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The Planetary Motor

Design and control of a
novel multi-rotor structure

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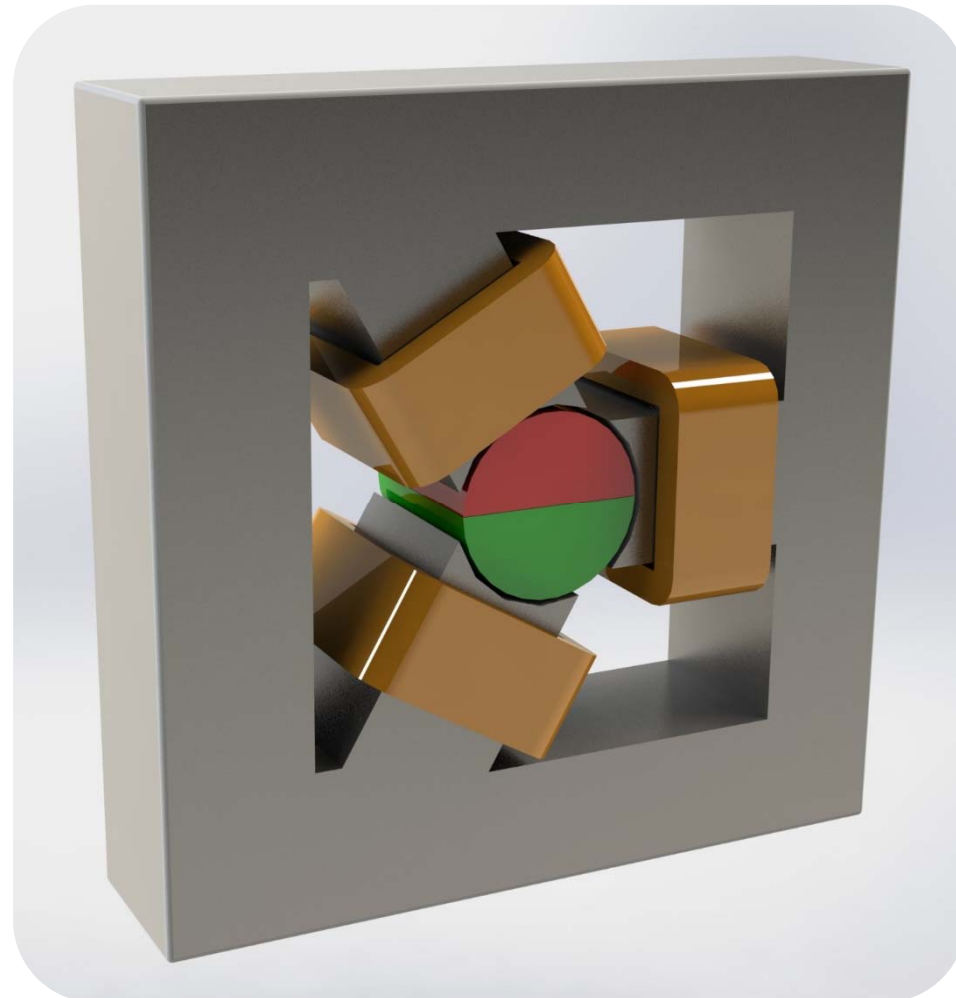
Technische Universität Wien

A3PS Nov. 2017

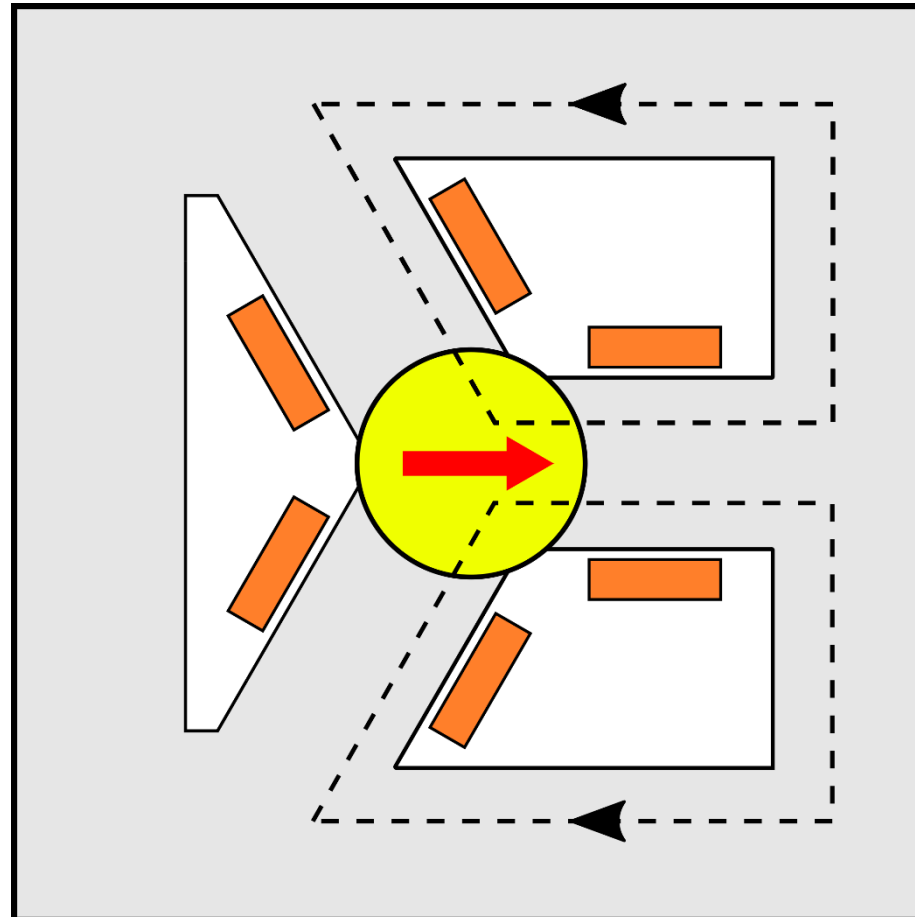
- Deriving the topology of the Planetary Motor
- Electrical equivalent circuit
- Functional prototype
- Control strategy
- Sensorless INFORM® method
- Applications
- Future work

