LR Gas Injector:

Magnetic circuit design

ing. Ciardiello Ferdinando

LR Gas Injector: Magnetic circuit design

Summary:

- Who is LandiRenzo?
- What is a gas injector?
- How does it work?
- Magnetic circuit description
- Target
- Magnetic parameters
- Coil design
- Material selection
- Problem: Geometry design
- Fem magnetic simulation
- Results
- Conclusions

LR Gas Injector: Magnetic circuit design

Who is LandiRenzo ?

LR Gas Injector: Magnetic circuit design

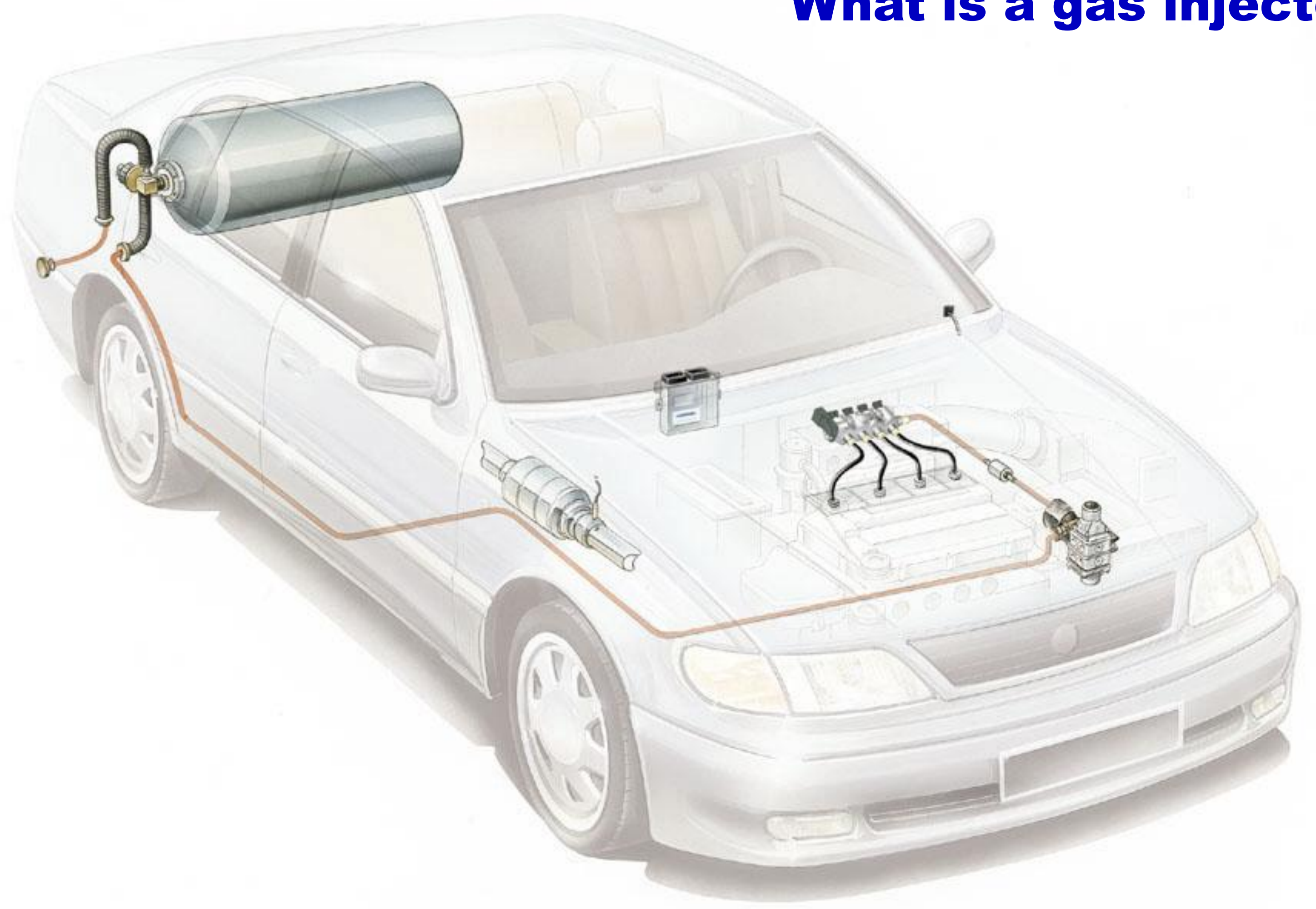
Who is LandiRenzo ?

Landi Renzo nel mondo

Europa	Africa	Asia	Oceania	America
Bulgaria	Algeria	Bangladesh	Australia	Brasile
Croazia	Egitto	Cina	Nuova Zelanda	
Estonia	Sud Africa	Corea		
Germania		India		
Grecia		Iran		
Italia		Malesia		
Lituania		Pakistan		
Paesi Bassi		Russia		
Polonia		Tailandia		
Repubblica Ceca		Turchia		
Romania				
Serbia				
Slovacchia				
Ungheria				

LR Gas Injector: Magnetic circuit design

What is a gas injector?



