CONFERENCE PRE-PRINT

INNOVATIVE AND EFFICIENT PLASMA MAGNETIC CONFINEMENT METHOD BASED ON AN OVERLOOKED HISTORICAL DISCOVERY

M.C. STOREY
Meranti Research Laboratories
Perth, Western Australia, Australia
Email: mstorey@meranti-research.net

J. SCHELFHOUT*, K. DE LACY, D. PFEFFERLÉ
University of Western Australia
Perth, Western Australia, Australia
* Present address: University of Oxford, Oxford, United Kingdom

L.R.O. STOREY
Meranti Research Laboratories
Cucuron, France

Abstract

In the late 1970s, European physicists Owen Storey and Laurent Cairó discovered and published a novel method of plasma confinement, building on an earlier discovery by American astrophysicist Eugene Parker. They proved that when a supersonically flowing plasma is confined by a magnetic field parallel to the flow, a secondary magnetic field discovered by Parker can emerge under certain conditions, reinforcing the confinement and reducing the requirement for the external magnetic field. The resulting overall confining field is concentrated within the thin static boundary layer between the plasma and the external field, while the bulk plasma remains both field-free and current-free. They suggested that this might be applicable to fusion and proposed a conceptual device exploiting this method, which they called the Plasma Storage Ring. The paper revisits this work and extends it to demonstrate two of its advantages in practice, through numerical simulations and physical experiments: the effectiveness and the energy efficiency of the plasma confinement. Preliminary results are presented. The confirmation of the theoretical results could open new pathways to the realisation of fusion energy with reduced complexity, cost, and potentially less dependence on rare isotopes.

1. INTRODUCTION

Controlled fusion is a tantalising source of reliable, equitable and sustainable energy, but after 80 years of research and experimentation, its promise has not yet been realised. Moreover, which technology will be "first to market" is not yet certain, and the development of supply chains to service the fusion industry carries significant risks of temporal misordering. In the early 1970s, the tokamak was deemed the most promising approach and became the focus of government-funded research for the following half-century, to the exclusion of virtually all other pathways then under investigation. This led to the collaborative ITER international experimental reactor project, currently under construction in southern France [1].

In the past decade, the combination of technological advances such as High-Temperature Superconductors (HTS) and cloud-based High-Performance Computing (HPC), and the realisation of the need to diversify the energy mix, enabled the emergence of an ecosystem of private fusion companies to investigate new ideas, or to revisit old ones with the benefit of the latest technologies. In spite of all this activity, the frontrunner of all fusion reactor concepts remains the tokamak, with stellarators also attracting a lot of interest [1,2].

Over 200 experimental tokamaks have been built by at least two generations of scientists and engineers, so they are well studied. They also have a relatively simple geometry. Unfortunately, they are prone to current-driven instabilities and damaging disruptions which have not yet been tamed. Scientific breakeven has not yet been achieved in a tokamak, partly because a significant fraction of the energy and auxiliary systems is devoted to sustaining the rotational transform needed for stability, rather than directly driving the fusion reactions. In contrast, stellarators are essentially free of disruptions, do not require an external rotational transform, and they can run continuously. However, their geometry is complex, as are their engineering and maintenance, and they are still far from breakeven, not yet being at a maturity stage of fusion energy gain factor optimisation [3].

CONFERENCE PRE-PRINT

Combining the merits of both devices without their respective drawbacks, an ideal plasma confinement device might have a simple and accessible layout, it would operate continuously and be inherently stable against the main instabilities.

The Plasma Storage Ring (PSR) proposed by Storey and Cairó is still a conceptual device at this time, but it has the potential to be simpler than a tokamak from both the physics and the engineering perspectives, and to run in steady-state operation. If these advantages are confirmed, the considerable work remaining to design a commercial fusion reactor utilising them would be greatly facilitated by all the existing relevant work done by the scientific community, in particular on the tokamak and the stellarator concepts.

In the present paper, two key aspects of the PSR are presented: the confinement method, in section 2, and its efficiency, in section 3. The concept was originally inspired by a discovery made in the late 1960s by American plasma physicist Eugene Parker and his team [4]. The confinement method is closely related to some proposed by James Tuck [5].

