inducfur Documentation

Release 1.0

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Contents:

CHAPTER 1

README of Induction Furnace

1.1 Presentation

Some notices and reflections to build an induction furnace.

You can view the docs on readthedocs and clone the sources from github

1.2 Getting started

In a bash-terminal:

```
git clone https://github.com/charlyoleg/induction_furnace.git
cd induction_furnace
npm install
npm run install_py
npm run the_docs
```

CHAPTER 2

Notes on Induction Furnace

2.1 Presentation

The *metal* is an interesting material because of its *rigidity*. This property let us make mechanical parts that are closed to an ideal solid, which shapes and dimensions do not vary regardless of the applied strength and temperatures.

The high rigidity of the metal is also an issue when it comes to form the shape of the parts. Direct strength become inefficient. Two methods let us bypass the rigidity property of the metal:

- the electro-erosion takes advantage of the electrical conductivity of the metal
- the fusion (i.e. foundry) takes advantage of the relative small quantity of energy required to melt a metal

For years, the difficulty was to bring the thermal energy to the metal at high temperature. But nowadays, thanks to the induction technology, it is quiet easy to bring this energy as the heat is generated within the metal.

2.2 Induction overview

An LC-circuit generates an alternative magnet field, which generates *Foucault current* (a.k.a. Eddy current), which generates heat thanks to the Ohmic law.

The Ohmic law:

$$W_{th} = R * I^2$$

Wth : the thermal power generated by a current

The Foucault current are limited to the area closed to the surface of the metal if the frequency is too high. This is the skin effect

Thickness of the skin effect:

$$Thickness = \frac{1}{\sqrt{conductivity * permeability * \pi * frequency}}$$

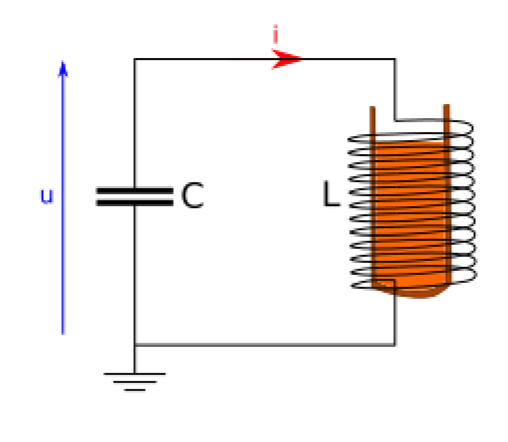
$$frequency = \frac{1}{Thickness^2 * \pi * conductivity * permeability}$$

Material Thickness	Iron	Copper
10 mm	0.05 Hz	43 Hz
8 mm	0.08 Hz	67 Hz
6 mm	0.1 Hz	119 Hz
4 mm	0.3 Hz	269 Hz
2 mm	1.2 Hz	1075 Hz
1 mm	5 Hz	4300 Hz

To get enough thickness for the *Foucault current*, we work with a frequency below 1kHz. So we can melt all metal. Also, at high temperature, the iron loses its high magnetic permeability, which makes it behave closer to the copper regarding the skin effect.

2.3 LC circuit

To create an alternative magnetic field, we need an oscillating circuit like the LC-circuit.



LC circuit

Formula:

$$u = L\frac{di}{dt}$$

$$i = C\frac{du}{dt}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$E_{cap} = \frac{Cu^2}{2}$$

$$E_{ind} = \frac{Li^2}{2}$$

2.4 Inductance sizing

The volume of 1kg of iron is 127000 mm^3. In chip, it may requires the double volume, that means 250000 mm^3 or 50*50*3.14*30, a cylinder of radius 50 mm and height 30 mm.

Cylindrical inductance:

$$L = \mu_0 N^2 \frac{A}{l}$$

$$\mu_0 = 4\pi 10^{-7} H m^1$$

Considering a cylindrical inductance of radius 80 mm (diameter: 160 mm) and a height of 30 mm. If the wire loop are distance of 5 mm, we get 6 loops for one way. For both ways, we get 12 loops:

$$A = 0.08^2 \pi = 0.02 m^2$$

$$l = 0.03 m$$

$$N = 12$$

$$L = 0.00012 H = 0.12 mH$$

2.5 Capacitor sizing

To reach a resonance frequency of 1kHz, we need a capacitor of:

$$C = \frac{1}{(2f\pi)^2 * L}$$

$$C = 0.000211 F = 0.211 mF$$

2.6 Power transfer

We want to transfer the energy from electricity to heat up to 1kW i.e. 1kJ/s. We have 1000 oscillations per second.

