Stable states of systems of bistable magnetostrictive wires against applied field, applied stress and spatial geometry

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Aim of this work is to explore the shape of the hysteresis loop of systems of bistable wires, as dependent on

- **mutual position of the wires,**
- **applied tensile stress.**

Overview:

-problem with the wire-wire interaction,

-conditions of the bistability,

-numerical results on the hysteresis loops.

Basic component: a ferromagnetic bistable wire

Composition $Fe_{77.5}B_{15}Si_{7.5}$

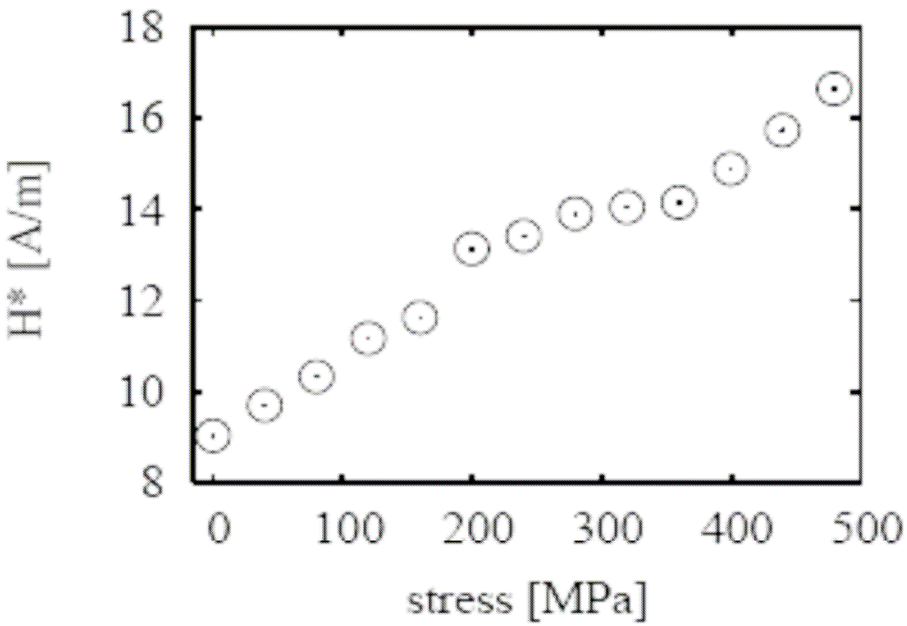
Length L = 10 cm

Diameter D = 120-125 µm

Magnetization $M = 0.7\ T / \mu_0 = 5.6 \cdot 10^5$ A/m

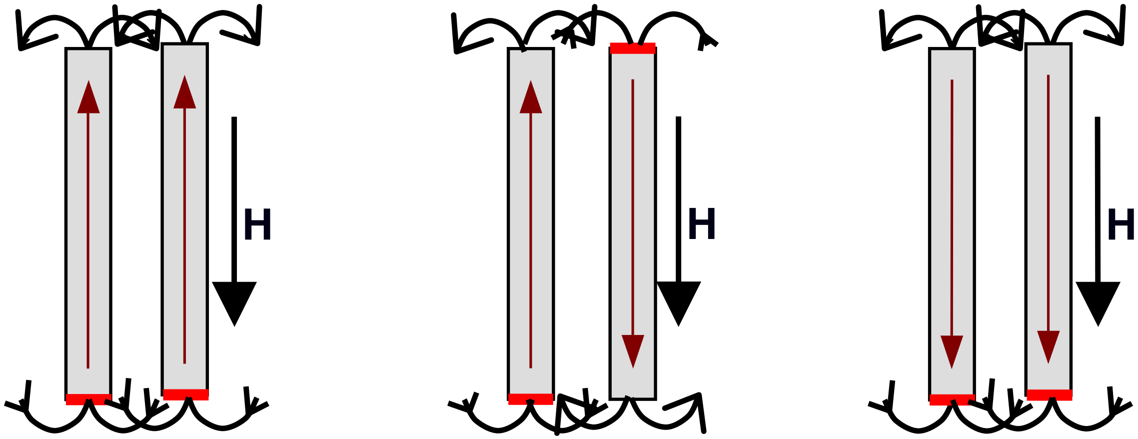
Consequence of the magnetoelastic coupling:

tensile stress dependence of the switching field.

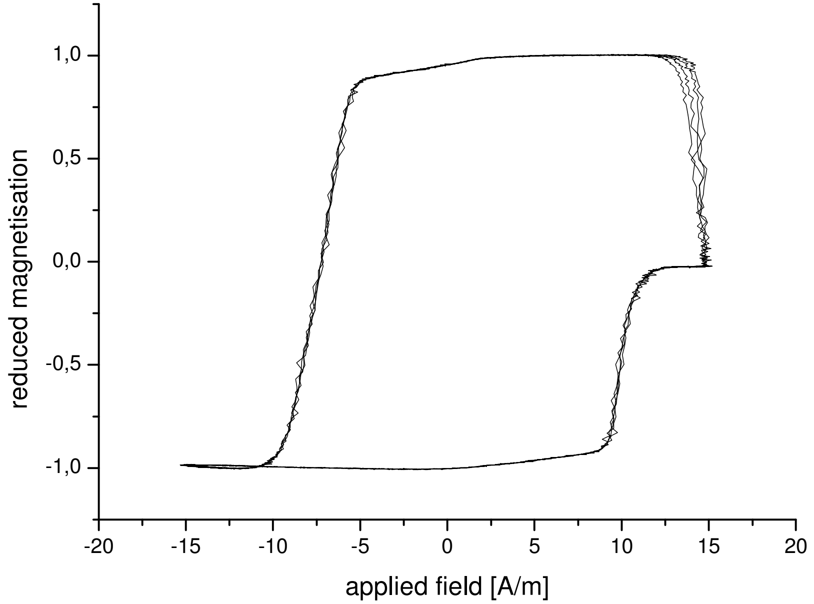


Central problem here: **the wire-wire interaction**

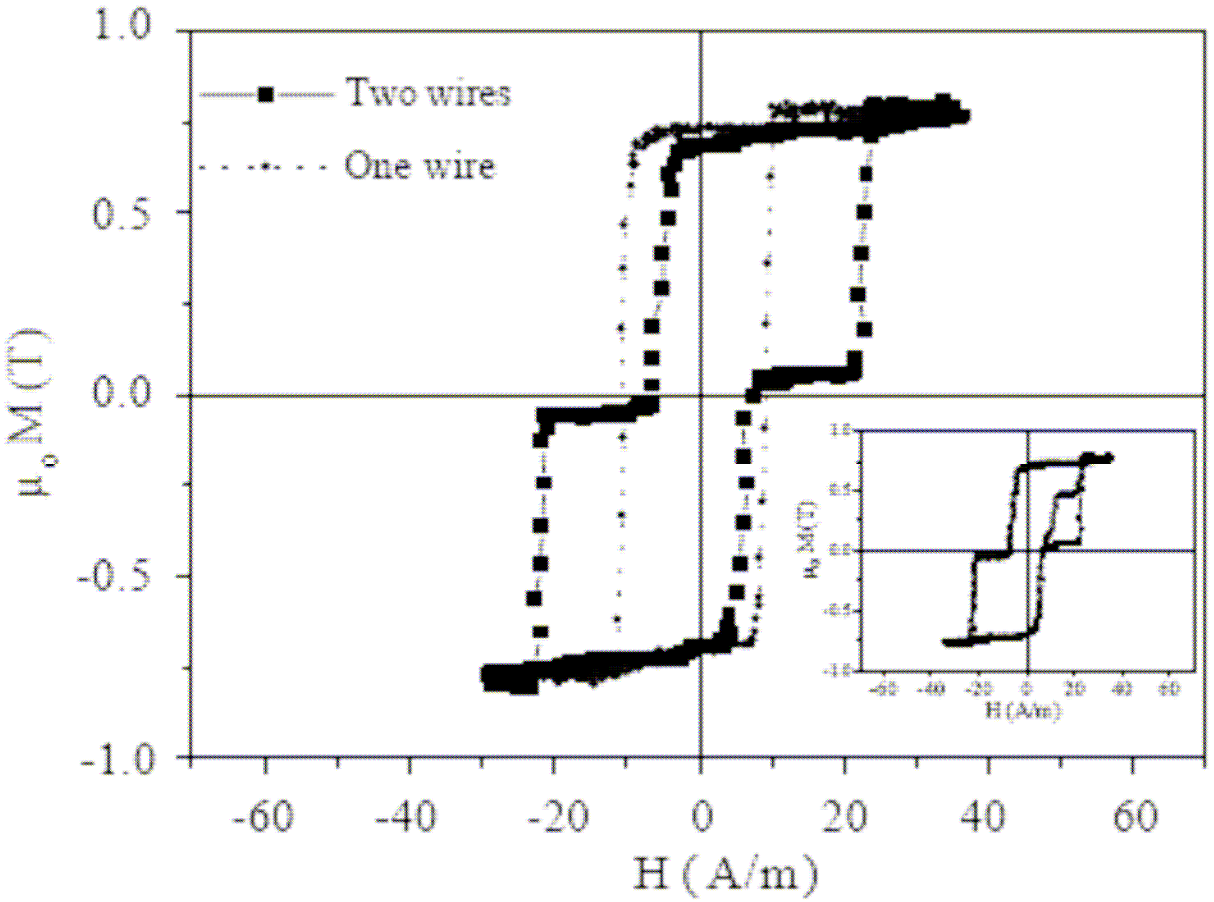
A sequence of switching for two parallel wires in a distance about 1 mm



