Application of magnetohydrodynamic pumps in the fuel loop of Dual Fluid Reactor

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New reactor concepts and safety analyses for the Polish Nuclear Energy Program
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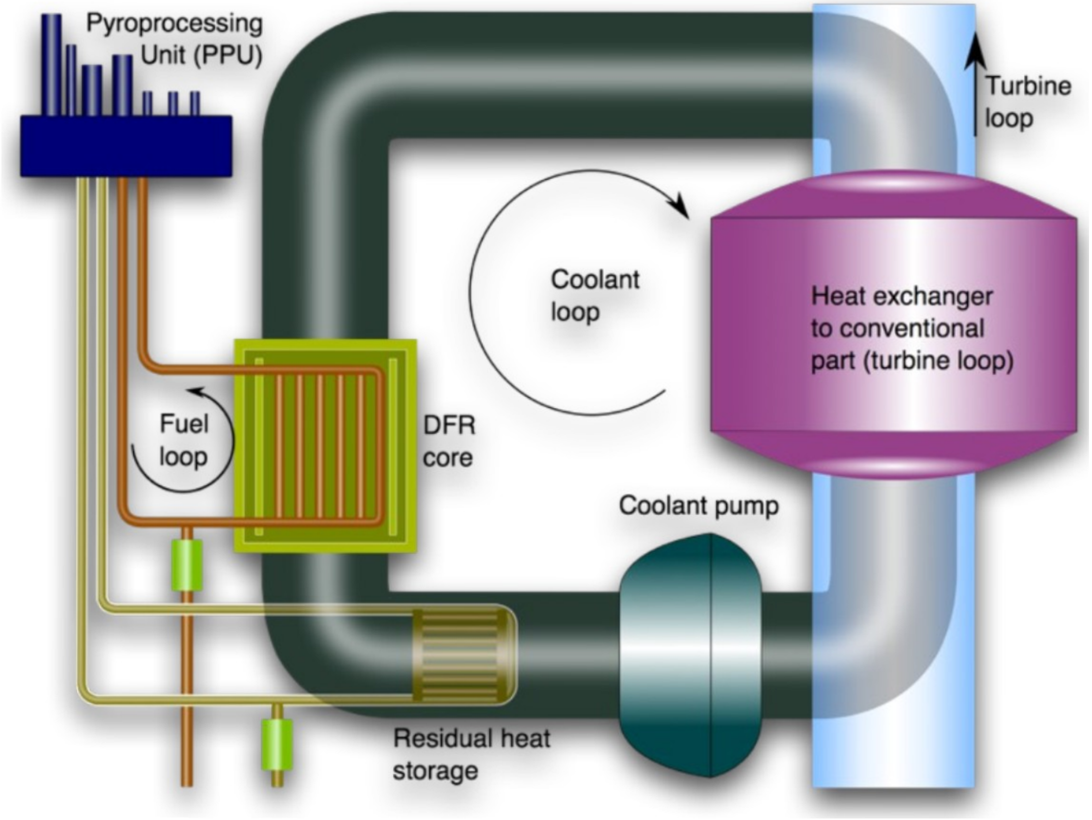
Agenda

- **Introduction (DFR, mini-demonstrator)**
- **Magnetohydrodynamic (MHD)**
- **Electromagnetic (MHD) pumps**
  - Conduction pumps
  - Induction pumps
  - Thermoelectric pumps
- **Uranium-Chromium eutectic**
- **Summary**

Dual Fluid Reactor

- The design of the DFR combines the molten salt reactor concept with that of a liquid-metal cooled reactor
- The fuel is a liquid metal or molten salt
- The coolant is lead



