The Serious Need For Data

Introduction:

For many years, this blog has aspired to give accurate information clearly. It has not been perfect. But, it has been fun. Posts have answered key questions, explained obscure references and offered context. The quality is high. Some posts took months to compose. You should read them.

However, we are reaching the limits of mere theory. We need to build it. We need to test it. The Polywell has not failed or worked - yet. We just don't know. We need a body of data - from a big machine. The Navy could save us some hassle by publishing.

The Polywell is a real plasma system. It will face real problems; like energy loss, power balance, instabilities and control issues. No one knows if these problems can kill the polywell. We have to try it.

News:

Events around the polywell continued to move forward, in the last half of 2013. In June, NBC news spoke with Taylor Wilson about his homemade fusion reactor [30]. His fusor is similar to a polywell. NBC's Brian Williams call Taylor: "incredible". This press is exciting. It should help fund fusion research. Also that month, the first polywell doctoral thesis was published [28]. At the core of this work, was data of trapped electrons inside a polywell. The work is strong; but it is limited to small, low power devices.

In October, the University of Sydney published again [29]. The team simulated electrons inside the polywell. The group wanted to know how long electrons would be confined – and where they were. Variables were then changed: the current, ring radius, and starting particle energy. Simulations revealed that the devices' behavior improved as it got bigger [29]. But, simulations are still not data. This work was presented at the 15th annual IEC conference in Kyoto, Japan [33]. In October, a polywell startup: Convergent Scientific Incorporated did its first investor call. They have measured electron trapping, built a fusor/polywell hybrid and have very good numerical simulations running. This post examines some of this work. The company wants to raise a million dollars for non-breakeven devices.

In November, the Polywell was included at the MIT co-lab conference [34]. Thanks to Dennis Peterson for making this happen. The following week, polywell work was presented at the 2013 APS conference in Denver, Colorado [35]. Jeff Kollasch - a new graduate student at Wisconsin - presented Vlasov-Poisson simulations of the polywells. Hopefully - this work will become another science publication. Also in November, a second polywell novel by William Flint: “To fly from folly: saving the polywell” went live on amazon [36]. In December, Dr. George Miley published the first IEC textbook [33]. This is a milestone - the field has its first textbook! Miley has been busy. His autobiography was also published in June [32]. The book documents his life and over five decades of fusion research.

In addition, two organizations have joined polywell/fusor space. The first is the North West Nuclear Consortium. Carl Greninger - a manager at Microsoft; has a created a high school physics class on fusors [37]. A group of 18 students and 4 instructors meet every Friday to do real nuclear fusion at Mr. Greningers’ home [38]. This has generated a lot of press and awards at science fairs. The other is Radiant Matter Research. This pair of Dutch students has the equipment and is on the path to building a polywell. This activity is exciting; but it is no substitute for real hard data.

Executive Summary:

This post examines a new design from Convergent Scientific Incorporated. The case for an open effort is made - by examining the result of a closed effort. CSI was founded in 2010, in Washington State. Presentations in the fall of 2013 offered insight into their work. CSI is simultaneously doing CUDA simulations and running multiple experiments. They have built an octahedron confinement grid: model one. Good magnetic design is discussed including: field uniformity, continuousness, symmetry, low curvature and non-intersections. The strengths and weakness of a “single-turn” cage are also mentioned. The geometry and magnetic field is examined at the corners, center and

cage surface. A device - 14 cm a side with 1,500 amps and a 1,000 Gauss field at the corners – is assumed to be model one. Analysis reveals that the field strength falls as size increases, the field rises linearly with current and the corner field is sensitive to the shape of the bends. Finally, an ideal geometry for a uniform field is mentioned.

