Study of Helicity Conservation during Magnetic Reconnection

Riley Crane

Princeton Plasma Physics Laboratory

November 17, 1998

Outline

1. Introduction to Magnetic Reconnection
2. Introduction to Magnetic Helicity
3. Relation Between Reconnection and Helicity
4. Purpose
5. Hypothesis
6. Results
7. Conclusion

1. **What is Magnetic Reconnection?**

Magnetic Reconnection is the topological breaking and rearranging of Magnetic field lines. It occurs when oppositely directed field lines diffuse through a plasma and annihilate one another.

2. Why is it Important?

- Solar Flares –Thought to play a key role in the evolution of solar dynamics and solar-related phenomenon.
- Plasma Confinement –Reconnection degrades confinement time and quality of many fusion schemes. Understanding it could prove crucial in overcoming confinement problems.
- Aurora (Northern Lights) –Reconnection is induced in the near-Earth magnetotail. This in turn accelerates the plasma in that region into the atmosphere. The plasma excites atoms which then (upon de-excitation) emit radiation in the visible spectrum.

Magnetic Helicity

1. **What is Helicity?**

   Helicity refers to the twistedness, knottedness, and connectedness of a topological magnetic configuration.

2. **How is it defined?**

   It is a globally defined quantity:

   $$K = \int_{volume} \vec{\mathbf{A}} \cdot \vec{\mathbf{B}} \, dV$$

   where $\vec{\mathbf{A}}$ is the magnetic vector potential and $\vec{\mathbf{B}}$ is the magnetic field.

3. What does it Represent?

- This quantity can be seen as representing **How much the magnetic field wraps around itself.**

4. Why is it important?

- Topology – Helicity represents a measure of the topology of a system.
- Reconnection Parameters – Helicity affects the shape of the Diffusion Region as well as the reconnection angle. These characteristics depend on the type of Helicity (fig. 4)
- A Theoretical Tool – Using conservation of Helicity along with a variational principle, one can account for the phenomenon in a Reverse-Field Pinch. Thus Helicity can be used as a theoretical tool.

Relation Between Magnetic Reconnection and Helicity

1. **Effects of *Global Helicity* on *Local Reconnection***

   - ## Topology

     Helicity – *a quantity representing the Topology of the system* – **is changed by local Magnetic Reconnection**

   - ## Reconnection Rates

     Magnetic field line annihilation rates are determined by type of Helicity.

   - ## Reconnection Angle

     The angle at which the magnetic field lines reconnect is determined by the Type of Helicity

   - ## Shape/Size of Diffusion Region

     The shape of the diffusion region – *namely Y-shaped or O-shaped* – **is dependent upon the type of Helicity (fig. 5)**

Relation between Magnetic Reconnection and Helicity

2. Effect of *Local Helicity* on *Global Reconnection*

- **Reconnection affects *Local* Helicity Conservation (fig. 5)**

  i. **Co-Helicity – Local Helicity (i.e. in Diffusion Region) Increases for "Push" Reconnection**

  ii. **Counter-Helicity – No net Helicity Change in Diffusion Region.**

  iii. **Null-Helicity – Helicity is Locally Constant.**

Relation between Magnetic Reconnection and Helicity

3. Effects of Reconnection on Helicity

Inside the diffusion region ideal MHD conditions breakdown – *specifically the Frozen-In Theorem* – **therefore Helicity (and Energy) can be changed or dissipated.**

4. Main Point of the Relation between Helicity and Reconnection

- **Co-Helicity "Push" Reconnection (this study):**

  If Global Helicity is Conserved

  ...then Local Helicity Increases.

Purpose

1. **Determine if Helicity is locally conserved.**

   - Qualitatively look at Change of Helicity, K, During Reconnection. Which is found to be:

   $$\frac{\partial K}{\partial t} \propto -2 \cdot \int \vec{\mathbf{E}} \cdot \vec{\mathbf{B}} dV$$

   - Compare Ratio of Helicity Change to Energy Change (during Reconnection).

     Which is proportional to:

   $$\left| \frac{W}{K} \frac{dK}{dW} \right| \sim 2 \cdot \frac{\delta}{L} \cdot \frac{| B_t |}{B_p}$$

2. Hypothesis

- Local Helicity (i.e. In the Diffusion Region) should Increase during Reconnection.

