SPACE TRIPS SUMMER SCHOOL

Theme 9: SPACE

Riga Latvia

June 17-20 , 2 0 1 4

MHD GENERATOR

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spaceTRIPS summer school Riga
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SCHEDULE OF THE PRESENTATION

1- Problematic of the subject

2 -The governing MHD equations

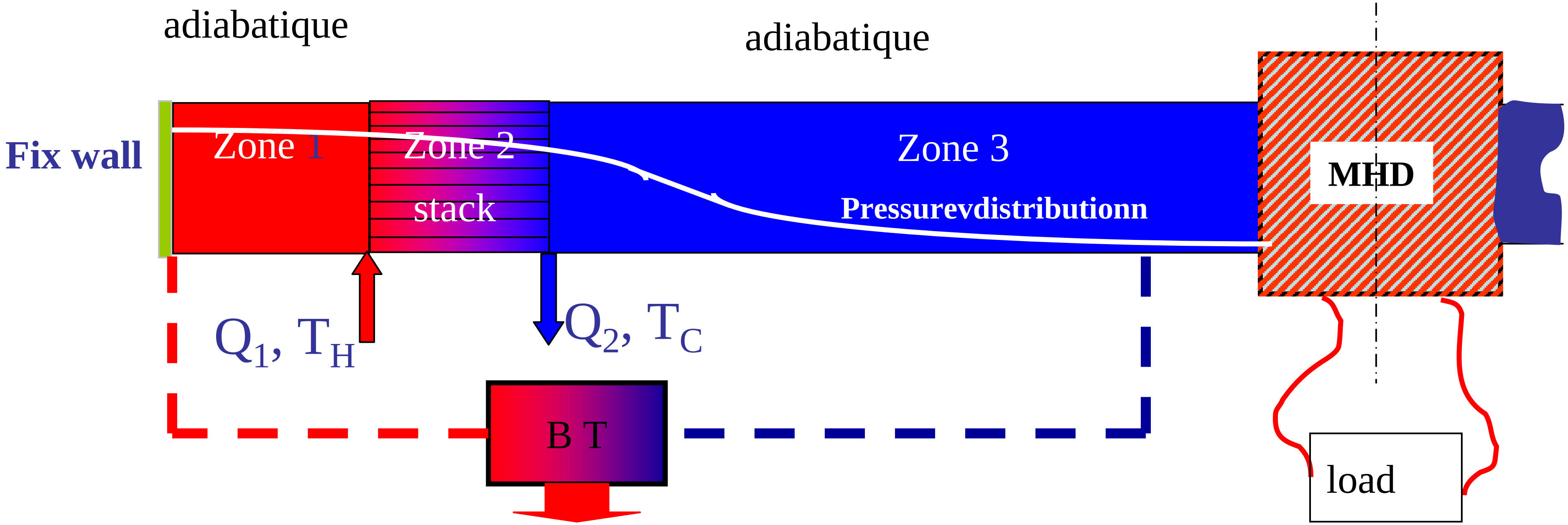
3- Different types of generators

4- Conducting generator

5- Inducting generators

6- Conclusion

PROBEMATIC



Direct production of electric energy from thermal energy by

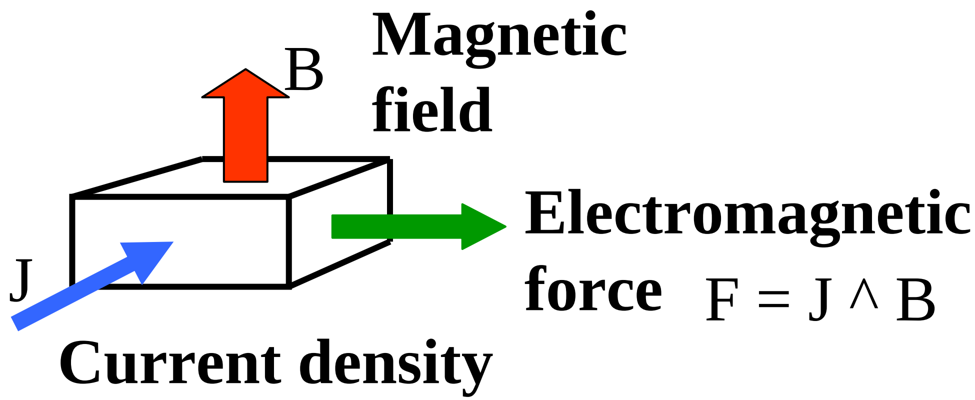
-Connection between Thermo acoustic loop and MHD generator
-Advantage: no moving mechanical part, quasi static engine
-System well adapted for the use on isolated site like in space

Optimisation of efficiency with reduced mass

MAIN MHD EQUATIONS

GENERAL PRESENTATION

(MHD Liquid Metal)



Forces acting on the fluid

-Inertia force
-Pressure force
-Viscous force
-Electromagnetic force

$$\frac{D\vec{V}}{Dt} = -\frac{1}{\rho}\,\overrightarrow{\text{grad}}\,P + \frac{\mu}{\rho}\,\Delta\vec{V} + \vec{J} \wedge \vec{B}$$

$$\text{Rot}\,\vec{E} = -\frac{D\vec{B}}{Dt}$$

$$\text{Rot}\,\vec{B} = \mu_o\,\vec{J}$$

$$\vec{J} = \sigma\,(\vec{E} + \vec{V} \wedge \vec{B})$$

$$\frac{D\vec{B}}{Dt} = (\vec{B}.\nabla)\vec{V} + \frac{1}{\mu_o\,\sigma}\,\Delta\vec{V}$$

NON DIMENSIONAL NUMBERS

$$\begin{cases} \dfrac{D\vec{\mathbf{B}}}{Dt} = (\vec{\mathbf{B}}.\nabla)\vec{\mathbf{V}} + \dfrac{1}{Rm}\Delta\vec{\mathbf{V}} \\ \dfrac{D\vec{\mathbf{V}}}{Dt} = -\dfrac{1}{\rho}\overrightarrow{\text{grad}}\,\mathbf{P} + \dfrac{1}{Re}\Delta\vec{\mathbf{V}} + \dfrac{M^2}{Re}\vec{\mathbf{J}} \wedge \vec{B} \end{cases}$$

$Re = \dfrac{Vo\ lo}{\nu}$ — **Reynolds number Inertia forces/Viscosity forces**

$M = Bolo\sqrt{\dfrac{\sigma}{\rho\nu}}$ — **Hartmann number, E.M. Forces/ Viscosity forces**

$Rm = \dfrac{Vo\ lo}{\lambda}$ — **Magnetic Reynolds number, Diffusion time/convection time**

$N = \dfrac{M^2}{Re}$ — **Interaction parameter E.M.forces/Inertia forces**

CHARACTERISTIC NON DIMENSIONAL NUMBERS

Concerned fluids:

Liquid metal: $\sigma \sim 10^6$
Electrolyte $\sigma \sim 10$

Characteristic scales

Lo (m)	B (T)	Vo (m/s)	ρ	ν
0.1->1	0.1 -> 10	0.1->1	10^3 >10^4	10^{-6}-> 10^{-7}

Characteristic parameters

Re	Rm	M	N
10^{2-}>10^5	1 ->10^5	1 ->10^5	0.1->100

CLASSIFICATION OF MHD PROBLEMS

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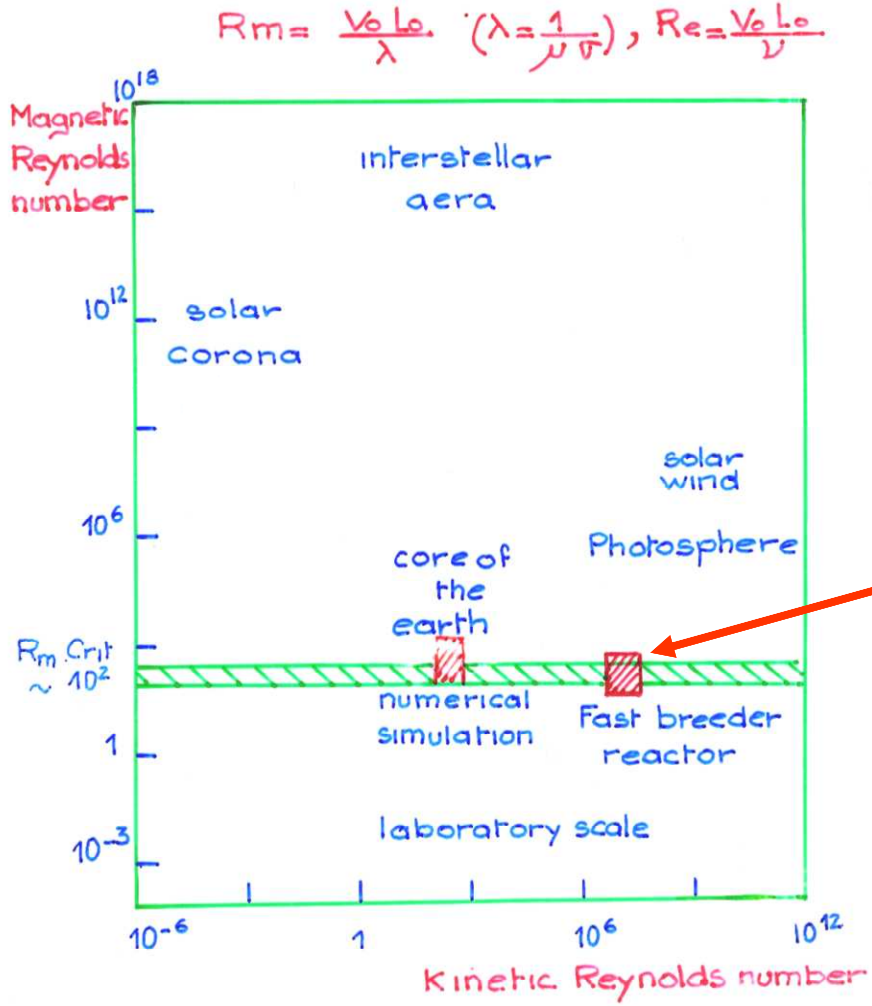