A History Lesson:

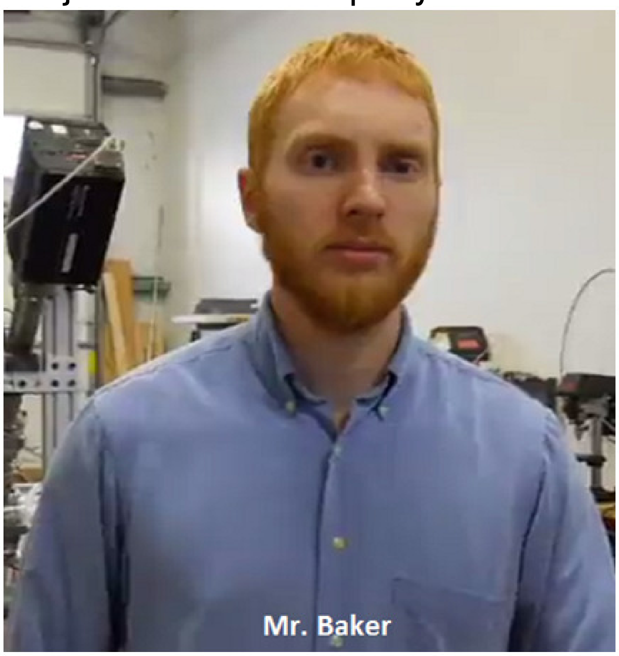
In 1999, a man named Alex Klein got an idea. His idea was to internally reflect ion beams [13]. The reflection was based off of magnetic mirror work from Israel [10]. Beams bounce around inside, collide and fuse. Klein worked on his idea for 10 years – getting a PhD, publishing and pitching it to a venture capitalist [11]. He saw this idea as having great value - so he strove to hide it from the public. After raising 3 million dollars, building a company and his reactor - it failed. The problem [11] was: "…the ions slowed down in the mirrors, wasting time there, leading to high losses…" Unfortunately few people knew about this effort. When the company folded, no one was trying to duplicate Kleins' work. Worst still: some people have purposed to repeat his idea. In fact beam schemes had already been patented in the eighties [18, 19, 20].

A Call for Openness:

Fusion is hard. No one has a solution for it yet. A common mistake people make, is thinking that they have the solution. They often try and hide it, patent it or conceal it. I argue: that this is a mistake. After working for ten years on a solution - only to hit a brick wall – if the work has not been made public, then it has been wasted. It is critical that these efforts are open. Only an open effort can be taken seriously by the public. Openness means explaining ideas, problems and failures. It means admitting if this fails. It also means educating a supporting community. It limits repeating bad ideas and helps create a market. Being open means explaining everything in simple English and correcting mistakes when they are found. Hiding behind an NDA, IP, jargon and obscure references is not being open.

Convergent Scientific:

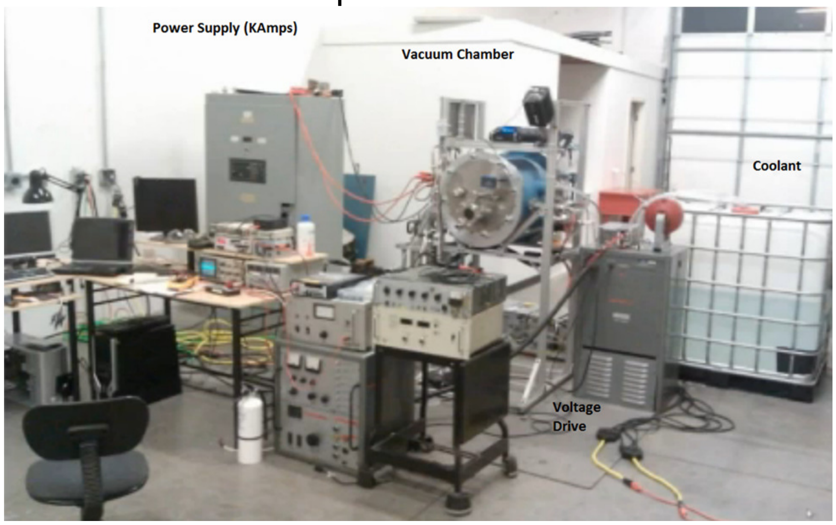
Convergent Scientific was founded in 2010, in Washington State. The company has deep roots in this field. The team formed from the ashes of two polywell companies. Devlin Baker, the chief technology officer, built his first fusor over thirteen years ago [1]. The chief operating officer has been in management positions for over 30 years. They also collaborated with Dr. Joel Rogers. Dr. Rogers has been studying nuclear physics at a national laboratory his entire career [1]. Joel has presented at every single IEC conference since 2008 and was in contact with Dr. Bussard while he was still alive [2, 3, 4]. In 2014, Dr. Rogers left CSI to join another company.

