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Optimization of A Reluctance Resolver

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Abstract— **Variable reluctance (VR) resolver is a transducer used for detecting rotational speed and position. It is an electromagnetic system and is good in reliability and durability. In the paper, an optimization model for the rotor shape of a VR is presented. The shape of the rotor is described by Fourier series. Taguchi optimization method combined with finite element method (FEM) is used to explore the optimal rotor shape for achieving the minimum error of angular position of VR. In the optimization, FEM is used to calculate the design sample, and verify the proposed design from Taguchi analysis. The object function of the optimization is built for identifying the error of the angular position. A VR with 3-pole pairs is used as example to show the effectiveness of the optimization model.**

Index Terms –Variable reluctance (VR) resolver, Taguchi, FEM.

I. Introduction

Among different angular displacement sensors, VR resolvers are most suitable for vehicle machines [1], because of their higher temperature resistance, anti-impact ability, small dimensions and so on.

As it is well known, the rotor shape and winding distributions are important factors affecting the accuracy of output signals[1], [2].

Nevertheless, many papers put strong emphasize on winding distributions and signal processing, and there is less mention of the design of rotor shape. Moreover, few can preciously describe the contour of the rotor.

This paper formulates the rotor shape by Fourier series. Furthermore, Taguchi, a sample optimization method that is free of complicated statistics theory and FEM are adopted to optimize a 3-X VR resolver.

II. Sinusoidal Design of Rotor Shape Based on Fourier Series

The rotor shape of the 3-X VR resolver is shown in Fig. 1(a). And the turns and polarities of coils on each tooth is shown in Fig. 1(b), (c).

It can be seen that sine and cosine output windings are alternate. Besides the relationship between stator teeth and rotor poles can be expressed by

$$Z = 2mp \tag{1}$$

where Z is the number of stator teeth, m and p respectively represent the phases of output windings and the pole pairs of the rotor.

Ref.[3] proposed an air-gap length function which indirectly described the rotor contour. In this section, the function of rotor radius based on Fourier series is further investigated. It can be expressed by

$$\begin{cases} r(\theta) = h_0 + \sum_{i=1}^{\infty} h_i \cos(ip\theta + \varphi_i) \\ h_0 = (1/\theta_1)\int_{\theta_0}^{\theta_0+\theta_1} r(\theta)d\theta \\ h_i = \sqrt{a_i^2 + b_i^2} \\ a_i = (2/\theta_1)\int_{\theta_0}^{\theta_0+\theta_1} r(\theta)\cos(ip\theta)d\theta \\ b_i = (2/\theta_1)\int_{\theta_0}^{\theta_0+\theta_1} r(\theta)\sin(ip\theta)d\theta \\ \varphi_i = -\arctan(b_i/a_i) \\ \theta_1 = 2\pi/p \end{cases} \tag{2}$$

where θ is the angle of rotation, h_i and h_0 are the form factors.

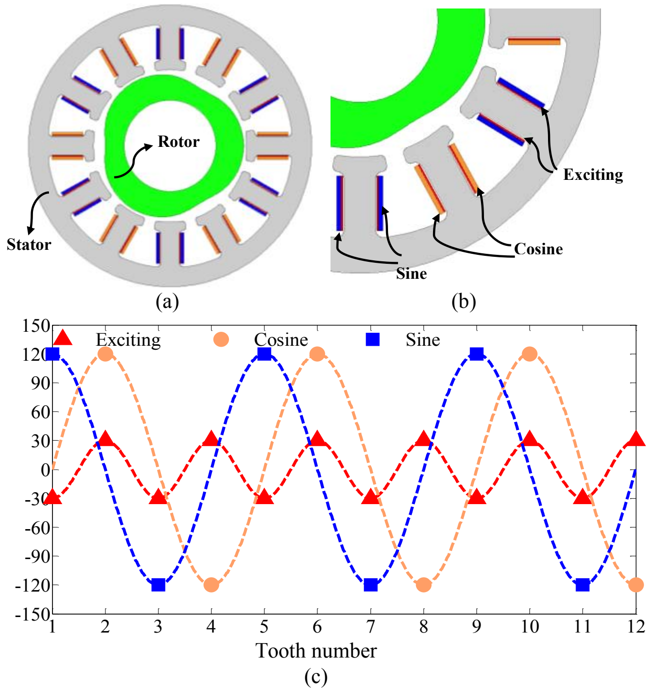

Fig. 1 3-X VR resolver with 12 stator slots. (a) Stator and rotor. (b) Local enlarged drawing. (c) Winding distributions.

III. Optimization of Rotor Shape

A. *FEM Model*

The FEM model which is adopted to simulate the output signals of the 3-X VR resolver is shown in Fig. 2.

