Société Française de Thermique
Société Française d'Acoustique
Groupe de Recherche Thermoacoustique

Groupe Énergétique et Thermodynamique – SFT
Groupe Instrumentation et Signal - SFA

Générateur thermo acoustique MHD pour la production directe d'électricité

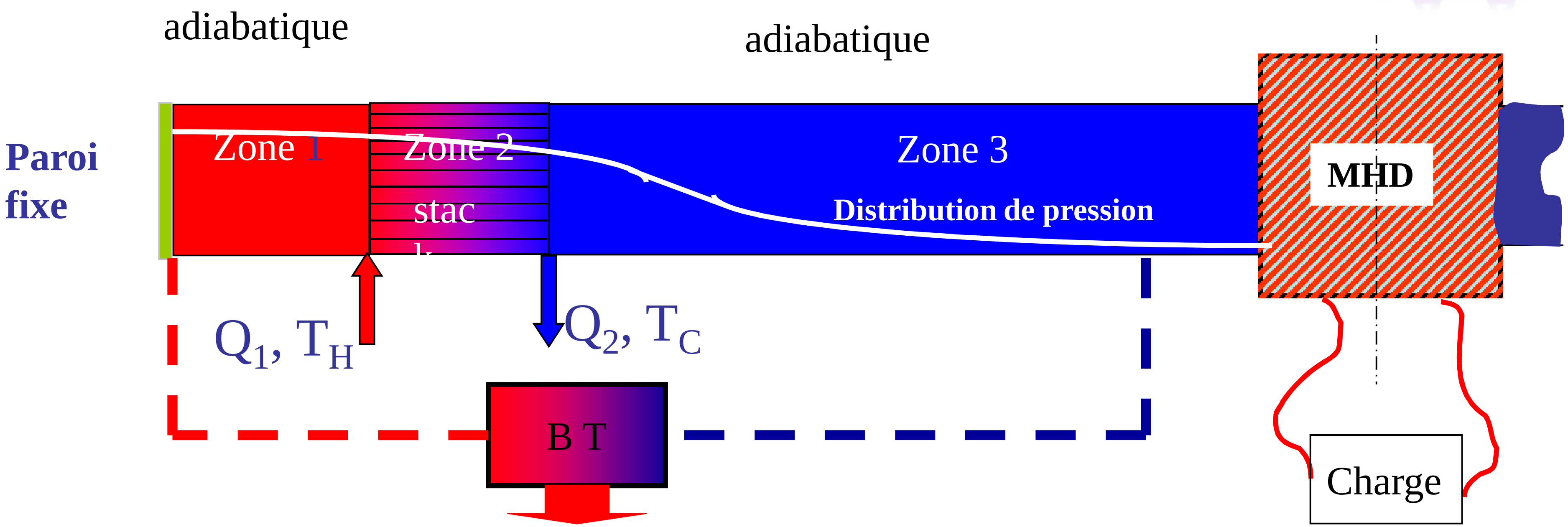
A Alemany
A Krauze

SFT SFA Presentation Paris le 10 12 2010

PLAN DE L'EXPOSE

1- La problématique

LA PROBLEMATIQUE



Production directe d’énergie électrique à partir d’énergie thermique

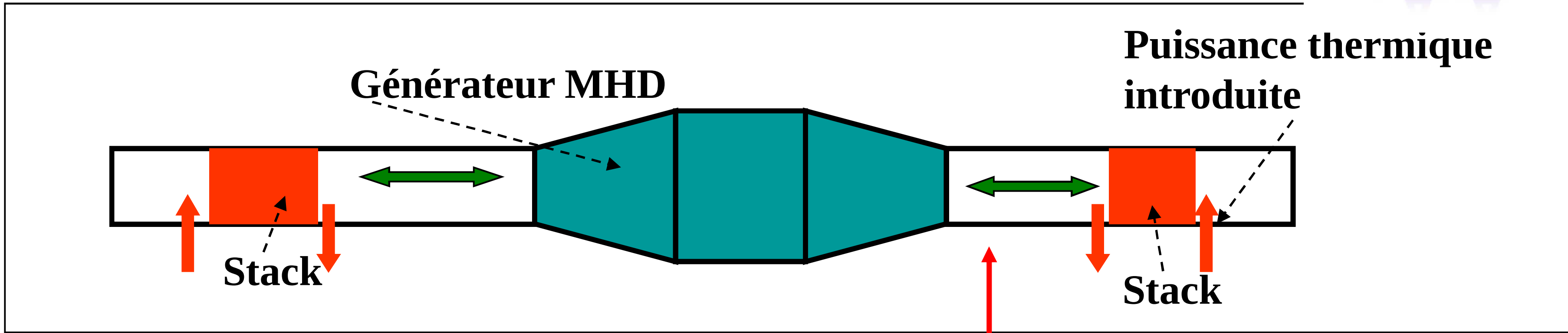
-Association d’un générateur thermo acoustique avec un générateur électrique MHD

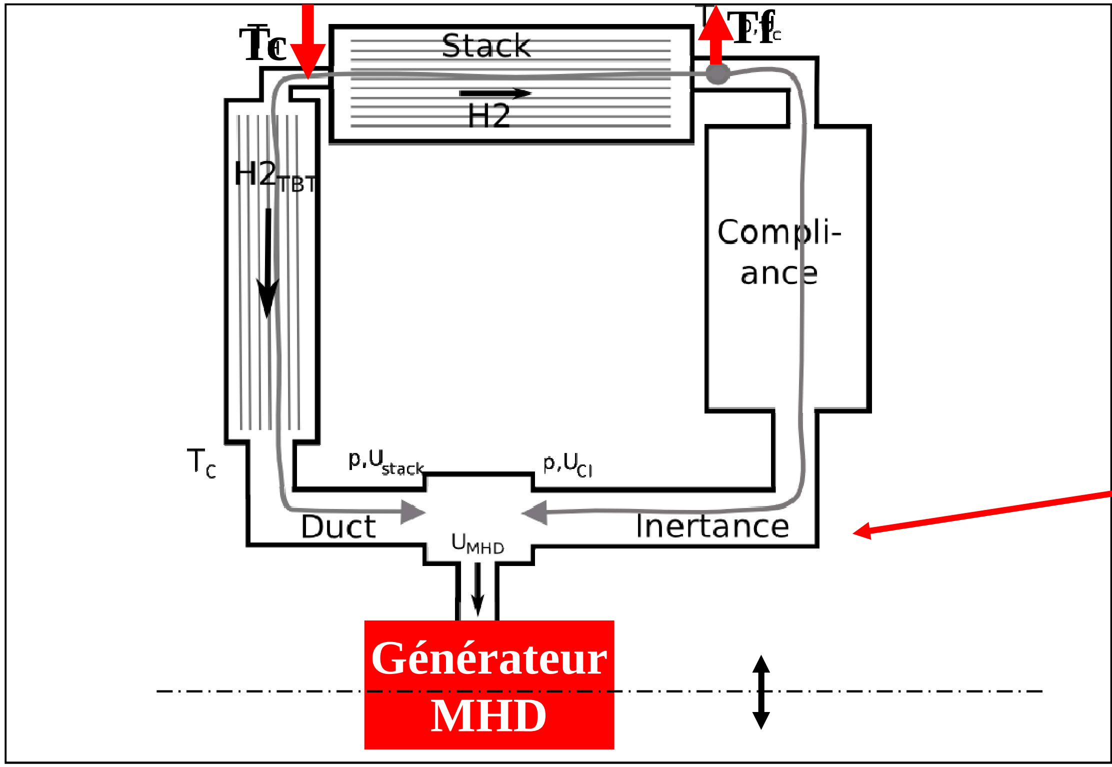
-Avantage: Pas de pièce mécanique mobile, système quasi statique

-Système adapté à l’utilisation en site isolé (Espace,…)

Optimisation du rendement énergétique
Réduction du poids.

LES 2 OPTIONS





Deux types de machines

ONDES STATIONNAIRE

ONDES PROGRESSIVES

2-Eléments de thermo acoustique

EQUATIONS LINEARISEES

- Supposition of all parameters linearized to first order : $X = X_m + X'.e^{i\omega t}$

Mean value — Perturbation

- Supposition of all calculations linearized to first order (primes products neglected)

$$
\left.
\begin{aligned}
p &= p_m + \mathrm{Re}\left(p'(x).e^{i\omega t}\right) \\
u &= \mathrm{Re}\left(u'(x,y).e^{i\omega t}\right) \\
T &= T_m(x) + \mathrm{Re}\left(T'(x,y).e^{i\omega t}\right) \\
\rho &= \rho_m(x) + \mathrm{Re}\left(\rho'(x,y).e^{i\omega t}\right) \\
S &= S_m(x) + \mathrm{Re}\left(S'(x,y).e^{i\omega t}\right)
\end{aligned}
\right\} \longrightarrow
$$

$$i\omega\rho' + \frac{\partial}{\partial x}(\rho_m u') + \frac{\partial}{\partial y}(\rho_m v') = 0$$

$$i\omega\rho_m u' = -\frac{dp'}{dx} + \mu\left(\frac{\partial^2 u'}{\partial x^2} + \frac{\partial^2 u'}{\partial y^2}\right)$$

$$i\omega\rho_m T_m S' + \rho_m T_m u' \frac{dS_m}{dx} = K\left(\frac{\partial^2 T'}{\partial x^2} + \frac{\partial^2 T'}{\partial y^2}\right)$$

