HIDRA: HYBRID ILLINOIS DEVICE FOR RESEARCH AND APPLICATIONS

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The Hybrid Illinois Device for Research and Applications (HIDRA) is a medium sized classical stellarator using a l = 2, m = 5 configuration with a major radius R = 0.72 m and minor radius a = 0.19 m. HIDRA will initially be operated with 26 kW of magnetron heating (2.45 GHz) and will operate with a magnetic fields $B_0 = 0.087$ *T to 0.5 T. Electron temperatures up to* $T_e = 20$ *eV and densities up to* $n_e = 1\times10^{18}\ m^{-3}$ *are expected with Bernstein wave heating (OXB). HIDRA has a flexible magnetic configuration due to the addition of vertical field coils. HIDRA will be used mainly in the development of new dedicated plasma material interaction experiments in a fusion type environment. Development of multi-scale and multi phase materials adaptive to extreme environment will be a focus of HIDRA and UIUC's expertise with in-situ diagnostics of materials will open up new opportunities for innovative material testing. HIDRA will also serve as an education and training the next generation of plasma and fusion scientists and engineers. Basic plasma physics with an emphasis on plasma material interactions will be a focus of HIDRA using established diagnostic techniques as well as the development of new diagnostics for understanding the basic plasma physics and plasma material interactions.*

I. MOTIVATION

One of the major outstanding issues in fusion is the plasma material interaction at the wall of the inner vacuum vessel and the divertor. Currently there are no materials that are satisfactory for use in fusion and this is a growing area of research in fusion.[1] Solving the issue of materials is crucial to having a viable fusion device operating. The plasma material interaction (PMI) affects not only the life time of the internal components, such as the wall and divertor, but also directly affects the performance of the plasma and the confinement and energy production. Materials have a significant impact on the performance of modern fusion devices. Solid materials such as tungsten are used as well as liquid metals, in particular lithium.[2]

With these PMI aspects in mind, this year the Center for Plasma Material Interactions (CPMI) have obtained from the Max-Planck Institute for Plasma Physics (MPIPP) in Greifswald, Germany a *medium-sized classical stellarator/tokamak hybrid.* This device (formerly WEGA in Greifswald[3]) was obtained to further the plasma and fusion research being performed at CPMI. Not only can this device be operated as a stellarator with long pulse and continuous operation but also it can operate as a tokamak exploring the shorter transient effects that materials and PFCs will need to tolerate. The Hybrid Illinois Device for Research and Applications (HIDRA), shown in figure 1, represents a quantum leap in the research capabilities of CPMI, not just in fusion but also generally in PMI research.

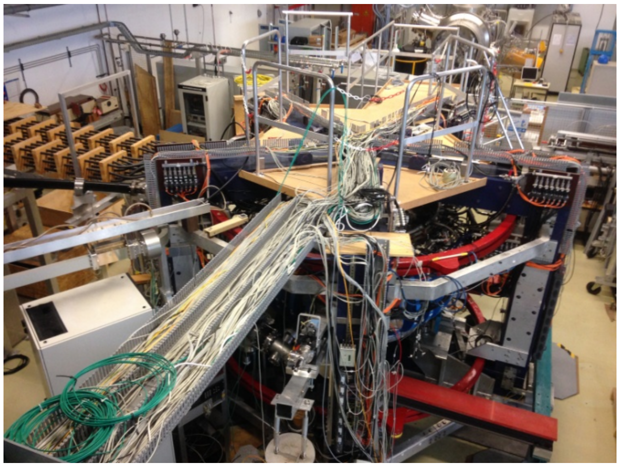

Fig. 1. Photo of HIDRA as it was still WEGA just before disassembly and shipping from Germany to Illinois.

II. HIDRA

HIDRA is as a 5 period, $l = 2$, $m = 5$ classical stellarator. It has a major radius $R = 0.72$ m and a minor radius $a = 0.19$ m. There are 40 toroidal field coils and 4 helical coils that wrap around on the outside of the vessel. There are also two vertical field coils that help shape the plasma.

The design of HIDRA allows the vacuum vessel to easily be opened into two section (half – tori) allowing for easy installation of components and a quick turnaround to be ready for operation.

