内置永磁同步电机电磁和控制耦合分析

中国一汽 新能源开发院

尹相睿

2019/11/21

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红旗
让理想飞扬

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01
前言
FOREWORD

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02
研究对象

Study Objective

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■ 电机参数

- 8极48槽三相交流永磁同步电机
- 1000rpm、4000rpm、6000rpm、8000rpm、10000rpm持续工况

■ 分析模型

- 2D瞬态电磁场
- 控制电路
- 损耗分析

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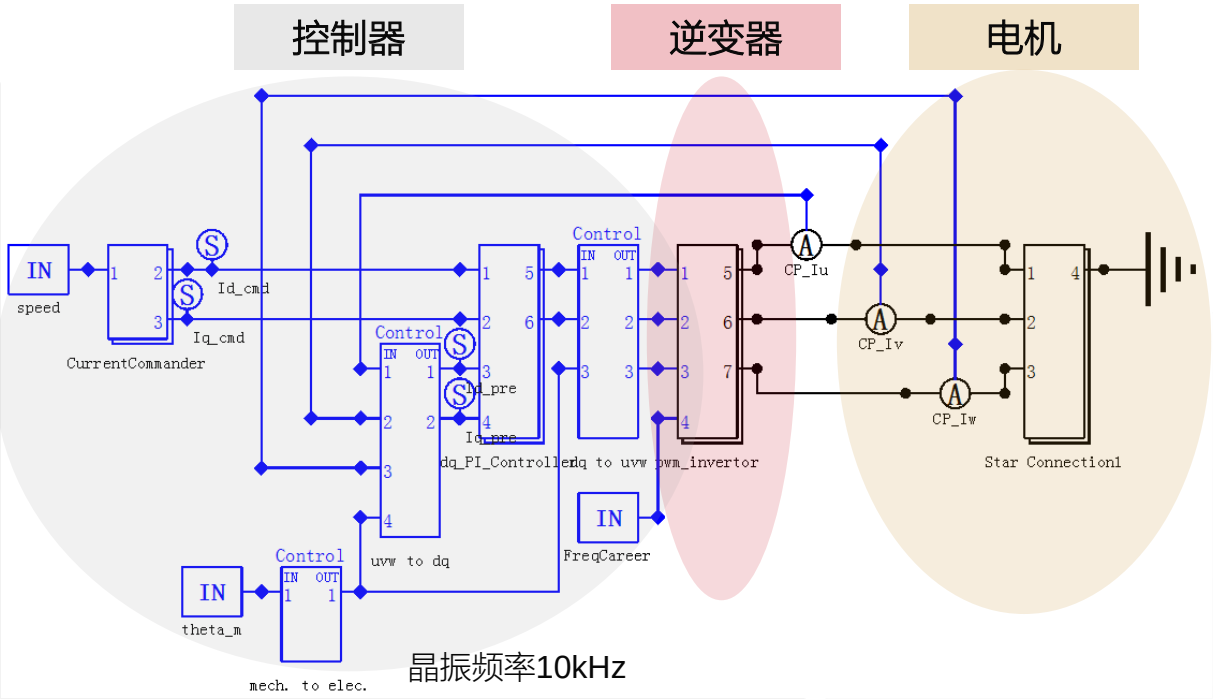
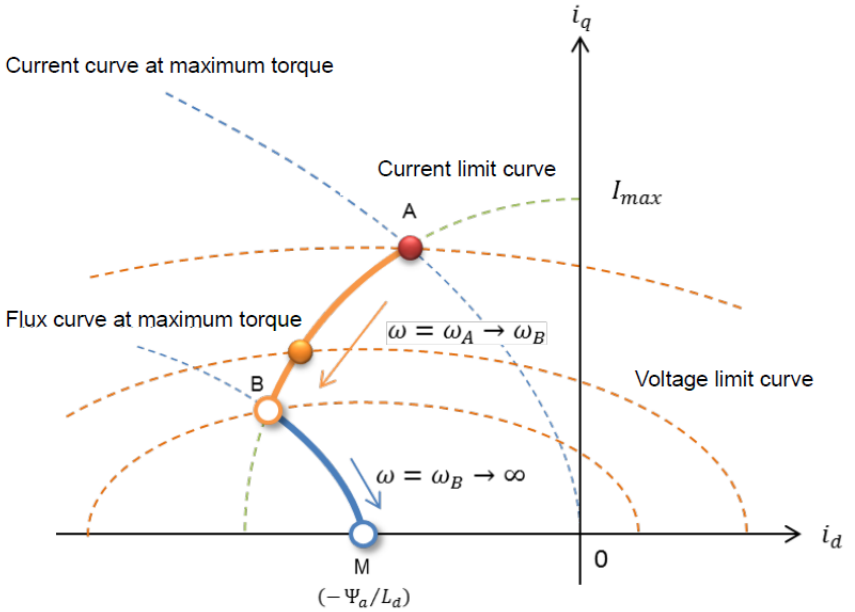
控制电路模型

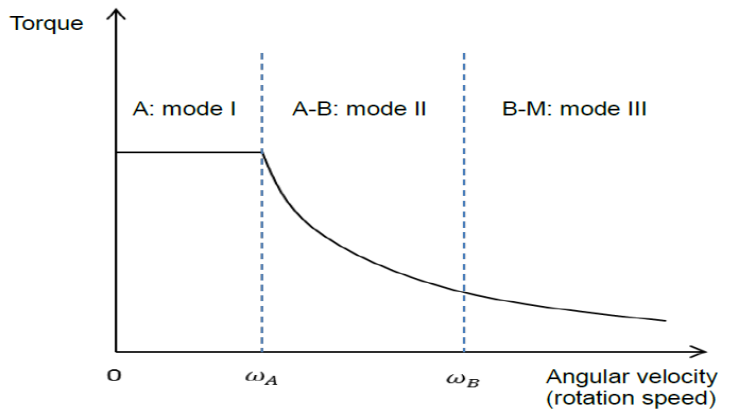


晶振频率10kHz

JMAG控制电路模型



定子电流矢量轨迹



控制方式

参考来源：JMAG案例JFT047FeedbackControl-e

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03
单转速性能分析

Performance Report

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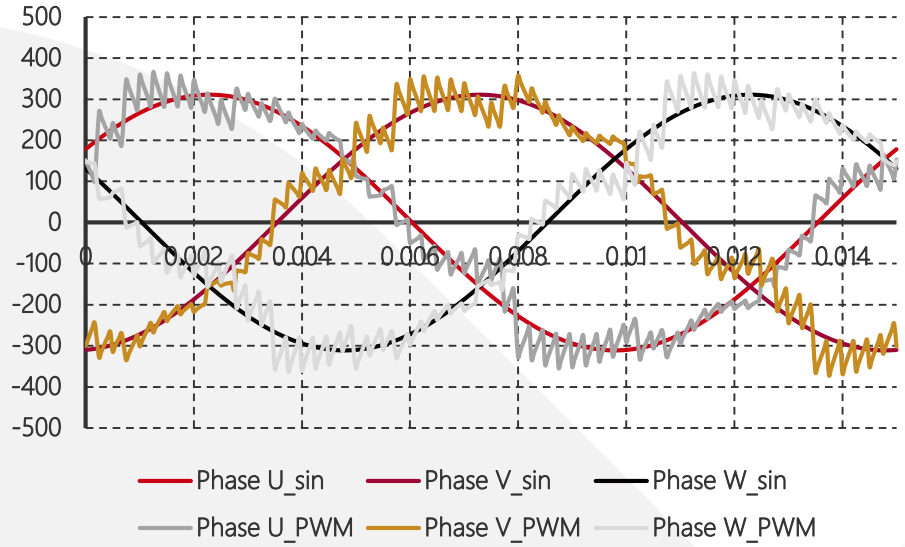
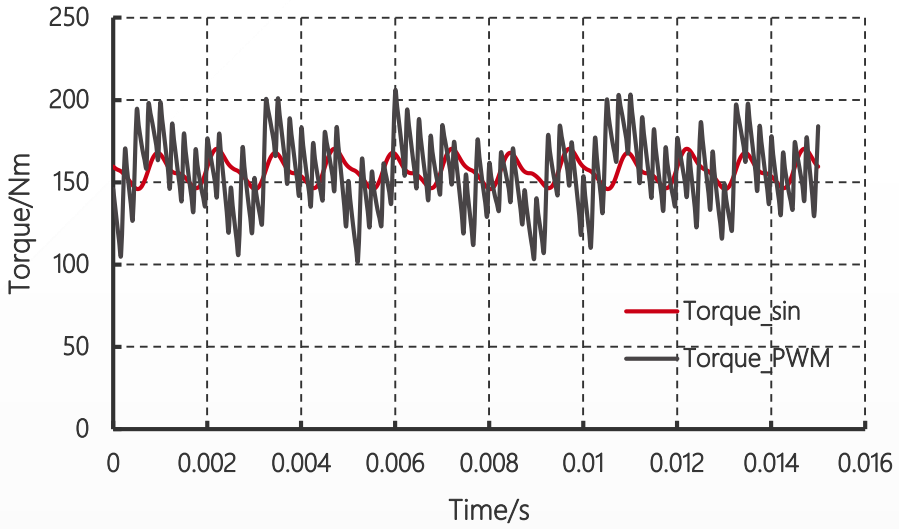
■ 单转速工况点：

