of an object, as well as a "relative" position, or a displacement, of the object. Furthermore, a position encoder may comprise any of a wide variety of linear and angular, or "rotary," position encoders. In some examples, position encoders may use contact-based sensing means to sense a position of an object by mechanically coupling the object to the position encoder, e.g., to a movable member or a rotating shaft of the position encoder, which may be mechanically coupled to a sensing element of the position encoder. In other examples, position encoders may employ a wide variety of contactless sensing means, such as optical, magnetic, capacitive, and inductive means, as some examples. Position encoders employing such contactless sensing means may be less susceptible to wear and may provide greater durability compared to contact-based position encoders.

[0003] As one example, a linear position encoder may sense a position of an object moving along a linear trajectory relative to the linear position encoder. For example, the linear position encoder may sense a position of an encoder "read-head" that is coupled to the object relative to an encoder track as the encoder read-head and the object move together along the encoder track. The position of the read-head relative to the encoder track may be sensed using mechanical, optical, magnetic, capacitive, or inductive means, as well as using other sensing means.

[0004] As another example, an angular, or rotary, position encoder may sense an angular position of an object that is rotating about an axis of rotation relative to the angular position encoder. For example, in the case of the angular position encoder employing magnetic sensing means, as described above, the angular position encoder may sense an angular position of a magnetic target that is coupled to the rotating object relative to one or more magnetic field sensors disposed within a base of the angular position encoder. The magnetic target may be disposed at a center of the base so as to generate a uniform magnetic field which varies from the perspective of the one or more magnetic field sensors based on the angular position of the magnetic target relative to the sensors. In this example, the one or more magnetic field sensors may include magnetoresistive (MR) sensors, Hall-Effect sensors, or other magnetic sensors.

SUMMARY

[0005] In general, this disclosure describes techniques for using an arc position encoder to sense an angular position of a rotating object over an extended angular position range. For example, the arc position encoder may comprise a 180-degree angular position sensing range. The techniques of this disclosure may, in some cases, enable extending the 180-degree sensing range of the arc position encoder, e.g., by incorporating additional structural and functional elements into the arc position encoder, such that the arc position encoder may be used to sense an angular position of a rotating object over a 360-degree angular position range.

[0006] In one example, an angular position sensing system for sensing an angular position of a rotating object over a 360-degree angular position range includes an arc position encoder comprising a 180-degree angular position sensing range, wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end, one or more polarity transition sensors disposed within the one or more of the first and second base extensions, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

[0007] In another example, a method of sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range includes receiving one or more polarity transition signals from one or more polarity transition sensors disposed on one or more of a first end and a second end of a base of the arc position encoder, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, receiving one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors, and determining the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals.

[0008] The details of one or more examples are set forth in the accompanying drawings and the description below. Other features, objects, and advantages in addition to those described below will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. **1** is a block diagram that illustrates one example of an angular position sensing system, consistent with the techniques of this disclosure.

[0010] FIG. **2** is a conceptual diagram that illustrates a front view of one example of an arc position encoder which may be used in conjunction with the example angular position sensing system of FIG. **1**, consistent with the techniques of this disclosure.

[0011] FIG. **3** is a conceptual diagram that illustrates a perspective view of the example arc position encoder of FIG. **2**, consistent with the techniques of this disclosure.

[0012] FIG. **4** is a flow diagram that illustrates one example of a method of sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range, consistent with the techniques of this disclosure.

DETAILED DESCRIPTION

[0013] In general, this disclosure describes techniques for using an arc position encoder to sense an angular position of a rotating object over an extended angular position range. For example, the arc position encoder may comprise a 180-degree angular position sensing range. As described in greater detail below, the techniques of this disclosure may, in some cases, enable extending the 180-degree sensing range of the arc position encoder, e.g., by incorporating additional structural and functional elements into the arc position encoder, such that the arc position encoder may be used to sense an angular position of a rotating object over a 360-degree angular position range.

[0014] An angular, or "rotary," position encoder may sense an angular position of an object that is rotating about an axis of rotation relative to the angular position encoder. For example, in the case of the angular position encoder employing magnetic sensing techniques, the angular position encoder may sense an angular position of a magnetic target that is coupled to the rotating object relative to one or more magnetic field sensors disposed within a base of the angular position encoder. The magnetic target may be disposed at a center of the base so as to generate a uniform magnetic field which varies from the perspective of the one or more magnetic field sensors based on the angular position of the magnetic target relative to the sensors. For example, the one or more magnetic field sensors may include magnetoresistive (MR) sensors, Hall-Effect sensors, or other magnetic sensors.

[0015] Existing angular position encoders, and, in particular, those employing magnetic sensing techniques, are generally configured to sense an angular position of a rotating object in one of a 180-degree and a 360-degree angular position range. For example, an angular position encoder configured to sense angular position of a rotating object over a 180-degree angular position range may comprise a 180-degree, or "arc" position encoder, which may include an arc base and one or more magnetic field sensors, e.g., MR sensors, or other sensors, disposed within the arc base. Alternatively, an angular position encoder configured to sense angular position of a rotating object over a full 360-degree angular position range may comprise a relatively more complex 360-degree, or "full-range," position encoder, which may include a circular base and one or more magnetic field sensors disposed within the circular base. In some examples, the circular base may require relatively more magnetic field sensors than the arc base of the arc position encoder in order to enable sensing the angular position of the rotating object over the 360-degree angular position range.

[0016] Accordingly, existing techniques for using angular position encoders to sense angular position of rotating objects include using full-range position encoders to sense angular position of rotating objects over a 360-degree range, as well as arc position encoders to sense angular position of rotating objects over a 180-degree range. Additionally, existing techniques may include combining multiple, e.g., two, arc position encoders to sense angular position of rotating objects over a 360-degree range. Furthermore, as previously described, full-range angular position encoders may require relatively more complex hardware, e.g., a circular base and a greater number of magnetic field sensors disposed within the circular base, as well as more complex processing of output signals of the magnetic field sensors, compared to arc position encoders. In contrast, arc position encoders may require relatively less complex hardware, e.g., an arc base and fewer magnetic field sensors disposed within the arc base, as well as less complex signal processing, compared to full-range angular position encoders. However, arc position encoders may have a limited angular position sensing range, i.e., a 180-degree angular position sensing range, as explained above.

[0017] As previously described, the techniques of this disclosure may, in some cases, enable extending a 180-degree sensing range of an arc position encoder. As one example consistent with the techniques described herein, the arc position encoder may include, in addition to one or more magnetic field sensors disposed within a base of the arc position encoder, one or more polarity transition sensors disposed within one or more base extensions of the base. For example, the one or more base extensions may be disposed on one or more ends of the base. According to the techniques, the one or more polarity transition sensors may be configured to sense transitions of opposing magnetic poles of a rotating magnetic target (e.g., North and South magnetic poles disposed on opposite ends of the magnetic target) of the arc position encoder, which may be coupled to the rotating object, into and out of the 180-degree sensing range. For example, at any given time, one of two such opposing magnetic poles may be located within the 180-degree sensing range, while the other of the two opposing magnetic poles may be located outside of the 180-degree sensing range. As such, the one or more polarity transition sensors may be configured to sense transitions of each of the two opposing magnetic poles into and out of the 180-degree sensing range.

[0018] Development of the techniques described herein has demonstrated that, in general, opposing magnetic poles of a rotating magnetic target of an arc position encoder produce substantially similar (e.g., symmetrical) responses with respect to one or more magnetic sensing elements disposed within a base of the arc position encoder. This is the case in particular with respect to MR sensors, which may generate substantially similar outputs in response to magnetic fields having a same field angle relative to each of the MR sensors, but opposite field polarities. The techniques of this disclosure may, in some cases, take advantage of the above-described phenomenon in order to extend the 180-degree sensing range of the arc position encoder, as described above.

[0019] For example, by sensing the transitions of the two opposing magnetic poles using the one or more polarity transition sensors in the manner described above, the arc position encoder may be configured to determine which of the two opposing magnetic poles is present within the 180-degree sensing range at any given time. The arc position encoder may be further configured to sense the position of the respective magnetic pole within the 180-degree sensing range (e.g., as the magnetic pole travels through the 180-degree sensing range) using the one or more magnetic field sensors. For example, the one or more magnetic field sensors may sense relative proximity of the respective magnetic pole to each of the one or more magnetic field sensors.

[0020] In some examples, the angular position of the respective magnetic pole within the 180-degree sensing range may correspond to an angular position of the rotating object coupled to the magnetic target within a corresponding 180-degree sub-range of the 360-degree angular position range. In this manner, for the two opposing magnetic poles described above, two such 180-degree sub-ranges may be defined within the 360-degree angular position range. Furthermore, because the two opposing magnetic poles are conventionally disposed on opposite ends of the magnetic target, as also described above, the two 180-degree sub-ranges may be 180-degrees out of phase with respect to one another. In other words, the two 180-degree sub-ranges may be consecutive and non-overlapping within the 360-degree angular position range, i.e., each 180-degree sub-range may comprise one half of the full 360-degree angular position range. As such, the arc position encoder may be configured to sense the angular position of each of the two opposing magnetic poles within the 180-degree sensing range when the respective magnetic pole is present within the sensing range, which may correspond to the angular position of the rotating object within each of the two 180-degree sub-ranges, or, collectively, within the full 360-degree angular position range.

[0021] As explained above, the techniques of this disclosure may, in some cases, effectively extend the 180-degree sensing range of the arc position encoder to encompass the 360-degree angular position range. As a result, the arc position encoder may be configured to sense the angular position of the magnetic target, and thereby the rotating object, over the extended 360-degree angular position range. In this manner, the techniques of this disclosure may reduce the complexity of angular position encoders used to sense angular position of rotating objects over a 360-degree angular position range, while requiring minimal additional structural and functional hardware and components, and signal processing resources.

[0022] FIG. **1** is a block diagram that illustrates one example of an angular position sensing system **100**, consistent with the techniques of this disclosure. As shown in FIG. **1**, system **100** includes a positive power supply **102**, a negative power supply **104**, a position input **106**, an arc position encoder **108**, one or more arc position encoder output signal (s) **110**, a processing module **112**, and one or more processing module output signal(s) **114**. System **100** may comprise an electro-mechanical system or device of any kind, including any combination of mechanical structural components and hardware, electro-mechanical transducers, discrete electronic components, digital and/or analog circuitry, and mechanical and electronic sub-systems or sub-devices of any kind. Examples of processing module **112** are described in greater detail below. Examples of arc position encoder **108** are also described in greater detail below, as well as with reference to arc position encoders **200** and **300** of FIGS. **2** and **3**, respectively.

[0023] In the example of FIG. **1**, position input **106** may comprise an angular position of a rotating object (not shown) within a 360-degree angular position range relative to arc position encoder **108**. In other words, position input **106** may represent a physical angular position of the rotating object within the 360-degree angular position range, relative to arc position encoder **108**. For example, the rotating object may be configured to rotate about an axis of rotation located in a center of a circle defined by a base or arc position encoder **108**, as will be described in greater detail below with reference to FIGS. **2** and **3**. In some examples, the rotating object may comprise any of a variety of rotating shafts, gears, or wheels. In other examples, the rotating object may comprise another object that rotates about the axis or rotation.

[0024] System **100**, and in particular, arc position encoder **108**, may be configured to convert position input **106** from an angular position of the rotating object to one or more electrical signals in order to generate arc position encoder output signal(s) **110**. For example, arc position encoder output signal (s) **110** may comprise one or more voltage and/or current signals indicative of position input **106**, i.e., of the angular position of the rotating object within the 360-degree angular position range relative to arc position encoder **108**. Furthermore, processing module **112** may be configured to process arc position encoder output signal(s) **110** to generate processing module output signal(s) **114**. Processing module output signal(s) **114** may comprise any combination of analog and/or digital signals or other information used to represent the angular position of the rotating object within the 360-degree angular position range. As one example, processing module output signal(s) **114** may comprise one or more values indicative of the exact angular position of the rotating object within the 360-degree angular position range (e.g., one or more values between 0 and 360 degrees, or 0 to 2π radians). As another example, processing module output signal(s) **114** may comprise one or more values indicative of an angular position of the rotating object within a subset (e.g., a 180-degree sub-range) of the 360-degree angular position range (e.g., one or more values between 0 and 180 degrees, or 0 to π radians), as well as one or more values indicative of the subset itself (e.g., one or more values indicating a first or a second 180-degree sub-range). In any case, processing module **112** may process arc position encoder output signal(s) **110** (e.g., filter, scale, normalize, level-shift, combine, etc.) in any manner to generate processing module output signal(s) **114**.

[0025] Processing module **112** may comprise any suitable arrangement of hardware, software, firmware, or any combination thereof, to perform the techniques attributed to processing module **112** in this disclosure. In general, processing module **112** may include any of one or more microprocessors, microcontrollers, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or any other equivalent integrated or discrete logic circuitry, as well as any combination of such components. Furthermore, processing module **112** may include various types of analog circuitry, in addition to, or in place of, the logic devices and circuitry described above.

[0026] Additionally, positive power supply **102** and negative power supply **104** may each comprise any power supply unit, module, or circuitry also included within system **100**, which may, in some examples, be integrated with arc position encoder **108** and/or processing module **112** within a common enclosure, or on a common printed circuit board (PCB). Although positive power supply **102**, negative power supply

104, position input **106**, arc position encoder **108**, arc position encoder output signal(s) **110**, processing module **112**, and processing module output signal(s) **114** of system **100** are described as separate units or modules for conceptual purposes, in some examples, any combination of these components of system **100** may be functionally integrated within a common enclosure or housing.

[0027] Additionally, in this disclosure, any reference made to a memory, or a memory device, used to store instructions, data, or other information, includes any volatile or non-volatile media, such as random access memory (RAM), read only memory (ROM), non-volatile RAM (NVRAM), electrically erasable programmable ROM (EEPROM), flash memory, and the like. In some examples, one or more memory devices may be external to system **100** and/or processing module **112**, for example, external to an enclosure or a common PCB used to enclose or house system **100** and/or processing module **112**. In other examples, the one or more memory devices may be internal to system **100** and/or processing module **112**, e.g., included within a common enclosure or on a common PCB.

[0028] According to the techniques of this disclosure, as one example, system **100**, including arc position encoder **108** and processing module **112**, may be configured to sense an angular position of a rotating object over a 360-degree angular position range. As previously described, the rotating object may comprise any of a variety of rotating shafts, gears, or wheels. For example, arc position encoder **108** may comprise a 180-degree angular position sensing range. In this example, arc position encoder **108** may include a base comprising an arc length defined by a first end and a second end of the base, and one or more magnetic field sensors disposed within the base between the first and second ends. For example, the arc length of the base may correspond to the 180-degree angular position sensing range of arc position encoder **108**. Furthermore, the one or more magnetic field sensors may comprise one or more MR sensors, or other magnetic sensors.

[0029] Also in this example, arc position encoder **108** may further include one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end. For example, each of the one or more of the first and second base extensions may be configured to extend from the respective one of the first and second ends in a direction that substantially follows a circumference of a circle defined by the base. As one example, each of the one or more of the first and second base extensions may be configured to extend from the respective one of the first and second ends so as to extend the arc length of the base beyond the arc length defined by the first and second ends. Additionally, arc position encoder **108** may include one or more polarity transition sensors disposed within the one or more of the first and second base extensions. For example, the one or more polarity transition sensors may comprise one or more MR sensors, Hall-Effect sensors, or other magnetic sensors. As one example, the polarity transition sensors of the one or more polarity transition sensors disposed within each of the one or more of the first and second base extensions may include one or more MR sensors, as well as one or more Hall-Effect sensors.

[0030] Furthermore, arc position sensor **108** may still further include a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field. For example, the first and second magnetic poles may each comprise one or more North (N) and South (S) magnetic poles of the magnetic target. In this example, the magnetic target may be coupled to the rotating object so as to rotate about an axis of rotation located in a center of the circle defined by the base.

[0031] Also in this example, at any given time, one of the first and second magnetic poles may be located within the 180-degree angular position sensing range of arc position encoder **108**, and another one of the first and second magnetic poles may be located outside of the 180-degree angular position sensing range. Stated another way, one of the first and second magnetic poles may be located between 0 and 180 degrees of the 360-degree angular position range, while the other one of the first and second magnetic poles may be located between 180 and 360 degrees of the 360-degree angular position range, at any given time.

[0032] In this manner, angular position sensing system **100** of FIG. **1** represents an example of an angular position sensing system for sensing an angular position of a rotating object over a 360-degree angular position range, the system comprising an arc position encoder comprising a 180-degree angular position sensing range, wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end, one or more polarity transition sensors disposed within the one or more of the first and second base extensions, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

[0033] FIG. **2** is a conceptual diagram that illustrates a front view of one example of an arc position encoder **200** which may be used in conjunction with the example angular position sensing system **100** of FIG. **1**, consistent with the techniques of this disclosure. In other words, arc position encoder **200** represents one example of arc position encoder **108** depicted in FIG. **1**.

[0034] As shown in FIG. **2**, arc position encoder **200** includes a base **202** comprising an arc length defined by a first end **216**A and a second end **216**B of base **202**, one or more magnetic field sensors **206**A-**206**E disposed within base **202** between first and second ends **216**A, **216**B, one or more of a first base extension **204**A disposed on first end **216**A, wherein first base extension **204**A extends from first end **216**A, and a second base extension **204**B disposed on second end **216**B, wherein second base extension **204**B extends from second end **216**B, one or more polarity transition sensors **208**A and **208**B disposed within the one or more of first and second base extensions **204**A, **204**B, and a magnetic target **210** comprising a first magnetic pole **214**A and a second magnetic pole

214B disposed on opposite ends of magnetic target 210 so as to generate a uniform magnetic field 228A and 228B.

[0035] In the example of FIG. 2, base 202 may comprise part of an enclosure or housing of arc position encoder 200. Furthermore, arc position encoder 200 may be configured to be mounted, via base 202, within another structure, such as a system (e.g., system 100 of FIG. 1) enclosure or housing, or a system chassis. In some examples, base 202 may further include one or more mounting holes or couplings (not shown), which may be used to mount base 202 within the structure or chassis.