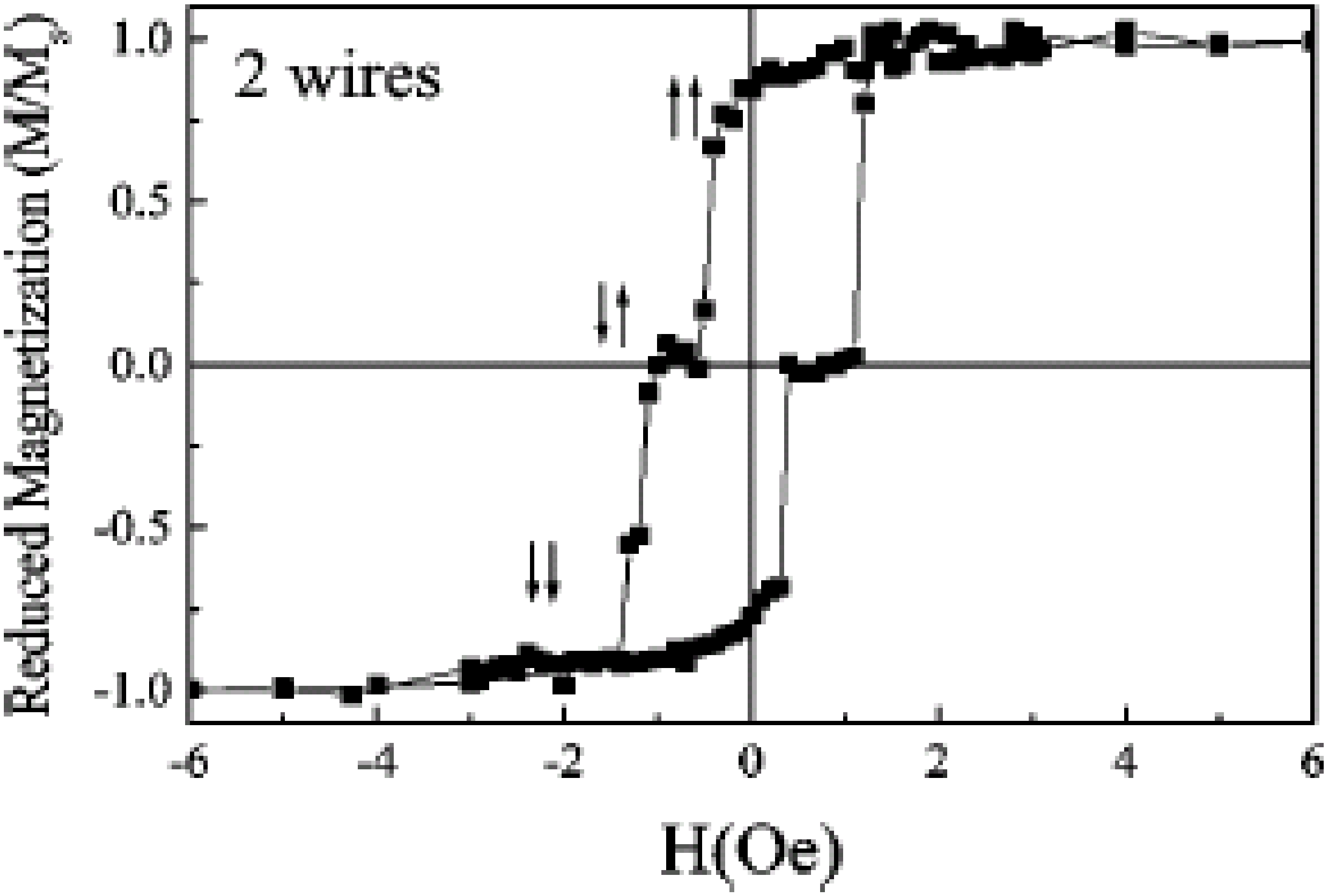
can lead to a hysteresis loop like this:
(Krupinska et al. 2003)



with the interaction field about **2 A/m**.
Other measurements give **10 A/m**.



Other data: about **5 A/m** when the wires of diameter of 131 μm touch each other (Velazquez and Vazquez, 2002).

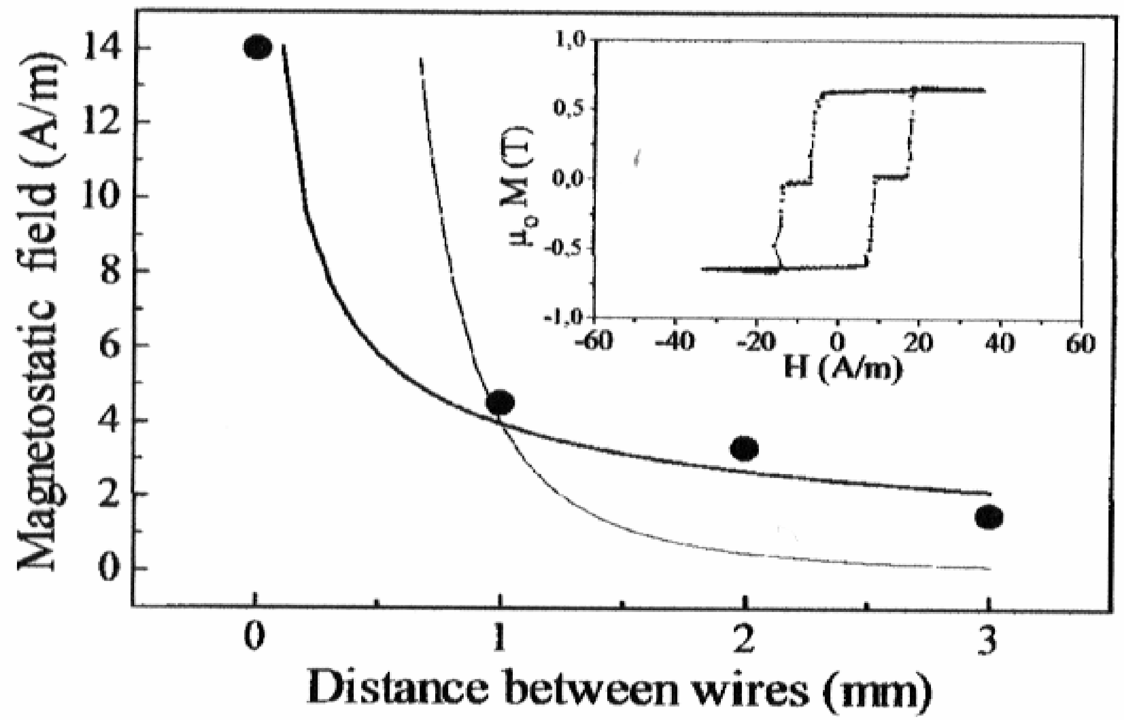


For microwires in distance 20 μm the interaction field is about **25 A/m**
(Sampaio et al. 2000)

The stray field – how to calculate it?

