Multi-Objective Optimization Design of Bearingless Permanent Magnet Synchronous Generator

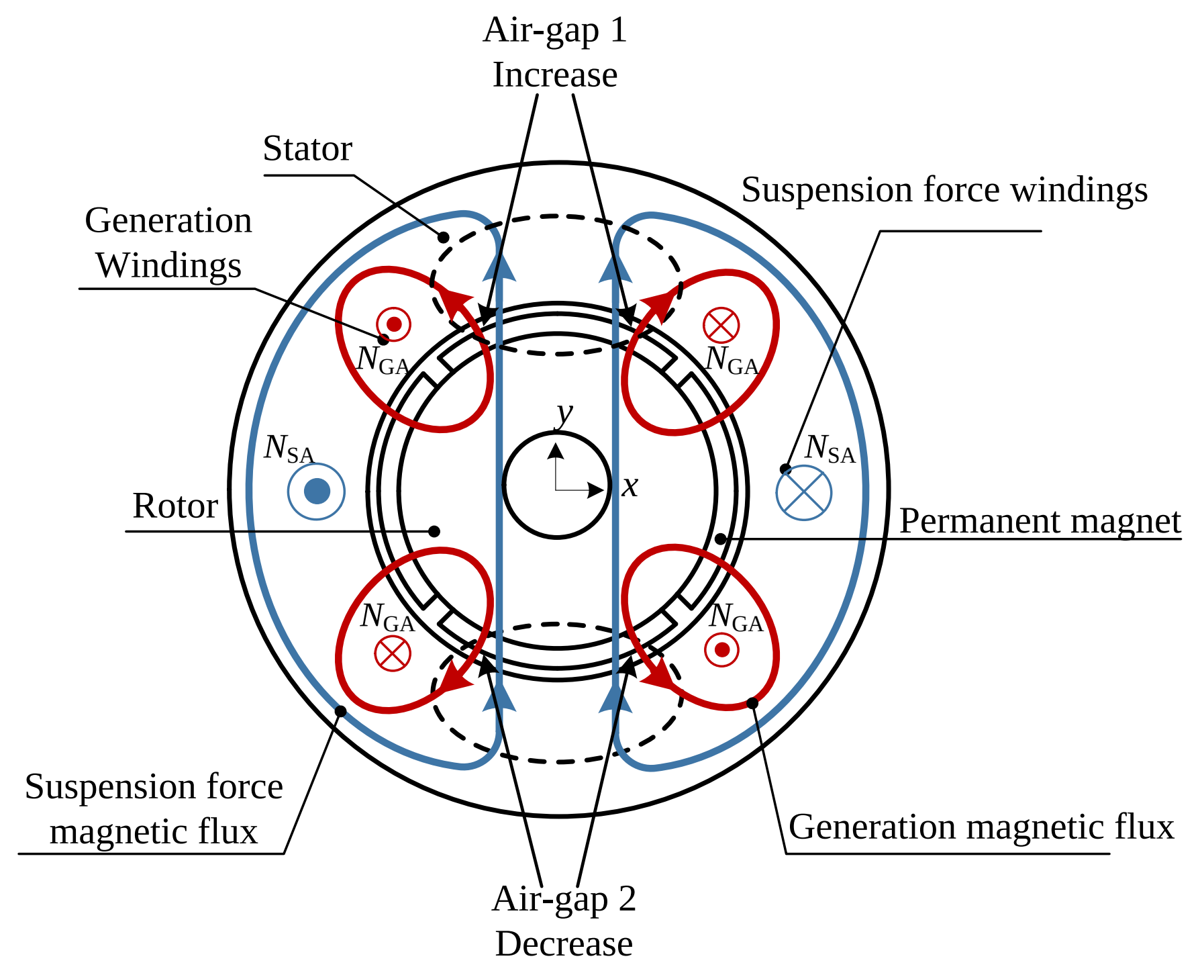
Yizhou Hua, Huangqiu Zhu and Ying Xu
School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China

26th International Conference on Magnet Technology
Poster ID :Wed-Mo-Po3.05-01(Poster Session)