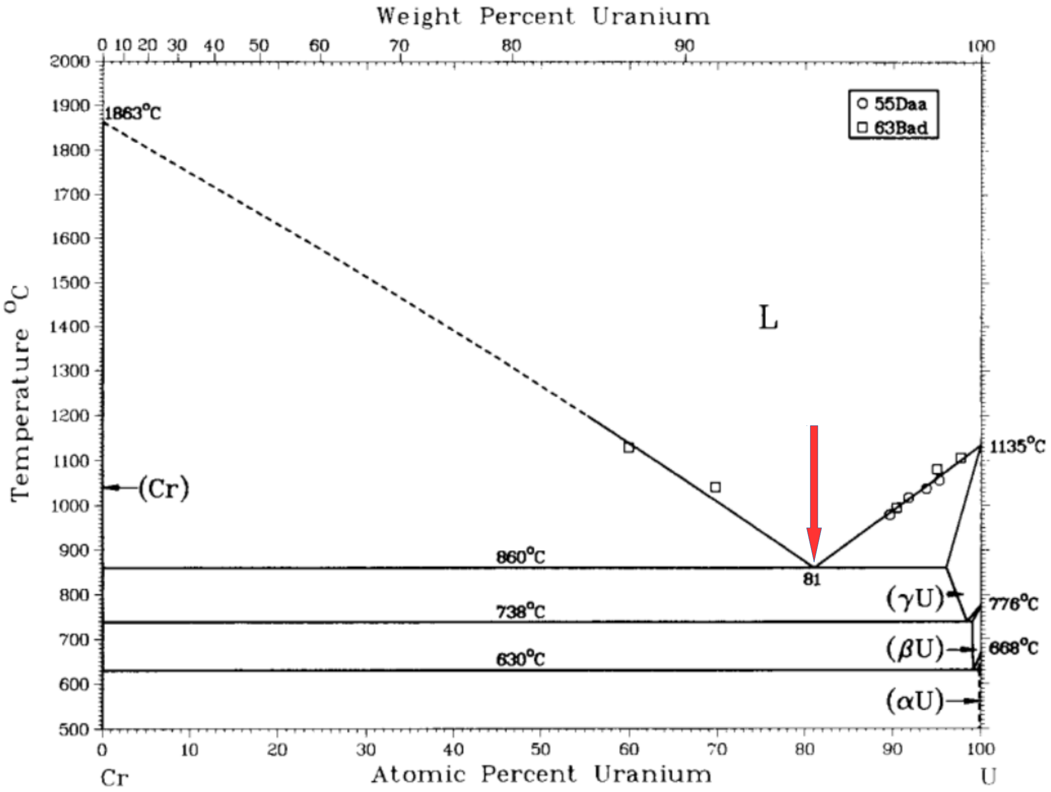
Dual Fluid Reactor [1]

Uranium – Chromium alloys

FUEL MIXTURE:

- Cr – 4.78%
- ^{235}U – 12.80%
- ^{238}U – 82.42%

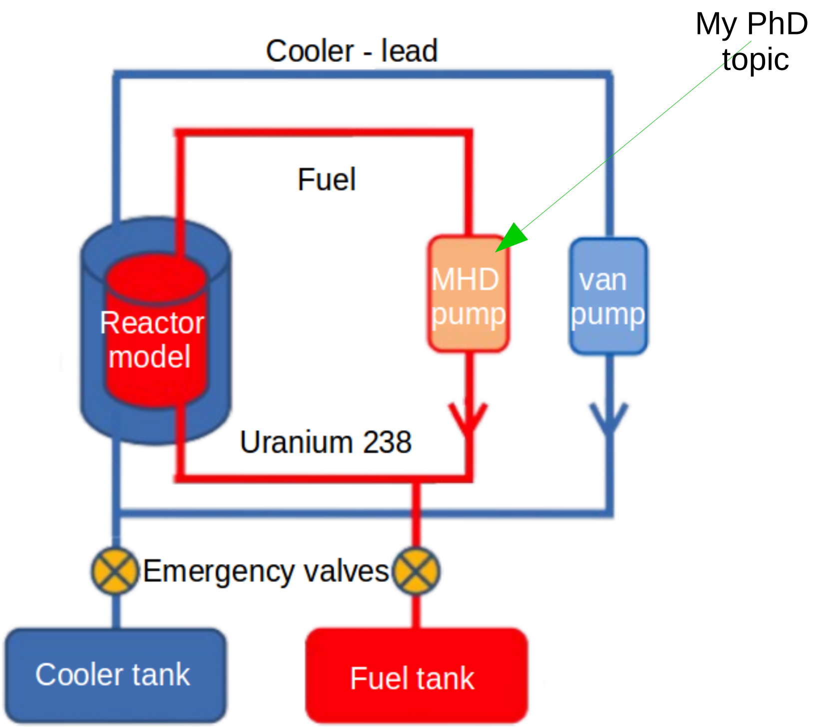
- The lowest melting point temperature



U-Cr phase diagram [Venkatraman M. Neuman J.P., Peterson D.,E, 1985]

Mini-demonstrator

- Two loops – fuel and coolant
- Two pumps: MHD and Van pump
- Fuel - Uranium 238
- Cooler - lead



Mini-demonstrator scheme[1]