- 电机转速 1000rpm
- 相电流 220Arms



三相电流曲线



电磁转矩曲线

✓ 控制电路产生的三相电流叠加了大量的高次谐波
✓ 控制电路产生的电磁转矩波动更为剧烈，转矩波动明显增大，且叠加大量高次扰动

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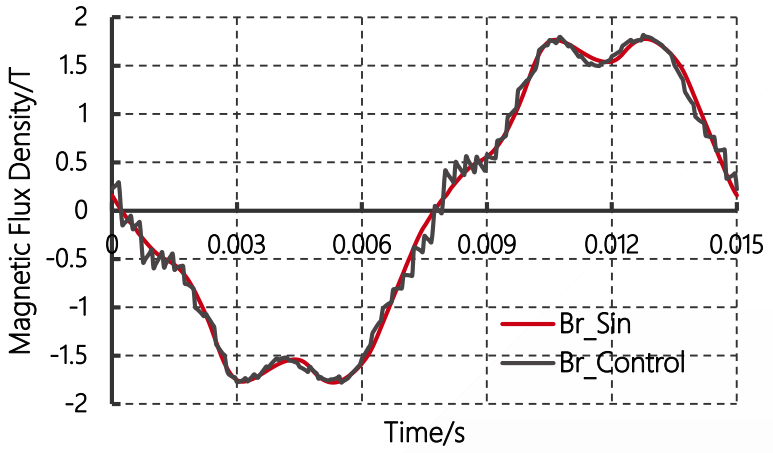
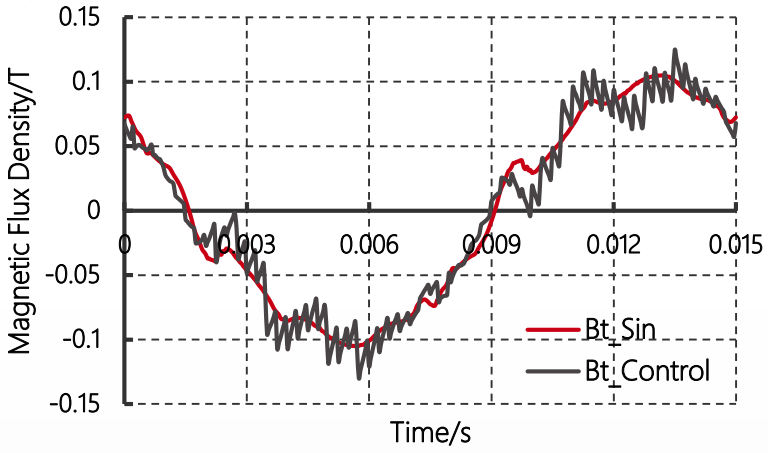
径向磁密

切向磁密

齿部





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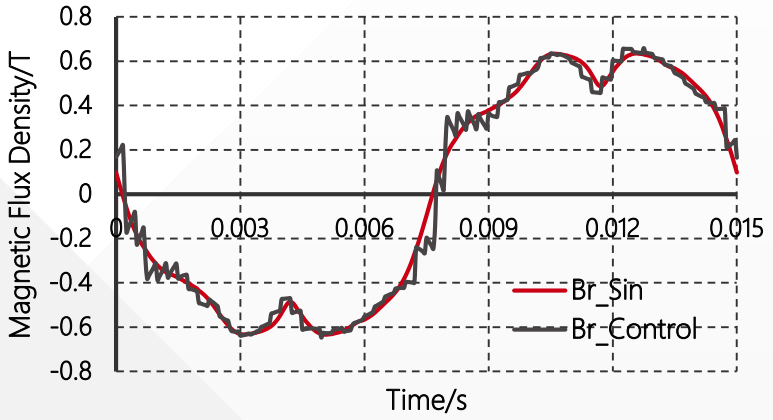

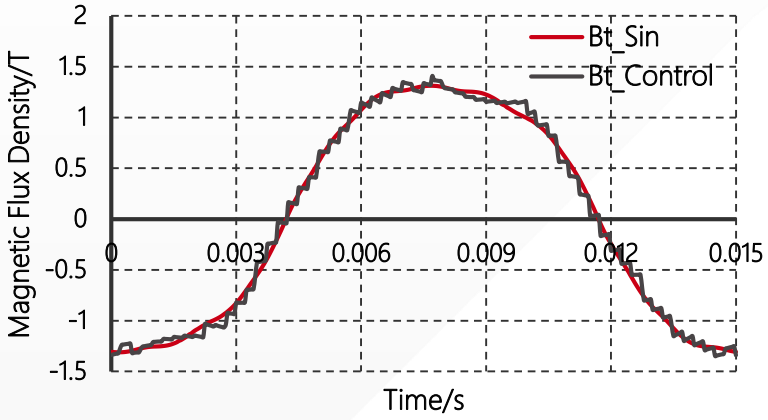

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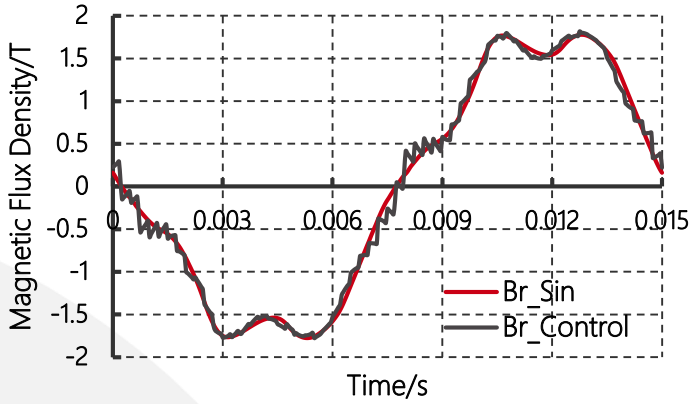
齿部 径向磁密



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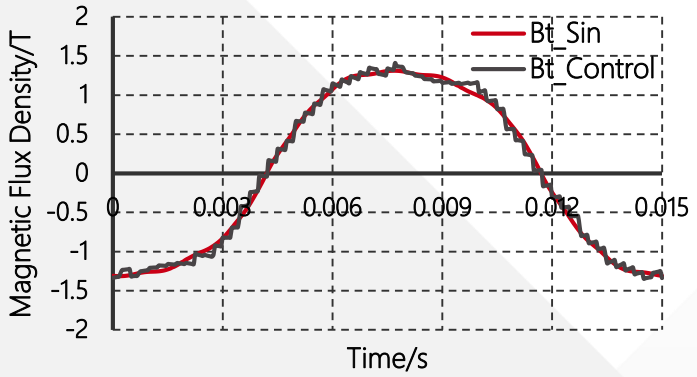
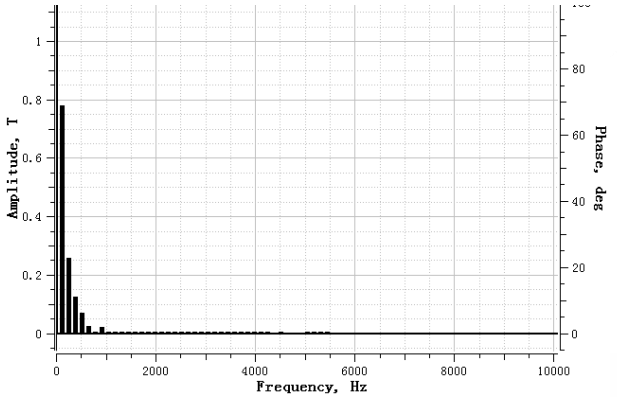
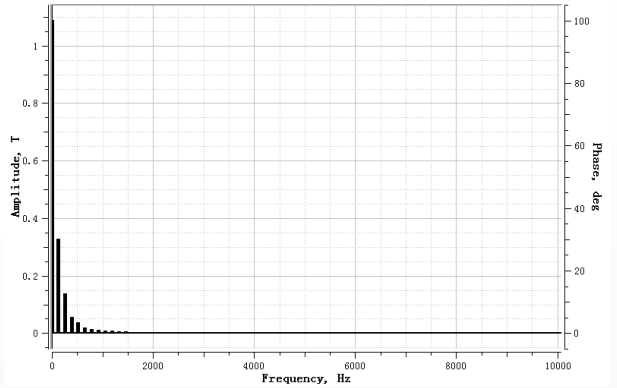
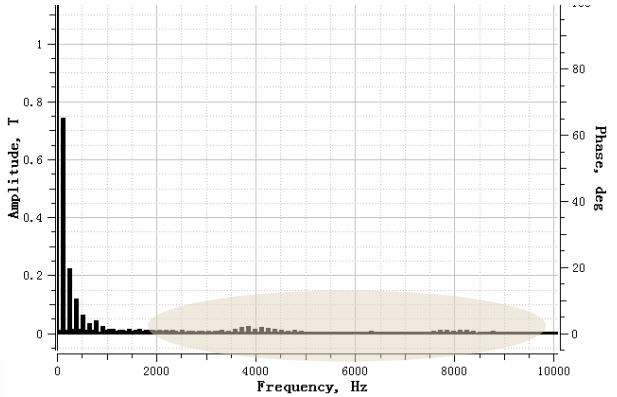