The Planetary Motor

- 3-phase motor
- 3 single coils
- 2-pole PM rotor

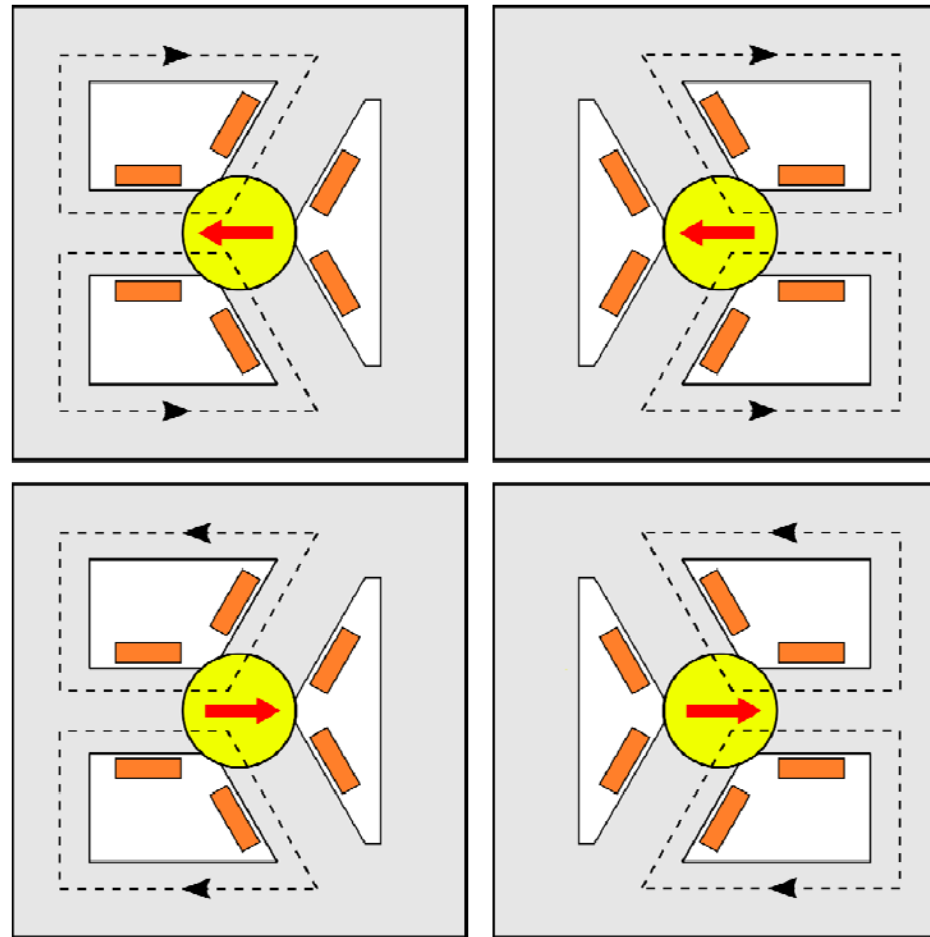


The Planetary Motor



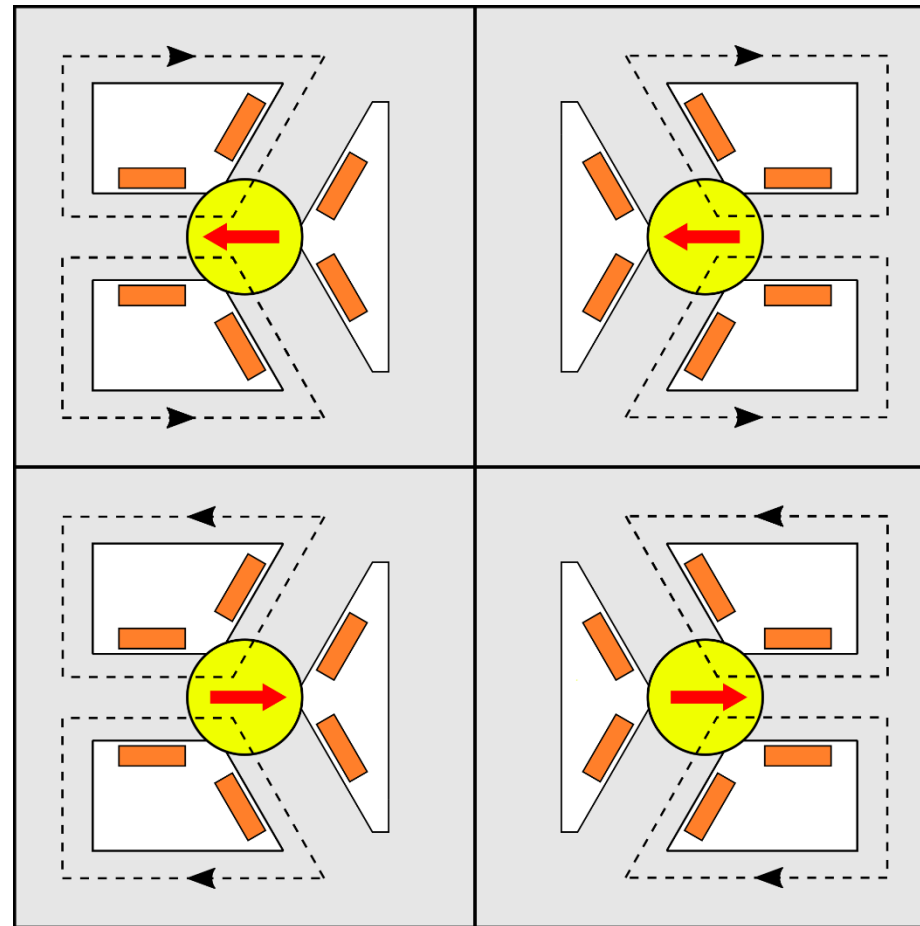
The Planetary Motor

- Arrange 4 equivalent motors symmetrically



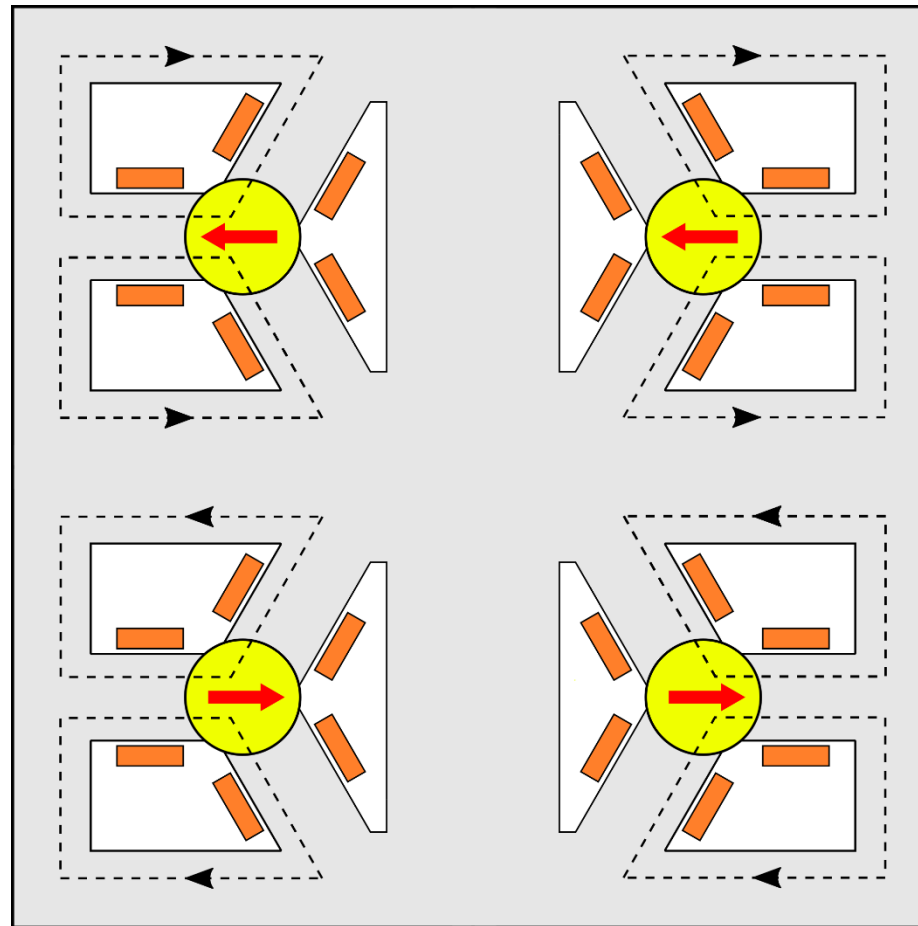
The Planetary Motor

- Combine into single structure



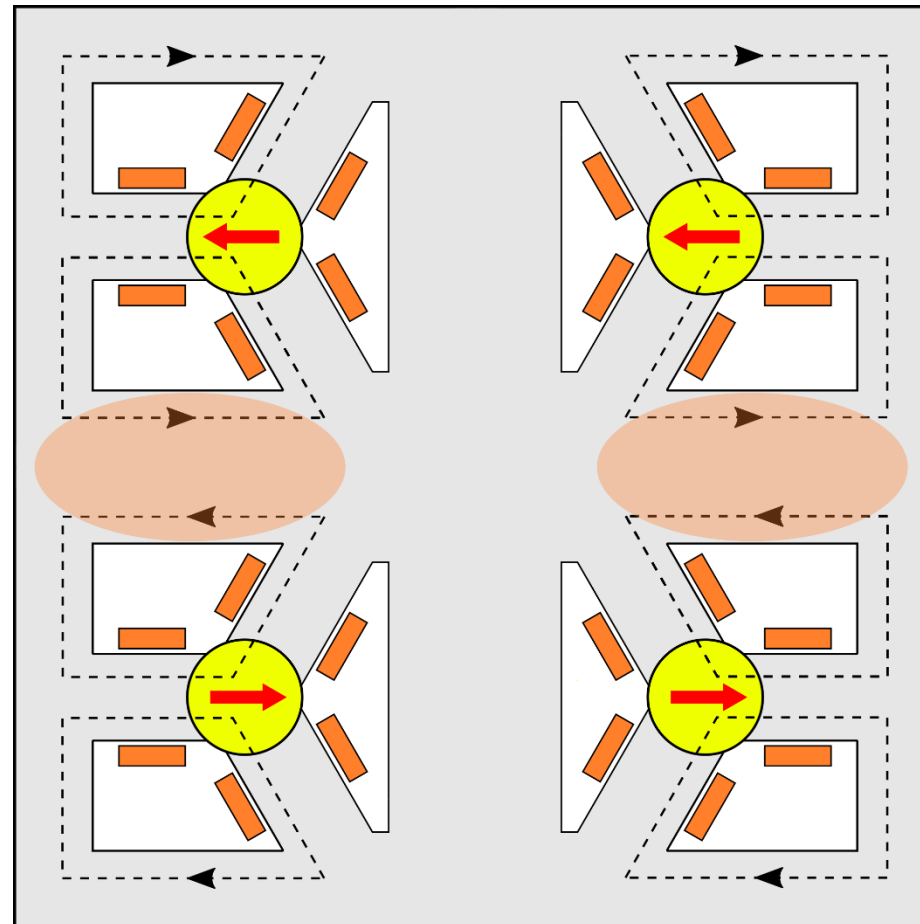
The Planetary Motor

- Combine into single structure



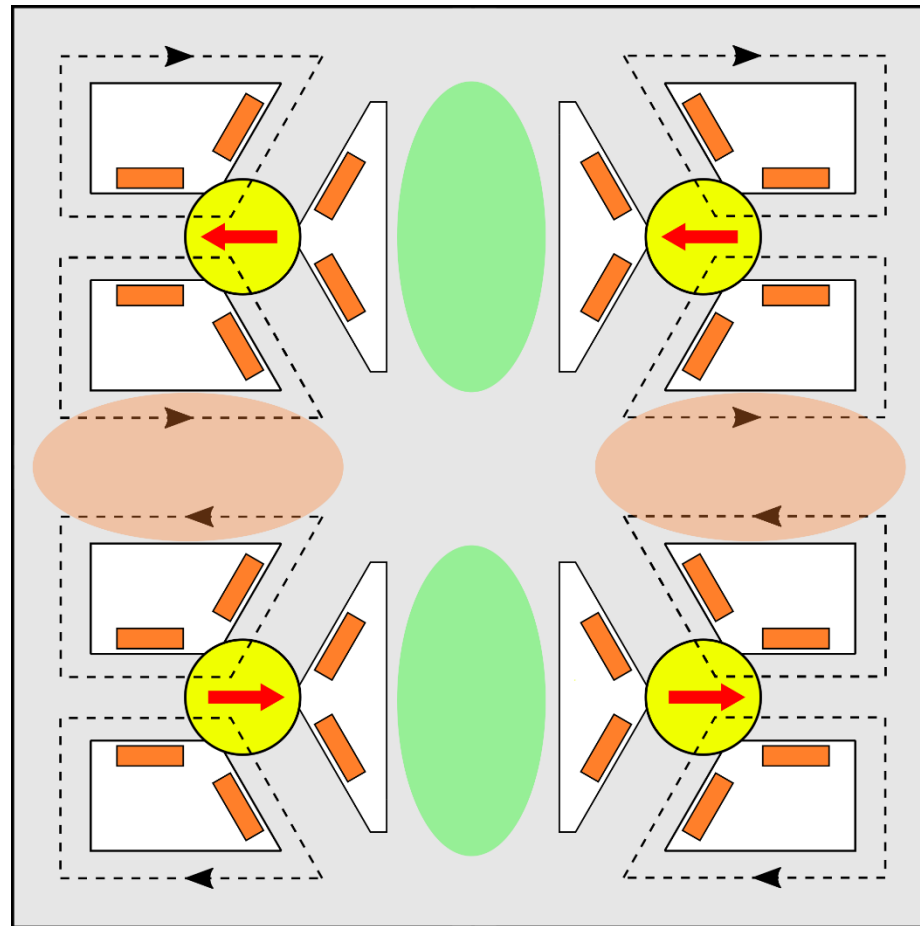
The Planetary Motor

- Areas of zero net flux



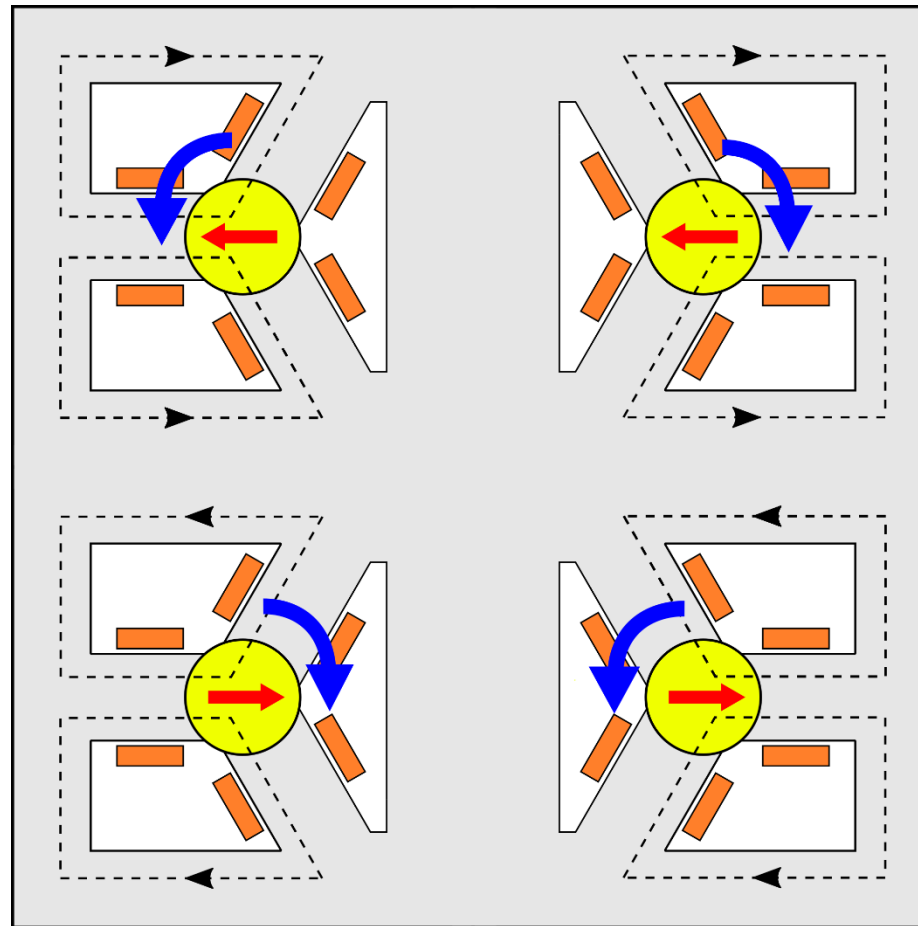
The Planetary Motor

- Areas of zero net flux



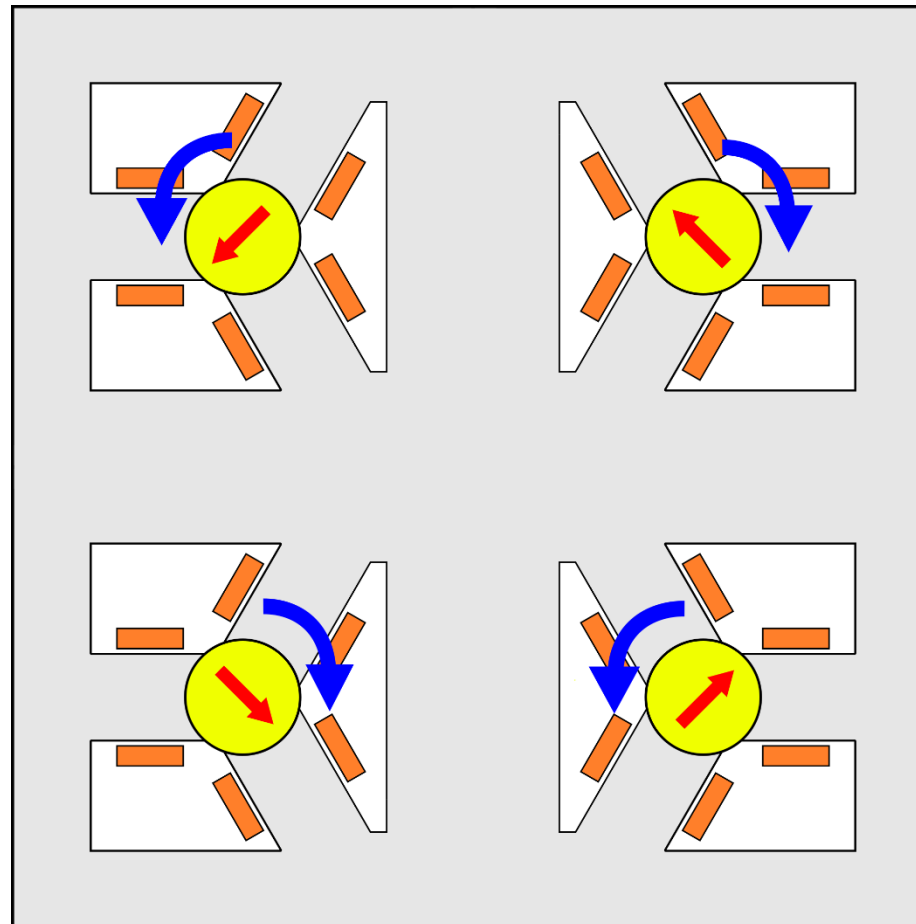
The Planetary Motor

- Rotors turn in opposite directions



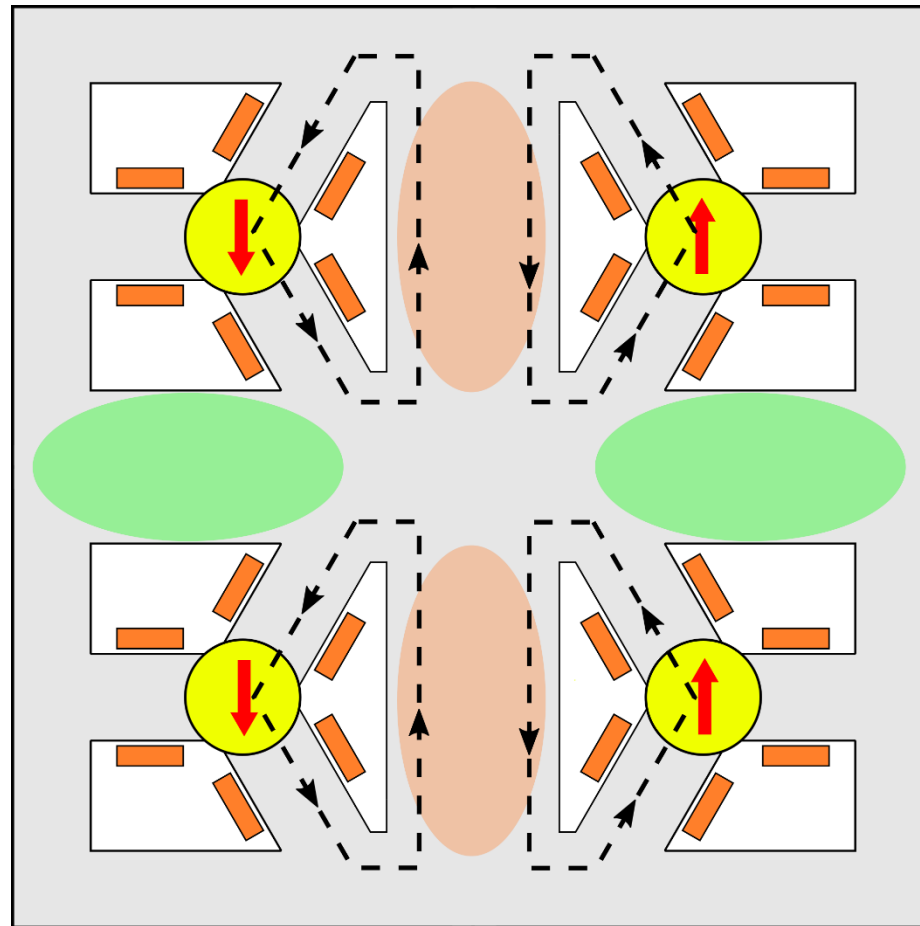