- from the dipolar interaction : $H=MV/(4\pi r^3)$

But it varies with distance too sharply (Velazquez et al. 2003) ...



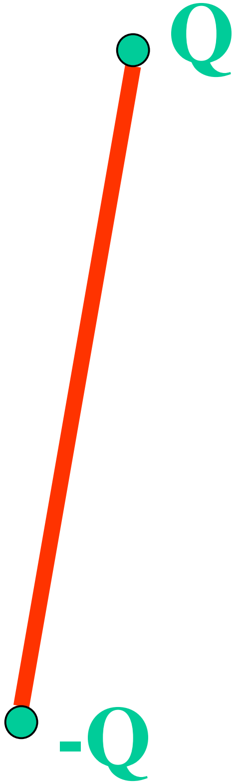
... and it is 5000 times larger than the experimental value.

Alternative approach: - uniform magnetization

- thin wires, $D << L$,
- interwire distance $r >> D$

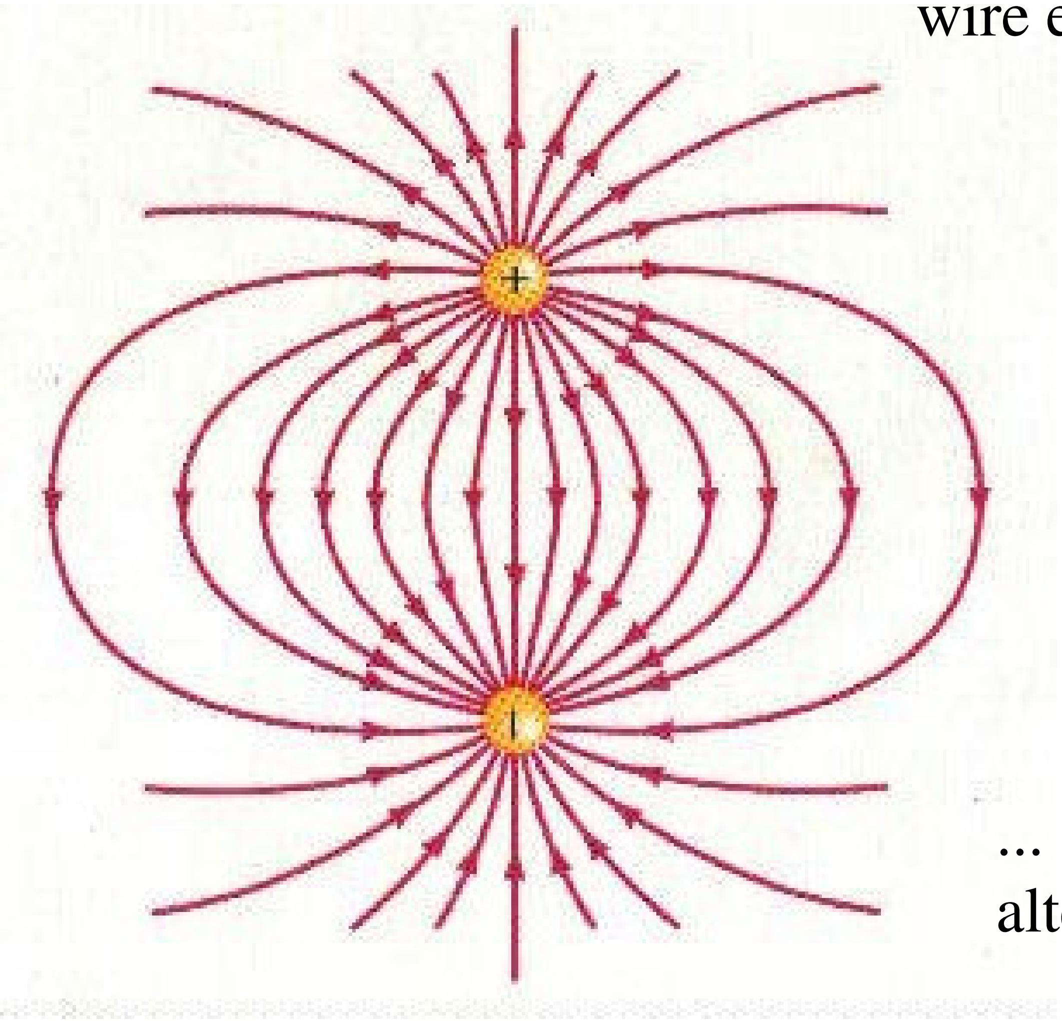
$\Rightarrow$ **point magnetic charges** $\boldsymbol{Q}$ at the ends (Velazquez et al., 2003)

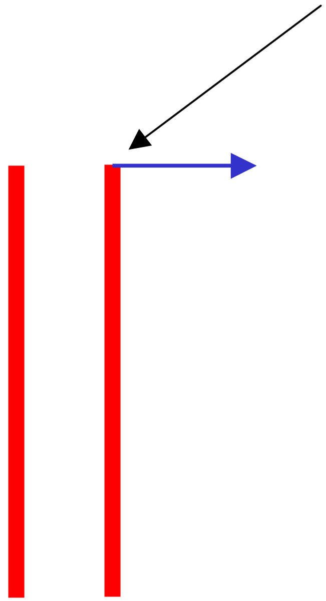
$$Q = \pi M D^2/4 = 0.0062 \text{ A m}$$



However:

The field from the neighboring wire end is horizontal ...





... and therefore it does not alter the switching field...

www-fen.upc.es/wfib/virtualab/marco/conocimi.htm

...while the field from the other end of the wire (Sampaio et al. 2000)

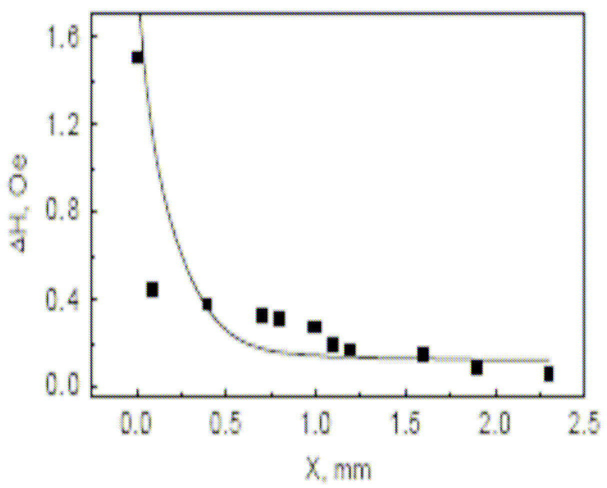
$$H = \frac{QL}{4\pi(L^2 + r^2)^{3/2}} \approx \frac{MD^2}{16L^2}$$

is 20 times smaller than the experimental value.

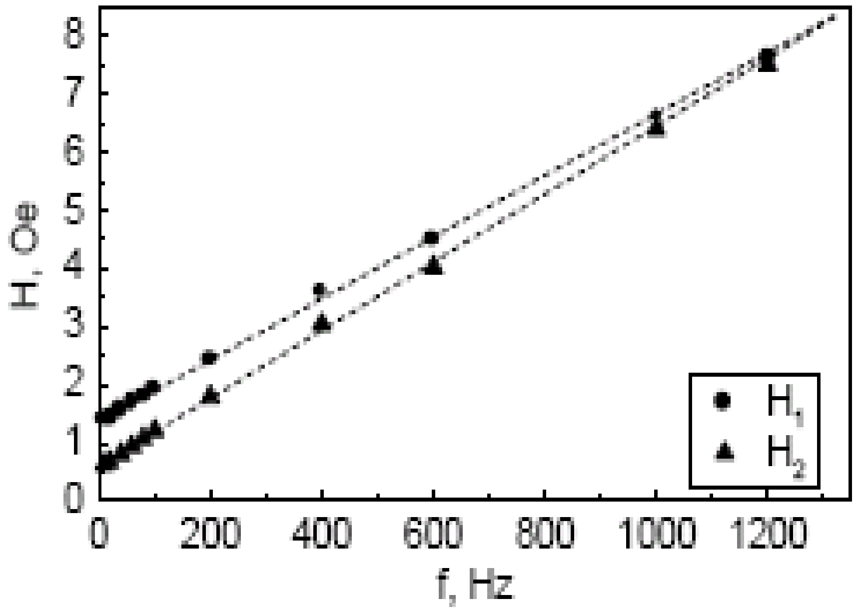
Note: the above formula was used to investigate the stray field of microwires as dependent on the wire length. There, its value is 50 times smaller than the experimental value.