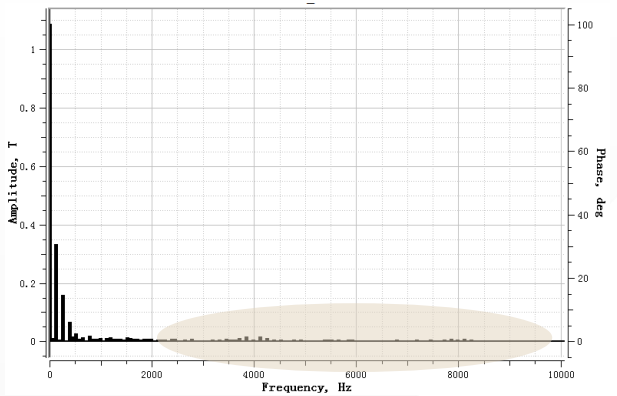
正弦激励





控制电路





✓ 控制电路的谐波成分更加丰富，定子磁密会产生较多的高次谐波分量，会对电机性能产生一定影响。

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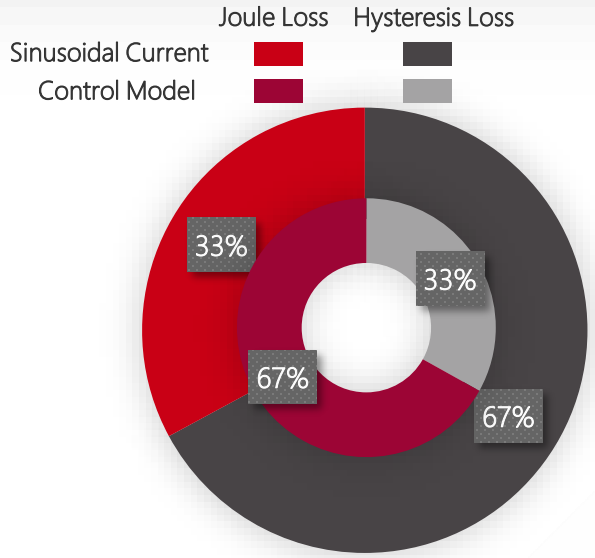
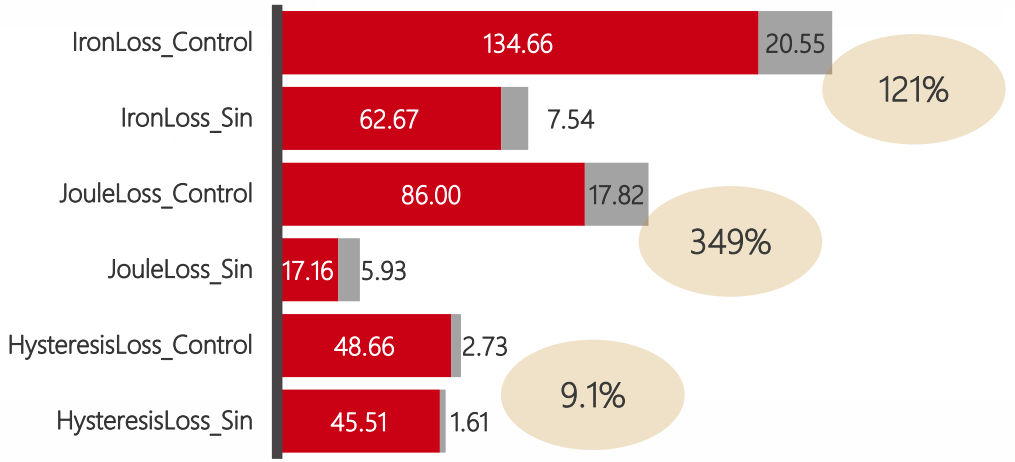
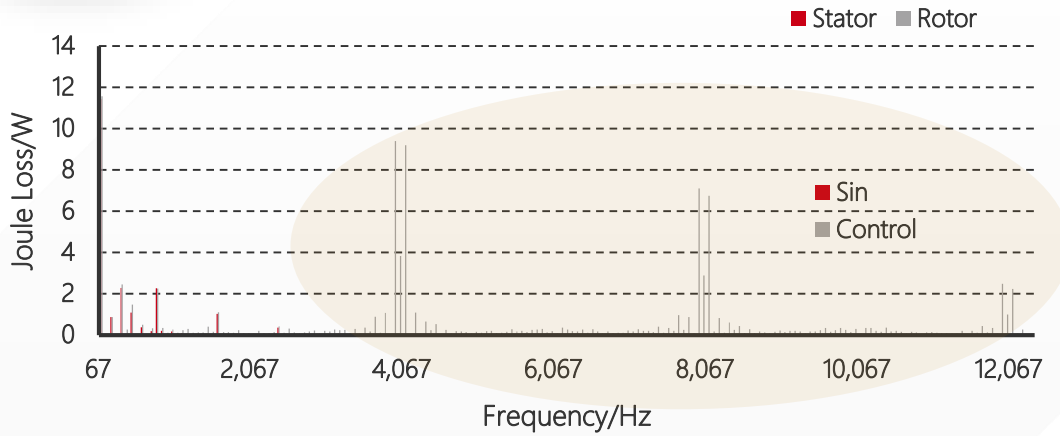
单转速性能分析

Performance Report







✓ 控制电路模型的铁损明显增加，主要是由于磁场的高次谐波丰富，导致铁损中的涡流损耗大幅增加

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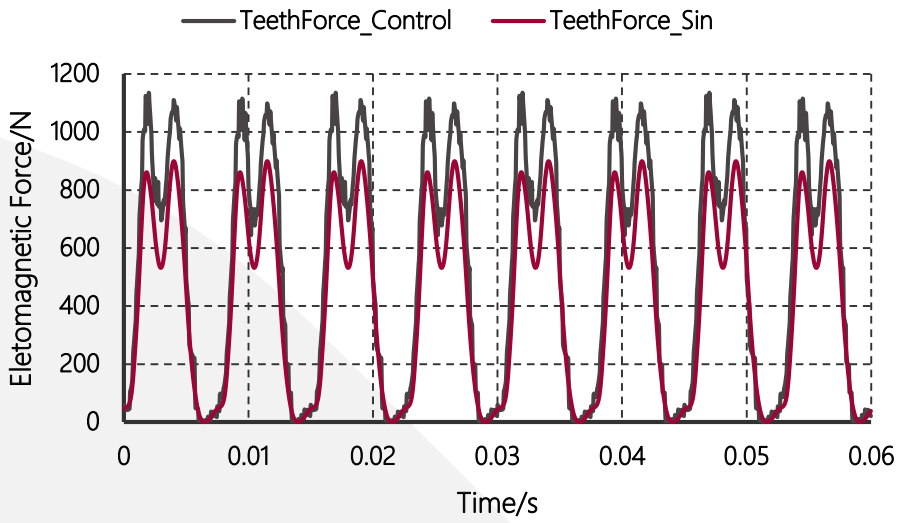
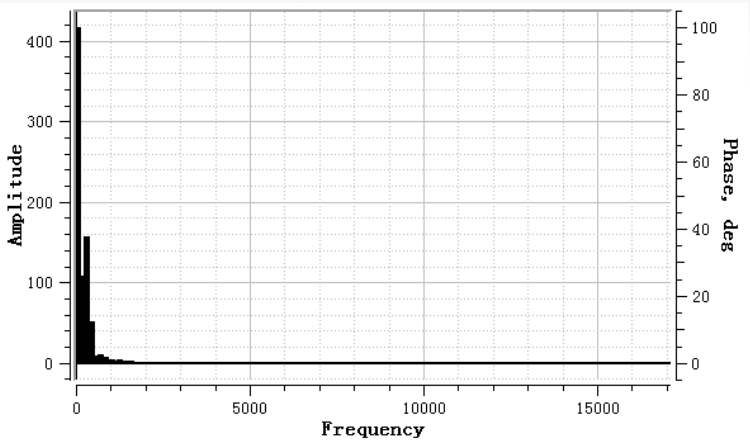
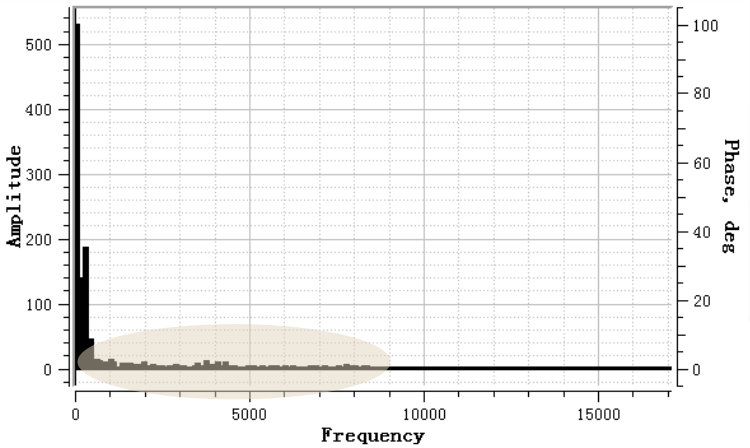