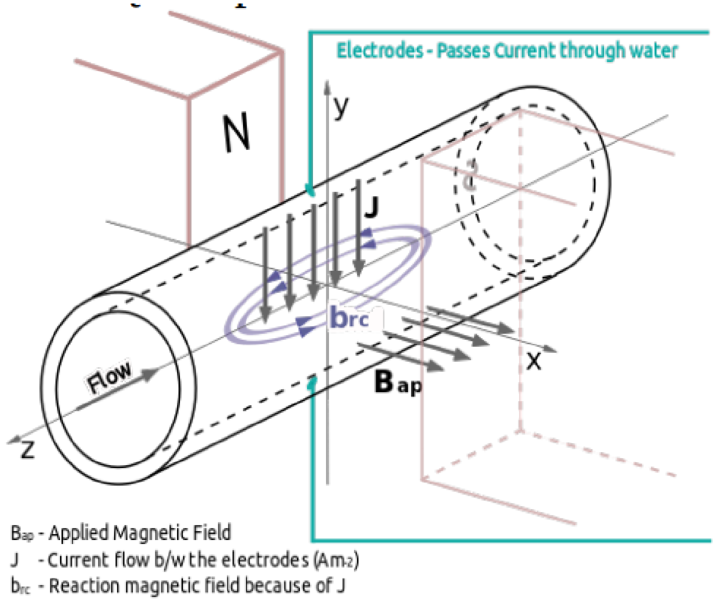
The PhD topic

- PhD topic: Analysis and development of an MHD Pump for the DFR

- Problems:
  - Check the technology MHD pump
  - Integrate MHD pump to mini-demostrator fuel loop
  - Very high temperature (1100-1300°C) – commercial MHD pump works max 800/900°C
  - Not enough information about Uranium-Chromium (4,78%) eutectic

Magneto-hydrodynamic (MHD) principle is an important interdisciplinary field. One of the most important applications of this effect is pumping of materials that are hard to pump using conventional pumps.

The pumping of liquid metal may use an electromagnetic device, which induces eddy currents in the metal.
These induced currents and their associated magnetic field generate the Lorentz force whose effect can be actually the pumping of the metal.



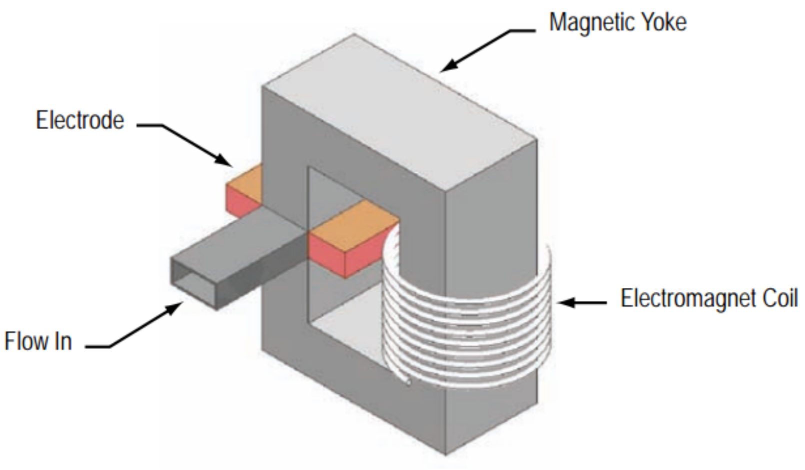
Magnetic and electric fields in MHD fluid [2]

DC conducton pumps

The DC conduction pump is the simplest EM pump design, employing either permanent magnets or electromagnets to generate the field within the liquid metal They possess no moving parts and can easily be integrated into pump designs