$$\rho' = \rho_m \chi_T p' - \rho_m \beta T'$$

- Exception for energy equation : energies are second order parameters

EQUATIONS PRINCIPALES

$$\frac{dU}{dx} = -Ap + B\frac{dT_m}{dx}U$$

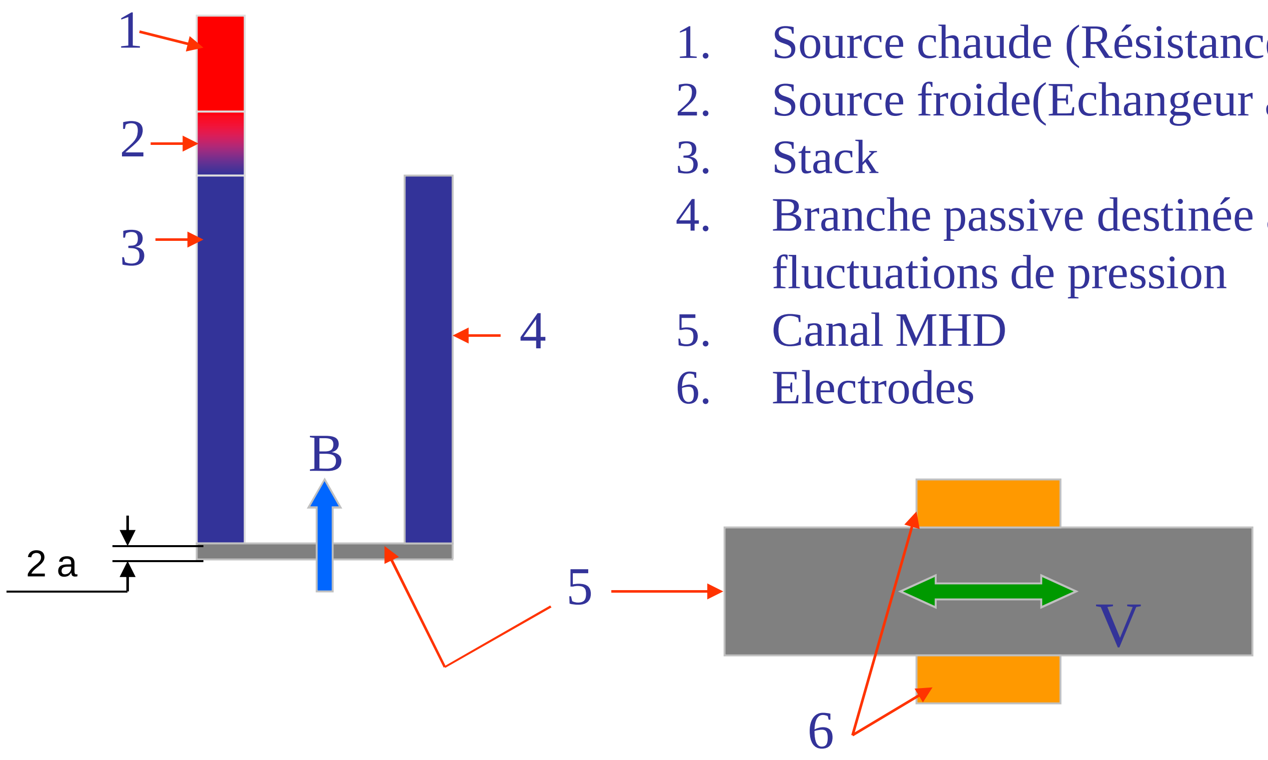
$$\dot{H}_2 = C\,\mathrm{Re}[p\,\tilde{U}] + \left(D\,|U|^2 - K\,A_{gas} - K_s\,A_{solid}\right)\frac{dT_m}{dx}$$

$$\frac{dp}{dx} = -EU$$

These equations model the evolution of the complex amplitudes p and U of the pressure and volume flow waves and the mean temperature Tm along the longitudinal direction x of the Generator element, and H'_2 is the enthalpy flow in the element. K and K_s are the heat conductivities of the fluid and the stack material. A_{gas} and A_{solid} are gas and solid material cross section areas. The complex coefficients A, B, E and real coefficients C, D are determined by the geometry of the machine, the type of the generator element, and the main properties of the fluid and stack material.

3-Dispositif expérimental et résultats

DISPOSITIF EXPERIMENTAL



1. Source chaude (Résistance électrique)
2. Source froide(Echangeur à eau)
3. Stack
4. Branche passive destinée à absorber les fluctuations de pression
5. Canal MHD
6. Electrodes

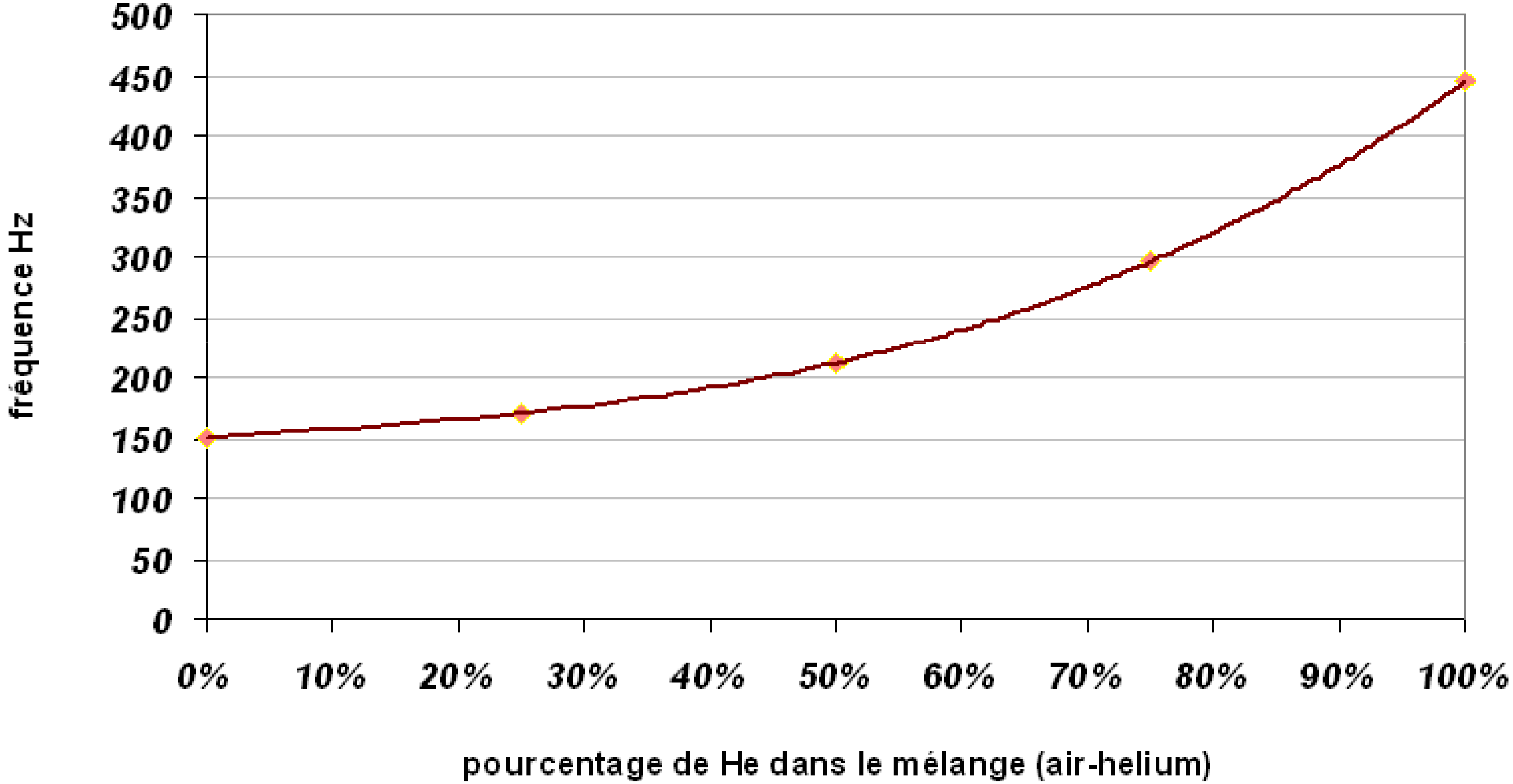
Objectifs: Validation des calculs

VUE DE L'EXPERIENCE

Le dispositif expérimental

Système de control et d'acquisition

MELANGE AIR HELIUM: EVOLUTION DE LA FREQUENCE THERMO ACOUSTIQUE



COMPARAISON DES RESULTATS

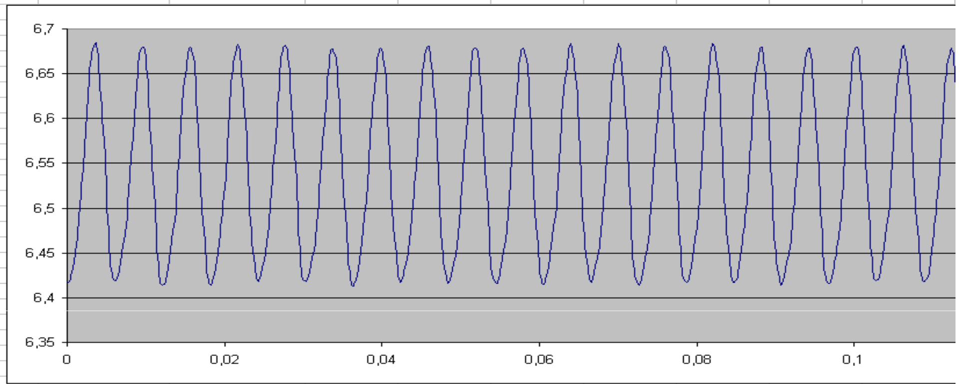
		stack en inox			stack en pot catalytique		
		Air	helium	melange	Air	helium	melange
3 bar	ΔP (bar)	0,125	X		0,245	0,120	
	fre.p (Hz)	152,50	X		147,50	427,00	
	ΔV (mV)	X	X		X	X	
	fre.v (Hz)	X	X		X	X	
4 bar	ΔP (bar)	0,210	X		0,286	0,200	
	fre.p (Hz)	151,50	X		146,50	427,00	
	ΔV (mV)	X	X		X	X	
	fre.v (Hz)	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