Experiments performed at the vicinity of the secondary pump of Superphenix (fast breeder reactor) do not revel any dynamo effect (Rm # 30).

Numerical simulation of the core flow of phenix and superphenix shows some possible dynamo effects but must be confirmed

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DIFFERENT TYPES OF GENERATORS

CONDUCTING GENERATOR

INDUCTION GENERATOR

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CONDUCTING GENERATOR

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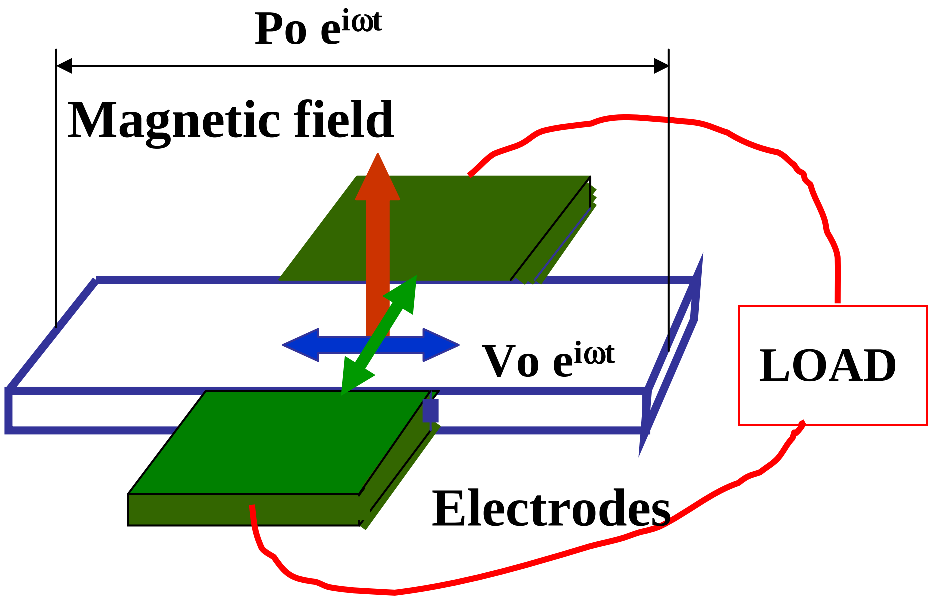


Conduction systems

Necessity of electrodes

Low voltage ~ 1 V

High current intensity

Difficulty of adaptation with the load

EQUATIONS AND BOUNDARY CONDITIONS

- Navier-Stokes equation $$iu'^{*} = -K_p + \frac{1}{R_\omega}\frac{\partial^2 u'^{*}}{\partial y^{*2}} + \frac{N}{R_m}\frac{\partial b_x'^{*}}{\partial y^{*}}$$

Elecromagnetic force

- Induction equation $$ib_x'^{*} = \frac{\partial u^{*}}{\partial y^{*}} + \frac{1}{R_m}\frac{\partial^2 b_x'^{*}}{\partial y^{*2}}$$

(Mixing of the Maxwell equations and Ohm law)

- No slip condition

1 $$u^{*}\left(y^{*}=1\right)=0$$

- Symetry conditions

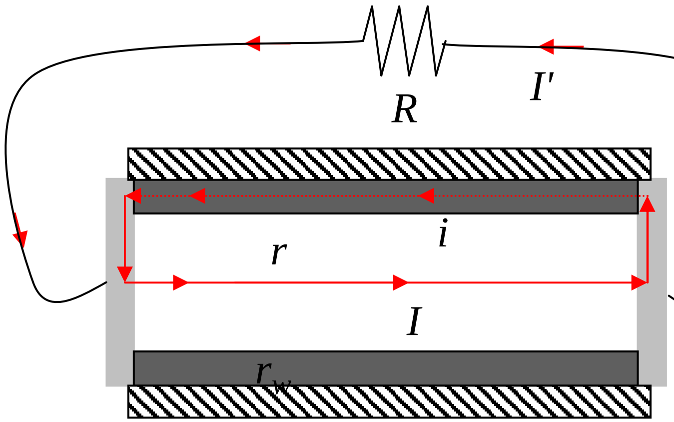
2 $$\frac{\partial u^{*}}{\partial y}\left(y=0\right)=0$$

3 $$b_x^{*}\left(y=0\right)=0$$

- Continuité du courant

$I+I'+i=0$

4 $$b_x^{*}\left(y^{*}=1\right)=\frac{K-1}{K}\frac{\partial b_x^{*}}{\partial y^{*}}\left(y^{*}=1\right)$$



Load factor

$$K=\frac{1}{1+\frac{r}{R}+C_w}$$

Conductance ratio

$$C_w=\frac{r}{r_w}=\frac{\sigma_w e_w}{\sigma a}$$

EFFICIENCY

P_e Electrical powerP_J

Pj Joule losses

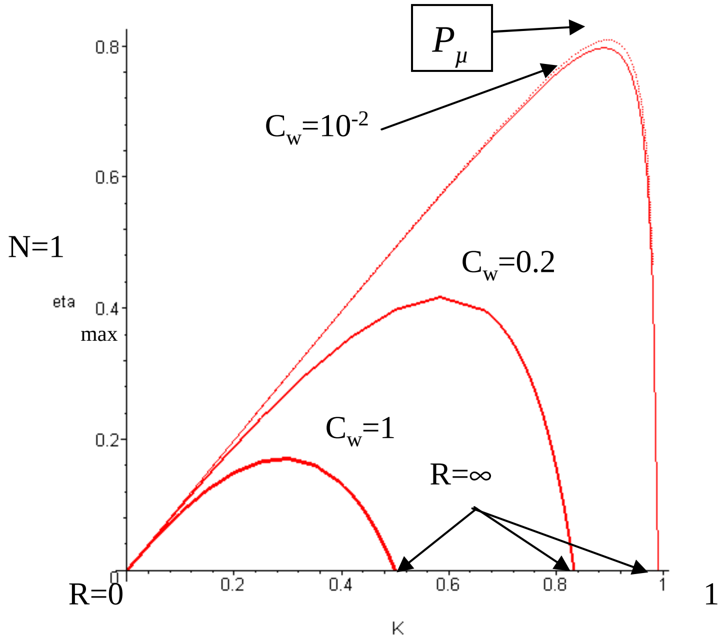
Pμ Friction losses

$$\eta = \frac{P_e}{P_e + P_J + P_\mu}$$

$$K = \frac{1}{1 + \frac{r}{R} + C_w}$$

$$C_w = \frac{\sigma_w e_w}{\sigma a}$$

$$N = \frac{B_0^2 \sigma}{\omega \rho}$$



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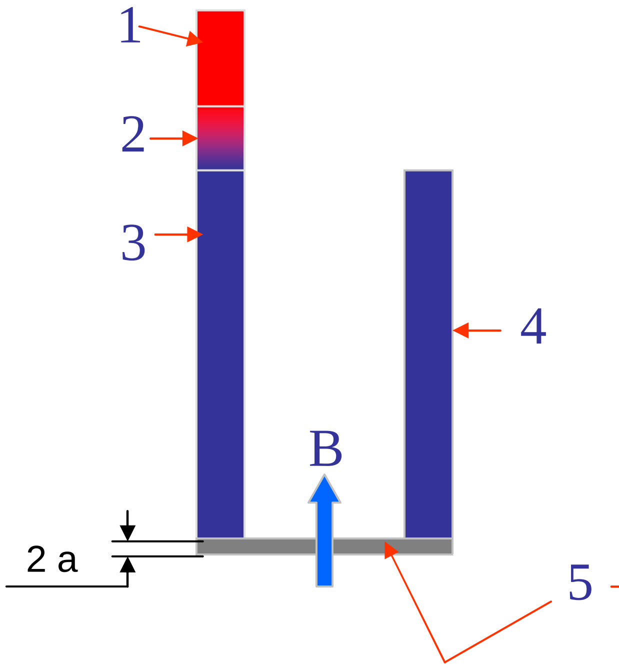
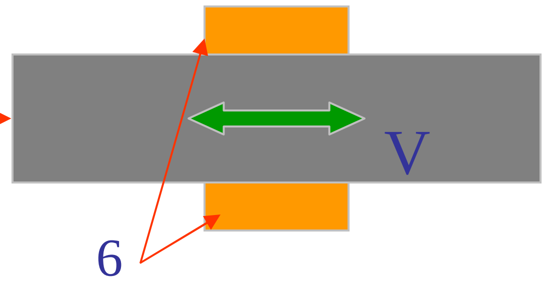
EXPERIMENTAL FACILITY AND RESULTS