The Planetary Motor

- Rotors turn in opposite directions



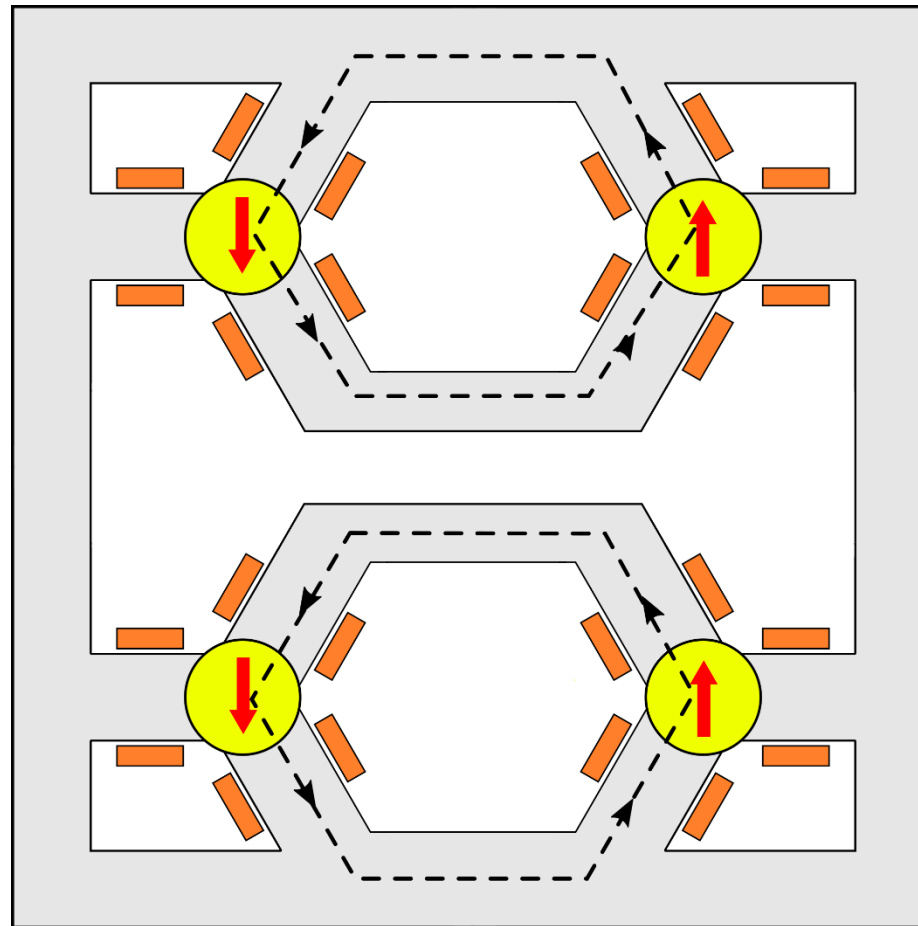
The Planetary Motor

- After 90deg: same areas with zero net flux



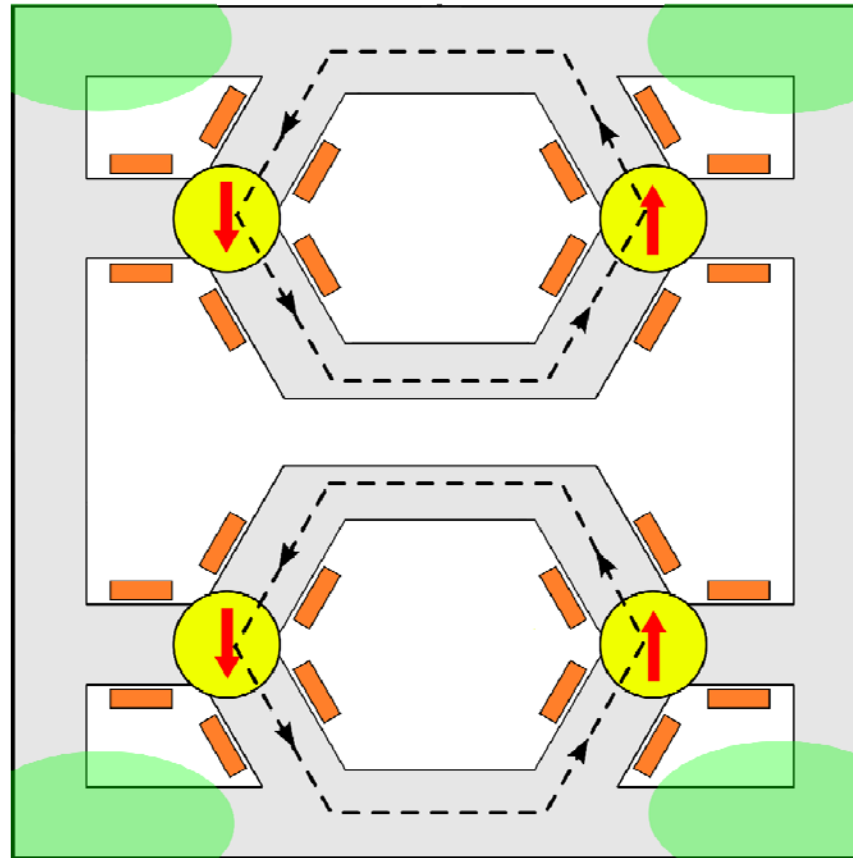
The Planetary Motor

- Omit magnetically inactive parts:



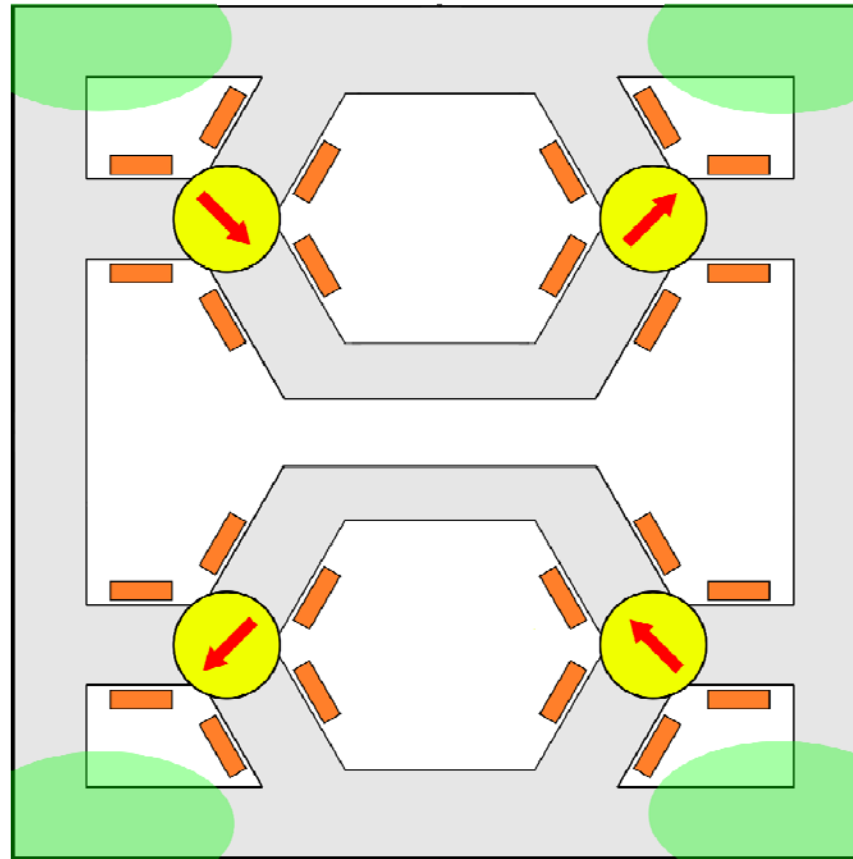
The Planetary Motor

- Corners are also magnetically inactive



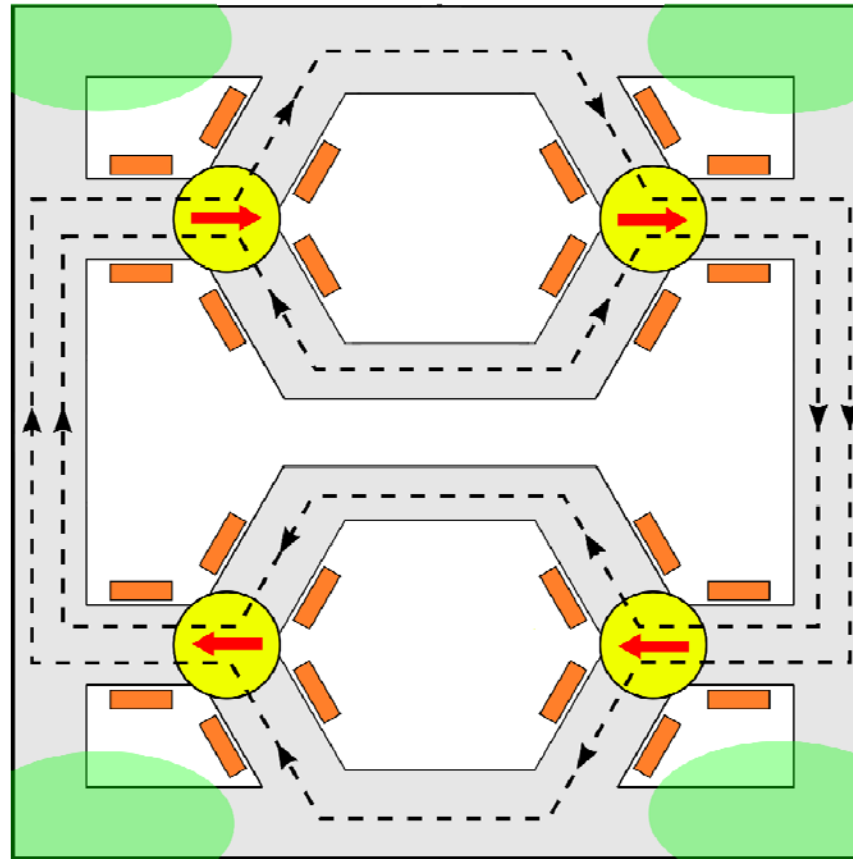
The Planetary Motor

- Corners are also magnetically inactive



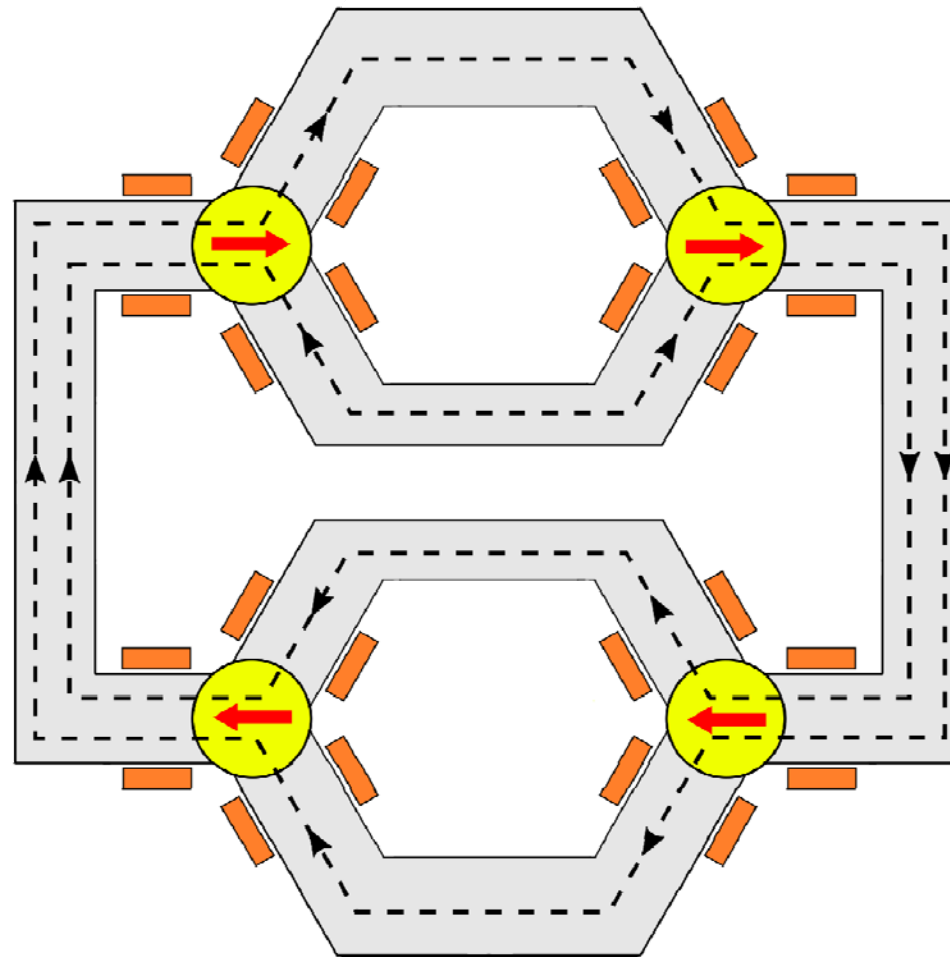
The Planetary Motor

- Corners are also magnetically inactive



The Planetary Motor

- Corners are also magnetically inactive



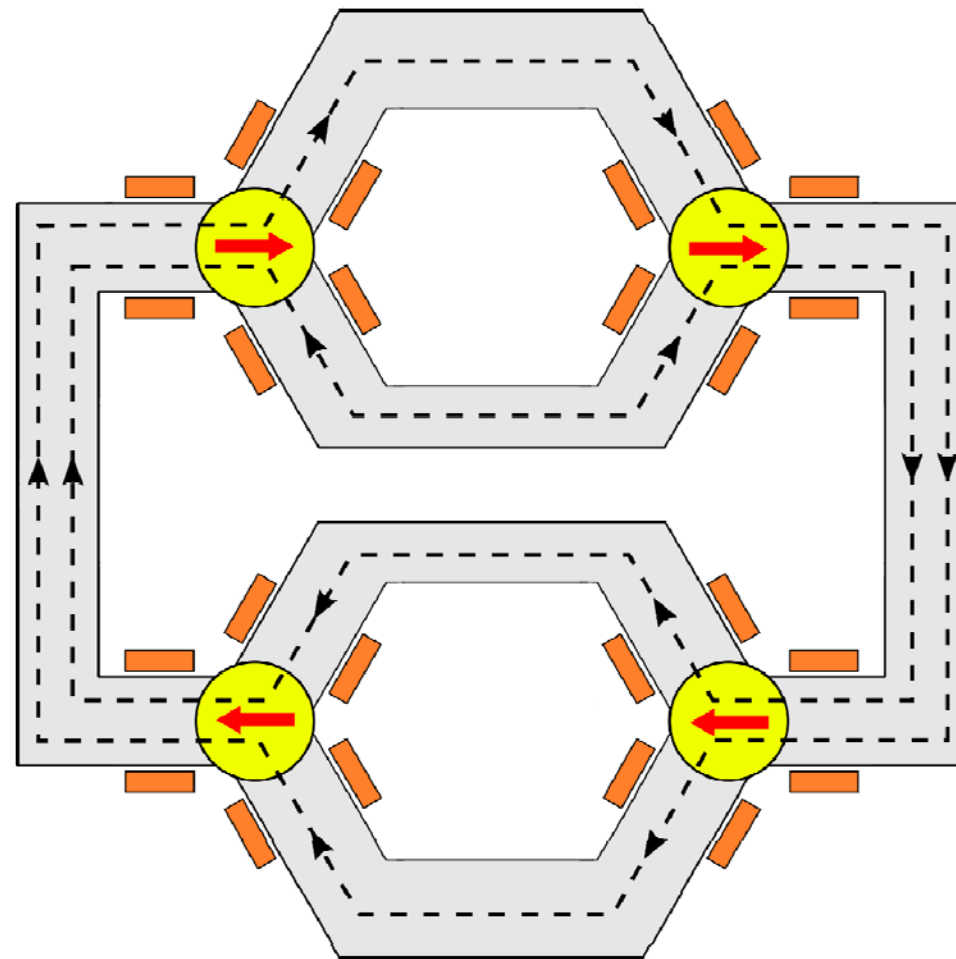
The Planetary Motor

- Omit magnetically inactive parts:

Reduced

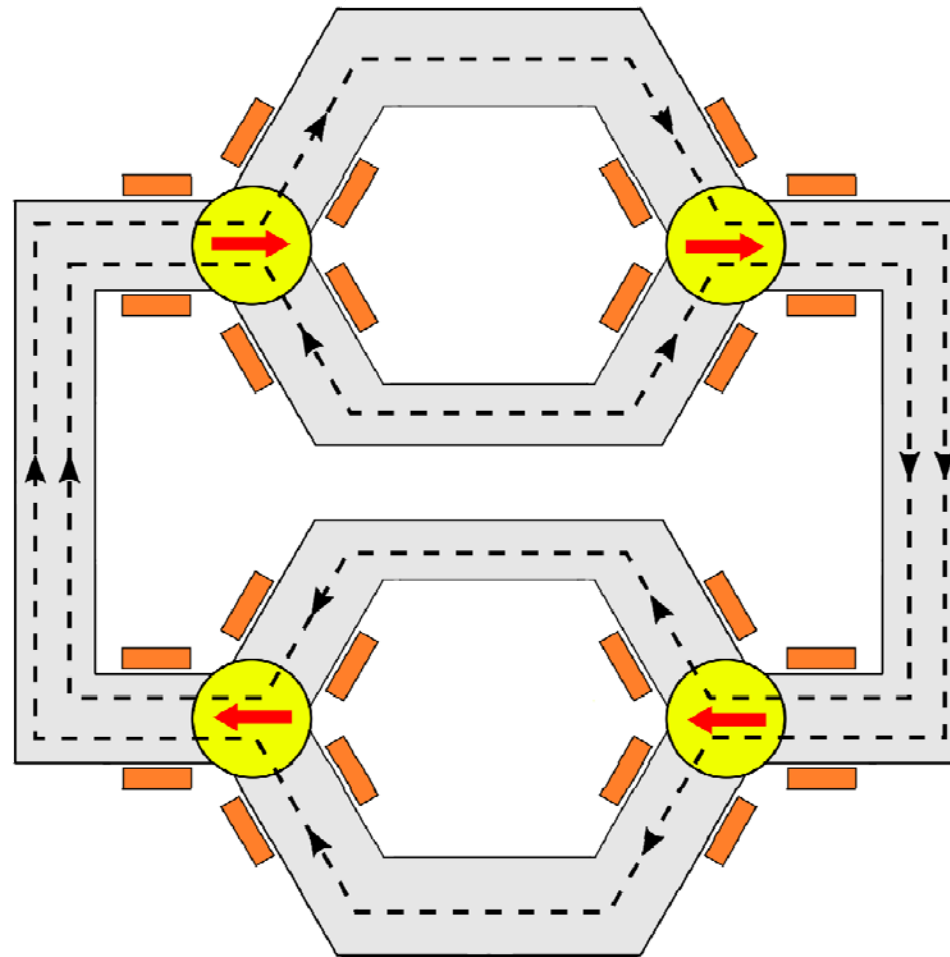
- Active mass
- Motor volume
- Iron losses

