ELECTROMAGNETIC LIQUID METAL WALL PHENOMENA

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APEX-6 MEETING

PPPL PRINCETON PLASMA PHYSICS LABORATORY

LIQUID WALLS

A sufficiently thick, flowing, liquid first wall and tritium breeding blanket which almost completely surrounds a fusioning tokamak DT plasma could provide superior features in a commercial MFE powerplant.

•Much of the costly complexity of conventional solid first wall designs would be eliminated.

•It would eliminate first wall damage from neutrons, from high heat flux, and from disruptions.

•Power density would not be limited by damage issues, so higher power density may be possible.

•It would eliminate solid surface tritium inventories which are not accessible.

•If sufficiently thick (> 1 m lithium), it would eliminate the need to develop exotic structural materials more resistant to neutron damage.

•If sufficiently thick (> 1 m lithium), it would reduce the activation and waste disposal requirements for structural materials.

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LIQUID WALLS

A nonconducting or poorly conducting liquid material containing lithium such as the molten salt, FLiBe, could provide a liquid first wall&breeding blanket with minimal MHD interactions. Centrifugal force would need to be used to keep it out of the plasma. However, use of molten lithium could also bring other benefits:

•Lithium is a ZERO activation material, and is not especially toxic.

•Lithium is low-Z (after hydrogen and helium) and so could be expected to have small impact on plasma radiation losses.

•Experience and some theory suggest lithium impurities may improve plasma performance.

•Lithium walls could reduce vacuum pumping problems.

•Use of a single element may simplify chemical processing of the blanket.

•Lithium could also be used for direct LMMHD production of electricity, using the TF magnets as the LMMHD power production magnets, further reducing capital costs for a fusion power plant.

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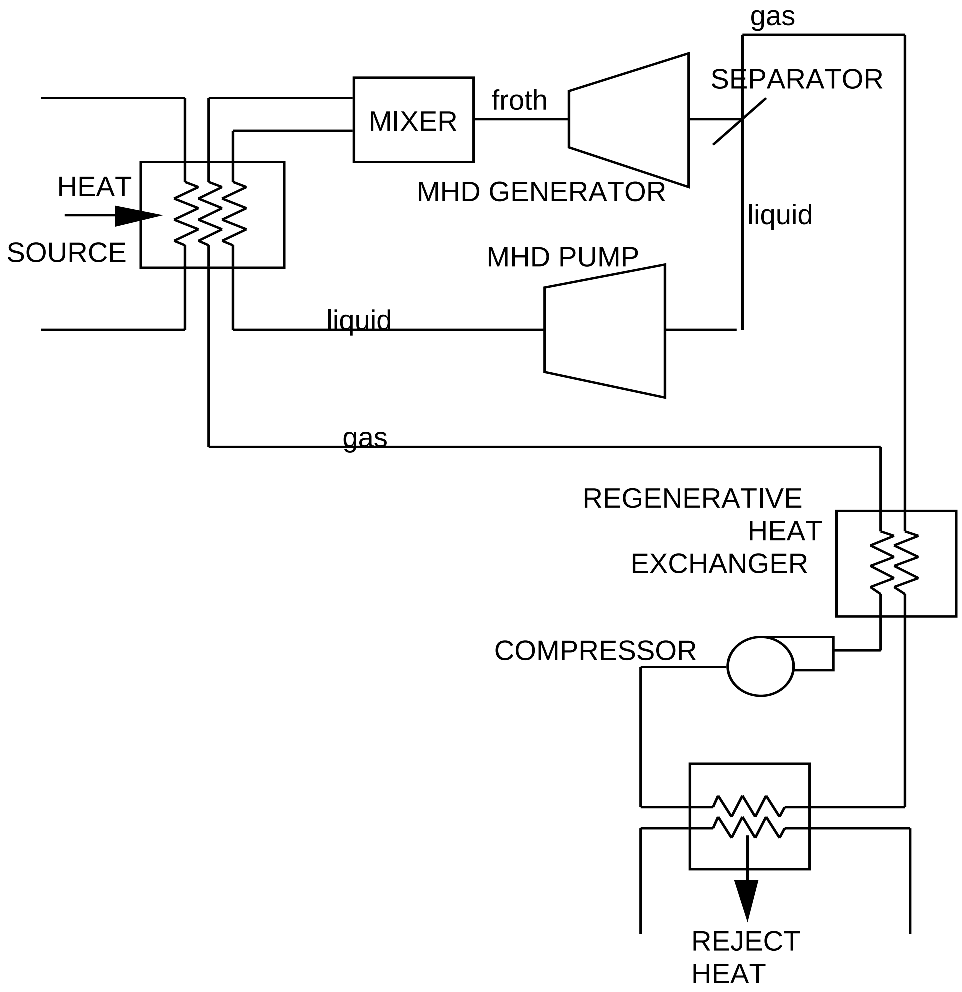
BASIC LMMHD CONVERSION CYCLE DIAGRAM

