End Edge Force Analysis in Stationary Discontinuous Armature concentrated-winding PMLSM with the shape of Novel Auxiliary Teeth

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***Abstract*— Recently, the stationary discontinuous armature permanent magnet linear synchronous motor (PMLSM) has been proposed in order to solve problems such as increase of material cost and maintenance free. However, cogging force is greatly generated by the end edge as the armature is arranged discontinuously. As the result, this decreases the control performance and causes vibration and noise of the machine acting as the trust force ripple during the drive. Thus, in this paper we proposed stair shaped installation of auxiliary teeth applying the auxiliary teeth on the end edge of armature of PMLSM with concentrated winding in order to reduce the end edge's cogging force generated by the discontinuous arrangement of the armature. Furthermore, we examined the end edge's cogging force according to the design parameter of the stair shaped auxiliary force through 2-D numerical analysis using the finite element method in order to verify the suitability of stair shaped auxiliary teeth.**

***Index Terms*— PMLSM, discontinuous arrangement, cogging force, end edge, stair shape auxiliary teeth, 2-D numerical analysis.**

I. INTRODUCTION

Recently, the permanent magnet linear synchronous motor (PMLSM) has been more widely used in the factory automation field such as electric railroad, transportation system and semiconductor production equipment than the existing system which uses rotation machine to change the rectilinear motion due to its high efficiency, detailed control and high energy density [1]. The general transportation system arranges the armature on the full length of transportation lines, however, when this method is applied to long distance transportation system, it causes increase of material cost. Thus, in order to resolve this problem, discontinuous arrangement method of the armature has been proposed [2]. Fig. 1 shows the stationary discontinuous arrangement of armature in PMLSM. As shown in Fig. 1 when the armature is arranged discontinuously the end edge always exists due to the structure. Due to this end edge, the cogging force is generated during the entry and ejection of the mover to the armature [3]. Moreover, the cogging force causes thrust force ripple generating noise, vibration and decline of performance. Many studies in regard the reduction of cogging force are in progress [4]. Methods such as skew of permanent magnet and installation of auxiliary pole and teeth are one of them. Therefore in this paper, we installed stair shaped auxiliary teeth on the end edge of stationary discontinuous armature PM-LSM with concentrated winding by applying auxiliary teeth as the reduction method of cogging force. Moreover, we

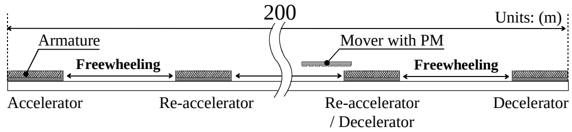

Fig. 1. Schematic representations of armature unit of the stationary discontinuous armature PMLSM with concentrated winding

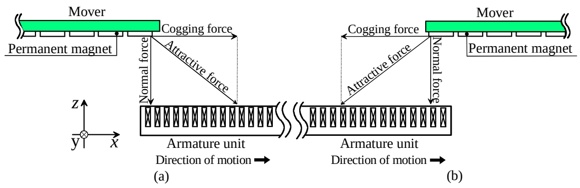

Fig. 2. Forces exerted in the mover at the end edge: (a) entry interval (entrance end) and (b) ejection interval (exit end)

analyzed the characteristics of changes in cogging force through 2-D numerical analysis using finite element method (FEM) and designed the auxiliary teeth of stair shape that minimizes the end edge's cogging force.

II. FORCE GENERATED AT THE END EDGE OF THE STATIONARY DISCONTINUOUS ARMATURE PMLSM WITH CONCENTRATED WINDING

In discontinuous arrangement method of PMLSM, when the mover pass through the boundary between the installation and non-installations parts of armature, the attractive force generated between the armature's core and the mover's permanent magnet is greatly fluctuated. Fig. 2 shows the effect that the force occurring at the end edge has on the mover. The attractive force generated when the mover enters the entry interval of the armature is an attractive force that directs toward the same direction as the operation direction of the mover. That is, the mover is accelerated by a force, which pulls the mover into the armature area. On the other hand, the attractive force generated when the mover exits the ejection interval of the armature is a force that directs toward the opposite direction to the operation direction of the mover. In other words, the mover becomes decelerated by the force, which pulls the mover back to the armature area. Therefore, this end edge's cogging force must be reduced.

III. COGGING FORCE AT THE END EDGE OF THE STATIONARY DISCONTINUOUS ARMATURE PMLSM WITH CONCENTRATED WINDING

In order to analyze the effect of the cogging force generated from the end edge, we used the 2-D numerical

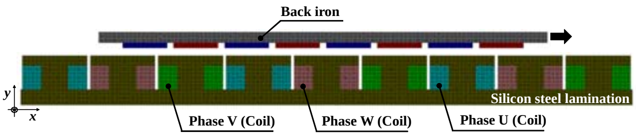

Fig. 3. Element divisions of the basic model for 2-D numerical analysis.