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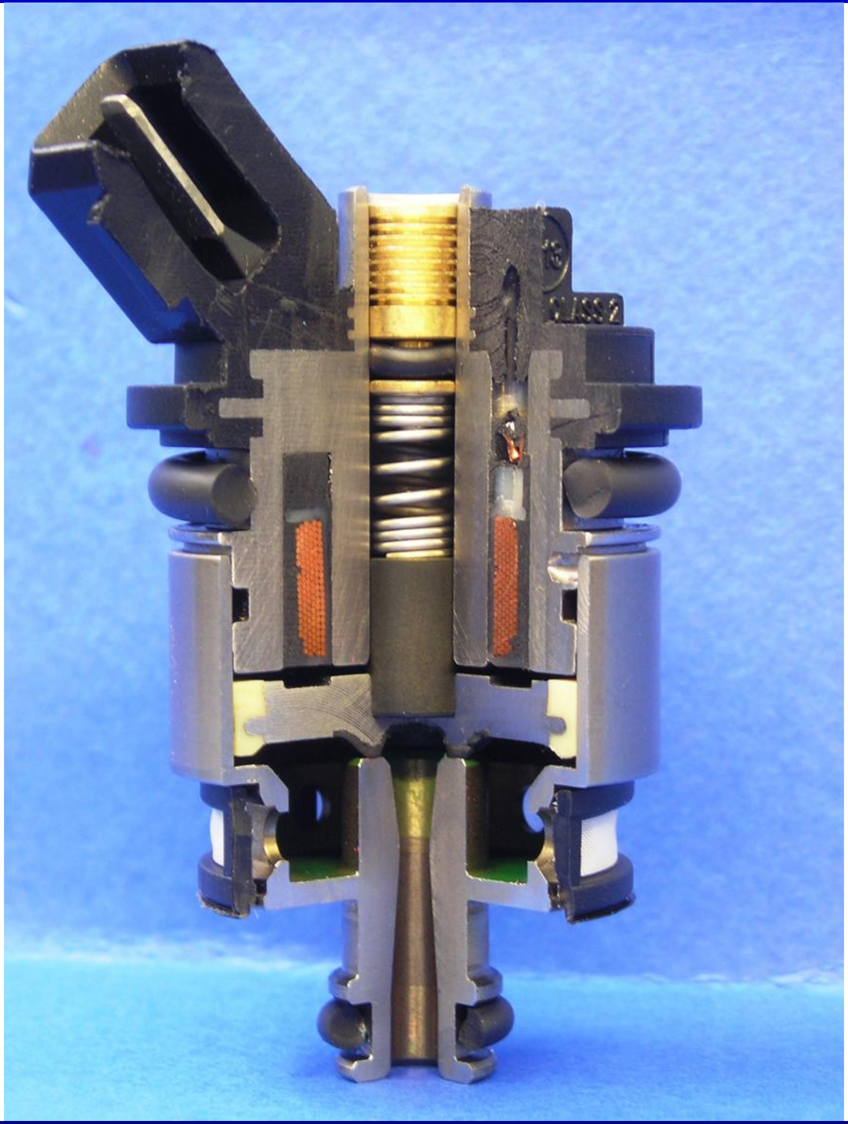
How does it work?



LR Gas Injector: Magnetic circuit design

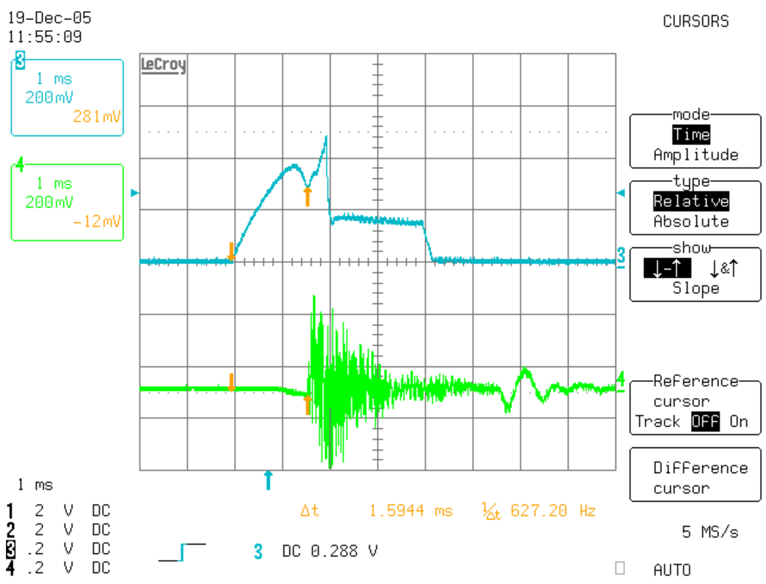
Target

The injector have to be very fast to open and to close. For these reasons the target became:

1. Maximize magnetic force
2. Maximize velocity to energize and to deenergize the magnet

Opening time = 1,7ms

Closing time = 1,5ms



LR Gas Injector: Magnetic circuit design

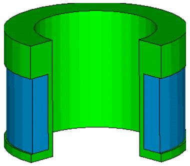
Magnetic parameters

To respect the target it is possible to work on many parameters:

1. Coil: Number of the wires of the coil and Resistance.
2. Type of command: Peak & hold / Saturation
3. Magnetic material.
4. Geometry of the magnet.

LR Gas Injector: Magnetic circuit design

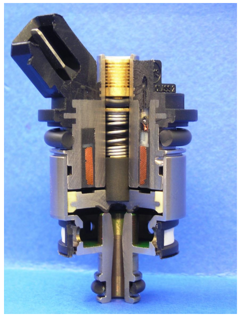
Magnetic parameters: Coil

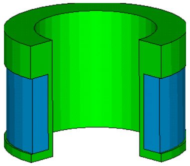


Coil geometry design: define the number of wires and the resistance

Versione	Diam interno Di (mm)	Diam esterno De (mm)	Altezza L (mm)	Tens. Alim. (V)	Diam Filo d (mm)	spire/cm^2	Resist. El.unit. (Ohm/m)	Diam. Medio Dm (mm)	Spess. [mm]	Area sezione A (cmq)	N° spire per strato	N° spire totali	N° strati totali	Sviluppo [m]	Riempimento	**Resist. Tot (Ohm)**	Corrente [A]	Pot. VxI (W)	**Amper--spire (Asp)**
G10	13	20,50			0,355 gr1														0,0
	14,3	19,00	8,23	4,34	0,392	620	0,1727	16,7	2,35	0,1935	*20,000*	*120,0*	*6,000*	6,28	0,75	*1,084*	4,004	*17,38*	*480,4*

