

Multiscale Multimodel Simulation of Micromagnetic Singularities

Christian Andreas

Forschungszentrum Jülich GmbH
Peter Grünberg Institute (PGI)
Electronic Properties (PGI-6)

Multiscale Multimodel Simulation of Micromagnetic Singularities

Christian Andreas

Schriften des Forschungszentrums Jülich
Reihe Schlüsseltechnologien / Key Technologies

Band / Volume 88

ISSN 1866-1807

ISBN 978-3-89336-983-6

Contents

| | | |
|-----------------------|--|-----------|
| 1 | Motivation | 1 |
| | | |
| Part I. Theory | | |
| 2 | Fundamentals of micromagnetism and the Heisenberg model | 9 |
| 2.1 | Classical Heisenberg model | 10 |
| 2.1.1 | Exchange interaction | 11 |
| 2.1.2 | Zeeman energy | 11 |
| 2.1.3 | Magnetostatic energy | 12 |
| 2.2 | Micromagnetic energy contributions | 14 |
| 2.2.1 | Exchange energy | 15 |
| 2.2.2 | Zeeman energy | 19 |
| 2.2.3 | Demagnetizing energy | 19 |
| 2.2.4 | Anisotropies | 22 |
| 2.3 | Dynamics of magnetization and magnetic moments | 23 |
| 2.3.1 | Effective field | 23 |
| 2.3.2 | Landau-Lifshitz-Gilbert equation | 25 |
| 3 | Basic micromagnetic structures | 27 |
| 3.1 | Domain walls | 27 |
| 3.1.1 | Bloch wall | 28 |
| 3.1.2 | Néel wall | 29 |
| 3.1.3 | Head-to-head domain wall | 30 |
| 3.2 | Vortices | 31 |
| 3.3 | Bloch points | 32 |
| 4 | Analytic treatment of Bloch points | 35 |
| 4.1 | Pontryagin index | 37 |
| 4.2 | Micromagnetic Bloch point exchange energy density | 38 |
| 4.3 | Demagnetizing energy | 39 |
| 4.4 | Equilibrium Bloch point angle γ | 41 |
| 4.5 | Bloch point propagation — a simple model | 42 |
| 4.6 | Summary | 45 |