[0036] As can be seen in FIG. 2, each of first and second base extensions 204A, 204B may extend from the respective one of first and second ends 216A, 216B in a direction that substantially follows a circumference of a circle defined by base 202. As one example, each of first and second base extensions 204A, 204B may be configured to extend from the respective one of first and second ends 216A, 216B so as to extend the arc length of base 202 beyond the arc length defined by first and second ends 216A, 216B. For example, as depicted in FIG. 2, first and second base extensions 204A, 204B may extend from first and second ends 216A, 216B to a first extension end 218A and a second extension end 218B, respectively. The arc length by which first and second base extensions 204A, 204B extend the arc length of base 202 beyond the arc length defined by first and second ends 216A, 216B is defined by positions of first and second extension ends 218A, 218B relative to first and second ends 216A, 216B, and may comprise any arc length. In other words, the arc length of each of first and second base extensions 204A, 204B may comprise any arc length. Furthermore, the arc lengths of first and second base extensions 204A, 204B may be different. Additionally, in some cases, arc position encoder 200 may include only one of first and second base extensions 204A, 204B. In any case, as shown in FIG. 2, the angular distance corresponding to the arc length of each of first and second base extensions 204A, 204B relative to the center of the circle defined by base 202 may be indicated by axis 222, axis 224A, and axis 224B.

[0037] As one example, in a case where the arc length of each of first and second base extensions 204A, 204B described above corresponds to an angular distance (as indicated by axis 222, axis 218A, and axis 218B) of 10-degrees, thereby adding a total of 20-degrees to the physical angular range of base 202 of 180-degrees, arc position encoder 200 may be referred to as a 200-degree arc position encoder. In this example, the physical angular range of base 202 (i.e., 180-degrees) and the angular distances corresponding to the arc lengths of first and second base extensions 204A, 204B (i.e., 10-degrees each, or 20-degrees collectively), are added to determine a total physical angular range of arc position encoder 200 (i.e., 200-degrees). In other examples, arc position encoder 200 may comprise a different (e.g., a smaller, or a larger) total physical angular range.

[0038] In some examples consistent with the techniques of this disclosure, the arc length and the corresponding angular distance of each of one or more of first and second base extensions 204A, 204B may be selected so as to correspond to an angular position sensing range of a single magnetic field sensor of magnetic field sensors 206A-206E (e.g., 10-degrees). For example, magnetic field sensors 206A-206E may be substantially uniformly spaced within base 202 between first and second ends 216A, 216B, such that each magnetic field sensor of magnetic field sensors 206A-206E is configured to sense relative proximity of one of first and second magnetic poles 214A, 214B located within the 180-degree angular position sensing range of arc position encoder 200 to the respective magnetic field sensor. As such, an angular position sensing range of a particular magnetic field sensor of magnetic field sensors 206A-206E may be a sub-set (e.g., 10-degrees) of the 180-degree sensing range of arc position encoder 200, and may be defined by the number and relative placement (e.g., a uniform spacing) of magnetic field sensors 206A-206E within base 202. In the examples described above, the arc length and the corresponding angular distance of each of first and second base extensions 204A, 204B may also correspond to this angular position sensing range of a particular magnetic field sensor of magnetic field sensors 206A-206E (e.g., 10-degrees).

[0039] Moreover, the one or more polarity transition sensors 208A and 208B may be disposed within the one or more of first and second base extensions 204A, 204B, e.g., at a center of the arc length, corresponding to a mid-point within the angular distance, of a particular base extension. In other examples, the arc lengths and corresponding angular distances of first and second base extensions 204A, 204B may be selected using other parameters and considerations. Furthermore, the one or more polarity transition sensors 208A and 208B may be disposed within the one or more of first and second base extensions 204A, 204B at different locations.

[0040] Additionally, in the example of FIG. 2, magnetic target 210 may be coupled to a rotating object (also not shown) using beam coupling 212 disposed within magnetic target 210, as shown in FIG. 2. Beam coupling 212 may comprise any of a wide variety of thread couplings, clamp couplings, or other types of couplings. For example, the rotating object, such as a rotating shaft, gear, or wheel, may be coupled to magnetic target 210 via beam coupling 212 so as to rotate together with magnetic target 210 about an axis of rotation located in the center of the circle defined by base 202. In the example of FIG. 2, the location of the axis of rotation may coincide with the location of beam coupling 212, such that the axis of rotation passes through beam coupling 212 and extends in an inward/outward direction (i.e., in and out of the page) relative to the front view of arc position encoder 200. For example, the rotating object and magnetic target 210 may rotate about the axis of rotation in one of a clockwise direction of rotation 220A and a counterclockwise direction of rotation 220B relative to base 202, as also shown in FIG. 2.

[0041] As also shown in FIG. 2, as magnetic target 210 rotates in one of clockwise direction of rotation 220A and counterclockwise direction of rotation 220B relative to base 202, magnetic field sensors 206A-206E may be configured to sense magnetic field 228A, 228B generated by magnetic target 210. For example, magnetic field sensors 206A-206E may be configured to sense relative proximity of one of first and second magnetic poles 214A, 214B located within the 180-degree angular position sensing range of arc position encoder 200 to each of magnetic field sensors 206A-206E, as explained in greater detail below. Additionally, polarity transition sensors 208A, 208B may be configured to sense transitions of each of first and second magnetic poles 214A, 214B into and out of the 180-degree sensing range, as also explained in greater detail below. In other examples, magnetic field sensors 206A-206E and polarity transition sensors 208A, 208B each may comprise more or fewer sensors.

[0042] According to the techniques of this disclosure, in one example, arc position encoder 200 may be included within an angular position sensing system (e.g., system **100** of FIG. **1**) for sensing an angular position of a rotating object (not shown) over a 360-degree angular position range. In this example, arc position encoder **200** may comprise a 180-degree angular position sensing range. For example, arc position encoder **200** may include base **202** comprising an arc length defined by first end **216**A and second end **216**B of base **202**, one or more magnetic field sensors **206**A-**206**E disposed within base **202** between first and second ends **216**A, **216**B, one or more of first base extension **204**A disposed on first end **216**A, wherein first base extension **204**A extends from first end **216**A, and second base extension **204**B disposed on second end **216**B, wherein second base extension **204**B extends from second end **216**B, one or more polarity transition sensors **208**A, **208**B disposed within the one or more of first and second base extensions **204**A, **204**B, and magnetic target **210** comprising first magnetic pole **214**A and second magnetic pole **214**B disposed on opposite ends of magnetic target **210** so as to generate uniform magnetic field **228**A, **228**B. In this example, magnetic target **210** may be coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by base **202**. Also in this example, at any given time, one of first and second magnetic poles **214**A, **214**B may be located within the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B may be located outside of the 180-degree angular position sensing range.

[0043] As another example, magnetic field sensors **206**A-**206**E may be configured to sense relative proximity of the one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range of arc position encoder **200** to each magnetic field sensor of magnetic field sensors **206**A-**206**E. For example, each of magnetic field sensors **206**A-**206**E may be configured to sense the one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range as the one of first and second magnetic poles **214**A, **214**B passes the respective one of magnetic field sensors **206**A-**206**E, and generate an output signal indicative of a position of the one of first and second magnetic poles **214**A, **214**B relative to the respective one of magnetic field sensors **206**A-**206**E. In this example, the position indicated by the output signal generated by each of magnetic field sensors **206**A-**206**E may comprise an angular position of the one of first and second magnetic poles **214**A, **214**B over a sub-range, e.g., a 10-degree sub-range, of the 180-degree sensing range of arc position encoder **200**, that corresponds to the respective one of magnetic field sensors **206**A-**206**E, and which may be referred to as an angular position sensing range of the respective one of magnetic field sensors **206**A-**206**E.

[0044] As explained in greater detail below, a processing module (e.g., processing module **112** of FIG. **1**) may be configured to combine the output signals generated by each of magnetic field sensors **206**A-**206**E to generate one or more common output signals (e.g., processing module output signal(s) **114** of FIG. **1**). For example, the one or more common output signals may indicate an angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range of arc position encoder **200**, when the respective one of first and second magnetic poles **214**A, **214**B is present within the 180-degree sensing range.

[0045] In this example, to generate the one or more common output signals, the processing module may be configured to combine (e.g., level-shift) the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range to determine the angular position of the rotating object over the 360-degree angular position range. In addition, the processing module may be further configured to process one or more of the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range, such as by performing any of a variety of filtering, level-shifting or translation, or other types of signal processing or conditioning. Finally, to generate the one or more common output signals, the processing module may be still further configured to linearize one or more of the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range and the angular position of the rotating object over the 360-degree angular position range, e.g., using the techniques described in commonly owned U.S. Pat. No. 7,030,604, or any other techniques applicable to linearization of output signals from a plurality of magnetic sensors (e.g., a magnetic sensor array). In other words, the one or more common output signals may comprise a linearized signal indicative of the angular position of the rotating object over the 360-degree angular position range. Finally, the processing module may be configured to output the one or more common output signals, and/or store the one or more common output signals in the one or more memories, or memory devices, described above with reference to system **100** of FIG. **1**.

[0046] As still another example, polarity transition sensors **208**A, **208**B may be configured to sense a transition of one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range.

[0047] As still another example, each of the one or more of first and second base extensions **204**A, **204**B may extend from the respective one of first and second ends **216**A, **216**B in a direction that substantially follows a circumference of the circle defined by base **202**. As one example, each of first and second base extensions **204**A, **204**B may be configured to extend from the respective one of first and second ends **216**A, **216**B so as to extend the arc length of base **202** beyond the arc length defined by first and second ends **216**A, **216**B. Alternatively, first and second base extensions **204**A, **204**B may extend from the respective one of first and second ends **216**A, **216**B in another direction, e.g., slightly inward or slightly outward from the circle defined by base **202**, or in a direction that is substantially tangential relative to the circle.

[0048] As still another example, the magnetic field sensors of magnetic field sensors **206**A-**206**E may be substantially uniformly spaced within base **202** between first and second ends **216**A, **216**B. Alternatively, the magnetic field sensors of magnetic field sensors **206**A-**206**E may be non-uniformly, or otherwise asymmetrically, spaced within base **202** between first and second ends **216**A, **216**B.

[0049] As still another example, magnetic field sensors **206**A-**206**E and polarity transition sensors **208**A, **208**B may be substantially uniformly spaced within base **202** and the one or more of first and second base extensions **204**A, **204**B.

[0050] As still other examples, each magnetic field sensor of magnetic field sensors **206**A-**206**E may comprise a magnetoresistive (MR) sensor. Alternatively, each magnetic field sensor of magnetic field sensors **206**A-**206**E may comprise a different type of magnetic field sensor. In a similar manner, each polarity transition sensor of polarity transition sensors **208**A, **208**B may comprise an MR sensor. Alternatively, each polarity transition sensor of polarity transition sensors **208**A, **208**B may comprise a Hall-Effect sensor. Furthermore, polarity transition sensors **208**A, **208**B may comprise one or more magnetoresistive (MR) sensors and one or more Hall-Effect sensors. For example, each of polarity transition sensors **208**A, **208**B may comprise one or more magnetoresistive (MR) sensors and one or more Hall-Effect sensors. In the example of FIG. **2**, for each of polarity transition sensors **208**A, **208**B, one or more magnetoresistive (MR) sensors and one or more Hall-Effect sensors may be disposed within each of first and second base extensions **204**A, **204**B.

[0051] In the examples described above, MR sensors may be used for magnetic sensors **206**A-**206**E, and MR and/or Hall-Effect sensors may be used for polarity transition sensors **208**A, **208**B. For example, while both MR and Hall-Effect sensors may be used to sense a presence of an external magnetic field (e.g., uniform magnetic field **228**A, **228**B generated by first and second magnetic poles **214**A, **214**B of magnetic target **210**, as described above and with reference to FIGS. **2** and **3**), these sensors differ greatly in their manner of operation.

[0052] As one example, an MR sensor may be generally configured to sense a magnitude of an external magnetic field applied to the MR sensor (e.g., until a point of saturation of the MR sensor), as well as an angle of the external magnetic field relative to the MR sensor. For example, the MR sensor may comprise one or more magnetoresistive elements a resistance of each of which changes in response to the angle (and, until the point of saturation, the magnitude) of the external magnetic field relative to the respective magnetoresistive element. For example, the change in resistance of each magnetoresistive element may be proportional to a difference between a direction of a bias current flowing through the element, and an angle of magnetization (which may be referred to as a magnetization vector) of the element by the external magnetic field. In this example, the angle of magnetization of the element by the external magnetic field is a function of the angle at which the external magnetic field is applied relative to the element. In other words, an MR sensor may respond in a similar manner to multiple magnetic fields that are applied to the MR sensor at a same angle, but have different, e.g., opposite, polarities.

[0053] In contrast, Hall-Effect sensors may generally be configured to sense a magnitude and a polarity of an external magnetic field applied transversely (i.e., at a particular angle) relative to a direction of a bias current flowing through a sensing element of the Hall-Effect sensor. The Hall-Effect sensor may sense the magnitude and polarity of the external magnetic field by generating a voltage across a dimension of the sensing element which is transverse to each of the direction of the bias current and the direction of the external magnetic field. The magnitude of this voltage (sometimes referred to as a Hall voltage) is proportional to the magnitude of the external magnetic field, and the polarity of the voltage is indicative of the polarity of the external magnetic field. Accordingly, because Hall-Effect sensors may generate an output in response to an external magnetic field that is dependent on a polarity of the external magnetic field, in one embodiment, using one or more MR sensors as magnetic field sensors **206**A-**206**E may be preferred. Alternatively, in other embodiments, magnetic field sensors **206**A-**206**E may comprise other sensors, as described above.

[0054] In still other examples, the angular position sensing system may further comprise a processing module (not shown) (e.g., processing module **112** of FIG. **1**) configured to determine one or more polarity transition output signals of polarity transition sensors **208**A, **208**B, determine one or more proximity output signals of magnetic field sensors **206**A-**296**E, and determine the angular position of the rotating object within the 360-degree angular position range, based at least in part on the one or more polarity transition output signals and the one or more proximity output signals.

[0055] In some examples, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module may be configured to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition output signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. In this example, the processing module may be further configured to determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity output signals.

[0056] In still other examples, the processing module may be further configured to determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to arc position encoder **200**, based at least in part on the determined angular position of the rotating object within the 360-degree angular position range. The particular techniques which may, in some examples, be used by the processing module to make these determinations will be described in greater detail below with reference to FIG. **4**.

[0057] Finally, the processing module may be further configured to determine a direction of angular rotation of the rotating object relative to arc position encoder **200**, based at least in part on the one or more polarity transition output signals. For example, the processing module may be configured to determine, based at least in part on the one or more polarity transition output signals, that a transition of one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range, has occurred. As one example, the processing module may be configured to determine the direction of angular rotation of the rotating object based on, e.g., which of first and second magnetic poles **214**A, **214**B has transitioned into and out of the 180-degree angular position sensing range. As another example, the processing module may be configured to determine the direction of angular rotation of the rotating object based on one or more previously detected transitions (e.g., indications of which may be stored in one or more memory devices within a corresponding angular position sensing system, e.g., system **100**) of first and second magnetic poles **214**A, **214**B into and out of the 180-degree angular position sensing range, and the currently detected transition.

[0058] In this manner, arc position encoder **200** of FIG. **2** represents an example of an arc position encoder included within an angular position sensing system for sensing an angular position of a rotating object over a 360-degree angular position range, wherein the arc position encoder comprises a 180-degree angular position sensing range, and wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end, one or more polarity transition sensors disposed within the one or more of the first and second base extensions, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

[0059] FIG. **3** is a conceptual diagram that illustrates a perspective view of the example arc position encoder **200** of FIG. **2**, consistent with the techniques of this disclosure. As shown in FIG. **3**, arc position encoder **300** includes a base **302**A and **302**B comprising an arc length defined by a first end **316**A and a second end **316**B of base **302**A, **302**B, one or more magnetic field sensors **306**A and **306**E disposed within base **302**A, **302**B between first and second ends **316**A, **316**B, one or more of a first base extension **304**A disposed on first end **316**A, wherein first base extension **304**A extends from first end **316**A, and a second base extension **304**B disposed on second end **316**B, wherein second base extension **304**B extends from second end **316**B, one or more polarity transition sensors **308**A and **308**B disposed within the one or more of first and second base extensions **304**A, **304**B, and a magnetic target **310** comprising a first magnetic pole **314**A and a second magnetic pole **314**B disposed on opposite ends of magnetic target **310** so as to generate a uniform magnetic field **328**A and **328**B.

[0060] In the example of FIG. **3**, base **302**A, **302**B is depicted using two sections (i.e., **302**A, **302**B) for purposes of illustrating arc position encoder **300** in greater detail. It should be understood that base **302**A, **302**B comprises a single base, e.g., base **202** of FIG. **2**, and that, although not shown in FIG. **3**, the sections of base **302**A, **302**B are joined to form a single base (e.g., base **302**) above the break-out dashed lines located above base **302**A, **302**B. Additionally, the perspective view of arc position encoder **300** depicts only two magnetic field sensors, i.e., magnetic field sensors **306**A and **306**E. It should also be understood that arc position encoder **300** may comprise one or more (e.g., 3, 4, 5, etc.) magnetic field sensors, e.g., **206**A-**206**E, as described with reference to FIG. **2**, disposed within base **302**A, **302**B between first and second ends **316**A, **316**B. Similarly, each of polarity transition sensors **308**A, **308**B may comprise one or more polarity transition sensors.

[0061] Furthermore, magnetic field sensors **306**A, **306**E and polarity transition sensors **308**A, **308**B, depicted as each having a cylindrical geometry, are depicted as having a same geometry for purposes of illustration only. As explained above with reference to FIG. **2**, each of magnetic field sensors **306**A, **306**B and polarity transition sensors **308**A, **308**B may comprise a same type of sensor, e.g., an MR sensor, or another type of sensor, and each of polarity transition sensors **308**A, **308**B may comprise one or more MR sensors and/or a Hall-Effect sensors, or one or more other sensors, in some examples.