In many cases the measurement of the distance dependence of the interacting field does not allow to assign a definite exponent of the postulated proportionality

$$H_{II} \propto r^{\alpha}$$



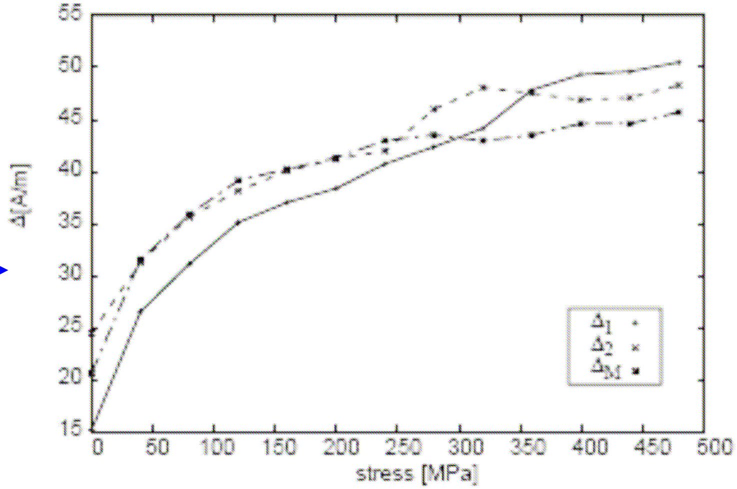
But why $\boldsymbol{H_{II}}$ depends also on the frequency of the applied field?



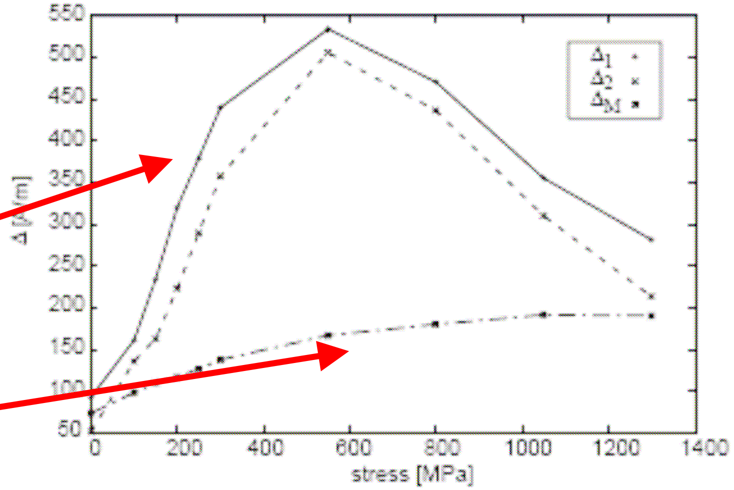
Chizhik et al., (2002)

There is an experimental evidence, that the hysteresis loop of the interacting wires is **not** a direct measure of the stray field (Gawronski et al. 2005):