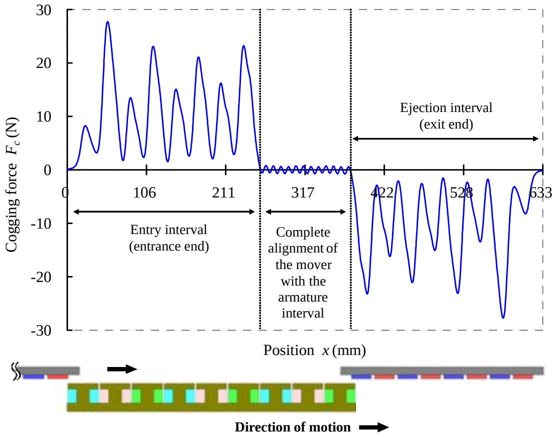

Fig. 4. Cogging force waveform of basic model.

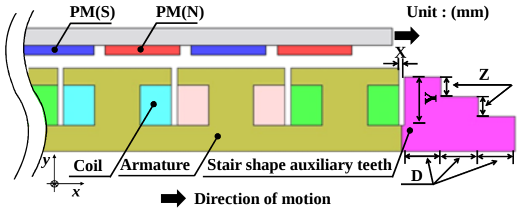

Fig. 5. Proposed model with auxiliary teeth of stair shape.

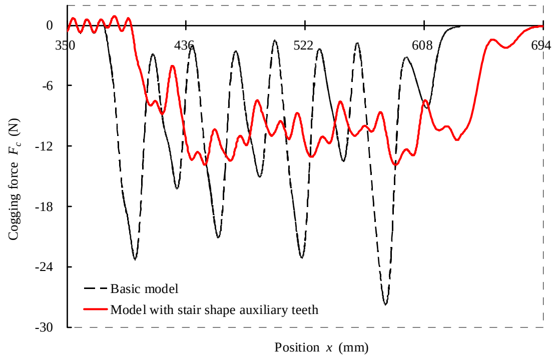

Fig. 6. Waveform of end edge's cogging force of each model.

analysis using FEM. Fig. 3 shows the element divisions of the basic model for 2-D numerical analysis. The full length of mover which is 264 mm with the 8-pole permanent magnets of Nd-Fe-B type was arranged on magnetic plate. Also, the length of armature was 360 mm and the number of turns per one phase for concentrated winding was 75 turns. The slot pitch is 40 mm and is composed of 9 slots. The number of nodes is 13133, and the number of elements is 24576. The amount of movement per step is an interval of 1 mm. The 2-D numerical analysis result of cogging force waveform of the basic model is shown in Fig. 4. As indicated by Fig. 4, the maximum end edge's cogging force generated from the entry and ejection intervals when the mover enters the armature is ±27.73 N, and the maximum cogging force generated when the mover and the armature are in complete alignment interval is ±0.8 N.

IV. Reduction Method of the Cogging Force at the End Edge of the Stationary Discontinuous Armature PMLSM with Concentrated Winding

In order to reduce more cogging force generated from the end edge, we propose the auxiliary teeth of stair shape applying the auxiliary teeth at the end edge of armature. Fig. 5 shows the model with the auxiliary teeth of stair shape. As shown in Fig. 5, the design parameter for the optimum design of the stair shaped auxiliary teeth has been decided according to the appropriate pitch (X) from armature, width (D) of stair shaped auxiliary teeth, height (Y), interval (Z) between steps, number of stair steps (S). We analyzed the cogging force generated at the end edge using 2-D numerical analysis with a FEM on them. The scale of analysis is from the armature area with the complete alignment of the mover to the end of the armature where the mover has completely exit. As the result of examining, the appropriate pitch of X from the armature in the case of the optimized auxiliary teeth of stair shape was 1 mm, height of Y 20 mm, the width of D of stair shaped auxiliary teeth was 19 mm, the interval between the steps of Z was 3 mm, and the numbers of stair-steps S was fixed to 3 steps. Fig. 6 shows the waveform of the end edge's cogging force of each model. From Fig. 6, it can be proved that the end edge's cogging force from the model which installed the stair shape auxiliary teeth of the end edge of the armature at the ejection interval is less than that of the basic model. In the basic model, the maximum cogging force is 27.73 N. However, the model which can decrease the end edge's cogging force, the maximum cogging force is 13.88 N.

V. Conclusion

In this paper, we proposed the stair shaped auxiliary teeth installation method by applying the auxiliary teeth at the edge of the armature in order to reduce the edge cogging force which functions as the thrust force ripple at the stationary discontinuous armature PMLSM with concentrated winding. From the results of the 2-D numerical analysis by the FEM, we confirmed that the cogging force of the end edge is a 49.95 % reduction was possible using model with the stair shape auxiliary teeth, compared with the basic model.

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