EXPERIMENTAL FACILITY

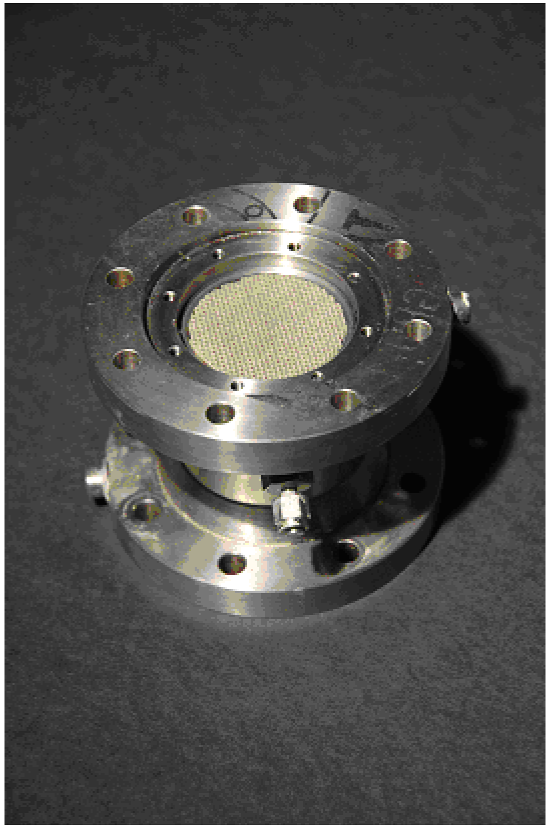


1. Hot source (Electrical resistance)
2. Cold source (Water exchanger)
3. Stack
4. Passive branch for compensate the pressure oscillation
5. MHD Channel
6. Electrodes



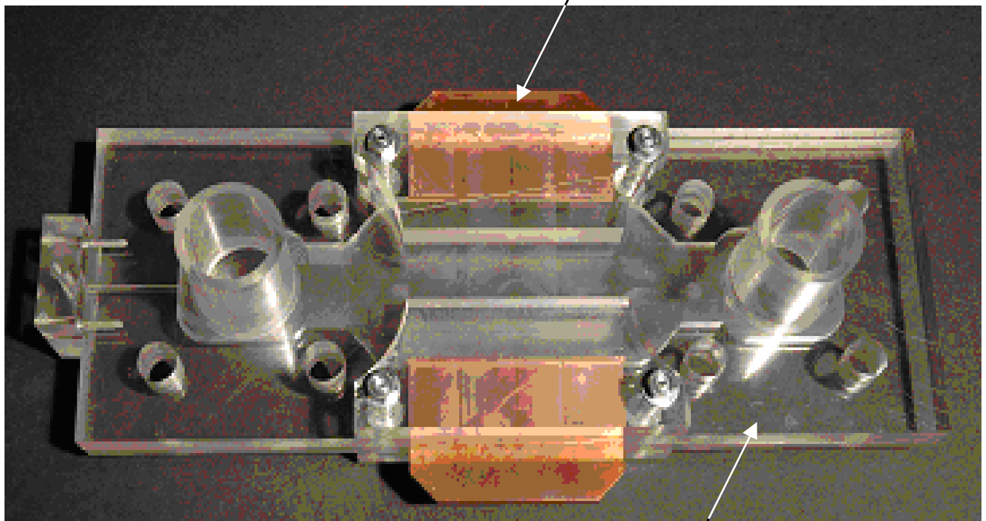
Objective: Validation of the feasibility

ELEMENTS OF THE FACILITY: STACK MHD AND CHANNEL



Stack realised with Catalytic tube of cars

Copper electrodes



MHD Channel

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THE FACILITY

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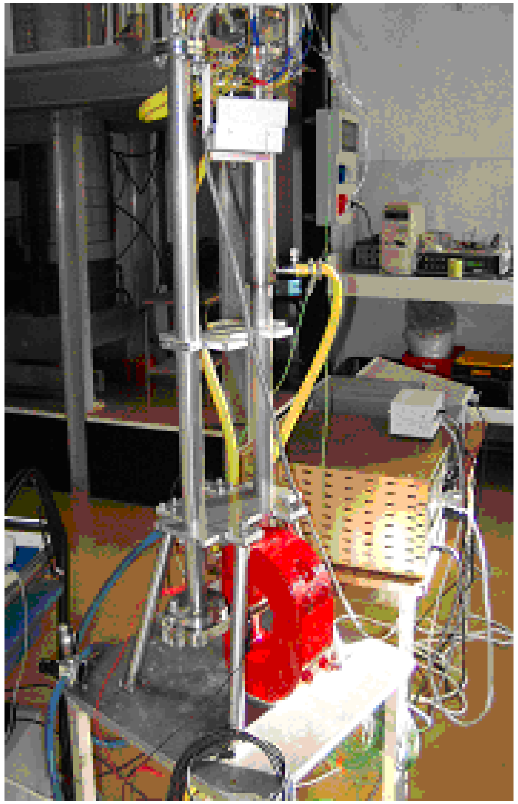
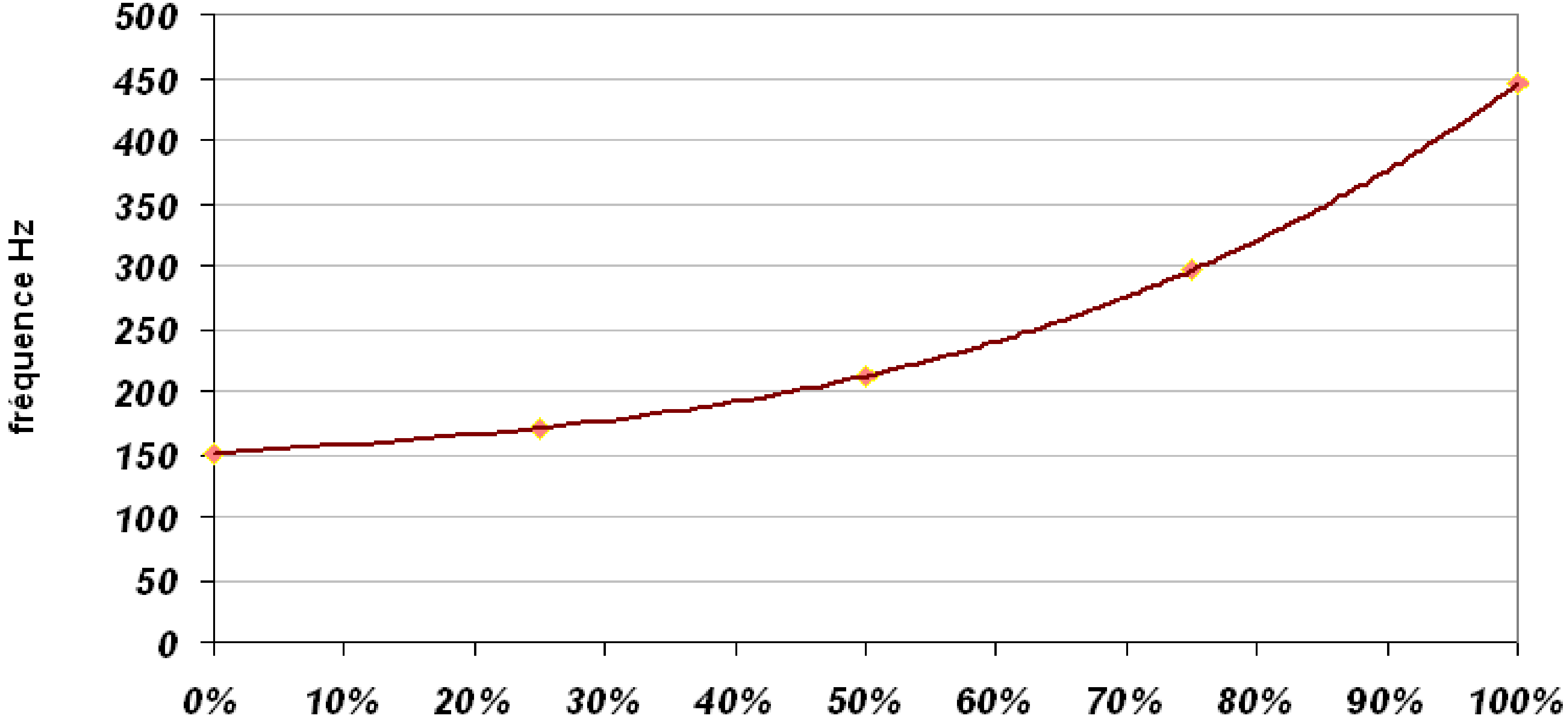