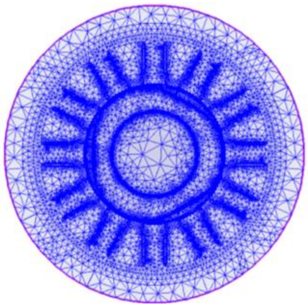

Fig. 2 The FEM model of the 3-X VR resolver

B. *TAGUCHI*

Ref.[4] introduces the principle and usage of taguchi.

This method effectively reduces the number of experiments or simulations by utilizing the orthogonal table. In addition, S/N ratio is adopted to select the best combination of factor level and determine the next optimization.

In this paper, one of the objective function is

$$\text{THD}=\sqrt{\sum_{n=2}^{\infty} V_n^2}\Big/V_1 \qquad (3)$$

where V_1 is the fundamental wave of output voltage, V_n are other harmonics except the fundamental wave.

Another objective function is

$$\text{Position error}=\max|\text{error}(i)| \qquad (4)$$

where error(i) represents the electrical angle error between the calculated value and the ideal value.

TABLE I
THE SIMULATION RESULTS OF SECOND STAGE

No	Factor A	Factor B	Factor C	Factor D	THD (%)	Position error (elec.deg)	S/N
1	1	1	1	1	0.196	0.1214	18.313
2	1	2	2	2	0.195	0.0748	22.524
3	1	3	3	3	0.222	0.0314	30.060
4	2	1	2	3	0.259	0.0253	31.950
5	2	2	3	1	0.317	0.0385	28.289
6	2	3	1	2	0.350	0.0716	22.899
7	3	1	3	2	0.405	0.0866	21.250
8	3	2	1	3	0.445	0.1221	18.266
9	3	3	2	1	0.527	0.1677	15.508

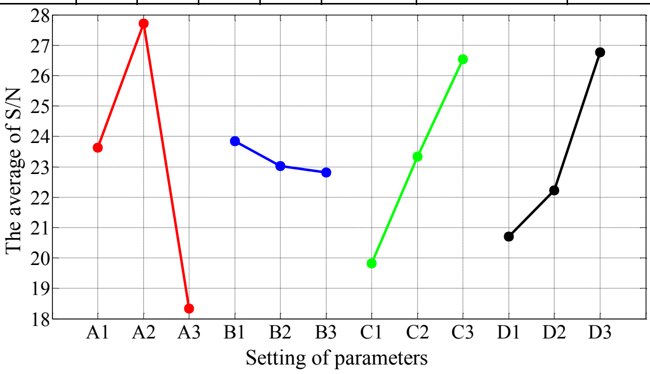

Fig. 3 The main effect diagram of S/N in the second stage

The simulation results of second stage are shown in TABLE I, where A= h_1 ,B= h_2 ,C= h_4 D= h_5 .And the best combination of factor level is A2,B1,C3,D3, as shown in Fig. 3.

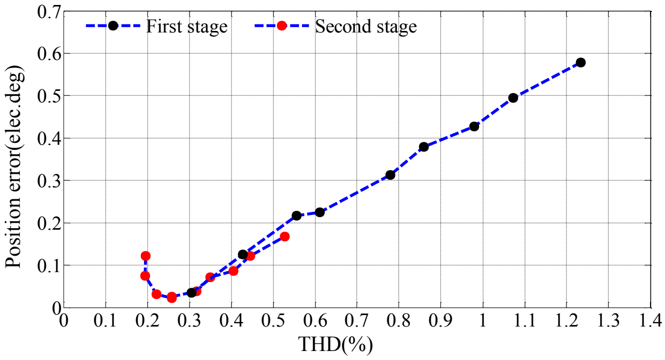

Fig. 4 The relationship between THD and position error

The relationship between THD and position error is shown in Fig. 4.

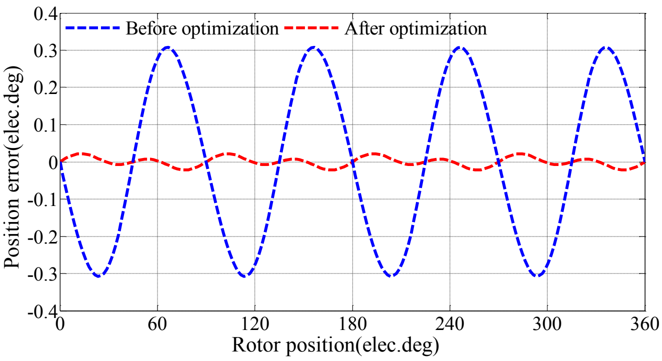

Fig. 5 Position errors of the 3-X VR resolver in FEM

As shown in Fig. 5,the position error declines from 0.3037° to 0.0220°. Moreover, the THD is also reduced from 0.755% to 0.258%.

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