LR Gas Injector: Magnetic circuit design





Magnetic parameters: Coil

To reduce the energizing time:

1. Minimize Resistance
2. Minimize Inductance
3. Minimize the number of wires

$$t_e = -\frac{L}{R} Ln\left(1 - \frac{IR}{V}\right)$$

$$L = \frac{\mu \cdot S \cdot N^2}{l}$$

μ=permeability

S= Iron section

N= number of wires

I=current that pass in the coil

L=Inductance

l=length of the circuit

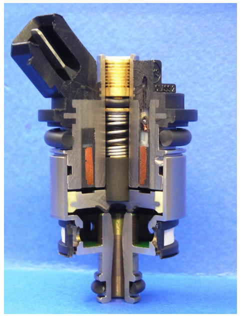
t_e=energizing time

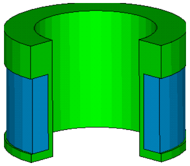
R=resistance of the coil

V=tensure

LR Gas Injector: Magnetic circuit design

Magnetic parameters: Coil





To increase the force:

1. Maximize the number of wires
2. Select the material with great permeability

$F=B*I*l$
$B=\mu*H$
$H=N*I$

μ=permeability

N= number of wires

I=current that pass in the coil

l=length of the circuit

H=fmm

F=fem

B=magnetic density

LR Gas Injector: Magnetic circuit design

Magnetic parameters

To respect the target it is possible to work on many parameters:

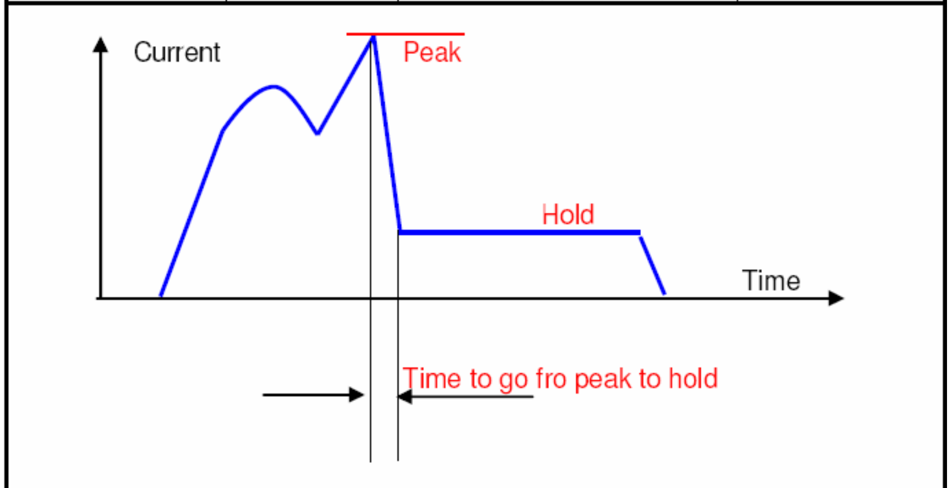
1. Coil: Number of the wires of the coil and Resistance.
2. **Type of command: Peak & hold / Saturation.**
3. Magnetic material.
4. Geometry of the magnet.

LR Gas Injector: Magnetic circuit design

Magnetic parameters

Type of command: Peak & hold

Electrical command for Landi Renzo injectors			
Current control			
Peak current	Hold current	Time to go fro peak to hold	PWM frequence
5A	1A	0,14ms	10kHz
Timer control			
Peak current	Hold current	Time to go fro peak to hold	PWM frequence
6A	1A	0,14ms	10kHz



Max force and max energizing/deenergizing velocity

LR Gas Injector: Magnetic circuit design

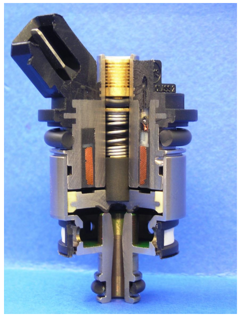
Magnetic parameters

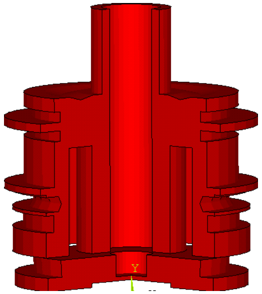
To respect the target it is possible to work on many parameters:

1. Coil: Number of the wires of the coil and Resistance.
2. Type of command: Peak & hold / Saturation
3. **Magnetic material.**
4. Geometry of the magnet.

LR Gas Injector: Magnetic circuit design

Magnetic parameters: Material selection





Target:

- Maximize magnetic force
- Maximize velocity to energize and to deenergize the magnet

$F=B*I*l$
$B=\mu*H$
$H=N*I$

μ=permeability

N= number of wires

I=current that pass in the coil

l=length of the circuit

H=fmm

F=fem

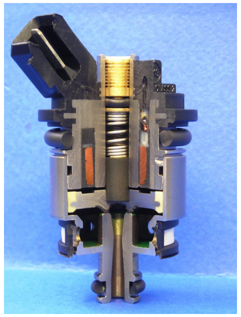
B=magnetic density

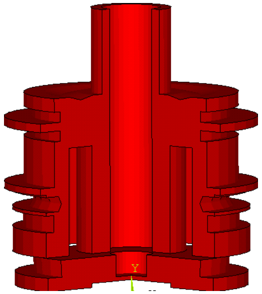
Select the right magnetic material considering:

1. Hysteresis curve
2. Max density
3. Max permeability

LR Gas Injector: Magnetic circuit design

Magnetic parameters: Material selection



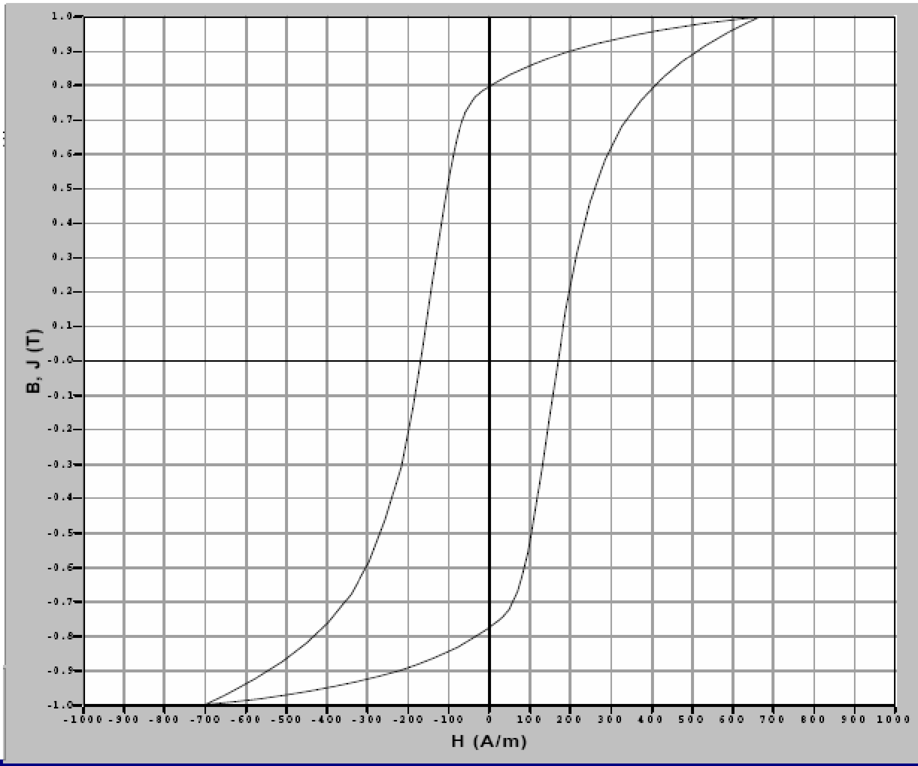


Target:

- Maximize magnetic force
- Maximize velocity to energize and to deenergize the magnet

$F=B*I*l$
$B=\mu*H$
$H=N*I$

1. **Hysteresis curve**
2. Max density
3. Max permeability

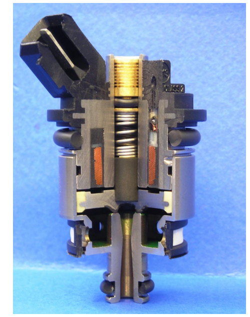


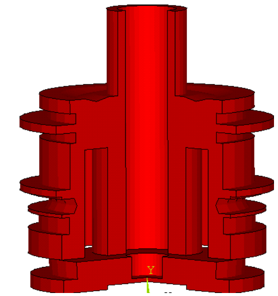
LR Gas Injector: Magnetic circuit design

Magnetic parameters: Material selection

Target:

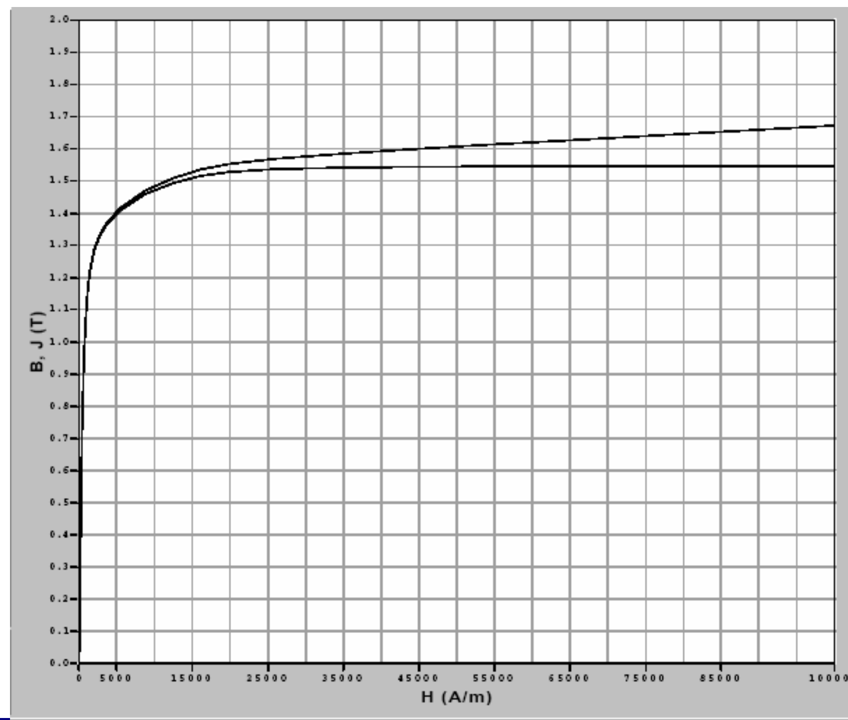
- Maximize magnetic force
- Maximize velocity to energize and to deenergize the magnet