- Ratio of Helicity Change to Energy Change should be of unit order in MRX.

$$\left| \frac{W}{K} \frac{dK}{dW} \right| \sim 1$$

Results

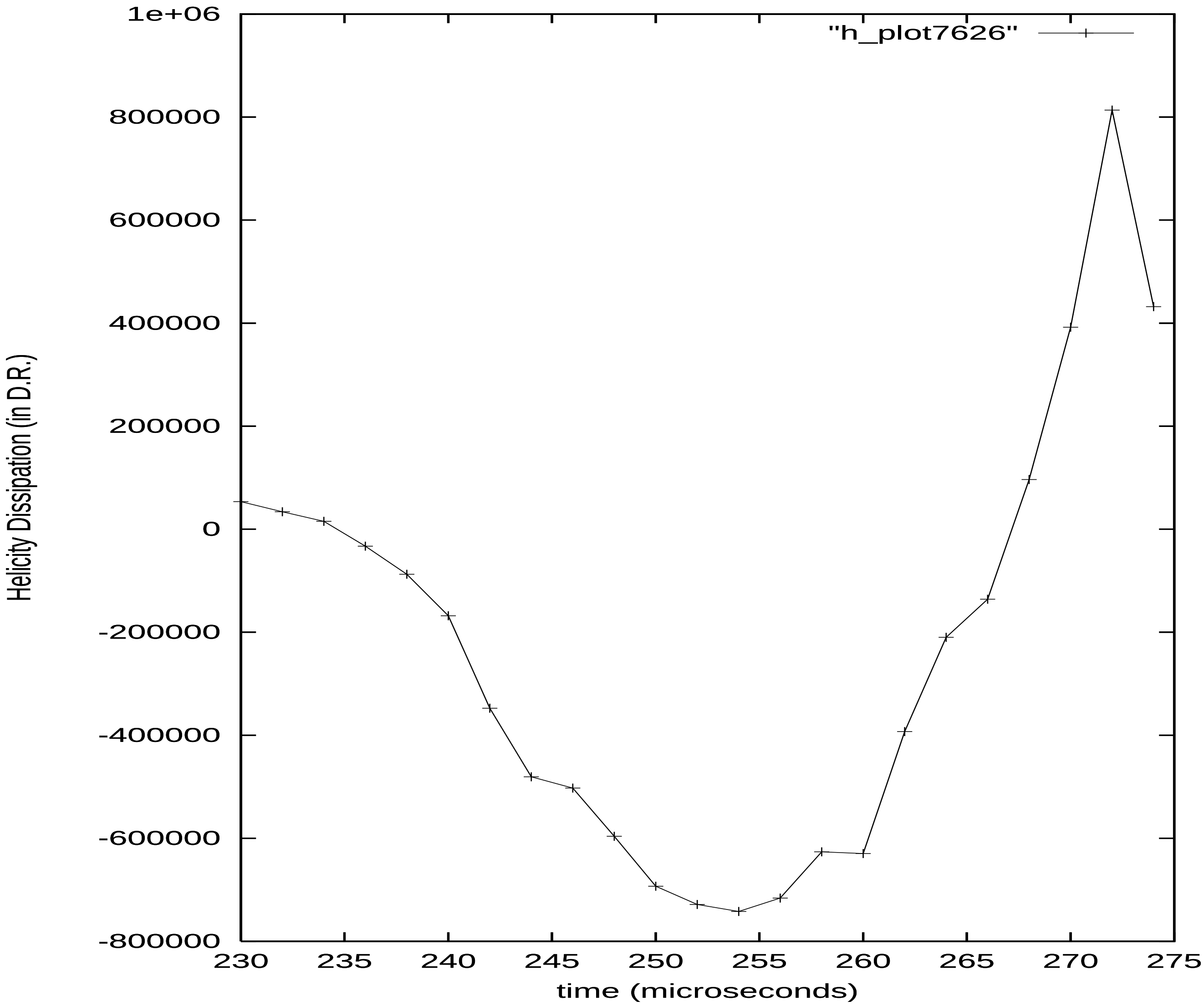

Figure 1: Notice Increase During Reconnection: $t \approx 260 - 275\mu s$

Results

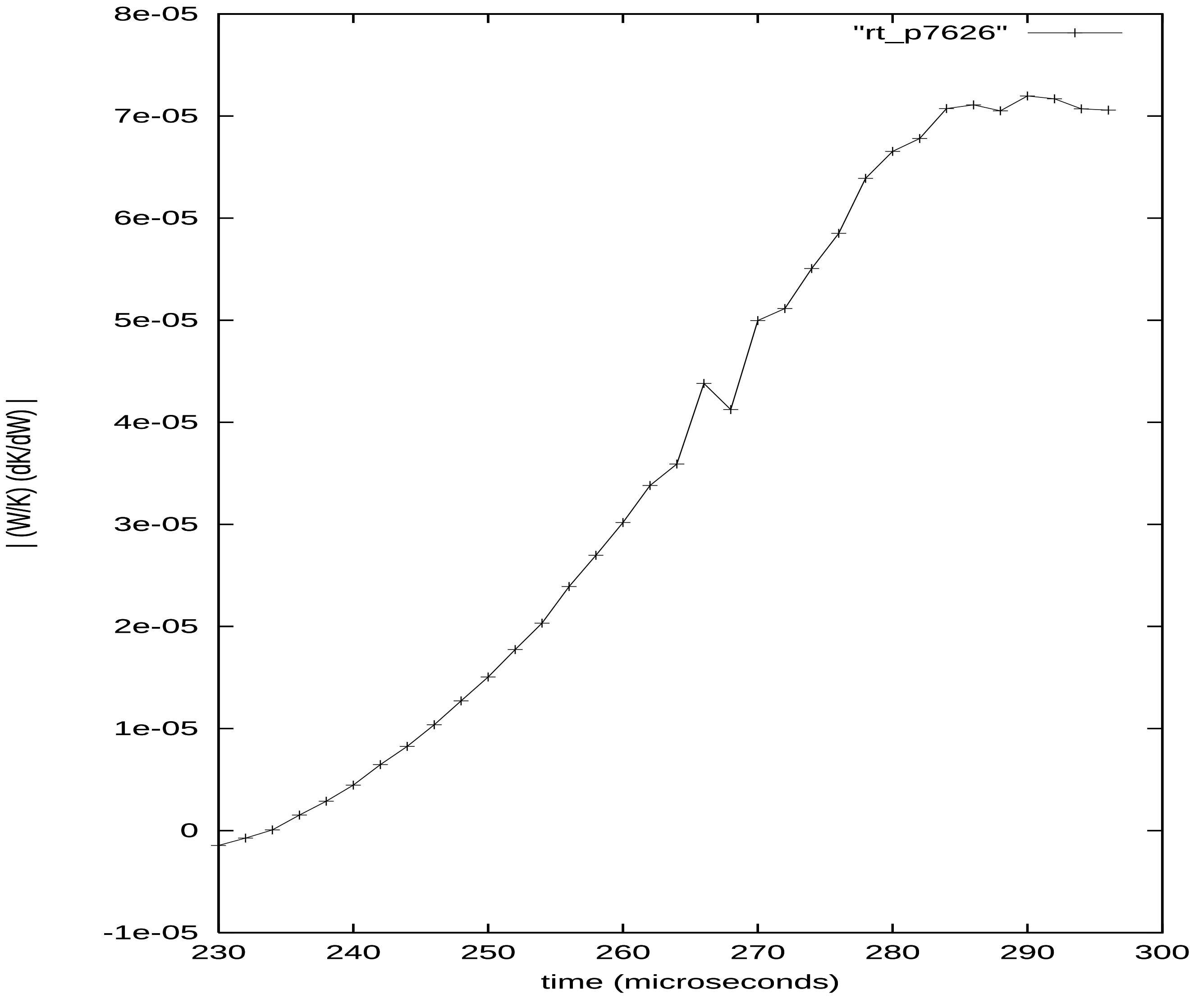

Figure 2: Notice that $\left| \frac{W}{K} \frac{dK}{dW} \right| \ll 1$

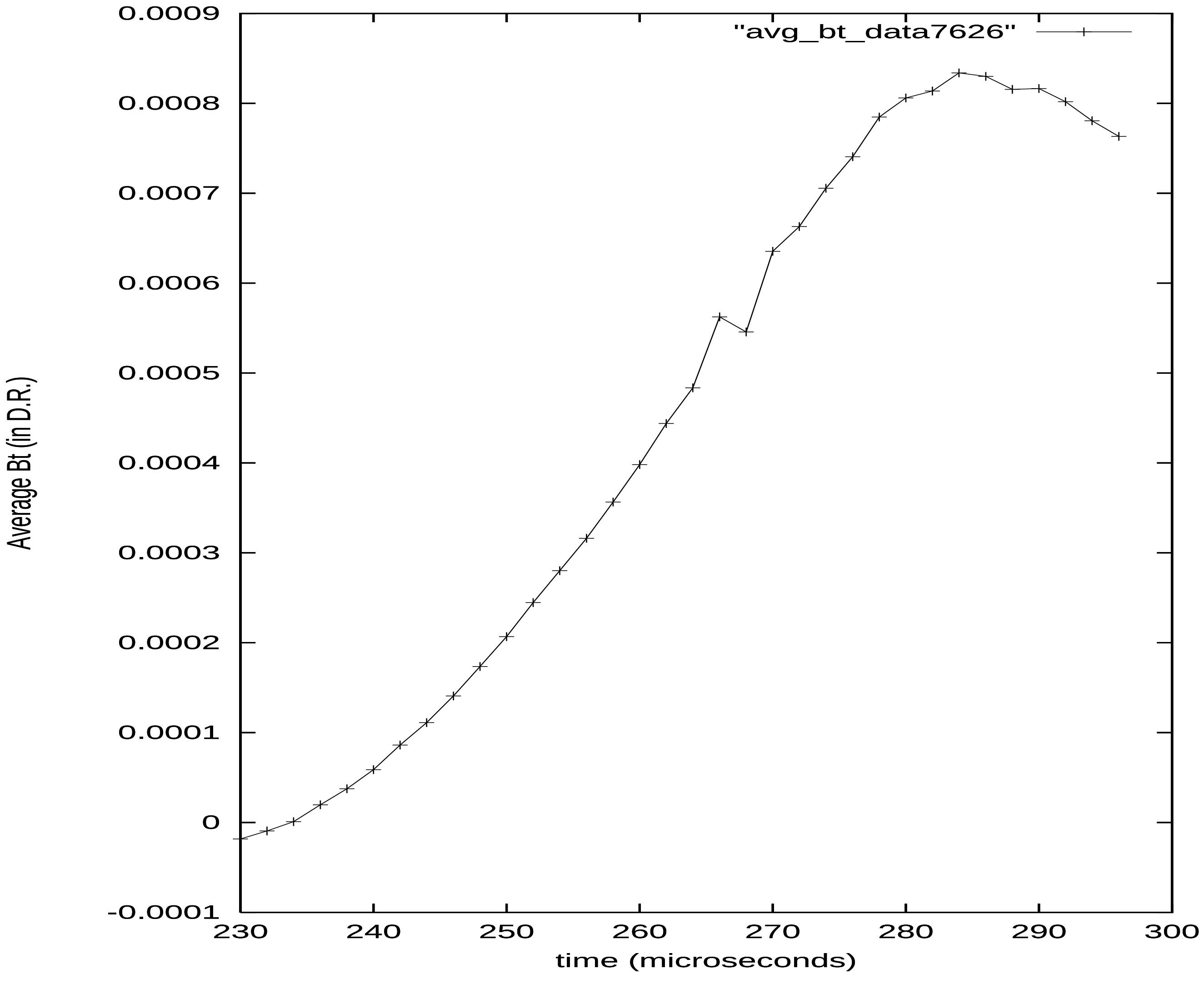

Figure 3: $\bar{B}_t$ is proportional to the change in Helicity with respect to the flux; Another measure of Helicity change. Note $\bar{B}_t \ll 1$

Conclusion

1. **Is Helicity Conserved Globally?**

- $\frac{\partial K}{\partial t}$ Increases During Reconnection

  Agreement with theory

- $\left| \frac{W}{K} \frac{dK}{dW} \right| < 1$

  Better than theory predicts for MRX

- There is **No Quantitative measure** of the error.

- **Helicity seems to be Globally Conserved.**

  There is good agreement with theory, but this evidence did not take into account errors associated with the data. So while Helicity appears to be Globally Conserved, more investigation is necessary.

Thanks

- This project was supported with funds from D.O.E.

- This is work done at PPPL during Summer '98.

- Thanks to Hantao Ji, Masaaki Yamada, Troy Carter, Scott Hsu, and Soren Zaharia for all of their advice and help. It was fun.

- Special Thanks to Pamela Lucas and James Morgan for their hard work in running the NUF Program.