SIGNAUX CARACTERISTIQUES PRESSION ET TENSION

ΔP_{max} = 0,319 bar

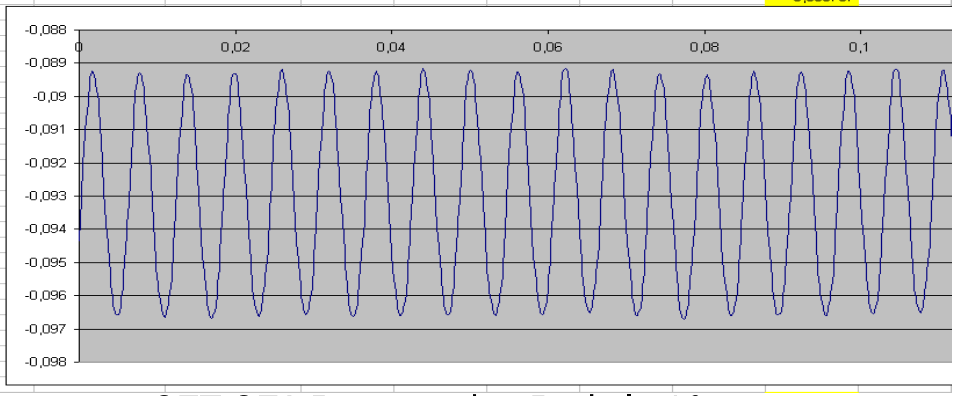
ΔV_{max} = 3,670 mV

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



ΔP = 0,319

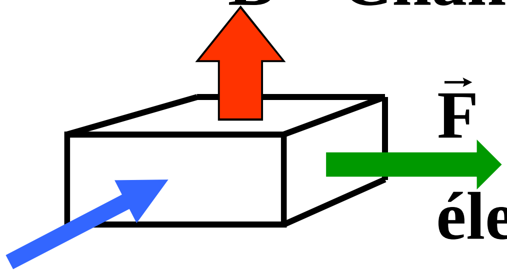
6,68492
6,680865
6,663022
6,660995
6,656534
6,626121
6,624499
6,620444
6,586787



4-Eléments de MHD

MHD: PRESENTATION GENERALE

Forces agissants sur le fluide



$\vec{B}$ Champ magnétique

$\vec{F}$ force élecromagnétique

$\vec{J}$ Courant élecrique

- -Force d'inertie
- -Force de pression
- -Force de viscosité
- -Force électromagnétique

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

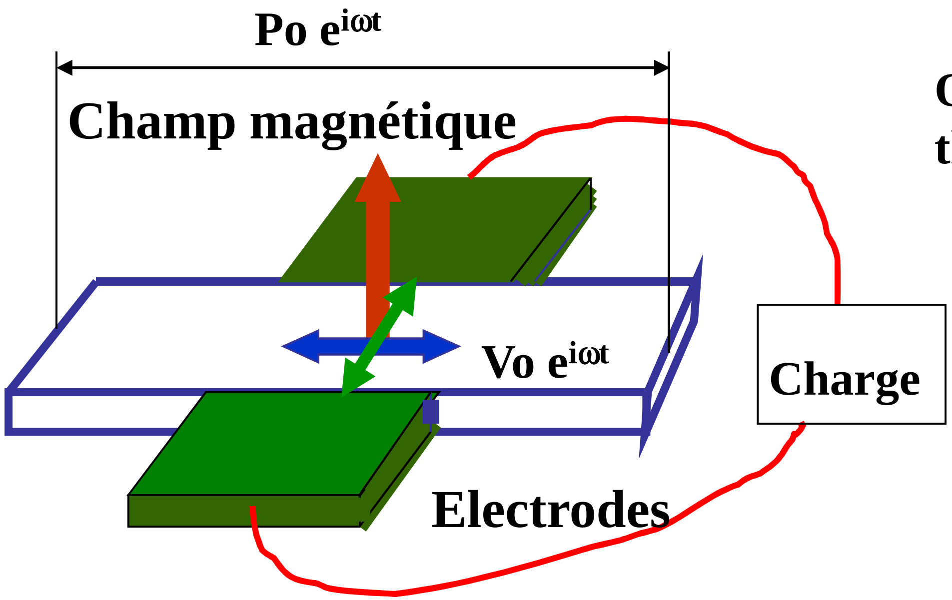
$$\mathrm{Rot}\,\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$

