Chaining Dynamics of a Pair of Ellipsoidal Micro-Particles Under a Uniform Magnetic Field

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Introduction: We numerically investigate particle-particle interactions and relative motions of a pair of paramagnetic elliptical particles by using direct numerical simulations that resolve magnetic and flow fields around the finite sized particles. The modeling is based on the finite element method and arbitrary Lagrangian-Eulerian approach with full consideration of particle-fluid-magnetic field interaction.

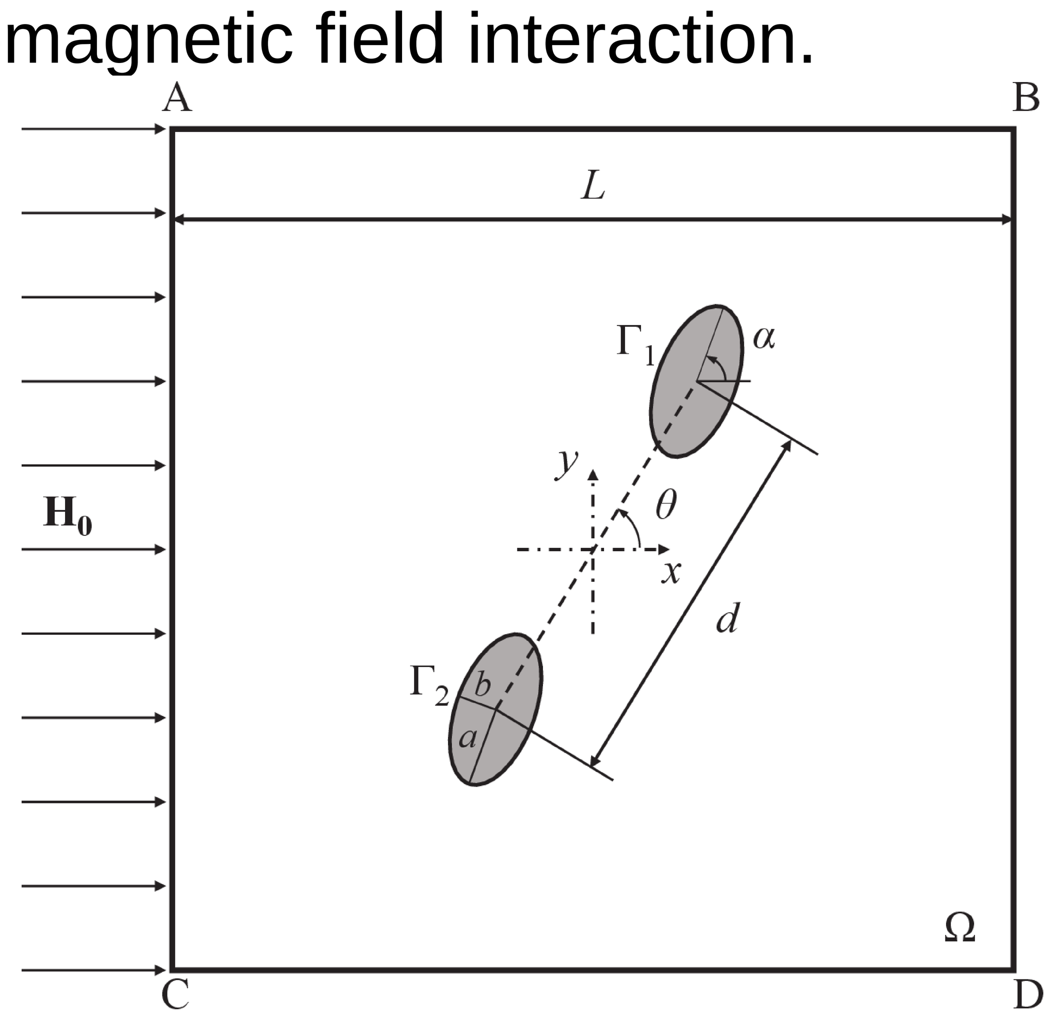

Figure 1. Schematic of numerical model

Computational Methods: The fluid field, **u**, is governed by the continuity equation and Stokes equation:

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot \left[-p\mathbf{I} + \eta_f \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T \right) \right]$$

