Inertial Electrodynamic Fusion and the Internal Combustion Engine

By Tom Ligon, June 17, 2007

Introduction

The Internet is all abuzz about the fusion experiments of the Energy Matter Conversion Corporation, conducted in the fall of 2005, which Dr. Robert W. Bussard claims demonstrate "proof of concept" of a new way to produce fusion, which he believes will lead to workable power plants.

A few critics of this approach have used various arguments to either claim that the method won't work, or that the experiment itself did not produce meaningful results. This article will attempt to show, by analogies to an earlier and well-known technology, just where I believe Inertial Electrodynamic Fusion (IEF) now stands, and what some of the misunderstandings are that limit the critics appreciation of IEF.

At least some of the technical criticisms of the approach are the result of misunderstandings of how the device works. The IEF approach, while it is a "hot fusion" method, is a vast departure from mainstream "thermonuclear" (Maxwellian heat-based) methods. The closest relative to IEF is Inertial Electrostatic Confinement fusion, typified by the Hirsch-Farnsworth fusor. The physics of IEC and IEF devices are so different from the heat-based approaches that the critics often simply make the mistake of applying the same assumptions and analysis to IEF machines that they would to a tokamak.

Four test runs of a device called WB-6 were run in November of 2005. Each of these produced short but intense bursts of deuterium-deuterium fusion. Each test produced only a few neutron counts. The final test attempt burned out one of the magnets that control electron confinement, ending the experiments. So one of the main questions is, are test results, each well less than a millisecond in duration, and producing only a few counts, truly significant?

The WB-6 experiments were conducted as the last of the available funds were running out. EMC2 was forced to close its doors. At present, a non-profit organization, EMC2 Fusion Development Corporation, is attempting to gather funds to re-start the research.

Very early in my involvement with IEF research, I recognized a parallel with internal combustion engines, and could imagine that the earliest developers of that technology might have faced similar criticism from critics who misunderstood their engines. This little parable uses the internal combustion engine to illustrate where IEF is, and what needs to happen to overcome the objections.

A Fictional Account

The following account is pure fiction, but one can imagine that it could have happened that way.

Dr. Heinrich Klauss greeted his visitors as they entered the dingy industrial building that served as his offices and laboratory.

"Greetings, mein herrs", he said. "Please, this way to the demonstration room. Refreshments await you. Please, make yourselves comfortable."

John Bullock sniffed haughtily. "I certainly hope this is not as great a waste of time as I expect. At the very least, I hope you serve decent tea."

Dr. Klauss bowed politely. "I humbly apologize if the tea is not to your liking, my good sir. But I believe you will find the demonstration interesting. And, I hope, convincing."

The visitors found their tea and pastries on a tray set up near the door, and then found their seats. Dr. Klauss stepped to a lecture bench at the front of the room. "Mein herrs, do you have any questions before we start?"

Dr. Douteur nodded. "Oui, monsieur. Am I to understand that you propose to use liquid fuel in this contraption? That seems absurd. It is a simple fact that liquids do not burn."

Klauss sighed. "Upon what do you base that assertion, Dr. Douteur? I do assume you have used oil lamps, and have an alcohol burner in your own lab."

Dr. Douteur snorted. "But of course. However, in both of those devices, the fuel is conducted via a wick to the point of combustion. The wick holds the fuel in the presence of heat, and the heat vaporizes the fuel, so that it is actually gas that burns. Surely, you will not have a wick in this engine?"

"Why, certainly not a wick," Klauss agreed. "Fuel is fed to the engine as a liquid, but must burn as a gas. I can either vaporize it, or perhaps use a fine mist of fuel which will quickly vaporize by itself. I chose liquid fuels because they are easy to deliver to the engine, simpler to store on a vehicle than gas, and because solid fuels such as coal are difficult to ignite explosively."

John Bullock laughed. "I was wondering if you would admit to that. The entire industrial world knows coal is the ideal fuel. And you propose an engine that cannot burn coal? This absurd contrivance of yours will never compete with the good, reliable, safe steam engine ... steam engines that burn coal, a fuel that will not explode into a great ball of flame."