Same power as 4
combined single motors



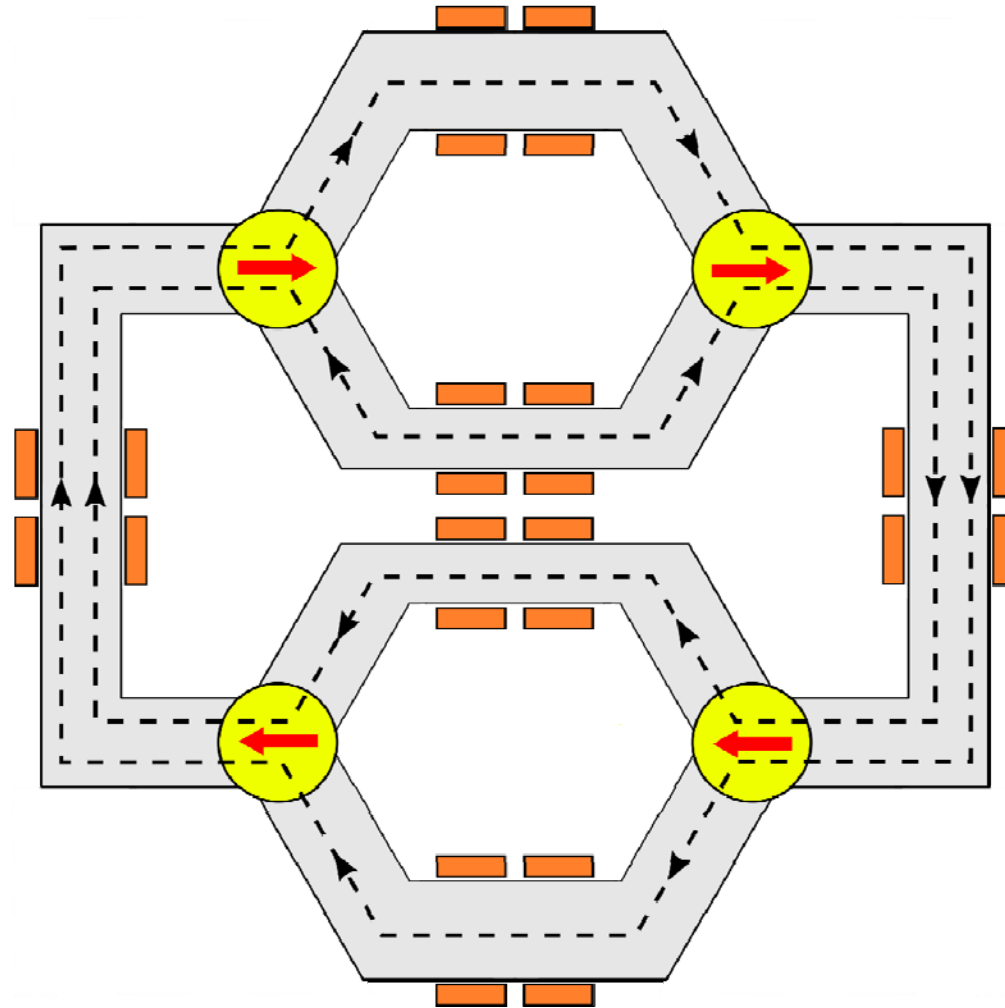
The Planetary Motor

- Combine coils



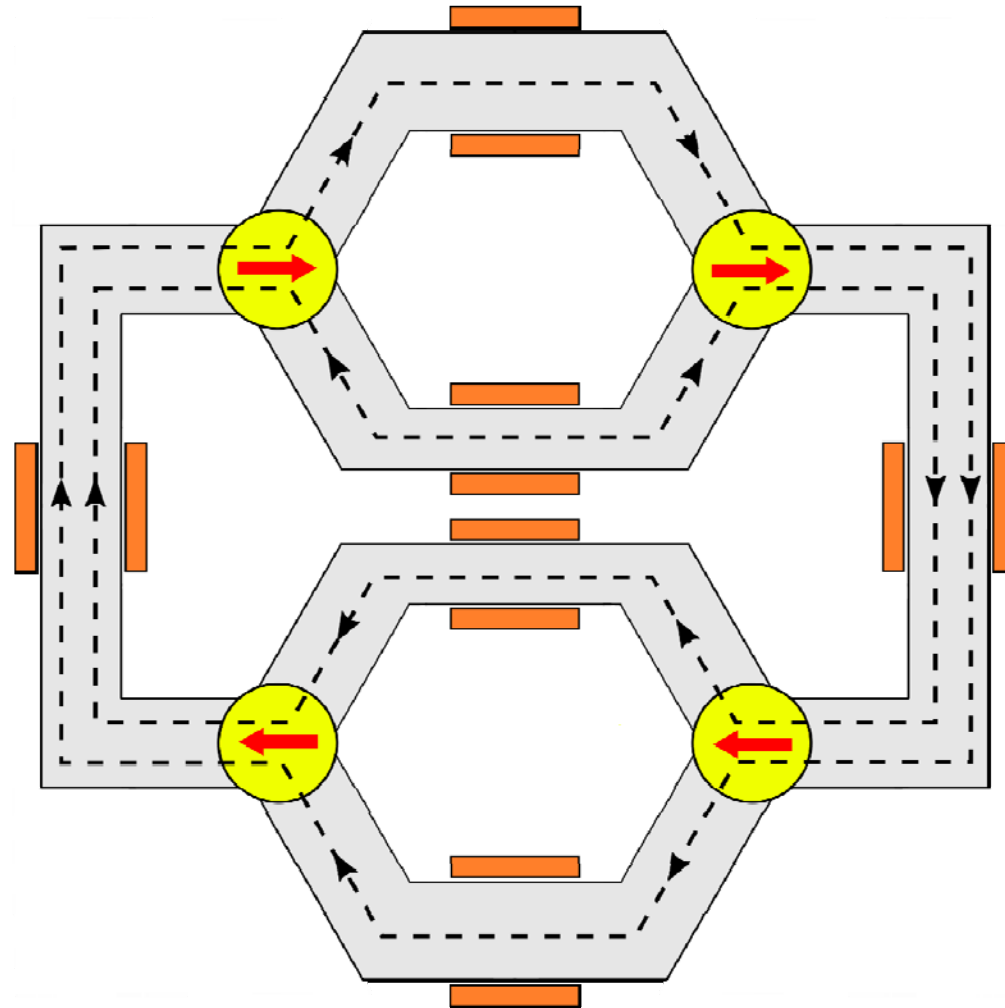
The Planetary Motor

- Combine coils



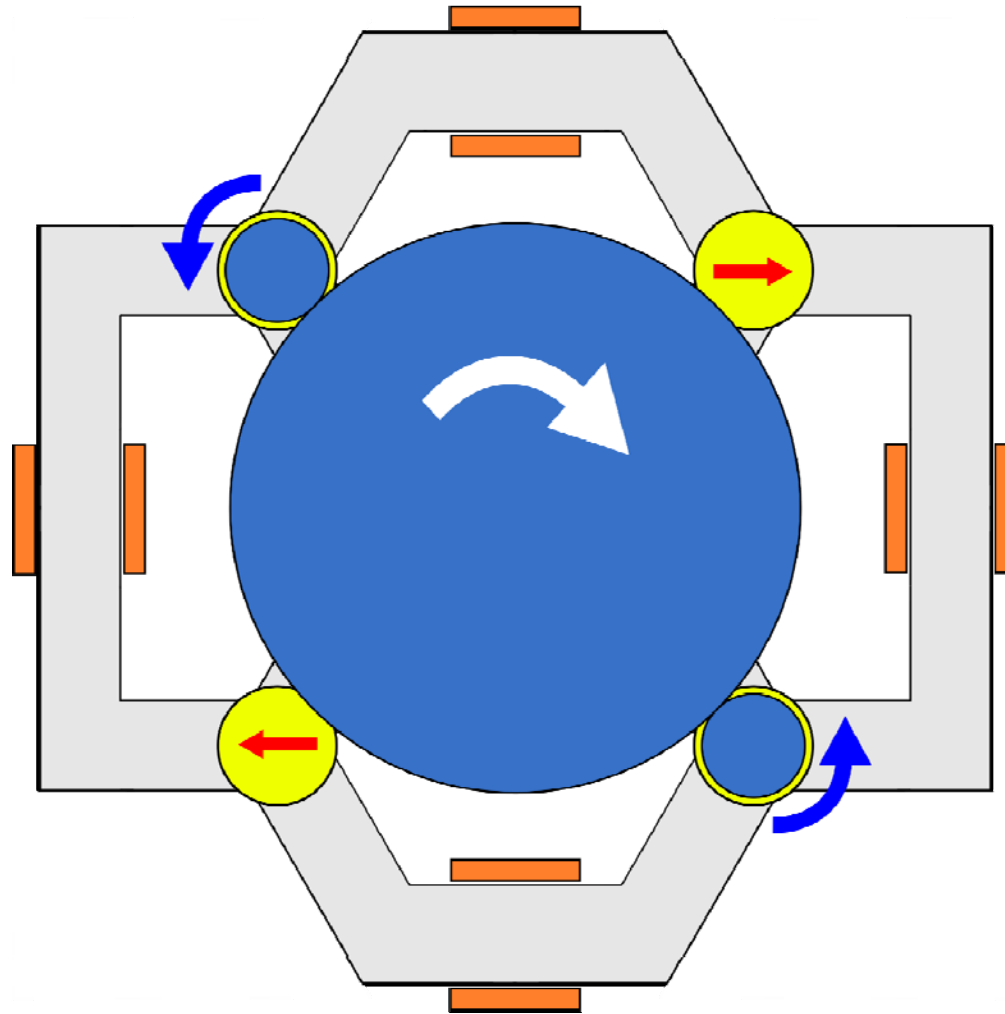
The Planetary Motor

- Combine coils: 12 coils \rightarrow 6 coils



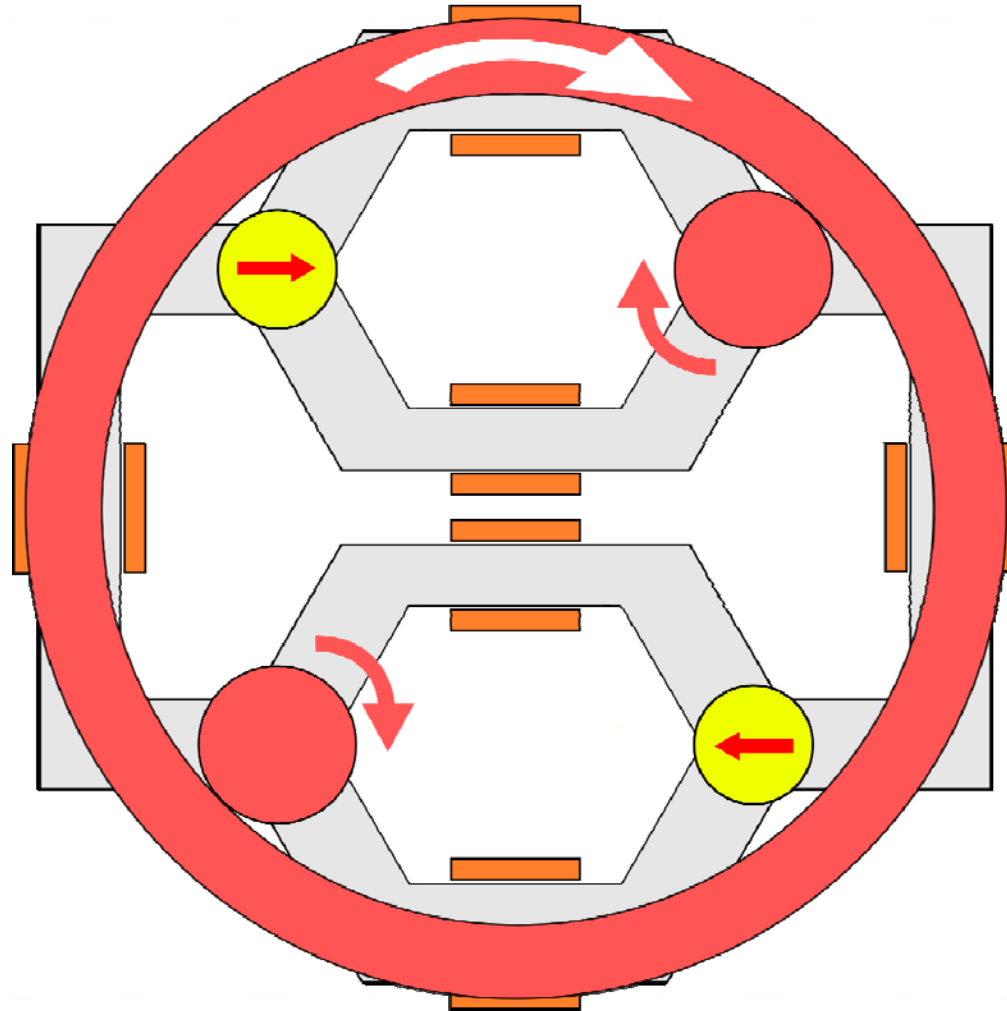
The Planetary Motor

- Integrated gear: sun gear



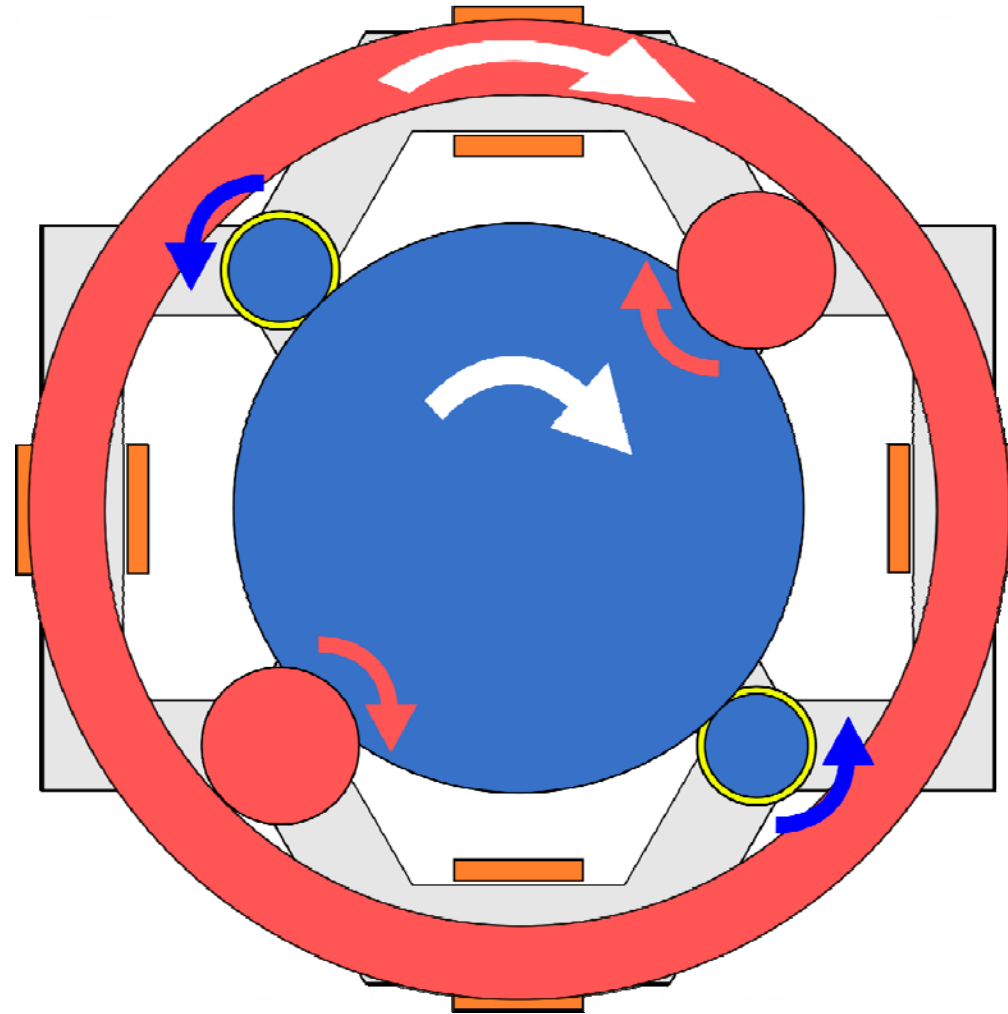
The Planetary Motor

- Integrated gear: ring gear



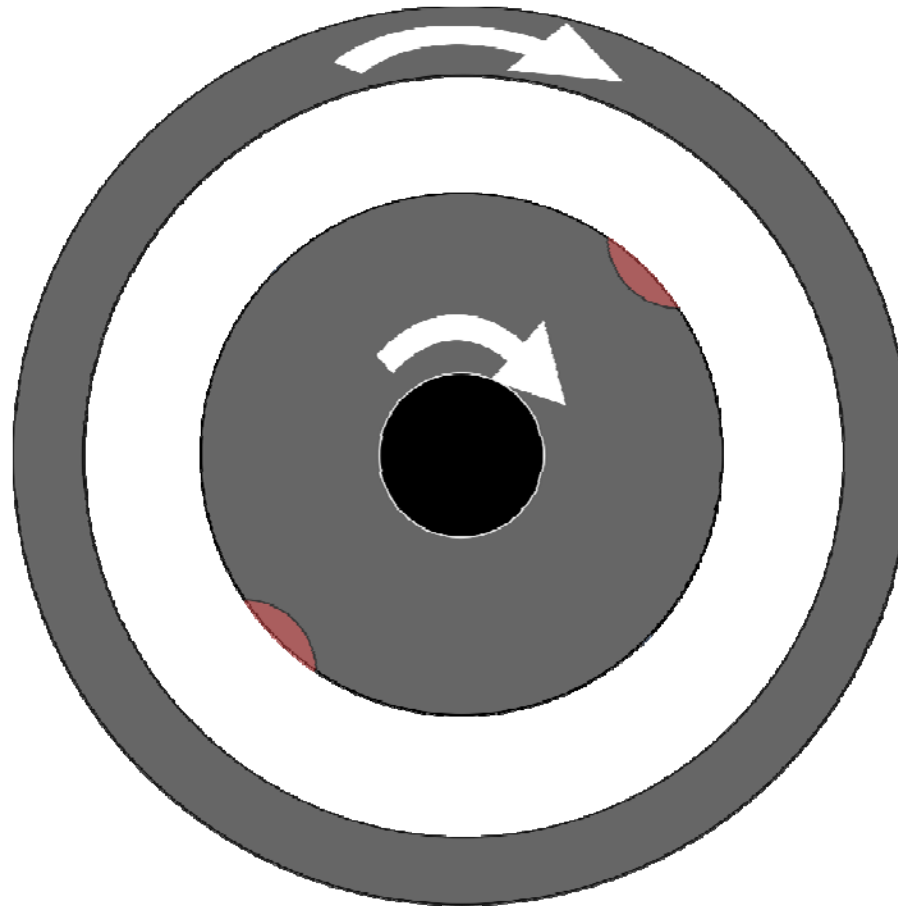
The Planetary Motor

- Integrated gear



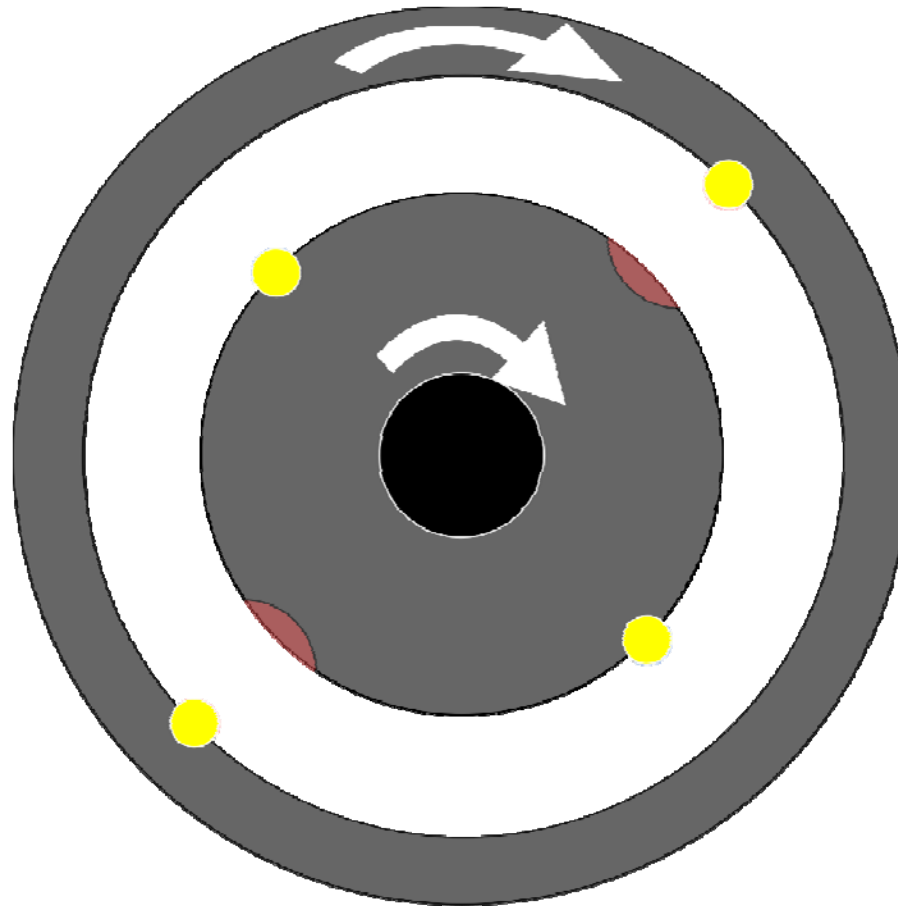
The Planetary Motor

- Integrated “planetary gear”
 - Sun gear and ring gear rotate at same speed → mechanical link for combined output power

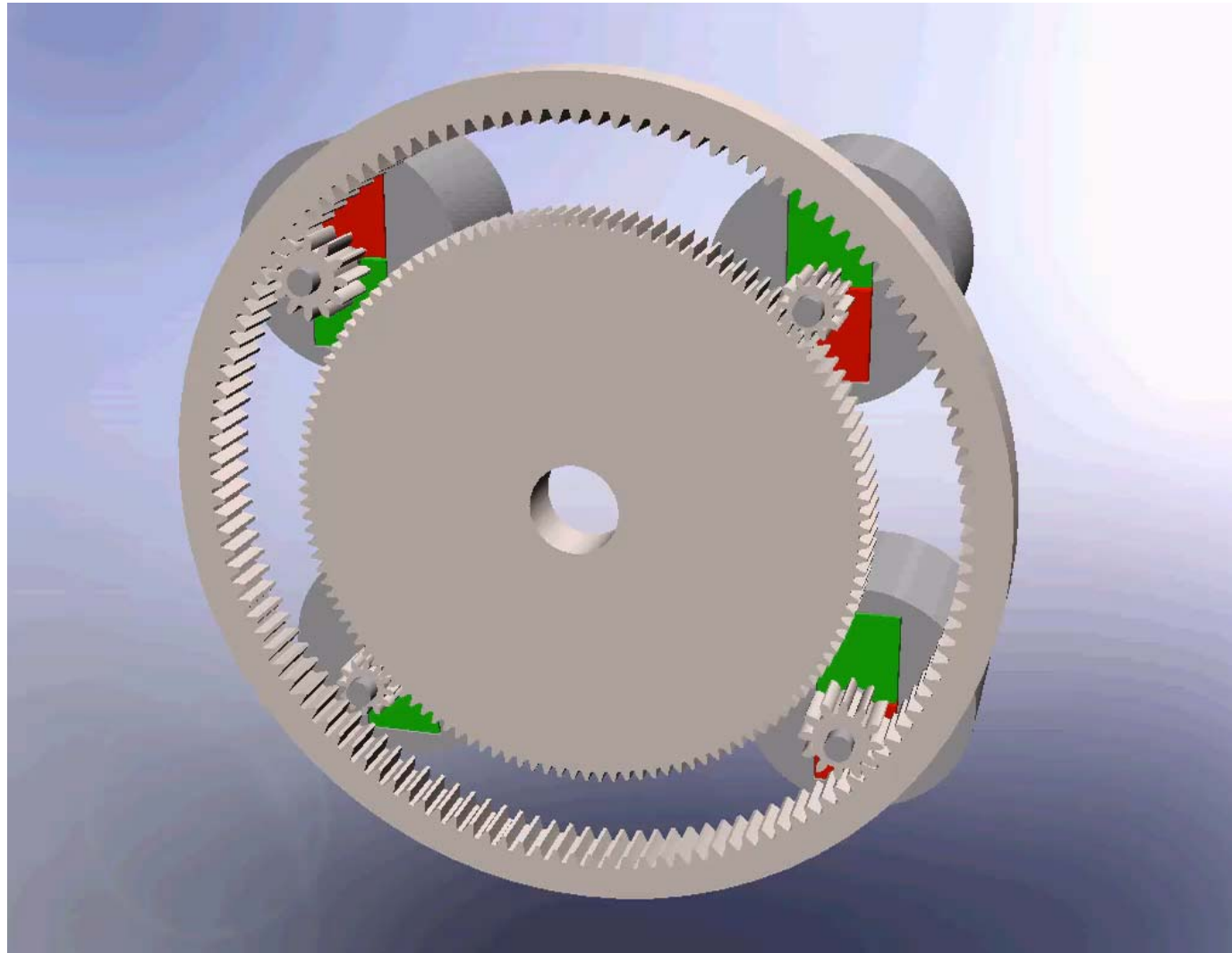


The Planetary Motor

- Integrated “planetary gear”
 - One point of contact for each gear (instead of two)
 - Gear ratios typ. 10:1



