1. Literature Review

Axial-flux machines have been becoming more and more popular everyday thanks to their short axial-length, higher torque and power densities. However, axial-flux machines are not very suitable for mass production purposes, because of their planar stator geometry which makes the production of the stator challenging. PCB motor offers a solution to this problem by the use of the precise and cheap manufacturing options of printed circuit board technology that enables AFPMSM with PCB winding to be used in small wind-turbines, water current turbines, hard-disk drives, video disk drives and spindle motors \cite{pcb-windturbine,pcb-windturbine2,rhombo,harddisk,concentric3}.

Fast and cheap PCB manufacturing process ensures that all printed circuit boards can be produced with precision in micrometers range which facilitates construction of small electric motors. Control algorithms such as model predictive control or direct torque control requires motor parameters to be known. After designing the printed circuit board, stator parameters can be calculated using finite element analysis tools. Since, every PCB will be identical to each other, thanks to the manufacturing precision, these control methods can accurately be implemented into the design. Moreover, there is no cogging torque due to air-cored stator structure. Lastly, PCB motors have fewer number of turns and large effective air gap which make the phase inductances low. The lower the inductance, the smaller the electrical time constant and the better the transient performance.

In literature, there are different winding designs for PCB motors. The concentric winding which is a very commonly used winding type, has a high induced voltage and torque output because of high flux linking area and long radial winding length. However, end winding connections of the concentric winding is long. As a result, resistance of the current path increases, so the thermal stress of stator windings is high and the efficiency of the motor is low. Alternatively, wave winding topologies are proposed in \cite{wave}. The main purpose in design is to increase the efficiency of the winding without losing the dynamic performance of the motor. A comparison of different windings for PCB motors are presented in \cite{comparison}, but it should be noted that PCB inner and outer diameters of various windings are chosen differently and fractional pitched stator coils are used.