If each oscillation transfers completely its energy in one oscillation, we need 1J in the LC-oscillation:

$$u = \sqrt{\frac{2E_{cap}}{C}} = 97.3(V)$$

$$i = \sqrt{\frac{2E_{ind}}{L}} = 129.1(A)$$

If 10% of the energy is transfer per oscillation, we need 10J oscillating in the LC-circuit:

```
u = 307 (V)
i = 408 (A)
```

If 1% of the energy is transfer per oscillation, we need 100J oscillating in the LC-circuit:

```
u =  973 (V)
i = 1291 (A)
```

CHAPTER 3

Notes on Metal

3.1 Presentation

When looking for a *rigid* substance, metal is a good choice compare to stone, wood, glass, ceramic, plastic. The *rigidity* is relevant when designing parts with the solid mechanics. In this matter, shapes and dimensions are considered invariant, regardless of the strength, pressure, collision and temperature conditions.

3.2 Metal overview

3.2.1 Rigidity

Material	Young's modulus	Yield stress	Yield strain	Thermal expansion
Units	GPa	MPa	%	10**-6/°C
Iron (Fe)	196	80	0.04	11.8
cast iron	83	400	0.4	10.5
Steel	204	1450	0.7	17
Aluminium (Al)	69	95	0.13	23.1
Aluminium alloy	75	470	0.64	
Copper (Cu)	124	33	0.03	17
Zinc (Zn)	78			

Example of thermal expansion:

```
An iron-part with a width of 10 cm gets longer of 11.8 um when the temperature
↪increases of 10 °C.
```

Example of limit of elasticity:

```
An iron-part under strength with a width of 10 cm gets longer of 200 um before
↪getting a plastic deformation.
```

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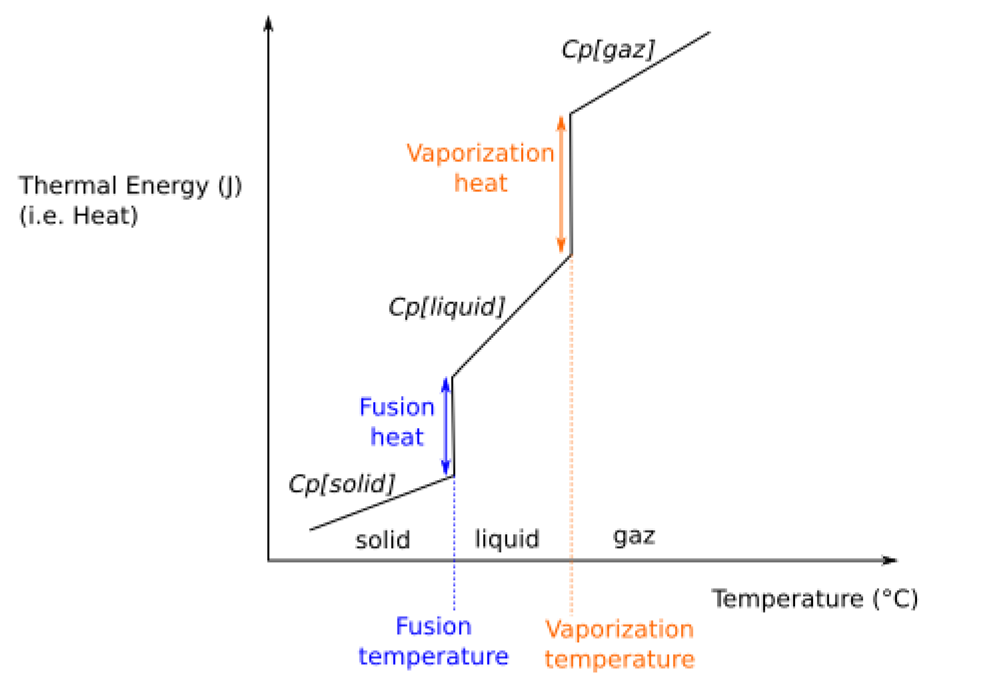
3.2.2 Auxiliary