某定子齿电磁力曲线

正弦激励



控制模型



- ✓ 控制电路与正弦激励下的定子齿电磁力分布形状基本相同，但有较大的幅值
- ✓ 控制电路下的定子齿电磁力多了较多的高次谐波成分

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04
多转速性能分析

Performance Report

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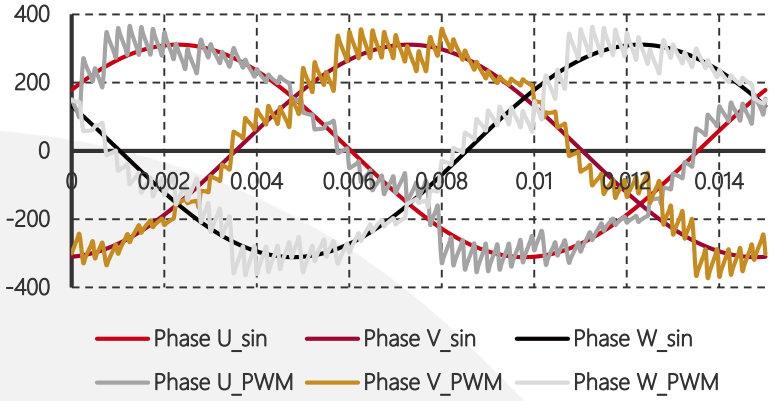
三相电流

1000rpm



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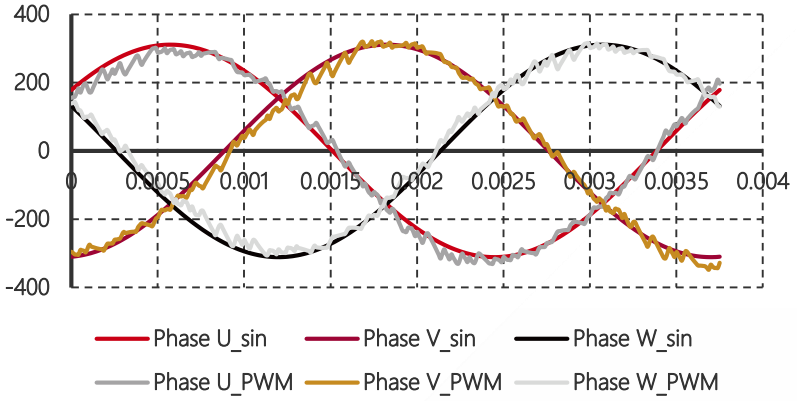

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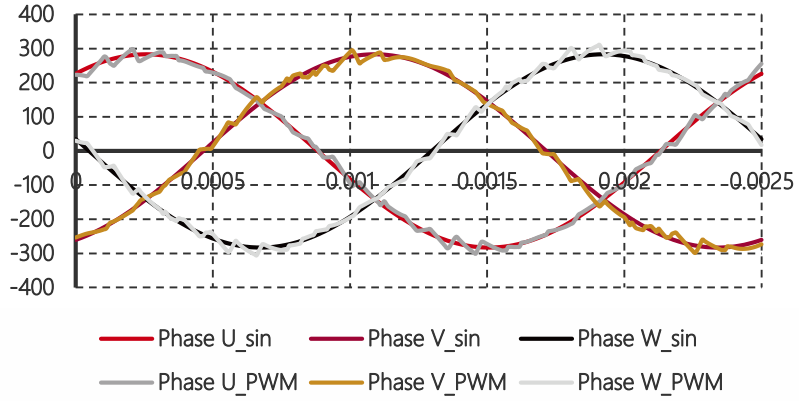

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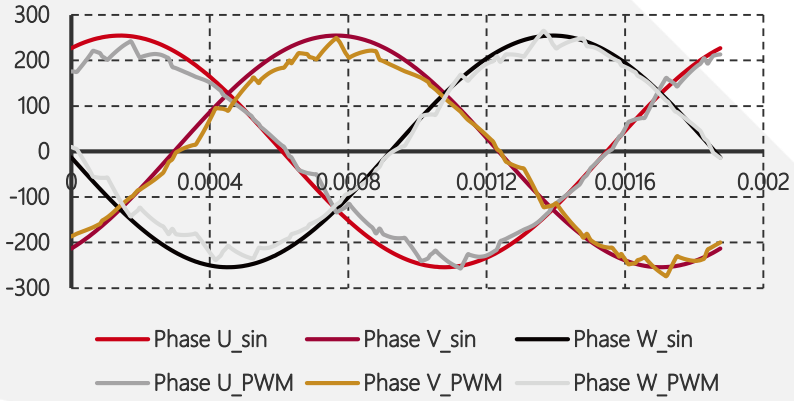

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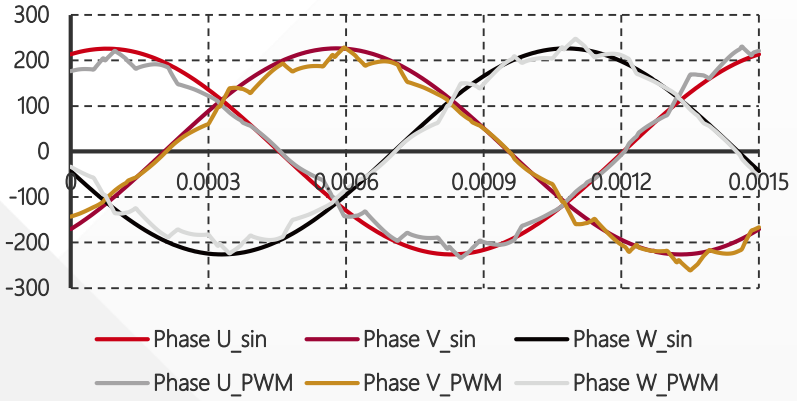

- ✓ 控制电路产生的电流都会具有大量毛刺，使得电流具有大量高次谐波
- ✓ 随着转速的升高，由于开关频率固定，每个周期的开关次数减少，控制电路产生的电流毛刺更为稀疏

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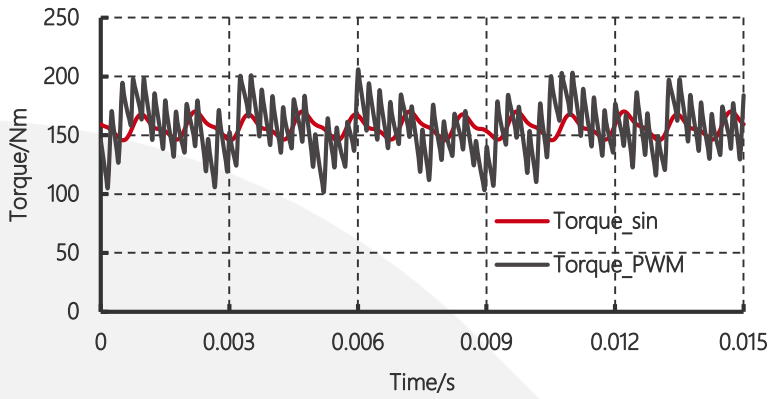
电磁转矩

1000rpm



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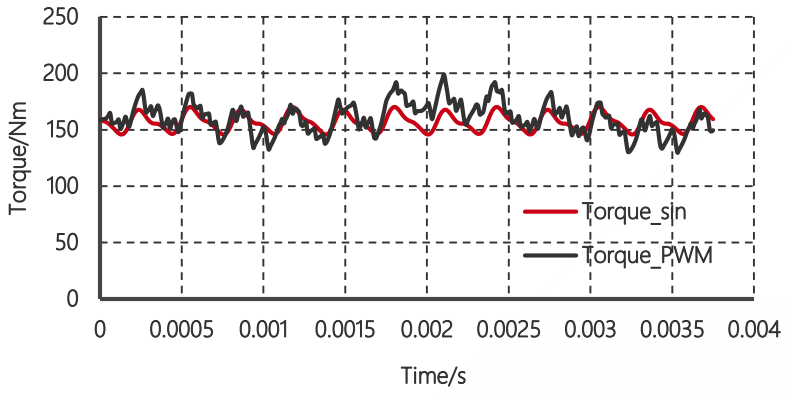

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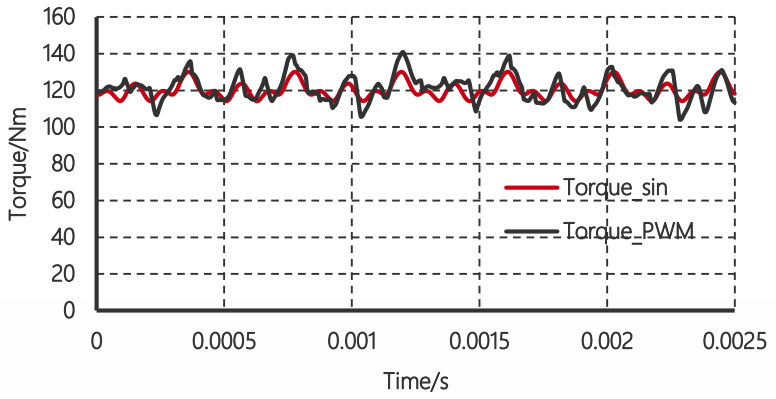

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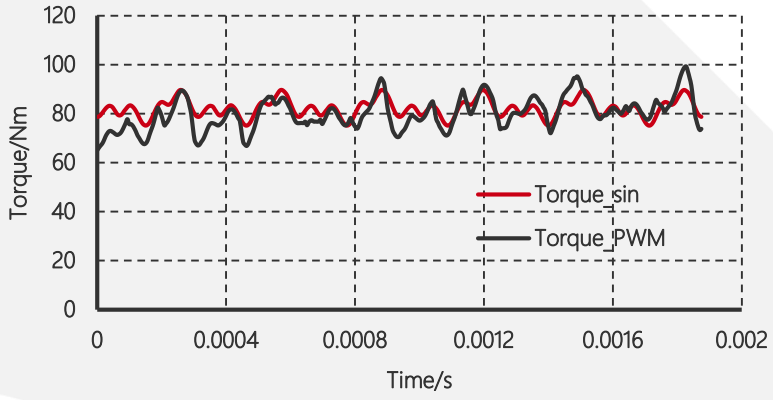