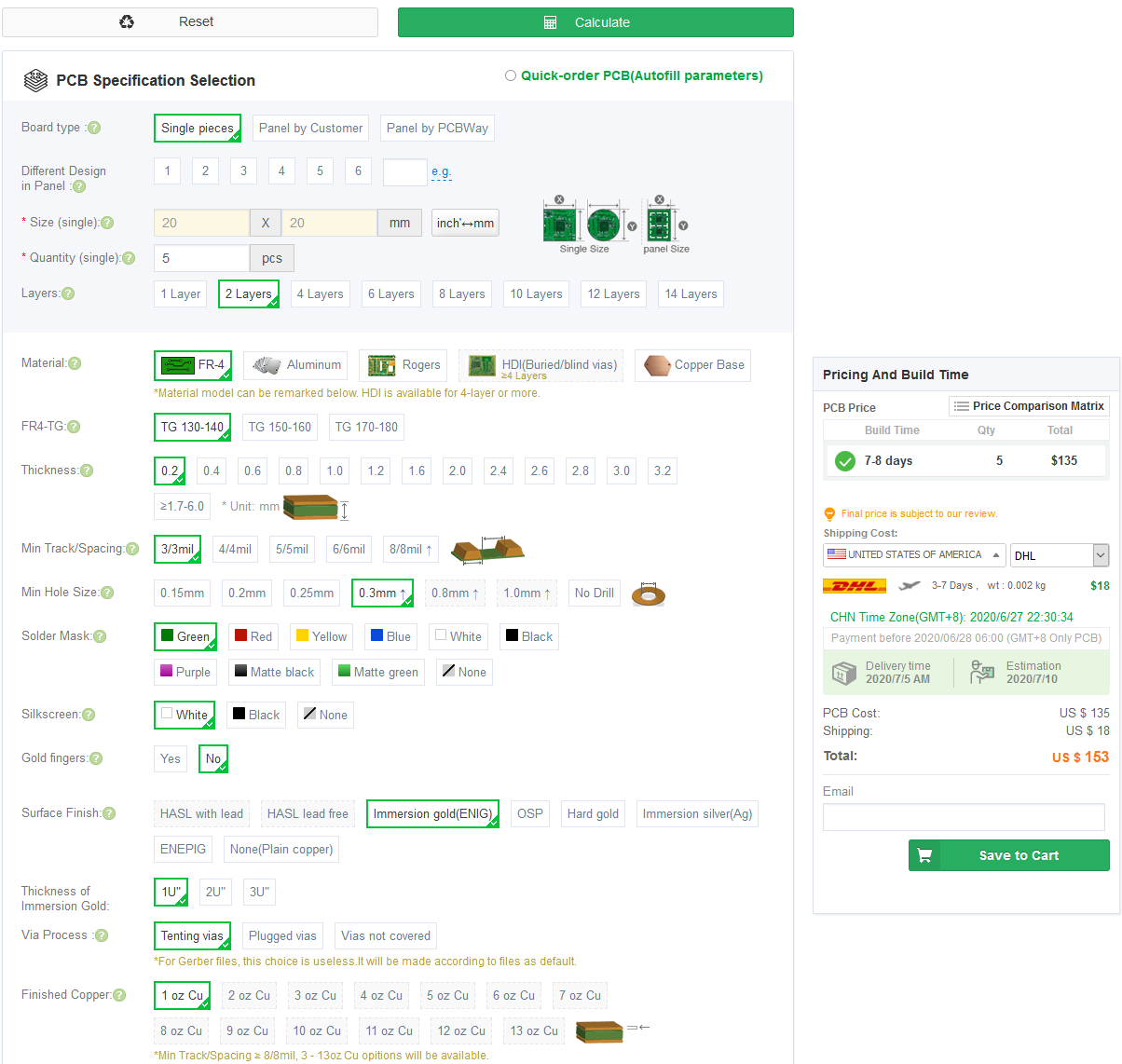
1. Analytical Calculation & Sizing

In this project, I have designed a double rotor-single stator permanent magnet axial-flux synchronous machine with PCB winding. In order find have better understanding about the analysis, which is presented in this report, I have tried to make a comparative analysis of an AFPMSM with PCB winding which is designed in REF. The spindle motor designed in REF, is a single-sided AFPMSM with a stator which has rhomboidal winding configuration. The thickness of the motor is 3 mm and inner and outer diameters are 5.8 and 15.8 mm respectively. I have tried to make the two motor designs as close as possible. However, the major difference between two designs is that the stator winding that is designed in REF, has rhomboidal winding configuration. The major disadvantage of this configuration is that PCB surface area is not utilized successfully. For this purpose, I have designed an unequal width radial winding. Next, I have used double rotor-single stator configuration. The reason why I have used this topology is that the speed of the motor is high as 12500 RPM. The eddy current losses at this speed would be dominating the performance of the motor. When double rotor configuration is used both of the rotor yokes will rotate at the same speed so that there will be no eddy current induced on the rotor yokes.

I have used N42 grade NdFeB permanent magnet which is shaped as sectors to have maximum use of rotor surface.

Table . Parameters of the designed motor.

|  |  |  |  |
| --- | --- | --- | --- |
| Outer diameter | 15.8 mm | Air gap length | 0.4 mm |
| Inner diameter | 6.3 mm | PCB thickness | 0.2 mm |
| Thickness of motor | 5 mm | Number of slots | 42 |
| Number of poles | 14 | Copper thickness | 1 oz/ft2 |
| Speed | 12500 RPM | Back core thickness | 0.6 mm |
| Ifull-load | 0.5 A | Magnet thickness | 1.4 mm |

Figure 1. Limitations of the production.