2. PLASMA CONFINEMENT EFFICACY

2.1. Earlier work

One of the earliest fusion reactor concepts was James L. Tuck's "picket fence": in a 1954 paper, he presented a series of pairs of current-carrying rings arranged in a torus [5]. The configuration was stable, on account of the Teller-Rosenbluth-Tuck criterion i.e. of the interchange stability, but it was also very leaky through the magnetic cusps. Tuck proposed several modifications of the concept, including the so-called "moving picket fence", wherein the currents in the rings are phased to create a traveling-wave magnetic pattern. He showed that this could effectively "plug" the leaks, but only if the wave travelled at unrealistically high phase speeds and RF power [5]. Fig. 1 is a schematic illustration of the linear version of the picket fence concept.

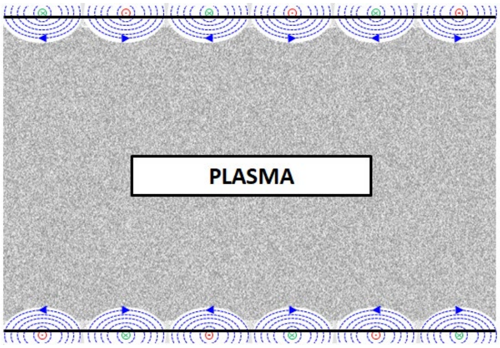

FIG. 1 – Tuck's linear picket fence concept, which leaked plasma through the magnetic cusps

2.2. PSR confinement

In the course of the work described in the next section, Storey and Cairó came to consider a picket fence configuration in which the currents and the magnetic fields do not vary, but the plasma flows around the minor axis of the torus, at a constant velocity. They considered a two-species plasma, with one type of ion and electrons, assumed isothermal for simplicity. This is illustrated schematically in Fig. 2. At zero velocity, the set-up is equivalent to Tuck's and is stable but leaky. As the rotation velocity increases, the number of ions escaping through the cusps reduces.

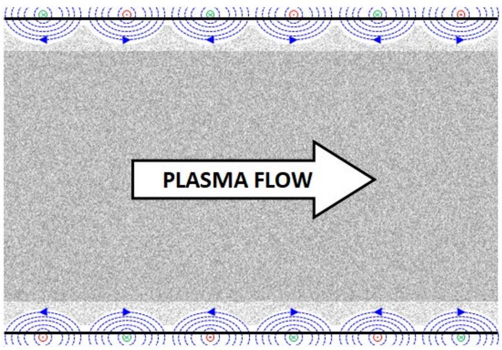

FIG. 2 – The PSR picket fence configuration

2.3. Demonstration by numerical simulation

Two numerical simulations have been specified: a simplified one-component simulation with non-interacting particles, and a full simulation of a two-component plasma, accounting for interactions and collisions.

CONFERENCE PRE-PRINT

3.3.1. Simulation of flow of non-interacting particles

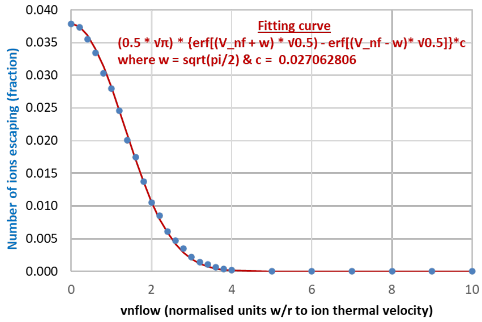

FIG. 3 – Simulation results of leakage for flow of non-interacting particles

A single-particle simulation in the two-dimensional configuration shown in Fig. 2 was constructed to study one bounce of a particle from the magnetic wall. The dimensions of the simulation domain were selected arbitrarily. The initial velocity of the particle was defined as the sum of a thermal velocity component sampled from a Maxwellian distribution and a prescribed flow velocity component in the direction indicated in the figure. This procedure was repeated 100,000 times for a given value of the flow velocity component, and then again for different values of that component, thereby simulating a flow of non-interacting particles using a Monte Carlo method. The results are the blue points shown in Fig. 3. The red curve has been fitted analytically, and the two constants have been determined by regression. It can be seen that the confinement becomes excellent from about Mach 5. Because this is a much simplified simulation, it is merely an encouraging indication: a full simulation must be run to confirm and characterise the confinement.