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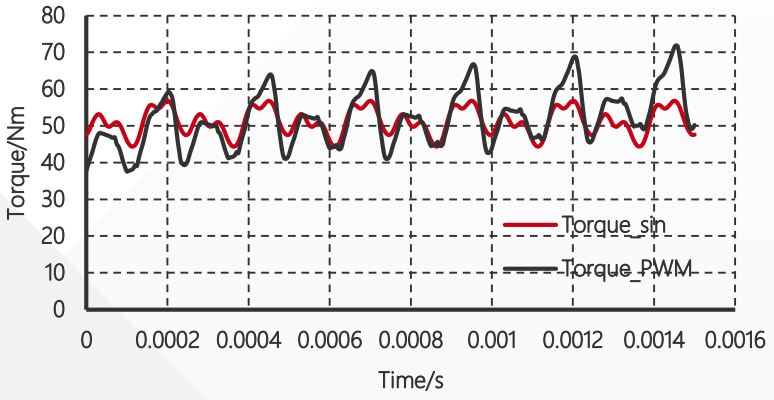

- ✓ 控制电路模型下的电磁转矩都具有较大的波动
- ✓ 随着转速的升高，控制电路模型下的电磁转矩高次波动有所缓解，但也使得偏差变大

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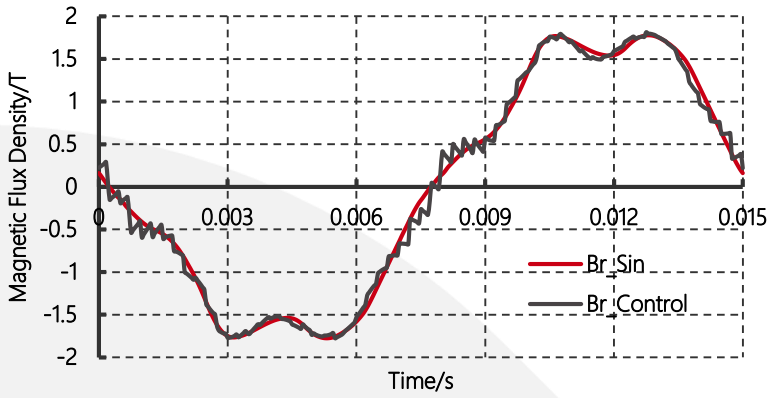
齿部径向磁密

1000rpm



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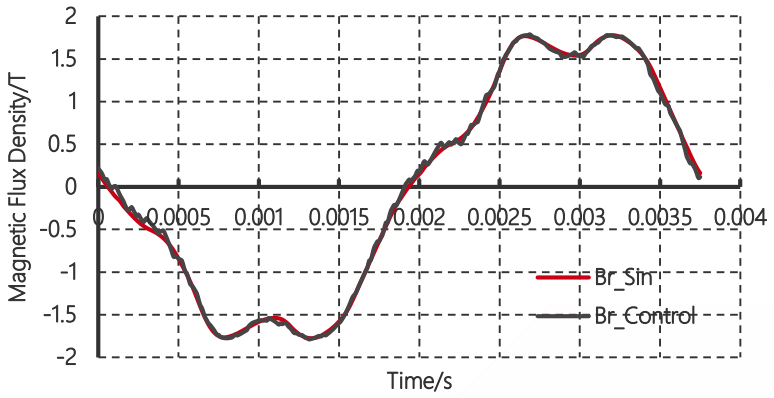

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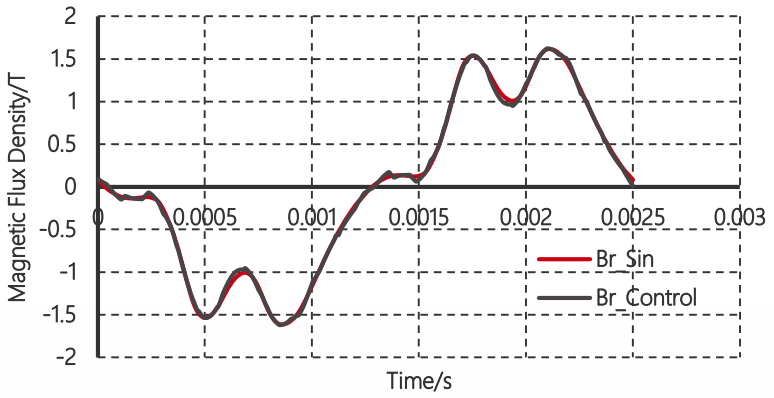

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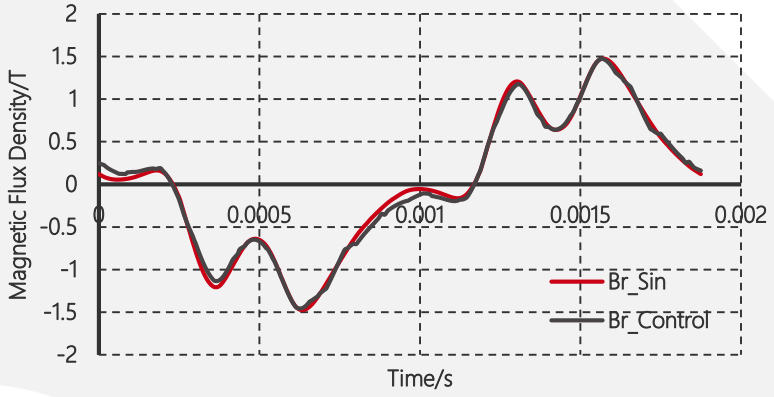

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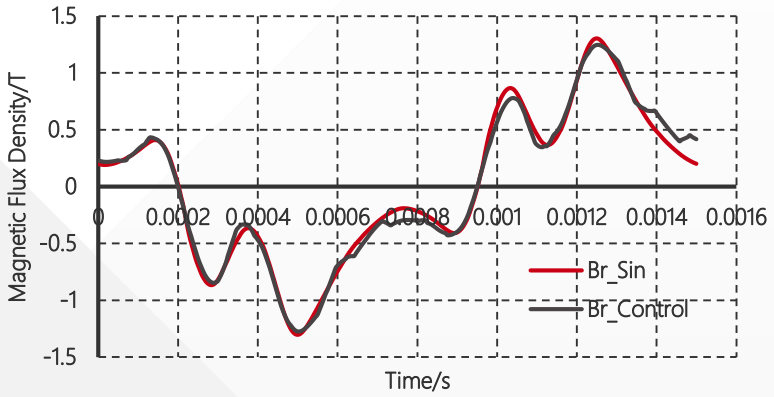

- ✓ 控制电路模型下的齿部径向磁密均带有高次谐波
- ✓ 随着转速的升高，磁场的高次波动减少

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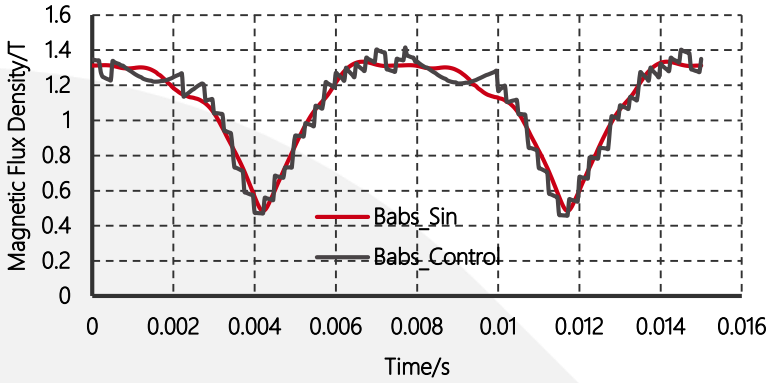
轭部磁密

1000rpm



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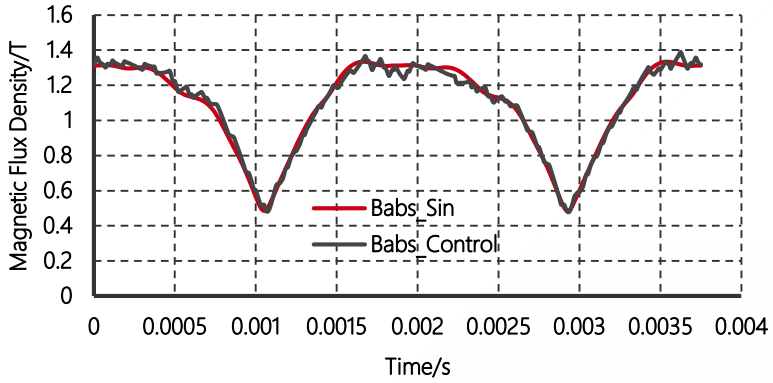