View of the facility. In red the permanent magnet used to obtain the electric signal

Apparatus used to analyse the signal: respectively the power supply, amplifier, filter, oscilloscope and, at the left, the computer with acquisition system

MIXTURE AIR/HELIUM: EVOLUTION OF THE THERMO ACOUSTIC FREQUENCY



Percentage of He in the air/he Mixture

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COMPARISON OF THE RESULTS

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			stack en inox			stack en pot catalytique		
			Air	helium	melange	Air	helium	melange
3 bar	ΔP	(bar)	0,125	X		0,245	0,120	
	fre.p	(Hz)	152,50	X		147,50	427,00	
	ΔV	(mV)	X	X		X	X	
	fre.v	(Hz)	X	X		X	X	
4 bar	ΔP	(bar)	0,210	X		0,286	0,200	
	fre.p	(Hz)	151,50	X		146,50	427,00	
	ΔV	(mV)	X	X		X	X	
	fre.v	(Hz)	X	X		X	X	
5 bar	ΔP	(bar)	0,272	X		0,229	0,228	0,346
	fre.p	(Hz)	151,50	X		146,10	425,00	275,00
	ΔV	(mV)	X	X		X	X	
	fre.v	(Hz)	X	X		X	X	
6 bar	ΔP	(bar)	0,322	X	0,313	0,324	0,259	
	fre.p	(Hz)	152,20	X	203,00	145,50	424,00	
	ΔV	(mV)	X	X	X	X	X	
	fre.v	(Hz)	X	X	X	X	X	
7 bar	ΔP	(bar)	0,386	0,094		0,314	0,281	
	fre.p	(Hz)	151,70	422,00		145,50	425,00	
	ΔV	(mV)	X	X		X	X	
	fre.v	(Hz)	X	X		X	X	
8 bar	ΔP	(bar)	0,432	0,178	0,520	0,322	0,311	0,937
	fre.p	(Hz)	152,60	426,00	208,00	145,50	426,00	208,00
	ΔV	(mV)	X	X	X	X	X	X
	fre.v	(Hz)	X	X	X	X	X	X

PRESSURE AND VELOCITY SIGNALS

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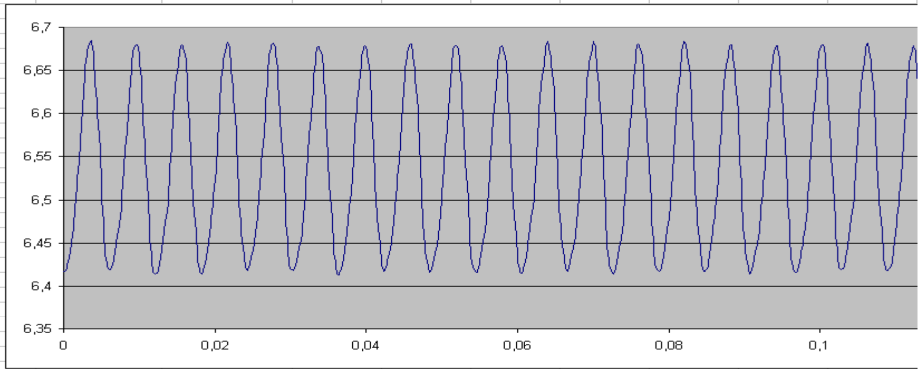
ΔP_{max} = 0,319 bar

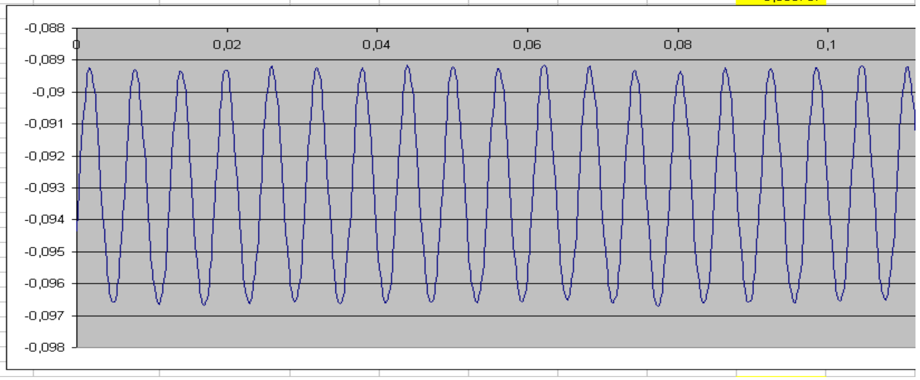
ΔV_{max} = 3,670 mV

P Fréquence	T Fréquence	dephasasage	Comment
165,46	165,46	-95,04	



ΔP = 0,319

6,68492
6,680865
6,663022
6,660995
6,656534
6,626121
6,624499
6,620444
6,586787



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INDUCTION SYSTEM

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WITH SOLID PISTON

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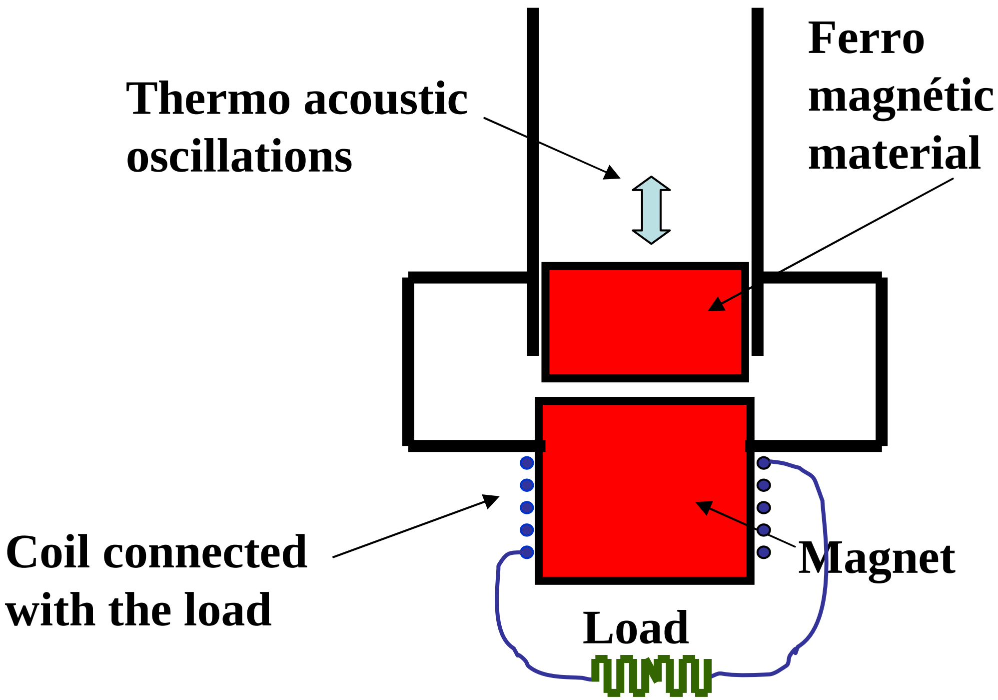