Stress dependence of the interaction field for wires of diameter 125 μm

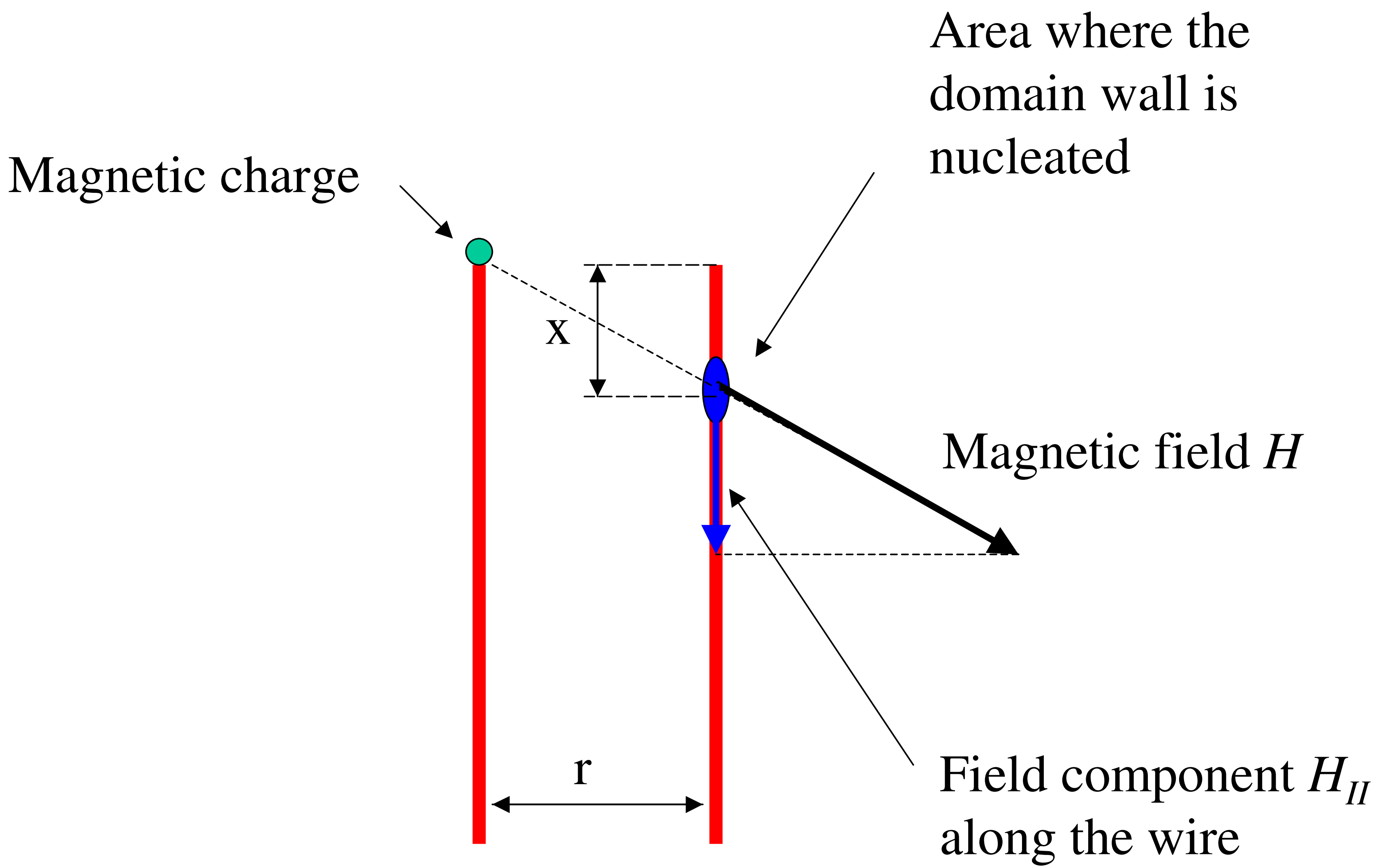


and for cold-drawn wires of diameter of 50 μm



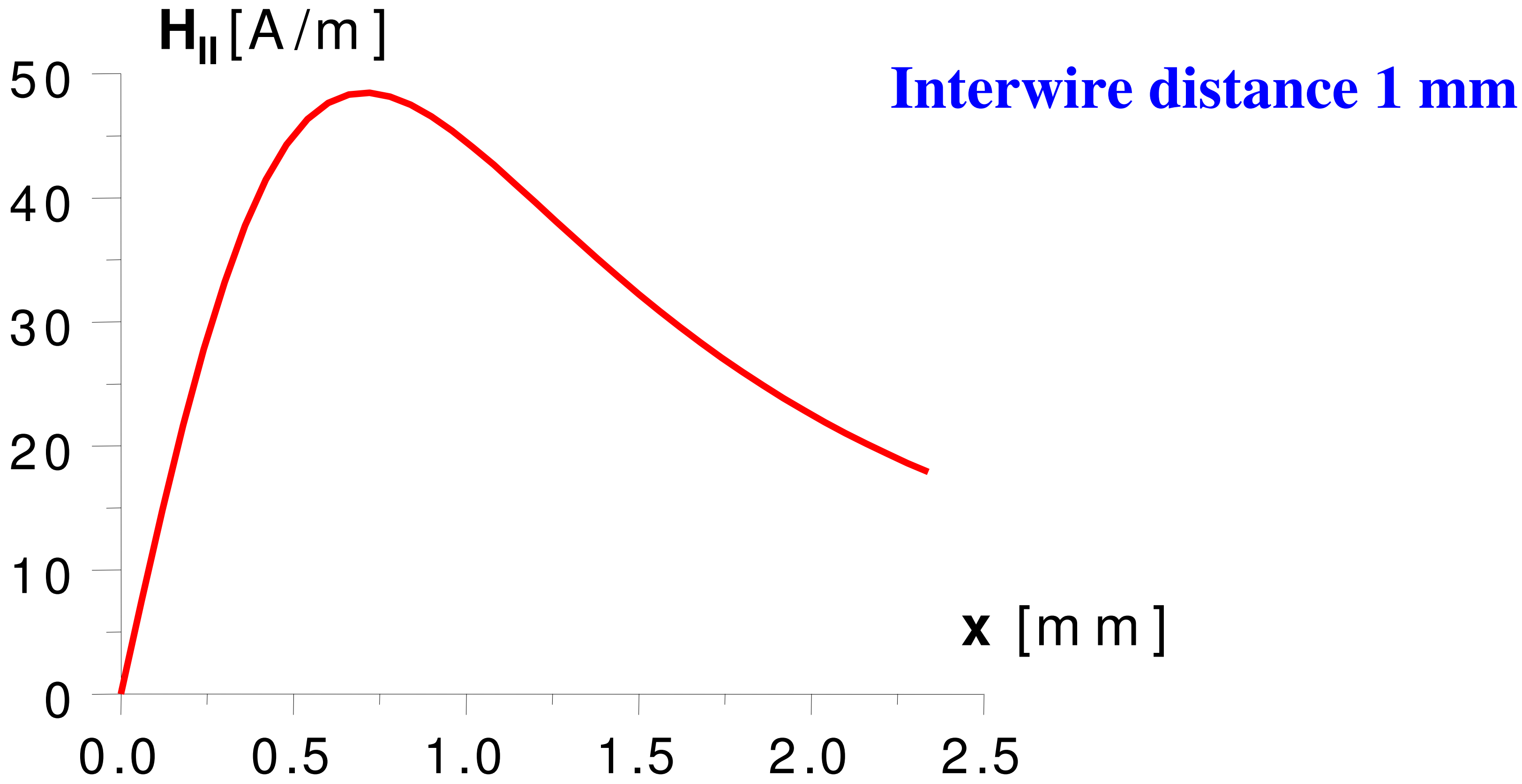
The stray field varies with the applied stress, and this cannot be reduced to the variation of the magnetization.

THE DOMAIN STRUCTURE NEAR THE WIRE ENDS



Area where the domain wall is nucleated
Magnetic charge
x
Magnetic field H
r
Field component H_{II} along the wire

$$H_{II} = \frac{Qx}{4\pi(r^2 + x^2)^{3/2}} = \frac{MD^2 x}{16(r^2 + x^2)^{3/2}}$$



Assuming, that the domain is nucleated at the wire end and its size is D, we get

$$H_{II} = \frac{MD^3}{16(r^2 + D^2)^{3/2}}$$

what gives about **7 A/m** for our wires, and **500 A/m** for microwires.

reasonable

20 times too large...

A conclusion from this point: for interwire distance comparable to the wire diameter the point charge approximation fails. In this region, we should recommend the approach of Velazquez et al. (2003) as a starting point.

Other conclusions from this point:

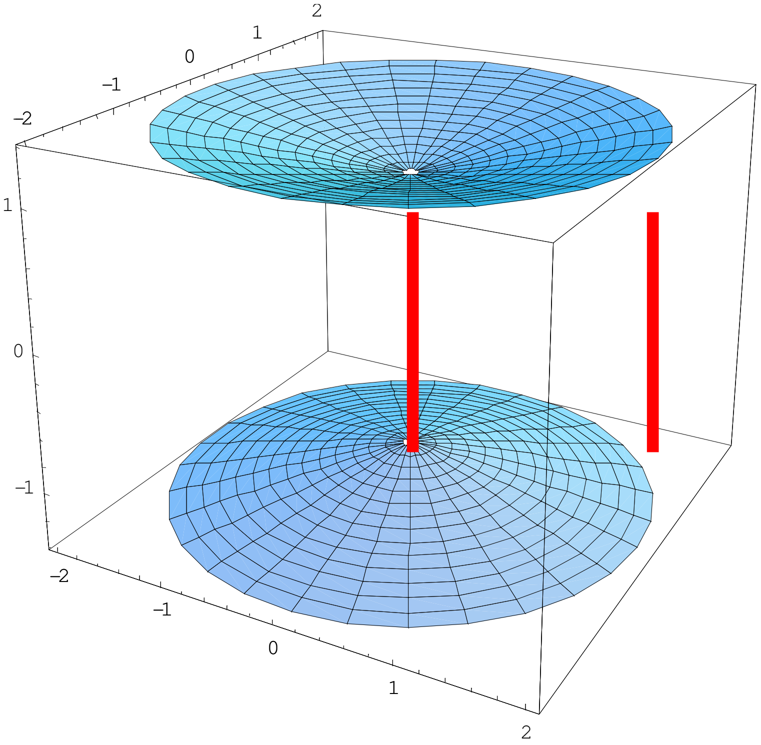
1. Once the interwire distance $r >> D$, the approximation of the point charge is acceptable.
2. Except the case of parallel wires, we can assume that the domain wall is nucleated at the wire end.

The bistability condition: $H_{II} \neq 0$ along the wire.

For two parallel wires and for $H=0$, the condition reduces to

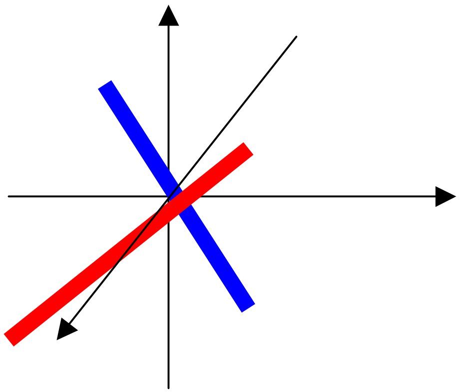
$$r^2 = \frac{(z+1)^2(z-1)^{2/3} - (z-1)^2(z+1)^{2/3}}{(z+1)^{2/3} - (z-1)^{2/3}}$$

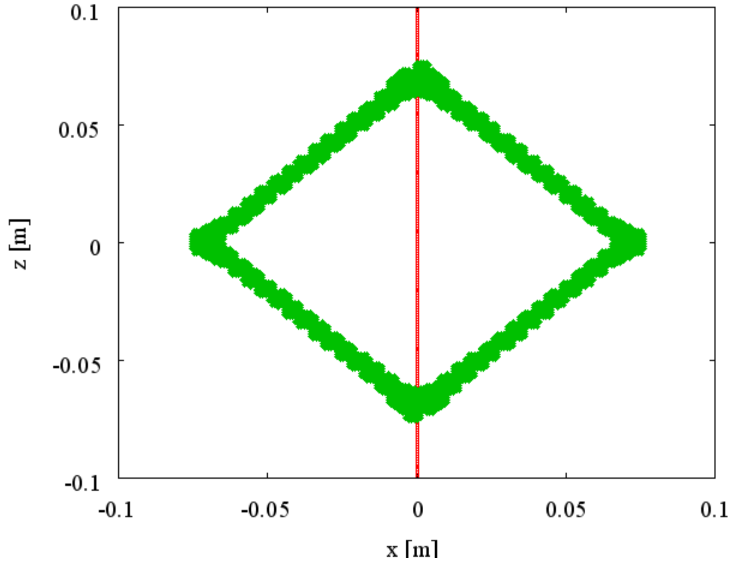
where (r,z) are in cyllindrical coordinates, with the source wire of length 2 at the centre.

