Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Modeling the optimal compensation capacitance of a giant magnetostrictive ultrasonic transducer with a loosely-coupled contactless power transfer system

Tian LAN

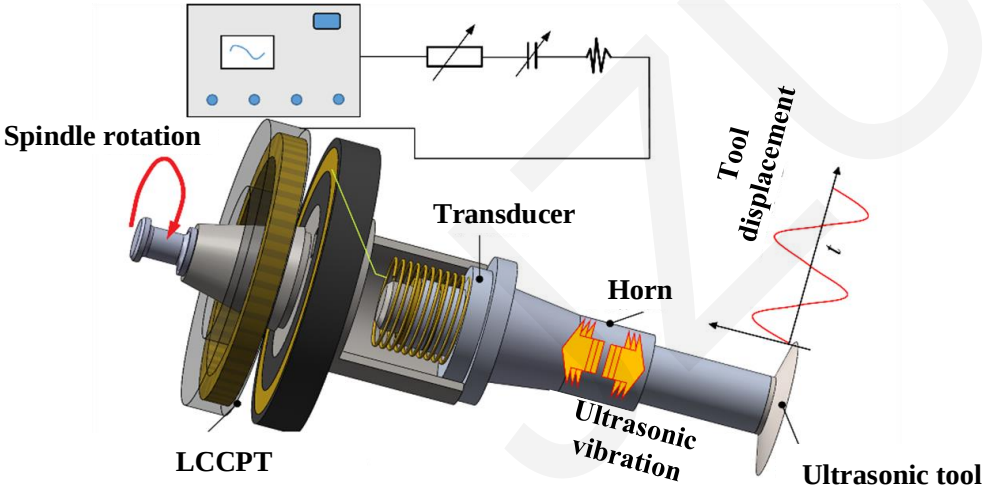
Cite this as: Tian LAN, Ping-fa FENG, Jian-jian WANG, Jian-fu ZHANG, Hui-lin ZHOU, 2022. Modeling the optimal compensation capacitance of a giant magnetostrictive ultrasonic transducer with a loosely-coupled contactless power transfer system. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 23(10):757-770. https://doi.org/10.1631/jzus.A2200367

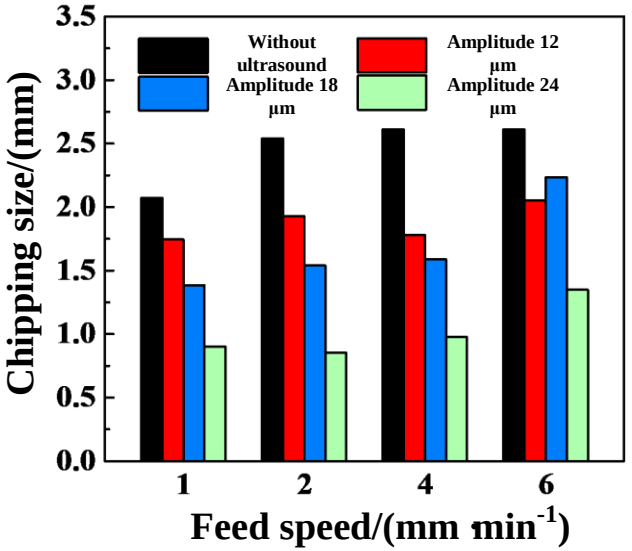
Rotary ultrasonic machining

※ Rotary ultrasonic machining : Remove materials using rotating ultrasonic tool

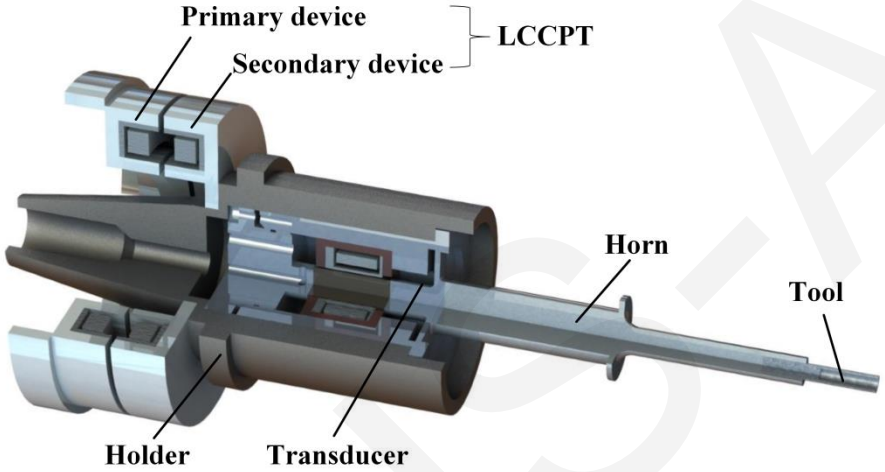
Effective methods for machining brittle materials