Induction system

No electrode
Adjustable voltage and intensity
Adaptability with the load

WITH LIQUID PISTON: INDUCTIVE MHD PROCESS

PRINCIPLES OF THE PROCESS

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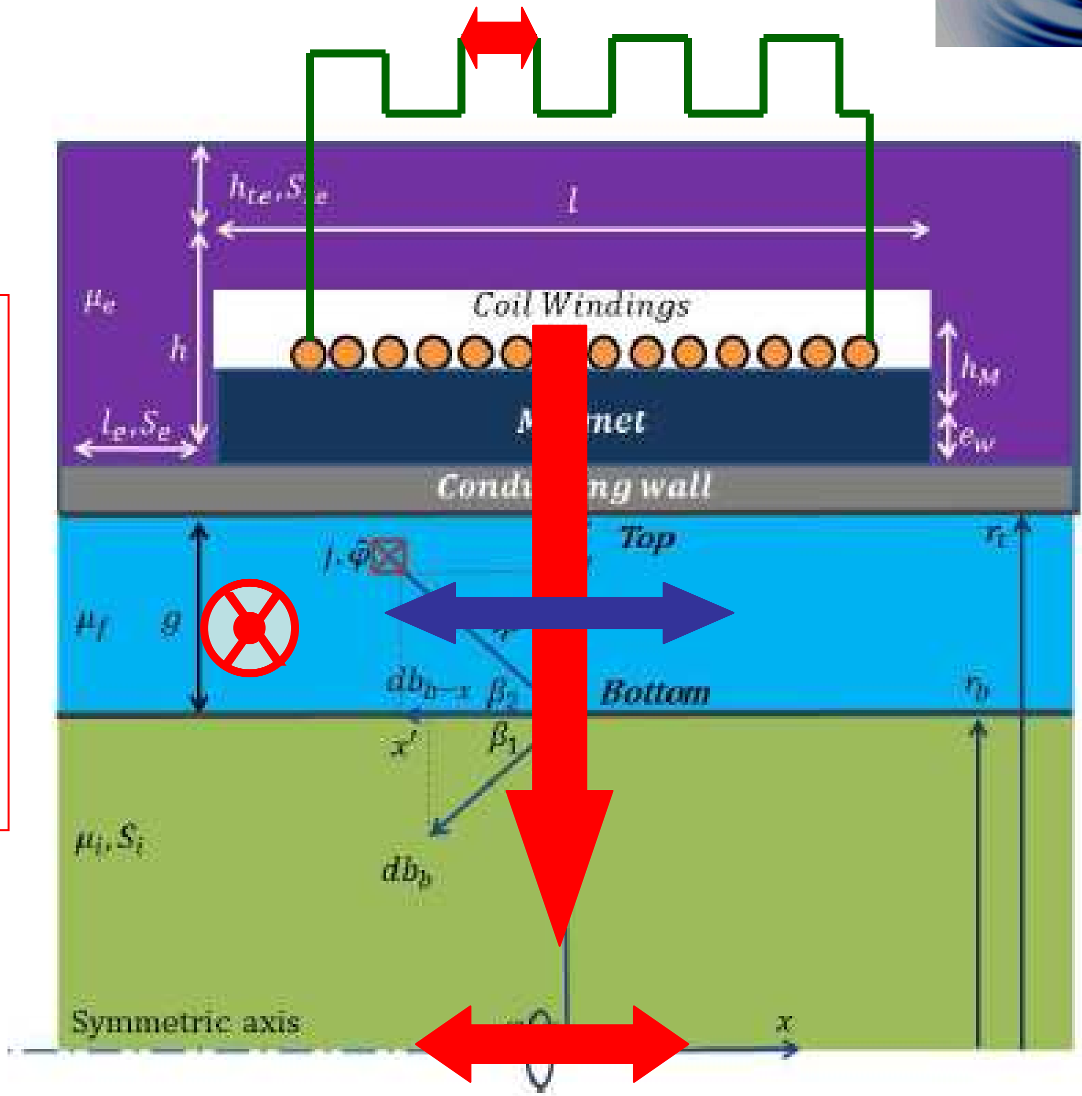
The interaction between the applied magnetic field with the pulsating flow generates and pulsating electrical current and a pulsating induced magnetic field in the core of the generator. The pulsation of magnetic flux induces an pulsating current in the coil connected with the load



EQUATIONS AND NON DIMENSIONAL NUMBERS

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Dimensionless analysis:

Characteristic scales:

$$\begin{cases} length = d \\ Magnetic\ Field = B_0 \\ Time = \frac{1}{\omega} \\ Velocity = \omega d \\ Current\ density = \frac{B_0}{\mu_0 . d} \\ Current = \frac{B_0 d}{\mu_0} \\ Electric\ field = B_0 d\omega \\ Electrical\ resistance = \frac{1}{\sigma d} \\ Electrical\ power = \frac{B_0^2 d}{\mu_0^2 \sigma} \end{cases}$$

Simplified equations

Navier-Stokes equation:

$$iu^* = -K_p + \frac{1}{R_\omega}.\left(\frac{\partial^2 u^*}{\partial r^{*2}}\right) + \frac{1}{R_\omega}.\left(\frac{\partial u^*}{r^* \partial r^*}\right) + \frac{N}{R_m}.\frac{\partial b_x^*}{\partial r^*}$$

Induction equation:

$$ib_x^* = \frac{u^*}{r^*} + \frac{\partial u^*}{\partial r^*} + \frac{1}{R_m}.\frac{\partial b_x^*}{r . \partial r^*} + \frac{1}{R_m}\frac{\partial^2 b_x^*}{\partial r^{*2}}$$

$$r = r_{ch} \gg a$$

Constants:

$$K_p = \frac{\Delta p}{L_B \rho \omega^2 d}$$ Dimensionless imposed pressure:

$$R_\omega = \frac{\rho \omega d^2}{\vartheta}$$ Reynolds number: Ratio of inertia forces to viscous forces

$$R_m = \mu_0 \sigma \omega d^2$$ Magnetic Reynolds number: Ratio of characteristic time of Magnetic field diffusion to convection

$$N = \frac{B_0^2 \sigma}{\omega \rho}$$ Interaction parameter: Ratio of electromagnetic forces over inertia forces

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BOUNDARY CONDITIONS

(1) Lower BC
b_{b-x} consists of:

1. b_{b-x1}: Because of induced current inside the fluid
2. b_{b-x2}: Because of induced current inside the wall
3. b_{b-x3}: Because of current in the load