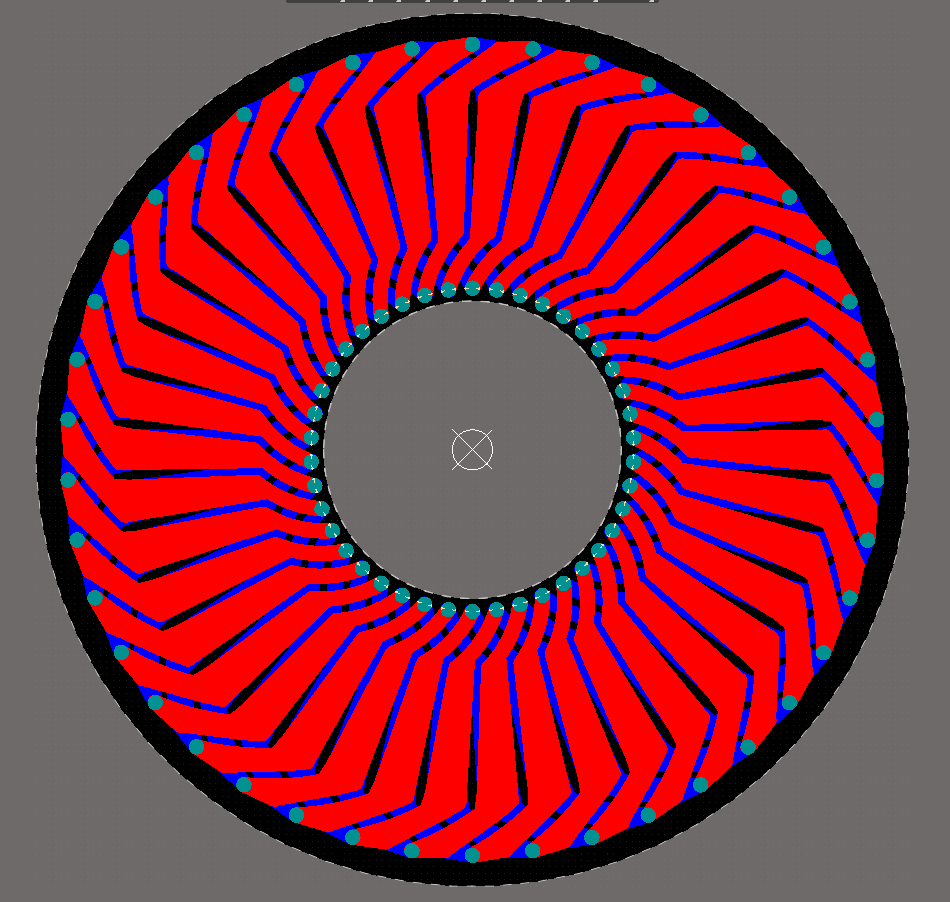


Figure 2. Designed unequal width radial winding stator.



Figure 3. Magnetic flux density distribution in the back core.