[0062] Also, in the example of FIG. **3**, magnetic target **310** is coupled to a rotating shaft **326** via beam coupling **312** disposed within magnetic target **310**. In some examples, rotating shaft **326** may be coupled to a rotating object (not shown). In other examples, rotating shaft **326** may itself be a rotating object, or part of a rotating object. Beam coupling **312** may comprise any of a wide variety of thread couplings, clamp couplings, or other types of couplings. In any case, the rotating object may be coupled to magnetic target **310** via beam coupling **312** so as to rotate together with magnetic target **310** about an axis of rotation located in a center of a circle defined by base **302**A, **302**B. In the example of FIG. **3**, the location of the axis of rotation may coincide with the location of beam coupling **312**, such that the axis of rotation passes through beam coupling **312** and extends in an inward/outward direction relative to a front view of arc position encoder **300**, as explained above with reference to arc position encoder **200** of FIG. **2**. For example, the rotating object and magnetic target **310** may rotate about the axis of rotation in one of a clockwise direction of rotation **320**A and a counterclockwise direction of rotation **320**B relative to base **302**A, **302**B, as also shown in FIG. **3**. In the example of FIG. **3**, magnetic target **310** is rotated 90-degrees in counterclockwise direction of rotation **320**B relative to magnetic target **210** as depicted in FIG. **2**.

[0063] In this manner, arc position encoder **300** of FIG. **3** represents an example of an arc position encoder included within an angular position sensing system for sensing an angular position of a rotating object over a 360-degree angular position range, wherein the arc position encoder comprises a 180-degree angular position sensing range, and wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end, one or more polarity transition sensors disposed within the one or more of the first and second base extensions, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

[0064] FIG. **4** is a flow diagram that illustrates one example of a method of sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range, consistent with the techniques of this disclosure. The techniques of FIG. **4** may generally be performed by any processing unit or processor, whether implemented in hardware, software, firmware, or a combination thereof, and when implemented in software or firmware, corresponding hardware may be provided to execute instructions for the software or firmware. For purposes of example, the techniques of FIG. **4** are described with respect to angular position sensing system **100** (FIG. **1**), arc position encoder **108** (FIG. **1**), **200** (FIG. **2**), and **300** (FIG. **3**), and processing module **112** (FIG. **1**), as well as various components thereof, although it should be understood that other systems or devices may be configured to perform similar techniques. Moreover, the steps illustrated in FIG. **4** may be performed in a different order or in parallel, and additional steps may be added and certain steps omitted, without departing from the techniques of this disclosure.

[0065] In one example, a processing module (e.g., **112**) of an angular position sensing system (e.g., **100**) that includes the processing module and an arc position encoder (e.g., **108**, **200**, and **300**) may be configured to sense an angular position of a rotating object over a 360-degree angular position range using the arc position encoder. In this example, the arc position encoder may comprise a 180-degree angular position sensing range.

[0066] For example, the processing module may initially receive one or more polarity transition signals from one or more polarity transition sensors disposed on one or more of a first end and a second end of a base of the arc position encoder, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range (**400**).

[0067] The processing module may further receive one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors (**402**).

[0068] The processing module may still further determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals (**404**).

[0069] In the above example, the one or more polarity transition sensors disposed on the one or more of the first and second ends of the base may comprise the one or more polarity transition sensors disposed within one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end, in a similar manner as described above with reference to FIGS. **2** and **3**. Furthermore, each of the one or more of the first and second base extensions may extend from the respective one of the first and second ends in a direction that substantially follows a circumference of the circle defined by the base, as also previously described.

[0070] Additionally, in some examples, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals, the processing module may determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. The processing module may further determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity signals.

[0071] In other examples, the processing module may determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the 360-degree angular position range. For example, the processing module may determine the angular speed (e.g., in radians/second (ω), degrees/second, or revolutions per minute (RPM)) of the rotating object based on the determined angular position of the rotating object within the 360-degree angular position range at a particular first point in time, which may be referred to as a first angular position, as well as based on a second, different angular position of the rotating object within the 360-degree angular position range at a subsequent second point in time. In this example, the processing module may determine the angular speed of the rotating object by dividing a difference between the first and second angular positions (e.g., second angular position-first angular position=Δ (angular position), which is proportional to the angular distance traveled by the rotating object) by a difference between the first and second times (e.g., second time-first time=Δ (time), which equals the time elapsed). For example, to determine the angular speed of the rotating object, the processing module may utilize the following expression:

$$\omega=\Delta(\text{angular position})/\Delta(\text{time}) \quad \text{EQ. 1}$$

[0072] Where ω corresponds to the angular speed of the rotating object, Δ (angular position) corresponds to a difference between the first and second angular positions, and Δ (time) corresponds to a difference between the first and second times. In other words, the angular speed of the rotating object may be expressed as a change in angular position of the rotating object over a unit of time.

[0073] In a similar manner, the processing module may determine the direction of angular rotation (e.g., clockwise or counterclockwise) of the rotating object relative to the arc position encoder based on the determined angular position of the rotating object within the 360-degree angular position range, which may once again be referred to as a first angular position, at a first point in time, by determining a second, different angular position of the rotating object within the 360-degree angular position range at a subsequent second point in time. In this example, the processing module may determine the direction of angular rotation by determining a sign of a difference between the first and second angular positions (e.g., sign of Δ (angular position), where Δ (angular position)=second angular position-first angular position). For example, to determine the direction of angular rotation of the rotating object, the processing module may utilize the following expression:

$$DIR=SIGN(\Delta(\text{angular position})) \quad \text{EQ. 2}$$

[0074] Where DIR corresponds to the direction of angular rotation of the rotating object, Δ (angular position) corresponds to the difference between the first and second angular position values, and SIGN indicates a sign operator used to determine the sign of the difference between the first and second angular position values. Accordingly, the direction of angular rotation of the rotating object may be represented using a sign (e.g., "+" or "−") that corresponds to the direction of angular rotation, which may, in turn, comprise one of e.g., a clockwise or a counterclockwise direction of rotation. In one example, DIR="+" may correspond to a clockwise direction of angular rotation of the rotating object, and DIR="−" may correspond to a counterclockwise direction of angular rotation of the rotating object. In other examples, different values of DIR may correspond to different directions of angular rotation of the rotating object.

[0075] Additionally, the processing module may determine the direction of angular rotation of the rotating object relative to the arc position encoder based at least in part on the one or more polarity transition signals. For example, as described above, the processing module may determine, based at least in part on the one or more polarity transition output signals, that a transition of one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, has occurred. As one example, the processing module may determine the direction of angular rotation of the rotating object based on, e.g., which of the first and second magnetic poles has transitioned into and out of the 180-degree angular position sensing range. As another example, the processing module may determine the direction of angular rotation of the rotating object based on one or more previously detected transitions (e.g., indications of which may be stored in one or more memories, or memory devices, within the angular position sensing system) of the first and second magnetic poles into and out of the 180-degree angular position sensing range, and the currently detected transition.

[0076] In some examples, the processing module may still further output one or more signals indicative of the determined angular position of the rotating object (**406**). As one example, the processing module may output a single signal indicative of the angular position of the rotating object over the 360-degree angular position sensing range, e.g., a value between 0 and 360 that is representative of the angular position of the rotating object within the 360-degree angular position range. Alternatively, as described above, the processing module may output a first signal indicative of whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range. As also described above, the first and second 180-degree angular position sub-ranges may be non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. Additionally, processing module may further output a second signal indicative of the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds.

[0077] Furthermore, as also described above, to output the one or more "output" signals indicative of the determined angular position of the rotating object, the processing module may combine (e.g., level-shift) the angular position of each of the first and second magnetic poles over the 180-degree sensing range, as indicated by the one or more proximity signals from the one or more magnetic field sensors, to determine the angular position of the rotating object over the 360-degree angular position range. For example, the processing module may combine the one or more proximity signals generated by the one or more magnetic field sensors for each of the first and second magnetic poles to generate the one or more output signals.

[0078] In addition, the processing module may further process the one or more proximity signals, prior to, or after the combining, such as by performing any of a variety of filtering, level-shifting or translation, or other types of signal processing or conditioning, to generate the one or more output signals. Finally, to generate the one or more output signals, the processing module may still further linearize one or more of the one or more proximity signals and the angular position of the rotating object over the 360-degree angular position range, e.g., using any techniques applicable to linearization of output signals from a plurality of magnetic sensors. In other words, the one or more output signals may comprise a linearized signal indicative of the angular position of the rotating object over the 360-degree angular position range.

[0079] Finally, as described above, the processing module may further output the one or more output signals, and/or store the one or more output signals in the one or more memories, or memory devices, described above with reference to system **100** of FIG. **1**.

[0080] In any case, the one or more output signals, whether represented as a single signal, or a plurality of signals, may comprise one or more analog signals, one or more digital signals, or any combination thereof.

[0081] The techniques of this disclosure may enable the angular position sensing system (e.g., angular position sensing system **100**) including the arc position encoder (e.g., arc position encoder **108**, **200**, **300**) and the processing module (e.g., processing module **112**), as described above, to sense the angular position of the rotating object over the 360-degree angular position range. Accordingly, in contrast to other angular position sensing techniques which may be used to sense an angular position of a rotating object over a 360-degree angular position range, for example, techniques using a plurality of (e.g., two) arc position encoders each comprising a 180-degree angular position sensing range, or a relatively more complex full-range angular position encoder, the techniques of this disclosure may enable sensing the angular position of the rotating object over the 360-degree angular position range using a single arc position encoder comprising a 180-degree angular position sensing range.

[0082] In this manner, the method of FIG. **4** represents an example of a method of sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range, the method comprising receiving one or more polarity transition signals from one or more polarity transition sensors disposed on one or more of a first end and a second end of a base of the arc position encoder, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, receiving one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors, and determining the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals.

[0083] The techniques of this disclosure may be implemented in a wide variety of computer devices. Any components, units, or modules that have been described are provided to emphasize functional aspects, and do not necessarily require realization by different hardware units. The techniques described herein may also be implemented in hardware, software, firmware, or any combination thereof. Any features described as modules, units, or components may be implemented together in an integrated logic device, or separately as discrete but interoperable logic devices. In some cases, various features may be implemented as an integrated circuit device, such as an integrated circuit chip, or chipset.

[0084] If any aspect of the techniques are implemented in software, the techniques may be realized at least in part by a computer-readable storage medium comprising instructions that, when executed in a processor, performs one or more of the methods described above. The computer-readable storage medium may comprise a tangible computer-readable storage medium, and may form part of a larger product. The computer-readable storage medium may comprise random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, and the like. The computer-readable storage medium may also comprise a non-volatile storage device, such as a hard-disk, magnetic tape, a compact disc (CD), digital versatile disc (DVD), Blu-ray disc, holographic data storage media, or other non-volatile storage device.

[0085] The memory, or memory devices, described herein, which may be used as part of the described techniques, may also be realized in any of a wide variety of memory, or memory devices, including but not limited to, RAM, SDRAM, NVRAM, EEPROM, FLASH memory, dynamic RAM (DRAM), magnetic RAM (MRAM), or other types of memory.

[0086] The term "processor" as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated software modules or hardware modules configured for performing the techniques of this disclosure. Even if implemented in software, the techniques may use hardware such as a processor to execute the software, and a memory to store the software. In any such cases, the computers described herein may define a specific machine that is capable of executing the specific functions described herein. Also, the techniques could be fully implemented in one or more circuits or logic elements, which could also be considered a processor.

[0087] Various examples have been described. These and other examples are within the scope of the following claims.

What is claimed is:

1. An angular position sensing system for sensing an angular position of a rotating object over a 360-degree angular position range, the system comprising:

an arc position encoder comprising a 180-degree angular position sensing range, wherein the arc position encoder includes:

a base comprising an arc length defined by a first end and a second end of the base;

one or more magnetic field sensors disposed within the base between the first and second ends;

one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end;

one or more polarity transition sensors disposed within the one or more of the first and second base extensions; and

a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

2. The angular position sensing system of claim **1**, wherein the one or more magnetic field sensors are configured to sense relative proximity of the one of the first and second magnetic poles located within the 180-degree angular position sensing range of the arc position encoder to each magnetic field sensor of the one or more magnetic field sensors.

3. The angular position sensing system of claim **1**, wherein the one or more polarity transition sensors are configured to sense a transition of one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range.

4. The angular position sensing system of claim **1**, wherein each of the one or more of the first and second base extensions extends from the respective one of the first and second ends in a direction that substantially follows a circumference of the circle defined by the base.

5. The angular position sensing system of claim **1**, wherein the magnetic field sensors of the one or more magnetic field sensors are substantially uniformly spaced within the base between the first and second ends.

6. The angular position sensing system of claim **1**, wherein the one or more magnetic field sensors and the one or more polarity transition sensors are substantially uniformly spaced within the base and the one or more of the first and second base extensions.

7. The angular position sensing system of claim **1**, wherein each magnetic field sensor of the one or more magnetic field sensors comprises a magnetoresistive (MR) sensor.

8. The angular position sensing system of claim **1**, wherein each polarity transition sensor of the one or more polarity transition sensors comprises a magnetoresistive (MR) sensor.

9. The angular position sensing system of claim **1**, wherein each polarity transition sensor of the one or more polarity transition sensors comprises a Hall-Effect sensor.

10. The angular position sensing system of claim **1**, wherein the one or more polarity transition sensors comprise one or more magnetoresistive (MR) sensors and one or more Hall-Effect sensors.

11. The angular position sensing system of claim **1**, further comprising a processing module configured to:

determine one or more polarity transition output signals of the one or more polarity transition sensors;

determine one or more proximity output signals of the one or more magnetic field sensors; and

determine the angular position of the rotating object within the 360-degree angular position range, based at least in part on the one or more polarity transition output signals and the one or more proximity output signals.

12. The angular position sensing system of claim **11**, wherein to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module is configured to:

determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition output signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range; and

determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity output signals.

13. The angular position sensing system of claim **11**, wherein the processing module is further configured to determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the 360-degree angular position range.

14. The angular position sensing system of claim **11**, wherein the processing module is further configured to determine a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the one or more polarity transition output signals.

15. A method of sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range, the method comprising:

receiving one or more polarity transition signals from one or more polarity transition sensors disposed on one or more of a first end and a second end of a base of the arc position encoder, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range;

receiving one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors; and

determining the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals.

16. The method of claim **15**, wherein the one or more polarity transition sensors disposed on the one or more of the first and second ends of the base comprises the one or more polarity transition sensors disposed within one or more of a first base extension disposed on the first end, wherein the first base extension extends from the first end, and a second base extension disposed on the second end, wherein the second base extension extends from the second end.

17. The method of claim **16**, wherein each of the one or more of the first and second base extensions extends from the respective one of the first and second ends in a direction that substantially follows a circumference of the circle defined by the base.

18. The method of claim **15**, wherein determining the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals comprises:

determining whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range; and

determining the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity signals.

19. The method of claim **15**, further comprising:

determining one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the 360-degree angular position range.

20. The method of claim **15**, further comprising:

determining a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the one or more polarity transition signals.

* * * * *

COMMENTARIES OF PATENT 3

Title: 180 Deg Arc position encoder with an extended angular position sensing range

Abstract: Disclosed are techniques for sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range. The encoder may include a base defined by first and second ends, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of first and second base extension disposed on the first and second ends, and one or more polarity transition sensors disposed within the one or more of the first and second base extensions. The encoders may further include a magnetic target having first and second magnetic poles disposed on opposite ends as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base.

Main topics:

- Angular position sensor extension technique
- 180 Deg angular position sensor can be used for 360-degree angle position sensing using this new technique

Concept:

Arc position sensor built with AMR sensing elements into base, along with rotating target coupled with rotating object. 180 arc position sensors are used to measure 360 Deg of rotating part with virtual extended sensing range. This patent explains how this extension is possible by using same elements (Base) along with target opposite polarity signal to measure greater than 180 deg to 360 Deg.

Benefit1: Space for angle position sensor reduction by half (50%) wrt current practice

Under current scenario in Electric vehicles, rotor position is mandatory to be measured online to operated PM based traction motor to control as precious as possible to give confront driving experience to driven customer under various driving worst case condition. This mandatory part occupies good amount of space in both pure electric drivetrain (BEV) and hybrid electric drivetrain (HPEV). To avoid the complexity in space this patent proposed to use, 180 Deg arc position sensor as a base (Stator) along with PM targets spread across 360 Deg which is attached with rotating component. Being less than 360 deg arc component, it is easy for mounting or assembly into the drivetrain, and shield cost also reduced due to this elimination.

Benefit2: Flexibility in assembly

With current 360 arc position sensors, assembly is not flexible. Complete 360 deg, mounting or space is required. So, drivetrain has to be designed along with bearing and other clamping plates according to those different parts and their assembly sequence. Using this reduced arc position sensor base (stator), based on the space availability around 360 Deg, mounting with respect to rotating part can be planned along with individual parts tolerance and total assembly tolerance. Usually front and rear drivetrain's concept and package sizes are different, to accommodate same Emachine and position sensor, this kind of flexibility in rotor position sensor is great gift for drivetrain designers.

Benefit3: No EM Metal shield

New sensor is being with active magnetic poles, it doesn't need any metal shield to protect from EM disturbance from Emotor main flux via end windings. This benefit reduces and cost and space required for shield itself.

Benefit4: Ingress protection

Being rated for IP67 or IP67K, no need to worry about Ingress protection for new sensor compared to existing VR sensors (windings are exposed)

Benefit5: Direct Analog processed signal

New sensor will give directly analog processed signal whereas in existing inverter software needs to process those signals to find the angle

US008816679B2

(12) United States Patent
Kunjappan et al.

(10) Patent No.: US 8,816,679 B2
(45) Date of Patent: Aug. 26, 2014

(54) **180-DEGREE ARC POSITION ENCODER WITH AN EXTENDED ANGULAR POSITION SENSING RANGE**

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(73) Assignee: **Honeywell International, Inc.**, Morristown, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 121 days.