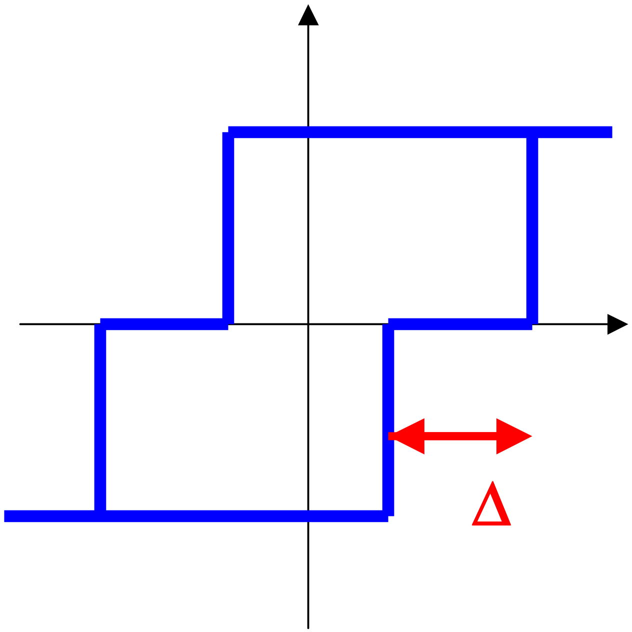


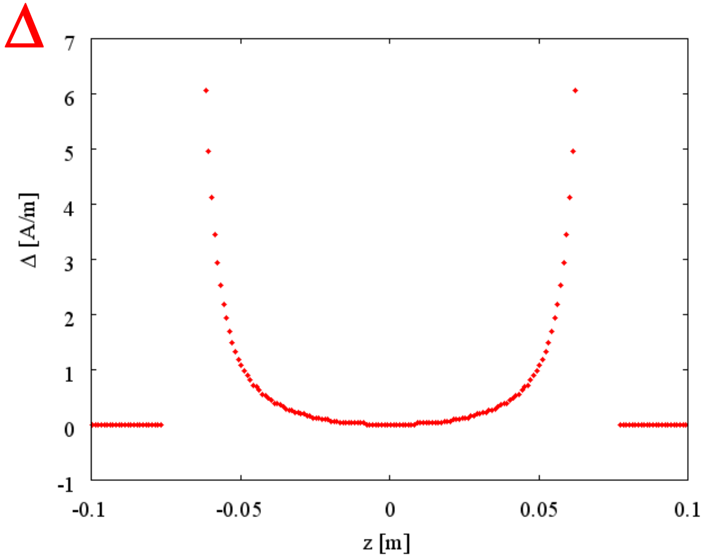
For other spatial configurations of the wire, the condition is to be solved numerically.The effective field is equal to the switching field H^*.

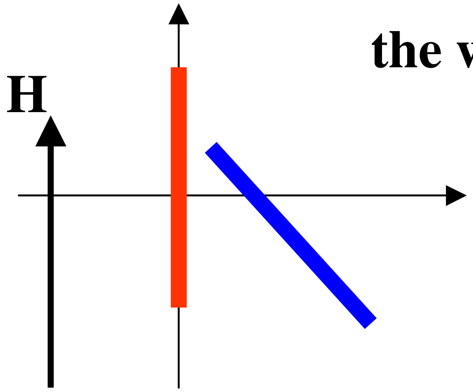
the wires



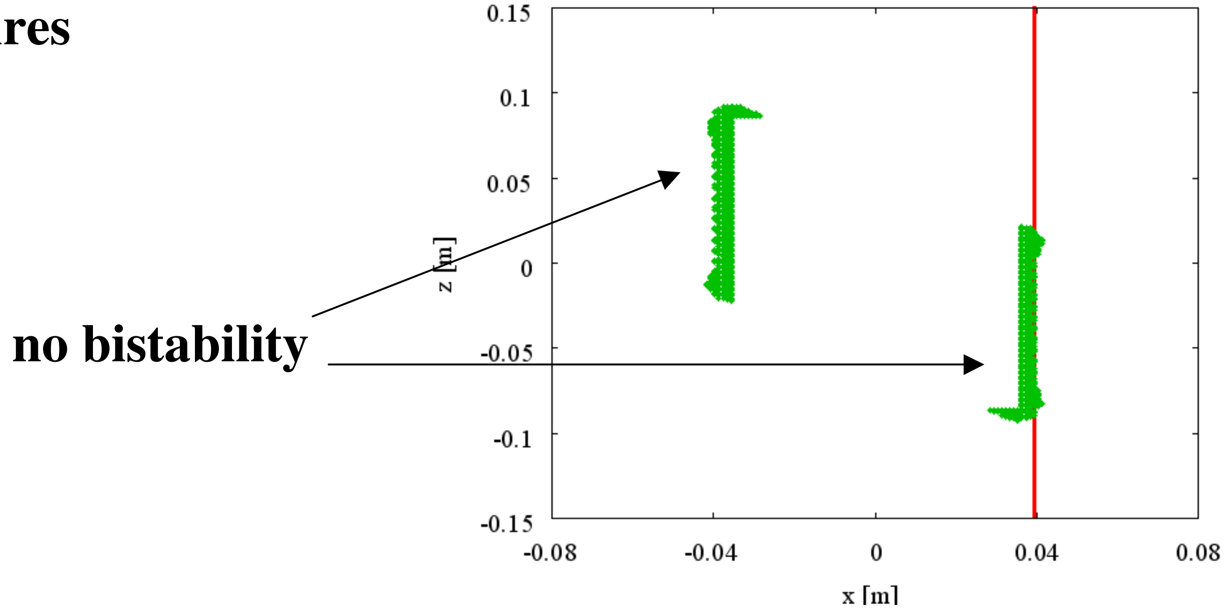

0.1
0.05
0
-0.05
-0.1
-0.1
-0.05
0
0.05
0.1
z [m]
x [m]

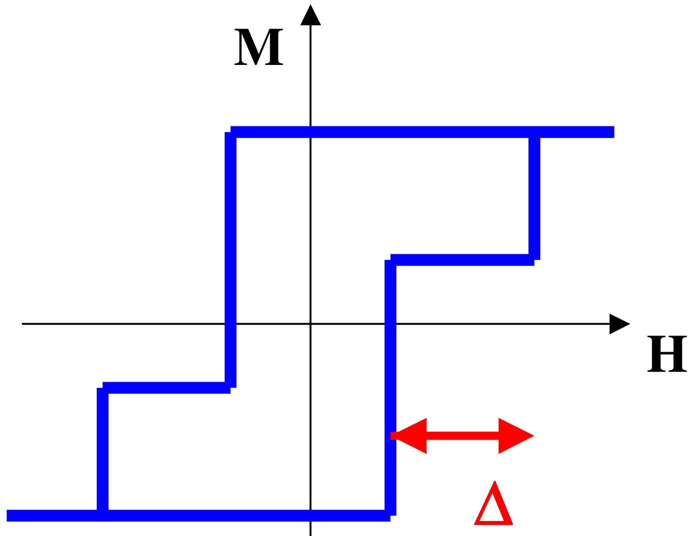

Δ

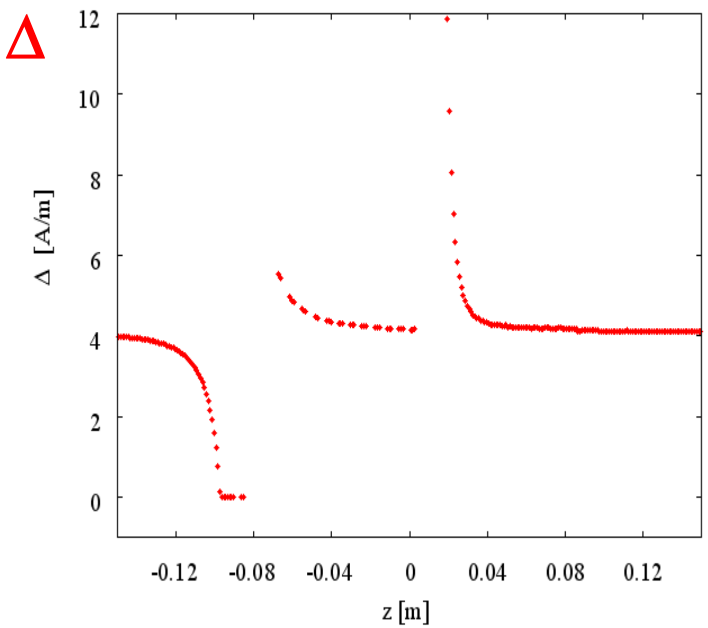

Δ
7
6
5
4
3
2
1
0
-1
Δ [A/m]
-0.1
-0.05
0
0.05
0.1
z [m]