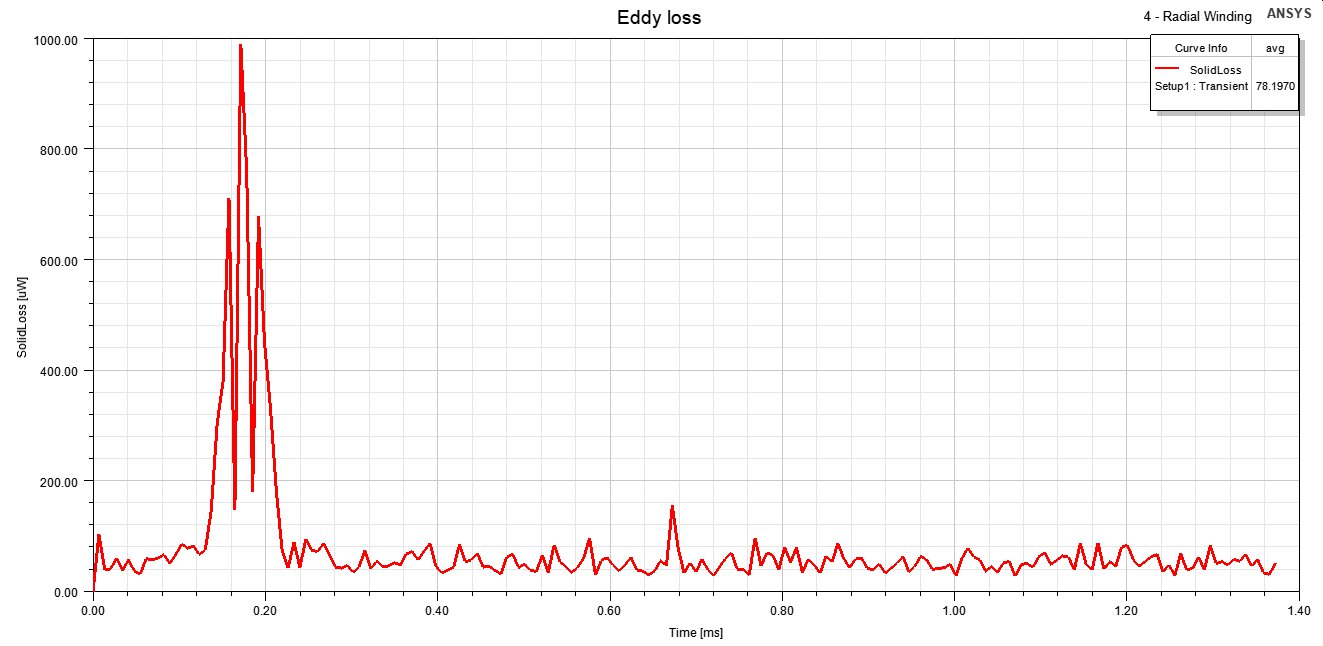


Figure 4. Eddy loss graph of the machine.

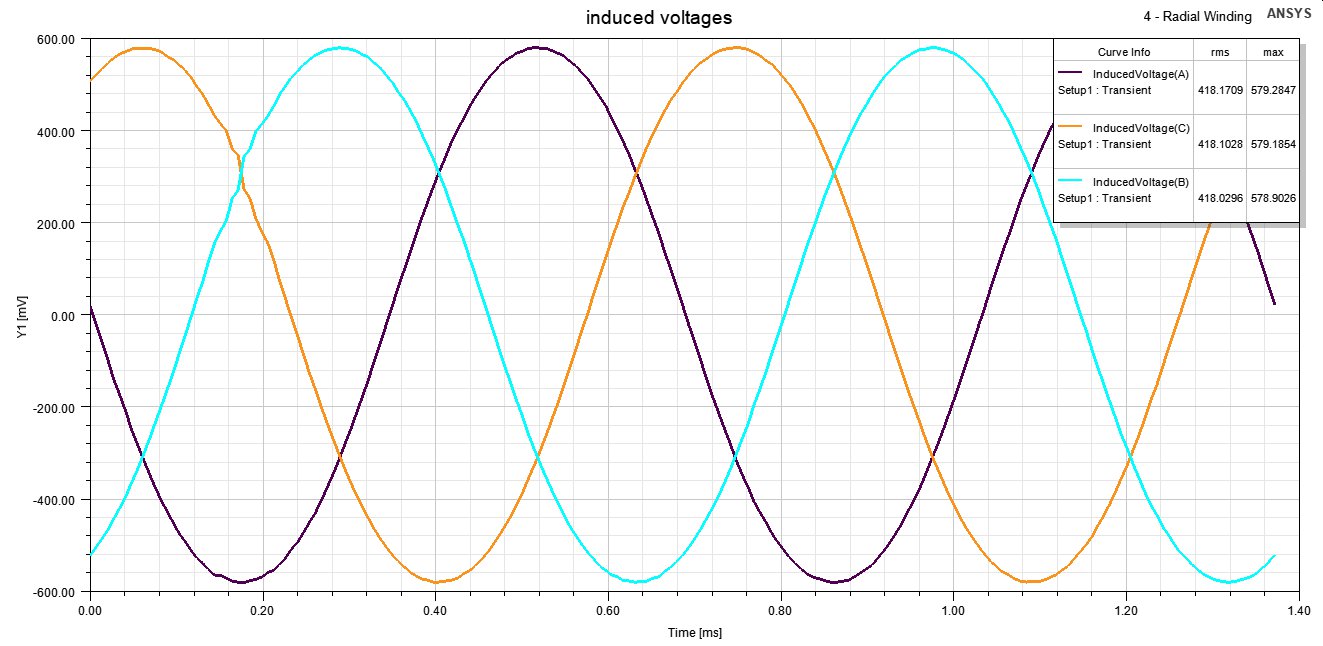


Figure 5. Induced voltage waveforms of the designed machine.