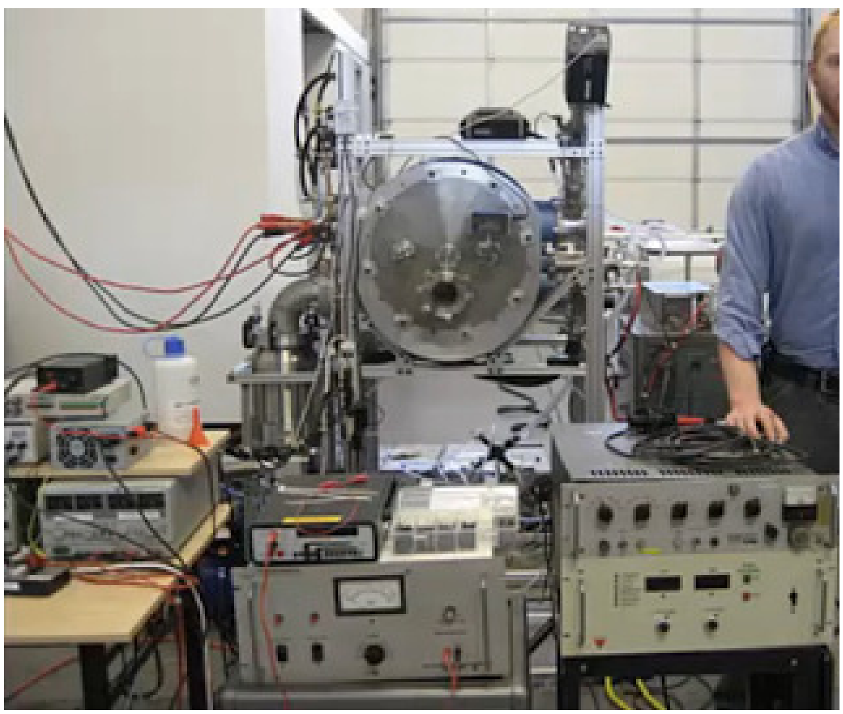


Devlin has done most of the experiments [7]. The tests mainly happened in 2012. Now, the focus has shifted to simulations [6]. Mr. Baker also has two relevant patents on polywell technology [39, 40].

Investor Call:

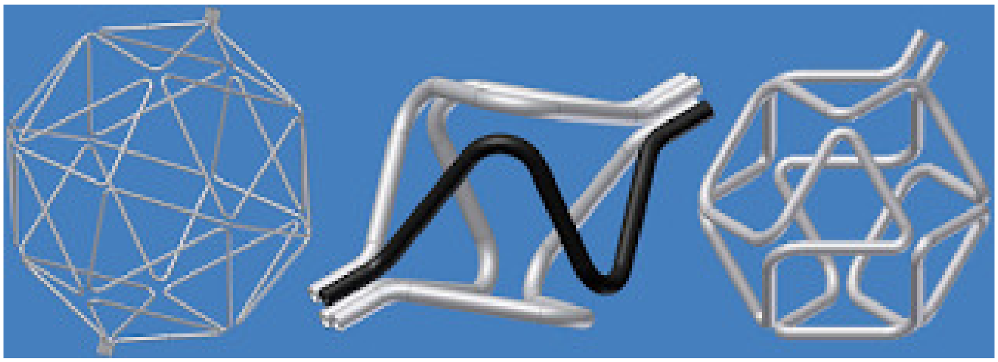
In the fall of 2013, Convergent Scientific did its first investor call. This consisted of web presentations posted online. These are: "The physics of IEC devices", "Numerical simulations of IEC plasmas" and "Commercial applications of IEC devices." These talks are intense. Mr. Baker had to cover a great deal of material in a very short amount of time. I spent a couple days going through the presentations. Overall, it was hard to decode without intimate knowledge of the material. It appears the company is following a two pronged strategy: building machines and simulating polywells. They have assembled a serious lab space.