Background

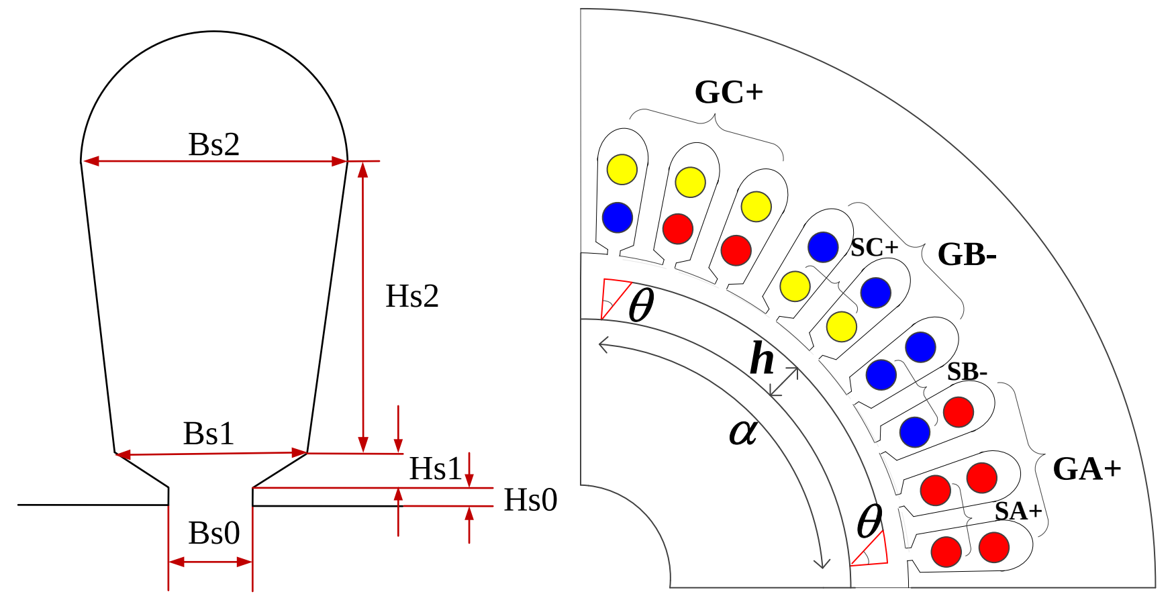
In order to realize the design objectives of high power generation performance and stable suspension capability, a multi-objective optimization method based on a response surface (RS) model and an improved multi-objective particle swarm optimization (MOPSO) algorithm is proposed and utilized to the multi-objective optimization design of a bearingless permanent magnet synchronous generator (BPMSG). Firstly, the operating principle of the BPMSG is introduced. Secondly, the design variables and the design objectives are determined and the design space is reduced by the sensitivity analysis. Thirdly, the RS models of design objectives are constructed and the improved MOPSO algorithm is applied to get the Pareto optimal sets. Finally, the initial generator and the optimal generator are compared using the finite element analysis software.

Working Principle



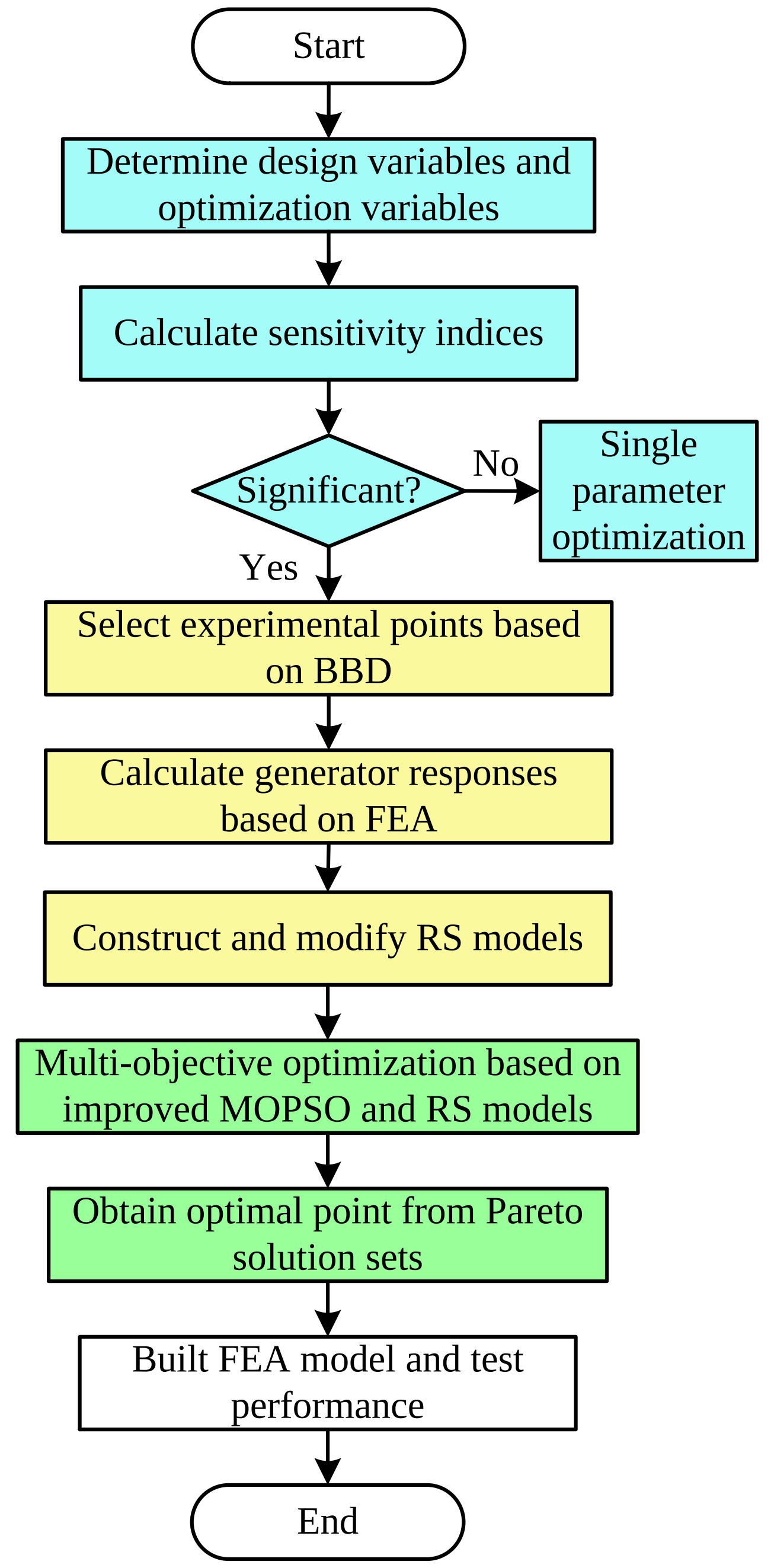
If the current direction of the suspension force windings is as shown in the figure above, a 2-pole suspension force magnetic field is produced, which increases the flux density in the air-gap 1 and decreases the flux density in the air-gap 2, thus producing a radial suspension force pointing to the positive direction of the y axis.

