Multiobjective Optimum Design of Single-Sided Linear Induction Motor using Kriging Surrogate Model

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Abstract. As electromagnetic devices, linear induction motors can produce powerful linear motion directly, which have been applied to high power system such as railway traction, electrodynamics vibrator, numerically controlled machine, etc. This paper presents an optimum design of a single-sided linear induction motor to improve its efficiency and power factor using the modified kriging surrogate model.

1 Introduction

Single-sided Linear induction motors (SLIM) are electromagnetic devices of directly converting electrical energy into mechanical energy to realize linear motion without any mechanical converters, which have been applied in various industries. Two critical indices— efficiency and power factor indicate the performance of motors and the ratio of energy consumption. For finding the optimum design parameters, a multi-objective optimization problem considering efficiency, power factor and the end effect is defined. As a reliable optimization tool, the modified kriging surrogate model with low computational cost and good accuracy of searching the global optimum design is utilized to deal with this multiobjective optimization problem.

2 Effect of design parameters on the performançe of the linear motor

The topology of the proposed SLIM which consists of a three-phase primary and an aluminium sheet laid on the secondary back iron is depicted in Fig. 1. In order to evaluate the output characteristics of SLIMs meanwhile considering SLIMs' end effect, as a prevalent equivalent circuit a Duncan per-phase equivalent circuit is applied [2] here in Fig. 2. The main parameters involved in Duncan circuit primary resistance (R_1) , leakage reactance (L_1), secondary resistance (X_2') and leakage reactance (L_2'). The relative motion between short primary and long secondary leads to longitudinal end effect which is included in the Duncan parameters by modification of the magnetizing branch.

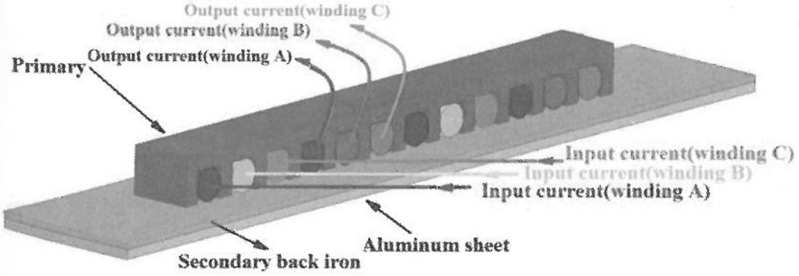

Figure 1: The topology of a SLIM

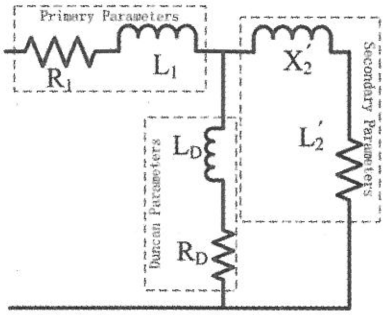

Figure2: Duncan equivalent circuit for SLIMs

If the air gap flux density between the primary and the double-layer secondary is maintained below 0.4T, the efficiency and power factor of SLIM are given by [3]

$$\text{Efficiency: } \eta = F_x 2f\tau(1-s)/(F_x 2f\tau + 3I^2R_1) \tag{1}$$

$$\text{Power Factor: } cos\varphi = (F_x 2f\tau + 3I^2R_1)/3VI \tag{2}$$

(F_x: the thrust; R_2: secondary resistance; s: Slip; I: primary phase current; R_1: primary resistance; f: primary frequency; τ: pole pitch; V: input voltage.)

3 Optimum design of SLIM using kriging surrogate model

3.1 Kriging surrogate model

As a kind of surrogate model, kriging can predict the shape of the objective function via spatial correlation of data using limited information. Many modifications of the kriging surrogate model presented in our previous work [4, 5] allow efficient and robust solution of large scale and multi-parameter optimisation task.

3.2 Effect of design parameters on the performance of the SLIM

In order to achieve optimum design of SLIMs, the efficiency and power factor of SLIMs are set as the critical indices of qualifying optimal solution. Figs. 3 and 4 show the variations of the efficiency and the power factor with the air gap width (AG) and the thickness of aluminum secondary sheet (AST) respectively. This optimization has been done in constant current of 200A, and the nominal frequency, mechanical velocity of primary are 60HZ, 20m/s, respectively. The test range of AG and AST is set as 3 mm$\leqslant$AG $\leqslant$5 mm and 1 mm $\leqslant$AST$\leqslant$4 mm; the corresponding step size is set as 0.1 mm and 0.15 mm respectively. The kriging surrogate model only required 5 FEM calls to find the optimum design (AG=3 mm, AST= 1.9 mm, efficiency=62.67%, power factor=0.607) compared with the full-scale test requiring 441 FEM calls.As an effective parameter on motor performance, an inrement in air gap width leads to more magnetizing current and lower power factor, meanwhile larger air gap also causes more losses hence lower efficiency and lower thrust on primary. The end-effect phenomenon, more multi-variable tests and comparison with other optimisation algorithms will be depicted in the full paper.

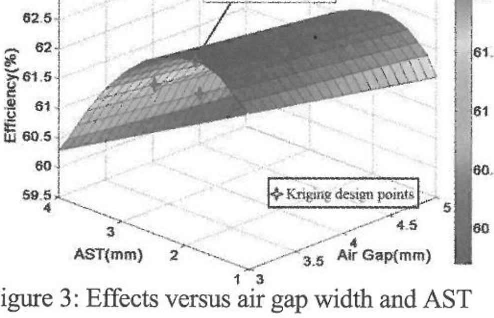

Figure 3: Effects versus air gap width and AST

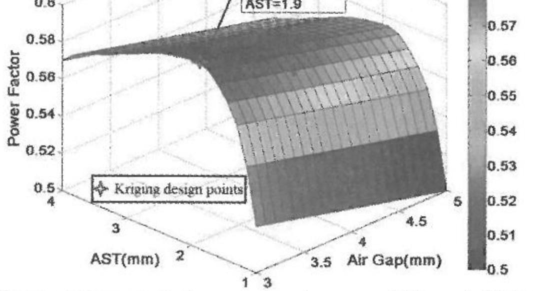

Figure 4:Power factor versus air gap width and AST

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