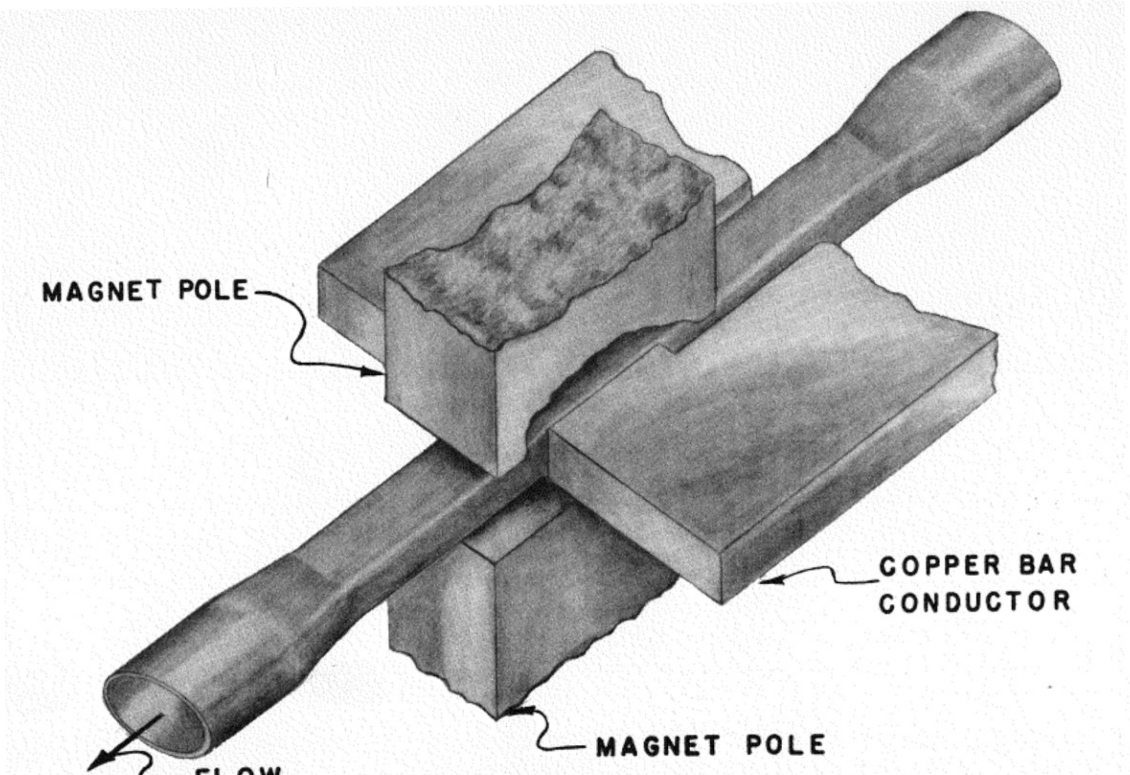
Advantages[3]:
→Simple design
→Low pump mass

Drawbacks[3]:
→High-current cabling mass
→High-I, low-U power condictioning
→Armature and ohmic heating losses



Schematic representation of a DC conduction pump [3]

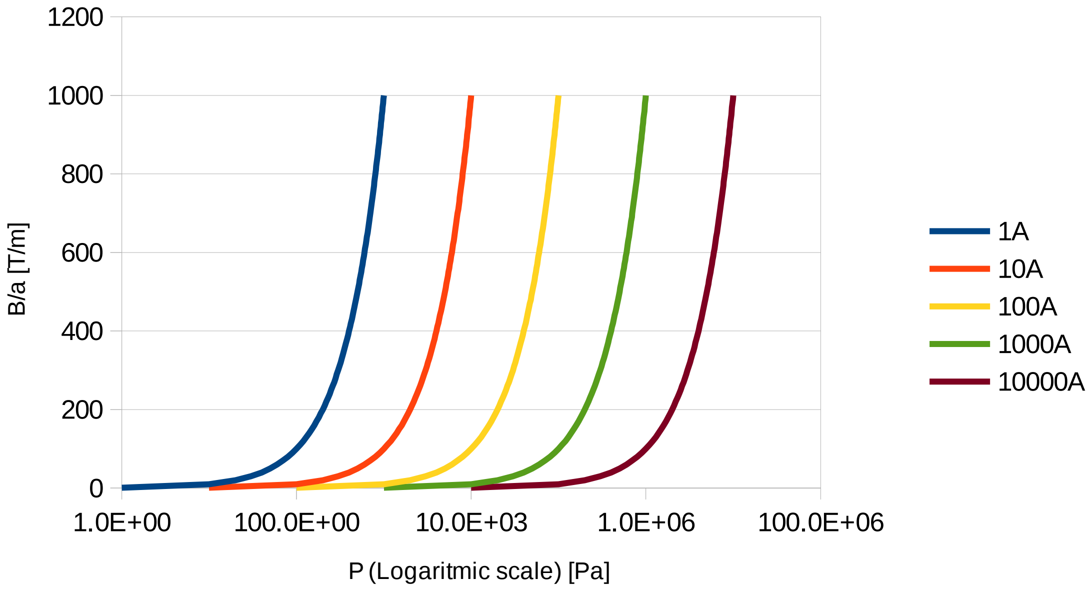
DC Conduction pump – U.S.A prototype



DC Conduction pumps [6]

B/a ratio są a function of desired pump pressure for varying values of pump current

- $F = B \cdot I \cdot b$
- $P = F / S = F / (a \cdot b)$
- $P = B \cdot I \cdot b / (a \cdot b)$
- $P = I \cdot (B / a)$