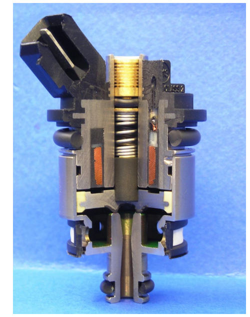
$$F=B*I*l$$
$$B=\mu*H$$
$$H=N*I$$

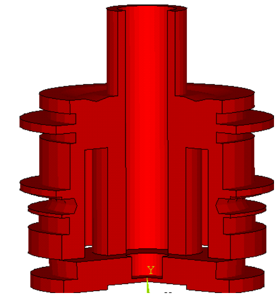
1. Hysteresis curve
2. **Max density**
3. Max permeability



LR Gas Injector: Magnetic circuit design

Magnetic parameters: Material selection



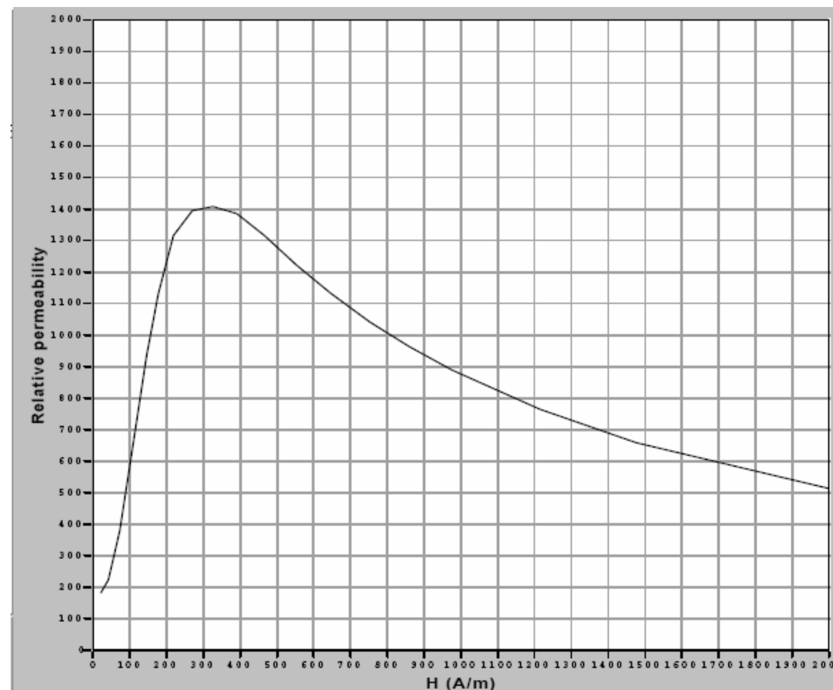


Target:

- Maximize magnetic force
- Maximize velocity to energize and to deenergize the magnet

$$F=B*I*l$$
$$B=\mu*H$$
$$H=N*I$$

1. Hysteresis curve
2. Max density
3. **Max permeability**



LR Gas Injector: Magnetic circuit design

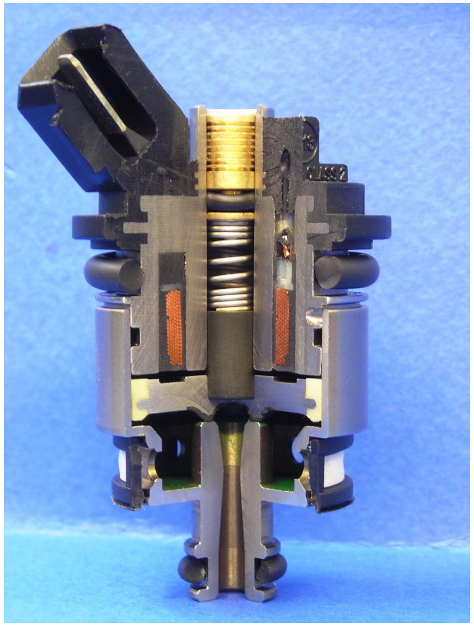
Magnetic parameters

To respect the target it is possible to work on many parameters:

1. Coil: Number of the wires of the coil and Resistance.
2. Type of command: Peak & hold / Saturation
3. Magnetic material.
4. **Geometry of the magnet.**

LR Gas Injector: Magnetic circuit design

Problem: Geometry design



After selecting the coil,

After selecting the command,

After selecting the material,

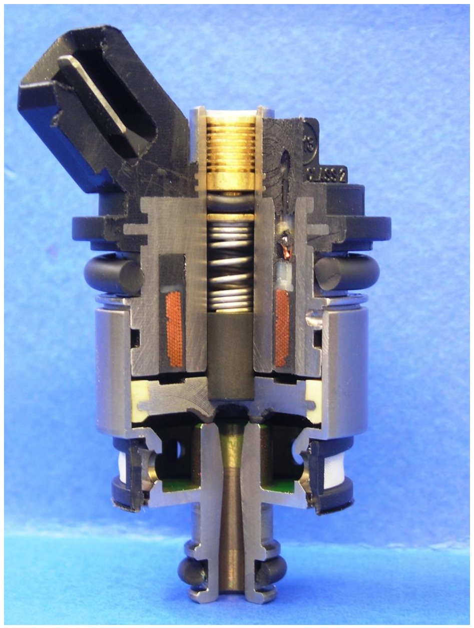
How we can unify all in a geometry to understand if the target is respected?