No-slip condition is set on the particle surface, so the fluid velocities on the particle surface Γ1 and Γ2 are given as:

$$\mathbf{u_i} = \mathbf{U}_{pi} + \boldsymbol{\omega}_{pi} \times (\mathbf{x}_{si} - \mathbf{x}_{pi})$$

The governing equations of the uniform magnetic field are given as:

$$\mathbf{H} = -\nabla V_m$$

$$\nabla \cdot \mathbf{H} = 0$$

The magnetic potential difference is set on the top and bottom walls. Magnetic insulation boundary condition is applied on the left and the right boundaries of the computational domain.

Results: Magnetic and flow fields

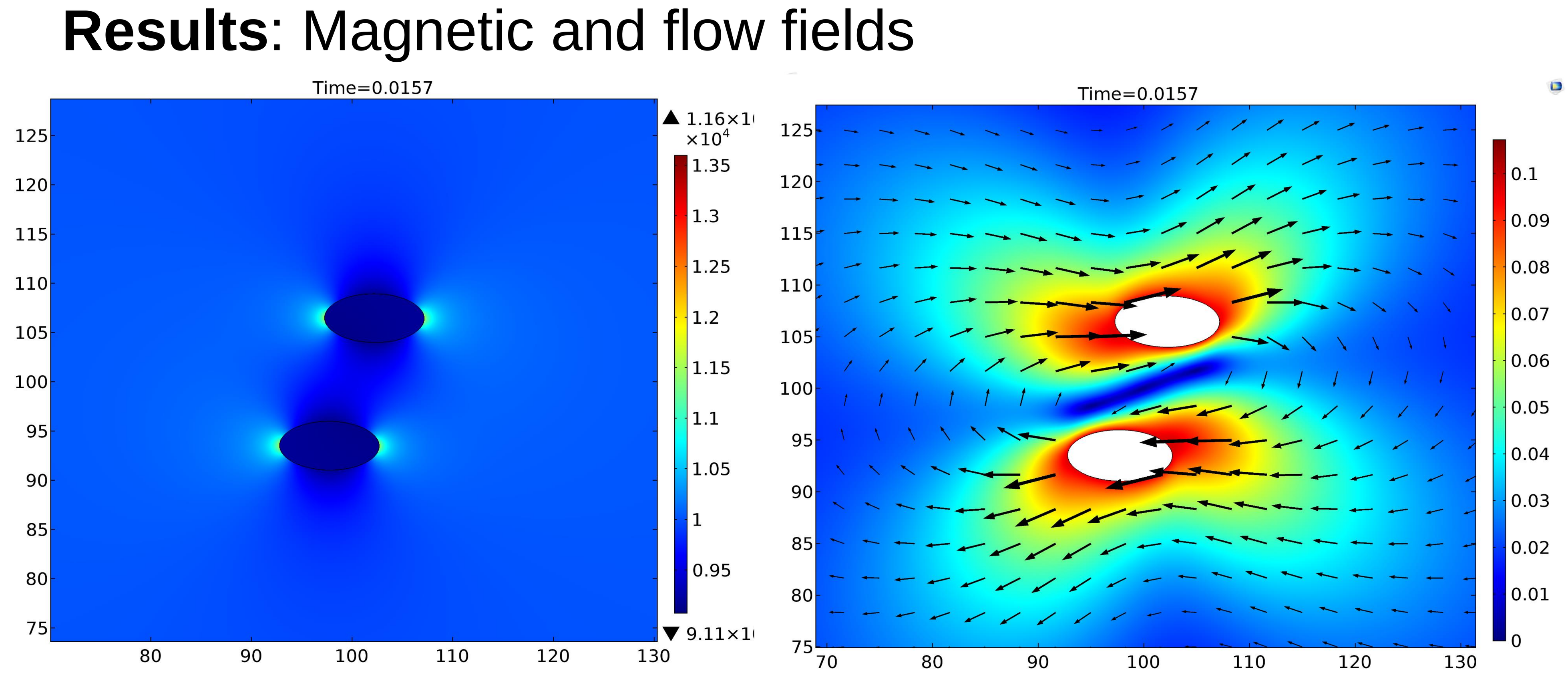

Figure 2. Magnetic field and velocity field around two particles with $r_p = 2$ when H_0=10000A/m.