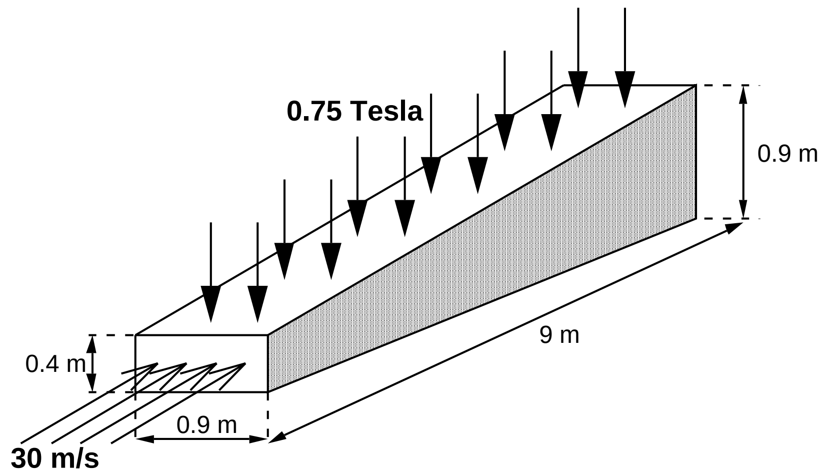
USING REGENERATIVE HEAT EXCHANGER



LMMHD POWER GENERATION

ANL's 1972 REPORT* FOR US NAVAL RESEARCH PROPOSED THESE LITHIUM/HELIUM DESIGN PARAMETERS:

INPUT TEMPERATURE	871°C
REJECT TEMPERATURE	16°C
THERMAL HEAT INPUT	72 MW ()
ELECTRICAL POWER OUTPUT	30 MW (EL)
ELECTRICAL VOLTAGE OUTPUT	20 VDC
ELECTRICAL CURRENT OUTPUT	1.5 MA
LITHIUM MASS FLOW RATE	2217.6 KG/S
HELIUM MASS FLOW RATE	31.7 KG/SEC
FLOW VELOCITY	30 M/S
MHD GEN. MAGNETIC FIELD	0.75 TESLA
MHD GEN. PRESSURE IN	75 ATM.
MHD GEN. PRESSURE OUT	25 ATM.
MHD GEN VOID FRACTION IN	64 %
MHD GEN VOID FRACTION OUT	84 %



ANL's PROPOSED 30 MEGAWATT ELECTRIC LMMHD GENERATOR DUCT PARAMETERS

(APPROXIMATE)

*by W.Amend et al, M.

Petrick Project Scientist

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ELECTROMAGNETIC INTERACTIONS(1)

However, use of a thick liquid metal wall with a tokamak introduces electromagnetic LMMHD interactions.

•LOW PRESSURE DROP

(The good news) is that LMMHD pressure drop losses are entirely missing from axisymmetric flows parallel to the symmetry axis of a purely toroidal field, with no electrical connection between inner and outer duct walls. Such axisymmetric ducts do not need insulation coatings.

•NEED TO FOLLOW POLOIDAL FLUX

If liquid metal flow in a poloidal plane cuts across poloidal flux lines, the resulting V X B electric field will produce a toroidal current locally in the liquid metal, which in turn will modify the poloidal field needed for plasma equilibrium. It therefore seems necessary to design the LM flow path following poloidal flux lines near the plasma's last closed flux surface.

If liquid metal flow follows paths near poloidal flux lines in a poloidal plane, it will typically not be moving in a purely vertical direction, but will have a radial velocity component.

ELECTROMAGNETIC INTERACTIONS(2)

•DIAMAGNETIC DRAG

The radial component of LM velocity through the toroidal field will introduce a diamagnetic drag force opposing that radial motion.

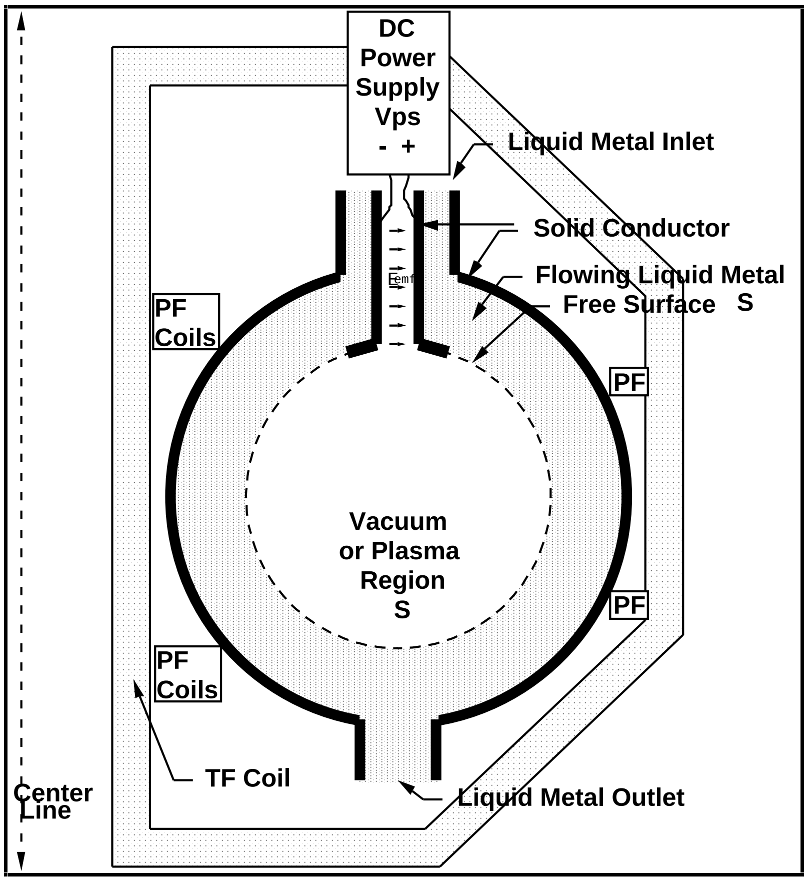
For outward radial motions the toroidal magnetic flux trapped in a liquid metal's constant volume shrinking cross section is compressed and stretched. At the same time, the 1/R toroidal magnetic flux density outside the liquid metal is lower at the larger major radius. This imbalance produces the diamagnetic drag opposing LM motion. The same process also opposes inwards motions.