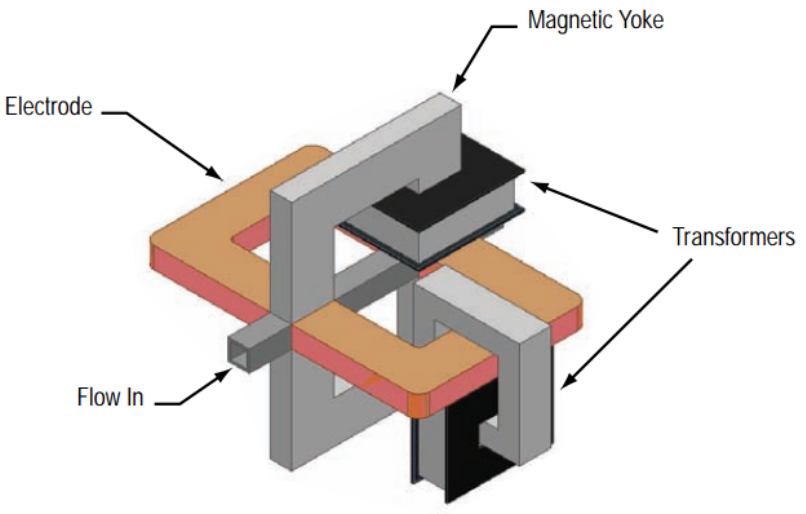
B/a ratio są a function of desired pump pressure for varying values of pump current[3]

AC conduction pumps

In na AC conduction pump, the current conducted into the fluid and the applied magnetic field are both time varying. Since the current is time varying, transformers can be employed to alter the input current and voltage levels to those required for pump operation

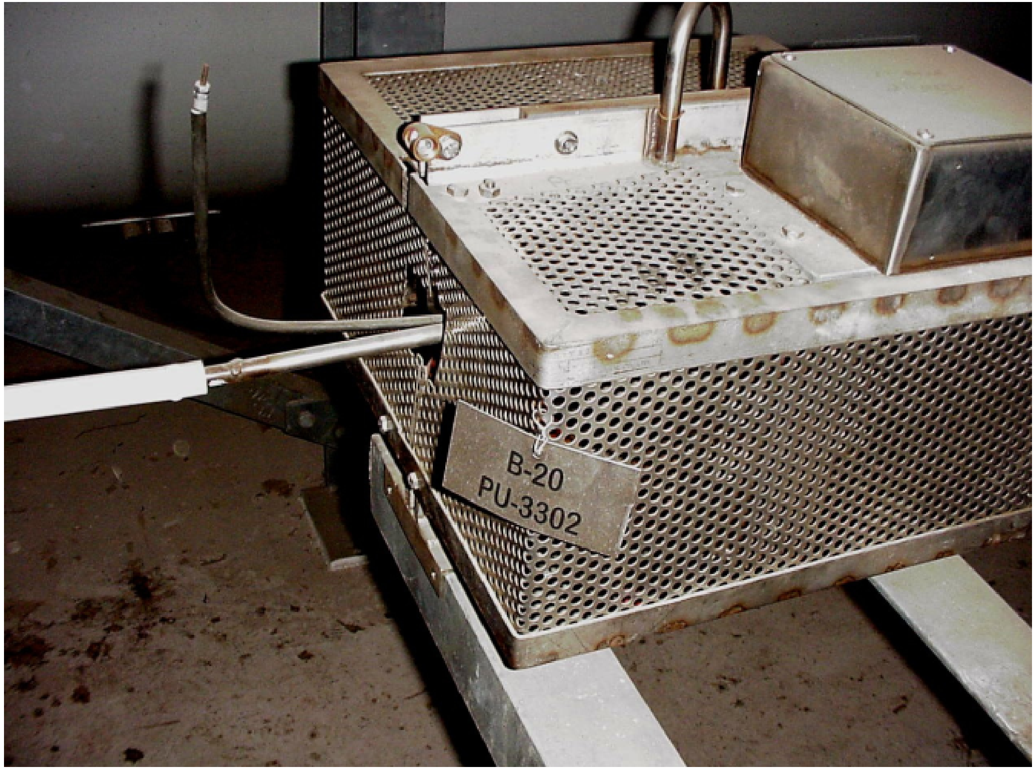
Advantages [3]:
→Power conditioning using transformers

Drawbacks[3]:
→Low pump efficiency
→Pulsating body force
→Armature and eddy current losses
→High transformer cooling requirements
→Large pump, difficult to integrate