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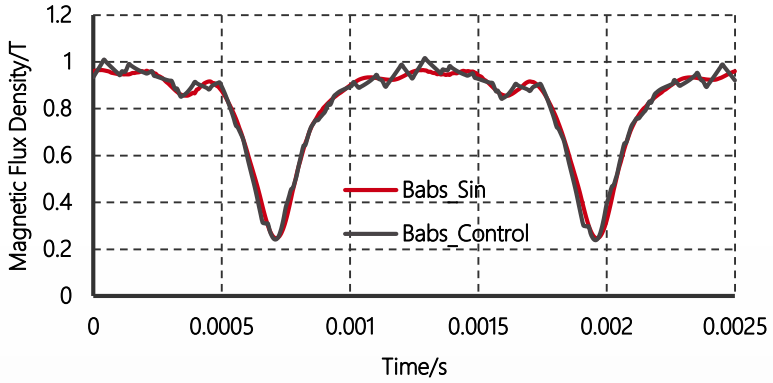

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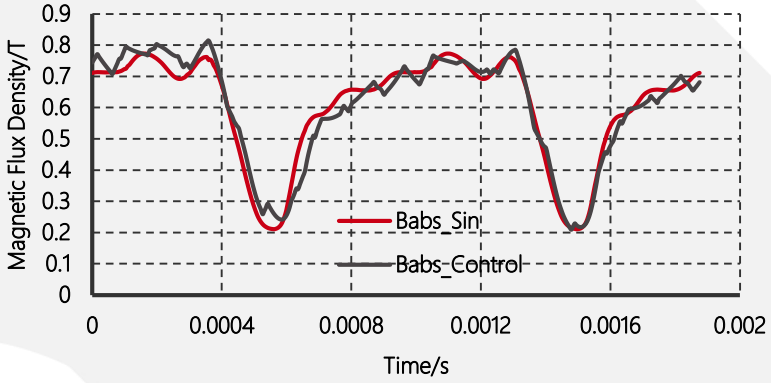

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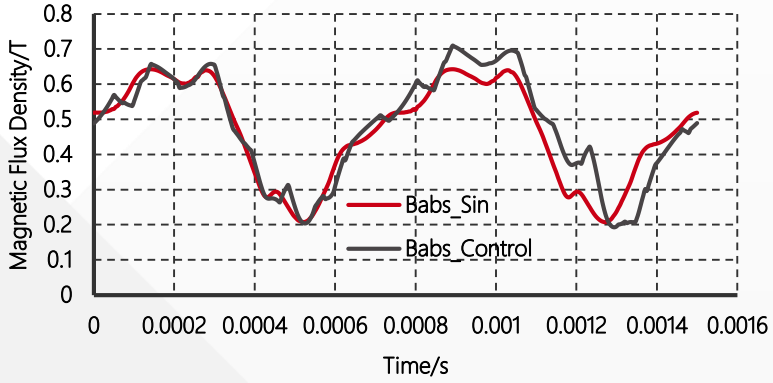

- ✓ 控制电路模型下的轭部磁密均带有高次谐波
- ✓ 随着转速的升高，磁场的高次波动减少，但也会与正弦激励差异增大

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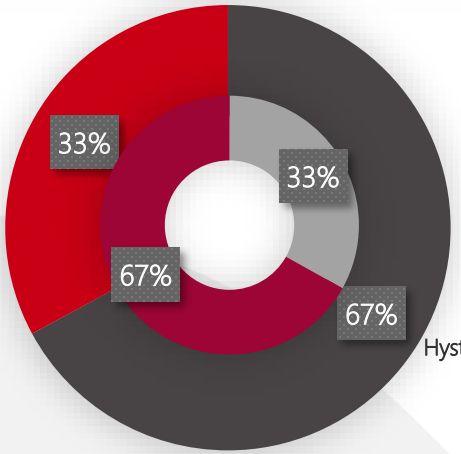
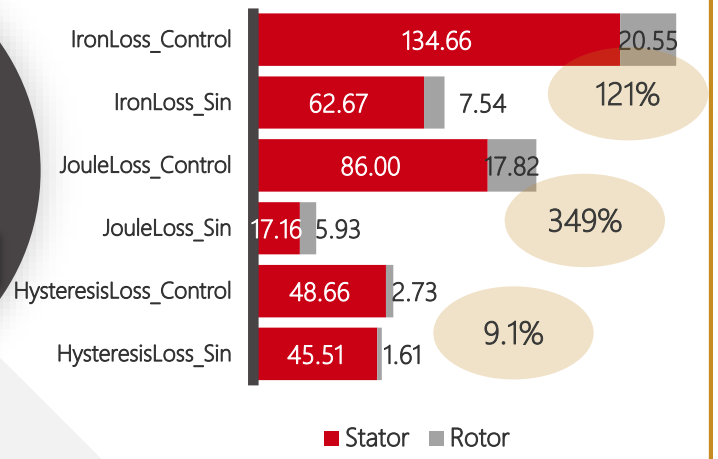
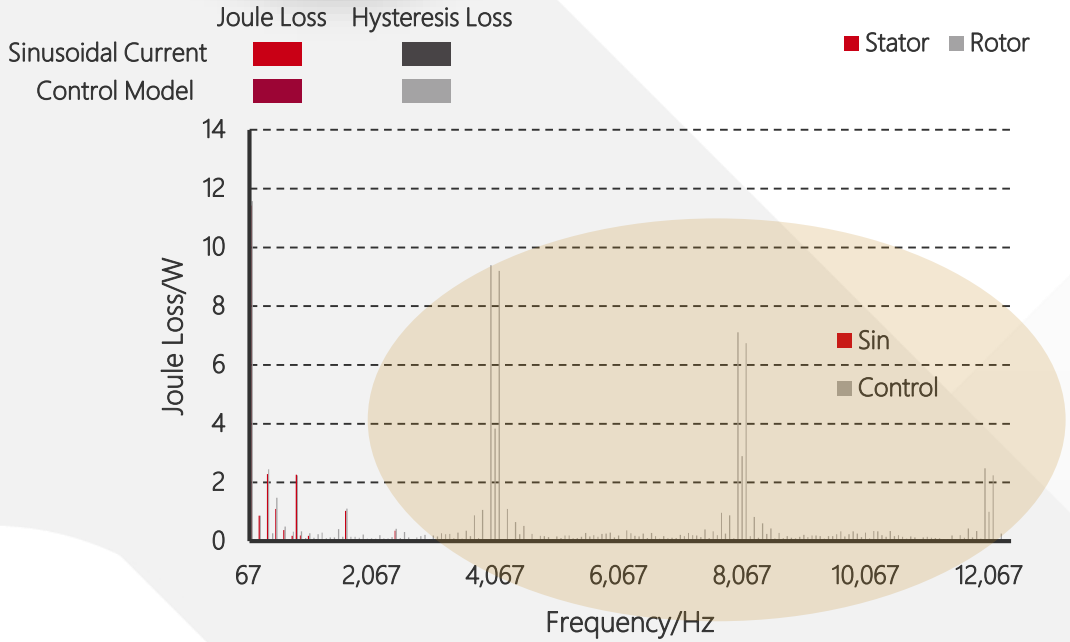
1000rpm







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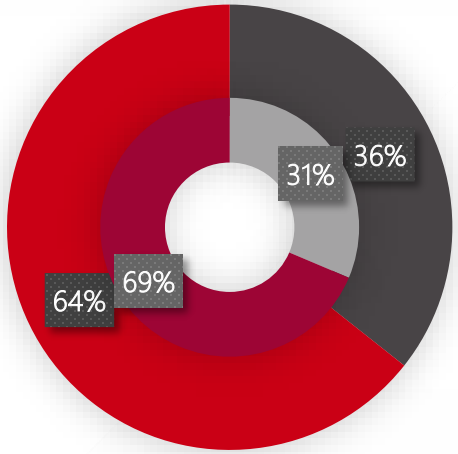