The Planetary Motor

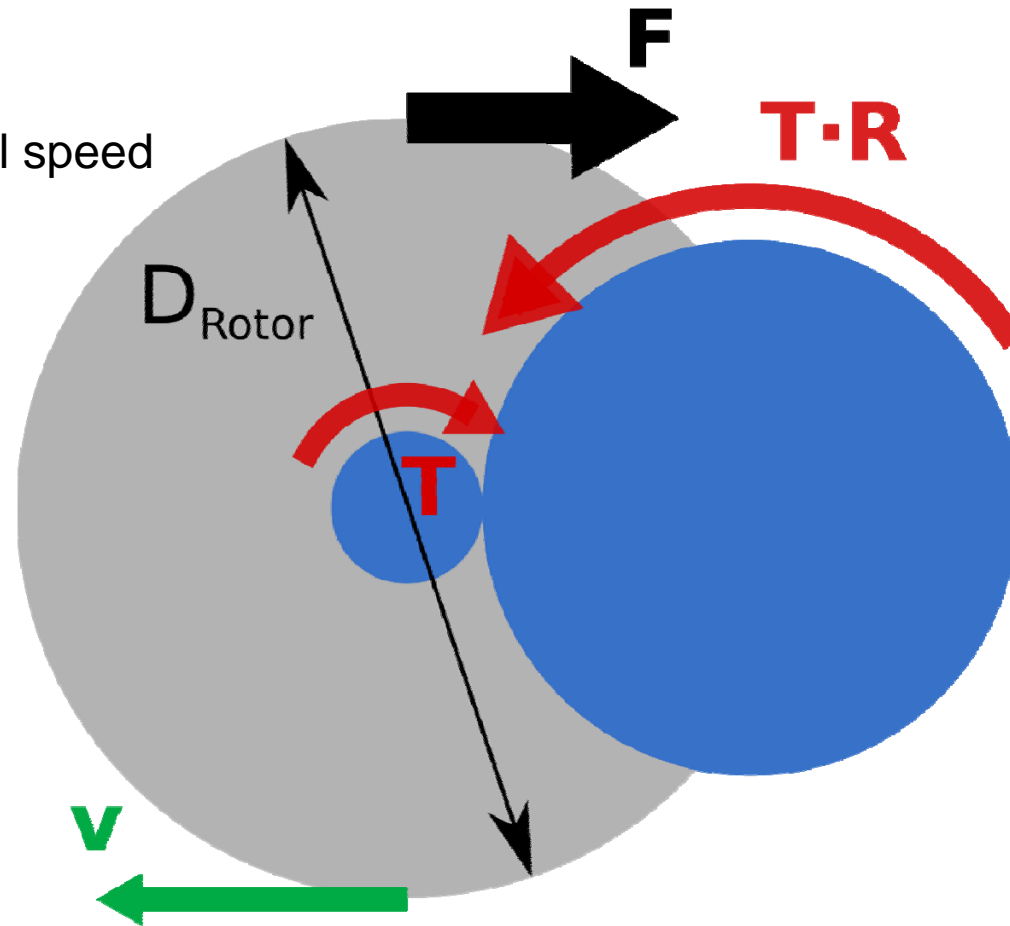


The Planetary Motor

Conventional motor + spur gear

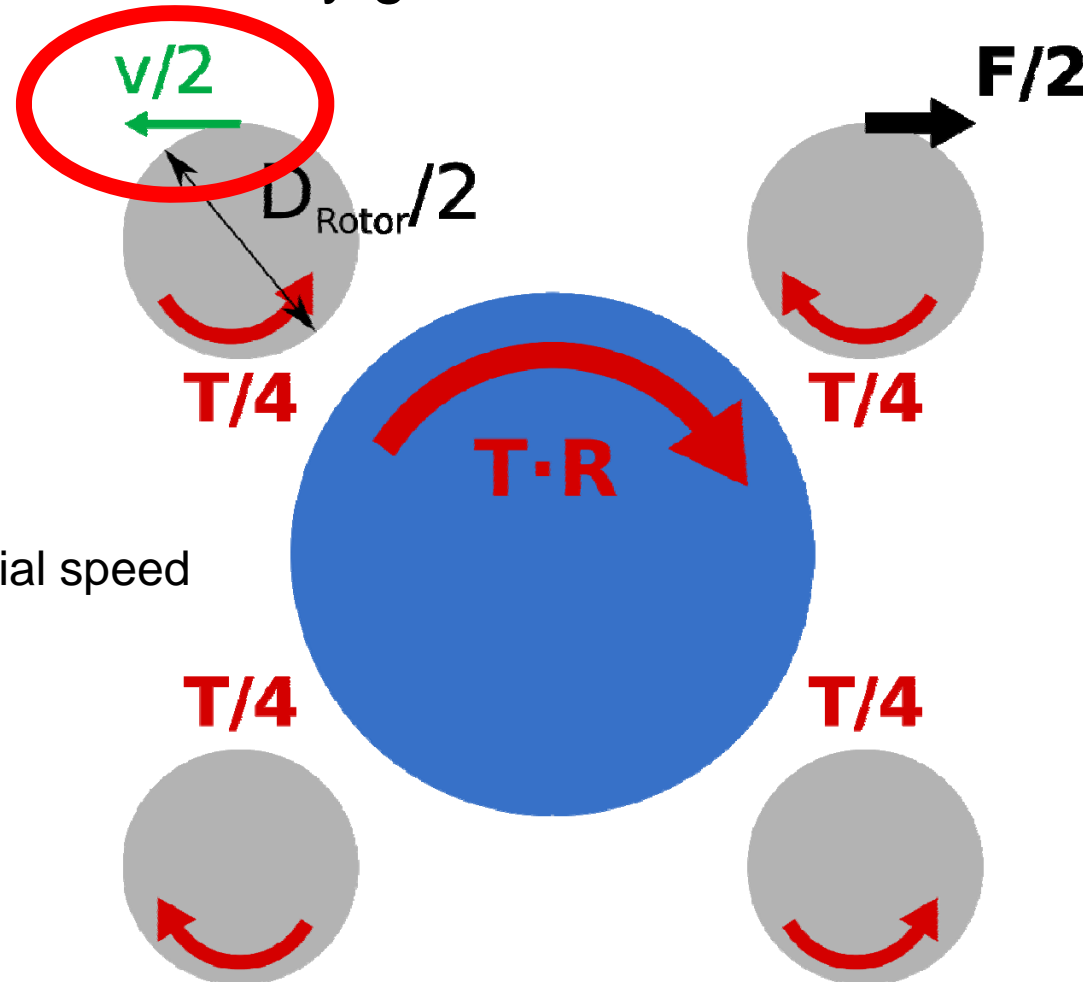
R... gear ratio

v ... circumferential speed



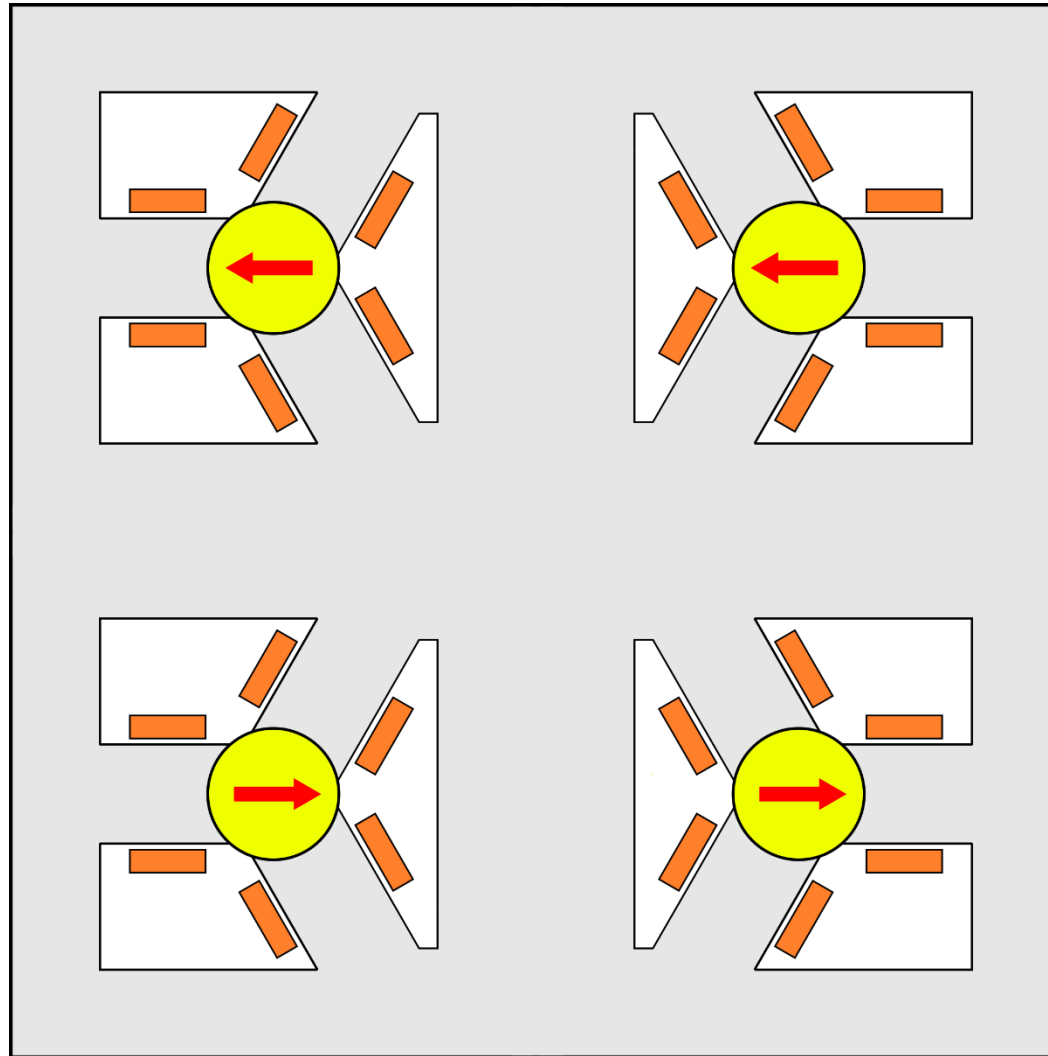
The Planetary Motor

Integrated Planetary gear

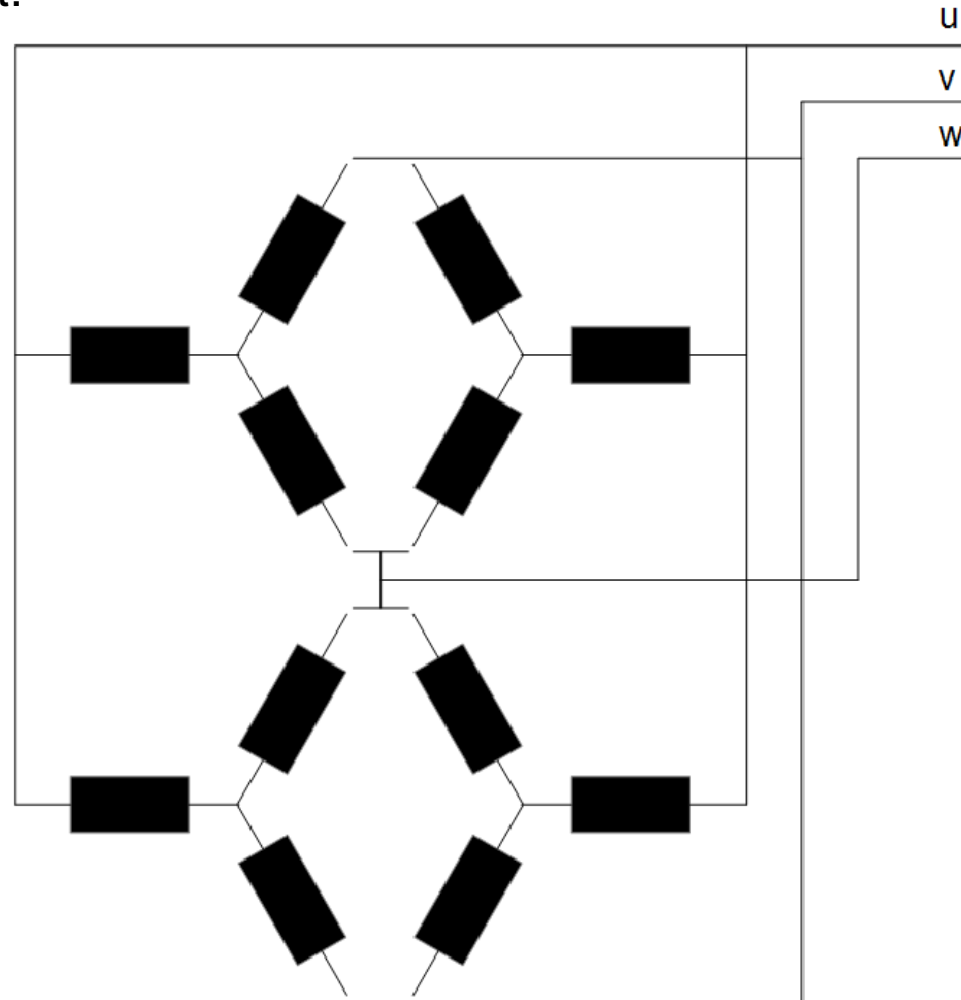


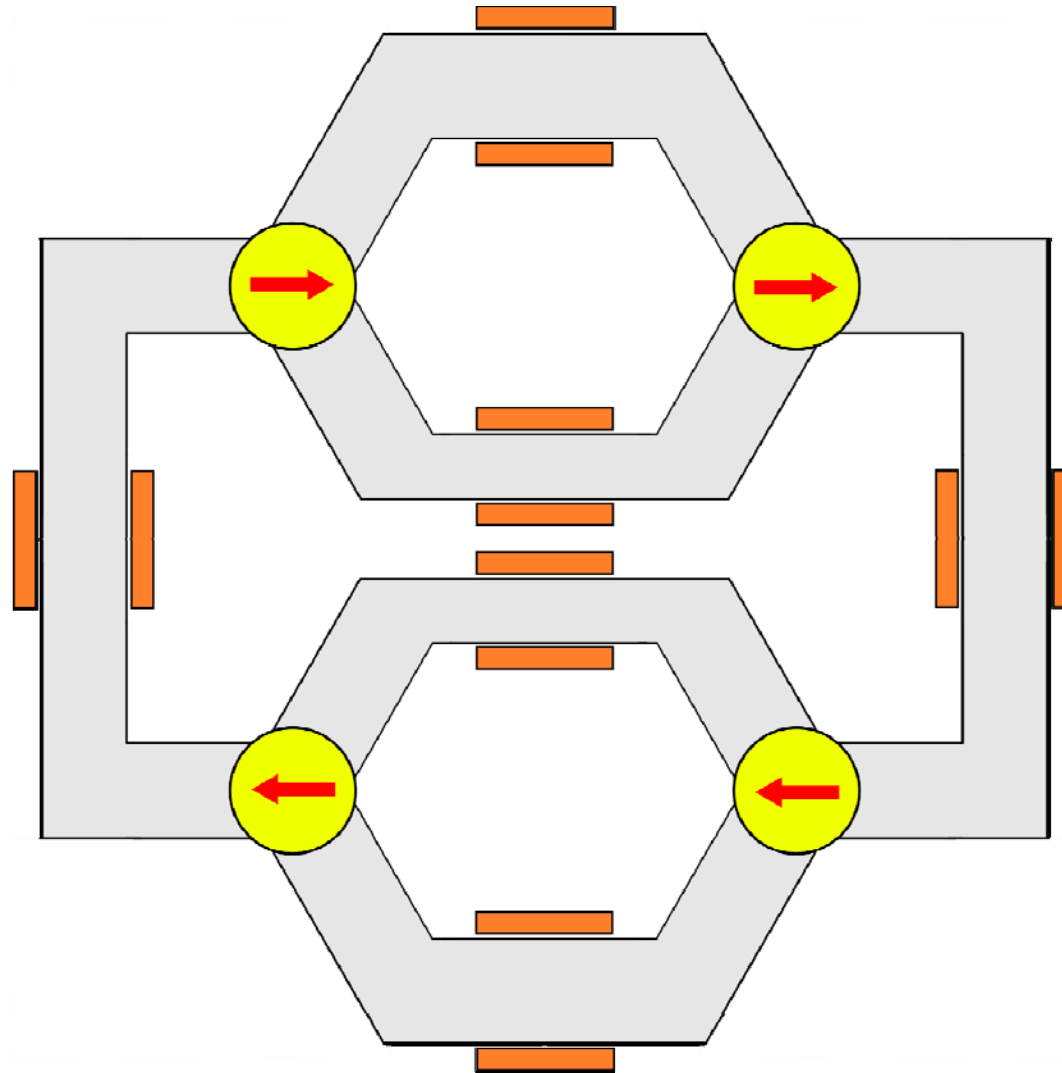
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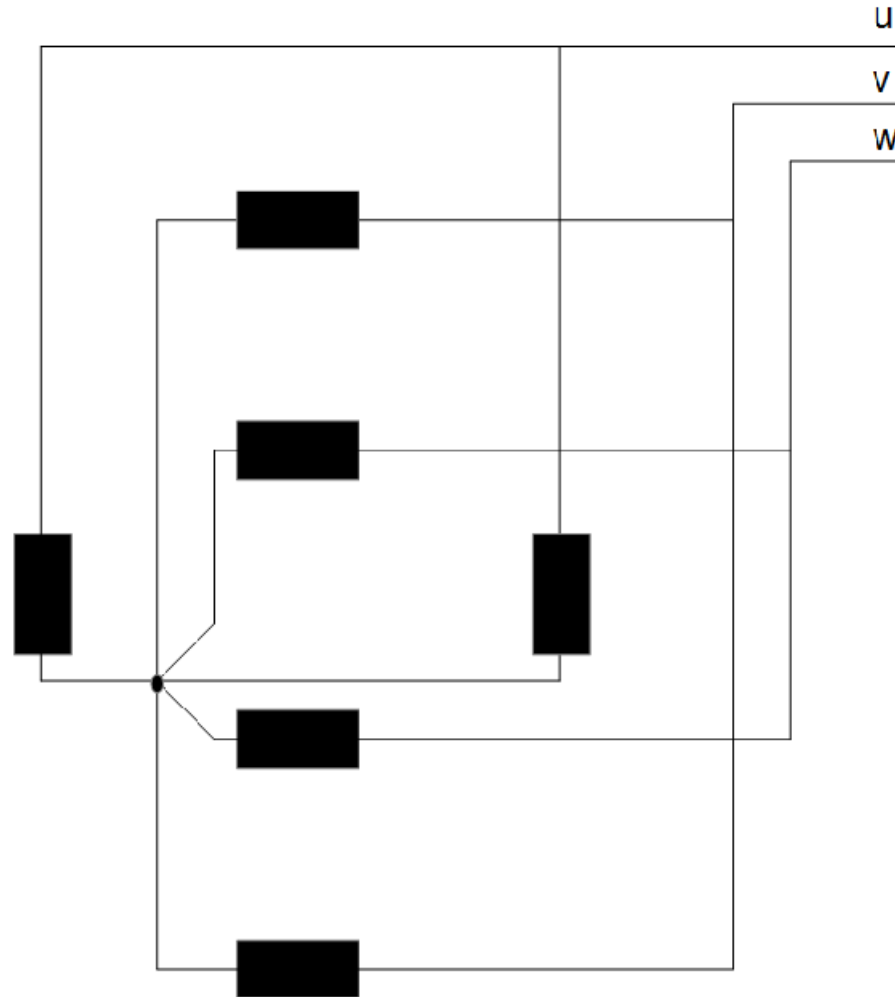