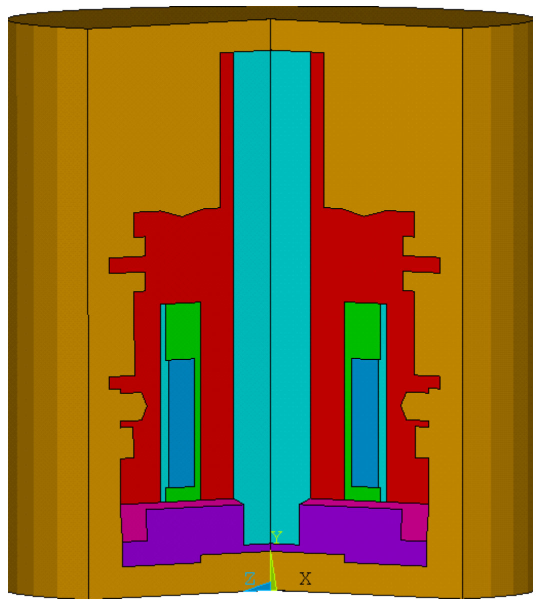
↓

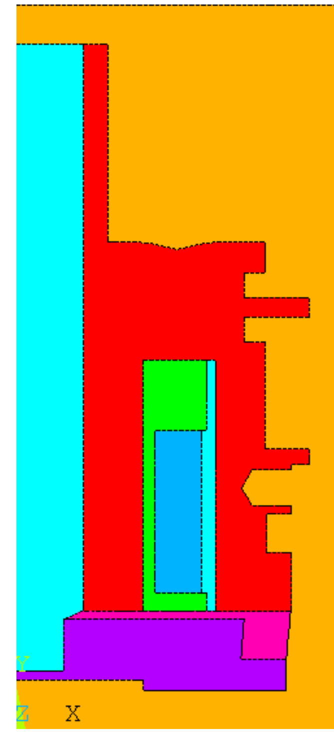
FEM SIMULATION

LR Gas Injector: Magnetic circuit design

Fem simulation: crate geometry







To reduce the calculation time and to obtain more precise simulations it is useful to simplify the geometry, passing from the 3D to a 2D geometry

LR Gas Injector: Magnetic circuit design

Fem simulation: Parametric file

Coil design

Command type

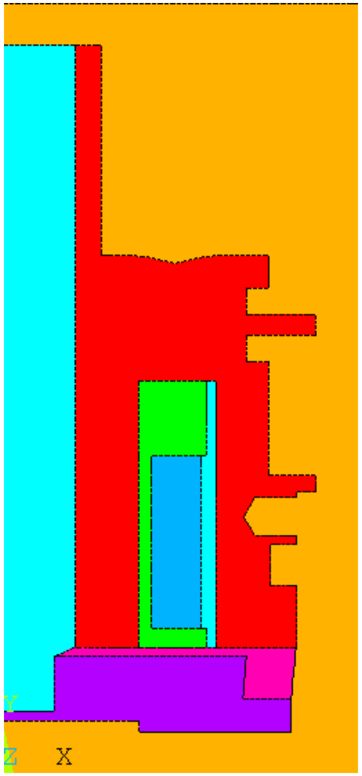
Material

Hypothetical geometry

Aa Magnete GI25.txt - Blocco note

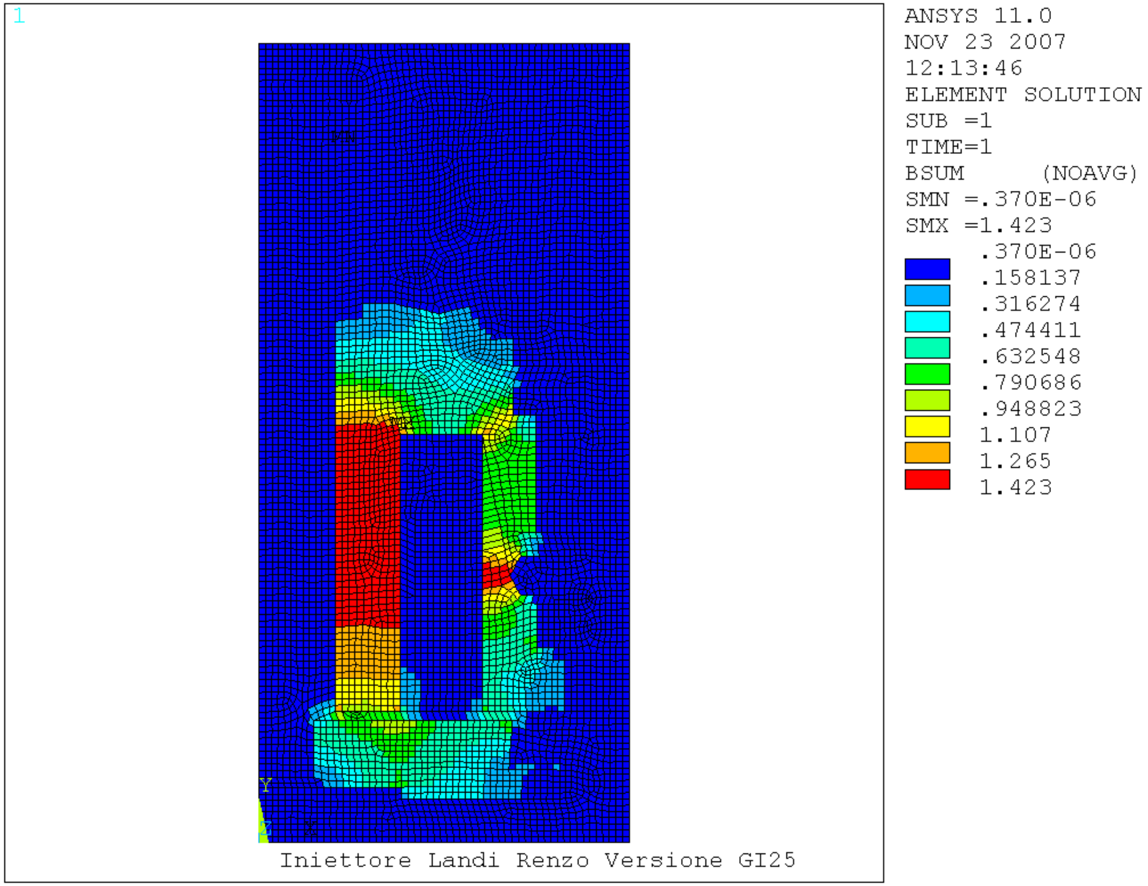
File Modifica Formato Visualizza ?

```
!         PARAMETRI  BOBINA
pi=acos(-1)                 ! PIGRECO
alfa=.0039                  ! Coefficiente termico del rame
rob=.0172e-6                ! [ohm*m]  Resistivita' del rame
rfil = (0.450e-3)/2         ! Raggio filo
resistenza = 0.025          ! resistenza dell'avvolgimento

tens=14                     ! Tensione alimentazione bobina (Volt)
vzen=68                     ! Tensione di taglio del diodo Zener
tstat=3*s                   ! Tempo simulazione analisi statica
dn=.2*s                     ! Diametro nominale filo nudo avvolgimento
hcaria = 20*1.163           ! Coefficiente convettivo aria esterna
taria = 130-273             ! Temperatura aria esterna
nspi=120                    ! Numero di spire
muz=12.57e-7                ! Permeabilita' dell'aria
cap=3.3e-6                  ! Capacita condensatore (Farad)
vc0=90                      ! Tensione iniziale condensatore

/com,  Fattore moltiplicante per variare le unita' di misura
/com                        ASSESGNAZIONE QUOTE PARAMETRI
/com,                   ASSEGNAZIONE PARAMETRI CALCOLI
ro=.6e-6                    ! [ohm*m]  Resistivita del ferro
cond=(1/ro)                 ! [Siemens/m] Conducibilita' del ferro
ttst=5e-6                         ! Tempo del time-step


!                           PARAMETRI GEOMETRICI



!    definizione aria circostante
haria=2*s                  ! altezza aria circostante
!
corrente = 4.00              ! corrente di alimentazione
!
!**********  definire il traferro con cui si vuole realizzare l'analisi  ******
!            inserendo un valore compreso tra hmin e hmax
hgap=0.42*s                                         !
!
!*******************************************************************************


!    definizione bobina

rbi = 7.15*s                                              ! raggio bobina interno
rbe = 9.50*s                                        ! raggio bobina esterno

hbt = 8.232*s                                        ! altezza totale bobina

fill = (pi*rfil*rfil*nspi)/((rbe-rbi)*hbt)          ! fattore di riempimento
robef = rob/(fill)                                        ! Resistività efficace

Potenza=resistenza*corrente*corrente
Volume=pi*(rbe*rbe-rbi*rbi)*hbt
Superficie=((rbe-rbi)*hbt)
per_medio=2*pi*((rbe+rbi)/2)
!hgen=Potenza/(Superficie*per_medio)
hgen=Potenza/volume

!   definizione rocchetto

sh = 3.618*s                         ! spessore assiale superiore rocchetto
shi = 0.9*s                        ! spessore assiale inferiore rocchetto
der = rbe*2+0.5*s                  ! diametro esterno rocchetto
rer = der/2                        ! raggio esterno rocchetto
```