Design Variables



9 parameters of the stator and permanent magnets are selected as design variables.

Optimization Flowchart


Start
Determine design variables and optimization variables
Calculate sensitivity indices
Significant?
No
Single parameter optimization
Yes
Select experimental points based on BBD
Calculate generator responses based on FEA
Construct and modify RS models
Multi-objective optimization based on improved MOPSO and RS models
Obtain optimal point from Pareto solution sets
Built FEA model and test performance
End

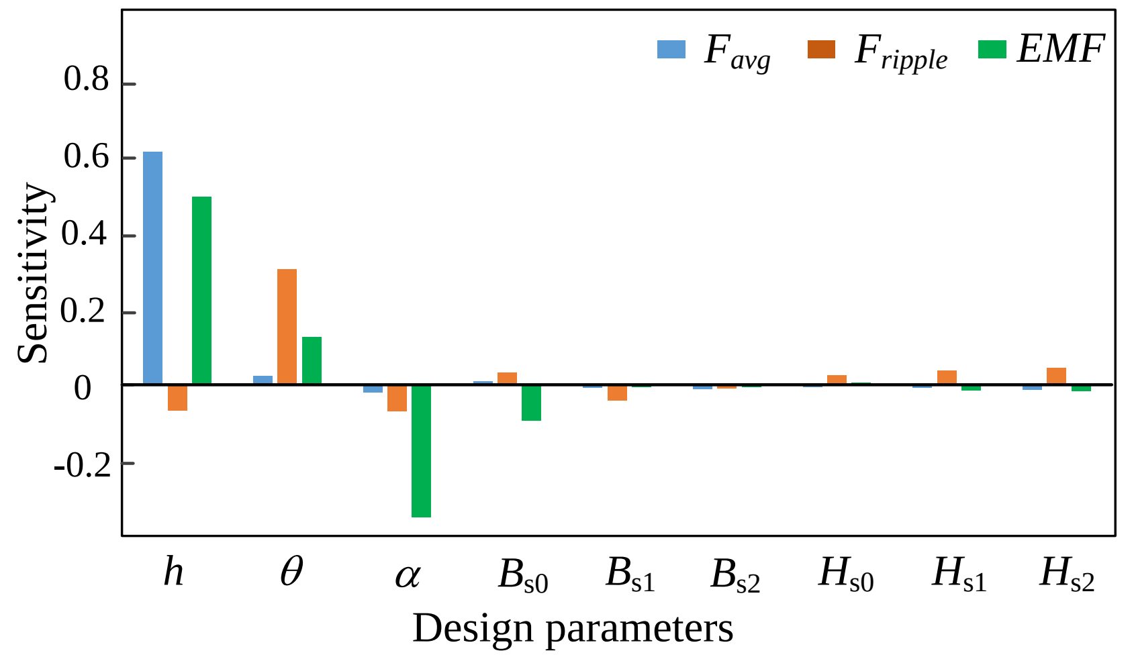
The proposed optimization method includes three modules, which are sensitivity analysis, RS models construction and optimization based on the improved MOPSO algorithm.