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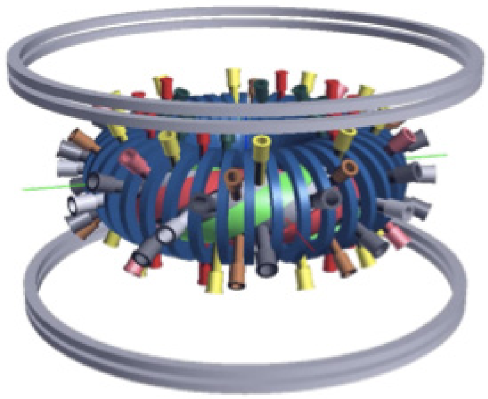

Fig. 2. Stripped down CAD drawing showing the magnetic coils, courtesy of IPP.

The machine is designed to operate up to B = 1 T however as WEGA, B = 0.087 - 0.5 T were more typical. Figure 2 shows a stripped down CAD drawing of HIDRA (as it was WEGA) showing the magnetic coils.

There is an iron core that runs through the center of HIDRA. This solid core that has two solenoids that allows HIDRA to operate as a tokamak, thus giving it the ability to operate as a hybrid device.

Heating of the plasma is performed using two magnetrons of 6 kW and 20 kW giving a total 26 kW of 2.45 GHz heating. When operating as WEGA typical temperatures T_e = 20 eV and n_e = 1×10^{18} m^{-3} were obtained with Bernstein wave heating (OXB). The power supply to the coils is done via a two 20 kV transformers, one supplying the toroidal coils and the other the helical coils, these run into rectifiers that allow steady state operation.

Diagnostics for initial operation include a Langmuir probe mounted on a fast reciprocating probe. The probe can traverse to the center of the plasma and back in 200 ms. This will allow T_e and n_e profiles of the plasma to be obtained. Langmuir probes at the minor radius will measure the edge plasma parameters and help determine the flux to the surface. Four visible cameras will help monitor the plasma.

Typical operation times are from tens of seconds to tens of minutes. Figure 3 shows an example magnetic flux surface for a B = 0.5 T magnetic field. Table I shows a summary of the basic parameters of HIDRA.

III. EXAMPLES OF PFC SOLUTIONS TO BE TESTED

HIDRA will be the test bed for many PMI and PFC concepts being developed and has essentially four set missions. First is to test self driven flows under high heat flux and transient conditions. Second to test a liquid lithium loop system and to determine whether, in fact, liquid lithium will provide low recycling and weather deuterium can be removed and recycled. The third mission is to test how a low recycling wall affects the transport and confinement properties in a long pulsed, three dimensional plasma. Last is to use it as a test-stand for new material development, edge diagnostics and development of materials analysis test-stand (HIDRA-MAT). It is intended that these missions will be developed and tested in HIDRA

As an example recent developments in PFC design with the Liquid Lithium/Metal Infused Trenches (LiMIT), Ref. 4 has shown a potentially viable solution for the divertor. LiMIT uses thermo - electric magneto - hydrodynamic's (TEMHD) to self drive liquid lithium. Initial test in HT-7 and MAGNUM-PSI (Ref. 5) have shown that LiMIT will work when in a horizontal position. Though these initial test showed the concept sound there still needs to be further development in a toroidal environment. HIDRA provides the opportunity to test the limits of LiMIT before installation on other machines. Also, it will be critical in the future that LiMIT be able to operate horizontally and at an angle for the first wall, divertor and limiters. LiMIT has been tested in a laboratory set up at CPMI where an electron beam provided the heat flux, and though also tested at

MAGNUM PSI and HT-7 it still needs to be further studied under toroidal conditions with a variable magnetic field and conditions to properly test the concept. HIDRA can provide this capability to trouble shoot and perfect LiMIT and other PFC concepts before installation on other larger machines.

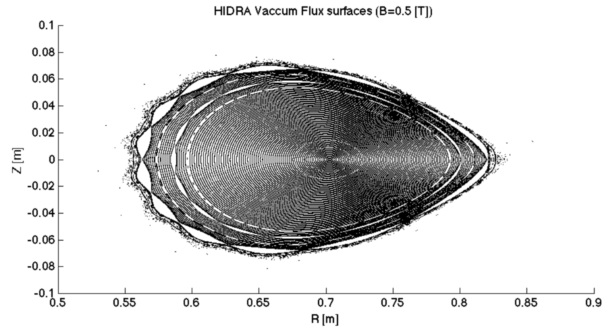

Fig. 3. Typical vacuum flux surface calculated for HIDRA for a B = 0.5 T field.