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(65) **Prior Publication Data**

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(51) **Int. Cl.**
G01B 7/30 (2006.01)

(52) **U.S. Cl.**
USPC **324/207.25**; 324/207.2; 324/207.21

(58) **Field of Classification Search**
CPC G01D 5/00; G01R 33/06; G01R 33/07; G01R 33/09; G01B 7/30
USPC 324/173, 174, 207.14, 207.2–207.26
See application file for complete search history.

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Assistant Examiner — Raul Rios Russo
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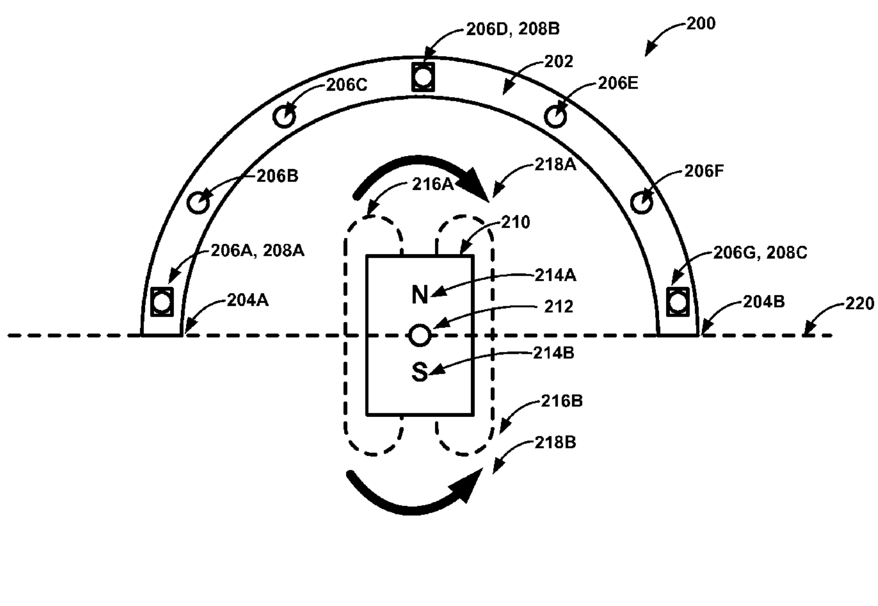
(57) **ABSTRACT**

This disclosure describes techniques for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range. The encoder may include a base comprising an arc length defined by a first and a second end, one or more magnetic field sensors disposed within the base between the first and second ends, and one or more polarity transition sensors also disposed within the base between the first and second ends. The encoder may further include a magnetic target that includes first and second magnetic poles disposed on opposite ends so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base.

20 Claims, 5 Drawing Sheets



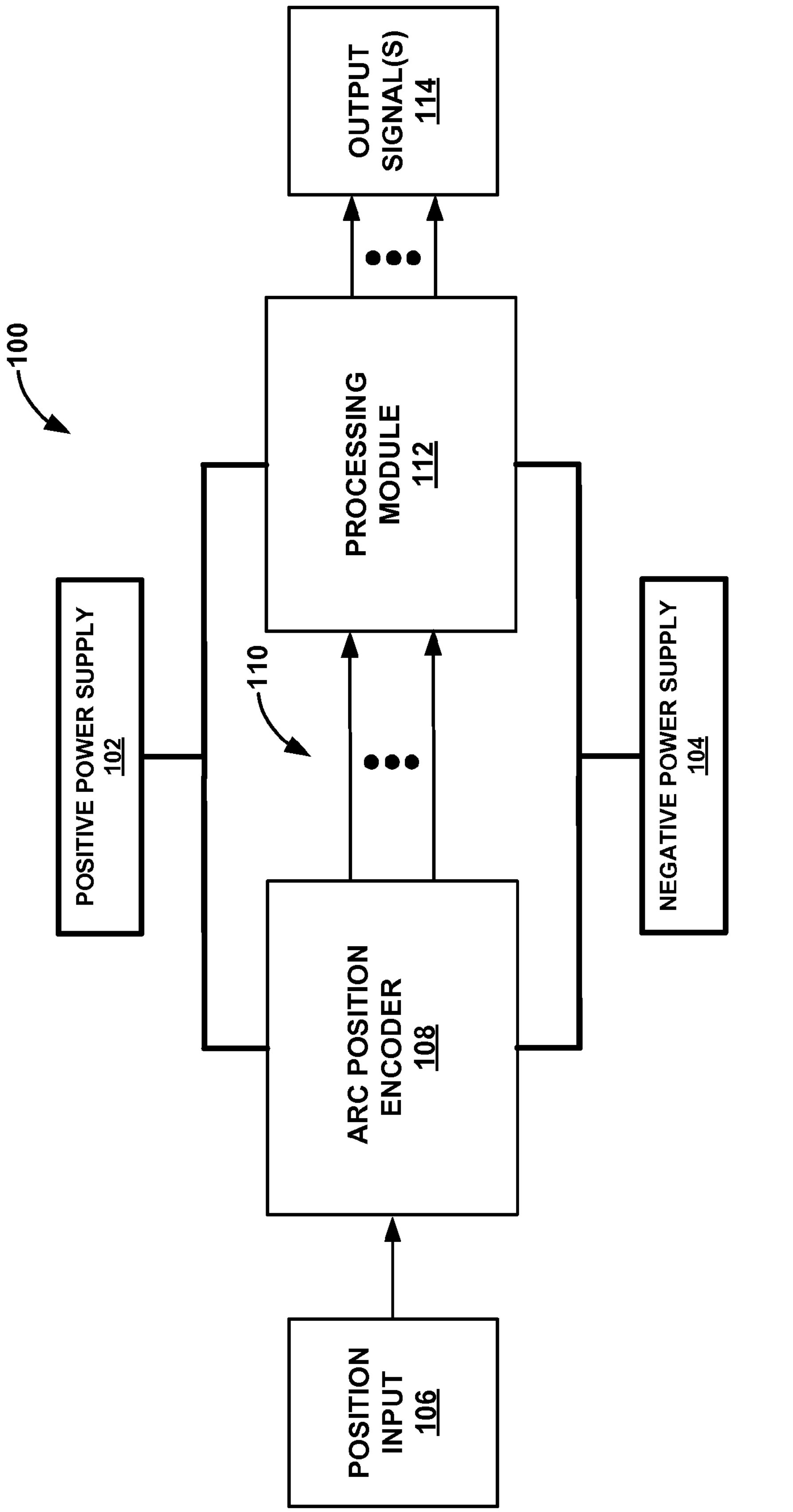

100
OUTPUT SIGNAL(S) 114
PROCESSING MODULE 112
POSITIVE POWER SUPPLY 102
110
NEGATIVE POWER SUPPLY 104
ARC POSITION ENCODER 108
POSITION INPUT 106

FIG. 1

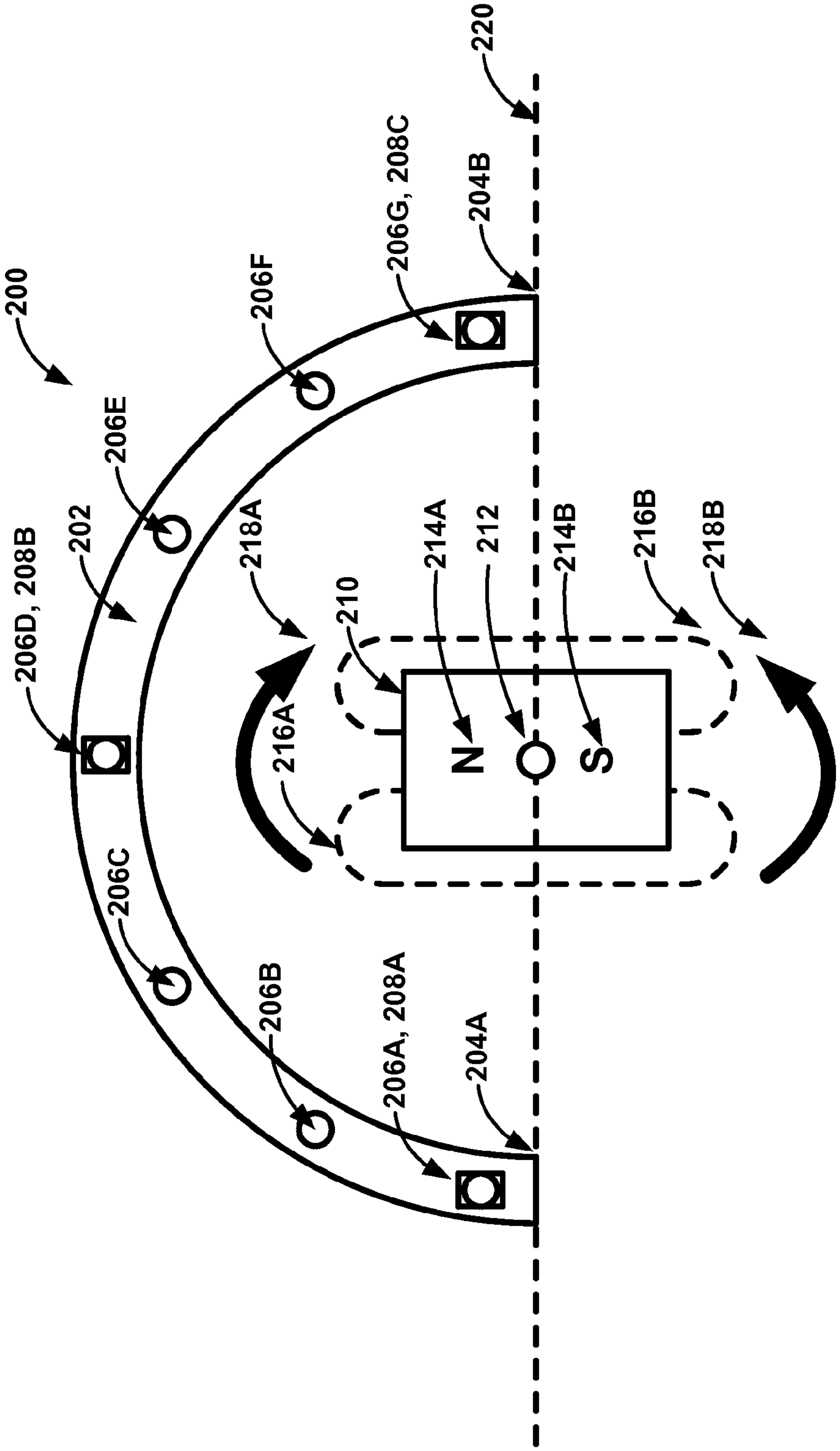

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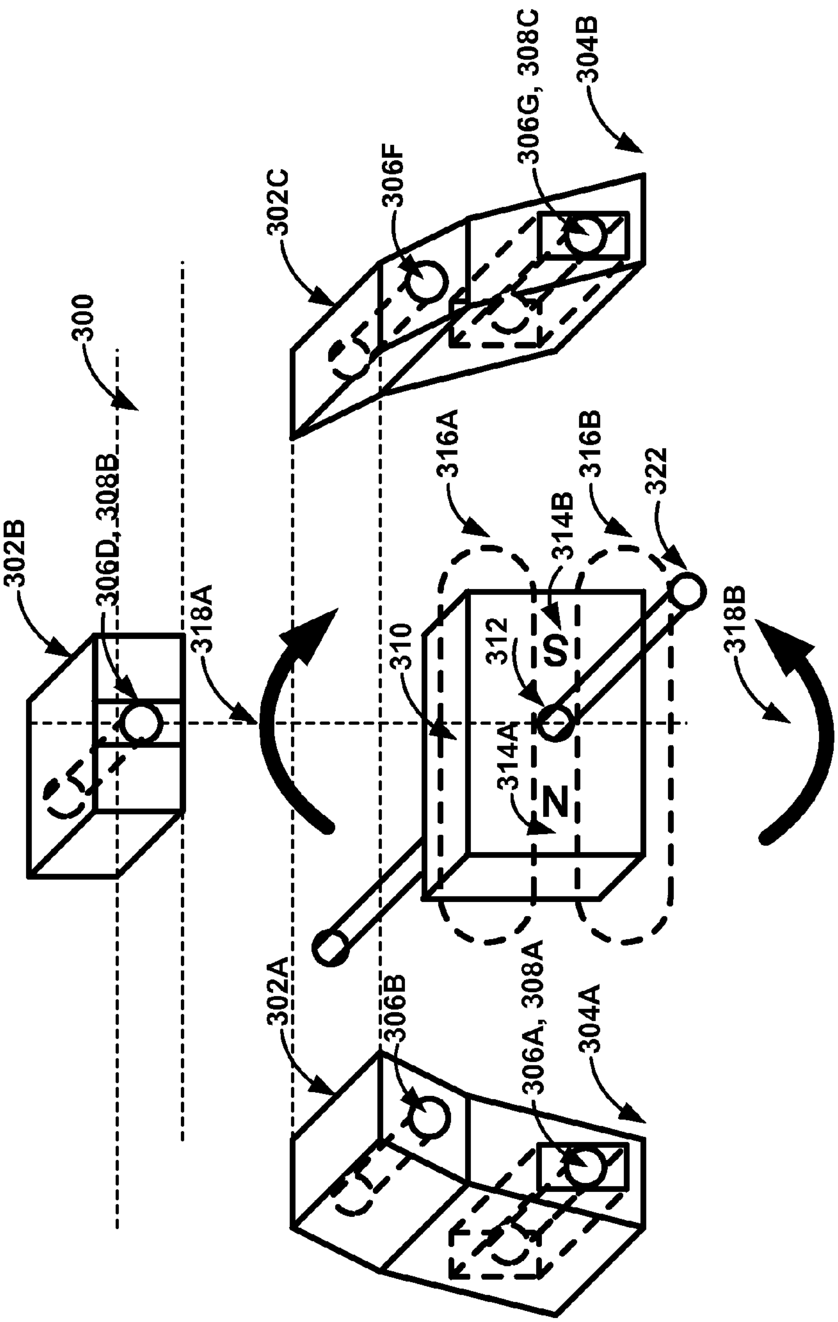
FIG. 2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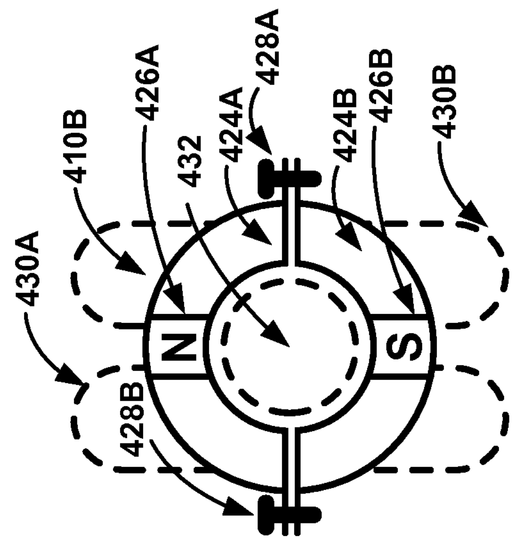
304A

FIG. 3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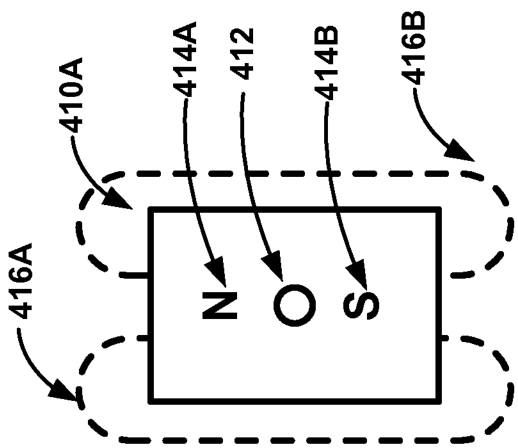
S

FIG. 4B


410A
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412
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416A
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FIG. 4A