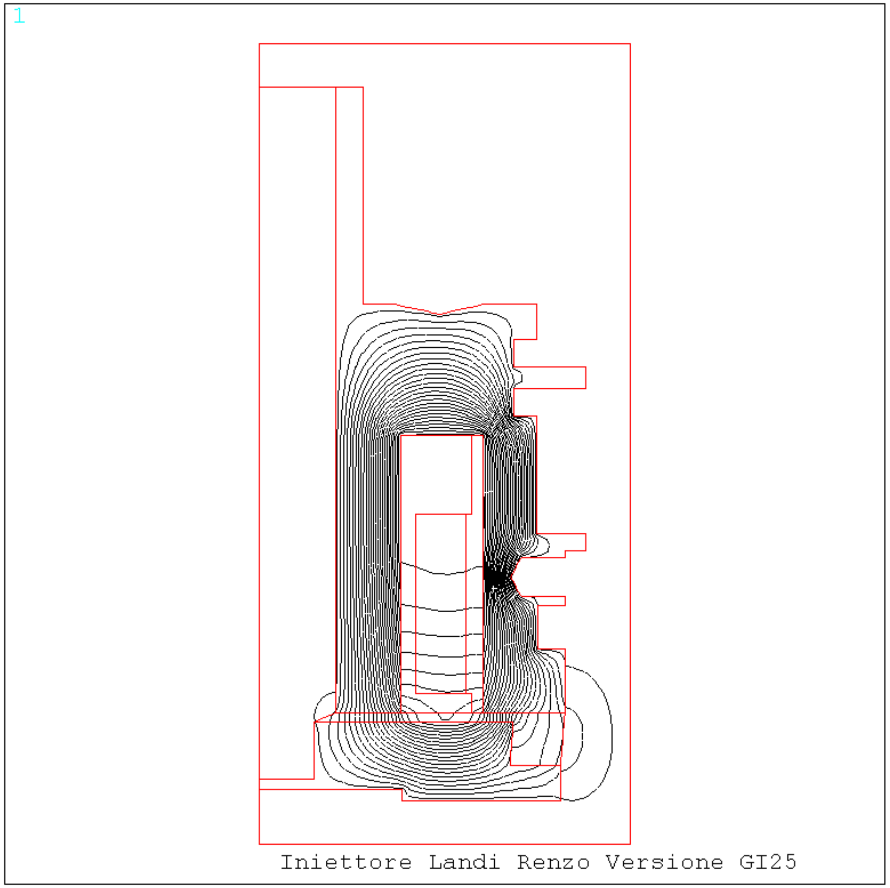
LR Gas Injector: Magnetic circuit design