Klauss shrugged. "No, steam engines explode in a great ball of steam."

Raul Jinete drew a small notepad from his coat. "My good Dr. Klauss, I am mystified how you intend to burn this fuel at all. I have here a set of calculations I have done in which I have calculated the entire range of possible mixtures of your liquid fuel ... I believe you say you use ethyl alcohol ... and air. I have calculated for a mixture of 100 percent air, and no combustion occurs. I have calculated for a mixture of 100 percent fuel, and no combustion occurs. And I have calculated for a mixture of equal parts air and fuel, and no combustion occurs. That, obviously, covers the entire range of possibilities, so clearly it is not possible to operate your engine on a mixture of liquid fuel and air, wouldn't you agree?"

Dr. Klauss reached under the lab bench and pulled out a large graduated cylinder, and a small bottle of alcohol. He poured a small amount of alcohol into the cylinder, placed his hand over the top, and shook the cylinder vigorously. He placed a playing card across the top of the cylinder, wiped his hand on his coat, and fumbled in the drawer for a box of matches. He lit a match, moved the card slightly to one side of the mouth of the cylinder, and applied the flame to the gap. A blue flame propagated from the match into the cylinder. The card shot into the air, and a front of flame propagated down the cylinder with a soft "whoosh."

"Evidently not, Senor Jinete. Perhaps you should have calculated for a mixture between 3.3% and 19% of ethanol in air."

Dr. Douteur raised an eyebrow. "Do you propose to operate your engine by flipping playing cards in the air? I have a teakettle in my kitchen that produces more pressure than that!"

Dr. Klauss shook his head. "No, no, you fail to understand. That demonstration was at ambient pressure. But the engine compresses the fuel and air to a pressure of about ten atmospheres, and then ignites it. The resulting combustion is far more vigorous that what you just witnessed."

Senor Jinete began scribbling furiously in his notebook.

John Bullock simply laughed. "So you will force a cylinder to compress this mixture? My dear sir, don't you realize that this will require work? How can you possibly expect to get work out of this engine if you must put work into it to make it operate?"

Dr. Klauss turned to the blackboard, and drew a pair of Cartesian axes, then drew a figure of two vertical, staggered lines connected by a pair of curves. "Did none of you read my papers? This bottom curve is the compression stroke. Yes, it takes work to compress the mixture. But here," he tapped the chalk on a vertical line, "I apply a spark to the mixture and it ignites, releasing heat, and, by the ideal gas law applied to a fixed volume, the pressure rapidly, almost instantly, increases. The piston then moves down until it reaches the bottom of its stroke, doing work, but at much higher pressure, so more work is produced than consumed. Finally, here, we open a valve to release the spent gases. The area enclosed by this figure represents the useful work performed."

Dr. Douteur tugged thoughtfully at his beard. "It would seem to me that your figure must be incorrect. You seem to believe that the combustion will cause the pressure in the cylinder to rise. What you fail to appreciate, monsieur, is that what will actually rise is temperature, and the temperature of the gas will be much greater than that of the walls of the cylinder, and your piston, and so the heat will flow from the gas into the walls until equilibrium is reached, and so you will wind up with no increase in pressure."

Dr. Klauss closed his eyes and took a deep breath. Releasing it, his face noticeably relaxed a grimace. "Were I so foolish to operate this engine at the pace of French winemaking, then certainly the heat would be lost to the walls. But any reasonable implementation of this technology will operate at many hundreds of cycles per minute, and very little of the heat will be lost to the walls. I have done these calculations, and will happily share them with you should you care to partner with me on the development of this engine."

Dr. Douteur smiled. "Ah, then it runs at the pace of German lovemaking."

Senor Jinete cleared his throat. "Pardon me, but it is abundantly clear from these calculations I have just made that there is absolutely no way such an engine can possibly operate. It is very clear that the temperatures produced will be absolutely hellish. At least a steam engine operates at temperatures easily tolerated by metals.

