The Reduction of Torque Ripple in Spoke type Transverse Flux Rotary Machine for Direct Drive Motor

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Abstract — TFRM(Transverse Flux Rotary Machine) has many defects. This paper develops spoke type 3 phase TFRM with new type stator(double bended) for high torque mean and low torque ripple, satisfying demanded speed and nominal torque in direct drive motor and compares optimized 3 phase TFRM with existing prototype TFRM. This paper presents the statistical optimum design of 3 phase TFRM for direct-drive motor system using the penalty method (characteristic function) with constraints to control penalty coefficients, ANOM (analysis of means) and table of orthogonal array. The optimized 3 phase TFRM has better performance in torque and speed with satisfaction to required performance for direct-drive motor system (speed [300 rpm], torque [75 Nm]).

I. INTRODUCTION

This paper introduces spoke type Transverse Flux Rotary Motor (TFRM) which has advantages such as high power density, robustness and simple structure. Even though TFRM has such advantages, it has relatively high torque ripple. This paper is focused on reduce torque ripple which is dealt with objective function and torque mean is applied to constraint function. At first step(screening method), seven design variables are selected and arranged in the table of mixed orthogonal array. The effective design variables are extracted by ANOVA. Motor performances on each experiment are checked torque ripple and torque mean by 3D FEM for accuracy because of 3D transverse flux magnetic circuit. At second step, with the use of the penalty method(characteristic function) and with constraints to control penalty coefficient can be obtained. The optimized result is compared between penalty method and initial model. The most desired design set is determined and we can get the effective of each design variables on the objective function. Therefore, It is more efficient to raise the precision optimization and reduce the iteration of experiment in optimization design by the applied optimization method[1-3].

II. VERIFICATION FOR 3 PHASE TFRM

Table I and Fig. 1 show comparison of simulation and experiment in reference model to verify the performance and prototype of developed TFRM model with new type stator(double bended) for direct-drive motor.

TABLE I
COMPARISON OF SIMULATION AND EXPERIMENT RESULT

TFRM reference model	Simulation	Experiment
Phase resistant (Ohm)	0.36	0.4
Phase inductance (mH)	7.4~19.3	8.5-20.5
Phase BEMF (V_{rms})	141	138
Phase torque/resultant torque	28/84	26/78

The simulation results are compared with experiment, and they are within 7 % deviation each other as shown in Table I.

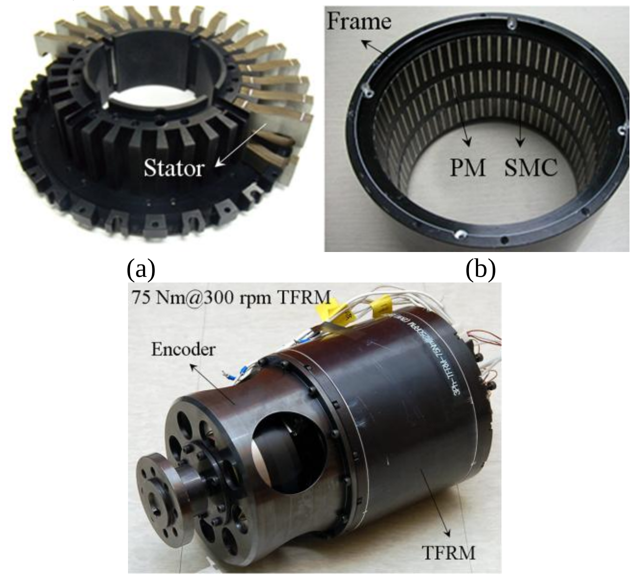

Fig. 1. Direct drive Transverse Flux Rotary Machine
(a) Double bended stator and supporter (b) Rotor (c) Prototype

III. PENALTY METHOD USING CHARACTERISTIC FUNCTION

A. Penalty method

The optimum design problem of TFLM to minimize torque ripple with the constraints of torque mean can be expressed as the following equations;

$$\text{Minimize : } T_{ripple(p-p)}(t_r, \cdots, t_{rt}) \tag{1}$$

$$\text{Subject to : } |T_{al}|/|T_{\max}|-1 \le 0 \tag{2}$$

where $T_{ripple(p-p)}(t_r, \cdots, t_{rt})$ is the torque ripple of TFLM with the several design variables, $T_{\max}$ is the simulation result and T_{al} is an allowable torque mean. With the help of the penalty term method, penalty functions corresponding to constraint is defined as follow;

$$T_{mean}(t_r, \cdots, t_{rt}) = \alpha \cdot Max\left[0, |T_{al}|/|T_{\max}|-1\right] \tag{3}$$

where α is a penalty coefficient that determine the extent of influence of each constraint to the characteristic function. Each penalty coefficient should be adjusted by considering the influence of the constraint on the characteristic function.

By combining the scaled objective function with the initial ripple of the initial TFLM, T_0 (torque mean of initial model) and penalty functions, the characteristic function can be defined as follows;

$$\Psi(t_r,\cdots,t_{rt})_{new} = T_{ripple(p-p)}(t_r,\cdots,t_{rt})/T_0 + T_{mean}(t_r,\cdots,t_{rt}) \quad (4)$$

B. *Screening method*

Selection of the design variables is very important setup in optimization procedure. Seven dimensions are selected as the design variables as shown in Fig. 2. Table II shows the design variables and levels. Torque ripple and torque mean of simulation result according to change of the design variables are used the table of mixed orthogonal array ($L_{18}2^1\times3^7$). The effective design variables are extracted by ANOVA. The table of mixed orthogonal array and ANOVA will be shown in full paper. The 3 phase average torque is calculated the 3 phase resultant torque from torque profile of single-phase periodic model.