(2) Upper magnetic BC

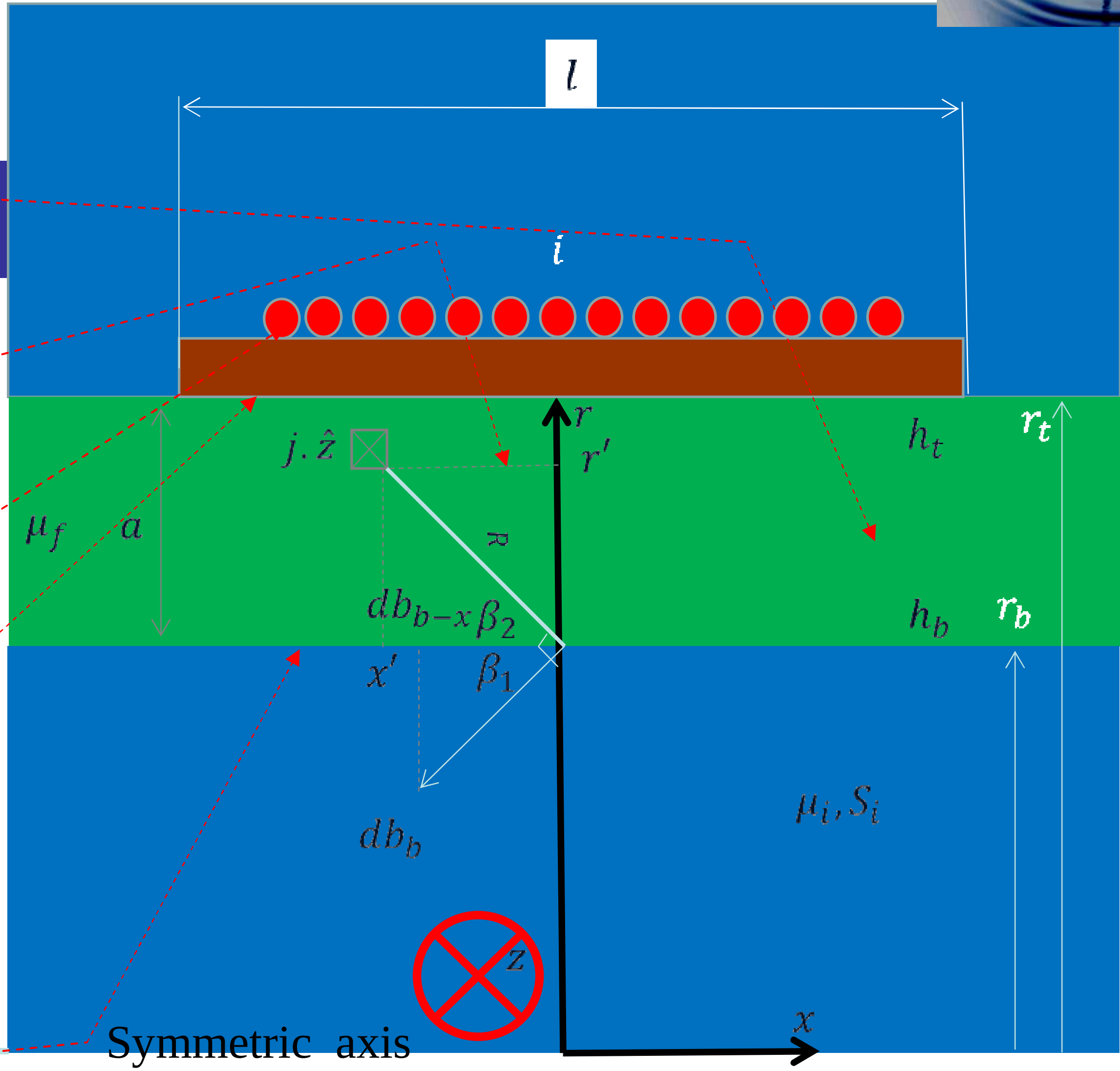
$b_t = f(b_b)$

(3) Upper velocity BC

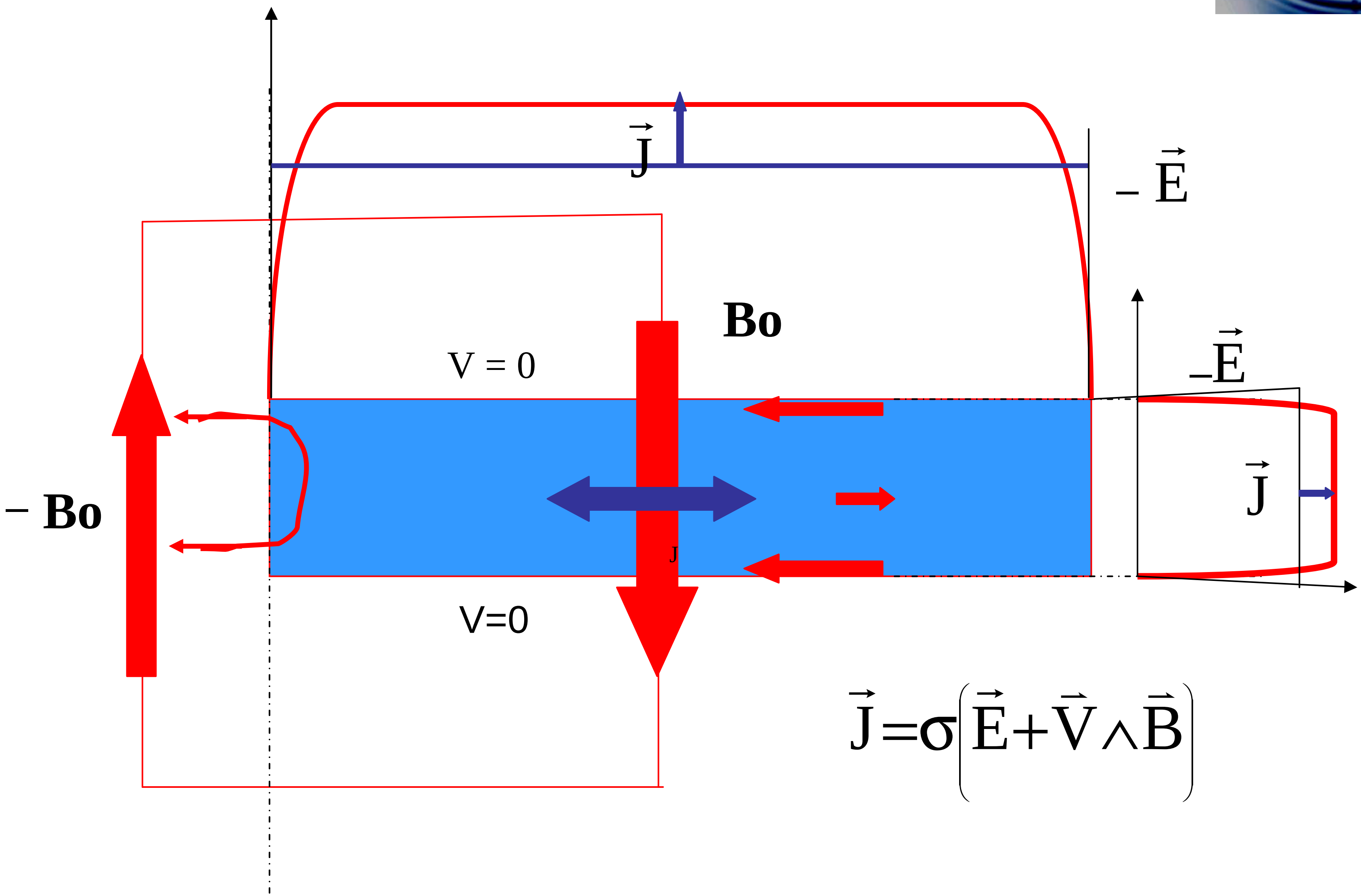
$u_t = 0$

(4) Lower velocity BC

$u_b = 0$



REMARKS ABOUT THE END EFFECTS



$$\vec{J} = \sigma\left(\vec{E} + \vec{V} \wedge \vec{B}\right)$$

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SOME RESULTS

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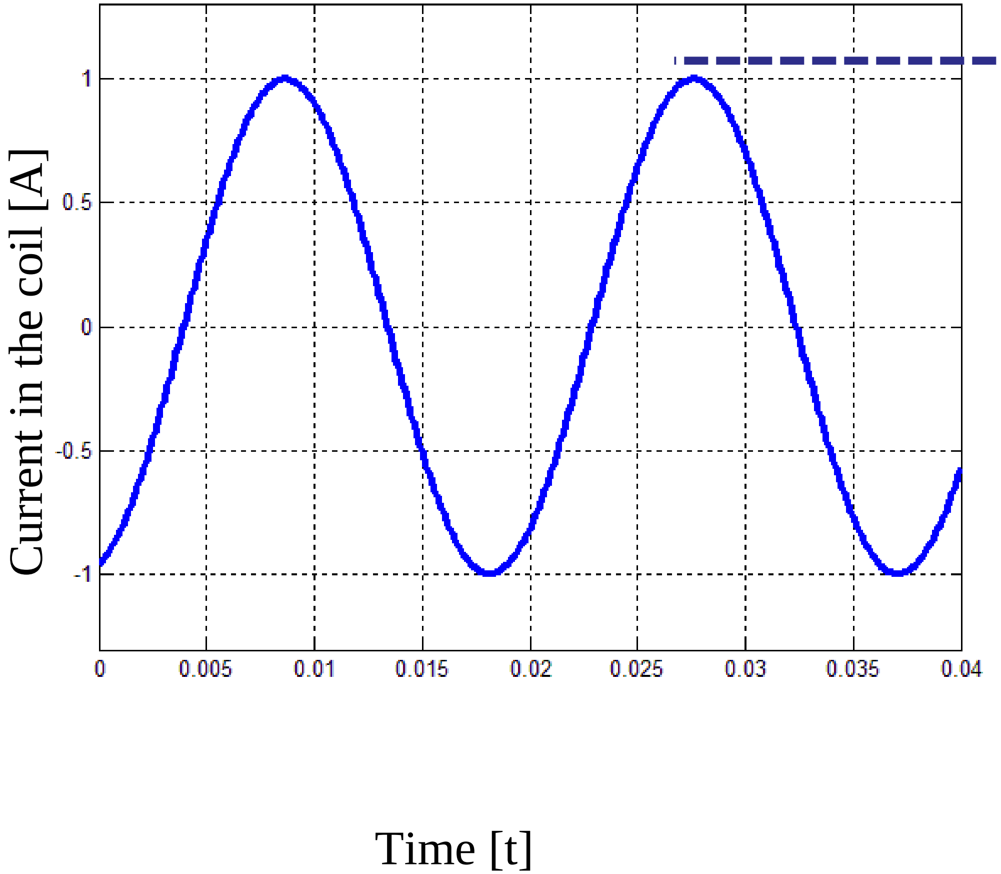


$\text{Analytical} = -1.02 \; - j0.265 \; [A]$

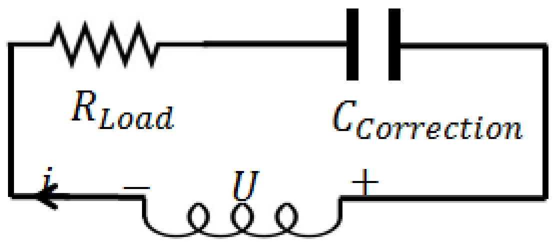
$\text{Numerical} = -1.096 \; - j0.253 \; [A]$