Material	Molar mass	Specific volume	Specific heat	Thermal conductivity	Electrical resistivity
Units	kg/mol	m3/kg	J/(kg.K)	W/(m.K)	Ohm.m
Iron (Fe)	0.05584	127.0 * 10**-6	444	80.4	9.70 * 10**-8
Aluminium (Al)	0.02698	370.4 * 10**-6	897	237	2.65 * 10**-8
Copper (Cu)	0.06354	111.6 * 10**-6	385	384.1	1.68 * 10**-8
Zinc (Zn)	0.06539	140.0 * 10**-6	380	116	5.90 * 10**-8

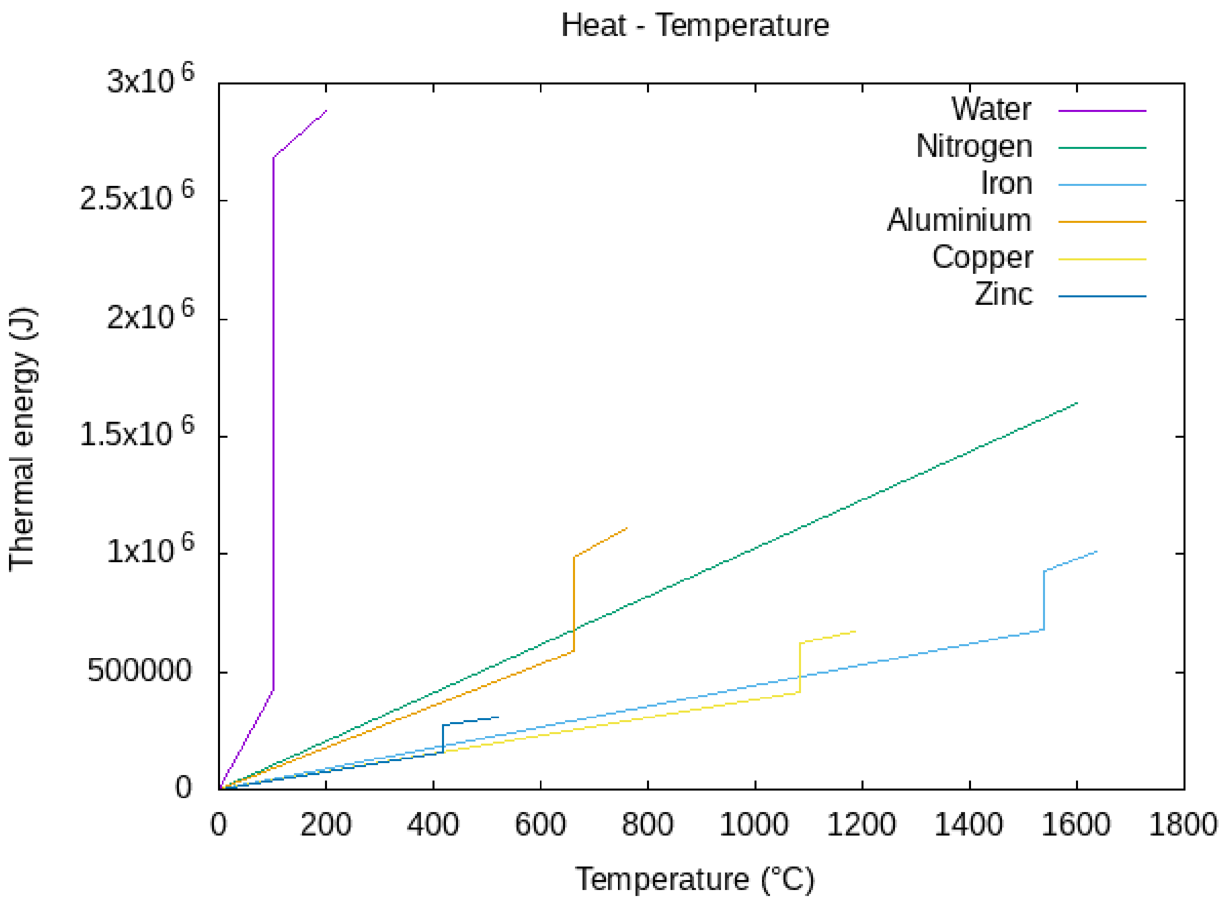
3.2.3 Energy for fusion

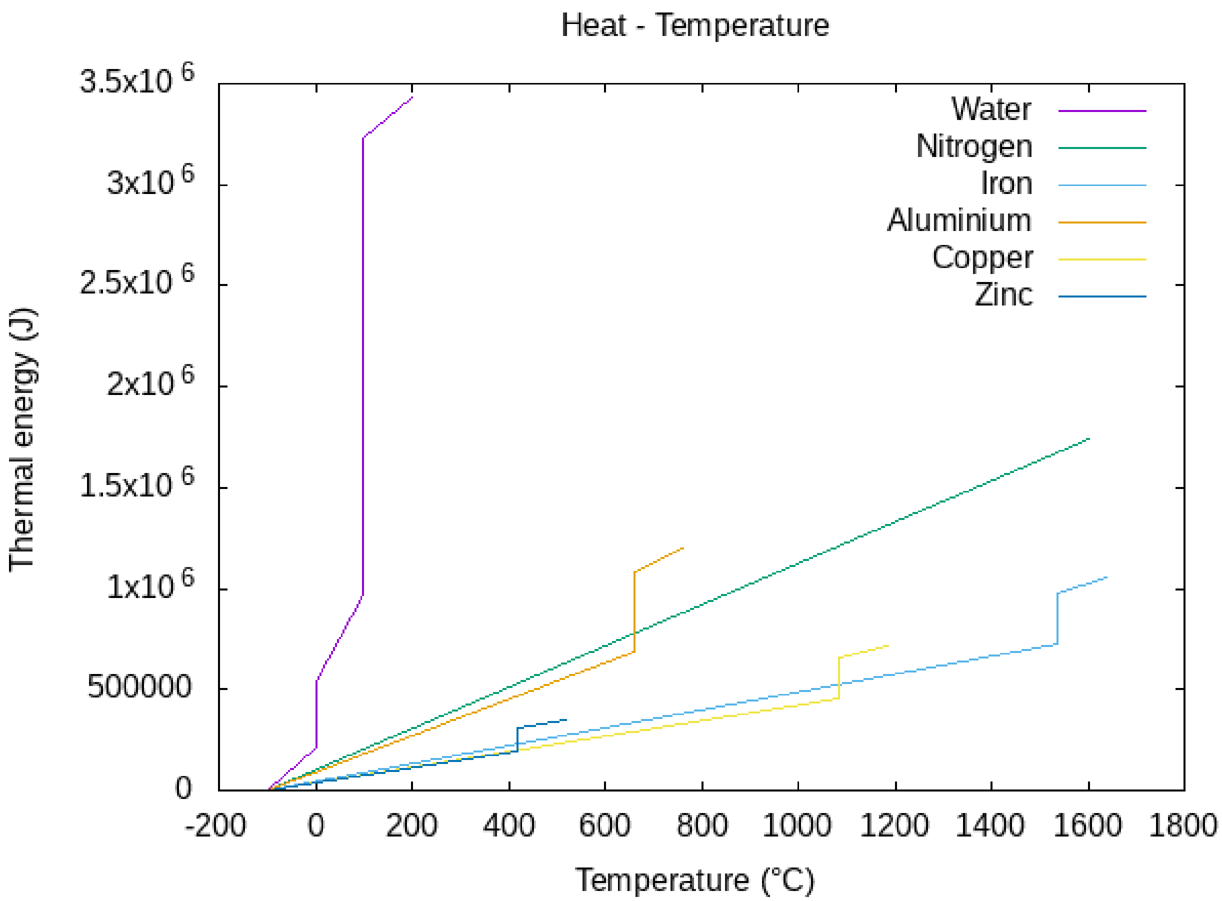


heat temperature diagram

At 101325 Pa (normal atmospheric pressure)

Material	Cp [solid]	Fusion Tc	Fusion heat	Cp [liquid]	Boiling Tc	Vaporization heat	Cp [gaz]
Units	J/(kg.K)	℃	J/kg	J/(kg.K)	℃	J/kg	J/(kg.K)
Water (H2O)	2108	0	334000	4187	100	2264705	1996
Nitrogen (N2)		-210	25700		-196	200000	1025
Iron (Fe)	444	1538	247134	820	2861	6214000	
Aluminium (Al)	897	660.3	396590	1180	2519	10859000	
Copper (Cu)	385	1084.6	206170	490	2562	4721000	
Zinc (Zn)	380	419.5	112402		907	1819000	