Design Variables

Design Variables

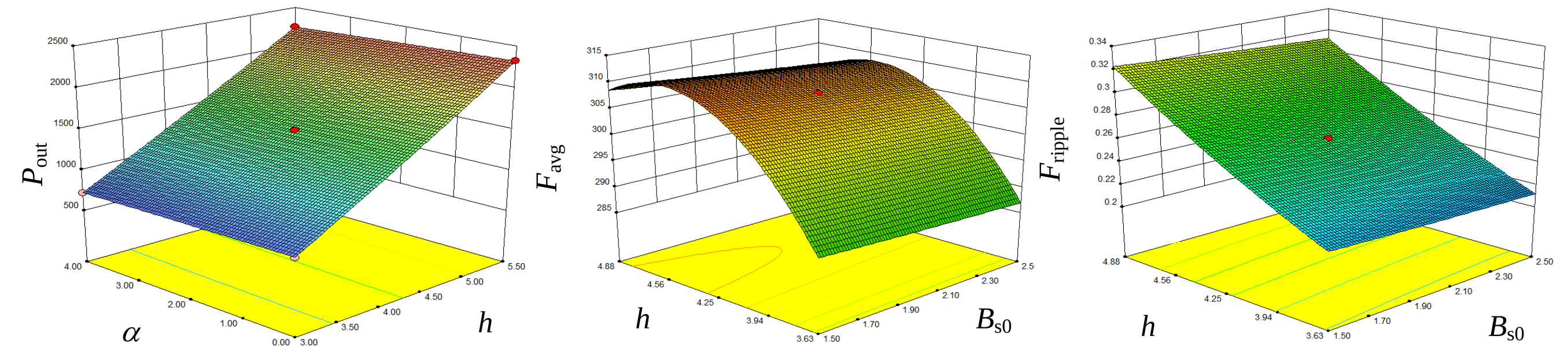
Symbol(Unit)	Quantity	Low level	High level
h(mm)	PM thickness	3	5.5
θ(deg)	PM pole arc angle	35	45
α(deg)	PM chamfering angle	0	35
B_{s0}(mm)	Slot opening width	1	3
B_{s1}(mm)	Slot wedge maximum width	3.5	5.5
B_{s2}(mm)	Slot body bottom width	6	8
H_{s0}(mm)	Slot opening	0.5	1
H_{s1}(mm)	Slot wedge height	0.5	1.5
H_{s2}(mm)	Slot body height	14	18

Sensitivity Analysis



As depicted in Fig. 4, comparing with other variables, h, θ, α and B_{s0} are more significant.

Response Surface Models



As shown in the figure above, the RS models have the extreme values, and the design variables have the optimal ranges, but the optimal ranges of each RS model are different.