$R_{Load} = 322\Omega$

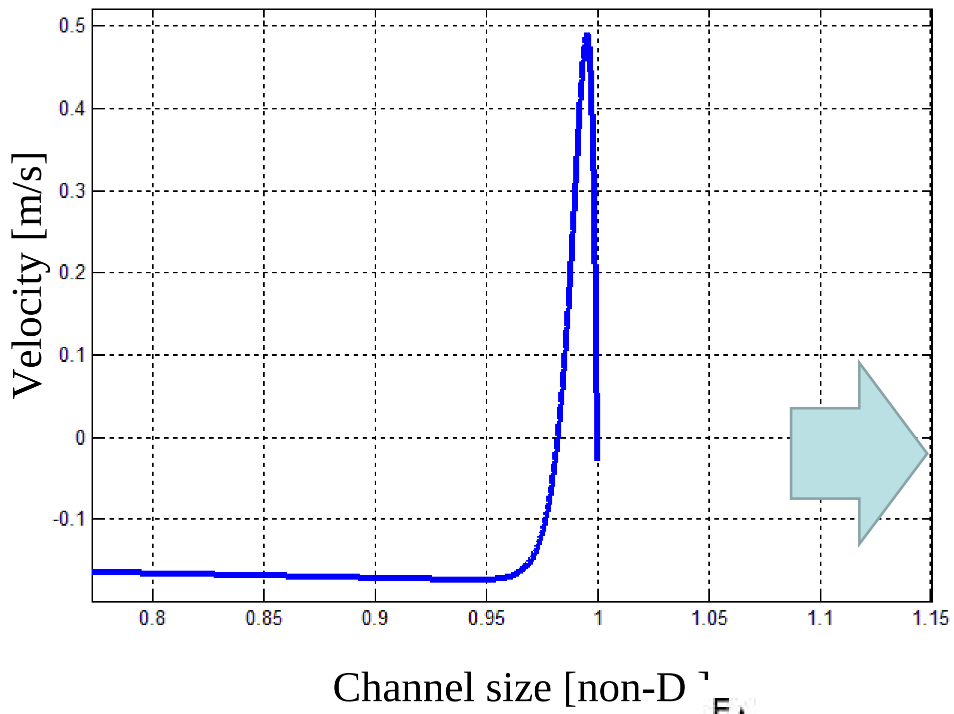
$r_{Coil} = 21\Omega$

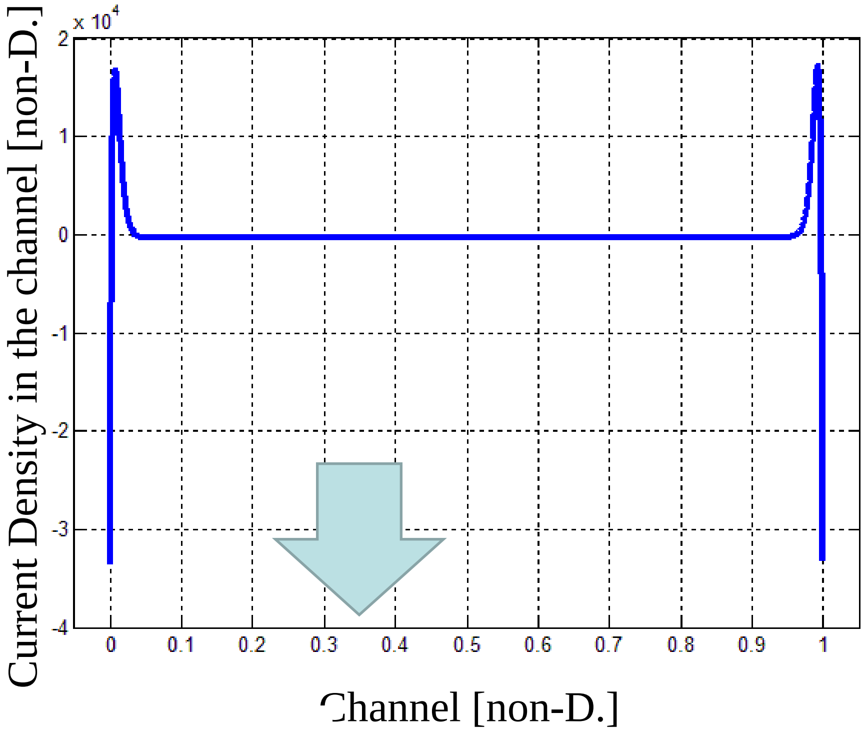
$C = 39\mu F$

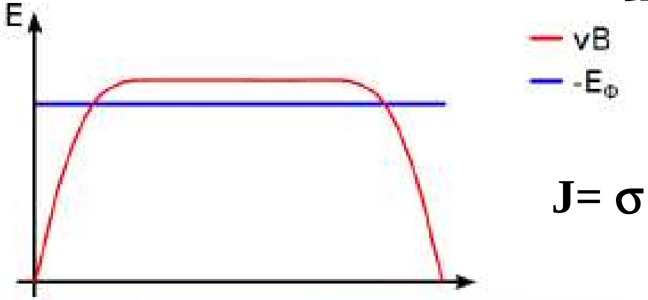
$Coil\ turns = 400$



REVERSED FLOW PHENOMENA NOT ACCESSIBLE BY THE NUMERICAL ANALYSIS

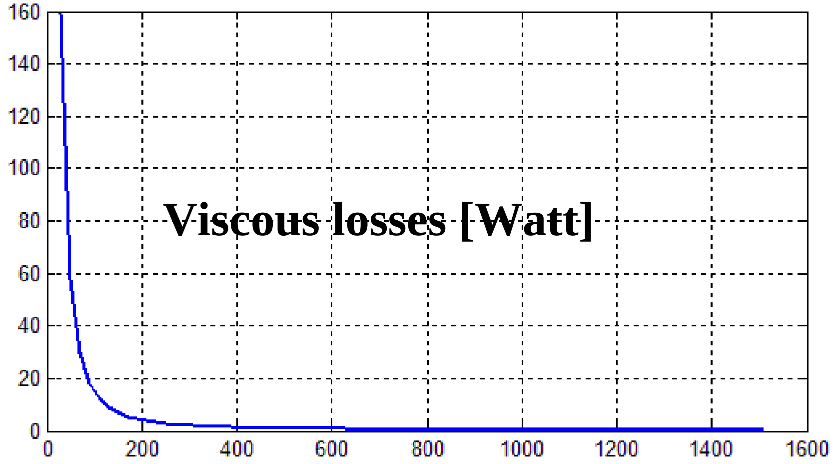


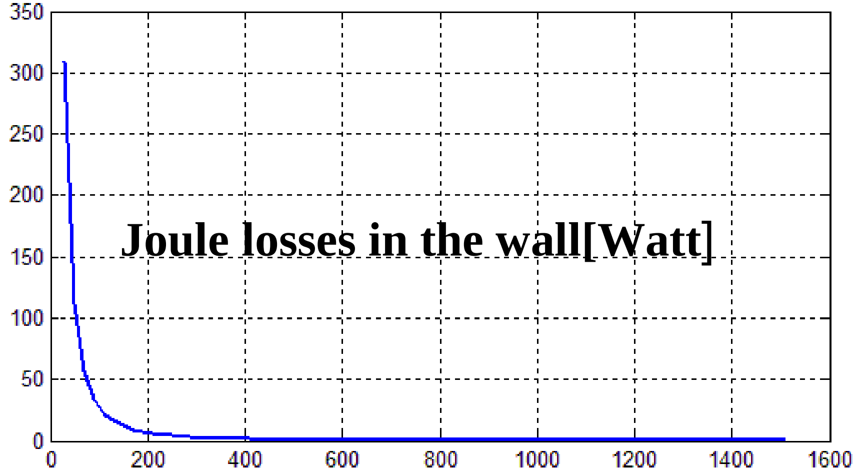


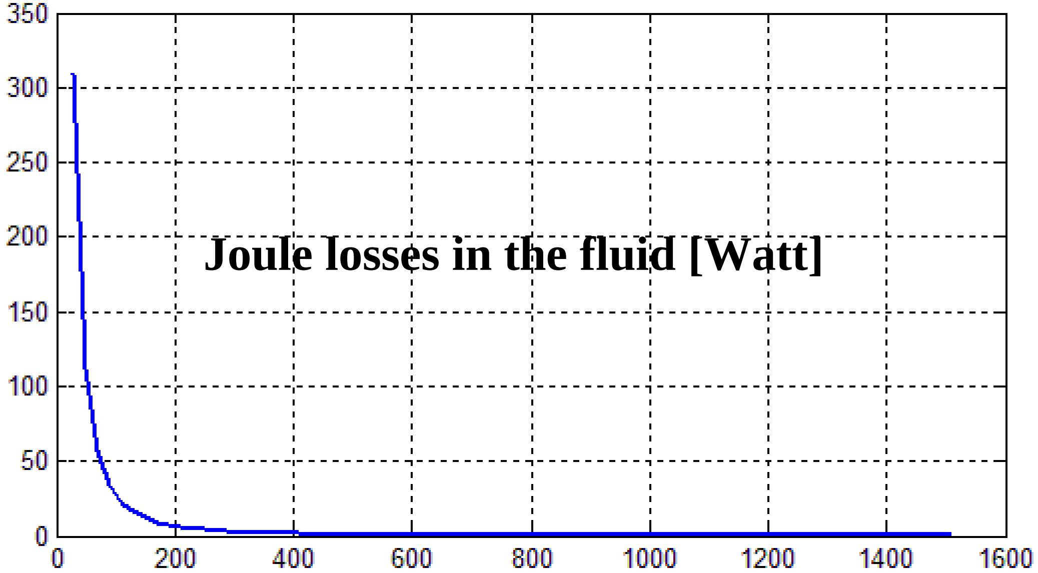


$$J = \sigma (E + V \wedge B)$$

EVOLUTION VERSUS THE FREQUENCY







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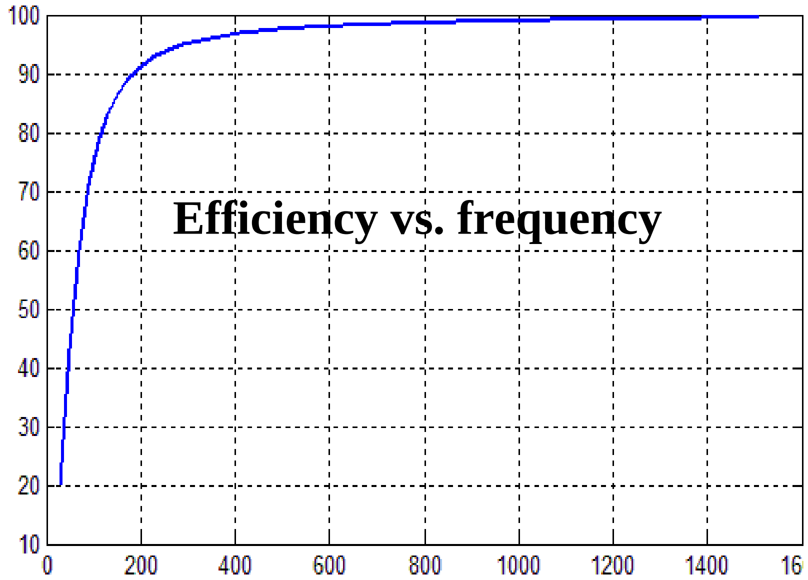
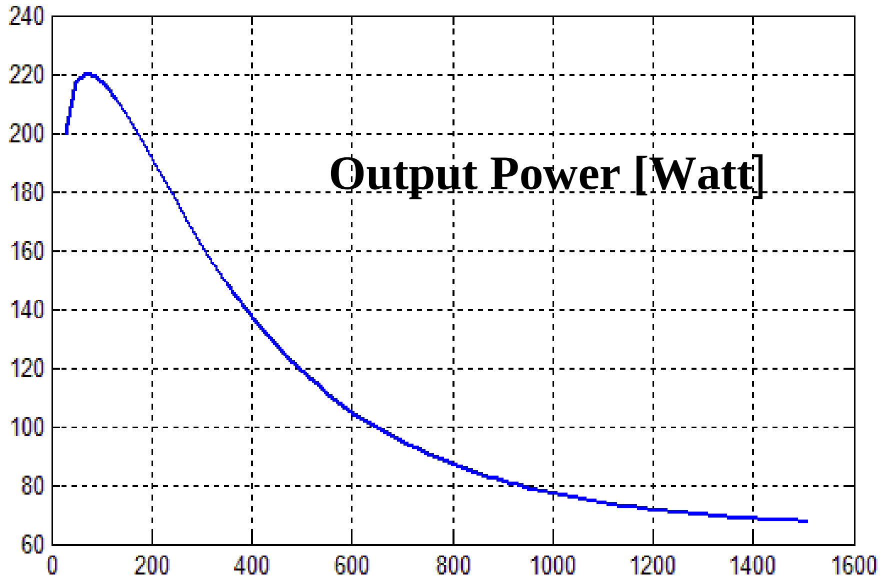
