Measurement 131 (2019) 162–172

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

The effect of winding arrangements on measurement accuracy of sinusoidal rotor resolver under fault conditions

F. Zare [a], Z. Nasiri-Gheidari [a,*], F. Tootoonchian [b]

[a] Electrical Engineering Department, Sharif University of Technology, Tehran, Iran
[b] Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 15 August 2017
Accepted 31 August 2018
Available online 1 September 2018

Keywords:
Variable reluctance (VR) resolvers
Winding arrangement
3-D time stepping finite element analysis

ABSTRACT

Variable reluctance (VR) resolvers are proposed for industrial applications due to their simple structure. In this paper the effect of different stator windings on position accuracy of the sinusoidal rotor VR resolver under different fault conditions is studied. The effect of pole numbers and winding configuration (concentric or distributed winding) are discussed. The studied faults are static and dynamic eccentricities, run out and short circuit on excitation or signal windings. The analyses are carried out using 3-D time stepping finite element method. Then, the prototype of the sensor as well as its test set up is constructed. Good agreement between simulation and experimental results validate the success of analysis.

1. Introduction

Resolvers are used for absolute measurement of mechanical angle [1]. Resolvers are often used in conjunction with motors. They are ideal to use for industrial applications where dust and air-borne liquids can obscure optical encoder signals. Numeric Controlled (NC) machines, coil winders, presses, precise phase shifters, in systems converting rectangular coordinates to polar coordinates; in trigonometric function systems and in precise feed-back signal systems of numerical control for machine tooling and positioning tables are some applications of resolvers [2–4]. The resolver's inherent resistance to shock and vibration makes it uniquely suited for moving platforms, and their reliability under these conditions lends a welcome hand to the designers of robots, gantries, and automotive transfer lines [2].

The reasons for superiority of variable reluctance (VR) resolvers to optical encoders are presented in [5,6]. VR resolvers have some preference to conventional resolvers due to removing excitation winding from rotor [7]. There are two types of VR resolvers. The first and usual VR resolvers work based on the sinusoidal variation of air-gap length (Fig. 1-a). The challenges of using this type of resolvers can be categorized into two groups: the stator problems and the rotor ones. The stator problems are related to complicated winding process. Each stator tooth equipped with all SIN, COS and excitation winding that is wound overlapping with sinusoidal distribution [8,9]. This challenge has been overcome by uniform non-overlapping tooth-coil winding that is proposed in [5–7]. The rotor problem is related to use sinusoidal design of air-gap length that needs an optimal shape for rotor. Recently, a novel design for rotor contour is presented that employs the injecting auxiliary air-gap permeance to increase the accuracy of the detected position [5]. However, there is high sensitivity of accuracy against mechanical eccentricity [10].

The second type of VR resolvers are axial flux reluctance (AFR) resolvers with sinusoidal rotor. The reluctance of these resolvers is changed with the stator and rotor coupling area [10–13]. The stator and rotor of the sinusoidal rotor resolver is shown in Fig. 1-b. The signal windings are wound on stator teeth (the stator has 12 teeth). Each teeth contains single layer, concentrated SIN or COS winding. The excitation winding is placed in the groove formed in the inner surface of stator middle part [12].

There are some works on design and analysis of this type of resolvers [10–13]. In [12] a new four pole rotor with 16 teeth on stator is proposed for AFR resolver. Authors show with increasing pole numbers (from 2 poles to 4 poles) the total harmonic distortion (THD) for envelops of output signals decreases. In [13] the performance of the four poles concentric winding resolver is discussed under different type of eccentricity errors.

In the present study the effect of winding arrangements (concentrated/distributed) and winding pole numbers are studied for sinusoidal rotor VR resolver under different fault conditions where the structure of the rotor is kept equal in the all the studies. The considered faults are static and dynamic eccentricities, run out error, short circuit error in excitation/signal winding. 3-D

* Corresponding author.
E-mail addresses: znasiri@sharif.edu (Z. Nasiri-Gheidari), tootoonchian@iust.ac.ir (F. Tootoonchian).

https://doi.org/10.1016/j.measurement.2018.08.074
0263-2241/

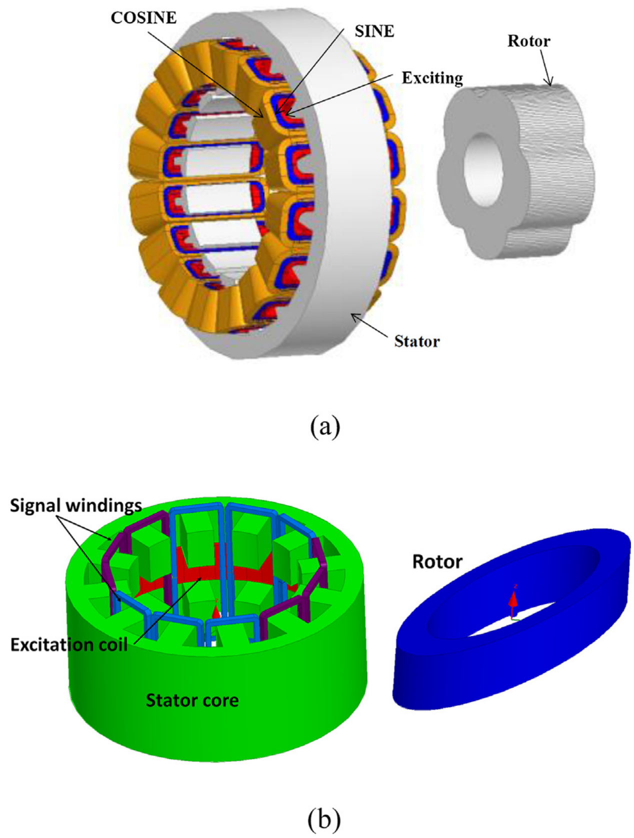

Fig. 1. VR resolvers: (a) with sinusoidal variation of air-gap length [6], and (b) with sinusoidal variation of the stator and the rotor coupling area.

non-linear time stepping finite element method is used for analysis. The comparison of different windings is carried out based on the error of calculated position with respect to the reference position. Then the prototype of sensor along with its test set up is constructed. Good agreement between simulation and experimental results validate the success of analysis.