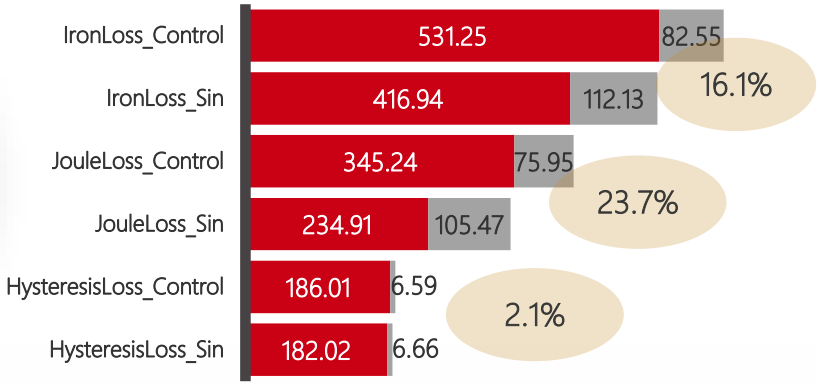

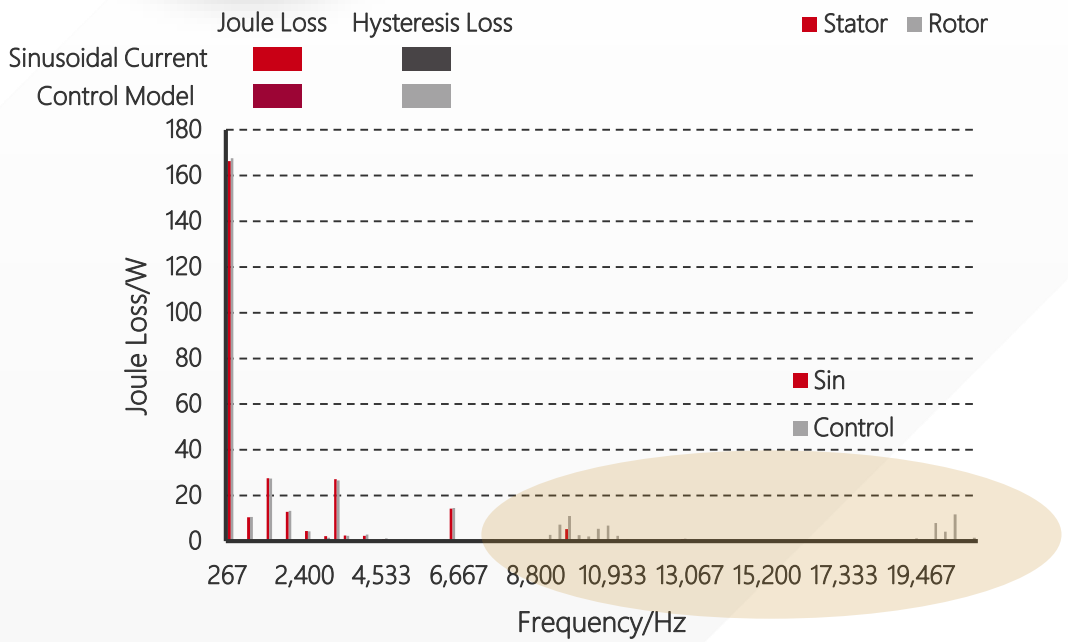

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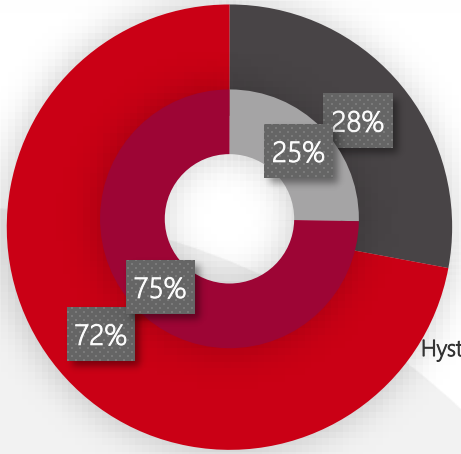
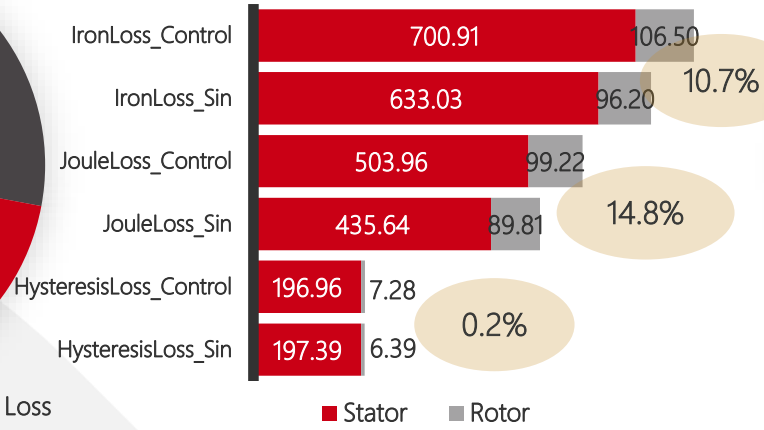
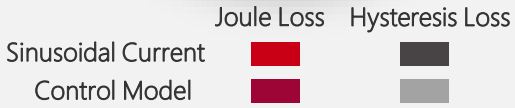
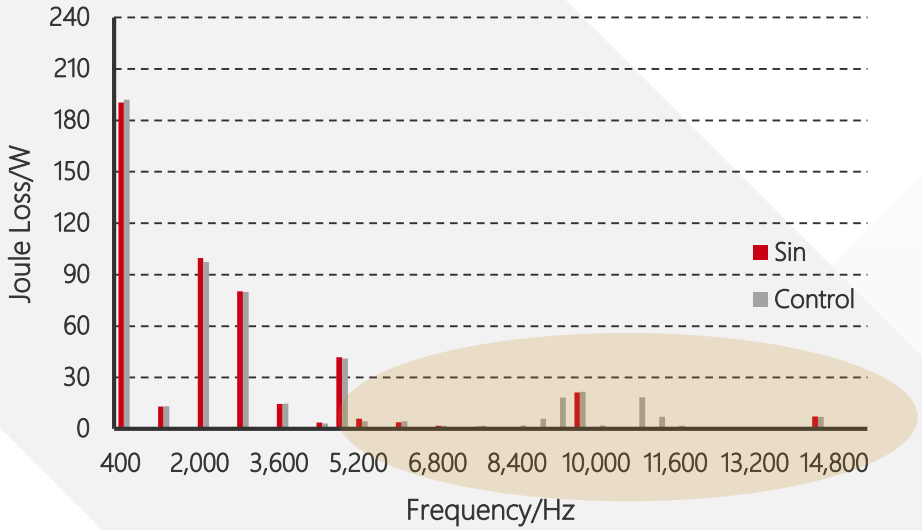
6000rpm









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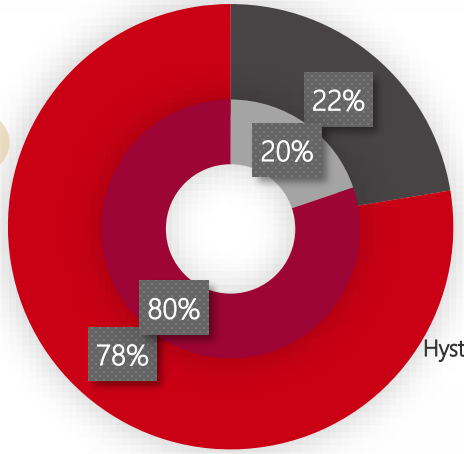