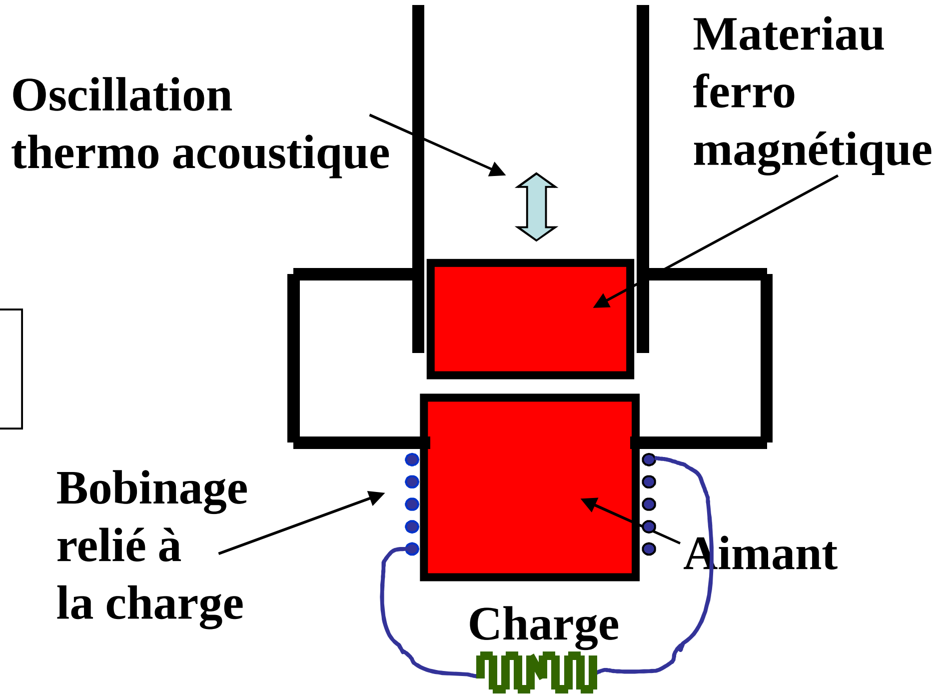
$$\mathrm{Rot}\,\vec{B} = \mu\vec{J}$$

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

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

DIFFÉRENTS TYPES DE GENERATEURS





Systèmes à conduction

Nécessité d'électrodes

Basse tension ~ 1 V

Fort courant

Difficulté d'adaptation à la charge

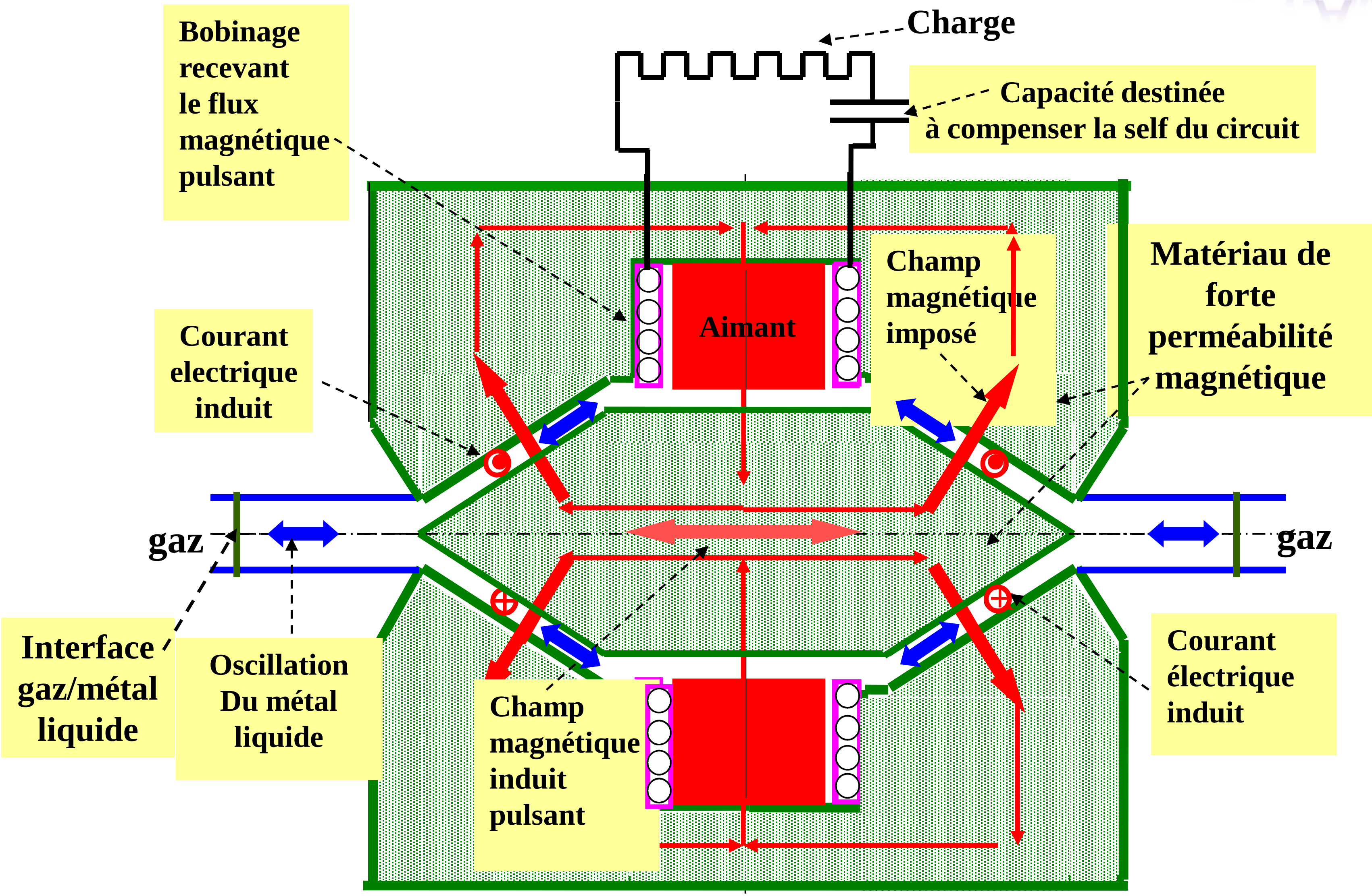
Systèmes à induction

Pas d'électrodes

Tension et courant ajustables

Bonne adaptation à la charge

GENERATEUR A INDUCTION: NOUVEAU CONCEPT



MISE EN EQUATION DU PROBLEME

Hypotheses

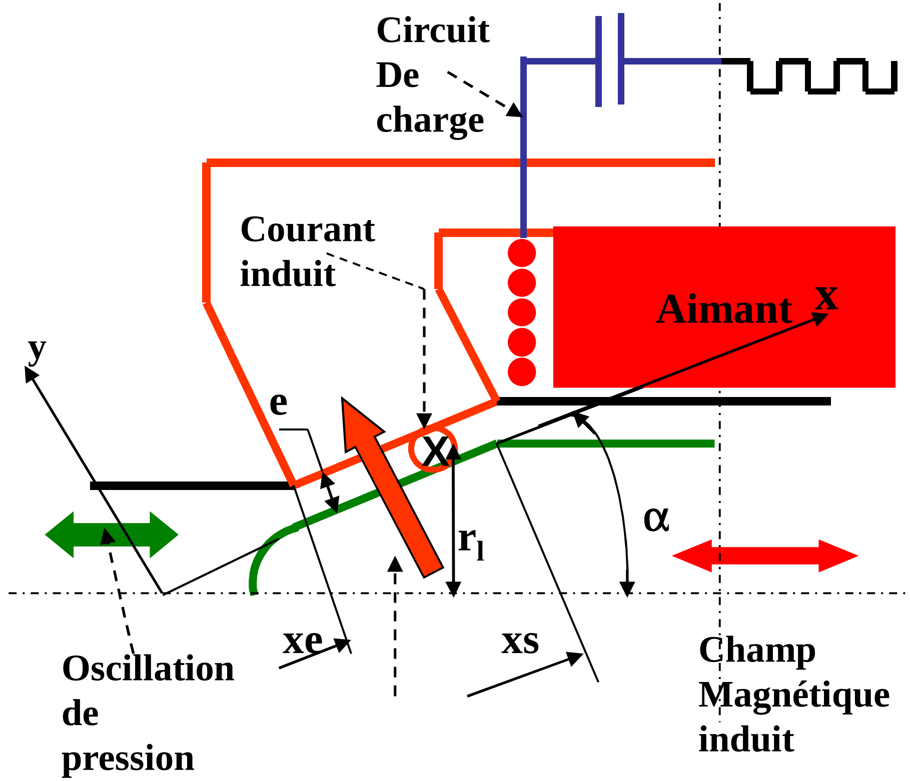
$\vec{B}=\vec{B}o+\vec{b}$ $\quad v=vo\,e^{i\omega t}$ $\quad \frac{b}{Bo}\ll 1$ $\quad \vec{b}=\vec{b}o\,e^{i\omega t}$

Equations

$$\mathrm{Rot}\,\vec{E}=-\frac{\partial \vec{b}}{\partial t} \;\Rightarrow\; E=\frac{-i\omega}{x}\int_{xe}^{x} x\,b_y\,dx \qquad \varphi=\int_{xe}^{x} x\,b_y\,dx$$

$$\mathrm{Rot}\,\vec{b}=\mu\vec{J} \;\Rightarrow\; j=\frac{1}{\mu}\frac{db}{dx}$$

$$\vec{J}=\sigma(\vec{E}+\vec{V}\wedge\vec{B}) \;\Rightarrow\; \frac{\partial}{\partial x}\left(\frac{1}{x}\frac{\partial\varphi}{\partial x}\right)+i\frac{\mu\sigma\omega}{x}\varphi=\mu\sigma VoBo$$



Conditions aux limites

$$\varphi(x=xe)=0 \qquad \frac{1}{x_s}\left(\frac{\partial\varphi}{\partial x}\right)_{x=xs}=\frac{\mu n I_o}{e}$$

Solutions

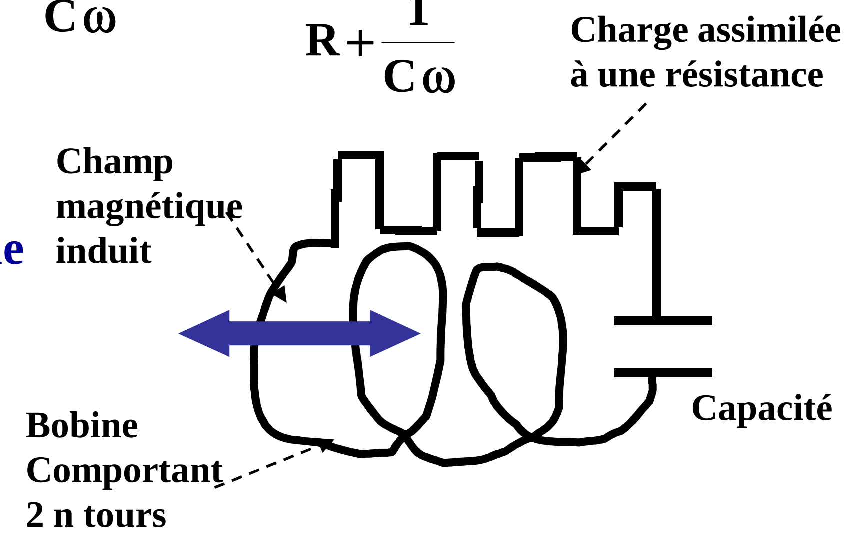
$$(2\pi\sin\alpha)\varphi=xAI_1(\gamma x)+xBK_1(\gamma x)+\frac{QoB_0}{i\omega e}$$

CIRCUIT ELECTRIQUE

Equation du circuit électrique

$$-\frac{\partial \Phi_t}{\partial t} = R\,Io + \frac{Io}{C\omega} \rightarrow -i\omega\Phi_t = R\,Io + \frac{Io}{C\omega} \rightarrow Io = -\frac{i\omega\Phi_t}{R+\frac{1}{C\omega}}$$

$$\Phi_t = (2n\pi\sin\alpha)\varphi_{x=xs}$$



Définition du rendement électrique

$$\eta = \frac{R I_o^2}{We} \qquad We = \int_{\text{Volume fluide}} \vec{F}e.\vec{V}\,dv$$

Détermination de l'énergie mécanique fournie

$$We = \int_{\text{Volume fluide}} \vec{F}e.\vec{V}\,dv$$

$$We = Qo\,Bo\left(\frac{1}{x_s}\left(\frac{\partial \Phi}{\partial x}\right)_{x=xs}\right)$$

Bilan énergétique: Le travaille des forces électromagnétiques est égal a la somme des pertes Joule dans le fluide et de l'énergie utilisée dans la charge

EVALUATION DES FLUCTUATIONS DE PRESSION

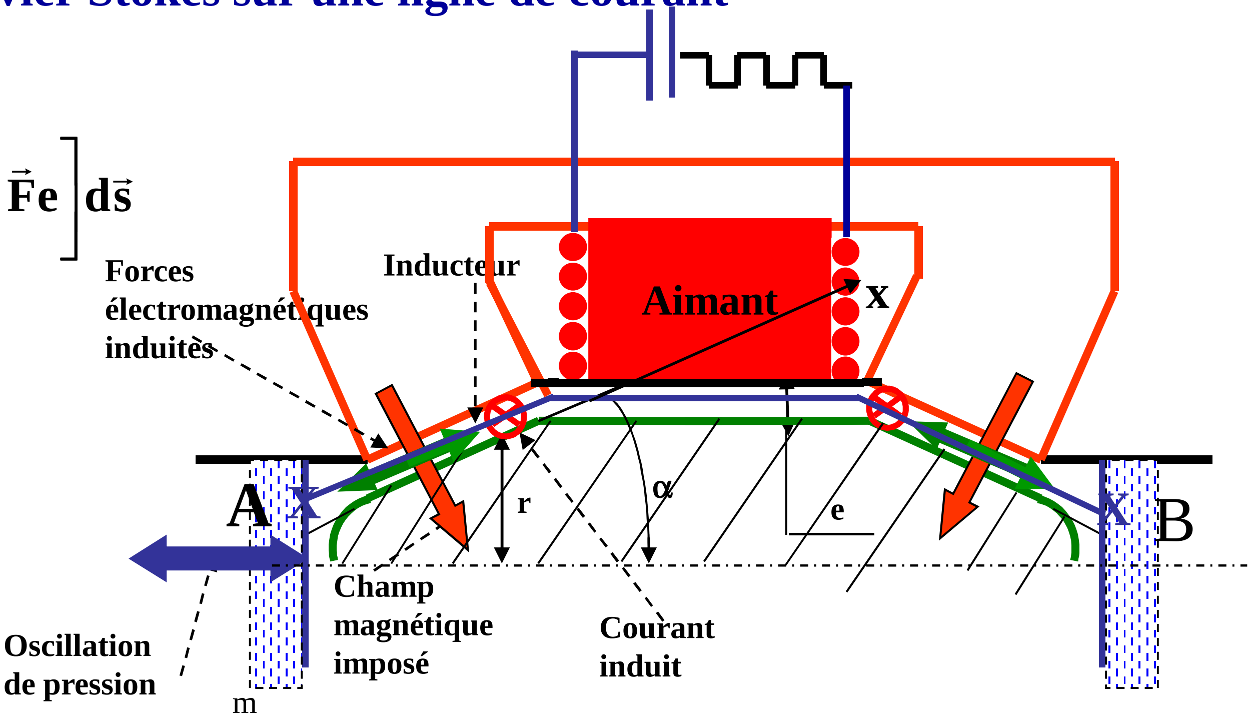
Intégration des équations de Navier Stokes sur une ligne de courant

$$\int_A^B \frac{\partial \vec{V}}{\partial t} d\vec{s} = \int_A^B \left[-\frac{1}{\rho} \left(\vec{\text{grad}} P + \rho \frac{V^2}{2} \right) + \vec{Fe} \right] d\vec{s}$$

$$2 Po\, e^{i\omega t} = \rho \int_A^B \frac{\partial \vec{V}}{\partial t} d\vec{s} + \rho \int_A^B \vec{Fe}\, d\vec{s}$$

$$2 Po = \rho \int_A^B i\, \omega\, V_{io(s)}\, ds + \rho \int_A^B Fe_{io}\, ds$$