Original Circuit:



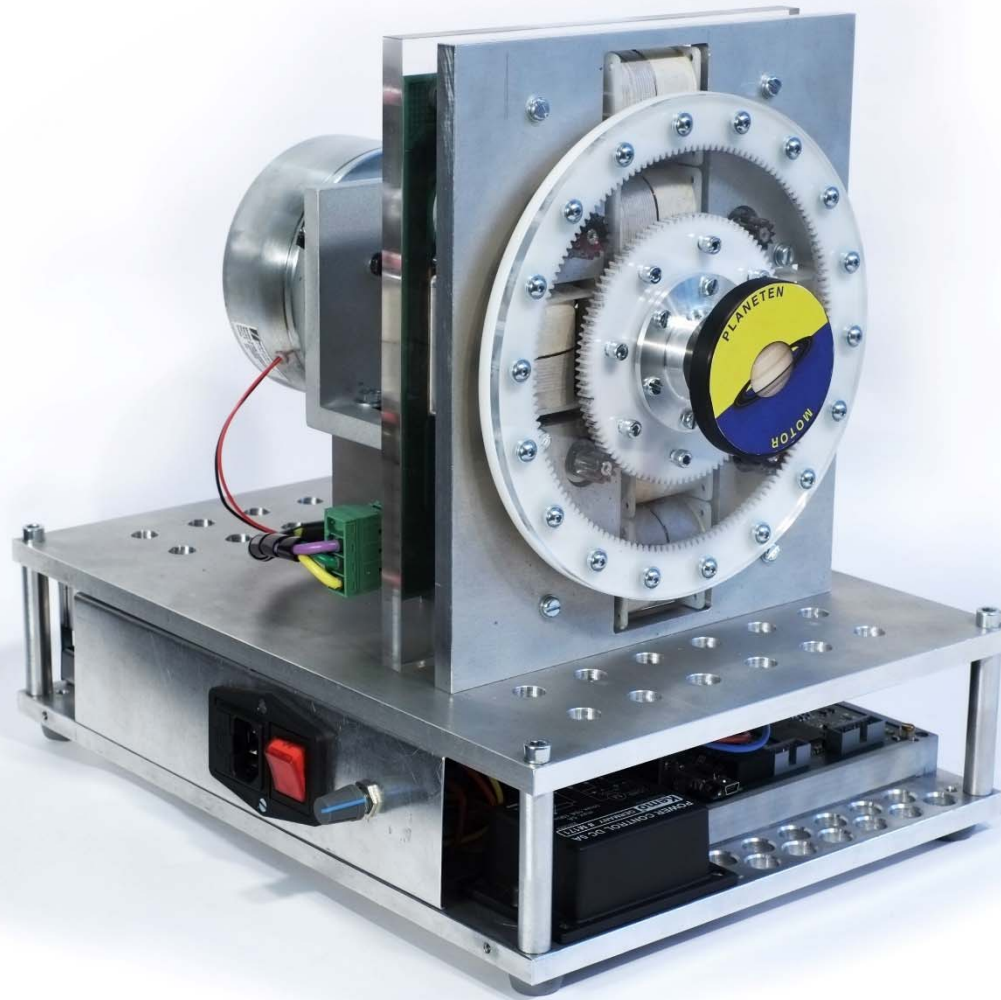


Reduced Circuit:

- 3-phase inverter
- Star or delta connection

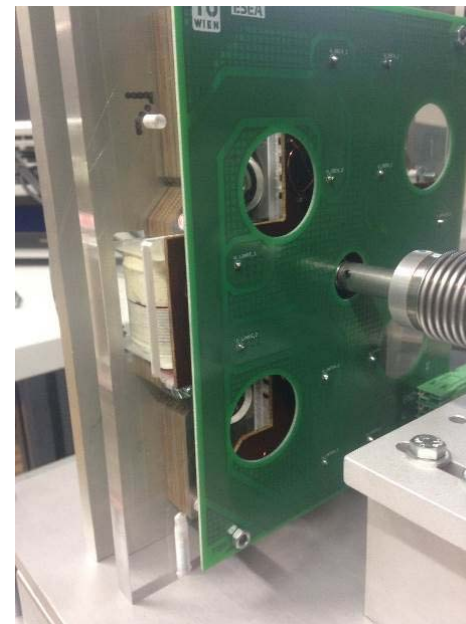


Functional Prototype



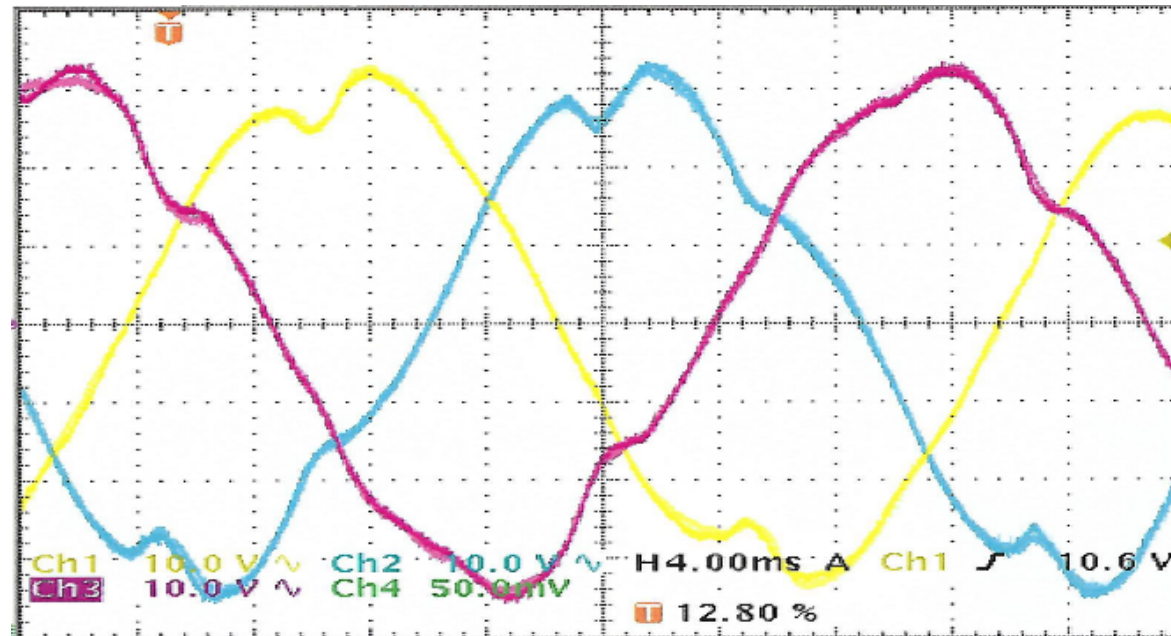
Functional Prototype

- 4 rotors and 3-phase stator winding
- 6 concentrated coils
- Gear ratio 10:1
- Sensorless control (INFORM / EMF)
- Connection of all coils on the rear side of the motor
 - Simple assembly