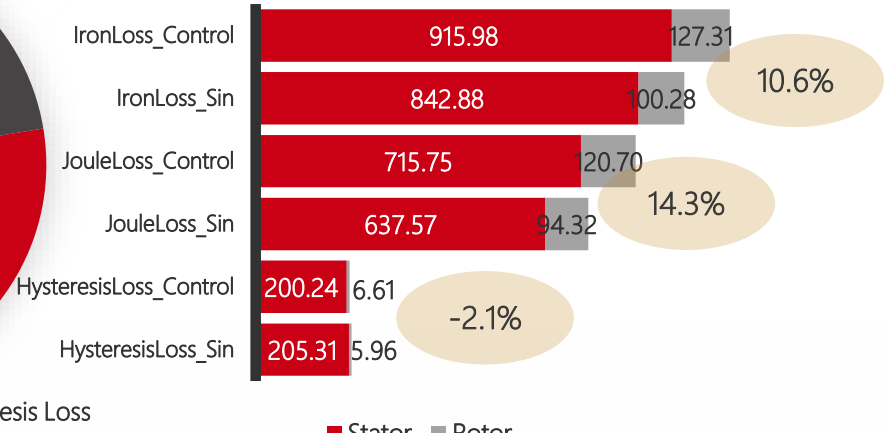

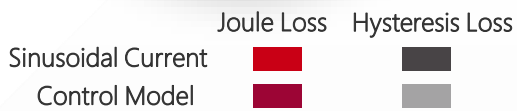

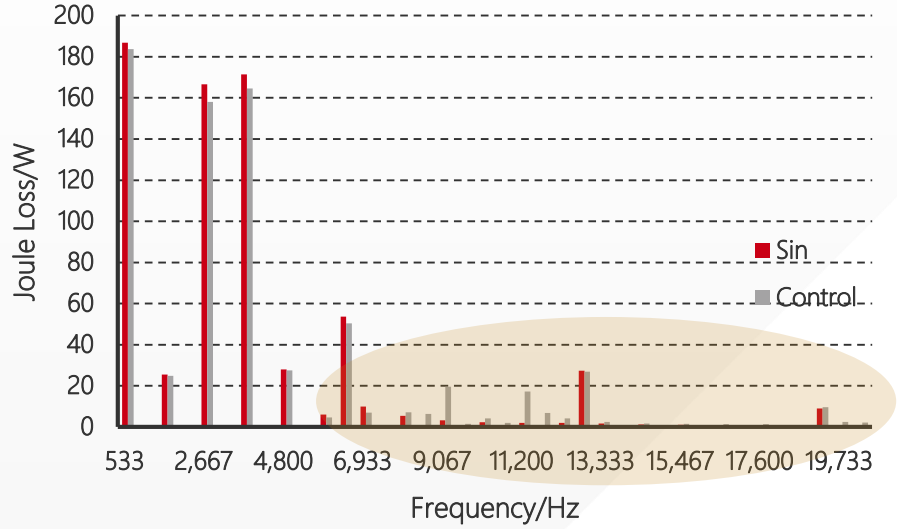

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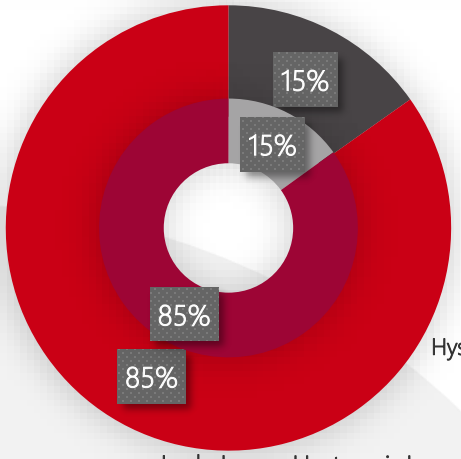
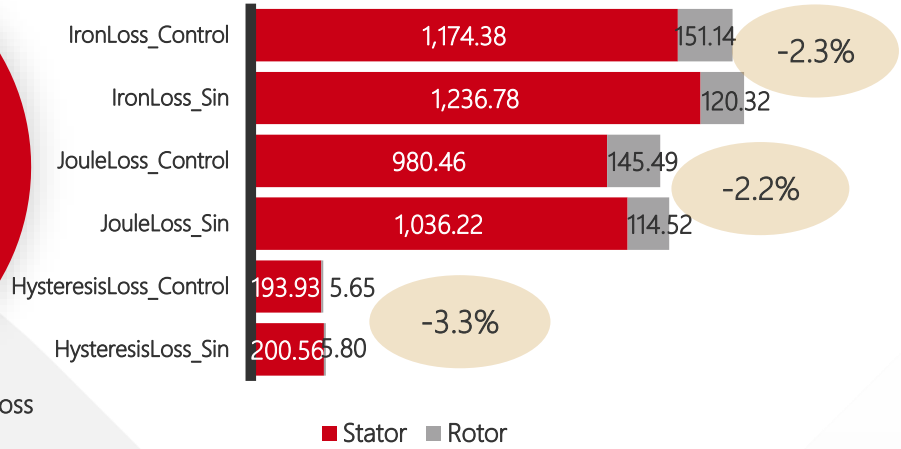
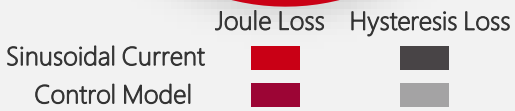
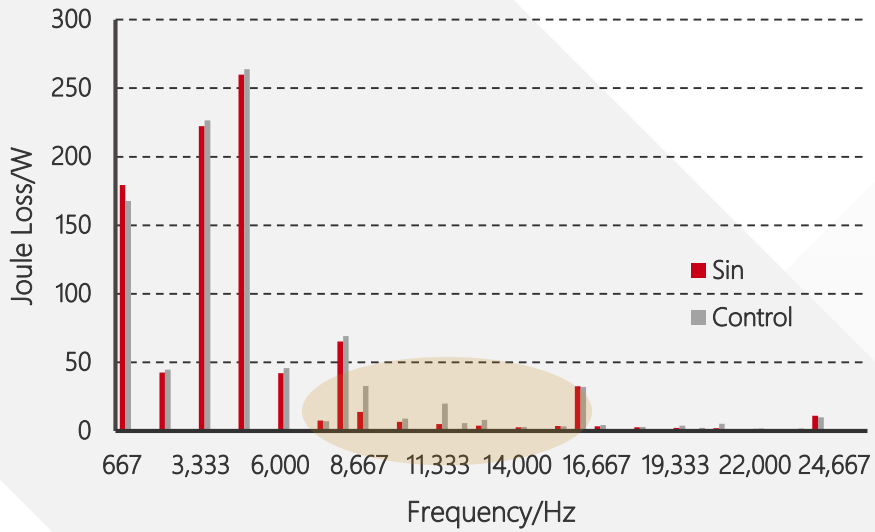
10000rpm









- ✓ 随着转速的增加，铁损中涡流损耗的占比逐渐增大
- ✓ 转子中的铁损远远小于定子的铁损，且大多集中在转子表面
- ✓ 控制模型的铁损远大于正弦激励下的电机铁损，但这种差距随着转速的升高逐渐减小，高速时几乎没有差异
- ✓ 控制模型和正弦激励模型的铁损差异主要来源于铁损中的涡流损耗，随着转速的升高，磁场的高频成分变分量差异变得不明显，两者涡流损耗的差异逐渐消失

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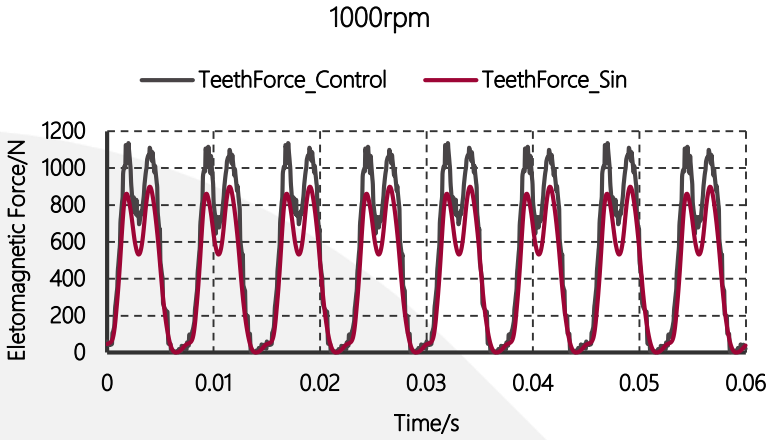
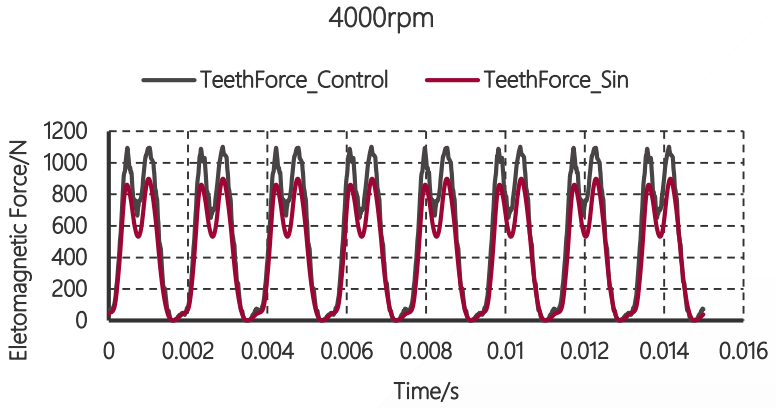
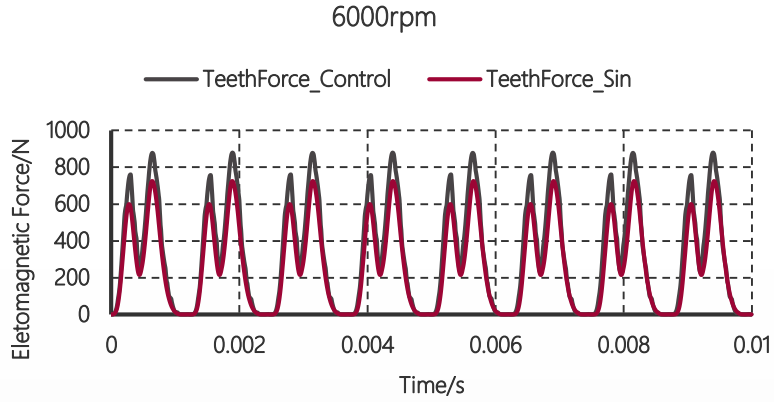
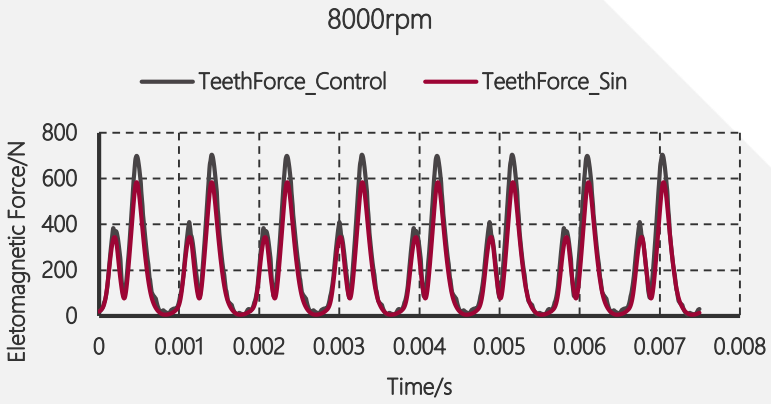
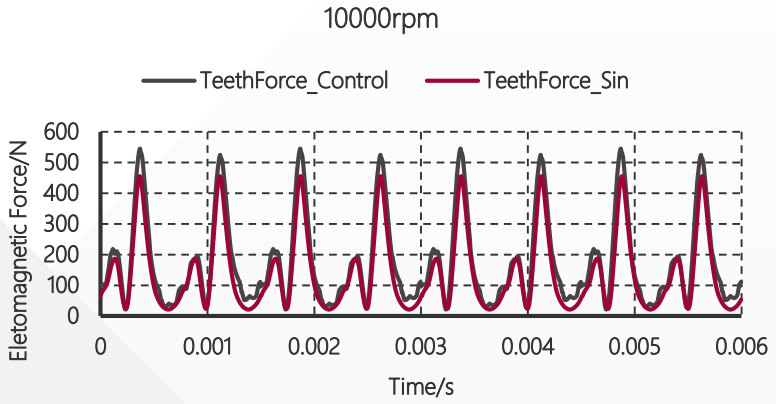
定子齿电磁力











✓ 控制电路与正弦激励下的定子齿电磁力分布形状基本相同，但具有更大的幅值，随着转速的升高，这种幅值差异逐渐缩小。

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05
下一步研究内容

Definition Of Next Steps

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更深入的研究内容。。。

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红旗
让理想飞扬

THANKS

中国一汽 第一汽车

2019/11/21

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