2. The structure of the studied resolver

The studied resolver has a laminated, slotted stator and a solid sinusoidal rotor. The rotor and the stator are shown in Fig. 1-b. The rotor is a ferromagnetic sinusoidal ring which can be taken using a non-ferromagnetic support. The stator has 12 axial slots containing signal windings and a peripheral slot in the middle of stator length containing excitation coil.

The studied resolver can be built in the form of pancake or encapsulated sensor. The stator core and the rotor for all studies are kept unchanged. Assuming 12 slots for the stator, the signal windings can be wound with 2- and 6- pole configuration.

Fig. 2 shows the winding diagram of signal windings for different winding methods and pole numbers. There is a difference between conventional method of coil's wiring and what is used in this paper for six-pole winding. The connections between coils is done in such a way that when the upper side of rotor is in front of a coil of one phase the lower side of rotor is in front of the other coil of the same phase with different polarity of current. It means as shown in Fig. 2-b, the output of first coil (X_1) is connected to fourth coil of the same phase (X_4) not to that of second coil (X_2). Considering this method of wring the two poles rotor can be used with six poles stator.

Geometrical dimensions and excitation parameters of the constructed sensor are presented in Table 1. It should be mentioned

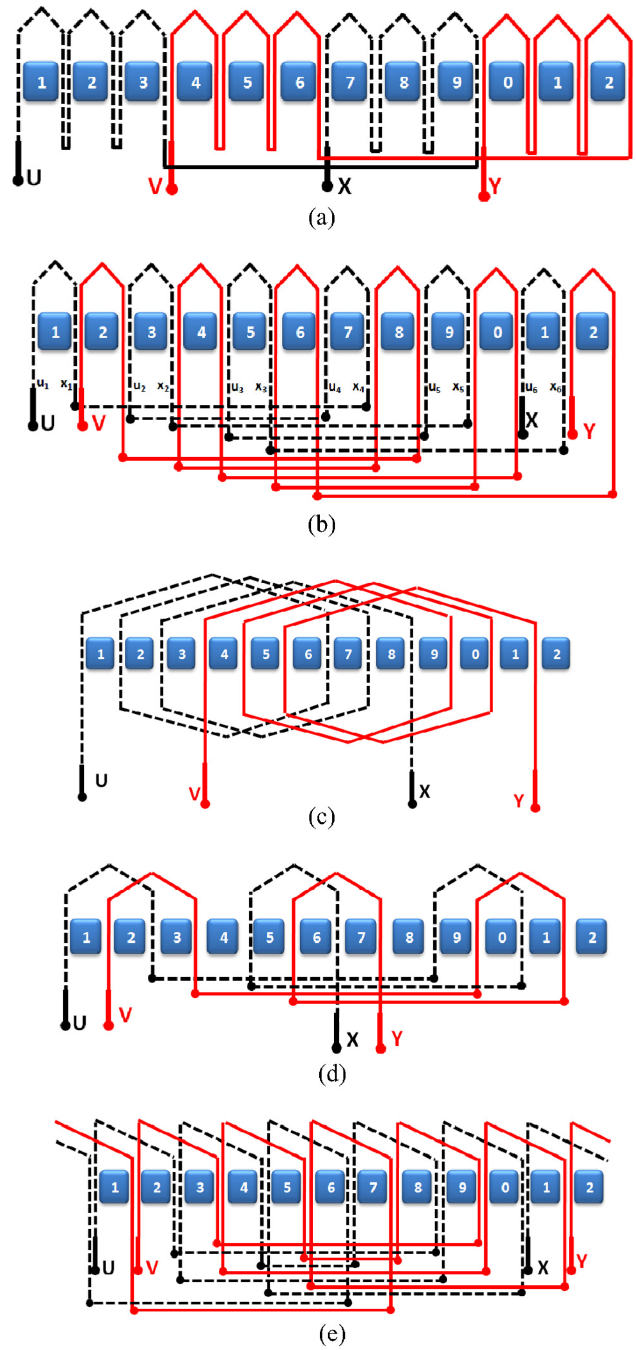

Fig. 2. Studied winding arrangements: (a) 2 poles concentrated windings, (b) 6 poles concentrated windings, (c) two poles single layer distributed windings, (d) six poles single layers distributed windings, and (e) six poles two layers distributed windings.

that the sensor can be constructed smaller than what is built in this paper. To reduce the construction cost (the cost of wire-cutting ferromagnetic sheets of the stator) accessible sheets of the stator of switched reluctance motor is employed for the stator of sensor. So, the rotor dimensions are calculated proportional to that of stator.

2.1. Finite element analysis of AFRs

Due to unsymmetrical structure of the studied sensor, 3-D analysis is required for performance calculation. Furthermore, to calculate induced voltages considering non-linear behavior of core