Schematic representation of an AC conduction pump[3]

AC Conduction Pump – Creative Engineers version



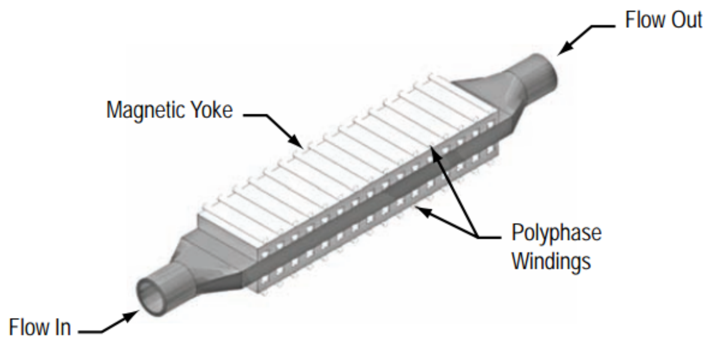
AC Conduction pump[3]

Induction pumps

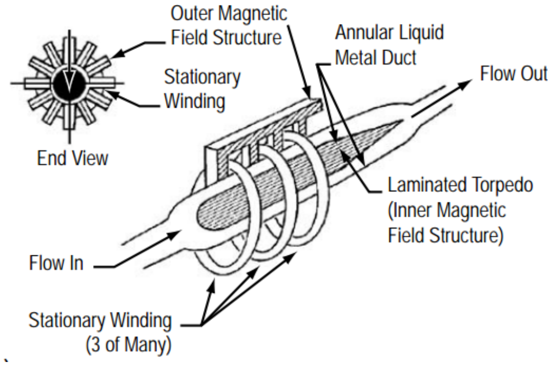
Induction pumps differ from conduction pumps in that the current in the conducting fluid is inducted by a traveling magnetic field. The magnetic field induces currents in the fluid that interact with the traveling magnetic field to yield a nett Lorentz force for the liquid metal.

Advantages:
→Power conditioning relatively lightweight at higher power
→Efficient over broad pump size and input power

Drawbacks:
→Complex design
→Pulsating body force
→End and eddy current losses
→Multiple power conditioning units for production of traveling wave
→If stator delaminate, winding cooling is reduced

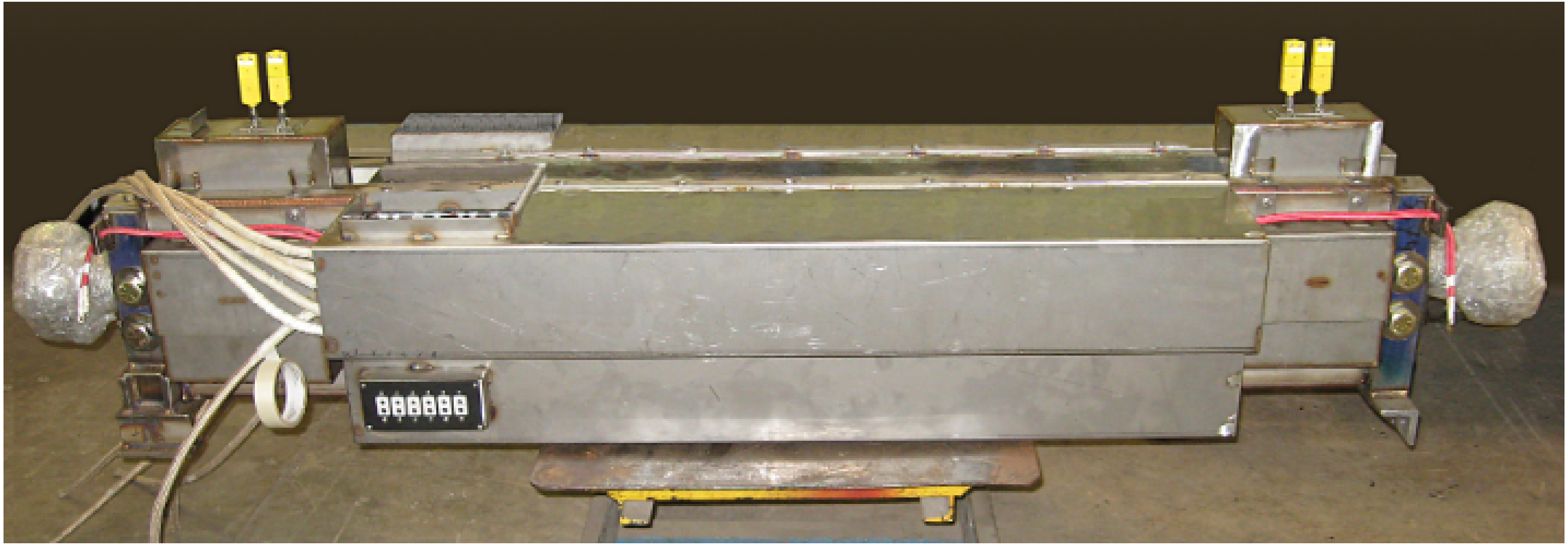


Schematic representation of a FLIP induction pump[3]