But what you propose is to set off high pressure explosions, hundreds of times a minute, far too rapidly for the heat to be extracted. This will shortly raise the temperature of the engine to temperatures far too high to be withstood by any known materials."

"But the engine will have a cooling system," Dr. Klauss retorted.

"Ah ha!" John Bullock held his belly as he laughed riotously. "First you say the gas will not lose heat to the walls because you will run it fast, then you admit that it will need to be cooled. And won't cooling it suck away all the energy that you should be using to do work?"

Dr. Klauss threw up his hands in despair. "Ach, such fools. There is nothing incompatible with these things. Yah, the engine will lose some heat to the walls. Yah, any practical engine will need some cooling to protect the materials of the walls. But properly designed and run, the rate of loss of heat to the walls will be minor compared to the utilization of that heat to do useful work."

"I will believe it only if I see it," Dr. Douteur stated bluntly.

"At last, the first reasonable suggestion I have heard all day." Dr. Klauss smiled. "Hans, please bring the engine in."

The faithful assistant opened the door to an adjoining lab, and pushed a heavy cart into the lecture hall. On top of the cart sat a complicated machine, featuring a vertical pipe, on top of which were two levers and a porcelain projection. Various pushrods and wires connected to devices lower down. The pipe was bolted to two heavy brackets rigged with jack screws, which were bolted to the table. Below the pipe was a crank supported on a pair of bearing blocks, with a connecting rod from the crank projecting up into the pipe. The crankshaft had a large flywheel on one end and a hand crank on the other. Hans brought the cart to rest adjacent to the lecture bench.

Dr. Klauss found an eyedropper in the drawer, and filled it partly with some alcohol. "Please notice, mein herrs, that to start this engine, it is not necessary to build a fire and heat water for half an hour. It is necessary only to enable the spark system, make a small quantity of fuel available, and start it moving. Hans, will you kindly turn the crank?"

The assistant carefully took position and placed his hands on the hand crank of the crankshaft. Dr. Klauss stood beside the engine, his eyedropper positioned over a valve on top of the pipe, evidently operated by one of the levers. Klauss nodded, and Hans turned the crank. After several turns, the doctor squeezed the dropper and the engine barked once. Hans staggered as the crank jumped from his hands, and Klauss jumped back.

"Sorry, gentlemen," he said to his clearly alarmed audience. "Even after running it a number of times, it does take one off-guard. Once again, Hans, and I'll try to keep the fuel flow steady this time."

Hans dutifully took position, and turned the crank. This time the engine fired twice.

"Better," Dr. Klauss said as he re-filled the eyedropper. "Again."

Hans cranked the engine again, and again it fired twice.

Dr. Klauss adjusted four jack screws on the cylinder mounts. "I am lowering the cylinder to increase the compression ratio. This should make it run more strongly. Hans, you know, of course, to be ready for more resistance. Ready?"

Hans turned the crank again, and this time they were rewarded by three solid firings.

Dr. Klauss bent over to inspect the crank. He picked up an oil can and applied a few drops of oil to the bearings, then adjusted the compression screws again. "One more time for good measure," he said as he refilled the eyedropper. "Of course, you realize, mein herrs, that any practical engine will have a proper fuel-metering system, perhaps a burette and an air valve."

Hans clearly needed more effort to turn the crank this time. The engine responded with a single loud bang, and a ragged disk of metal the size of a large coin shot out of the bottom of the cylinder and bounced onto the floor. The engine continued to turn for several seconds, evidently with no compression.

Hans gingerly turned the crank, and felt no resistance. "Sorry, doctor, but the piston evidently failed."

Dr. Klauss sighed. "Well, that will be all for today, then. Please understand, this piston is cast from bronze, and it is not the best choice. With proper funding I can find a metal which will better withstand the heat and pressure. Bronze is all we can work with in the present facility."

John Bullock laughed. "Well, I, for one, enjoyed this immensely. Sir, you have, without a doubt, developed the most elaborate, noisy, and impractical means of wasting perfectly good alcohol imaginable. Good day to you, sir. I shall return to my company and tell them that this new engine will never be a threat to our steam engines."