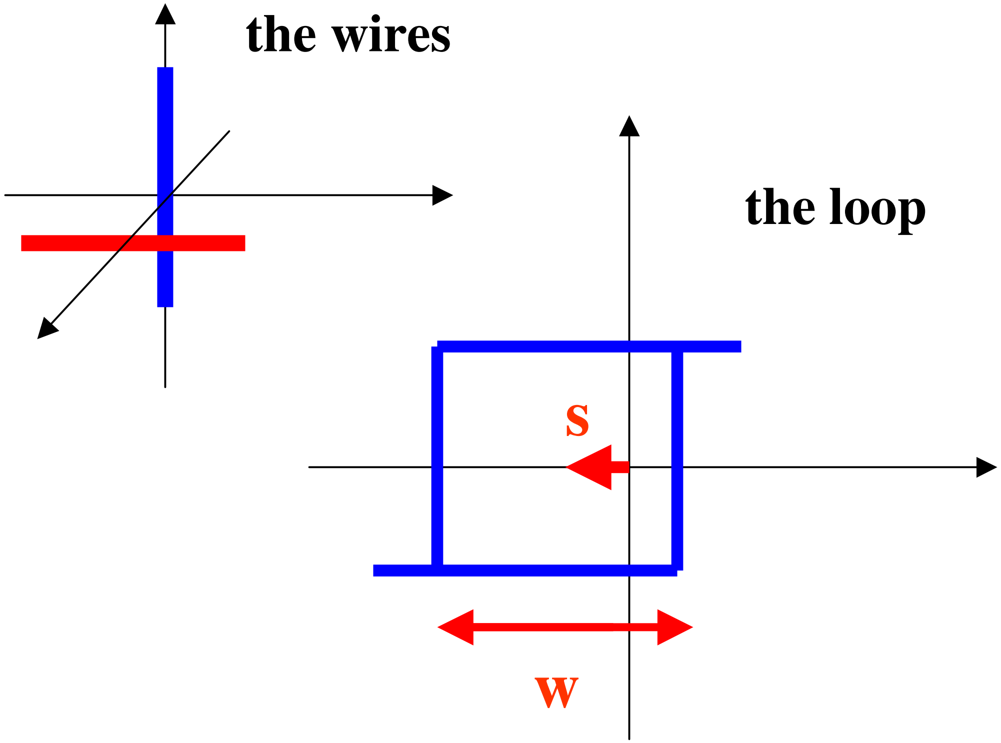

H

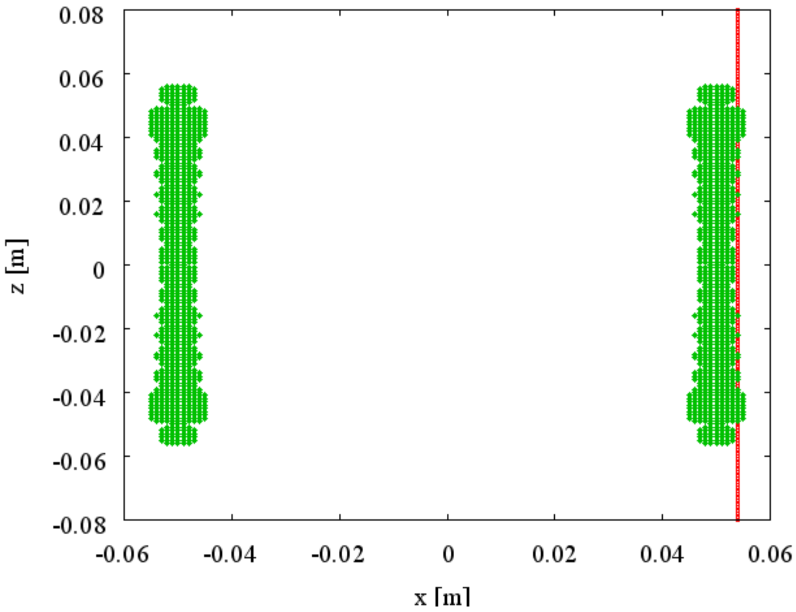
the wires

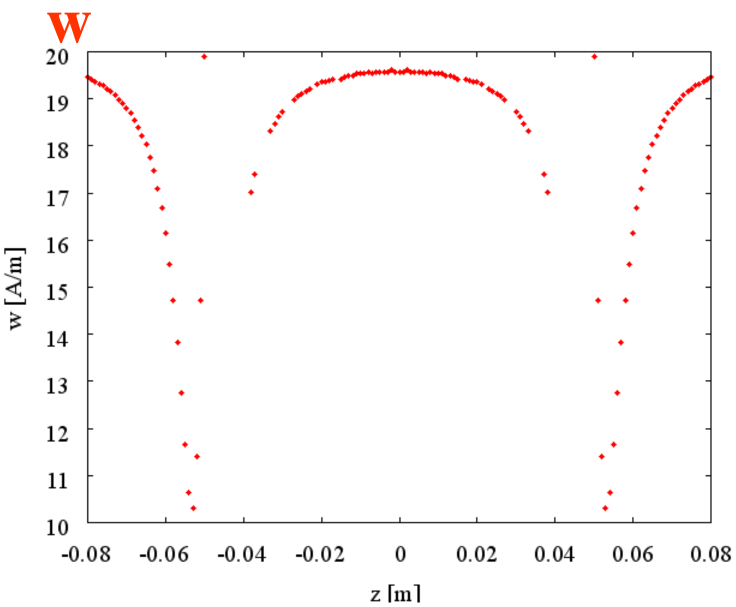

no bistability
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
z [m]
-0.08
-0.04
0
0.04
0.08
x [m]

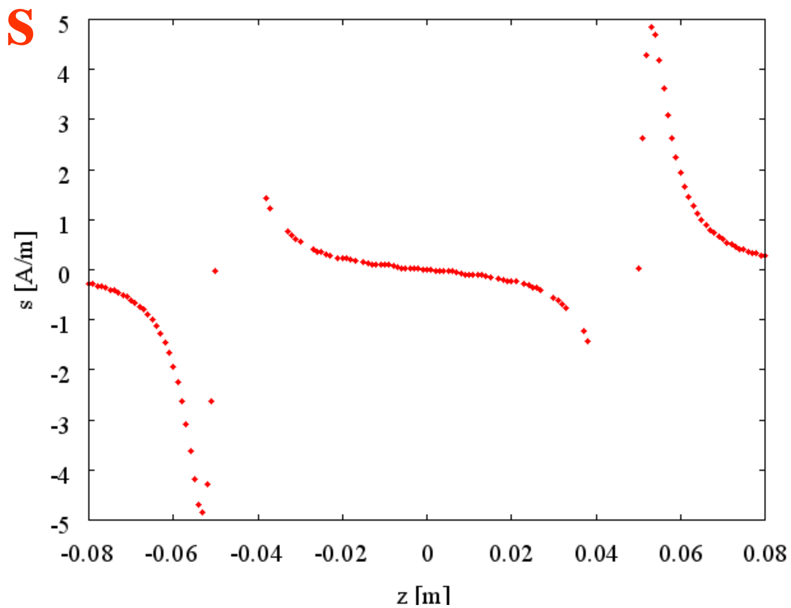

M
H
Δ


Δ
12
10
8
6
4
2
0
Δ [A/m]
-0.12
-0.08
-0.04
0
0.04
0.08
0.12
z [m]