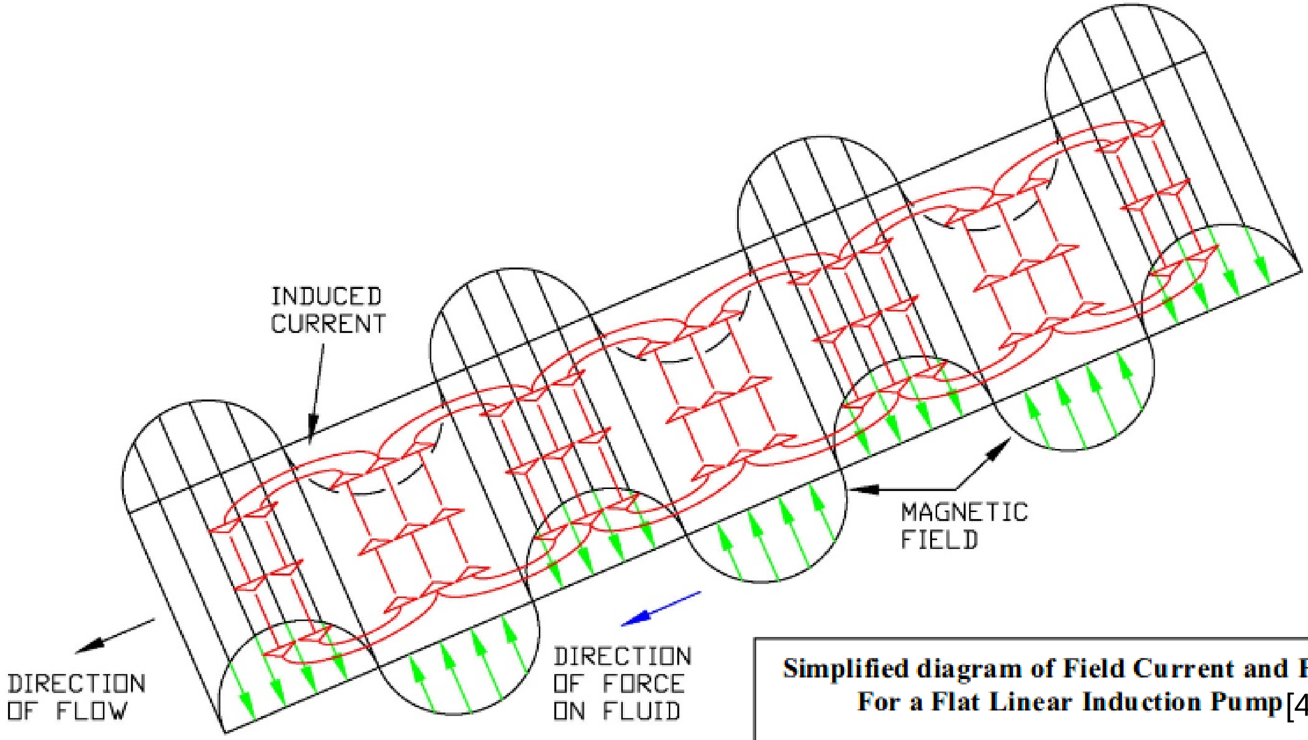
Schematic representation of a ALIP induction pump[3]

FLIP – Creative Engineers version



Induction pump[3]