BILAN



$$\frac{\partial}{\partial x}\left(\frac{1}{x}\frac{\partial \varphi}{\partial x}\right) + i\frac{\mu\sigma\omega}{x}\varphi = \mu\sigma Vo Bo \longrightarrow b = f(Io)$$

$$-\frac{\partial \Phi_t}{\partial t} = R\, Io + \frac{Io}{C\omega} \longrightarrow Io$$

$$2 Po = \rho \int_A^B i\, \omega\, V_{io(s)}\, ds + \rho \int_A^B Fe_{io}\, ds \longrightarrow Po$$

Résolution numérique par MATLAB

EQUATIONS PRINCIPALES DU GENERATEUR MHD

$$\frac{db}{dx} + \frac{e'}{e} b - \frac{i\omega\mu_0\sigma}{r} \int_0^x br dx' = -\mu_0 \sigma v B$$

$$-b_s e_s = \mu_0 N I_R$$

$$-i\omega\Phi_t = R\, I_R - \frac{i I_R}{C\,\omega}$$

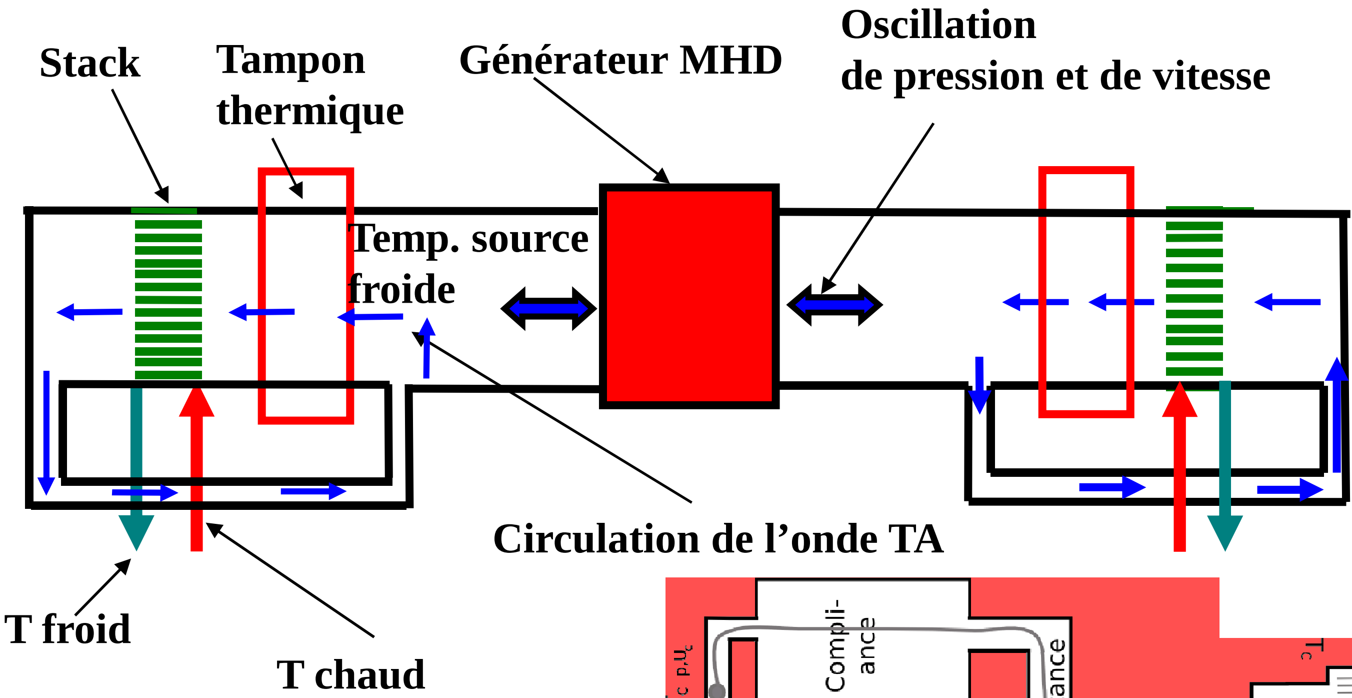
$$-2p_{in} = -\rho \int_A^B i\,\omega\, v\, ds + \rho \int_A^B f_{EM}\, ds$$

In these equations, b represents the amplitude of the induced magnetic field component that is perpendicular to the longitudinal direction x along a narrow gap (bs is its value at the gap exit), B is the perpendicular component of the imposed permanent magnetic field, r is the distance of a gap element to the symmetry axis (radius), and e is the gap thickness (es is the gap thickness at the gap exit). ϕt is the total magnetic flux crossing the N wires of the coil connected to the load; σ is electric conductivity of the liquid metal in the generator, and v is the amplitude of the velocity fluctuations. R, IR, and C are respectively the load resistance, the induced current on the load, and the capacitance used to improve the efficiency of the generator by compensation of the self.

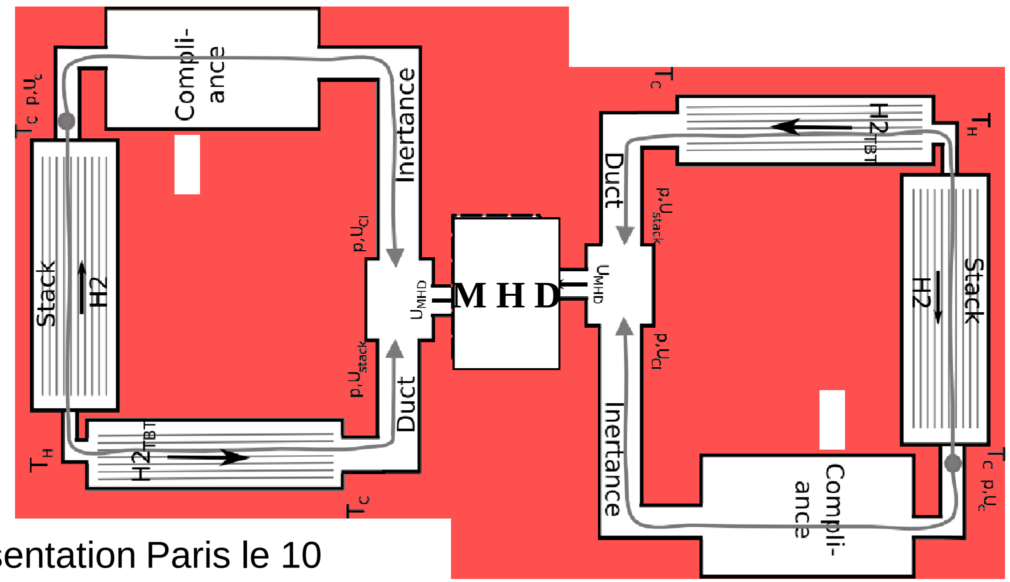
5-Le système global envisagé

STRUCTURE GENERALE

**Générateur MHD localisé entre
2 générateurs thermo acoustique à onde progressive**



Configuration générale du générateur Thermo acoustique(Stirling)

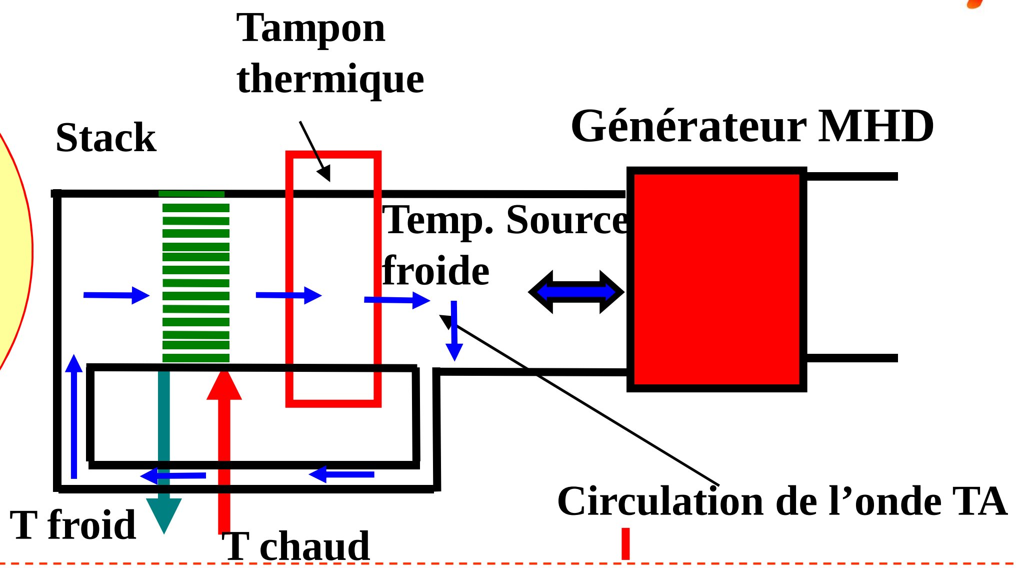


6- Le couplage thermo acoustique/MHD

LE COUPLAGE

P = Z V MHD

P = Z V TA



Principales caractéristiques de la source chaude et paramètres électriques

Module thermo acoustique

Conditions d’entrée dans Le module TA

Module générateur MHD

Donne amplitudes des fluctuations de vitesse et pression

Conditions de cohérence avec les hypothèses

PARTIE 2

PARTIE 1

LE COUPLAGE:
BASE SUR LA NOTION D'IMPEDENCE

<u>Méthode de calcul:</u>

$$Z\ (TA) = p_{TA} / U_{TA}, \quad Z(MHD) = p_{MHD} / U_{MHD}$$

Boucle de calcul: itération sur l'annulation de la différence

$$Z(TA) - Z\ (MHD) = 0$$

Paramètres d'ajustement

Fréquence de l'onde TA
Amplitude de l'onde de pression
à l'entrée du stack

Thermo acoustique :