Field Redesign:

People have long wondered about redesigning the containing magnetic field. They argue that the magnetic mirror effect is independent of direction. The mirror will reflect particles when they move into denser fields [10]. This happens only under certain conditions; but it will happen regardless of if the field points one way, or the other [23]. Redesigning has been a source of much speculation. At last check, over 850 posts online debated different designs [15, 9]. Endolith, an electrical engineer, has argued for the new design of an 8-sided spherical cage [16]. Alternative designs have even been patented - going back to the 1980's [18, 19, 20]. Some examples are shown below.



Keys to "Good" Fields:

In reality, many of these designs will fail. They look good on paper, but in reality will fail to hold in particles. Failure hinges on the structure of magnetic fields inside. We do not understand everything about magnetic containment. However, there are some principles that can be used to gauge good designs:

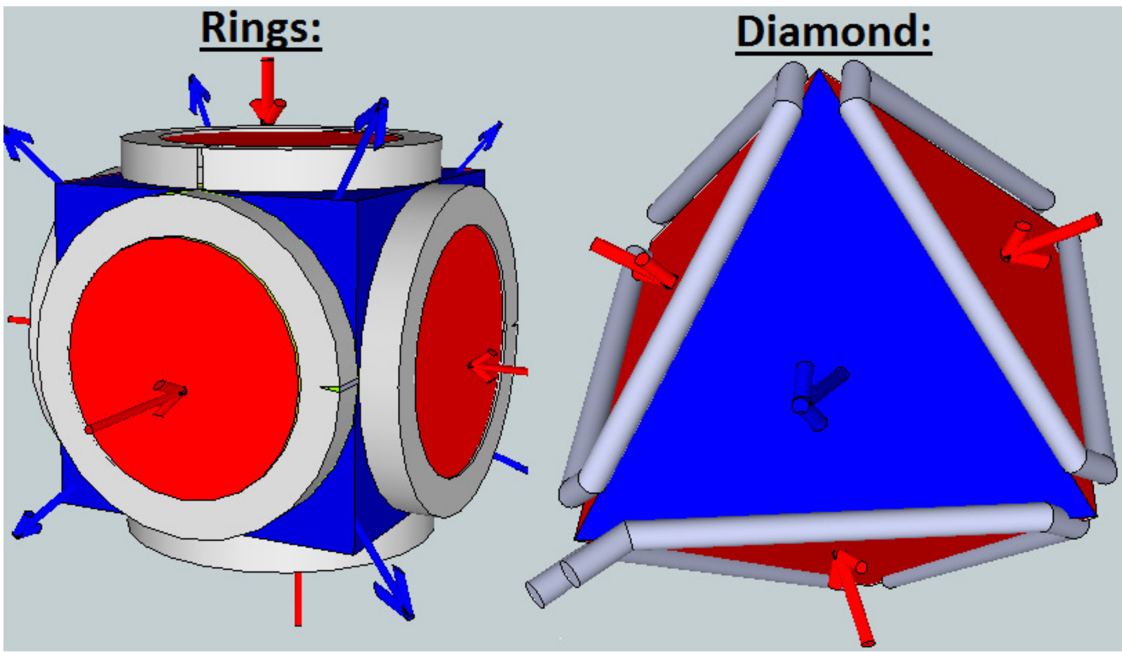
1. **Uniform Strength:** Electrons in the center should see uniform field strength in all directions. This is like water held in a pool. The walls of the pool must be the same height. This was the driving force behind WB6– the ring location forced the corners and the sides to have equal field strength [24].

2. **Continuous Fields**: None of the fields must run into a metal surface. This drives up conduction losses and was the reason for HEPS failure.