Current and magnetic field in FLIP



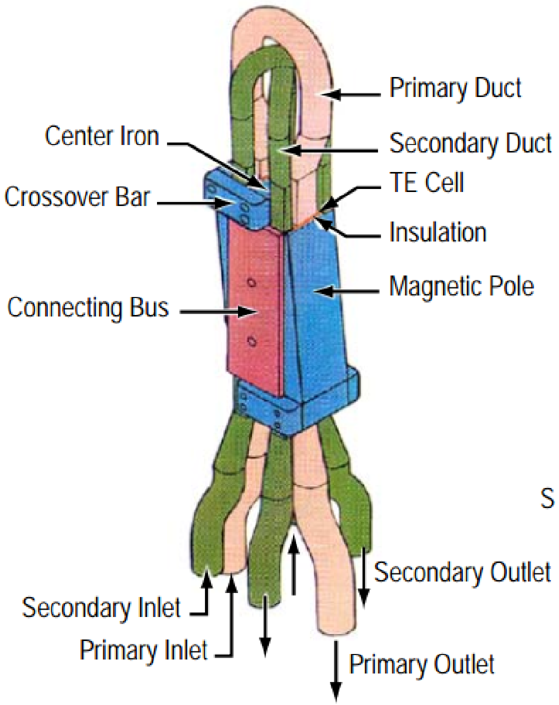
Simplified diagram of Field Current and Flow For a Flat Linear Induction Pump[4]

Thermoelectric pumps

TE pumps are similar to DC conduction pumps in many respects. A magnetic field is typically applied using pernaments magnets. This pumps use a mechanism called the Seebeck effect.

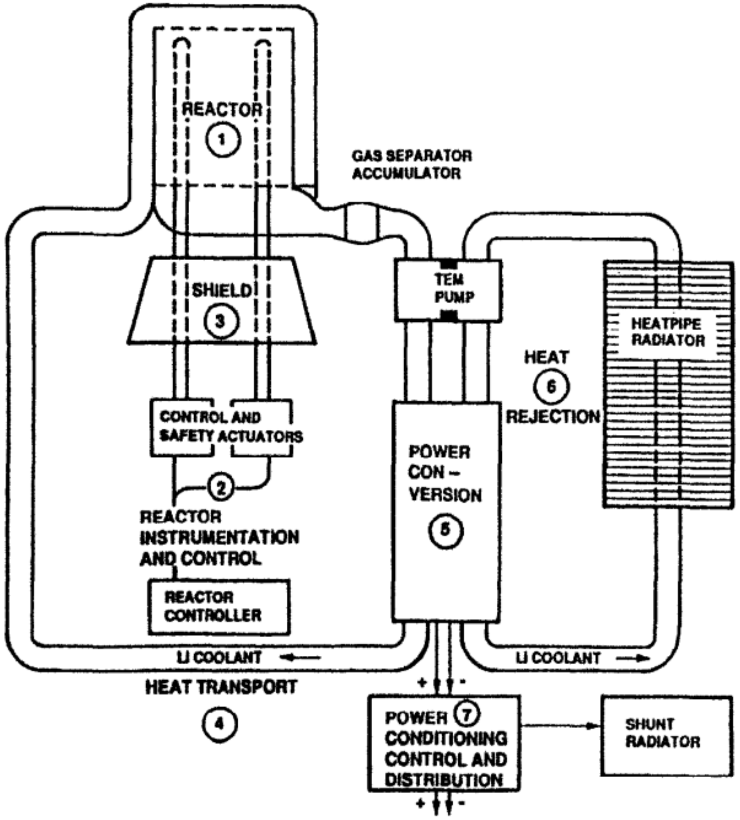
Advantages:
→Low system mass
→Simple design
→No external input required
→Self-starting and self-regulating

Drawbacks:
→Conductively coupled TE elements
→Failure if TE elements delaminate or lose conductive coupling
→Armature and ohmic heating losses



Schematic representation of a thermoelectric pump[3]

SP100 – Space reactor



SP100 funcional layout [5]

Conclusion

- Probably the best construction for DFR is DC conduction pump
  - Low flow
  - Simple construction

- The next step is design simple loop (micro-demonstrator) and testing MHD pump
  - First fluid will be lead-bismuth eutectic (low melting point temperature)

Literature

1. Huke A., Ruprecht G., Weissbach D., Gottlieb S., Hussein A., Czerski K., The Dual Fluid Reactor – A novel concept for a fast nuclear reactor of high efficiency, Annals of Nuclear Energym 2015.
2. Baker, R.S., Tessier, M.J. Handbook of electromagnetic pump technology. United States: N. p., 1987
3. Polzin, K.A.,"Liquid metal pump technologies for nuclear surface power," American Nuclear Society Space Nuclear Conference, Paper 2002, June 2007.
4. www.creativeengineers.com/alkali-metal-engineering-experts/specialized-equipment-for-use-with-liquid-metal/electromagnetic-pumps/
5. Demuth S. F., SP100 Space Reactor Design, Progress in Nuclear Energy, Vol. 42, 2003

Thank you for attention

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