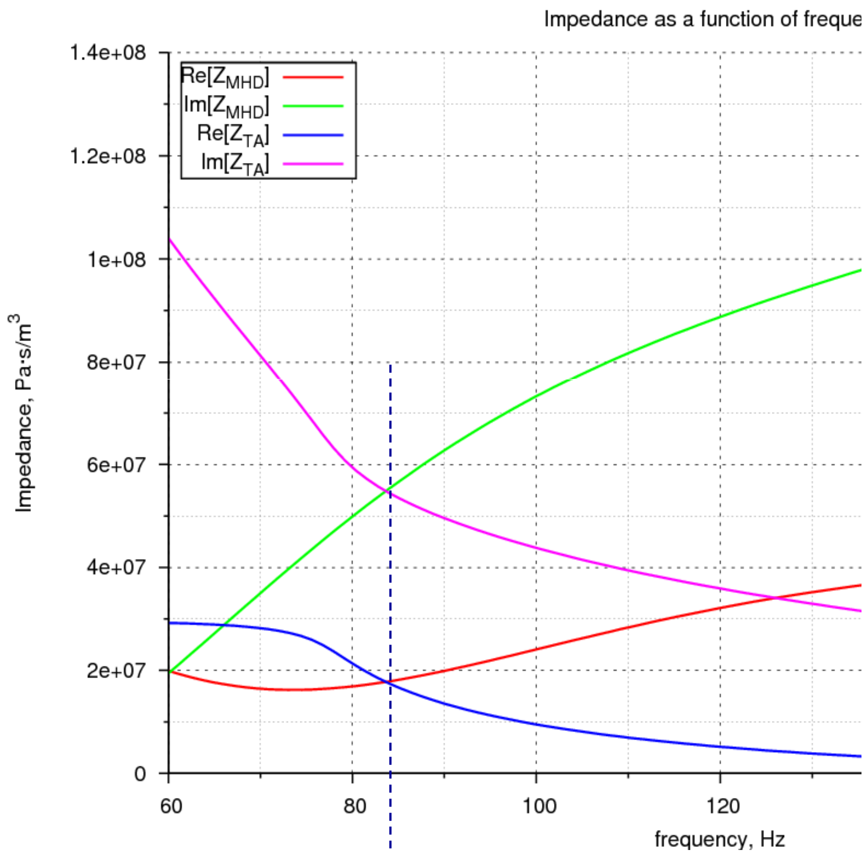
Paramètres fixés:
Géométrie
Propriétés physiques
Puissance thermique introduite
Température de source froide

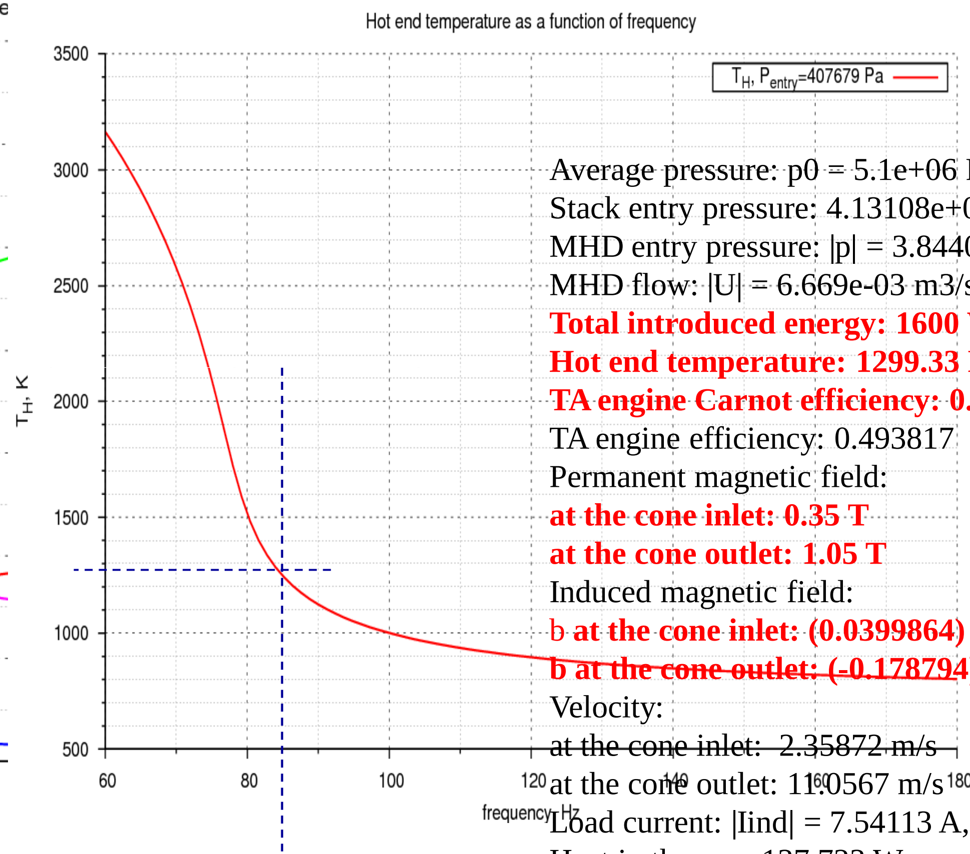
MHD

Paramètres fixés:
Géométrie
Propriétés physiques
Intensité du champ magnétique
Module du débit de sodium

UNE SOLUTION

Working frequency: 83.6362876487958Hz

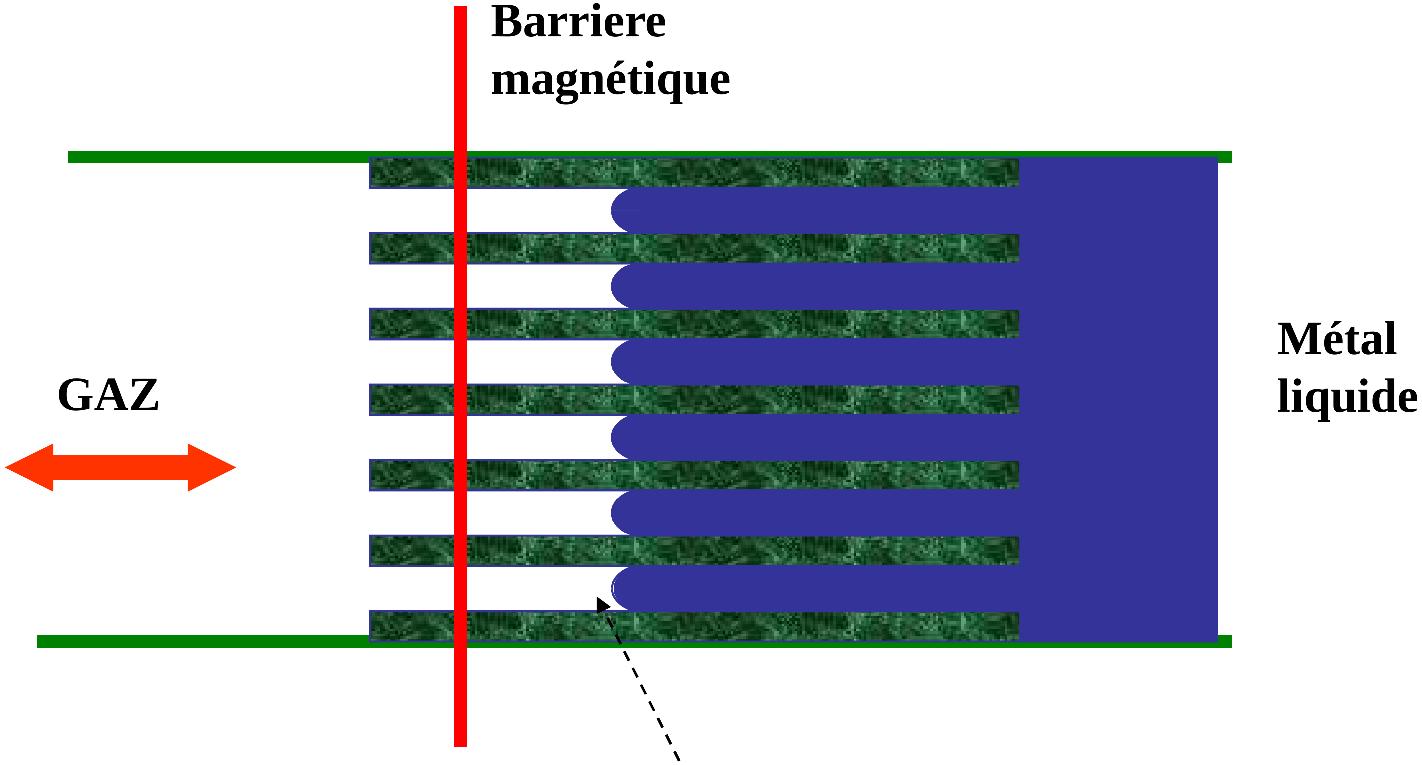




Average pressure: p0 = 5.1e+06 Pa
Stack entry pressure: 4.13108e+05 Pa
MHD entry pressure: |p| = 3.8440e+05
MHD flow: |U| = 6.669e-03 m3/s
Total introduced energy: 1600 W
Hot end temperature: 1299.33 K
TA engine Carnot efficiency: 0.65778
TA engine efficiency: 0.493817
Permanent magnetic field:
at the cone inlet: 0.35 T
at the cone outlet: 1.05 T
Induced magnetic field:
b at the cone inlet: (0.0399864) T
b at the cone outlet: (-0.178794) T
Velocity:
at the cone inlet: 2.35872 m/s
at the cone outlet: 11.0567 m/s
Load current: |Iind| = 7.54113 A,
Heat in the gap: 137.723 W
Heat on the load: 514.661 W
Total heat in the MHD engine: 790.108 W
MHD engine efficiency: 0.651381
Total efficiency rate: 0.321663125