TABLE I. Summary of HIDRAs Parameters

Major Radius	0.72 m
Minor Radius	0.19 m
Aspect Ratio	3.8
Field Periods	5
Field Strength	0.5 T
Pulse Length	< 60 min
Initial Heating	26 kW

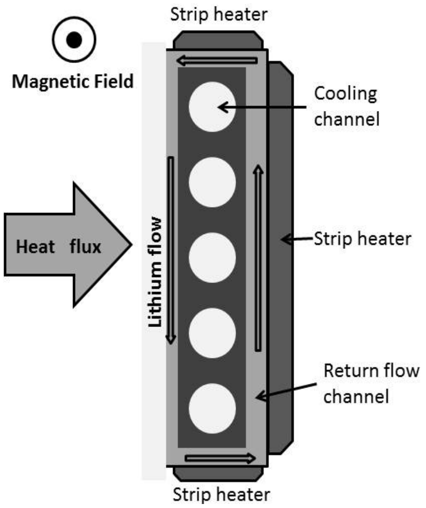

Fig. 4. Schematic of the vertical LiMIT concept.[6]

Recently a LiMIT device has been developed to test operation at different angles and vertically.[6] A schematic of the vertical LiMIT is shown in figure 4. However HIDRA would be needed to fully develop a circulating loop to supply lithium to LiMIT which is a critical piece of technology that has yet to be fully developed. LiMIT is an example of the first and second missions where a liquid metal PFC can be tested and at the same time it can be integrated with a liquid metal loop to test deuterium retention and recycling.

Another PMI issue that is having a large impact is tungsten Fuzz. CPMI has been able to recreate fuzz using a helicon plasma source on tungsten wire.[7] However, understanding the mechanisms behind the fuzz formation under fusion relevant conditions, which is in a toroidal magnetic environment, is crucial and HIDRA along with a proposed materials test stand, HIDRA-MAT (Refs. 8-10) which is based on the MAPP diagnostic, can go a long way to answering these questions. Under the right plasma conditions, HIDRA can achieve ion fluxes at the wall of $\Gamma_i = 10^{21} - 10^{22}$ m^{-2}s^{-1}. This is enough to start probing the mechanisms for fuzz formation. These are comparable to the ion fluxes seen by other machines such as LTX, (Ref. 11) C-Mod, (Ref. 12) TEXTOR, (Ref. 13) and TORE SUPRA, (Ref. 14) shown in table II.

TABLE II. Comparison of HIDRA with Some Other Machines

	T_e (eV)	n_e, (m^{-3})	Γ_i, (m^{-2}s^{-1})
HIDRA	25	1×10^{18}	$< 1\times10^{22}$
LTX	200	1×10^{19}	N/A
C-MOD	5000	1×10^{21}	$< 5\times10^{23}$
TEXTOR	1000	2×10^{19}	5×10^{22}
Tore Supra	2000	5×10^{19}	1×10^{22}

The ability to test concepts such as LiMIT and tungsten fuzz without needing to rely on other devices will be advantageous to developing and testing quickly PFC concepts before they are then applied to larger machines like NSTX-U or EAST.

HIDRA will also play an important role in helping to validate computational modelling of edge plasmas and plasma surface interaction (PSI). Development of near wall kinetic models that will interface with edge and material codes will help test the extreme conditions of plasma material interactions. It will be used to reconcile 2D/3D models, such as coupling kinetic solvers with fluid solvers. Along with the computational resources at UIUC such as the petascale computing facility, HIDRA will help benchmark near wall, material and plasma edge codes.

IV. CURRENT STATUS AND ASSEMBLY

Currently HIDRA is being assembled at CPMI at the University of Illinois Urbana-Champaign campus. The transformers and rectifiers are in place the vacuum vessel, center stack and magnetic systems are in place.

The next step will be the designing and installation of external componets and systems for the machine. The cooling system for the mag nets is being designed and will be installed in the summer of 2015. and The power systems to run the magnets is currently under construction and will have 2.2 MW of power brought in to run HIDRA. First plasma in HIDRA is expected to be in the middle of September 2015.

V. CONCLUSIONS

HIDRA is the first fusion machine solely dedicated to the study of the PMI and PFC issue and is currently being assembled at CPMI at the University of Illinois in Urbana Champaign. It represents a quantum leap in the capabilities that CPMI has in developing the next generation of plasma facing components that will be used in future machines and will also help to answer some key questions in fusion regarding to the technological challenges and aspects of low recycling lithium PFCs.

By being a hybrid design it allows PMI and PFCs to be studies under not only long pulse/steady state but also transient plasma conditions. Current PFC designs, such as LiMIT, will be studied and tested in HIDRA before deployment in larger machines.

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