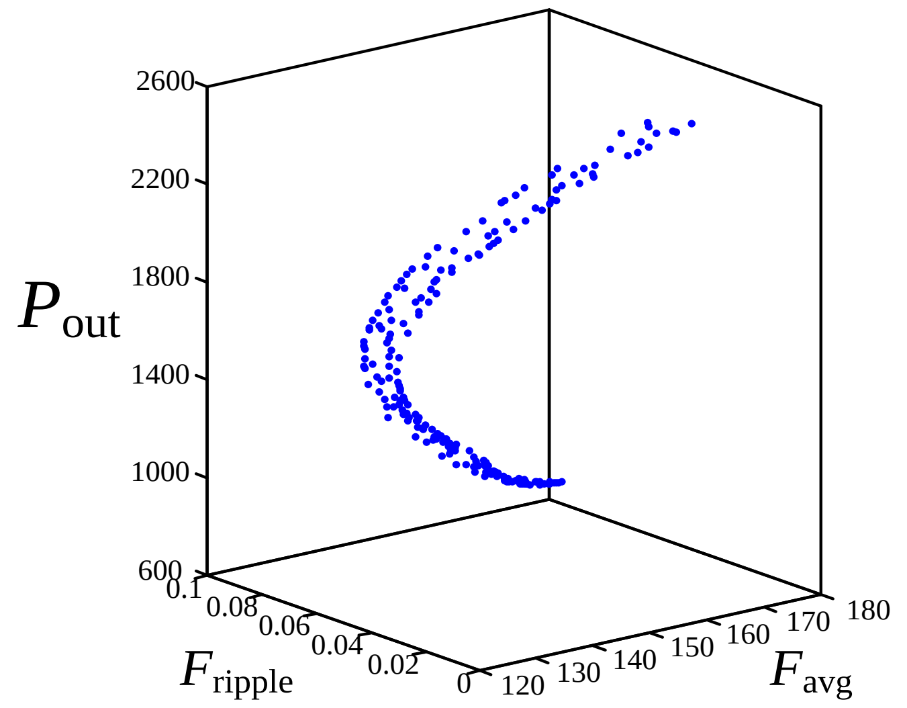
Improved MOPSO

$$X_{id}^{k+1}=\left\lceil \left|\left(X_{id}^{k}+V_{id}^{k+1}\right)\%X_{\max}\right|\right\rceil$$

In these equations, k is the number of current iterations, d=1,2,...,D, i=1,2,...,x_{Size}, x_{Size} is the total amount of particles in the population, c_1 and c_2 are acceleration coefficients, r_1 and r_2 are random numbers in [0,1], weighting coefficient w can be constant. For better results, the weighting coefficient ω is modified as

$$\omega(k)=\omega_{\max}-(\omega_{\max}-\omega_{\min})\left(\frac{k}{G_{\max}}\right)^2$$

where $\omega_{\max}$ is the initial inertia weight, $\omega_{\min}$ is the inertia weight of the maximum generation, $G_{\max}$ is the maximum generation number of iteration. Compared with linear decreasing inertia weight, the value of ω in the early stage is larger and changes slowly, which better maintains the global search ability. While in the later stage, ω changes faster, which improves the local optimizing ability of the algorithm.

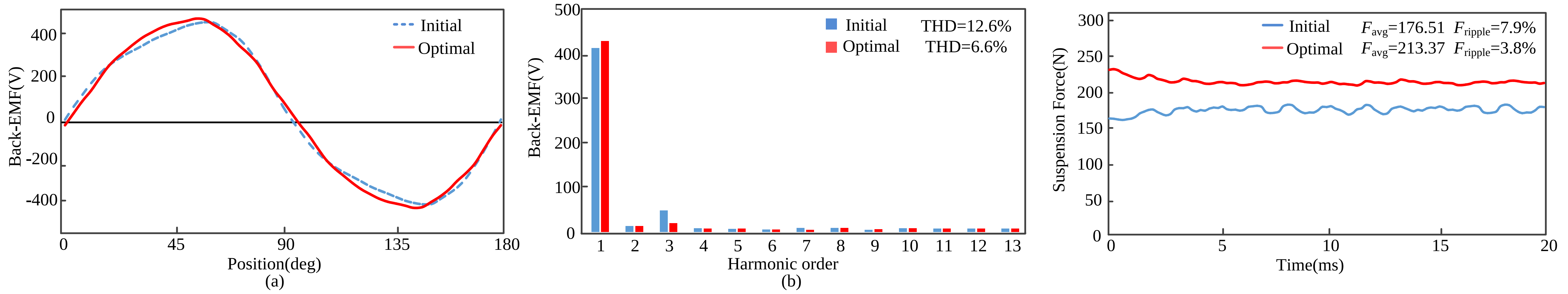


Optimal sets of three optimization objectives

Initial and Optimal Designs

Symbol(Unit)	Initial	Optimal
h(mm)	4.25	4.31
θ(deg)	40	36.17
α(deg)	17.5	29.5
B_{s0}(mm)	2	3
B_{s1}(mm)	4.5	4
B_{s2}(mm)	7	6
H_{s0}(mm)	0.75	0.5
H_{s1}(mm)	1	0.5
H_{s2}(mm)	16	14

Comparison of Motor Performance



(a)
(b)

Compared with the initial generator, the average suspension force of the optimal generator is increased by 21%, the suspension force ripple of the optimal generator is decreased by 52%. It can be calculated that the THD of the initial and optimal generator is 12.6% and 6.6%

Conclusion

A multi-objective optimization method of BPMSG is put forward in this paper, which includes the sensitivity analysis, the RS modeling and the optimization of the improved MOPSO algorithm. The electromagnetic performances of the optimal generator and the initial generator are compared by FEA software. The results show that the average torque and suspension force of the optimal generator are increased, the torque ripple and suspension force ripple are decreased, and the output voltage waveform is more sinusoidal. Therefore, the proposed BPMSG multi-objective optimization method can conveniently and effectively obtain the optimal generator, which improves the overall electromagnetic performance and greatly shorten the optimization time.