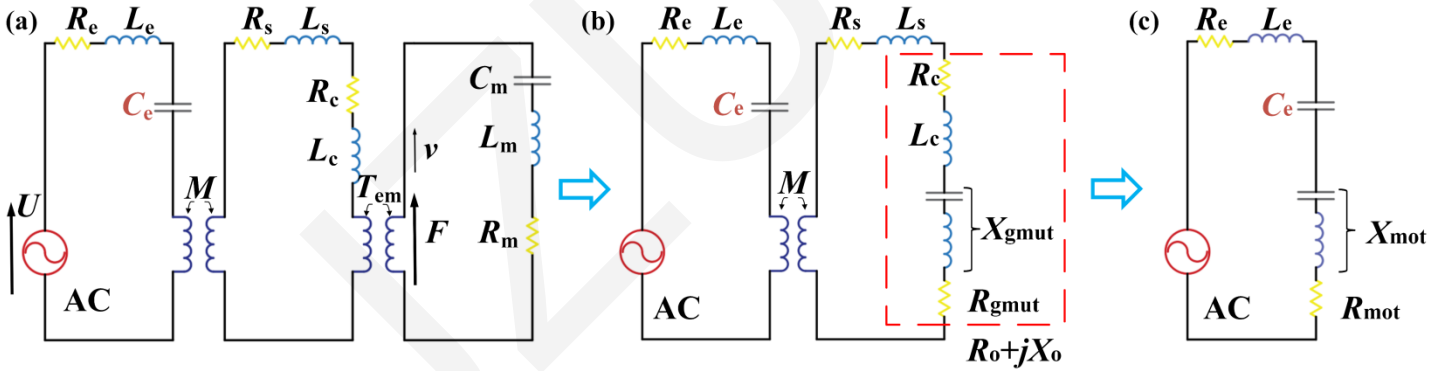
- Reduce cutting force by 50% - 80%
- Reduce surface and subsurface damage





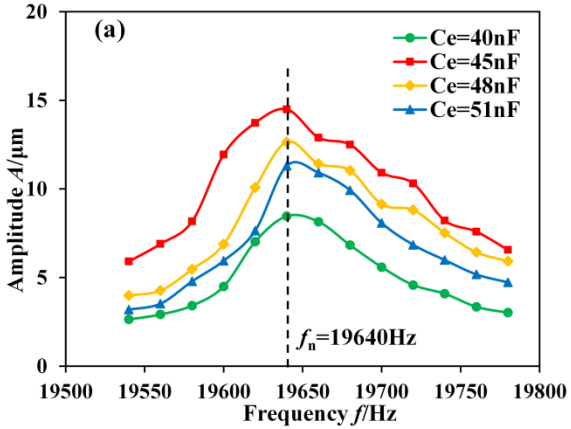
GMUPS

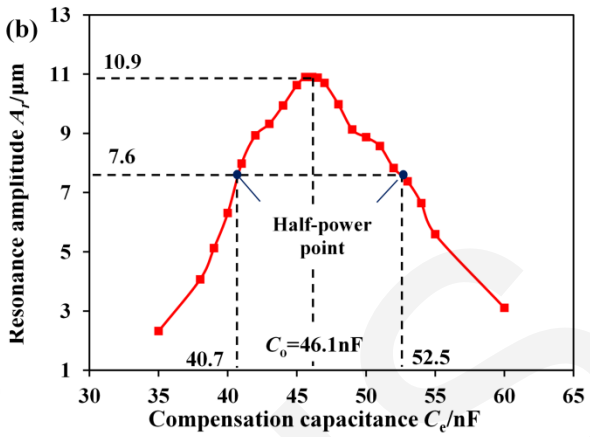




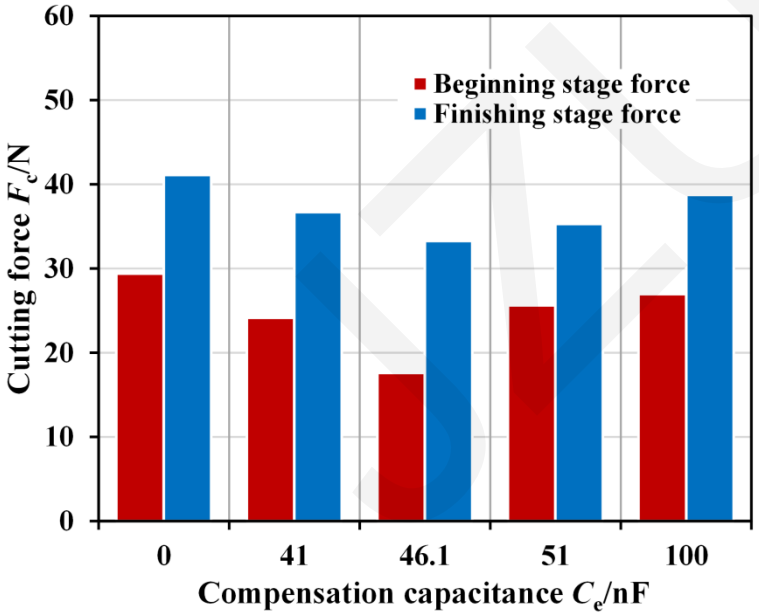
Structure of GMUPS with LCCPT and its electro-mechanical equivalent circuit and the mapping circuits.