Senor Jinete picked up his notebook. "I, too, shall now take my leave. You have proved only that it will work for a very short time, and then, as I said, it will not take the heat." He followed Bullock to the exit.

Dr. Douteur stood pensively, stroking his beard as he gazed at the machine. "A cooling system, you say? Stronger pistons? Have you considered building a case around the crank and filling it with a lubricant? Hmmm. But no, the piston would be uncooled, and then oil striking it would burn. And I think you will never be able to seal the piston well enough to prevent the hot gasses from escaping. And then there is the noise. This will terrify the horses. I am sorry, Dr. Klauss, but call me back if you ever get it working well, and then I will invest in it. Good day, monsieur."

As the last man left, Dr. Klauss turned to Hans. "Sorry, Hans. We'll have to shut down then. The landlord has given us only until the end of the week."

Hans shook his head. "You'll not be rid of me that easily. I'll go back to work for my old employer at the machine shop. I'll find some spare time and make you some better pistons. You work on that fuel burette idea. You and I both know that this engine is the future of transportation. It will be built, mein herr."

Critics

Critics of IEF have four major points of objection.

1) They expect the device will quickly "thermalize", that is, lose its nature as a particle accelerator and become simply a container full of hot plasma. This is based on the idea that non-fusion collisions in this device will do what they do in a tokamak: create a random distribution of particle energies and directions of movement rather than the orderly motion IEF theory predicts.

2) Because they believe the device will thermalize, they also believe that the resulting energy distribution will cause some ions to acquire more energy than the average, allowing them to escape the "potential well" that confines them. Notice that objection 2 relies on objection 1.

3) The most desirable fuel to burn in an IEF machine is the fusion of a hydrogen nucleus (a proton) with the nucleus of the most common isotope of boron, B11. A criticism has been raised that this fuel is impossible to utilize, with the primary objection being a phenomenon called bremsstrahlung radiation. This phenomenon makes this fuel absolutely hopeless for a tokamak fuel.

4) The objection has been raised that the means of confining electrons in an IEF machine is inherently leaky, and this will pose so great a loss that net power operation will be impossible.

Please realize that nothing a little parable like this will be able to convey will have the scientific rigor to prove or disprove these objections. All I am trying to do is illustrate that there are two sides of the issue, and suggest that the truth requires a correct understanding of the way the device works. If objections are based on incorrect assumptions, the objections will be invalid, just as making assumptions about internal combustion engines based on an understanding of steam engines would likely lead to wrong conclusions.

In my internal combustion energy analogy, the presumption of thermalization might be analogous to the presumption that the machine cannot make power because all of the heat will be lost to the walls. That would be true enough if one simply put hot gas in a cylinder and waited long enough. Someone with a steam engine background might, in fact, be preoccupied with the problem of loss of heat from their boiler. But an internal combustion engine is a dynamic machine, the parts in constant motion, and the combustion occurring in short pulses. Some heat is lost to the walls, but the motion is so fast that the engine still works. Likewise, the term Electrodynamic in IEF emphasizes the fact that everything in these machines is dynamic. While there is some tendency of these machines to thermalize, the opportunity to do so is brief, and not much occurs on any given pass through the machine. And Dr. Bussard describes a self-correcting mechanism of the machine, which he calls "annealing", which tends to remove any thermal scatter on every pass of the ions.

It is important to know that the process Dr. Bussard describes will only work over a fairly narrow range of density. If the density is raised too far, the number of collisions occurring in the wrong places in the machine will, indeed, cause it to thermalize, but if the density is too low, the reaction rate suffers. Here, the internal combustion engine analogy is very strong, as an internal combustion engine must control the fuel/air mixture fairly precisely. This might have seemed a difficult problem to overcome in the early days, but they invented the carburetor, and later electronic fuel injection. The same will be true of any workable version of IEF.