Results: The effect of particle initial position and aspect ratio

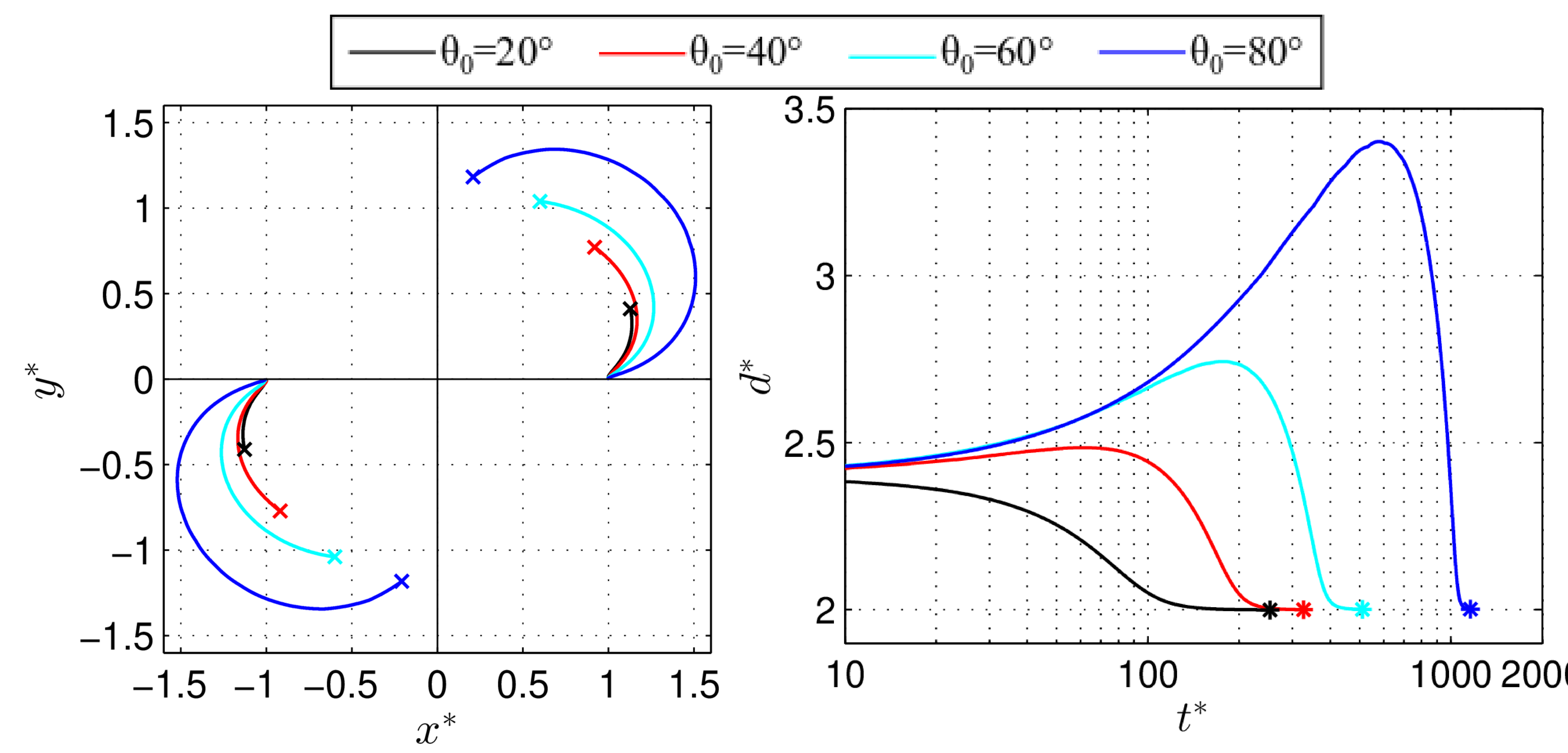

Figure 3.The effect of initial relative angle between two particles on the particle-particle interaction when r_p = 2 and $d_0{}^*$ = 2.4.

