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学位論文題目　STUDY ON LINEAR SYNCHRONOUS MOTOR DESIGN FOR OIL PALM CUTTER
(オイルパームカッター用リニア同期モータ設計に関する研究)

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論 文 内 容 の 要 旨

This thesis discussed about design and development of linear synchronous motor for oil palm cutter. The main motivation on this research is to improve productivity of oil palm in order to meet is world demand through mechanization of oil palm harvesting tool. In Malaysia, the Malaysian Palm Oil Board (MPOB) has introduced a mechanical based harvesting tool called *Cantas*TM. The *Cantas*TM has undergone several fields testing sessions. Based on the findings, the *Cantas*TM could improve the oil palm harvesting productivity about 3 times. Despite of impressive performance of the *Cantas*TM, this tool become inefficient to harvest oil palm fresh fruit bunch located about 8 meter height. Therefore, a by wire harvesting tool named E-Cutter has been proposed to replace the *Cantas*TM especially to harvest higher oil palm fresh fruit bunch. The E-cutter offer flexibility features that capable to eliminate the mechanical limitation of the *Cantas*TM.

The E-Cutter consists of three major parts which are electrical generation system, motor driver and actuator. But, in this research, design and develop of the E-Cutter's actuator is focused. Since a linear oscillation motion is required for E-Cutter during cutting activity, a linear motor was chose to be applied as E-Cutter's actuator. There are two design target has

been set which are cutting force higher than 200 N and total weight lower than 2.0 kg.

Despite of all types of linear motor, linear synchronous motor (LSM) is seen as appropriate candidate as E-Cutter's actuator due to capability to produce high thrust density and continuous mover. The LSM could be design either with magnet or called as permanent magnet linear synchronous motor (PMLSM) or without magnet or called as switched reluctance linear synchronous motor (SRLSM). The PMLSM is known it capability to produce high thrust density while the SRLSM could eliminates use of permanent magnet since the permanent magnet was reported having supply chain problem recently. Based on each advantage, a permanent magnet cylindrical linear synchronous motor (PMCLSM) and a switched reluctance cylindrical linear synchronous motor (SRCLSM) were designed to observe their feasibility to be used as E-Cutter's actuator. The PMCLSM and the SRCLSM were evaluated using 4 performance indexes and was compared to about 200 models of commercialized permanent magnet linear motor (PMLM) to proven it capability to produced high performance characteristics.

A 6 phase structure topology was chose to be used to design the SRCLSM. Instead of traditional 6 phase structure, the 6 phase SRCLSM was designed with 2 sections of 3 phase stator with the second section was shifted half of teeth pitch, τ_p compared to the first section. However, since the performance of 6 phase SRCLSM was estimated by it single phase performance. A single phase SRCLSM was then manufactured to validate the simulation result. Static thrust characteristics was then measured and compared to the simulation result. Based on comparison, it is found that, the measurement result has significant difference compared to the simulation output. One of the reason is due to manufacturing tolerance, Δx. Based on the comparison between ideal SRCLSM model with the SRCLSM with manufacturing tolerance, Δx, it was suggested that, the SRCLSM was manufactured with -50 μm of manufacturing tolerance, Δx. Furthermore, it is estimated that the SRCLSM need about 7.3 A of current, I to fulfil the thrust requirement. The amount of current, I is seem high compared to size of copper wire used to construct the SRCLSM coil. Even though total weight of the 6 phase SRCLSM was 30 % lower than the E-Cutter's actuator restricted weight, however due to the thrust produced is significantly lower compared to the targeted thrust, process to make the SRCLSM fulfil both design target is seem to be unfeasible despite the SRCLSM structure is too sensitive against the manufacturing tolerance, Δx.

For the PMCLSM, 3 phase structure topology with 6 slot 8 pole combination structure was selected. The structure of the PMCLSM has undergone 2 stage of design to make sure it fulfill design target. During structural design, several structure parameters have been considered which are height of coil, h_c, radius of permanent magnet, r_{pm}, total radius, r_{total} and shaft radius, r_s while the other parameters remain constant. Based on structural optimization, the optimize model of the PMCLSM that fulfil the design target has been obtained. The PMCLSM found to produce about 208 N of average thrust, F_{ave} at input power, P_{in} of 114 W and total weight of 1.8 kg. The PMCLSM also it is found could produce higher thrust density compared to the commercialized PMLM. As for result validation, the 3 phase PMCLSM has been manufactured. Instead of dynamic thrust observed during simulation stage, on measurement stage, static thrust characteristic was measured. The static thrust characteristic of the PMCLSM was measured on each individual phase. The measured static thrust characteristic was then compared between measured and simulated result. Based on comparison, it is found that, the profile of static thrust characteristic has a good agreement between simulated and measured result for each individual phase of the PMCLSM.

On the other hand, it is shown that, magnetic field density saturation happen at current higher than 1.5 A since the measured thrust is not increased as the current increased higher than 1.5 A. Furthermore, it is shown that, 200 N of thrust was not able to be achieved. The maximum thrust, F_{max} is 133 N (U phase), 157 N (V phase) and 180 N (W phase) has been obtained. Despite of lower measured static thrust characteristic compared to aimed thrust, the PMCLSM still shown a potential to be implement as E-Cutter's actuator due to capability to produce high thrust at lower than it restricted weight. However, the magnetic flux density saturation occurrence make the PMCLSM's thrust was limited. Design step of the PMCLSM need to continue by optimizing the coil and stator yoke size. On top of that, the coil parameter such as copper wire diameter, ϕ_c and coil turn, N also need to be optimized.