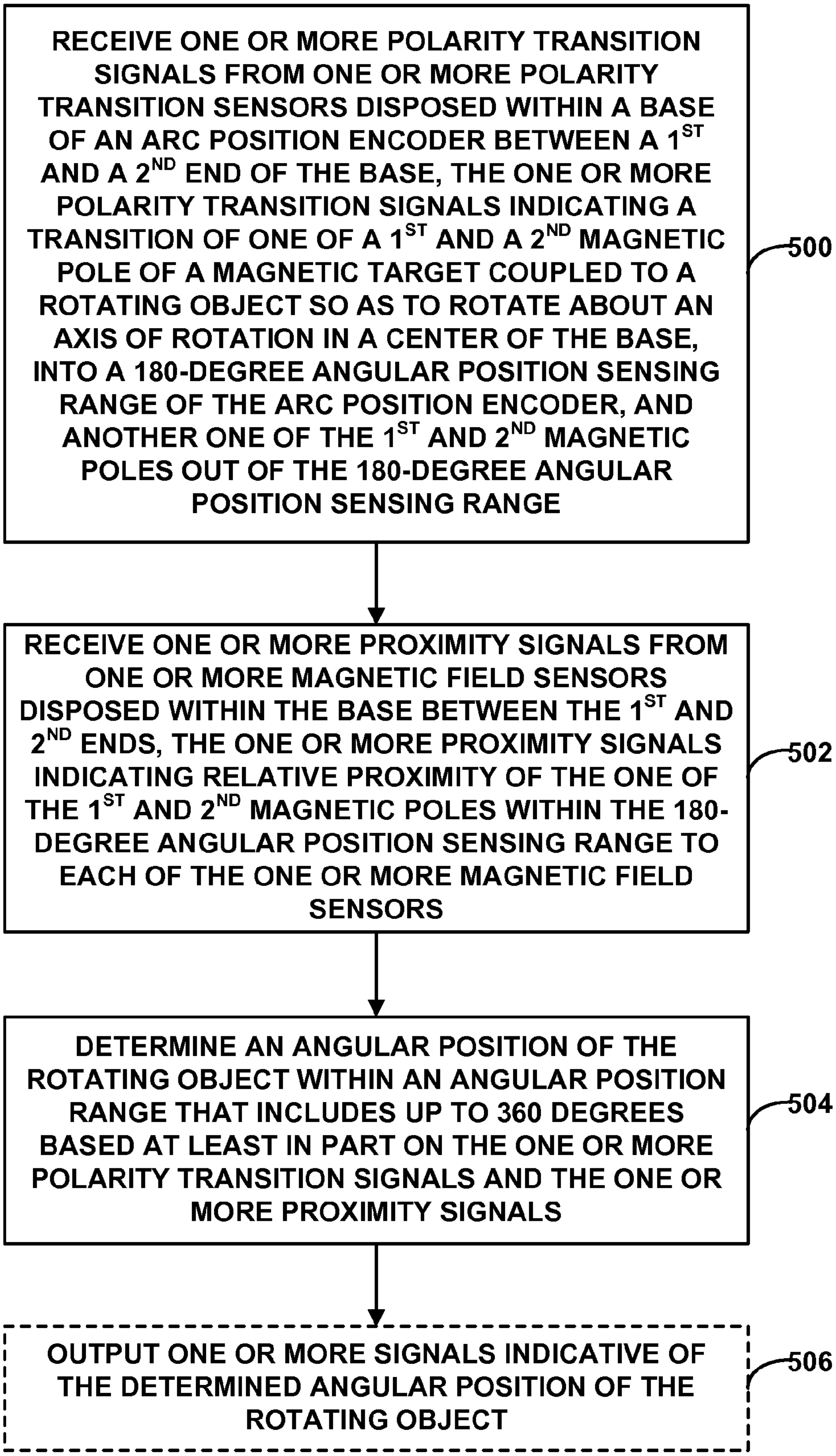
RECEIVE ONE OR MORE POLARITY TRANSITION SIGNALS FROM ONE OR MORE POLARITY TRANSITION SENSORS DISPOSED WITHIN A BASE OF AN ARC POSITION ENCODER BETWEEN A 1ST AND A 2ND END OF THE BASE, THE ONE OR MORE POLARITY TRANSITION SIGNALS INDICATING A TRANSITION OF ONE OF A 1ST AND A 2ND MAGNETIC POLE OF A MAGNETIC TARGET COUPLED TO A ROTATING OBJECT SO AS TO ROTATE ABOUT AN AXIS OF ROTATION IN A CENTER OF THE BASE, INTO A 180-DEGREE ANGULAR POSITION SENSING RANGE OF THE ARC POSITION ENCODER, AND ANOTHER ONE OF THE 1ST AND 2ND MAGNETIC POLES OUT OF THE 180-DEGREE ANGULAR POSITION SENSING RANGE
500
RECEIVE ONE OR MORE PROXIMITY SIGNALS FROM ONE OR MORE MAGNETIC FIELD SENSORS DISPOSED WITHIN THE BASE BETWEEN THE 1ST AND 2ND ENDS, THE ONE OR MORE PROXIMITY SIGNALS INDICATING RELATIVE PROXIMITY OF THE ONE OF THE 1ST AND 2ND MAGNETIC POLES WITHIN THE 180-DEGREE ANGULAR POSITION SENSING RANGE TO EACH OF THE ONE OR MORE MAGNETIC FIELD SENSORS
502
DETERMINE AN ANGULAR POSITION OF THE ROTATING OBJECT WITHIN AN ANGULAR POSITION RANGE THAT INCLUDES UP TO 360 DEGREES BASED AT LEAST IN PART ON THE ONE OR MORE POLARITY TRANSITION SIGNALS AND THE ONE OR MORE PROXIMITY SIGNALS
504
OUTPUT ONE OR MORE SIGNALS INDICATIVE OF THE DETERMINED ANGULAR POSITION OF THE ROTATING OBJECT
506

FIG. 5

180-DEGREE ARC POSITION ENCODER WITH AN EXTENDED ANGULAR POSITION SENSING RANGE

TECHNICAL FIELD

This disclosure relates to position encoders, and more particularly, to techniques for using a position encoder to sense an angular position of a rotating object.

BACKGROUND

Position encoders are among a number of electro-mechanical transducers that may be used to sense a position of an object. Position encoders may be configured to sense an actual, or "absolute," position of an object, as well as a "relative" position, or a displacement, of the object. Furthermore, a position encoder may comprise any of a wide variety of linear and angular, or "rotary," position encoders. In some examples, position encoders may use contact-based sensing means to sense a position of an object by mechanically coupling the object to the position encoder, e.g., to a movable member or a rotating shaft of the position encoder, which may be mechanically coupled to a sensing element of the position encoder. In other examples, position encoders may employ a wide variety of contactless sensing means, such as optical, magnetic, capacitive, and inductive means, as some examples. Position encoders employing such contactless sensing means may be less susceptible to wear and may provide greater durability compared to contact-based position encoders.

As one example, a linear position encoder may sense a position of an object moving along a linear trajectory relative to the linear position encoder. For example, the linear position encoder may sense a position of an encoder "read-head" that is coupled to the object relative to an encoder track as the encoder read-head and the object move together along the encoder track. The position of the read-head relative to the encoder track may be sensed using mechanical, optical, magnetic, capacitive, or inductive means, as well as using other sensing means.

As another example, an angular, or rotary, position encoder may sense an angular position of an object that is rotating about an axis of rotation relative to the angular position encoder. For example, in the case of the angular position encoder employing magnetic sensing means, as described above, the angular position encoder may sense an angular position of a magnetic target that is coupled to the rotating object relative to one or more magnetic field sensors disposed within a base of the angular position encoder. The magnetic target may be disposed substantially at a center of the base so as to generate a uniform magnetic field which varies from the perspective of the one or more magnetic field sensors based on the angular position of the magnetic target relative to the sensors. In this example, the one or more magnetic field sensors may include magnetoresistive (MR) sensors, Hall-Effect sensors, or other magnetic sensors.

SUMMARY

In general, this disclosure describes techniques for using an arc position encoder to sense an angular position of a rotating object over an extended angular position range. For example, the arc position encoder may comprise a substantially 180-degree angular position sensing range, e.g., an angular position sensing range that is within +/−1%, 5%, or 10% of 180 degrees, as some examples. The techniques of this disclosure may, in some cases, enable extending the 180-degree sensing range of the arc position encoder, for example, by incorporating additional functional elements into the arc position encoder, and without adding any structural elements that may substantially increase the outer dimensions of the arc position encoder, such that the arc position encoder may be used to sense an angular position of a rotating object over an angular position range that includes up to 360 degrees.

In particular, the techniques described herein may enable extending the 180-degree sensing range of the arc position encoder such that the arc position encoder may be used to sense the angular position of the rotating object anywhere within a 360-degree angular position range, i.e., anywhere within an angular position range that includes up to 360 degrees. More specifically, the techniques may enable the arc position encoder to sense the angular position of the rotating object within the 180-degree sensing range of the arc position encoder, as well as outside of the 180-degree sensing range and anywhere within the remaining 180-degree angular position range, wherein the 180-degree sensing range and the remaining 180-degree angular position range collectively define the 360-degree angular position range. For example, using the techniques of this disclosure, the arc position encoder may be configured to sense the angular position of the rotating object within the 360-degree angular position range, or within a subset of the 360-degree angular position range, e.g., a 270-degree angular position range.

In one example, an angular position sensing system for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees includes an arc position encoder comprising a substantially 180-degree angular position sensing range, wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more polarity transition sensors disposed within the base between the first and second ends, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

In another example, a method of sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range includes receiving one or more polarity transition signals from one or more polarity transition sensors disposed within a base of the arc position encoder between a first end and a second end of the base, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, receiving one or more proximity signals from one or more magnetic field sensors dis-

posed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors, and determining the angular position of the rotating object within the angular position range that includes up to 360 degrees based at least in part on the one or more polarity transition signals and the one or more proximity signals.

The details of one or more examples are set forth in the accompanying drawings and the description below. Other features, objects, and advantages in addition to those described below will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram that illustrates one example of an angular position sensing system, consistent with the techniques of this disclosure.

FIG. **2** is a conceptual diagram that illustrates a front view of one example of an arc position encoder which may be used in conjunction with the example angular position sensing system of FIG. **1**, consistent with the techniques of this disclosure.

FIG. **3** is a conceptual diagram that illustrates a perspective view of the example arc position encoder of FIG. **2**, consistent with the techniques of this disclosure.

FIGS. **4**A and **4**B are conceptual diagrams that each illustrate a front view of an example magnetic target that may be used as part of the example arc position encoder of each of FIGS. **2** and **3**, consistent with the techniques of this disclosure.

FIG. **5** is a flow diagram that illustrates one example of a method of sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range, consistent with the techniques of this disclosure.

DETAILED DESCRIPTION

In general, this disclosure describes techniques for using an arc position encoder to sense an angular position of a rotating object over an extended angular position range. For example, the arc position encoder may comprise a substantially 180-degree angular position sensing range, e.g., an angular position sensing range that is within +/−1%, 5%, or 10% of 180 degrees, as some examples. As described in greater detail below, the techniques of this disclosure may, in some cases, enable extending the 180-degree sensing range of the arc position encoder, for example, by incorporating additional functional elements into the arc position encoder, and without adding any structural elements that may substantially increase the outer dimensions of the arc position encoder, such that the arc position encoder may be used to sense an angular position of a rotating object over an angular position range that includes up to 360 degrees.

In particular, the techniques described herein may enable extending the 180-degree sensing range of the arc position encoder such that the arc position encoder may be used to sense the angular position of the rotating object anywhere within a 360-degree angular position range, i.e., anywhere within an angular position range that includes up to 360 degrees. More specifically, the techniques may enable the arc position encoder to sense the angular position of the rotating object within the 180-degree sensing range of the arc position encoder, as well as outside of the 180-degree sensing range and anywhere within the remaining 180-degree angular position range, wherein the 180-degree sensing range and the remaining 180-degree angular position range collectively define the 360-degree angular position range. For example, using the techniques of this disclosure, the arc position encoder may be configured to sense the angular position of the rotating object within the 360-degree angular position range, or within a subset of the 360-degree angular position range, e.g., a 270-degree angular position range.

An angular, or "rotary," position encoder may sense an angular position of an object that is rotating about an axis of rotation relative to the angular position encoder. For example, in the case of the angular position encoder employing magnetic sensing techniques, the angular position encoder may sense an angular position of a magnetic target that is coupled to the rotating object relative to one or more magnetic field sensors disposed within a base of the angular position encoder. The magnetic target may be disposed substantially at a center of the base so as to generate a uniform magnetic field which varies from the perspective of the one or more magnetic field sensors based on the angular position of the magnetic target relative to the sensors. For example, the one or more magnetic field sensors may include magnetoresistive (MR) sensors, Hall-Effect sensors, or other magnetic sensors. In some examples, in instances where MR sensors are used, each MR sensor may be configured in a Wheatstone-Bridge configuration, or another configuration.

Existing angular position encoders, and, in particular, those employing magnetic sensing techniques, are generally configured to sense an angular position of a rotating object in one of a 180-degree and a 360-degree angular position range. For example, an angular position encoder configured to sense an angular position of a rotating object over a 180-degree angular position range may comprise a 180-degree, or "arc" position encoder, which may include an arc base and one or more magnetic field sensors, e.g., MR sensors, or other sensors, disposed within the arc base. Alternatively, an angular position encoder configured to sense an angular position of a rotating object over a full 360-degree angular position range may comprise a relatively more complex 360-degree, or "full-range," position encoder, which may include a circular base and one or more magnetic field sensors disposed within the circular base. In some examples, the circular base may require relatively more magnetic field sensors than the arc base of the arc position encoder in order to enable sensing the angular position of the rotating object over the 360-degree angular position range.

Accordingly, existing techniques for using angular position encoders to sense angular position of rotating objects include using full-range position encoders to sense angular position of rotating objects over a 360-degree range, as well as arc position encoders to sense angular position of rotating objects over a 180-degree range. Additionally, existing techniques may include combining multiple, e.g., two, arc position encoders to sense angular position of rotating objects over a 360-degree range. Furthermore, as previously described, full-range angular position encoders may require relatively more complex hardware, e.g., a circular base and a greater number of magnetic field sensors disposed within the circular base, as well as more complex processing of output signals of the magnetic field sensors, compared to arc position encoders. In contrast, arc position encoders may require relatively less complex hardware, e.g., an arc base and fewer magnetic field sensors disposed within the arc base, as well as less complex signal processing, compared to full-range angular position encoders. However, arc position encoders may have a limited angular position sensing range, i.e., a 180-degree angular position sensing range, as explained above.

As previously described, the techniques of this disclosure may, in some cases, enable extending a substantially 180-degree sensing range of an arc position encoder. As one example consistent with the techniques described herein, the arc position encoder may include, in addition to one or more magnetic field sensors disposed within a base of the arc position encoder, one or more polarity transition sensors also disposed within the base. For example, the one or more polarity transition sensors may be disposed substantially at one or more ends of the base. In some examples, additional polarity transition sensors may be disposed substantially away from the ends along an arc length of the base (e.g., at a middle point along the arc length of the base). According to the techniques, the one or more polarity transition sensors may be configured to sense transitions of opposing magnetic poles of a rotating magnetic target (e.g., North and South magnetic poles disposed on opposite ends of the magnetic target) of the arc position encoder, which may be coupled to the rotating object, into and out of the 180-degree sensing range. For example, at any given time, one of two such opposing magnetic poles may be located within the 180-degree sensing range, while the other of the two opposing magnetic poles may be located outside of the 180-degree sensing range. As such, the one or more polarity transition sensors may be configured to sense transitions of each of the two opposing magnetic poles into and out of the 180-degree sensing range. In some examples, the one or more polarity transition sensors disposed substantially at the one or more ends of the base and the additional polarity transition sensors disposed substantially away from the ends along the arc length of the base may be used to sense the transitions, wherein the additional polarity transition sensors may be used to verify the transitions sensed by the one or more polarity transition sensors disposed substantially at the one or more ends of the base.

Development of the techniques described herein has demonstrated that, in general, opposing magnetic poles of a rotating magnetic target of an arc position encoder produce substantially similar (e.g., symmetrical) responses with respect to one or more magnetic sensing elements disposed within a base of the arc position encoder. This is the case in particular with respect to MR sensors, which may generate substantially similar outputs in response to magnetic fields having a same field angle relative to each of the MR sensors, but opposite field polarities. The techniques of this disclosure may, in some cases, take advantage of the above-described phenomenon in order to extend the substantially 180-degree sensing range of the arc position encoder, as described above.

For example, by sensing the transitions of the two opposing magnetic poles using the one or more polarity transition sensors in the manner described above, the arc position encoder may be configured to determine which of the two opposing magnetic poles is present within the 180-degree sensing range at any given time. The arc position encoder may be further configured to sense the position of the respective magnetic pole within the 180-degree sensing range (e.g., as the magnetic pole travels through the 180-degree sensing range) using the one or more magnetic field sensors. For example, the one or more magnetic field sensors may sense relative proximity of the respective magnetic pole to each of the one or more magnetic field sensors.

In some examples, the angular position of the respective magnetic pole within the 180-degree sensing range may correspond to an angular position of the rotating object coupled to the magnetic target within a corresponding 180-degree sub-range of the 360-degree angular position range. In this manner, for the two opposing magnetic poles described above, two such 180-degree sub-ranges may be defined within the 360-degree angular position range. Furthermore, because the two opposing magnetic poles are conventionally disposed on opposite ends of the magnetic target, as also described above, the two 180-degree sub-ranges may be 180-degrees out of phase with respect to one another. In other words, the two 180-degree sub-ranges may be consecutive and non-overlapping within the 360-degree angular position range, i.e., each 180-degree sub-range may comprise one half of the full 360-degree angular position range. As such, the arc position encoder may be configured to sense the angular position of each of the two opposing magnetic poles within the 180-degree sensing range when the respective magnetic pole is present within the sensing range, which may correspond to the angular position of the rotating object within each of the two 180-degree sub-ranges, or, collectively, within the full 360-degree angular position range.

As explained above, the techniques of this disclosure may, in some cases, effectively extend the substantially 180-degree sensing range of the arc position encoder to encompass the 360-degree angular position range. As a result, the arc position encoder may be configured to sense the angular position of the magnetic target, and thereby the rotating object, over the extended 360-degree angular position range, i.e., anywhere within an angular position range that includes up to 360 degrees. In this manner, the techniques of this disclosure may reduce the complexity of angular position encoders used to sense angular position of rotating objects over a 360-degree angular position range, while requiring minimal additional functional components and signal processing resources, and without requiring any additional structural elements that may substantially increase the outer dimensions of the arc position encoder.

FIG. **1** is a block diagram that illustrates one example of an angular position sensing system **100**, consistent with the techniques of this disclosure. As shown in FIG. **1**, system **100** includes a positive power supply **102**, a negative power supply **104**, a position input **106**, an arc position encoder **108**, one or more arc position encoder output signal(s) **110**, a processing module **112**, and one or more processing module output signal(s) **114**. System **100** may comprise an electro-mechanical system or device of any kind, including any combination of mechanical structural components and hardware, electro-mechanical transducers, discrete electronic components, digital and/or analog circuitry, and mechanical and electronic sub-systems or sub-devices of any kind. Examples of processing module **112** are described in greater detail below. Examples of arc position encoder **108** are also described in greater detail below, as well as with reference to arc position encoders **200** and **300** of FIGS. **2** and **3**, respectively.

In the example of FIG. **1**, position input **106** may comprise an angular position of a rotating object (not shown) within a 360-degree angular position range relative to arc position encoder **108**. In other words, position input **106** may represent a physical angular position of the rotating object within the 360-degree angular position range (i.e., anywhere within an angular position range that includes up to 360 degrees), relative to arc position encoder **108**. For example, the rotating object may be configured to rotate about an axis of rotation located substantially in a center of a circle defined by a base or arc position encoder **108**, as will be described in greater detail below with reference to FIGS. **2** and **3**. In some examples, the rotating object may comprise any of a variety of rotating shafts, gears, or wheels. In other examples, the rotating object may comprise another object that rotates about the axis or rotation.