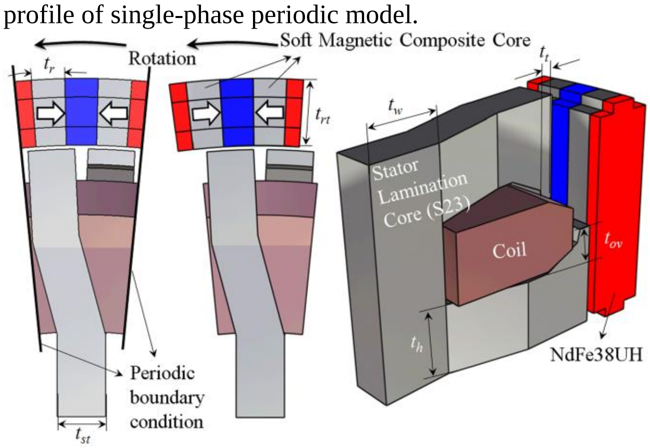

Fig. 2. Design variables of direct drive TFRM

TABLE II
DESIGN VARIABLES OF TFRM

Design Variable / Level	t_r	t_{st}	t_w	t_h	t_{ov}	t_t	t_{rt}
1	2.73	4.9	9.35	9.35	5.1	1.19	6.8
2	3.315	5.95	11	11	6	1.4	8
3	3.9	7	12.65	12.65	6.9	1.61	9.2

TABLE III
CCD (CENTRAL COMPOSITE DESIGN) OF 3-PHASE TFRM

EXP.	t_r	t_{st}	t_{rt}	$T_{ripple(p-p)}$	T_{mean}	Characteristic function
1	3.51	6.3	6.93	12.56	88.28	1.41851
2	3.9	6.3	6.93	12.99	87.37	1.70588
3	3.51	7	6.93	7.25	89.49	0.68617
4	3.9	7	6.93	10.92	91.15	0.82704
5	3.51	6.3	7.7	15.20	90.71	1.15095
6	3.9	6.3	7.7	25.11	91.09	1.90192
7	3.51	7	7.7	10.68	94.89	0.80913
8	3.9	7	7.7	11.65	92.54	0.8826
9	3.37701	6.65	7.315	17.30	92.53	1.31011
10	4.03299	6.65	7.315	25.17	95.39	1.90648
11	3.705	6.0613	7.315	7.48	88.20	1.05747
12	3.705	7.2387	7.315	8.30	93.08	0.62811
13	3.705	6.65	6.66743	7.80	89.36	0.76323
14	3.705	6.65	7.96257	9.77	95.54	0.74022
15	3.705	6.65	7.315	7.48	88.20	1.05747

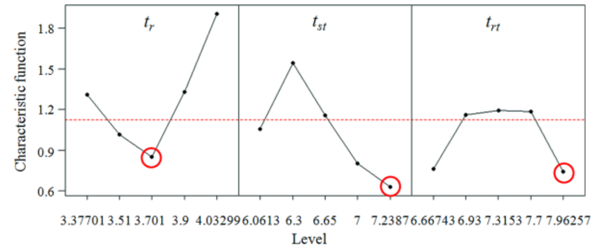

Fig. 3. Main effects for characteristic function

TABLE IV
COMPARISON OF INITIAL AND OPTIMUM MODEL(PENALTY METHOD)

KERI TFRM model	$T_{ripple(0-p)}$ (%)	T_{mean} (Nm)
Initial	7.92	83.36
Optimum (Penalty method) verification model	2.09	97.60

The desired optimum set is determined by main effect of characteristic function considering constraint of torque mean in Fig. 3. Table III represents CCD (Central Composite Design), which is determined by considering the number of the selected effective design variables and each level of them. For the solution of a constraint problem, it is required to prepare a characteristic function by which the feasibility of constraints can be evaluated. Table IV shows comparison of initial and optimum model. Torque ripple is reduced 69.01% and torque mean is improved 8.44 % of initially designed a TFRM model. Fig. 4 shows torque ripple and torque mean of the optimized TFRM and initial model.

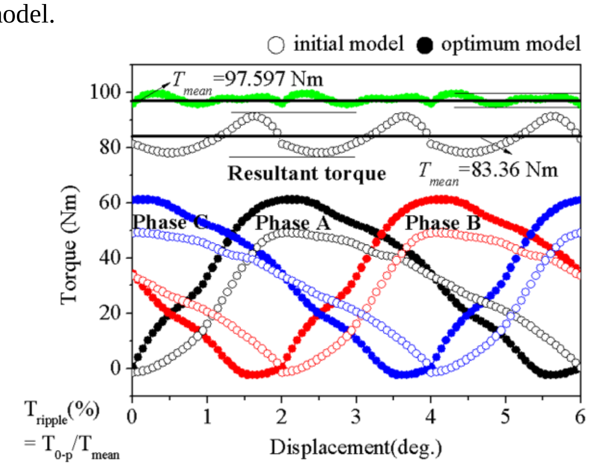

Fig. 4. Torque ripple and torque mean of the optimized TFRM

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