Fem simulation results: magnetic density



LR Gas Injector: Magnetic circuit design

Fem simulation results: Flux lines



LR Gas Injector: Magnetic circuit design

Fem simulation results: Magnetic force and Inductance

lmatrix.out

File

```
 _____________ LMATRIX SOLUTION SUMMARY _______________

Flux linkage of coil     1. =     0.17248E-01
Self inductance of coil  1. =     0.35849E-01

Inductance matrix is stored in array parameter induct  ( 1., 2.)

Inductance matrix is stored in file induct  .txt

 __________________________________________________
```

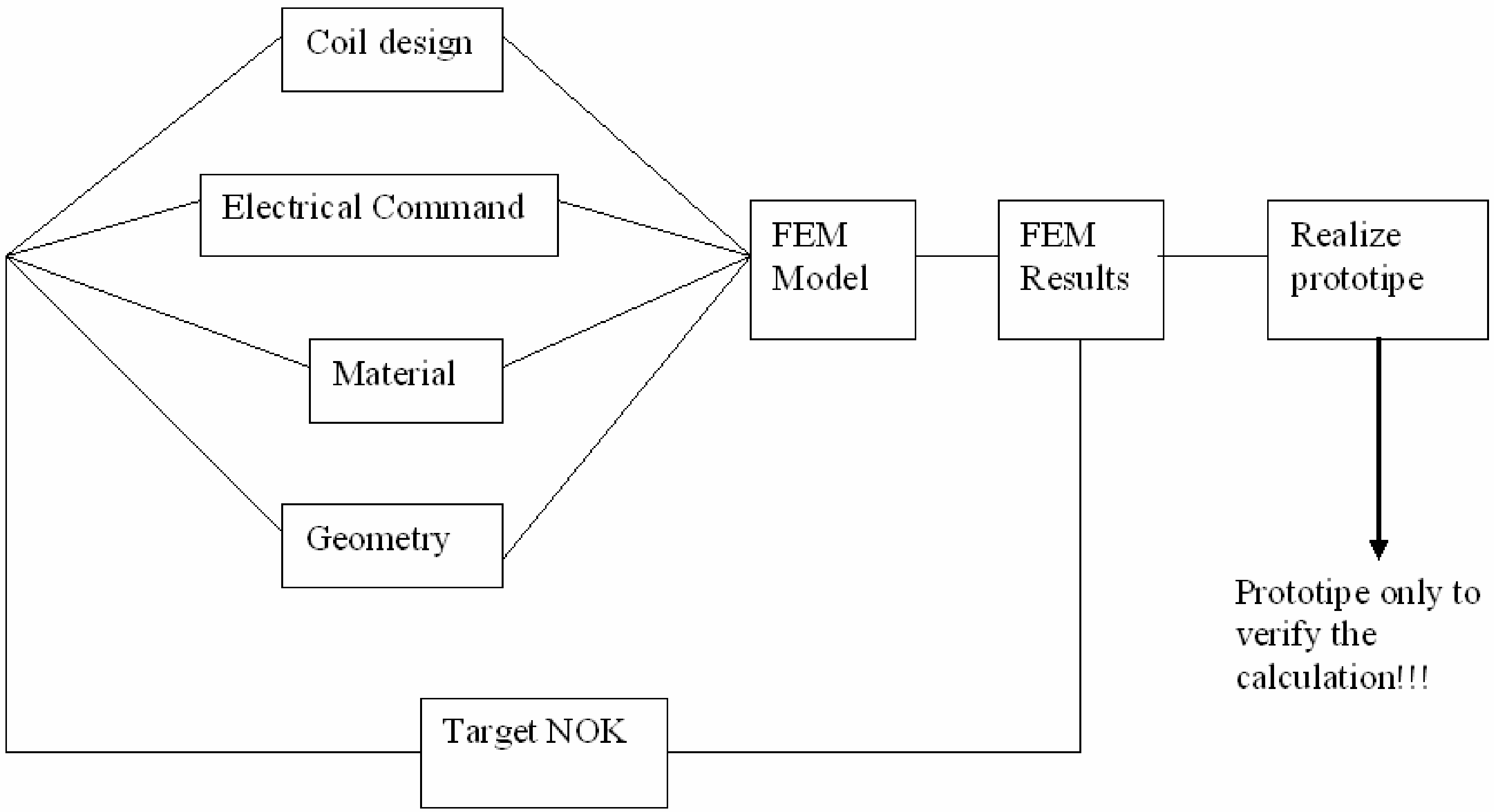
fmagsum.out

File

```
               SUMMARY OF FORCES BY VIRTUAL WORK
Load Step Number:        1.
Substep Number:          1.
Time:              0.1000E+01
Units of Force:          ( N )
Component         Force-Y
   ANCORINA    0.12981E+02

 ______________________________
           SUMMARY OF FORCES BY MAXWELL STRESS TENSOR
Units of Force:  ( N )
Component         Force-Y
   ANCORINA    0.13178E+02

 ______________________________
Note: Maxwell forces are in the Global Cartesian coordinate system.
Virtual work forces are in the element ESYS coordinate system.
The forces correspond to a full 360 degree revolution of the cross
section (an axisymmetric model).
The following element table items are available for printing and
plotting of the forces obtained by Virtual Work and the Maxwell Stress
Tensor methods.
    Element Item Name      Method       Direction
         FVW_Y          Virtual Work        Y
         FMX_Y          Maxwell Stress      Y
 ____________________________________________________________
```

LR Gas Injector: Magnetic circuit design

Virtual modeling cycle



LR Gas Injector: Magnetic circuit design

Conclusions:

•With FEM simulation it is possible to see the magnetism that is invisible to human eyes.

•With Fem simulation it is possible to have a value of inductance and force that is very difficult to measure experimentally.

•With Fem simulation it is possible to optimize a magnetic circuit in a very simply way.

•With Fem simulation you reduce cost and time improving the quality