3. **Not Intersecting**: Fields which stream particles past one another - lead to counter-streaming, two stream and sheet-sheet instabilities [27].

4. **Low Curvature:** Bent fields, fling plasma outward, leading to conduction losses [26]. This effect worsens with tighter curvature.

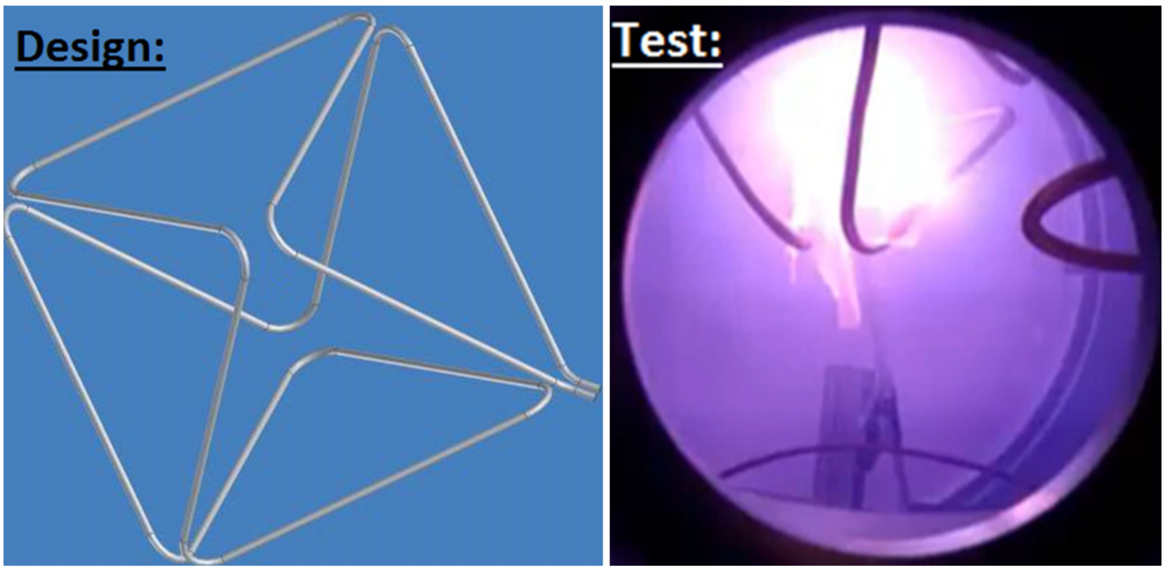
5. **Symmetry:** Symmetry has been true throughout most of magnetic confinements' history. In polywells, this means that the same fields cannot butt up against each other. An inward pointed field cannot be next to another inward pointed field. This is shown best with two simple geometries: six rings in a cube and an eight sided diamond. See below. Notice that no red surfaces meet. Each design can be expanded by adding more rings or loops.



These rules also show up in the tokamak world. Problems arise when they are broken. Variations in tokamak fields lead to flaws in containment [41]. High curvature in tokamaks leads to fuel being lost [20]. Tokamaks must neutralize their particle streams before injecting them into the plasma [42]. Ideally, we want magnetic configurations that follow these rules. Bussard first patented that diamond shape, in 1989 [21, 22]. The document show a prominent figure of an octahedron. CSI has built this. They report that they have run current through it and, trapped electrons within it [17].

Model 1:

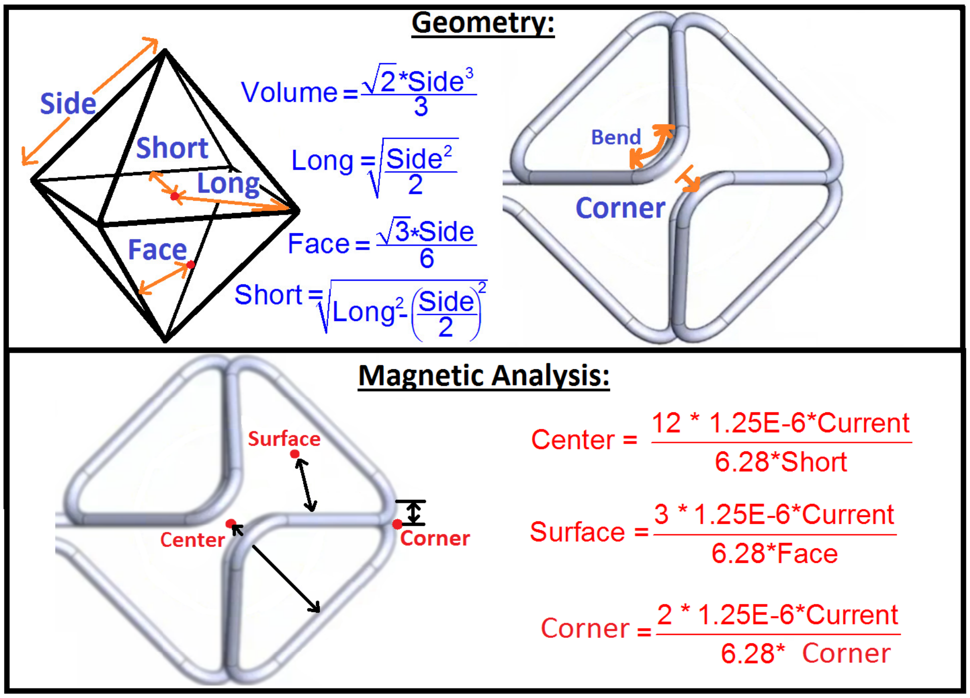
This design is known as model 1. It is very odd looking, when compared with the ring structure. First, it is made only by one wire; it is a “single turn” magnet. The change has trade offs. It hurts the device, because it requires hundreds of times more current to get the same fields. But, it helps the device, because it reduces the amount of extra surfaces (struts, connectors, feed lines) in the center. The wire bends are notable. It is likely - that the most interesting and problematic physics occurs there.



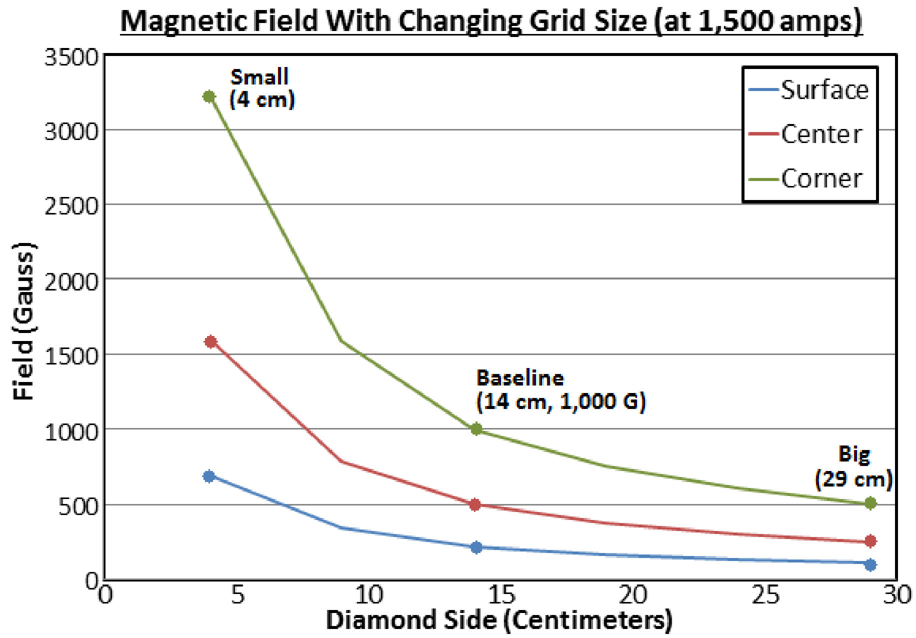
CSI has said that several experiments were done. These included testing several materials for the wire, such as copper, tungsten and Rhodium[6]. They had problems excess heat, so some designs included cooling tubes inside [14]. It is also possible that geometries beyond the octahedron were attempted. In addition, a polywell/fusor hybrid was also tested. The company will not disclose the exact dimensions of model 1. However, from the parameters provided in their presentations [6] and on their website [23], I can discern a range of sizes.