INTERFACE LIQUIDE GAZ

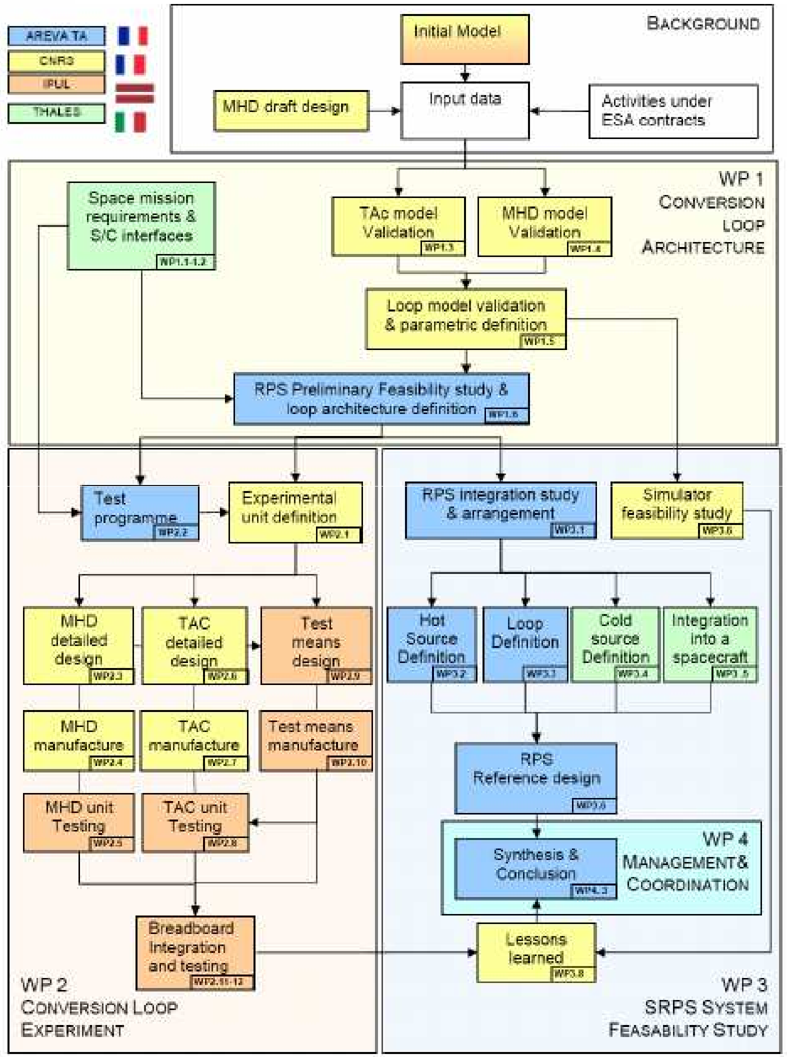
Problème de l'interface liquide gaz pour une application spatiale en l'absence de gravité → **A tester**



Interface contrôlée par la tension superficielle

7-Perspectives

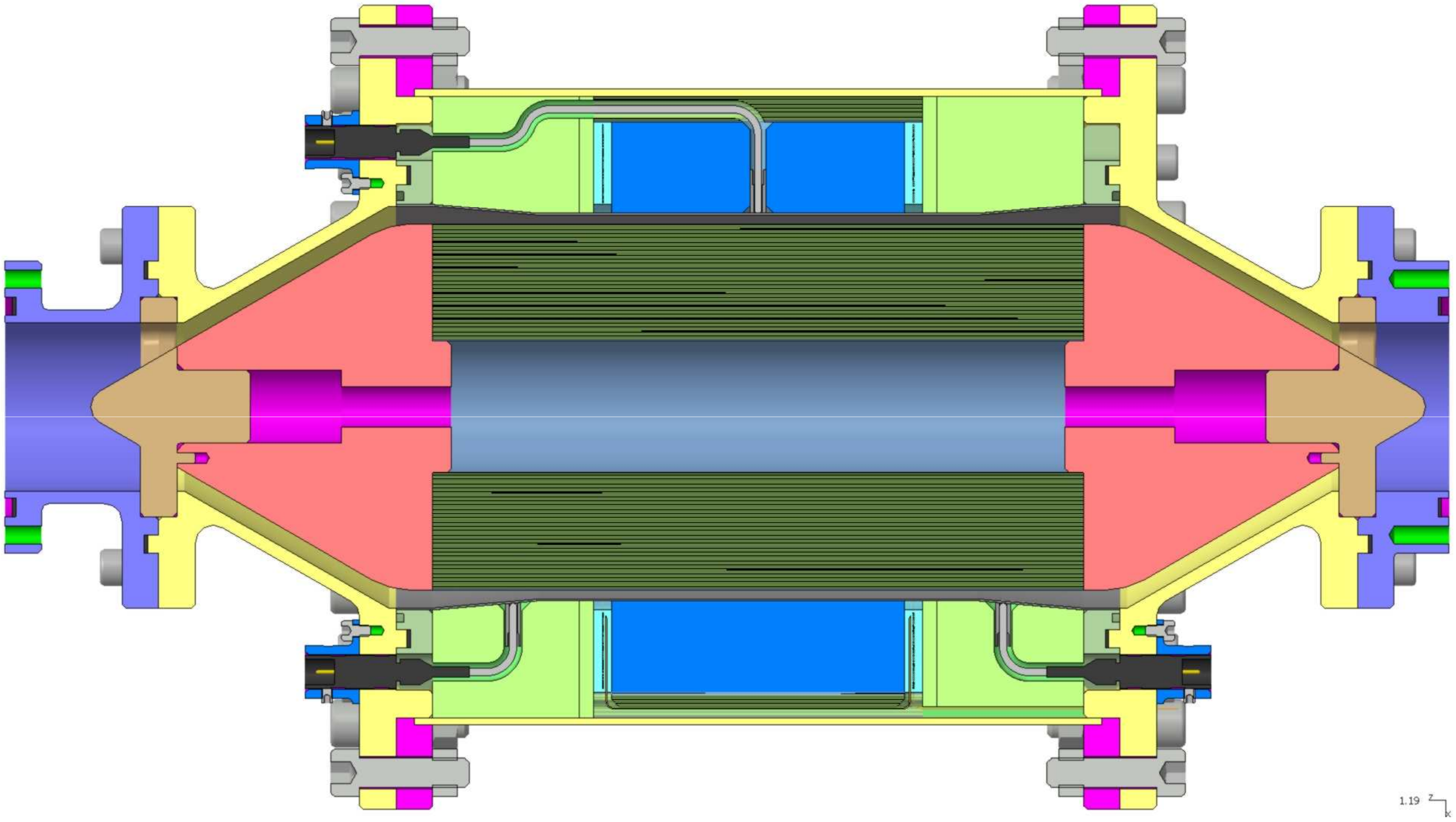
Space Thermoacoustic Radio-Isotopic Power System



The project is submitted to the FP7 Space call 4. It takes place in activity 9.2 “Strengthening the foundations of space science and technology”, area 9.2.1 “Research to support space science and exploration”. It answers to SPA 2011.2.1-02: Research and development for space exploration and more precisely to

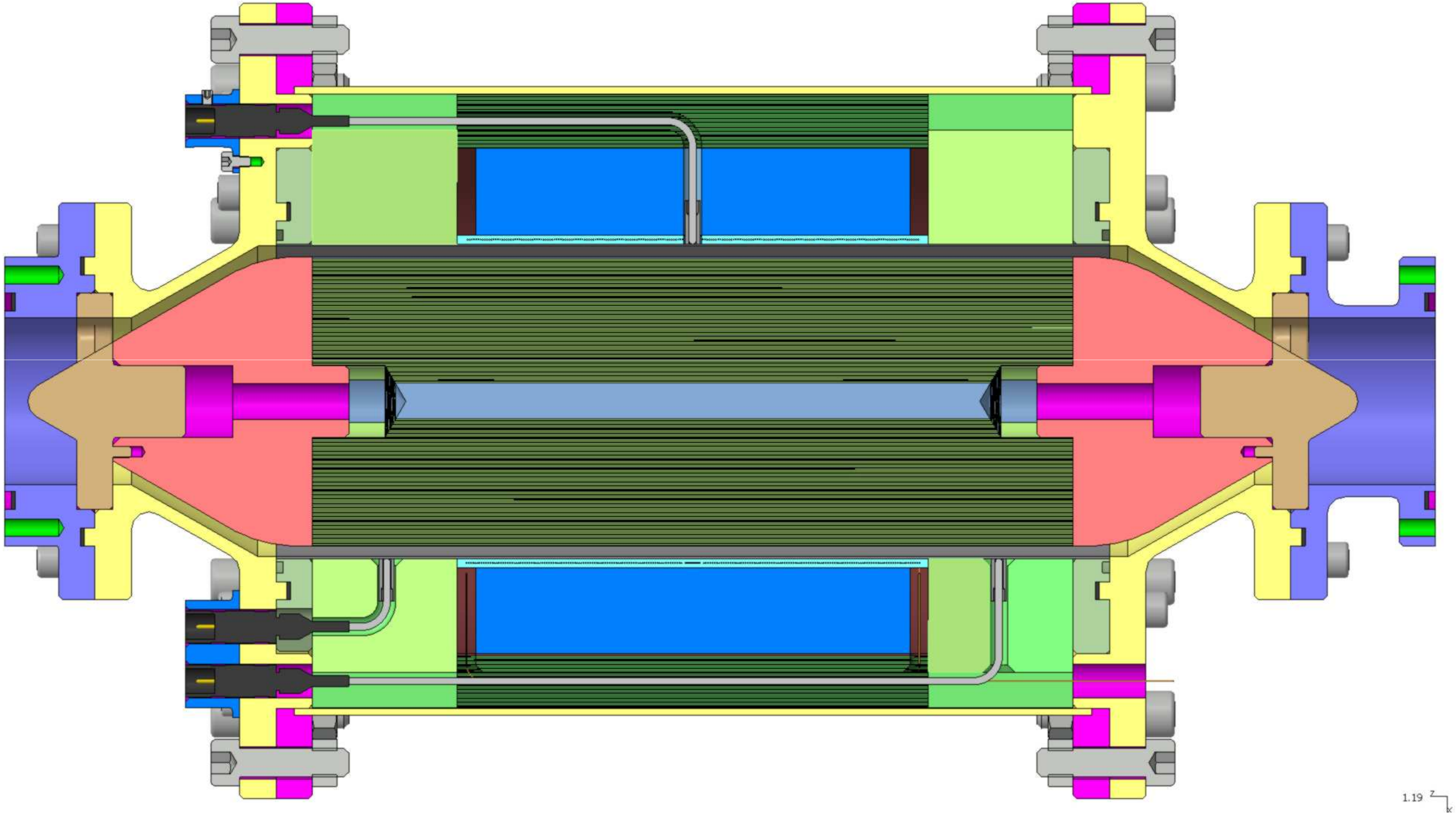
“in space power generation making use of novel power sources”.