Energy to melt 1 kg of metal:

```
Water-steam    :  100 * 4187 + 2264705 = 2683405 J  <=> 0.745 kW/h
Iron           : 1538 *  444 +  247134 =  930006 J  <=> 0.258 kW/h
Aluminium      :  669 *  897 +  396590 =  996683 J  <=> 0.276 kW/h
Copper         : 1084 *  385 +  206170 =  623510 J  <=> 0.173 kW/h
Zinc           :  419 *  380 +  112402 =  271622 J  <=> 0.075 kW/h
```

Reminder:

$$1bar = 100000Pa$$

$$1Pa = 1Nm^{-2} = 1Jm^{-3}$$

$$1cal = 4.1855J$$

$$1mol = 6.022 * 10^{23}$$

3.2.4 Auxiliary table

Material	Molar mass	Specific volume	Thermal conductivity	Electrical resistivity	Magnetic permeability
Units	kg/mol	m3/kg	W/(m.K)	Ohm.m	H/m
Ice (H2O)	0.018	0.00109			
Water (H2O)	0.018	0.00100	0.6	20	0.99
Steam (H2O)	0.018	1.24			
Nitrogen (N2)	0.02802	0.799	0.026	10**9	1.00
Iron (Fe)	0.05584	127.0 * 10**-6	80.4	9.70 * 10**-8	5000
Aluminium (Al)	0.02698	370.4 * 10**-6	237	2.65 * 10**-8	1.00
Copper (Cu)	0.06354	111.6 * 10**-6	384.1	1.68 * 10**-8	0.99
Zinc (Zn)	0.06539	140.0 * 10**-6	116	5.90 * 10**-8	0.99

CHAPTER 4

Notes on capacitors

4.1 Alumina capacitor

4.1.1 Alumina

Alumina or *aluminium oxide* (Al_2O_3) seems to have good properties to be used as insulator to build a capacitor.

Aluminium oxide characteristics:

- density: 3.987 kg/dm3
- thermal conductivity: 30 W.m-1.K-1
- dielectric strength: 14.6 MV.m-1
- relative permittivity: 9.0

Insulator thickness for a *breakdown voltage* of 3.5V:

$$\frac{3.5}{14.6 * 10^6} = 0.24 * 10^{-6} m = 0.24 \mu m$$

4.1.2 Capacitor geometry

We consider a a stack of *parallel-plate capacitor*.

- Insulator layer thickness: 0.24 um
- square surface of 0.1 m x 0.1 m = 0.01 m2
- height: 0.1 m
- volume: 0.1 * 0.1 * 0.1 = 1 dm3 = 1 L
- mass: 1.0 * 3.987 = 4 kg
- number of layers:

$$\frac{0.1}{0.24 * 10^{-6}} = 416000 layers$$

4.1.3 Capacitance

For one layer:

$$C = \epsilon_0 * \epsilon_r * \frac{surface}{thickness} = 8.85 * 10^{-12} * 9.0 * \frac{0.01}{0.24 * 10^{-6}} = 3.31 * 10^{-6} F$$

For the complete capacitor:

$$416000 * 3.31 * 10^{-6} = 1.38F$$

4.1.4 Energy

Stored energy at 3.0V:

$$E = \frac{1}{2} * C * u^2 = 0.5 * 1.38 * 3^2 = 6.2J = 0.0017Wh$$

4.1.5 Specific energy

$$\frac{6.2J}{4.0kg} = 1.55J/kg = 0.00043Wh/kg$$

4.1.6 Energy density

$$\frac{6.2J}{1.0L} = 6.2J/L = 0.0017Wh/L$$

4.2 Commercial ultracapacitors

4.2.1 Skeleton technologies

https://www.skeletontech.com/

According to their datasheet:

- Specific energy: 5.3 Wh/kg
- Energy density: 6.4 Wh/L

4.3 Conclusion

The naive approach with *alumina* insulator provides poor result compare to the current state of the art of the industry.

- Specific energy ratio:

$$\frac{5.3}{0.00043} = 12325$$

- Energy density ratio:

$$\frac{6.4}{0.0017} = 3764.7$$

CHAPTER 5

Indices and tables

- genindex
- modindex
- search