System **100**, and in particular, arc position encoder **108**, may be configured to convert position input **106** from an angular position of the rotating object to one or more electrical signals in order to generate arc position encoder output signal(s) **110**. For example, arc position encoder output signal(s) **110** may comprise one or more voltage and/or current signals indicative of position input **106**, i.e., of the angular position of the rotating object within the 360-degree angular position range relative to arc position encoder **108**. Furthermore, processing module **112** may be configured to process arc position encoder output signal(s) **110** to generate processing module output signal(s) **114**. Processing module output signal(s) **114** may comprise any combination of analog and/or digital signals or other information used to represent the angular position of the rotating object within the 360-degree angular position range. As one example, processing module output signal(s) **114** may comprise one or more values indicative of the exact angular position of the rotating object within the 360-degree angular position range (e.g., one or more values between 0 and 360 degrees, or 0 to 2π radians). As another example, processing module output signal(s) **114** may comprise one or more values indicative of an angular position of the rotating object within a subset (e.g., a 180-degree sub-range) of the 360-degree angular position range (e.g., one or more values between 0 and 180 degrees, or 0 to π radians), as well as one or more values indicative of the subset itself (e.g., one or more values indicating a first or a second 180-degree sub-range). In any case, processing module **112** may process arc position encoder output signal(s) **110** (e.g., filter, scale, normalize, level-shift, combine, etc.,) in any manner to generate processing module output signal(s) **114**.

Processing module **112** may comprise any suitable arrangement of hardware, software, firmware, or any combination thereof, to perform the techniques attributed to processing module **112** in this disclosure. In general, processing module **112** may include any of one or more microprocessors, microcontrollers, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or any other equivalent integrated or discrete logic circuitry, as well as any combination of such components. Furthermore, processing module **112** may include various types of analog circuitry, in addition to, or in place of, the logic devices and circuitry described above.

Additionally, positive power supply **102** and negative power supply **104** may each comprise any power supply unit, module, or circuitry also included within system **100**, which may, in some examples, be integrated with arc position encoder **108** and/or processing module **112** within a common enclosure, or on a common printed circuit board (PCB). Although positive power supply **102**, negative power supply **104**, position input **106**, arc position encoder **108**, arc position encoder output signal(s) **110**, processing module **112**, and processing module output signal(s) **114** of system **100** are described as separate units or modules for conceptual purposes, in some examples, any combination of these components of system **100** may be functionally integrated within a common enclosure, housing, or electronics, such as an electronic device (e.g., an ASIC).

Additionally, in this disclosure, any reference made to a memory, or a memory device, used to store instructions, data, or other information, includes any volatile or non-volatile media, such as random access memory (RAM), read only memory (ROM), non-volatile RAM (NVRAM), electrically erasable programmable ROM (EEPROM), flash memory, and the like. In some examples, one or more memory devices may be external to system **100** and/or processing module **112**, for example, external to an enclosure or a common PCB used to enclose or house system **100** and/or processing module **112**. In other examples, the one or more memory devices may be internal to system **100** and/or processing module **112**, e.g., included within a common enclosure or on a common PCB.

According to the techniques of this disclosure, as one example, system **100**, including arc position encoder **108** and processing module **112**, may be configured to sense an angular position of a rotating object over an angular position range that includes up to 360 degrees. As previously described, the rotating object may comprise any of a variety of rotating shafts, gears, or wheels. For example, arc position encoder **108** may comprise a substantially 180-degree angular position sensing range, e.g., an angular position sensing range that is within +/−1%, 5%, or 10% of 180 degrees, as some examples. In this example, arc position encoder **108** may include a base comprising an arc length defined by a first end and a second end of the base, and one or more magnetic field sensors disposed within the base between the first and second ends. For example, the arc length of the base may correspond to the 180-degree angular position sensing range of arc position encoder **108**. Furthermore, the one or more magnetic field sensors may comprise one or more MR sensors, or other magnetic sensors. Also in this example, arc position encoder **108** may further include one or more polarity transition sensors disposed within the base between the first and second ends. For example, the one or more polarity transition sensors may comprise one or more MR sensors, Hall-Effect sensors, or other magnetic sensors.

Furthermore, arc position encoder **108** may still further include a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field. For example, the first and second magnetic poles may each comprise one or more North (N) and South (S) magnetic poles of the magnetic target. In this example, the magnetic target may be coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base.

Also in this example, at any given time, one of the first and second magnetic poles may be located within the 180-degree angular position sensing range of arc position encoder **108**, and another one of the first and second magnetic poles may be located outside of the 180-degree angular position sensing range. Stated another way, one of the first and second magnetic poles may be located between 0 and 180 degrees of the 360-degree angular position range, while the other one of the first and second magnetic poles may be located between 180 and 360 degrees of the 360-degree angular position range, at any given time.

In this manner, angular position sensing system **100** of FIG. **1** represents an example of an angular position sensing system for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees, the system comprising an arc position encoder comprising a substantially 180-degree angular position sensing range, wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more polarity transition sensors disposed within the base between the first and second ends, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

FIG. **2** is a conceptual diagram that illustrates a front view of one example of an arc position encoder **200** which may be used in conjunction with the example angular position sensing system **100** of FIG. **1**, consistent with the techniques of this disclosure. In other words, arc position encoder **200** represents one example of arc position encoder **108** depicted in FIG. **1**.

As shown in FIG. **2**, arc position encoder **200** includes a base **202** comprising an arc length defined by a first end **204**A and a second end **204**B of base **202**, as defined by horizontal axis **220**, one or more magnetic field sensors **206**A-**206**G disposed within base **202** between first and second ends **204**A, **204**B, one or more polarity transition sensors **208**A, **208**B, and **208**C disposed within base **202**, and a magnetic target **210** comprising a first magnetic pole **214**A and a second magnetic pole **214**B disposed on opposite ends of magnetic target **210** so as to generate a uniform magnetic field **216**A and **216**B. Magnetic target **210** may also comprise a beam coupling **212**, as also shown in FIG. **2**.

In the example of FIG. **2**, base **202** may comprise part of an enclosure or housing of arc position encoder **200**. Furthermore, arc position encoder **200** may be configured to be mounted, via base **202**, within another structure, such as a system (e.g., system **100** of FIG. **1**) enclosure or housing, or a system chassis. In some examples, base **202** may further include one or more mounting holes or couplings (not shown), which may be used to mount base **202** within the structure or chassis.

As can be seen in FIG. **2**, a total physical angular range of arc position encoder **200**, as defined by base **202**, comprises substantially 180-degrees. In other examples, arc position encoder **200** may comprise a different (e.g., a smaller, or a larger) total physical angular range, i.e., base **202** may comprise a longer or a shorter arc length. Additionally, in some examples, more or fewer magnetic field sensors and polarity transition sensors may be disposed within base **202**. Furthermore, in other examples, the relative placement of magnetic field sensors **206**A-**206**G and polarity transition sensors **208**A, **208**B, **208**C, as well as any other magnetic field sensors and polarity transition sensors, within base **202**, may be different from the placement depicted in FIG. **2**.

For example, magnetic field sensors **206**A-**206**G and polarity transition sensors **208**A, **208**B, **208**C are depicted in FIG. **2** as substantially uniformly spaced within base **202** between first and second ends **204**A, **204**B. As one example, magnetic field sensors **206**A-**206**G and polarity transition sensors **208**A, **208**B, **208**C may be spaced within base **202** in a non-uniform manner, or using another spacing or distribution scheme. As one example, polarity transition sensor **208**B may be disposed within base **202** at a point along the arc length of base **202** that is substantially offset, or away from a middle point of the arc length relative to first and second ends **204**A, **204**B. As another example, only a subset of polarity transition sensors **208**A, **208**B, **208**C may be disposed within base **202**, e.g., one or more of polarity transition sensors **208**A, **208**C may be disposed within base **202** substantially at one or more of first and second ends **204**A, **204**B.

In the example of FIG. **2**, the total physical angular range of arc position encoder **200** corresponds to a substantially 180-degree angular position sensing range of arc position encoder **200**. In other words, base **202** of arc position encoder **200** spans substantially 180-degrees so as to define the 180-degree angular position sensing range of arc position encoder **200**. In the example of FIG. **2**, the 180-degree angular position sensing range is further defined by magnetic field sensors **206**A-**206**G disposed within base **202**, and, more specifically, their relative placement within base **202**. For example, the substantially uniform distribution, or spacing, of magnetic field sensors **206**A-**206**G within base **202** between first and second ends **204**A, **204**B, as well as the presence of magnetic field sensors **206**A, **206**G substantially at first and second ends **204**A, **204**B, respectively, as depicted in FIG. **2**, defines the 180-degree angular position sensing range of arc position encoder **200**.

Moreover, each of magnetic field sensors **206**A-**206**G is configured to sense relative proximity of one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range of arc position encoder **200** to the respective magnetic field sensor. As such, an angular position sensing range of a particular one of magnetic field sensors **206**A-**206**G may be a sub-set (e.g., 30-degrees, or 5-degrees) of the 180-degree sensing range of arc position encoder **200**, and may be defined by the number and relative placement (e.g., a uniform spacing) of magnetic field sensors **206**A-**206**G within base **202**.

As previously explained, in other examples, arc position encoder **200** may comprise a different total physical angular range as defined by base **202**, as well as a different number and/or relative placement of magnetic field sensors **206**A-**206**G within base **202**. For example, base **202** of arc position encoder **200** may span an arc length that is slightly longer than 180 degrees, while magnetic field sensors **206**A-**206**G, or any other magnetic field sensors, may be disposed within a 180-degree subset of the arc length of base **202** so as to define the 180-degree angular position sensing range of arc position encoder **200**.

Additionally, in the example of FIG. **2**, magnetic target **210** may be coupled to a rotating object (also not shown) using beam coupling **212** disposed within magnetic target **210**, as shown in FIG. **2**. Beam coupling **212** may comprise any of a wide variety of thread couplings, clamp couplings, or other types of couplings. For example, the rotating object, such as a rotating shaft, gear, or wheel, may be coupled to magnetic target **210** via beam coupling **212** so as to rotate together with magnetic target **210** about an axis of rotation located substantially in a center of a circle defined by base **202**, i.e., at or near the center of the circle. In the example of FIG. **2**, the location of the axis of rotation may coincide with the location of beam coupling **212**, such that the axis of rotation passes through beam coupling **212** and extends in an inward/outward direction (i.e., in and out of the page) relative to the front view of arc position encoder **200**. For example, the rotating object and magnetic target **210** may rotate about the axis of rotation in one of a clockwise direction of rotation **218**A and a counter-clockwise direction of rotation **218**B relative to base **202**, as also shown in FIG. **2**.

As also shown in FIG. **2**, as magnetic target **210** rotates in one of clockwise direction of rotation **218**A and counter-clockwise direction of rotation **218**B relative to base **202**, magnetic field sensors **206**A-**206**G may be configured to sense magnetic field **216**A, **216**B generated by magnetic target **210**. For example, magnetic field sensors **206**A-**206**G may be configured to sense relative proximity of one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range of arc position encoder **200** to each of magnetic field sensors **206**A-**206**G, as explained in greater detail below. Additionally, polarity transition sensors **208**A, **208**B, **208**C may be configured to sense transitions of each of first and second magnetic poles **214**A, **214**B into and out of the 180-degree sensing range, as also explained in greater detail below. In other examples, magnetic field sensors **206**A-**206**E and polarity transition sensors **208**A, **208**B each may comprise more or fewer sensors, as already explained above.

According to the techniques of this disclosure, in one example, arc position encoder **200** may be included within an angular position sensing system (e.g., system **100** of FIG. **1**) for sensing an angular position of a rotating object (not shown) over an angular position range that includes up to 360 degrees, i.e., anywhere within an angular position range that includes up to 360 degrees. In this example, arc position encoder **200** may comprise a substantially 180-degree angular position sensing range. For example, arc position encoder **200** may include base **202** comprising an arc length defined by first end **204**A and second end **204**B of base **202**, one or more magnetic field sensors **206**A-**206**G disposed within base **202** between first and second ends **204**A, **204**B, one or more polarity transition sensors **208**A, **208**B, **208**C disposed within base **202** between first and second ends **204**A, **204**B, and magnetic target **210** comprising first magnetic pole **214**A and second magnetic pole **214**B disposed on opposite ends of magnetic target **210** so as to generate uniform magnetic field **216**A, **216**B. In this example, magnetic target **210** may be coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by base **202**. Also in this example, at any given time, one of first and second magnetic poles **214**A, **214**B may be located within the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B may be located outside of the 180-degree angular position sensing range.

As another example, magnetic field sensors **206**A-**206**G may be configured to sense relative proximity of the one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range of arc position encoder **200** to each magnetic field sensor of magnetic field sensors **206**A-**206**G. For example, each of magnetic field sensors **206**A-**206**G may be configured to sense the one of first and second magnetic poles **214**A, **214**B located within the 180-degree angular position sensing range as the one of first and second magnetic poles **214**A, **214**B passes the respective one of magnetic field sensors **206**A-**206**G, and generate an output signal indicative of a position of the one of first and second magnetic poles **214**A, **214**B relative to the respective one of magnetic field sensors **206**A-**206**G. In this example, the position indicated by the output signal generated by each of magnetic field sensors **206**A-**206**G may comprise an angular position of the one of first and second magnetic poles **214**A, **214**B over a sub-range, e.g., a 30-degree sub-range, or an 5-degree sub-range, of the 180-degree sensing range of arc position encoder **200**, that corresponds to the respective one of magnetic field sensors **206**A-**206**G, and which may be referred to as an angular position sensing range of the respective one of magnetic field sensors **206**A-**206**G.

As explained in greater detail below, a processing module (e.g., processing module **112** of FIG. **1**) may be configured to combine the output signals generated by each of magnetic field sensors **206**A-**206**G to generate one or more common output signals (e.g., processing module output signal(s) **114** of FIG. **1**). For example, the one or more common output signals may indicate an angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range of arc position encoder **200**, when the respective one of first and second magnetic poles **214**A, **214**B is present within the 180-degree sensing range.

In this example, to generate the one or more common output signals, the processing module may be configured to combine (e.g., level-shift) the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range to determine the angular position of the rotating object over the angular position range that includes up to 360 degrees. In addition, the processing module may be further configured to process one or more of the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range, such as by performing any of a variety of filtering, level-shifting or translation, or other types of signal processing or conditioning. Finally, to generate the one or more common output signals, the processing module may be still further configured to linearize one or more of the angular position of each of first and second magnetic poles **214**A, **214**B over the 180-degree sensing range and the angular position of the rotating object over the angular position range that includes up to 360 degrees, e.g., using the techniques described in commonly owned U.S. Pat. No. 7,030,604, or any other techniques applicable to linearization of output signals from a plurality of magnetic sensors (e.g., a magnetic sensor array). In other words, the one or more common output signals may comprise a linearized signal indicative of the angular position of the rotating object over the angular position range that includes up to 360 degrees. Finally, the processing module may be configured to output the one or more common output signals, and/or store the one or more common output signals in the one or more memories, or memory devices, described above with reference to system **100** of FIG. **1**.

Additionally, as described above, the magnetic field sensors of magnetic field sensors **206**A-**206**G may be substantially uniformly spaced within base **202** between first and second ends **204**A, **204**B. Alternatively, the magnetic field sensors of magnetic field sensors **206**A-**206**G may be non-uniformly, or otherwise asymmetrically, spaced within base **202** between first and second ends **204**A, **204**B.

As still another example, polarity transition sensors **208**A, **208**B, **208**C may be configured to sense a transition of one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range.

For example, to sense the transition of the one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and the other one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range, each polarity transition sensor of polarity transition sensors **208**A, **208**B, **208**C may be configured to sense a presence of one of first and second magnetic poles **214**A, **214**B within substantially close proximity to the respective one of polarity transition sensors **208**A, **208**B, **208**C, as the one of first and second magnetic poles **214**A, **214**B passes the respective one of polarity transition sensors **208**A, **208**B, **208**C.

In some examples, polarity transition sensors **208**A, **208**B, **208**C may comprise latching sensors configured to latch the transition of the one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and the other one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range, sensed by polarity transition sensors **208**A, **208**B, **208**C. Alternatively, a processing module (not shown) (e.g., processing module **112** of FIG. **1**), as described in greater detail below, may provide this latching functionality for each of polarity transition sensors **208**A, **208**B, **208**C. For example, the processing module may poll, or otherwise monitor each of polarity transition sensors **208**A, **208**B, **208**C to detect the transition of the one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and the other one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range, as the transition is sensed by the respective one of polarity transition sensors **208**A, **208**B, **208**C. In this manner, polarity transition sensors **208**A, **208**B, **208**C may comprise non-latching (e.g., lower cost) sensors, while still allowing for latching functionality for each of polarity transition sensors **208**A, **208**B, **208**C.

Additionally, as described above, polarity transition sensors **208**A, **208**B, **208**C may be substantially uniformly spaced within base **202** between first and second ends **204**A, **204**B. Alternatively, polarity transition sensors **208**A, **208**B, **208**C may be non-uniformly, or otherwise asymmetrically, spaced within base **202** between first and second ends **204**A, **204**B.

In some examples, polarity transition sensors **208**A, **208**B, **208**C may comprise one or more of polarity transition sensors **208**A, **208**B, **208**C disposed substantially at one or more of first and second ends **204**A, **204**B of base **202**. Additionally, in other examples, the one or more of polarity transition sensors **208**A, **208**B, **208**C disposed substantially at the one or more of first and second ends **204**A, **204**B of base **202** may comprise a first one or more of polarity transition sensors **208**A, **208**B, **208**C, wherein polarity transition sensors **208**A, **208**B, **208**C may further comprise a second one or more of polarity transition sensors **208**A, **208**B, **208**C disposed substantially away from first and second ends **204**A, **204**B along the arc length of base **202**.

As still other examples, each magnetic field sensor of magnetic field sensors **206**A-**206**G may comprise a magnetoresistive (MR) sensor. Alternatively, each magnetic field sensor of magnetic field sensors **206**A-**206**G may comprise a Hall-Effect sensor, or another sensor. In a similar manner, each polarity transition sensor of polarity transition sensors **208**A, **208**B, **208**C may comprise an MR sensor. Alternatively, each polarity transition sensor of polarity transition sensors **208**A, **208**B, **208**C may comprise a Hall-Effect sensor, or another sensor.