Optimal compensation capacitance



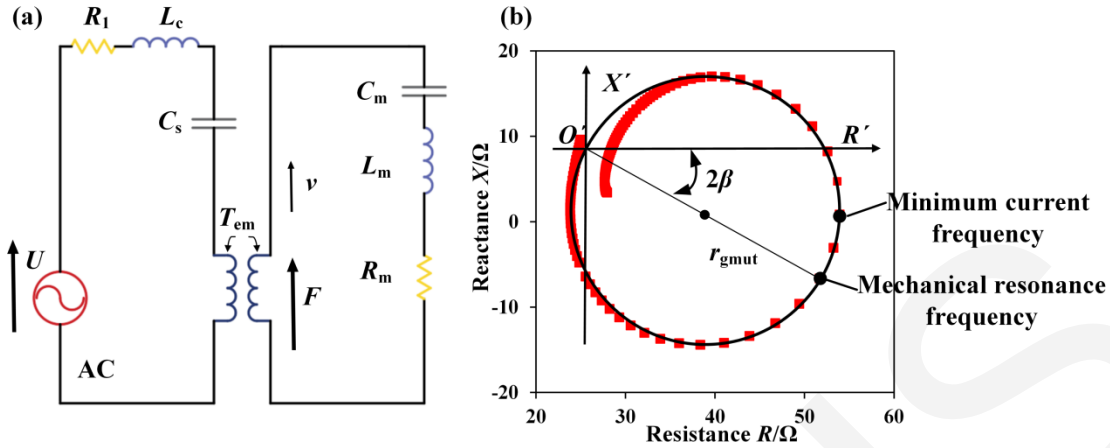


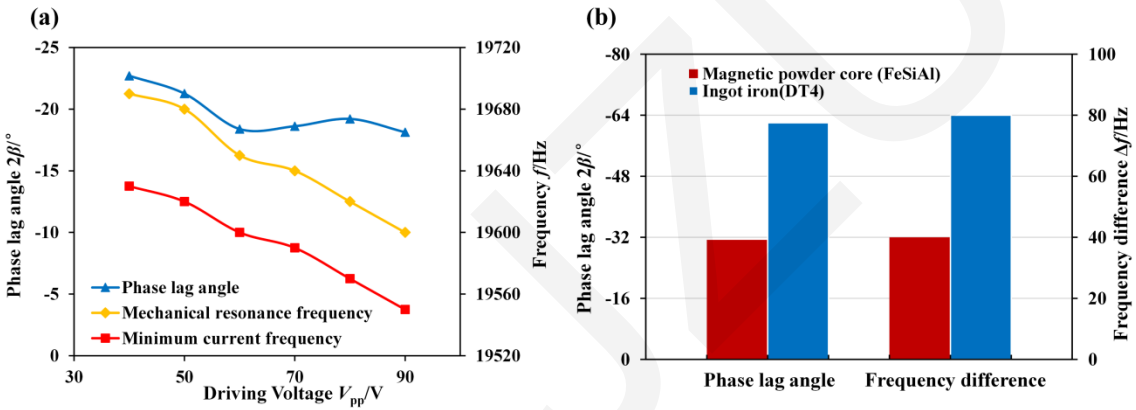
The adoption of optimal compensation capacitance shows superior performance for both idle and machining conditions.



The system can obtain the maximum amplitude and achieve the highest energy efficiency, while the cutting force is the smallest in the whole process of machining when the optimal compensation capacitance is adopted.

Phase lag angle





The phase lag angle between the electrical circuit and the equivalent mechanical circuit of the system results in a discrepancy between the minimum current frequency and the mechanical resonance frequency.

The driving voltage has little effect on the phase lag angle before reaching magnetic saturation. However, the material properties of the magnetic conductive structure, such as core loss, notably affect the phase lag angle.

Conclusions

In this study, the model of optimal compensation capacitance for giant magnetostrictive transducers (GMUPS) with a loosely coupled contactless power transfer (LCCPT) is developed to achieve maximum energy utilization efficiency. The model stresses the phase lag angle between the mechanical and electrical circuits, while considering the non-negligible loss in energy conversion caused by the core loss and the skin effect in giant magnetostrictive material. Idle vibration experiments and machining tests are conducted to verify the developed model. The following conclusions are drawn:

(1)The adoption of optimal compensation capacitance shows superior performance for both idle and machining conditions.

(2)The use of LCCPT and the value of the compensation capacitance significantly affect the electrical characteristics of the system but have only a slight effect on the mechanical resonance frequency.

(3)Selecting the magnetic conductive material with low loss at high frequency can effectively reduce the phase lag angle.