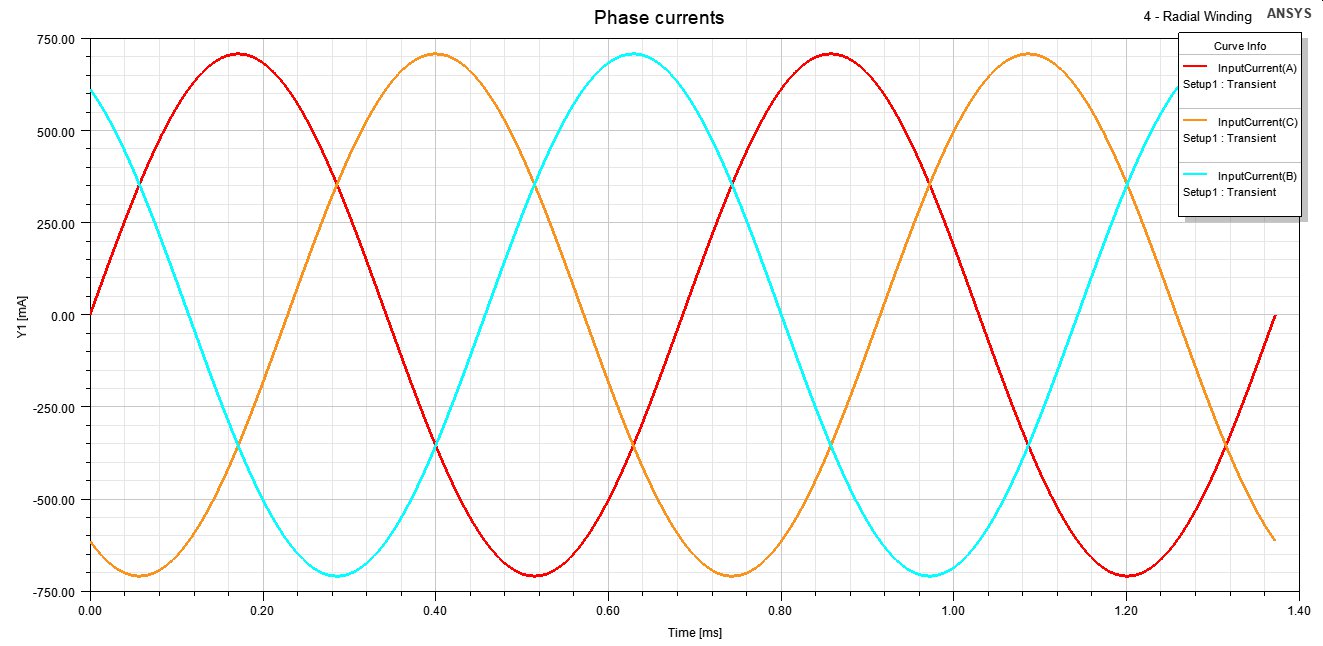


Figure 6. Input current waveforms of the motor.