In the examples described above, MR or Hall-Effect sensors may be used for one or both of magnetic field sensors **206**A-**206**G and polarity transition sensors **208**A, **208**B, **208**C. For example, while both MR and Hall-Effect sensors may be used to sense a presence of an external magnetic field (e.g., uniform magnetic field **216**A, **216**B generated by first and second magnetic poles **214**A, **214**B of magnetic target **210**, as described above and with reference to FIGS. **2** and **3**), these sensors differ greatly in their manner of operation.

As one example, an MR sensor may be generally configured to sense a magnitude of an external magnetic field applied to the MR sensor (e.g., until a point of saturation of the MR sensor), as well as an angle of the external magnetic field relative to the MR sensor. For example, the MR sensor may comprise one or more magnetoresistive elements a resistance of each of which changes in response to the angle (and, until the point of saturation, the magnitude) of the external magnetic field relative to the respective magnetoresistive element. For example, the change in resistance of each magnetoresistive element may be proportional to a difference between a direction of a bias current flowing through the element, and an angle of magnetization (which may be referred to as a magnetization vector) of the element by the external magnetic field. In this example, the angle of magnetization of the element by the external magnetic field is a function of the angle at which the external magnetic field is applied relative to the element. In other words, an MR sensor may respond in a similar manner to multiple magnetic fields that are applied to the MR sensor at a same angle, but have different, e.g., opposite, polarities.

In contrast, Hall-Effect sensors may generally be configured to sense a magnitude and a polarity of an external magnetic field applied transversely (i.e., at a particular angle) relative to a direction of a bias current flowing through a sensing element of the Hall-Effect sensor. The Hall-Effect sensor may sense the magnitude and polarity of the external magnetic field by generating a voltage across a dimension of the sensing element which is transverse to each of the direction of the bias current and the direction of the external magnetic field. The magnitude of this voltage (sometimes referred to as a Hall voltage) is proportional to the magnitude of the external magnetic field, and the polarity of the voltage is indicative of the polarity of the external magnetic field. Accordingly, because Hall-Effect sensors may generate an output in response to an external magnetic field that is dependent on a polarity of the external magnetic field, in one embodiment, using one or more MR sensors as magnetic field sensors **206**A-**206**G may be preferred. Alternatively, in other embodiments, magnetic field sensors **206**A-**206**G may comprise other sensors, as described above.

In still other examples, the angular position sensing system may further comprise a processing module (not shown) (e.g., processing module **112** of FIG. **1**) configured to determine one or more polarity transition output signals of polarity transition sensors **208**A, **208**B, **208**C, determine one or more proximity output signals of magnetic field sensors **206**A-**206**G, and determine the angular position of the rotating object within the angular position range that includes up to 360 degrees, based at least in part on the one or more polarity transition output signals and the one or more proximity output signals.

In some examples, the angular position range may comprise a 360-degree angular position range (or a substantially 360-degree angular position range). In these examples, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module may be configured to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition output signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. In these examples, the processing module may be further configured to determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity output signals.

In other examples, polarity transition sensors **208**A, **208**B, **208**C may comprise a first one or more of polarity transition sensors **208**A, **208**B, **208**C disposed substantially at one or more of first and second ends **204**A, **204**B of base **202**, and a second one or more of polarity transition sensors **208**A, **208**B, **208**C disposed substantially away from first and second ends **204**A, **204**B along the arc length of base **202**. In these examples, to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to the first or the second 180-degree angular position sub-range of the 360-degree angular position range based at least in part on the one or more polarity transition output signals, the processing module may be configured to perform the determination based at least in part on the one or more polarity transition output signals of the first one or more of polarity transition sensors **208**A, **208**B, **208**C, and verify the determination based at least in part on the one or more polarity transition output signals of the second one or more of polarity transition sensors **208**A, **208**B, **208**C.

In still other examples, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module may be configured to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a particular subset (e.g., a "quadrant") of the first or the second 180-degree angular position sub-range described above, based at least in part on the one or more polarity transition output signals. In these examples, the processing module may be further configured to determine whether the angular position of the rotating object corresponds to the first or the second 180-degree angular position sub-range based at least in part on the determined subset. Finally, having determined the one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object corresponds, the processing module may be further configured to determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges, based at least in part on the one or more proximity output signals. In these examples, each (i.e., all three) of polarity transition sensors **208**A, **208**B, **208**C and their respective polarity transition output signals may be used, wherein each of polarity transition sensors **208**A, **208**B, **208**C comprises at least one polarity transition sensor (e.g., a Hall-Effect sensor). In other examples, additional polarity transition sensors may be used.

In still other examples, the processing module may be further configured to determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to arc position encoder **200**, based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees. The particular techniques which may, in some examples, be used by the processing module to make these determinations will be described in greater detail below with reference to FIG. **5**.

Finally, in some examples, the processing module may be further configured to determine the direction of angular rotation of the rotating object relative to arc position encoder **200** based at least in part on the one or more polarity transition output signals. For example, rather than being configured to determine the direction of angular rotation of the rotating object relative to arc position encoder **200** based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees, as described above, the processing module may be configured to determine the direction of angular rotation directly from the one or more polarity transition output signals. In some examples, various properties of the one or more polarity transition output signals, e.g., a phase difference, times of occurrence, or timing, generally, of two or more of such signals, may be indicative of the direction of angular rotation of the rotating object relative to arc position encoder **200**.

For example, the processing module may be configured to determine, based at least in part on the one or more polarity transition output signals, that a transition of one of first and second magnetic poles **214**A, **214**B into the 180-degree angular position sensing range of arc position encoder **200**, and another one of first and second magnetic poles **214**A, **214**B out of the 180-degree angular position sensing range, has occurred. As one example, the processing module may be configured to determine the direction of angular rotation of the rotating object based on, e.g., which of first and second magnetic poles **214**A, **214**B has transitioned into and out of the 180-degree angular position sensing range. As another example, the processing module may be configured to determine the direction of angular rotation of the rotating object based on one or more previously detected transitions (e.g., indications of which may be stored in one or more memories, or memory devices, within a corresponding angular position sensing system, e.g., system **100**) of first and second magnetic poles **214**A, **214**B into and out of the 180-degree angular position sensing range, and the currently detected transition.

In this manner, arc position encoder **200** of FIG. **2** represents an example of an arc position encoder included within an angular position sensing system for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees, wherein the arc position encoder comprises a substantially 180-degree angular position sensing range, and wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more polarity transition sensors disposed within the base between the first and second ends, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

FIG. **3** is a conceptual diagram that illustrates a perspective view of the example arc position encoder **200** of FIG. **2**, consistent with the techniques of this disclosure. As shown in FIG. **3**, arc position encoder **300** includes a base **302**A, **302**B, and **302**C comprising an arc length defined by a first end **304**A and a second end **304**B of base **302**A, **302**B, **302**C, one or more magnetic field sensors **306**A, **306**D, and **306**G disposed within base **302**A, **302**B, **302**C between first and second ends **304**A, **304**B, one or more polarity transition sensors **308**A, **308**B, and **308**C disposed within base **302**A, **302**B, **302**C, respectively, and a magnetic target **310** comprising a first magnetic pole **314**A and a second magnetic pole **314**B disposed on opposite ends of magnetic target **310** so as to generate a uniform magnetic field **316**A and **316**B.

In the example of FIG. **3**, base **302**A, **302**B, **302**C is depicted using three sections (i.e., **302**A, **302**B, **302**C) for purposes of illustrating arc position encoder **300** in greater detail. It should be understood that base **302**A, **302**B, **302**C comprises a single base, e.g., base **202** of FIG. **2**, and that, although not shown in FIG. **3**, the sections of base **302**A, **302**B, **302**C are joined to form a single base (e.g., base **302**) above the break-out dashed lines located above base **302**A, **302**C, and below the break-out dashed lines located below base **302**B. Additionally, the perspective view of arc position encoder **300** depicts only three magnetic field sensors, i.e., magnetic field sensors **306**A, **306**D, **306**G. It should also be understood that arc position encoder **300** may comprise one or more (e.g., 3, 4, 5, etc.) magnetic field sensors, e.g., **206**A-

206G, as described with reference to FIG. **2**, disposed within base **302**A, **302**B, **302**C, between first and second ends **304**A, **304**B. Similarly, each of polarity transition sensors **308**A, **308**B, **308**C may comprise one or more polarity transition sensors. Additionally, although not shown in FIG. **3**, more or fewer polarity transition sensors may be disposed within base **302**A, **302**B, **302**C.

Furthermore, magnetic field sensors **306**A, **306**D, **306**G, depicted as each having a cylindrical geometry, and polarity transition sensors **308**A, **308**B, **308**C, depicted as each having a rectangular solid geometry (or vice versa), are depicted as different sensors for purposes of illustration only. As explained above with reference to FIG. **2**, each of magnetic field sensors **306**A, **306**D, **306**G and polarity transition sensors **308**A, **308**B, **308**C may comprise a same type of sensor, e.g., an MR sensor, or a Hall-Effect Sensor, or another type of sensor in some examples. Additionally, magnetic field sensors **306**A, **306**D, **306**G and polarity transition sensors **308**A, **308**B, **308**C may not be co-located as depicted in FIG. **3**. In other words, in some examples, one or more of magnetic field sensors **306**A, **306**D, **306**G and one or more of polarity transition sensors **308**A, **308**B, **308**C may be shifted relative to one another along the arc length of base **302**A, **302**B, **302**C.

Also, in the example of FIG. **3**, magnetic target **310** is coupled to a rotating shaft **322** via beam coupling **312** disposed within magnetic target **310**. In some examples, rotating shaft **322** may be coupled to a rotating object (not shown). In other examples, rotating shaft **322** may itself be a rotating object, or part of a rotating object. Beam coupling **312** may comprise any of a wide variety of thread couplings, clamp couplings, or other types of couplings. In any case, the rotating object may be coupled to magnetic target **310** via beam coupling **312** so as to rotate together with magnetic target **310** about an axis of rotation located substantially in a center of a circle defined by base **302**A, **302**B, **302**C. In the example of FIG. **3**, the location of the axis of rotation may coincide with the location of beam coupling **312**, such that the axis of rotation passes through beam coupling **312** and extends in an inward/outward direction relative to a front view of arc position encoder **300**, as explained above with reference to arc position encoder **200** of FIG. **2**. For example, the rotating object and magnetic target **310** may rotate about the axis of rotation in one of a clockwise direction of rotation **318**A and a counterclockwise direction of rotation **318**B relative to base **302**A, **302**B, **302**C as also shown in FIG. **3**. In the example of FIG. **3**, magnetic target **310** is rotated 90-degrees in counterclockwise direction of rotation **318**B relative to magnetic target **210** as depicted in FIG. **2**.

In this manner, arc position encoder **300** of FIG. **3** represents an example of an arc position encoder included within an angular position sensing system for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees, wherein the arc position encoder comprises a substantially 180-degree angular position sensing range, and wherein the arc position encoder includes a base comprising an arc length defined by a first end and a second end of the base, one or more magnetic field sensors disposed within the base between the first and second ends, one or more polarity transition sensors disposed within the base between the first and second ends, and a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

FIGS. **4**A and **4**B are conceptual diagrams that each illustrate a front view of an example magnetic target that may be used as part of each of the example arc position encoders **200** and **300** of FIGS. **2** and **3**, respectively, consistent with the techniques of this disclosure. In other words, the magnetic target **410**A of FIG. **4**A and the magnetic target **410**B of FIG. **4**B each represent one example of each of magnetic targets **210** and **310** of FIGS. **2** and **3**, respectively.

As shown in FIG. **4**A, as one example, magnetic target **410**A may comprise a first magnetic pole **414**A and a second magnetic pole **414**B disposed on opposite ends of magnetic target **410**A so as to generate a uniform magnetic field **416**A and **416**B. Additionally, magnetic target **410**A may also comprise a beam coupling **412**, as also shown in FIG. **4**A, which may be used to couple magnetic target **410**A to a rotating object (e.g., a rotating shaft, such as rotating shaft **322** of FIG. **3**). In other words, in some examples, magnetic target **410**A may comprise a rectangular geometry and a coupling scheme for coupling magnetic target **410**A to a rotating object as depicted in FIG. **4**A, as has already been described above with reference to each of magnetic targets **210** and **310** of FIGS. **2** and **3**, respectively.

As shown in FIG. **4**B, as another example, rather than comprising a rectangular geometry as described above with reference to FIG. **4**A, magnetic target **410**B may comprise a circular magnet holder that includes two semi-circular portions **424**A and **424**B. Magnetic target **410**B may further comprise a first magnetic pole **426**A and a second magnetic pole **426**B disposed on opposite ends of magnetic target **410**B within the respective ones of portions **424**A, **424**B, so as to generate a uniform magnetic field **430**A and **430**B. Magnetic target **410**B may also comprise as a first coupling means **428**A and a second coupling means **428**B. In the example of FIG. **4**B, each of first and second coupling means **428**A, **428**B may comprise any of a wide variety of coupling means, such as, e.g., thread couplings, clamp couplings, or other types of couplings. As depicted in FIG. **4**B, first and second coupling means **428**A, **428**B each comprise a threaded bolt- or screw-based coupling.

For example, using the above-described configuration as depicted in FIG. **4**B, magnetic target **410**B may be coupled to a rotating object (e.g., a rotating shaft, such as rotating shaft **322** of FIG. **3**), an example of which is depicted as cross-section **432** in FIG. **4**B. In other words, portions **424**A, **424**B of magnetic target **410**B may be clamped, or otherwise attached to the rotating object, such as a cylindrical shaft, by clamping each of portions **424**A, **424**B around the rotating object, in some examples.

FIG. **5** is a flow diagram that illustrates one example of a method of sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range, consistent with the techniques of this disclosure. The techniques of FIG. **5** may generally be performed by any processing unit or processor, whether implemented in hardware, software, firmware, or a combination thereof, and when implemented in software or firmware, corresponding hardware may be provided to execute instructions for the software or firmware. For purposes of example, the techniques of FIG. **5** are described with respect to angular position sensing system **100** (FIG. **1**), arc position encoder **108** (FIG. **1**), **200** (FIG. **2**), and **300** (FIG. **3**), and processing module **112** (FIG. **1**), as well as various components thereof, although it should be understood that other systems or devices may be configured to perform similar techniques. Moreover, the steps illustrated in FIG. **5** may be performed in a different order or in parallel, and additional steps may be added and certain steps omitted, without departing from the techniques of this disclosure.

In one example, a processing module (e.g., **112**) of an angular position sensing system (e.g., **100**) that includes the processing module and an arc position encoder (e.g., **108**, **200**, and **300**) may be configured to sense an angular position of a rotating object over an angular position range that includes up to 360 degrees using the arc position encoder. In this example, the arc position encoder may comprise a substantially 180-degree angular position sensing range.

For example, the processing module may initially receive one or more polarity transition signals from one or more polarity transition sensors disposed within a base of the arc position encoder between a first end and a second end of the base, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range (**500**).

The processing module may further receive one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors (**502**).

The processing module may still further determine the angular position of the rotating object within the angular position range that includes up to 360 degrees based at least in part on the one or more polarity transition signals and the one or more proximity signals (**504**).

In some examples, to sense the transition of the one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and the other one of the first and second magnetic poles out of the 180-degree angular position sensing range, each polarity transition sensor of the one or more polarity transition sensors may sense a presence of one of the first and second magnetic poles within substantially close proximity to the respective one of the one or more polarity transition sensors, as the one of the first and second magnetic poles passes the respective one of the one or more polarity transition sensors. Also, in other examples, the one or more polarity transition sensors may comprise latching sensors configured to latch the transition of the one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and the other one of the first and second magnetic poles out of the 180-degree angular position sensing range, sensed by the one or more polarity transition sensors.

Additionally, in some examples, the angular position range may comprise a 360-degree angular position range (or a substantially 360-degree angular position range). In these examples, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals, the processing module may determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. The processing module may further determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity signals.

As one example, the one or more polarity transition sensors may comprise a first one or more of the one or more polarity transition sensors disposed substantially at one or more of the first and second ends of the base and a second one or more of the one or more polarity transition sensors disposed substantially away from the first and second ends along the arc length of the base. In this example, to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to the first or the second 180-degree angular position sub-range of the 360-degree angular position range based at least in part on the one or more polarity transition signals, the processing module may perform the determination based at least in part on the one or more polarity transition signals of the first one or more of the one or more polarity transition sensors, and verify the determination based at least in part on the one or more polarity transition signals of the second one or more of the one or more polarity transition sensors.

As previously described, as another example, to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module may be configured to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a particular subset (e.g., a "quadrant") of the first or the second 180-degree angular position sub-range described above, based at least in part on the one or more polarity transition output signals. In these examples, the processing module may be further configured to determine whether the angular position of the rotating object corresponds to the first or the second 180-degree angular position sub-range based at least in part on the determined subset. Finally, having determined the one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object corresponds, the processing module may be further configured to determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges, based at least in part on the one or more proximity output signals. In these examples, three or more polarity transition sensors and their respective polarity transition output signals may be used, wherein each of the polarity transition sensors may comprise at least one polarity transition sensor (e.g., a Hall-Effect sensor). In other examples, additional polarity transition sensors may be used.

In other examples, the processing module may determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees. For example, the processing module may determine the angular speed (e.g., in radians/second (w), degrees/second, or revolutions per minute (RPM)) of the rotating object based on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees at a particular first point in time, which may be referred to as a first angular position, as well as based on a second, different angular position of the rotating object within the angular position range at a subsequent second point in time. In this example, the processing module may determine the angular speed of the rotating object by dividing a difference between the first and second angular positions (e.g., second angular position-first angular position=Δ (angular position), which is proportional to the angular distance traveled by the rotating object) by a difference between the first and second times (e.g., second time-first time=Δ (time), which equals the time elapsed). For example, to determine the angular speed of the rotating object, the processing module may utilize the following expression:

$$\omega=\Delta(\text{angular position})/\Delta(\text{time}) \qquad \text{EQ. 1}$$

Where ω corresponds to the angular speed of the rotating object, Δ (angular position) corresponds to a difference between the first and second angular positions, and Δ (time) corresponds to a difference between the first and second times. In other words, the angular speed of the rotating object may be expressed as a change in angular position of the rotating object over a unit of time.