The strength of the diamagnetic drag effect depends on how rapidly the flux imbalance diffuses away. The parameter, $\lambda = 1/\mu_0\sigma$ = 0.36 s m^{-2}, predicts magnetic diffusion through 1.7 meters of lithium in one second.

The strength of the drag varies strongly with the vertical extent of the liquid metal and with its shape. (It seems to be inherently two-dimensional.) Some simple approximate formulas have been derived for very thin layers, but have not been confirmed.

ELECTROMAGNETIC INTERACTIONS(3)

•INJECTED POLOIDAL CURRENT **In order to oppose the diamagnetic drag force, poloidal current is injected into the flowing liquid metal.**



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ELECTROMAGNETIC INTERACTIONS(4)

INJECTED POLOIDAL CURRENT.

The injected poloidal current needs to closely follow the poloidal field direction in order to avoid a toroidal swirl motion in the liquid metal.

MAGNETIC PROPULSION OF LM (IDENTIFIED BY L. ZAKHAROV)

Nonuniformity of J X B produced by the injected poloidal current and toroidal field produces a pressure gradient along the solid wall located behind the liquid. This pressure gradient will tend to move the LM towards increasing major radius. With thin layers, use of high currents may result in high speed free surface flows. With thicker layers and less intense currens, it may still be significant phenomenon.

FREE SURFACE SHAPE

The shape of the free surface will not necessarily be of uniform layer thickness. The free surface shape results from interplay of flow parameters in a way not yet known. It is expected sensitive to injected current strength, injected fluid speed, and shape of backing surface.

COMPUTER SIMULATION STATUS

Not yet working. But very close.

Coded in DEC-extended Fortran, residing on PPPL's VAX cluster.

Unstructured grid code is completely tested, including a solution adaptive grid point migration algorithm.

"Galerkin" gradient tested; this permits "mixed finite element method" with piecewise linear elements to be used for any order evolution PDE via explicit integration.

Now testing PPE; minor glitches with non-Dirichlet BCs.

Some PPL physicists have volunteered to help with evaluation testing (after it produces some intelligible output).

AXISYMMETRIC LM EXPERIMENT

Symbol	Name	Expanation	Formula
Fr	Froude Number	$\sqrt{\frac{\text{Inertial Force Density}}{\text{Gravitational Force Density}}}$	$\frac{U}{\sqrt{gL}}$
EmGd *(new)*	EmGd Number	$\left[\frac{\text{Driven EM Force Density}}{\text{Gravitational Force Density}}\right]$	$\frac{B_0(\Delta B_{LM})}{\rho g \mu_0 L}$
EmGp *(new)*	EmGp Number	$\left[\frac{\text{Passive EM Force Density}}{\text{Gravitational Force Density}}\right]$	$\frac{\sigma}{\rho g} B_0^2 U$
Rm	Magnetic Reynolds Number	$\left[\frac{\text{Induced Magnetic Field}}{\text{Applied Magnetic Field}}\right]$	$\mu_0 \sigma v L$
Ha	Hartmann Number	$\sqrt{\frac{\text{Passive EM Force Density}}{\text{Viscous Force Density}}}$	$B_0 L \sqrt{\frac{\sigma}{\rho\nu}}$
We	Weber Number	$\left[\frac{\text{Inertial Force Density}}{\text{Surface Tension Force Density}}\right]$	$\frac{\rho}{\gamma} U^2 L$
Re $=Ha^2Fr^2/Wp$	Reynolds Number	$\left[\frac{\text{Inertial Force Density}}{\text{Viscous Force Density}}\right]$	$\frac{UL}{\nu}$
S (aka N) $=Wp/Fr^2$	Stuart Number akaInteractionParameter	$\left[\frac{\text{Passive EM Force Density}}{\text{Inertial Force Density}}\right]$	$\frac{\sigma}{\rho} \frac{B_0^2 L}{U}$

A small collaborative tabletop experiment would be useful. Experiment should have a toroidal field magnet system, an axisymmetric chamber, a liquid metal, and flow diagnostics.

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