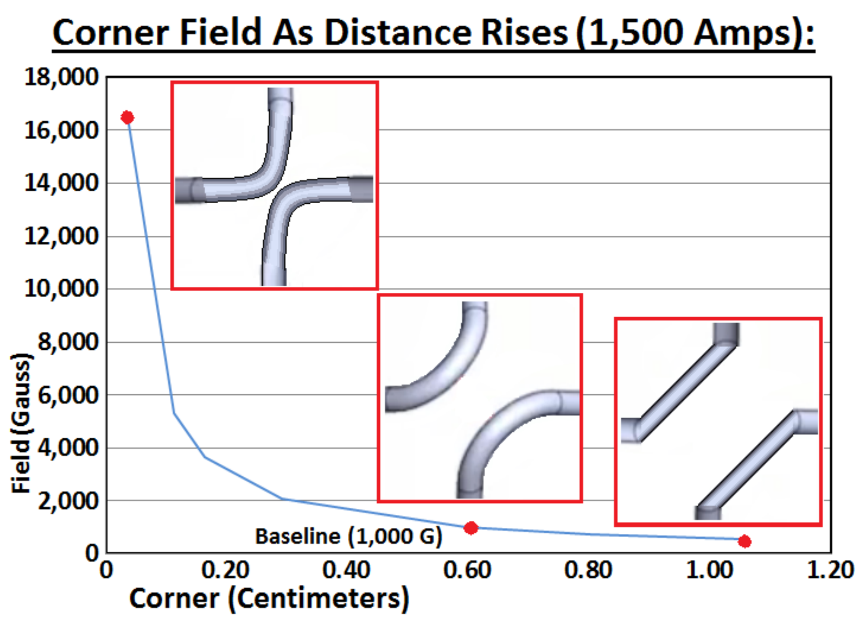
Basic Math:

You can define this geometry with four variables. The first is the length of one side of the diamond. CSI lists the plasma as having a volume of 1.4E-3 cubic meters [23]. If this is the total volume inside the cage; then model one is fourteen centimeters per side. Alternatively, they give an average confinement radius of 16 centimeters [23]. If this is the average distance from cage to device center then model one is twenty-six centimeters per side. The next two variables describe the bend. The first is the length of wire involved in the bend. The second is the smallest gap between two bent wires. It is this gap which drives the magnetic field at the corner. The last parameter is the thickness of the copper wire. With these four variables, we can completely define the geometry.



With the geometry defined, analyzing the magnetic field around the diamond is easy. Analysis is done by applying the Biot-Savart law to different locations [25]. The strongest field occurs at the corners. At the corner, two wires come very close together. This is similar to the joint in normal polywells. CSI gives the strongest field as 1,000 Gauss, at 1,500 amps [22]. Using this, the bend variables can be found. The next location is device center. The field here is generated by twelve wires. The weakest field is located on the surface of the diamond. The field here is created by three wires. A comparison of these three locations is plotted below.

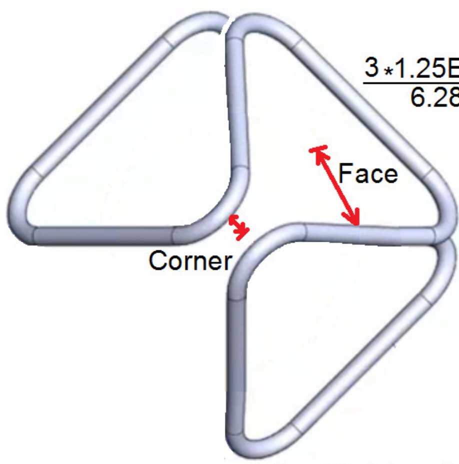




Field Design:

These equations say plenty about how to design the perfect field. A big issue with the diamond grid is that it is a single wire. It may be possible to snake many wires together inside the grid; but if it remains “single turn”, low field strength should be a concern. These equations say much about getting around that problem. First, as the diamond gets bigger, the field strength drops exponentially. Next, the field strength rises linearly with current. Finally, the highest field is at the corners - and here, it is very sensitive to the shape of the bends. The corner field varies wildly. This gives designers a lot of flexibility. Their goal could be to get the surface and corner fields equal. This was the principal used in designing WB6 and may significantly help containment. The optimum geometry for this is when the face distance is 1.5 times the corner distance. This is design is shown below. Finally, by assuming a current direction - we can quickly determine the vector field. This is also shown below.

Ideal Grid Design For Uniform Magnetic Field:



$$\frac{3*1.25E\text{-}6*Current}{6.28*Face} = \frac{2*1.25E\text{-}6*Current}{6.28*Corner}$$

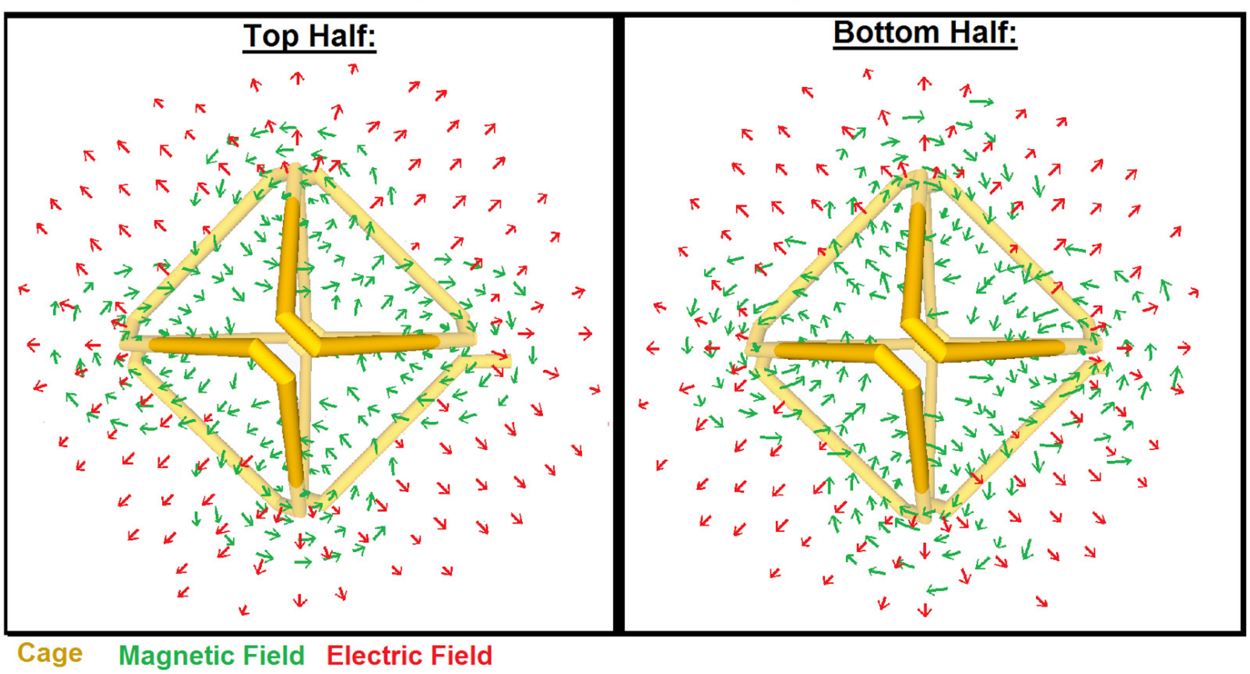
$$\downarrow$$

$$\frac{3}{Face} = \frac{2}{Corner}$$

$$\downarrow$$

$$Face = 1.5*Corner$$

The Fields of Model One:



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