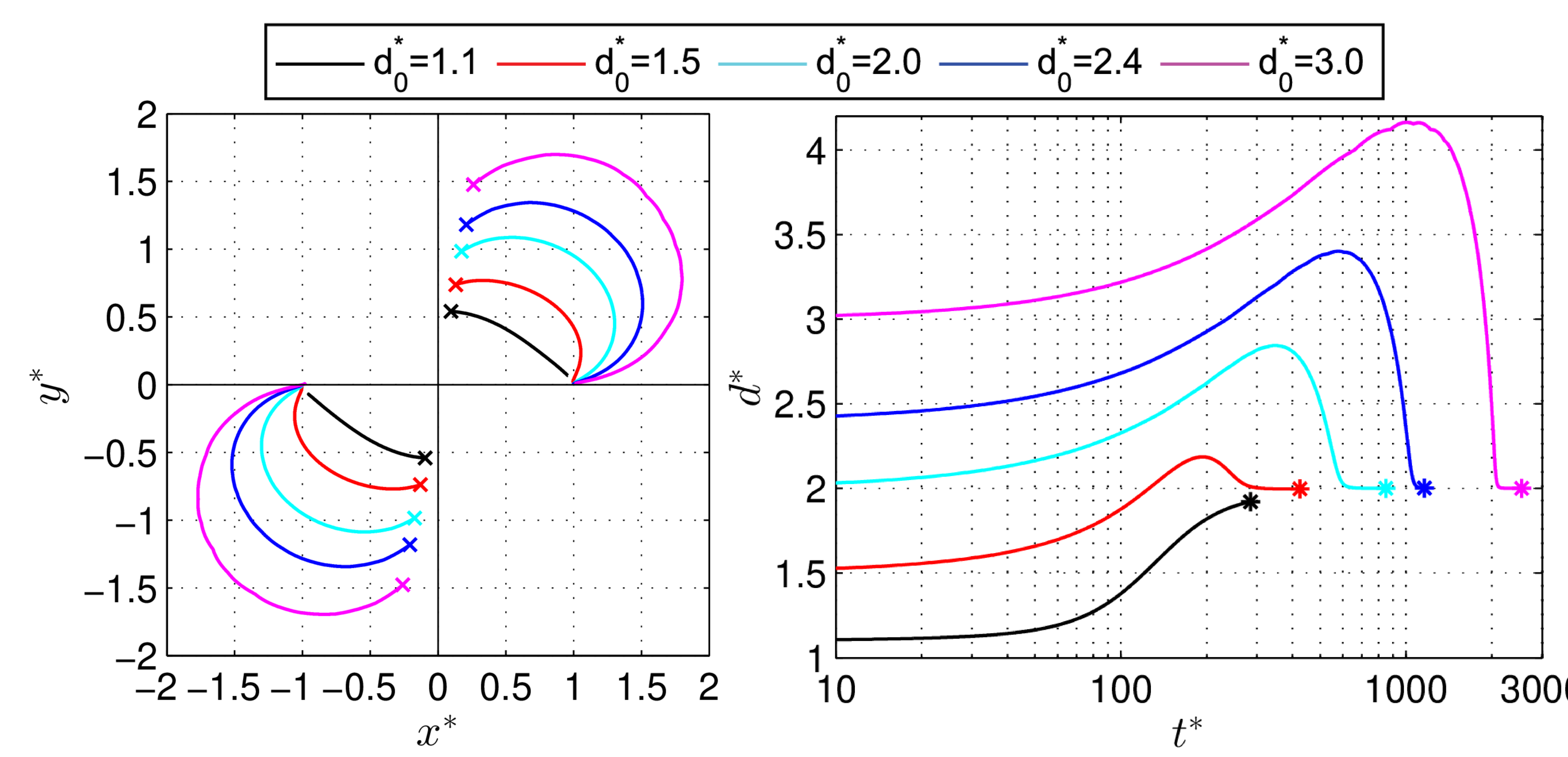

Figure 4. The effect of initial center-to-center distance on the particle-particle interaction when r_p = 2 and θ_0 = 80°