3.3.2. Full simulation of flowing two-component plasma

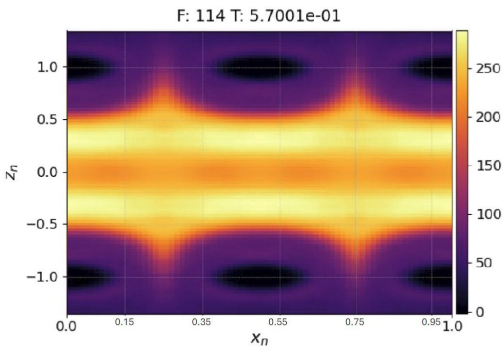

FIG. 4 – Ion spatial density in a one-cell module of a stationary picket-fence during Gkeyll simulation startup phase

The construction of a full simulation model of a PSR module has been attempted using the open-source software framework Gkeyll which uses continuum (Eulerian) methods, discretising the distributions over a grid and solving the partial differential equations by finite differences [6]. The simulation was intended to demonstrate both the confinement efficacy (this section) and its efficiency (section 3). We have run into difficulties implementing the simulation, which relate to the compatibility of different elements of the software and the fast-evolving HPC hardware, to the coordinate system, the initialisation, and to the numerical complexity of simulating different phenomena at vastly different spatial scales causing excessive run times. As illustrated in Fig. 4, we were able to initiate the simulation, but not to run it past the startup phase. We have decided to use a different software framework, and have now identified and gained access to one which we expect will be better suited for this simulation [7].

2.4. Demonstration by laboratory experiment

We are planning a laboratory experiment combining the setup described in section 3.3.2 below with the configuration shown in Fig. 2, for the purpose of demonstrating in practice both the efficacy of the confinement (this section) and the emergence of Parker's Effect (section 3). We are currently seeking international collaborators for such an experiment as the necessary resources are not available in Australia.

3. PLASMA CONFINEMENT EFFICIENCY

3.1 Earlier work

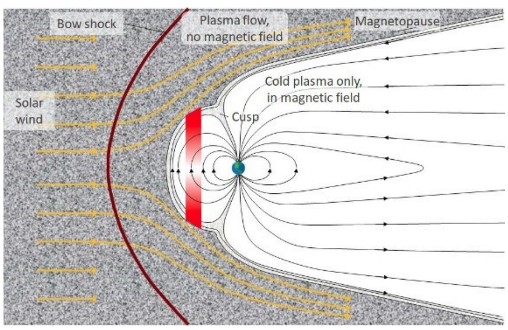

FIG. 5 – Parker's model of the magnetosphere

When investigating, in the late 1960s, a simplified model of the flow of the solar wind around Earth's magnetic field, Eugene Parker and his colleagues discovered theoretically that where the solar wind is parallel to the magnetic field on the dayside (in red on Fig. 5), in the thin boundary layer between the plasma and the field, a secondary magnetic field would arise, stronger than the primary field in the ratio of the flow speed to the ion thermal speed.

$$B_{secondary} = \mathcal{O}(\frac{v_{flow}}{v_{thermal}}) * B_{magnetospheric}$$

CONFERENCE PRE-PRINT

This effect causes the boundary layer to become unstable, under certain circumstances [4]. It has never been observed experimentally or in numerical simulation, mainly because it has never been sought.

In the late 1970s, Storey and Cairó reviewed Parker's Effect, as they named it, and showed that if the flowing plasma was confined by the magnetic field rather than the inverse, then the effect would reinforce the confinement. Only at the interface between the flowing plasma and the external magnetic field (the "boundary layer"), the ions create a strong current which in turn creates an internal magnetic field, leading to a net pinching effect. They showed that for that pinch to persist, the axial current must flow in a closed loop, suggesting a toroidal system which they called the Plasma Storage Ring or PSR (see Fig. 6). The bulk plasma remains field-free and current-free, as illustrated in Fig. 7. They suggested that this effect may have applications to fusion [8].