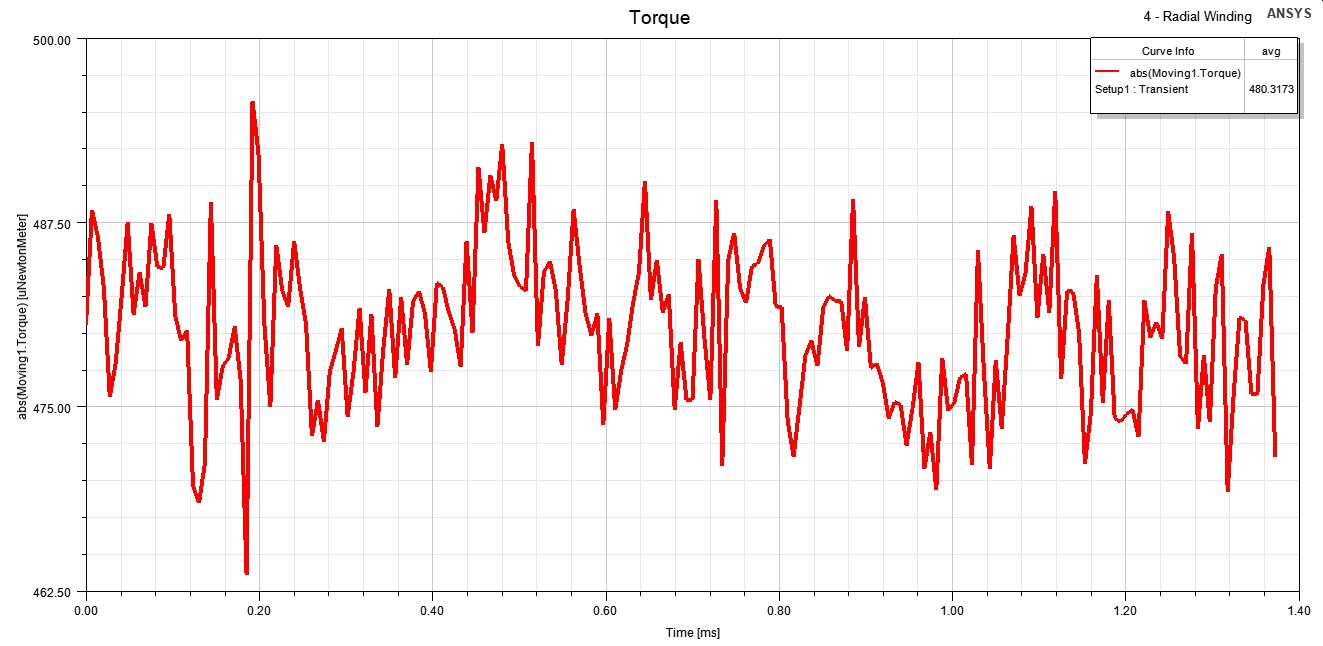


Figure 7. Created torque of the machine.