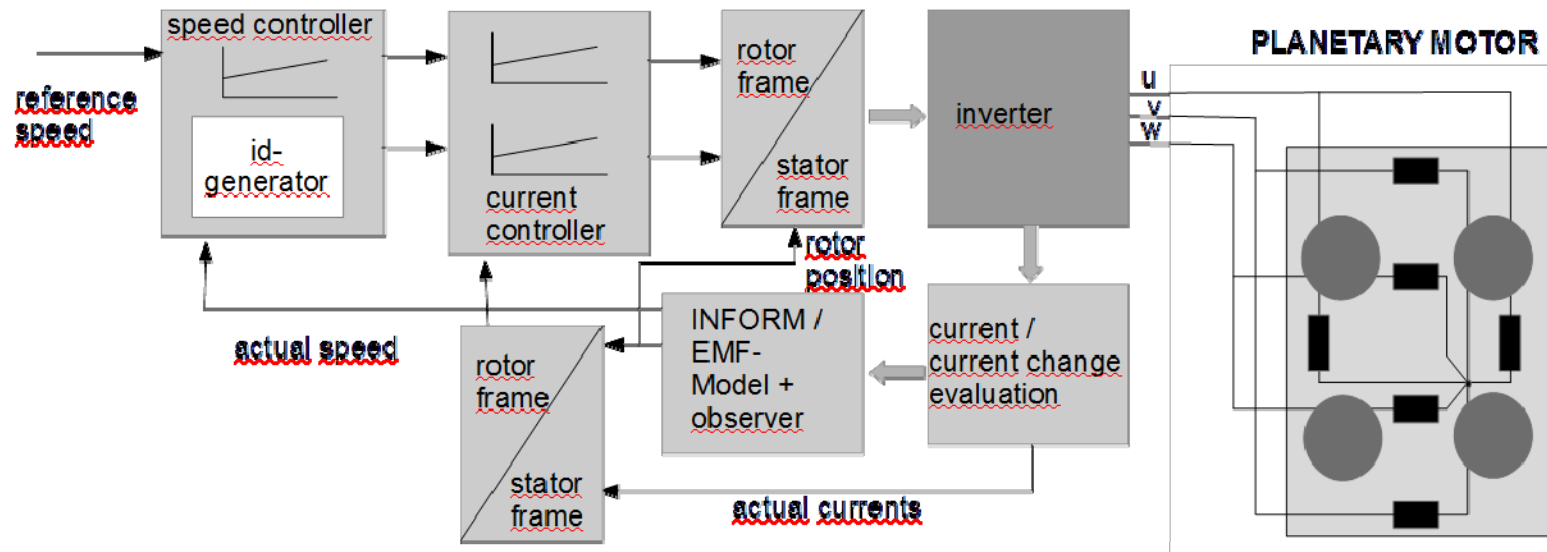


Functional Prototype

Terminal voltages at 200rpm on output shaft:



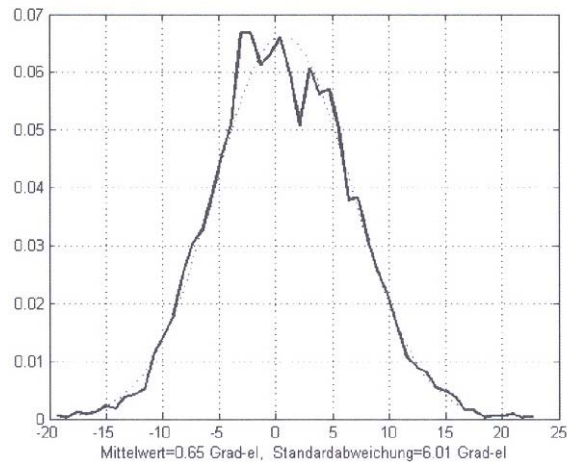
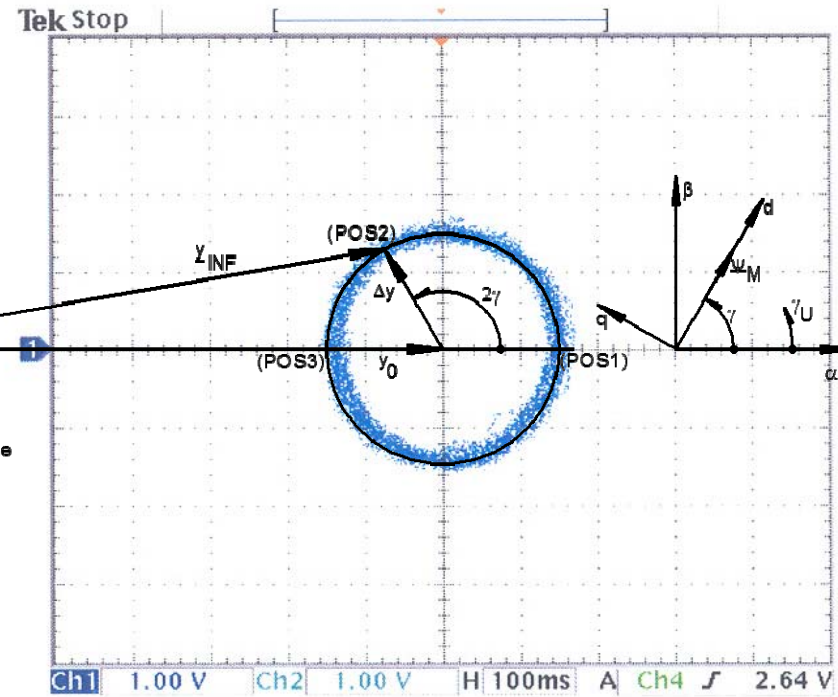
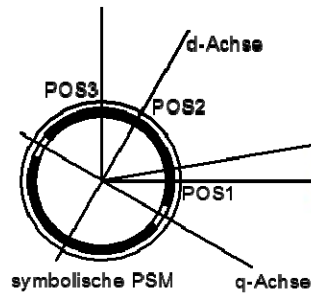
Control Strategy



Control Strategy

- High-speed range ($> 10\%$ rated speed):
EMF-method
 - Based on induced voltage
 - State of the art
- Low-speed range and standstill:
INFORM® method
 - Based on inductance differences
 - Already used in series applications

$$\underline{l} = \frac{\underline{u}_s}{di_s/dt}$$



INFORM-error:

- mean 0.65deg
- Standard deviation 6.01deg (electrical)

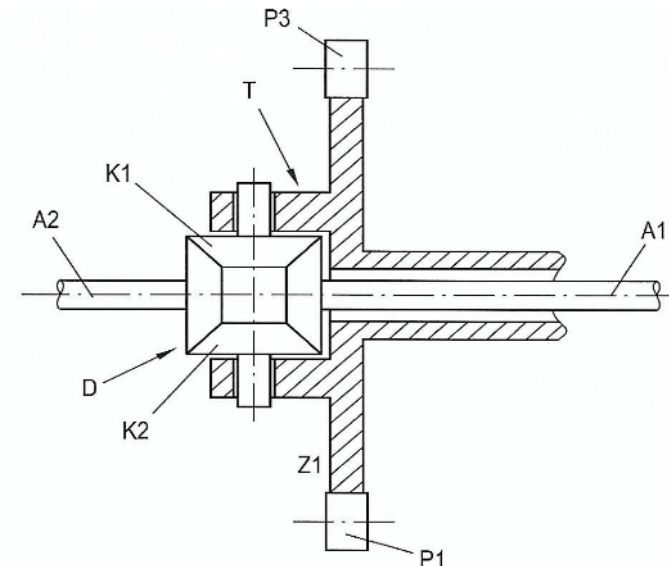
Applications

- Electric vehicle axle drive
 - Integrated gear box
 - Hollow central motor shaft → differential drive

- Wheel-hub motor

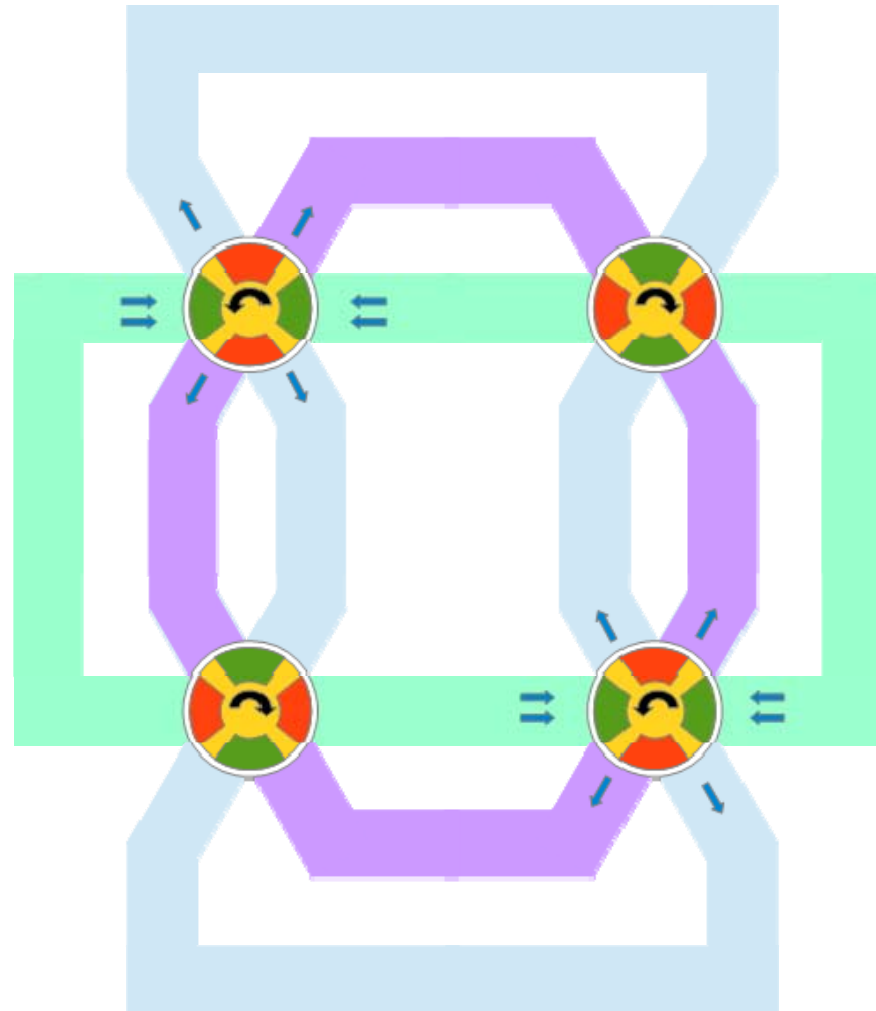
- Low speed / high torque

- Wind power

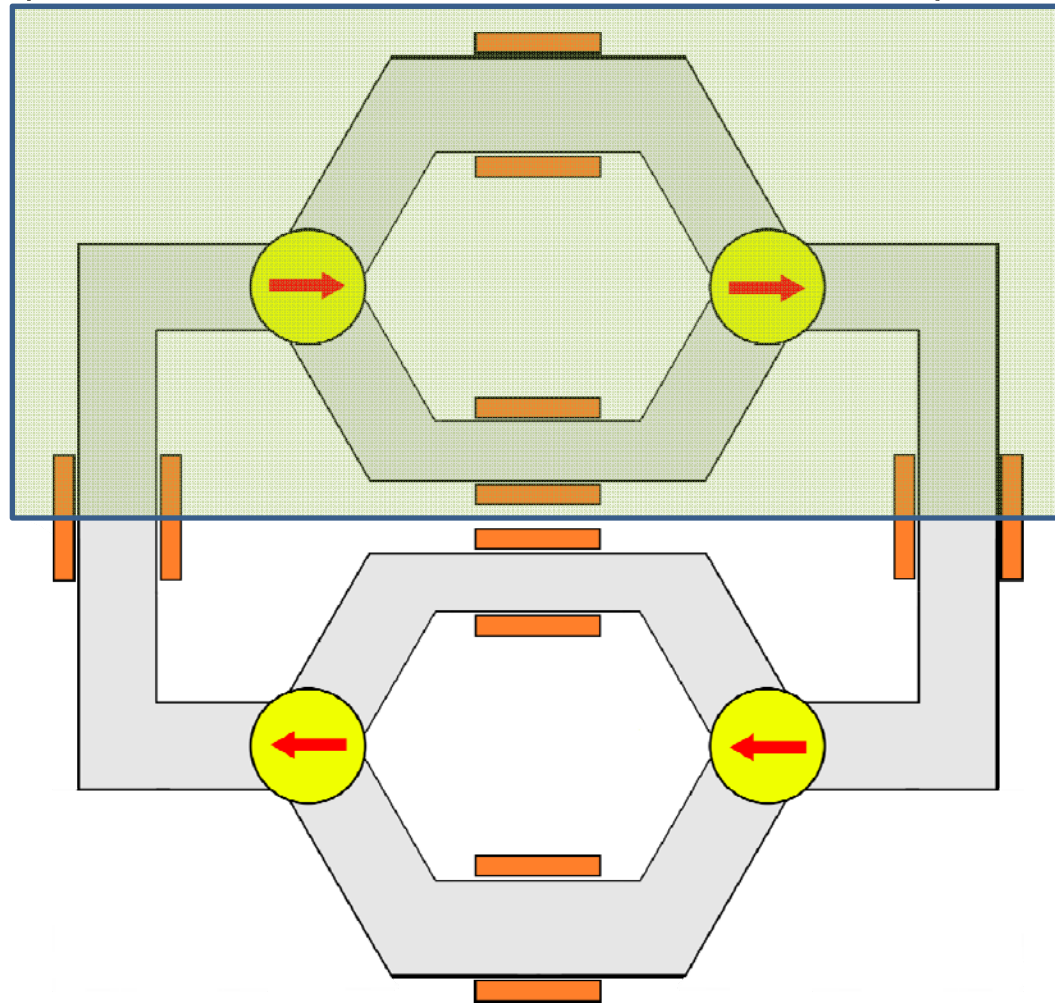


PLANETARY MOTOR with differential gear D (housing T, bevel wheels K1, K2), functionally combined with sun wheel Z1. Planets P1, P3 (shown without connected rotors of the electrical part). Half axes A1, A2, connected to driving wheels

- 4-pole rotors
- 12 coils



6 rotors (series connection of 3 elements)



Conclusion

- 1 rotor → 4 rotors: half circumferential speed at same power
- Integrated transmission
 - Low speed / high torque applications
- Simple assembly
 - Concentrated coils
 - Integrated coil connections and power electronics on rear side possible
- Standard 3-phase inverters
 - Sensorless control



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Thank you for your attention

TU Wien offers cooperation
Please contact us!

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