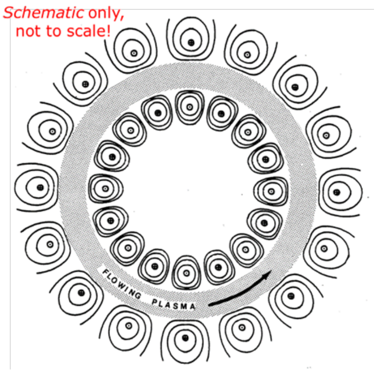

FIG. 6 – Plasma Storage Ring concept

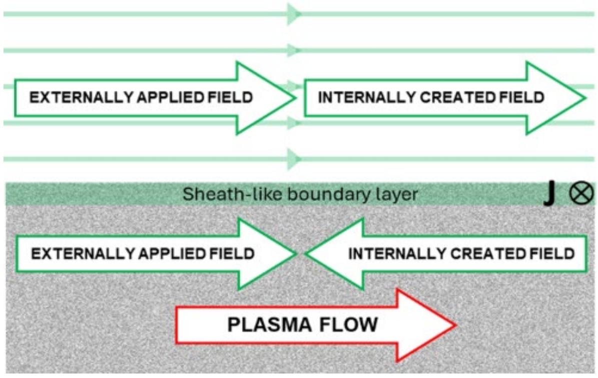

FIG. 7 – Parker's Effect

3.2 PSR confinement using Parker's Effect

Studying theoretically a simple system consisting of a jet of plasma flowing inside a single current-carrying ring, Storey and Cairó considered the global beta as a figure of merit addressing the energetic efficiency of the confinement method:

$$\beta = \frac{p_{plasma}}{p_{magnetic}}$$

They found that the global beta increases with the flow velocity of the plasma, up to a threshold, then it decreases again – see Fig. 8. The β values are of the order of 10 times those of a spherical tokamak, and 100 times those of a conventional tokamak.

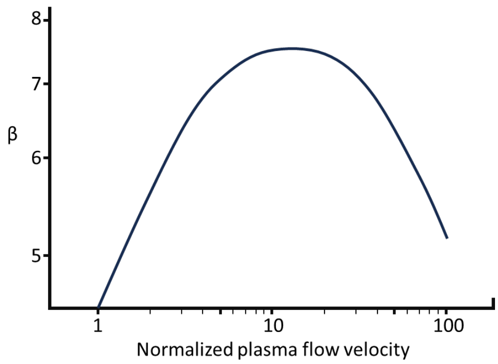

FIG. 8 – Global beta variation with flow speed

All else being equal, fusion power scales roughly with the square of β, so a tenfold increase in β could in principle mean some 100 times more fusion power density. In practice, however, magnetic field, volume, temperature, and stability constraints modify this scaling, so the real gain would not be as large - but still highly significant.

This demonstrates the theoretical efficiency of the proposed confinement method using Parker's Effect.

3.3 Demonstration by numerical simulation

3.3.1. Demonstration of the emergence of Parker's Effect

A numerical simulation can be implemented with the exclusive objective of demonstrating the emergence of Parker's Effect and characterising it. This could be done by simulating the setup illustrated in Fig. 9 below. This has not yet been undertaken and we are seeking collaborators for such a simulation.

CONFERENCE PRE-PRINT

3.3.2. Demonstration of the PSR confinement using Parker's Effect

The scope of the numerical simulation described in subsection 3.3.2 would include the demonstration of the emergence of Parker's Effect and its characterisation. It should be a full kinetic simulation of a cell of the PSR as illustrated in Fig. 2, and would enable the characterisation of:
— The transition to steady-state;
— The emergence of Parker's Effect;
— The susceptibility to instabilities;
— The effectiveness of the confinement with flow velocity;
— The rates of momentum and energy loss of the velocity component in the flow direction;
— The structure of the boundary layer.
This work is planned and we are seeking collaborators to accelerate it.

3.4 Demonstration by laboratory experiment

3.4.1 Demonstration of the emergence of Parker's Effect

We plan to do a laboratory experiment to study the flow of a plasma jet through a current-carrying ring to observe and characterise the emergence of Parker's Effect. A supersonic collimated plasma jet would flow along the axis of a rotationally-symmetric magnetic field, created by a steady electric current in an external conducting ring [9]. We are currently seeking international collaborators for such an experiment as the necessary resources are not readily available in Australia.

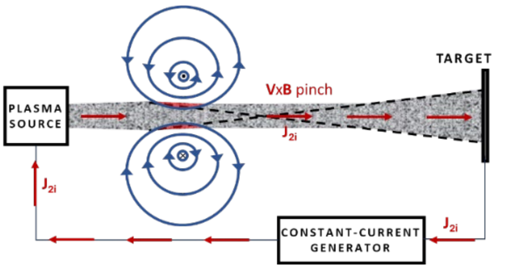

FIG. 9 – Plasma jet flowing in a current carrying-ring to demonstrate the emergence of Parker's Effect

3.4.2 Demonstration of the PSR confinement using Parker's Effect

We plan to extend the previous experiment by lining up a series of current carrying rings in a configuration like that illustrated by Fig. 2, specifically to demonstrate the emergence of Parker's Effect.