If this mechanism does, indeed, work as described, it will automatically remove objection 2. If there is no thermalization, there is no upscatter.

Objection 3, bremsstrahlung radiation, is a very complex subject. The essence is that high-velocity electrons, at high density, especially in the presence of ions that have a lot of electrical charge on their nuclei, will cause the electrons to lose energy in the form of x-rays. This objection is not a serious problem for deuterium and deuterium-tritium fuel systems, even according to the critics. The objection does apply to p-B11, which requires much more severe conditions to cause fusion.

Here, we might even extend the analogy to the diesel engine. Diesel fuel is terribly prone to being ignited by the heat of compression, and will cause premature detonation if burned in a spark ignition engine. Alcohol is very resistant to this phenomenon, and gasoline is relatively resistant to it. In fact, diesel engines don't even have spark plugs, they control ignition by injecting the fuel once the compression stroke is completed. Overall, the Otto and Diesel cycles are very similar, but the more "exotic" fuel requires special measures to achieve proper operation. But diesels are desirable because they can operate at higher pressure, and so more efficiently, than the spark ignition fuels, and the fuel, at least in the early days, was cheaper.

The first way in which the bremsstrahlung problem is mitigated is a natural process of the machine itself. The electrons that form the potential well are at very high energy at the outer boundaries of the machine, but their density is lower there. In the center, where their density is high, they have given up most of their kinetic energy in the process of creating the potential well that drives the fusion reaction. Still, the ions are at their most energetic in the center of the machine, so the objection has been raised that they will "heat" the electrons and make them produce bremsstrahlung. The machine has its own mechanism for correcting this, a process similar to the edge-annealing process, based again on the Electrodynamic nature of the machine. The electrons never spend very long in the center of the machine, so they limit the amount of energy they can pick up there, and they tend to lose that energy back to the ions at the outer edge where that annealing is going on. In addition, the "virtual anode height" in the center of the machine is a function of ion density there, and it can be manipulated to reduce the problem (this might be seen as analogous to changing compression ratio of a spark ignition engine to control detonation). Finally, control of the relative abundance of hydrogen and boron can be used to mitigate the problem. Using all three together, Dr. Bussard predicts that bremsstrahlung can be reduced to easily manageable levels.

That leaves the electron leakage problems from the cusps. That phenomenon was, in fact, a valid objection for one form of these machines, which has been abandoned. The newer form (utilizing a "MAgrid" accelerating anode for the electrons) is essentially immune to the problem, as it simply recirculates any electrons that leak out. Here, the internal combustion engine analogy is a bit strained, but the closest approximation might be the invention of piston rings.

Finally, WB-6 admittedly did not run very long. But it did, in fact, run. Would it be correct to abandon it because it because it burned out a coil after a few brief fusion operations? Had the early internal combustion engine developers felt this way, we might all still be walking. WB-6 clearly proved this idea can pop a few times. So the question now is, can we build it bigger, and stronger, and get it firing on all eight cylinders?

I say it is easily worth a try. If you agree, visit EMC2 Fusion, and make a donation.

For More Information

You can learn more here:

Easy Low Cost No Radiation Fusion

You can find the details on the design of an open source fusion test reactor here:

IEC Fusion Technology blog

And here:

IEC Fusion Newsgroup

The US Navy has funded the next phase of Polywell research that is now ongoing and has so far achieved positive results. You can read about the initial results at:

WB-7 First Plasma

This is no reason to let up. The Navy plans a five year program to construct a 100 MW test reactor. With more money they could speed up development. With enough cash a three year time line ought not be difficult. Two years is an outside possibility if we really pour it on.

Help Lobby

Keep the pressure on your Congress critters. We need to push this as hard as possible if the experimental results are positive.

You can contact them by e-mail, fax, letter, or phone. Phone is best for the initial contact because it insures a human response. Tell them if they get with the program we can have a working fusion reactor in as little as three years. To do that they are going to have to Manhattanize the project. A full up scientific and industrial effort.

Here is contact info for the government:

House of Representatives

The Senate

The President

Light up their tails!