GENERATEUR MHD: BOBINES LATERALES



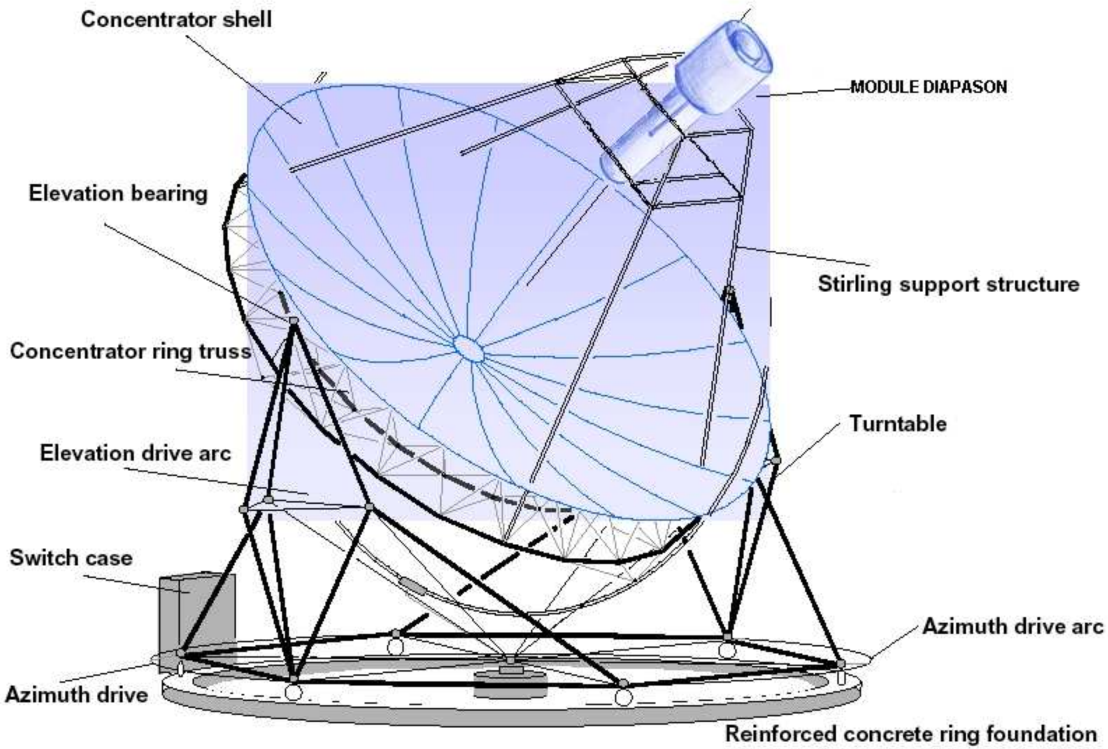
SFT SFA Presentation Paris le 10
12 2010

GENERATEUR MHD:
BOBINE LONGITUDINALE



CONCLUSION ET REMARQUE

En combinant un générateur thermo acoustique avec un générateur MHD à induction il parait possible d'obtenir du courant électrique sans aucune pièce métallique mobile avec un rendement global de l'ordre de 50%



Le spatial n'est pas un véritable marché industriel c'est une vitrine

Des applications intéressantes concernent les énergies renouvelables a des niveaux de puissances bien supérieures de l'ordre de quelques dizaines de Kilowatt.

Des possibilités sont également offertes dans le domaine des récupérations de rejets industriels

REMARQUE

Le Pasteur Robert Stirling est né le 25 octobre1790, à Gloag dans le comté de Perthshire en Ecosse. Il est mort le 6 juin 1878 à Galston, ville située à 30 km environ au sud de Glasgow.

Le principe du moteur stirling est connu depuis fort longtemps

Le générateur Thermo acoustique qui se développe depuis peu à les mêmes potentialités

Par exemple les 2 systèmes sont réversibles et sont capables tout deux de produire soit de l'énergie soit du froid.

Concernant le rendement la comparaison est ouverte et peut être discutée en ce qui concerne lequel des 2 systèmes à le meilleur potentiel

Mais si l'on considère la simplicité il est clair que la conclusion est clairement en faveur de la thermo acoustique

.

Pamir 2011

Address

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Access to Borgo

By plane : Bastia International airport
- Bastia Airport 15 km

By boat : From Marseille, Toulon, Nice
- Bastia Port 20 km

Organisation

Location

Corsica, the "Island of Beauty" certainly lives up to its name : real natural wonders.
Borgo "Pineto" - Corsica, a dream club :
To the south of Bastia, the "Pineto" club in Borgo stretches along a huge fine sandy beach in a stunning setting. In the heart of a beautiful 18-hectare pine forest, the "New Generation" bungalows offer the perfect and natural environment. Close to Bastia airport, Cap Corse and all the beauty of Corsica, Borgo is only a stone's throw from beach (practically a private beach) where the sea is ideal.
The "Pineto" club offers you the best watersports : a directly accessible beach, the watersports centre and a huge, palm-lined swimming pool.
The ideally situated "Pineto" club in Borgo is the perfect base from which to enjoy magical discoveries like Bastia and the Cap Corse, Saint-Florent and the vineyards of Patrimonio, the beaches of the east coast, Calvi and the villages of the Balagne area, the Île Rousse, Corte and the Regional Nature Park in Corsica, Porto-Vecchio, Bonifacio…

Accommodation

Single or double rooms are close to the restaurant and the conference room. Participants will have to pay themselves their accommodation fees (149€* per day for single room with private facilities, 119€* per day for single room with shared facilities for 2 persons, 109€* per day for double room with shared facilities for 4 persons).
* including room, breakfast, lunch and dinner
Reservation necessary before May 15, 2011
Registration : http://pamir2011.sal.lv
CONTACT : congres@floralis.fr

Registration Fee

The registration fee will be 380€ and 280€ for PhD students. This fee covers the conference proceedings, the gala dinner and excursion.
The payment will be made in euros only before May 15, 2011. After that date, an additional 50 euros for late penalties will be applied.
Registration : http://pamir2011.sal.lv
CONTACT : congres@floralis.fr

pamir GAMAS

8th pamir International Conference

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A. Alemany, C Laige, France,

Co chairmen :
J.P. Chopart, France - J. Freibergs, Latvia

Secretary : B. Collovati, , France

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Pamir 2011

Programme

Message from the chairmen

This new pamir conference corresponds to the Twentieth anniversary of this manifestation which was organized for the first time in September 1991 at the Cadarache Castel in close collaboration between the CNRS and the CEA. This was a symbolic event for the Latvian scientists who attended an International Conference in France for most of them for the first time after the independence of their country.

To celebrate this anniversary it was decided to place this 8 th conference under the common hospice of the CNRS and CEA in close collaboration with our colleagues from Latvia.

This manifestation is also the opportunity to manifest the vitality of the magneto sciences in Europe especially through the activities of an European group of research, GAMAS, open structure involving several European countries benefiting also of the participation of non European countries.

The enlarged topics of the Conference takes into account the present interest of the MHD community within the domain of the liquid metal technologies which corresponds to an important development in the frame of Energy, for example but not exclusively, by considering the important programs related to the new generation of Sodium Fast Neutron Reactors and the ITER experimental fusion Reactor.

The organizers have the aim to facilitate the access at the Conference to the young scientists and scientists from unfavoured countries, and to promote the close collaboration between engineers, private companies and researchers which is a very important aspect in the development of magneto sciences.

Principal topics

A. Basic MHD

A.1 Convection and heat transfer in MHD

A.2 Dynamo

A.3 Instability and transition to turbulence

A.4 Jets and surface waves

A.5 Modeling of MHD turbulence

A.6 Numerical and experimental methods

A.7 Strong magnetic field

A.8 Novel MHD problems and applications

A.9 Reviews and history

B. Liquid metal technologies for coolant applications

B.1 Power generation

B.2 MHD pumps and Flow Control

B.3 Measuring techniques for liquid metals

B.4 Corrosion by liquid metal

B-5 Liquid metal mixing

C. Applied MHD for material applications

C. 1 Metallurgical applications

C. 2 Magneto-electrolysis

C. 3 MHD in crystal growth

C. 4 Electromagnetic processing of materials

C. 5 Electromagnetic levitation

C.-6 Magneto static

D. Ferrofluids

D.1 Magnetic liquids

D.2 Electrohydrodynamics

D.3 Magnetorheological suspensions

D.4 Magnetism, magnetic particles and biological applications.

Abstract Submission

Abstracts should be submitted electronically by e-mail to pamir@simag.grenoble-inp.fr prior to December 17, 2010. Length of abstracts is limited to 500 words. Please select one or two subjects from the topic list above and specify them in the e-mail subject line.

Submission to : pamir@simap.grenoble-inp.fr

Web Site

http://pamir2011.sal.lv

Proceedings

A volume of proceedings will be distributed to all participants upon registration. Instructions for preparation of full paper will be sent together with notification of acceptance.

Committee Members

Organising committee

A. Alemany, M. Alradi, J.P. Chopart, B. Collovati, A.L. Daltin, JFreibergs, C. Latge

Scientific committee

Abdou M., USA
Alemany A., France
Alradi M., Syria
Aogaki R., Japan
Balbaud F CEA France
Beaugnon E France
Blums E., Latvia
Bouabdallah A., Algeria
Buligins L., Latvia
Cebers A., Latvia
Chopart J.P., France
Cuevas S., Mexico
Daviaud F., France
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Freibergs J., Latvia
Frick P., Russia
Gailitis A., Latvia
Gerbeth G., Germany
Laffont G. France
Latgé C., France
Li Puma A., France
Martemianov S., France
Mogi I., Japan
Molokov S., UK
Mond M. Israel
Odenbach S.,Germany
Proctor M.R.E., UK
Skorvanek I Slovakia
Taniguchi S., Japan
Tessaroto M. Italy
Thess A., Germany
Uhlemann M., Germany
Zabinski P Poland

Calendar of events

Deadline for abstracts : December 17, 2010
Notification to authors : February 26, 2011
Deadline for full paper : April 30, 2011
Registration prior : May 15, 2011