4. OUTSTANDING QUESTIONS

While the focus of this paper is the efficacy and efficiency of the confinement of plasma using the PSR concept and Parker's Effect, we understand that there are many questions that need to be investigated to determine whether this concept might be a viable for controlled fusion applications. These questions include:
— The characterisation of the remaining instabilities;
— The characterisation of the bulk flow velocity, plasma density and temperature, and the external requirements to maintain them;
— Initiation and maintenance of plasma flow;
— Centrifugal effects of the rotational flow;
— Plasma heating;
— The handling of runaway electrons, alpha particles and neutrons;
— Behaviour at high energies;
— Triple product of such a device;
— Etc.

Our small, independent research team, which includes the original scientists Owen Storey and Laurent Cairó, has carried out extensive theoretical work on the ideas discussed here, as well as related aspects not covered in this summary. However, the primary objective of this paper is to bring attention to the opportunity for collaboration on a focused experimental effort to demonstrate the validity of Parker's Effect in practice, and to test the Plasma Storage Ring (PSR) concept that seeks to exploit it.

CONFERENCE PRE-PRINT

5. CONCLUSIONS

The work of Storey and Cairó in the 1970s was primarily theoretical. Possibly due to the lack of experimental validation at the time, it has remained largely overlooked—until now. Their research proposed that an open magnetic confinement scheme could offer significant advantages over mainstream concepts. In other words, it may be possible for multipole cusp devices to achieve confinement comparable to, or even better than, that of closed-field devices, while also providing inherent stability against major instabilities, geometric simplicity, and a naturally large aspect ratio.

Assessing these possibilities is not overly difficult, especially since much of the required theoretical groundwork has already been prepared or initiated by our research group. Encouraged by preliminary results, we are continuing this investigation and are seeking collaborators primarily to accelerate the work. Quantitatively, we are at a Technology Readiness Level of 2, transitioning to 3 [10]. If these experiments were to confirm the original findings and claims, they could open new pathways toward the realization of fusion energy—offering reduced complexity and potentially greater efficiency.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of:
— The Pawsey Supercomputing Centre in Perth, Western Australia, for access to the Magnus supercomputer on which some results presented here were produced;
— The National Computational Infrastructure (NCI), in Canberra, Australia, for access to the Gadi supercomputer on which some results presented here were produced.

REFERENCES

[1] Fusion Industry Association, The Global Fusion Industry in 2025: Fusion Companies Survey, Fusion Industry Association, Washington, DC (2025), https://www.fusionindustryassociation.org/wp-content/uploads/2025/07/FIA-Global-Fusion-Industry-Report-2025.pdf
[2] Rainford, T., The Race for Fusion: Understanding the Changing Global Picture (2025), https://fusionenergyinsights.com/blog/post/the-race-for-fusion-understanding-the-changing-global-picture
[3] Reinders, L.J., The Fairy Tale of Nuclear Fusion, Springer, Cham (2021).
[4] Parker, E.N., "Dynamical properties of the magnetosphere", Physics of the Magnetosphere: Based upon the Proceedings of the Conference Held at Boston College June 19–28, 1967, Springer, Dordrecht (1968) 3–64.
[5] Tuck, J.L., "Picket fence", Conference on Thermonuclear Reactions (Proc. Conf. Princeton, 1954), Washington Report No. 184, Washington, DC (1954).
[6] Juno J, Hakim A, TenBarge J, Shi E and Dorland W 2018 Discontinuous Galerkin algorithms for fully kinetic plasmas J. Comput. Phys. 353 110–47
[7] Park J, Lapenta G, Gonzalez-Herrero D and Krall N A 2019 Discovery of an electron gyroradius scale current layer, Front. Astron. Space Sci. 6 74
[8] Storey L R O and Cairó L 1979 Kinetic theory of the boundary layer between a flowing isotropic plasma and a magnetic field, Magnetospheric Boundary Layers 148
[9] Storey L R O and Cairó L 1978 On the boundary layer between a flowing plasma and a magnetic field. I. The conditions for equilibrium, Centre de Recherches en Physique de l'Environnement, Orléans Tech. Note CRPE 63
[10] European Association of Research and Technology Organisations 2014, The TRL scale as a research and innovation policy tool, EARTO recommendations (30 April 2014)