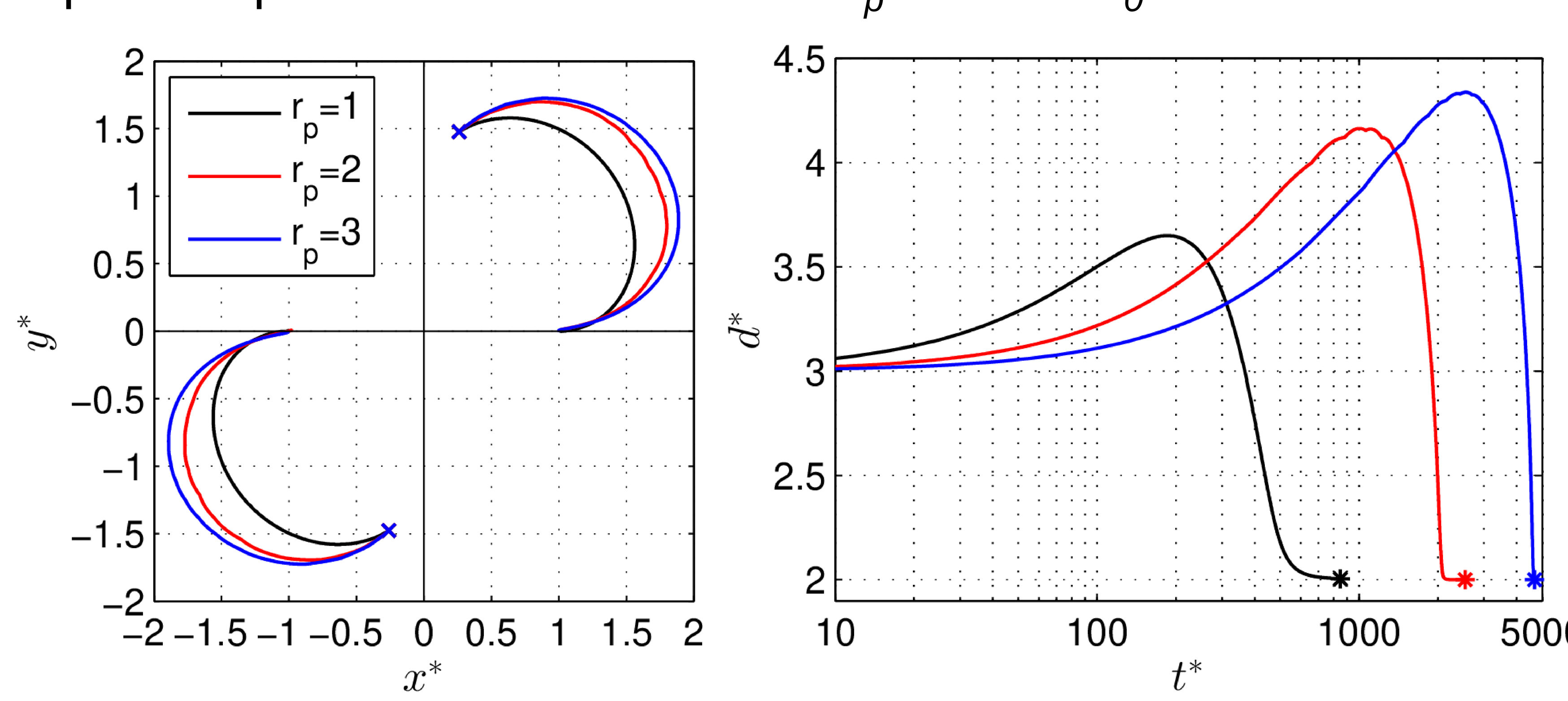

Figure 5. The effect of particle aspect ratio on the particle-particle interaction when $d_0{}^*$ = 3.0 and θ_0 = 80°

Conclusions: The particles with larger initial relative angles and distances need more time to form a stable chain and smaller final particle and relative orientation angles. For a larger particle aspect ratio, more time is required to form a chain, and the final particle and the relative orientation angles are larger.

References:

1. A. Shine and R. Armstrong. The rotation of a suspended axisymmetric ellipsoid in a magnetic field. Rheologica Acta, 26(2):152-161, 1987.
2. J. A. Stratton. Electromagnetic theory. John Wiley & Sons, 2007.