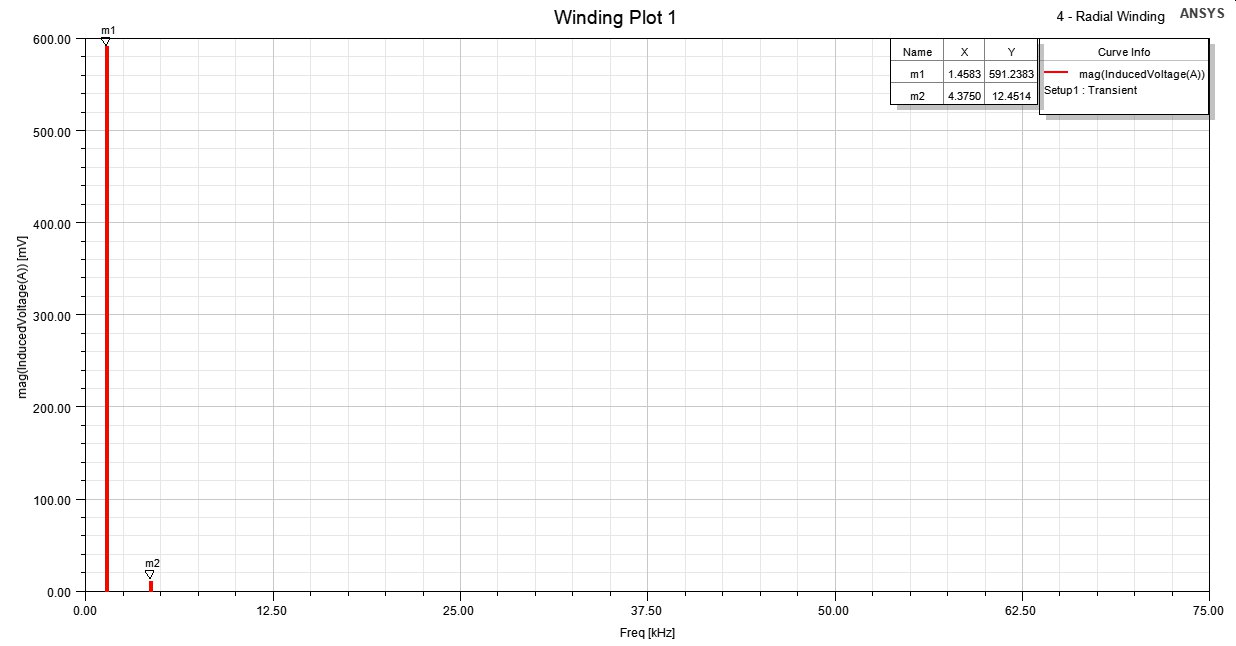


Figure 8. FFT result of the induced voltage waveform.

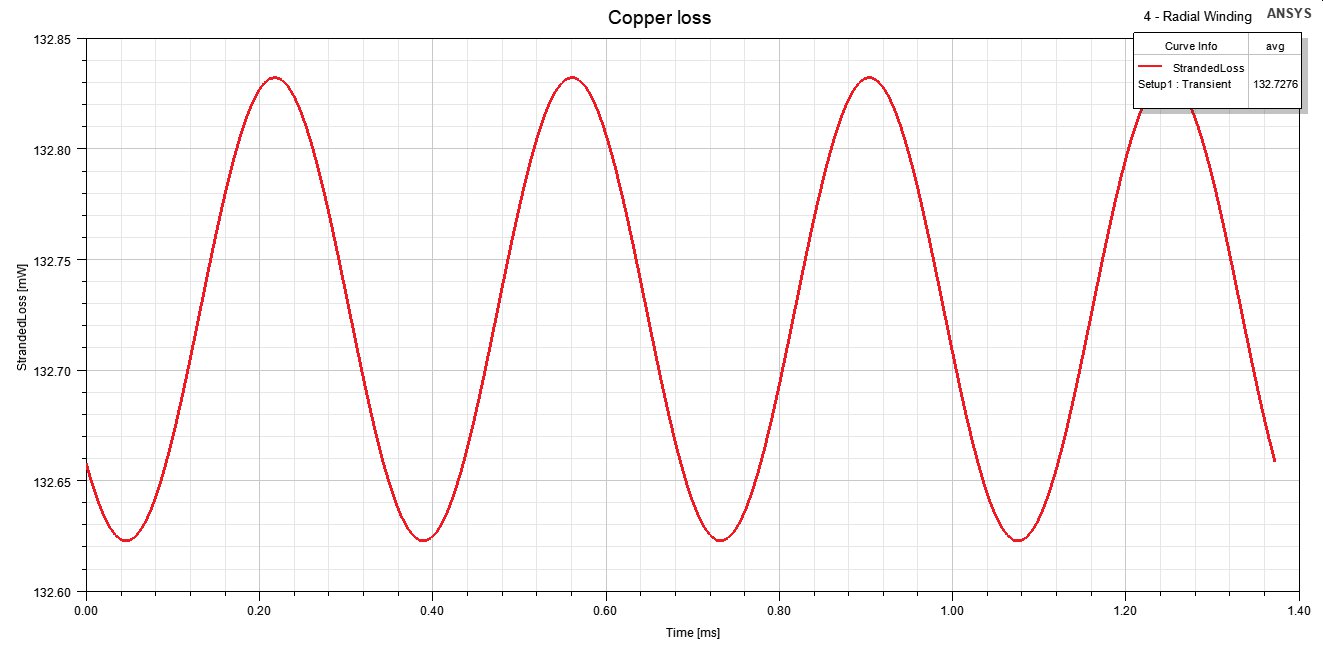


Figure 9. Copper loss of the windings.