POWER AN EFFICIENCY VERSUS THE FREQUENCY





OUTPUT POWER VERSUS CAPACITANCE AND RESISTANCE VALUES

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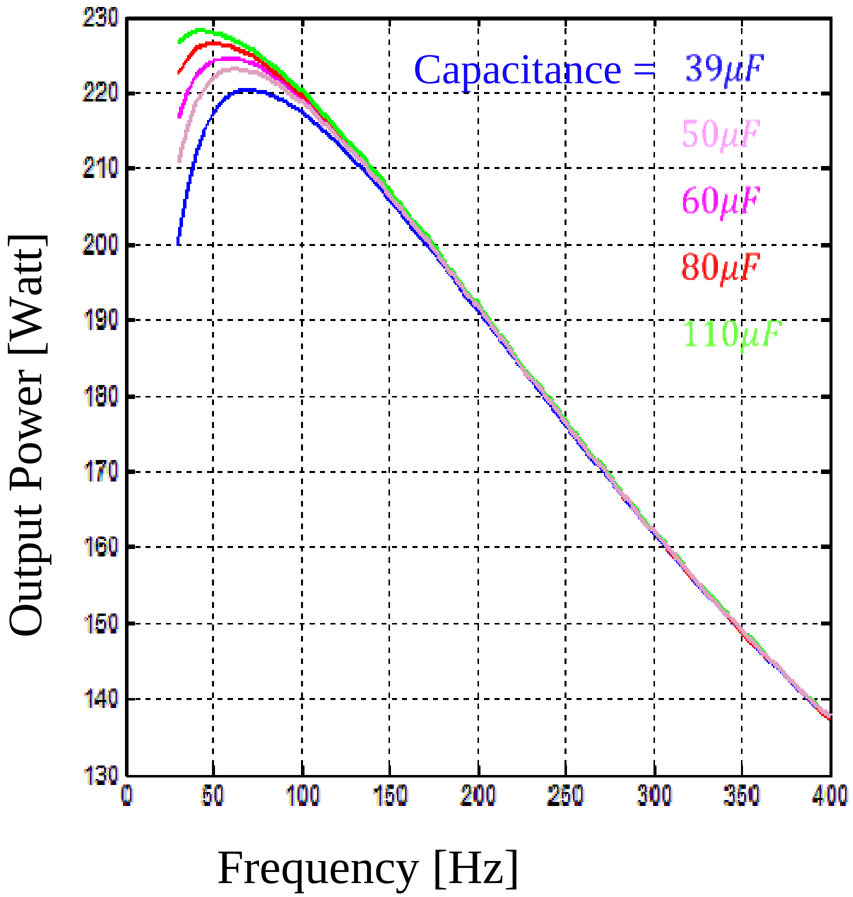
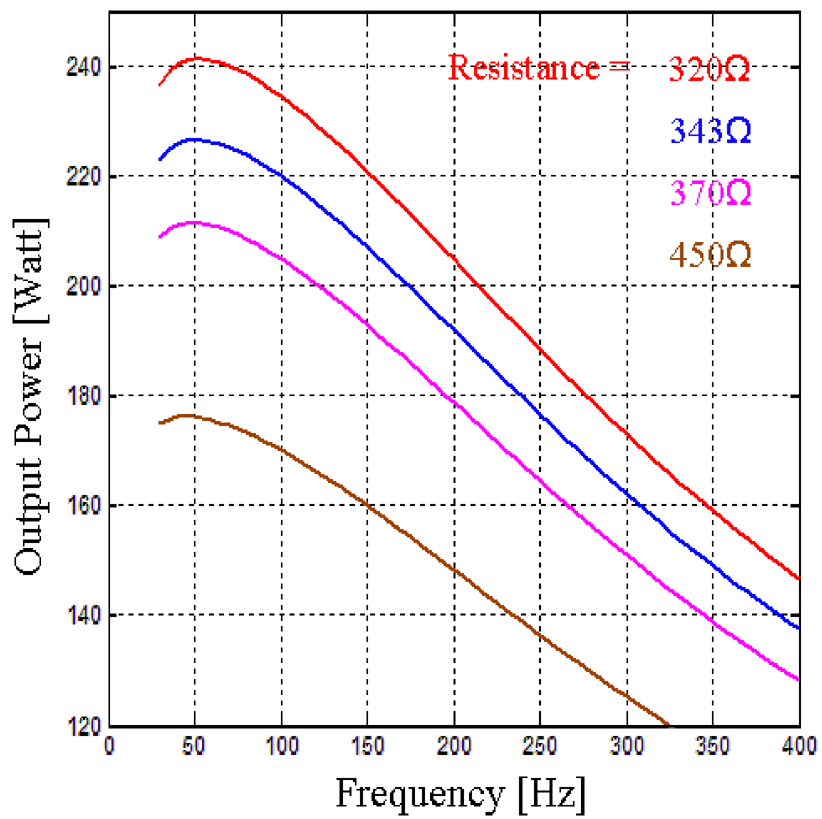


C = 80 μF



CONCLUSION

- The MHD generator is exempt of any mechanical moving part

-The construction is extremely simple and so the reliability excellent for space

-The electricity is generated at useful AC intensity and voltage

- The adaptation to the load is easy

-The option chosen is certainly non optimised

-The possibility of improved efficiency is important