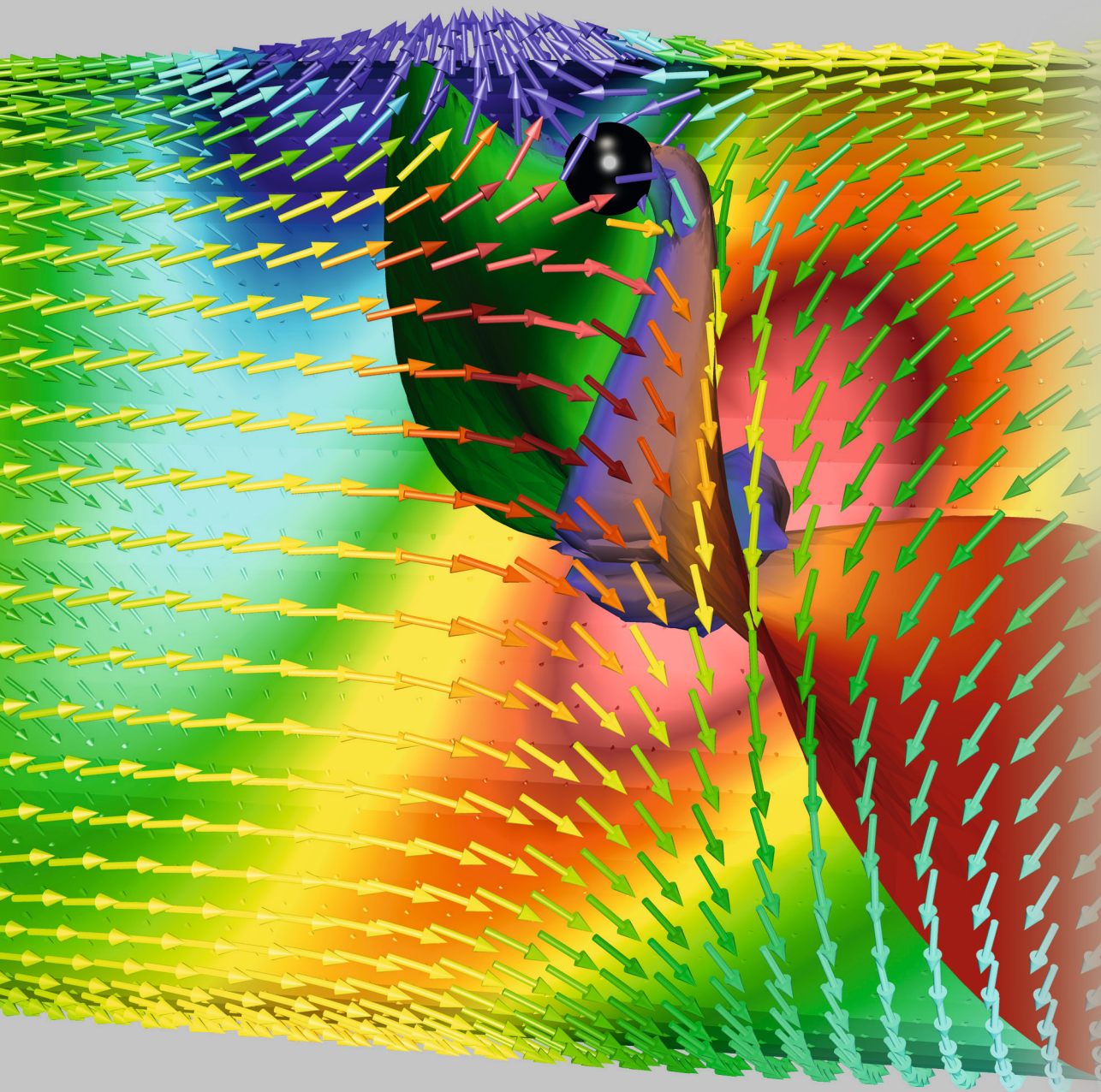
Part II. Numerics

| | | |
|----------|--|-----------|
| 5 | Finite element method | 49 |
| 5.1 | Mathematical overview of FEM | 50 |
| 5.1.1 | Simplex elements | 50 |
| 5.1.2 | Shape functions | 51 |
| 5.1.3 | Spatial differentiation | 51 |
| 5.1.4 | Spatial integration | 53 |
| 5.1.5 | Laplace operator | 53 |
| 5.1.6 | Demagnetization potential | 58 |
| 5.1.7 | Sparse matrices | 61 |
| 5.2 | Mapping between finite element meshes | 64 |
| 5.3 | Mesh generation | 66 |
| 6 | Implementation | 67 |
| 6.1 | Sample | 68 |
| 6.2 | Multi-model sphere | 69 |
| 6.2.1 | Core region | 70 |
| 6.2.2 | Coarsening | 72 |
| 6.3 | Calottes | 74 |
| 6.4 | Synchronization | 76 |
| 6.5 | Time integration of the equation of motion | 78 |
| 6.5.1 | Time integrator routine | 81 |
| 6.5.2 | Propagation | 82 |
| 6.5.3 | Multi-model spheres for (potential) Bloch points | 82 |
| 6.6 | Execution pipeline | 84 |
| 7 | Numerical stability tests | 87 |
| 7.1 | Abrupt mesh transitions | 87 |
| 7.2 | Energy artifacts of multiple structures | 91 |

Part III. Numerical results

| | | |
|-----------|---|------------|
| 8 | Bloch points in nanowires | 95 |
| 8.1 | Spin wave dispersion relation | 96 |
| 9 | Equilibrium Bloch point configuration | 101 |
| 10 | Depinning of Bloch points | 105 |
| 10.1 | Differences between <i>n.n.</i> and <i>Fe-like</i> exchange interaction in the dynamic regime | 107 |
| 11 | Chiralities of vortex domain walls | 109 |

| | |
|--|------------|
| 12 Bad chirality Bloch points | 113 |
| 12.1 Low field regime | 113 |
| 12.2 Walker breakdown of vortex domain walls | 117 |
| 12.2.1 Details of the Walker breakdown process | 118 |
| 12.2.2 Walker breakdown from a topological point of view | 121 |
| 12.3 Chirality change | 124 |
| 12.4 Summary | 124 |
| 13 Good chirality Bloch points | 127 |
| 13.1 Submagnonic propagation | 129 |
| 13.2 Laminar supermagnonic propagation | 132 |
| 13.3 Oscillatory supermagnonic propagation | 133 |
| 13.4 Turbulent Bloch point propagation | 136 |
| 13.5 Summary | 139 |
| 14 Bloch point positions inside of the lattice | 141 |
| 15 Conclusion | 145 |
| | |
| Appendix | |
| List of abbreviations | 151 |
| English résumé | 163 |
| References | 173 |
| Publications | 185 |
| Acknowledgment | 187 |



Schlüsseltechnologien / Key Technologies
Band / Volume 88
ISBN 978-3-89336-983-6