In a similar manner, the processing module may determine the direction of angular rotation (e.g., clockwise or counterclockwise) of the rotating object relative to the arc position encoder based on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees, which may once again be referred to as a first angular position, at a first point in time, by determining a second, different angular position of the rotating object within the angular position range at a subsequent second point in time. In this example, the processing module may determine the direction of angular rotation by determining a sign of a difference between the first and second angular positions (e.g., sign of Δ (angular position), where Δ (angular position)=second angular position-first angular position). For example, to determine the direction of angular rotation of the rotating object, the processing module may utilize the following expression:

$$\text{DIR}=\text{SIGN}(\Delta(\text{angular position})) \qquad \text{EQ. 2}$$

Where DIR corresponds to the direction of angular rotation of the rotating object, Δ (angular position) corresponds to the difference between the first and second angular positions, and SIGN indicates a sign operator used to determine the sign of the difference between the first and second angular positions. Accordingly, the direction of angular rotation of the rotating object may be represented using a sign (e.g., "+" or "−") that corresponds to the direction of angular rotation, which may, in turn, comprise one of e.g., a clockwise and a counterclockwise direction of rotation. In one example, DIR="+" may correspond to a clockwise direction of angular rotation of the rotating object, and DIR="−" may correspond to a counterclockwise direction of angular rotation of the rotating object. In other examples, different values of DIR may correspond to different directions of angular rotation of the rotating object.

Additionally, the processing module may determine the direction of angular rotation of the rotating object relative to the arc position encoder based at least in part on the one or more polarity transition signals. For example, rather than determining the direction of angular rotation of the rotating object relative to the arc position encoder based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees, as described above, the processing module may determine the direction of angular rotation directly from the one or more polarity transition signals. In some examples, various properties of the one or more polarity transition signals, e.g., a phase difference, times of occurrence, or timing, generally, of two or more of such signals, may be indicative of the direction of angular rotation of the rotating object relative to the arc position encoder.

For example, as described above, the processing module may determine, based at least in part on the one or more polarity transition output signals, that a transition of one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, has occurred. As one example, the processing module may determine the direction of angular rotation of the rotating object based on, e.g., which of the first and second magnetic poles has transitioned into and out of the 180-degree angular position sensing range. As another example, the processing module may determine the direction of angular rotation of the rotating object based on one or more previously detected transitions (e.g., indications of which may be stored in one or more memories, or memory devices, within the angular position sensing system) of the first and second magnetic poles into and out of the 180-degree angular position sensing range, and the currently detected transition.

In some examples, the processing module may still further output one or more signals indicative of the determined angular position of the rotating object (**506**). As one example, the processing module may output a single signal indicative of the angular position of the rotating object over the angular position sensing range that includes up to 360 degrees, e.g., a value between 0 and 360, or another value, that is representative of the angular position of the rotating object within the angular position range. Alternatively, as described above, in cases where the angular position range comprises a 360-degree angular position range, the processing module may output a first signal indicative of whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range. As also described above, the first and second 180-degree angular position sub-ranges may be non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range. Additionally, the processing module may further output a second signal indicative of the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds.

Furthermore, as also described above, to output the one or more "output" signals indicative of the determined angular position of the rotating object, the processing module may combine (e.g., level-shift) the angular position of each of the first and second magnetic poles over the 180-degree sensing range, as indicated by the one or more proximity signals from the one or more magnetic field sensors, to determine the angular position of the rotating object over the angular position range that includes up to 360 degrees. For example, the processing module may combine the one or more proximity signals generated by the one or more magnetic field sensors for each of the first and second magnetic poles when the respective one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, to generate the one or more output signals.

In addition, the processing module may further process the one or more proximity signals, prior to, or after the combining, such as by performing any of a variety of filtering, level-shifting or translation, or other types of signal processing or conditioning, to generate the one or more output signals. Finally, to generate the one or more output signals, the processing module may still further linearize one or more of the one or more proximity signals and the angular position of the rotating object over the angular position range that includes up to 360 degrees, e.g., using any techniques applicable to linearization of output signals from a plurality of magnetic sensors. In other words, the one or more output signals may comprise a linearized signal indicative of the angular position of the rotating object over the angular position range that includes up to 360 degrees.

Finally, as described above, the processing module may further output the one or more output signals, and/or store the one or more output signals in the one or more memories, or memory devices, described above with reference to system **100** of FIG. **1**.

In any case, the one or more output signals, whether represented as a single signal, or a plurality of signals, may comprise one or more analog signals, one or more digital signals, or any combination thereof.

The techniques of this disclosure may enable the angular position sensing system (e.g., angular position sensing system **100**) including the arc position encoder (e.g., arc position encoder **108**, **200**, **300**) and the processing module (e.g., processing module **112**), as described above, to sense the angular position of the rotating object over the angular position range that includes up to 360 degrees, i.e., anywhere within an angular position range that includes up to 360 degrees. Accordingly, in contrast to other angular position sensing techniques which may be used to sense an angular position of a rotating object over an angular position range that includes up to 360 degrees, for example, techniques using a plurality of (e.g., two) arc position encoders each comprising a 180-degree angular position sensing range, or a relatively more complex full-range angular position encoder, the techniques of this disclosure may enable sensing the angular position of the rotating object over the angular position range using a single arc position encoder comprising a substantially 180-degree angular position sensing range.

In this manner, the method of FIG. **5** represents an example of a method of sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range, the method comprising receiving one or more polarity transition signals from one or more polarity transition sensors disposed within a base of the arc position encoder between a first end and a second end of the base, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range, receiving one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors, and determining the angular position of the rotating object within the angular position range that includes up to 360 degrees based at least in part on the one or more polarity transition signals and the one or more proximity signals.

The techniques of this disclosure may be implemented in a wide variety of computer devices. Any components, units, or modules that have been described are provided to emphasize functional aspects, and do not necessarily require realization by different hardware units. The techniques described herein may also be implemented in hardware, software, firmware, or any combination thereof. Any features described as modules, units, or components may be implemented together in an integrated logic device, or separately as discrete but interoperable logic devices. In some cases, various features may be implemented as an integrated circuit device, such as an integrated circuit chip, or chipset.

If any aspects of the techniques are implemented in software, the techniques may be realized at least in part by a computer-readable storage medium comprising instructions that, when executed in a processor, performs one or more of the methods described above. The computer-readable storage medium may comprise a tangible computer-readable storage medium, and may form part of a larger product. The computer-readable storage medium may comprise random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, and the like. The computer-readable storage medium may also comprise a non-volatile storage device, such as a hard-disk, magnetic tape, a compact disc (CD), digital versatile disc (DVD), Blu-ray disc, holographic data storage media, or other non-volatile storage device.

The memory, or memory devices, described herein, which may be used as part of the described techniques, may also be realized in any of a wide variety of memory, or memory devices, including but not limited to, RAM, SDRAM, NVRAM, EEPROM, FLASH memory, dynamic RAM (DRAM), magnetic RAM (MRAM), or other types of memory.

The term "processor" as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated software modules or hardware modules configured for performing the techniques of this disclosure. Even if implemented in software, the techniques may use hardware such as a processor to execute the software, and a memory to store the software. In any such cases, the computers described herein may define a specific machine that is capable of executing the specific functions described herein. Also, the techniques could be fully implemented in one or more circuits or logic elements, which could also be considered a processor.

Various examples have been described. These and other examples are within the scope of the following claims.

What is claimed is:

1. An angular position sensing system for sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees, the system comprising:

an arc position encoder comprising a substantially 180-degree angular position sensing range, wherein the arc position encoder includes:

a base comprising an arc length defined by a first end and a second end of the base;

one or more magnetic field sensors disposed within the base between the first and second ends;

one or more polarity transition sensors disposed within the base between the first and second ends; and

a magnetic target comprising a first magnetic pole and a second magnetic pole disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, and wherein, at any given time, one of the first and second magnetic poles is located within the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles is located outside of the 180-degree angular position sensing range.

2. The angular position sensing system of claim 1, wherein the one or more magnetic field sensors are configured to sense relative proximity of the one of the first and second magnetic poles located within the 180-degree angular position sensing range of the arc position encoder to each magnetic field sensor of the one or more magnetic field sensors.

3. The angular position sensing system of claim 1, wherein the one or more magnetic field sensors are substantially uniformly spaced within the base between the first and second ends.

4. The angular position sensing system of claim 1, wherein the one or more polarity transition sensors are configured to sense a transition of one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range.

5. The angular position sensing system of claim 4, wherein to sense the transition of the one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and the other one of the first and second magnetic poles out of the 180-degree angular position sensing range, each polarity transition sensor of the one or more polarity transition sensors is configured to sense a presence of one of the first and second magnetic poles within substantially close proximity to the respective one of the one or more polarity transition sensors, as the one of the first and second magnetic poles passes the respective one of the one or more polarity transition sensors.

6. The angular position sensing system of claim 4, wherein the one or more polarity transition sensors comprise latching sensors configured to latch the transition of the one of the first and second magnetic poles into the 180-degree angular position sensing range of the arc position encoder, and the other one of the first and second magnetic poles out of the 180-degree angular position sensing range, sensed by the one or more polarity transition sensors.

7. The angular position sensing system of claim 1, wherein the one or more polarity transition sensors are substantially uniformly spaced within the base between the first and second ends.

8. The angular position sensing system of claim 1, wherein the one or more polarity transition sensors comprise one or more of the one or more polarity transition sensors disposed substantially at one or more of the first and second ends of the base.

9. The angular position sensing system of claim 8, wherein the one or more of the one or more polarity transition sensors disposed substantially at the one or more of the first and second ends of the base comprise a first one or more of the one or more polarity transition sensors, and wherein the one or more polarity transition sensors further comprise a second one or more of the one or more polarity transition sensors disposed substantially away from the first and second ends along the arc length of the base.

10. The angular position sensing system of claim 1, wherein each magnetic field sensor of the one or more magnetic field sensors comprises a magnetoresistive (MR) sensor.

11. The angular position sensing system of claim 1, wherein each polarity transition sensor of the one or more polarity transition sensors comprises one of a Hall-Effect sensor and a magnetoresistive (MR) sensor.

12. The angular position sensing system of claim 1, further comprising a processing module configured to:

determine one or more polarity transition output signals of the one or more polarity transition sensors;

determine one or more proximity output signals of the one or more magnetic field sensors; and

determine the angular position of the rotating object within the angular position range that includes up to 360 degrees, based at least in part on the one or more polarity transition output signals and the one or more proximity output signals.

13. The angular position sensing system of claim 12, wherein the angular position range comprises a 360-degree angular position range, and wherein to determine the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition output signals and the one or more proximity output signals, the processing module is configured to:

determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition output signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range; and

determine the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity output signals.

14. The angular position sensing system of claim 13, wherein the one or more polarity transition sensors comprise a first one or more of the one or more polarity transition sensors disposed substantially at one or more of the first and second ends of the base and a second one or more of the one or more polarity transition sensors disposed substantially away from the first and second ends along the arc length of the base, and wherein to determine whether the angular position of the rotating object within the 360-degree angular position range corresponds to the first or the second 180-degree angular position sub-range of the 360-degree angular position range based at least in part on the one or more polarity transition output signals, the processing module is configured to:

perform the determination based at least in part on the one or more polarity transition output signals of the first one or more of the one or more polarity transition sensors; and

verify the determination based at least in part on the one or more polarity transition output signals of the second one or more of the one or more polarity transition sensors.

15. The angular position sensing system of claim **12**, wherein the processing module is further configured to determine one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees.

16. The angular position sensing system of claim **12**, wherein the processing module is further configured to determine a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the one or more polarity transition output signals.

17. A method of sensing an angular position of a rotating object over an angular position range that includes up to 360 degrees using an arc position encoder comprising a substantially 180-degree angular position sensing range, the method comprising:

receiving one or more polarity transition signals from one or more polarity transition sensors disposed within a base of the arc position encoder between a first end and a second end of the base, the one or more polarity transition signals indicating a transition of one of a first magnetic pole and a second magnetic pole of a magnetic target coupled to the rotating object so as to rotate about an axis of rotation located substantially in a center of a circle defined by the base, wherein the first and second magnetic poles are disposed on opposite ends of the magnetic target so as to generate a uniform magnetic field, into the 180-degree angular position sensing range of the arc position encoder, and another one of the first and second magnetic poles out of the 180-degree angular position sensing range;

receiving one or more proximity signals from one or more magnetic field sensors disposed within the base between the first and second ends, the one or more proximity signals indicating relative proximity of the one of the first and second magnetic poles within the 180-degree angular position sensing range of the arc position encoder to each of the one or more magnetic field sensors; and

determining the angular position of the rotating object within the angular position range that includes up to 360 degrees based at least in part on the one or more polarity transition signals and the one or more proximity signals.

18. The method of claim **17**, wherein the angular position range comprises a 360-degree angular position range, and wherein determining the angular position of the rotating object within the 360-degree angular position range based at least in part on the one or more polarity transition signals and the one or more proximity signals comprises:

determining whether the angular position of the rotating object within the 360-degree angular position range corresponds to a first or a second 180-degree angular position sub-range of the 360-degree angular position range, based at least in part on the one or more polarity transition signals, wherein the first and second 180-degree angular position sub-ranges are non-overlapping consecutive angular position sub-ranges within the 360-degree angular position range; and

determining the angular position of the rotating object within the respective one of the first and second 180-degree angular position sub-ranges to which the angular position of the rotating object within the 360-degree angular position range corresponds, based at least in part on the one or more proximity signals.

19. The method of claim **18**, wherein the one or more polarity transition sensors comprise a first one or more of the one or more polarity transition sensors disposed substantially at one or more of the first and second ends of the base and a second one or more of the one or more polarity transition sensors disposed substantially away from the first and second ends along the arc length of the base, and wherein determining whether the angular position of the rotating object within the 360-degree angular position range corresponds to the first or the second 180-degree angular position sub-range of the 360-degree angular position range based at least in part on the one or more polarity transition signals comprises:

performing the determination based at least in part on the one or more polarity transition signals of the first one or more of the one or more polarity transition sensors; and

verifying the determination based at least in part on the one or more polarity transition signals of the second one or more of the one or more polarity transition sensors.

20. The method of claim **17**, further comprising:

determining one or more of an angular speed of the rotating object and a direction of angular rotation of the rotating object relative to the arc position encoder, based at least in part on the determined angular position of the rotating object within the angular position range that includes up to 360 degrees.

* * * * *

CONCLUSION AND RECOMMENDATION

Summary: As per inventions details, documented on 3 Patents here, usage of 180 degree(mechanical) rotating sensor to measure 360 degree angle position on realtime along with condition monitoring of those sensors would eliminate the space constraints issues and increase the reliability of the complete system along with perfect control of system dynamics throughout the product life cycle.

Benefit for EV market: E-drive EDU system major requirement is less weight and less volume. To attain this main goal in every system, above explained inventions are very useful to use those 180 Degree rotary sensors to measure 360 Deg angle. Brief explanation as follow as about the invention core idea. Disclosed are techniques for sensing an angular position of a rotating object over a 360-degree angular position range using an arc position encoder comprising a 180-degree angular position sensing range. The encoder may include a base defined by first and second ends, one or more magnetic field sensors disposed within the base between the first and second ends, one or more of first and second base extension disposed on the first and second ends, and one or more polarity transition sensors disposed within the one or more of the first and second base extensions. The encoders may further include a magnetic target having first and second magnetic poles disposed on opposite ends as to generate a uniform magnetic field, wherein the magnetic target is coupled to the rotating object so as to rotate about an axis of rotation located in a center of a circle defined by the base. Being active sensing(with magnetic poles) compared to existing passive sensing(VR sensing), shielding from EMotors endwinding flux for the sensors are not needed or special space for shields are also eliminated. This reduces the cost involved for metal shields and space also. Existing VR resolvers needs to be ingress protected if EDU is flooded with Oil(cooling for motor). But new sensors are already potted to IP67 or IP67K levels, no additional care to be taken for Oil immersion or water or dust exposure to sensors. One more major advantage is flexibility in the air gap between moving and stationary part of sensor. Existing sensor(VR) needs nominal air gap of 0.5mm with 0.5mm offset in all directions approximately to meet the accuracy levels. But new sensors will functions with 8mm airgap with 2mm tolerances between stationary and rotating parts. This reduces the overall tolerance stackup issues related to resolver and mainly on machining cost for individual parts. Handling and installation will be very easy in new sensors compared to existing(which has exposed copper windings and connectors). Ruggedness and durability characteristics also paying advantages to new sensor combination compared to existing one. Both existing and new sensors doesn’t have and moving part, so no wear and tear for both sensor system. On electrical input side, new sensors need only 5Vdc not like existing sensor, which needs high frequency signal from inverter to make VR sensor active.

Implication:

Eventhough new sensor combination has lot of benefits, there are very few mild issues with this concept compared to existing solution. Output signal have both sinus and cosine signal induced due to change in magnetic field of rotor wrt stator field. This concept leads to less error on angle prediction. But still the guranteed accuracy of existing sensors(VR) is around 0.5 Deg(Mech) along with specfic offsets on all direction and temperature. The new sensor concepts will have 0.11 Deg(Mech) under ideal condition for 180 Deg sensing range. When it extends to 360 Deg(mech) measureing range, error tend to increase more than 0.5 Deg(Mech). Other main issue is existing sensors can be used upto 30000 RPM speed compoent to measure the angle with accuracy range of 0,5 Deg(Mech). But with new sensor combination the maximum speed can be from 8k to 10k RPM. So in coming days, improving the maximum speed range and accuracy at that speed would be a real challenge to make this complete new concept into real feasible solution for transporation market for dynamic Electric engine control system.

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