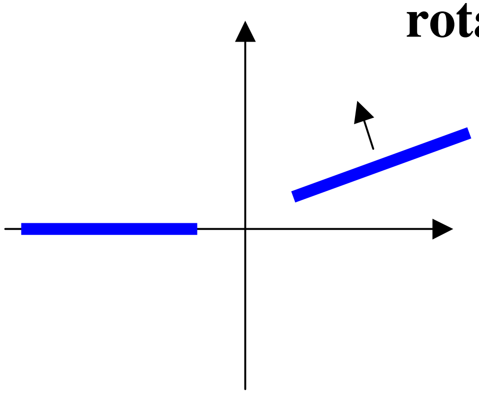

the wires
the loop
s
w

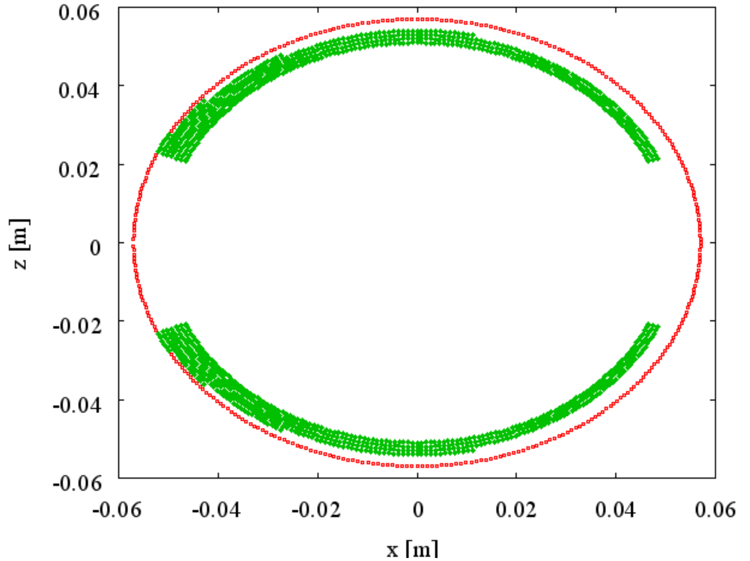

z [m]
x [m]
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06


w
w [A/m]
z [m]
20
19
18
17
16
15
14
13
12
11
10
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08


S
s [A/m]
z [m]
5
4
3
2
1
0
-1
-2
-3
-4
-5
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08

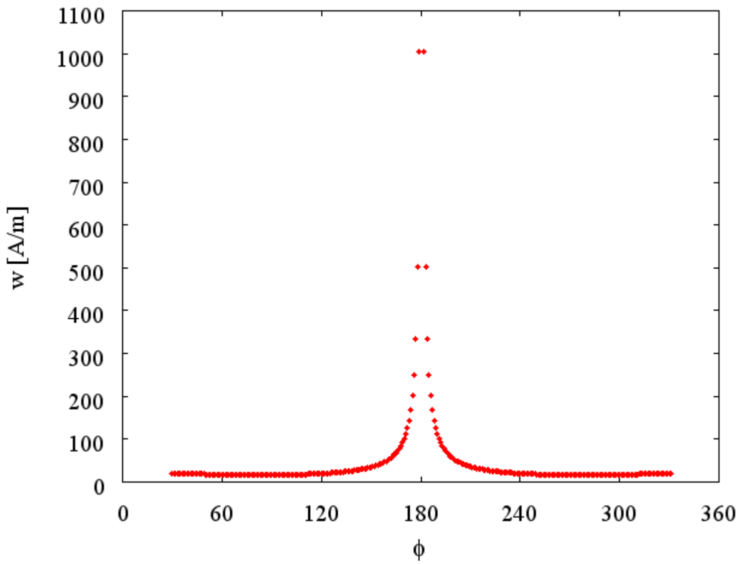
rotation





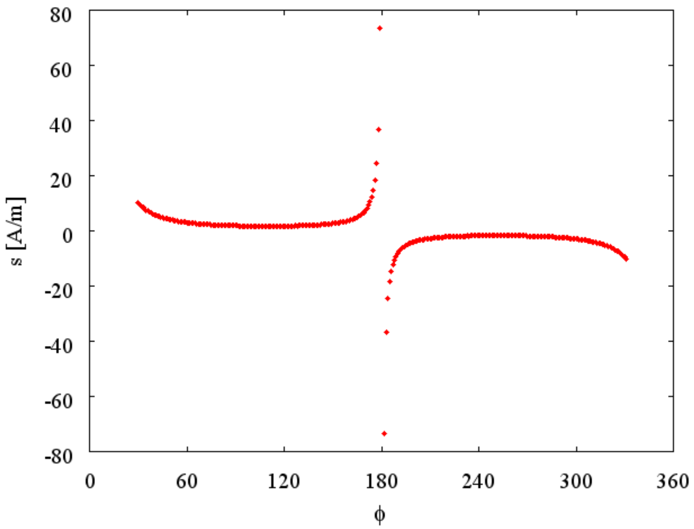
z [m]
x [m]
0.06
0.04
0.02
0
-0.02
-0.04
-0.06

w

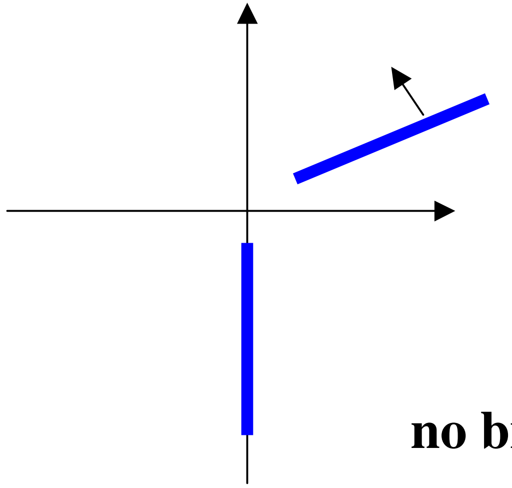


w [A/m]
ϕ
1100
1000
900
800
700
600
500
400
300
200
100
0
0
60
120
180
240
300
360

S

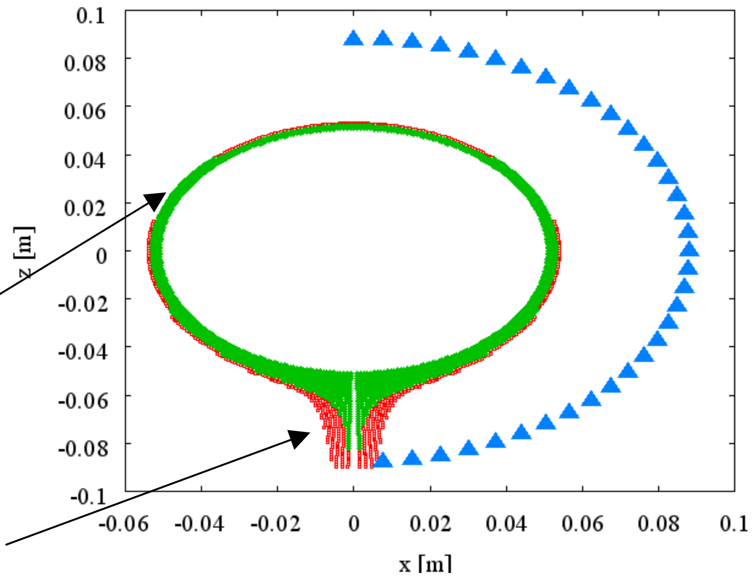


s [A/m]
ϕ
80
60
40
20
0
-20
-40
-60
-80
0
60
120
180
240
300
360

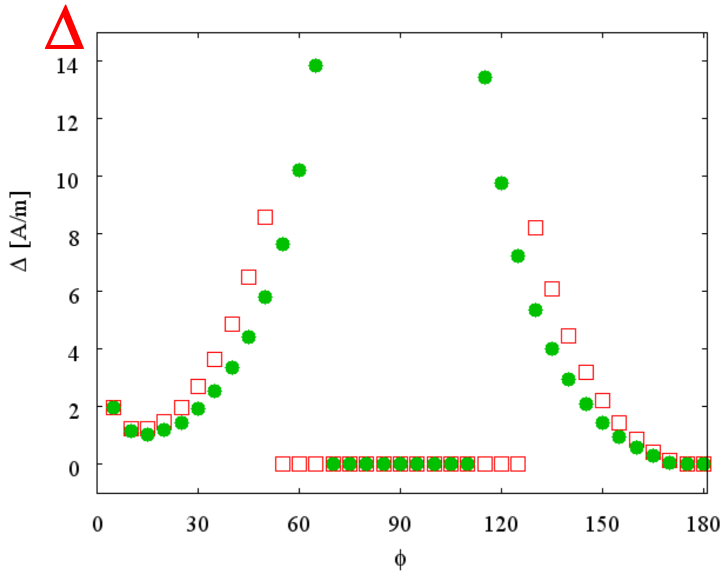


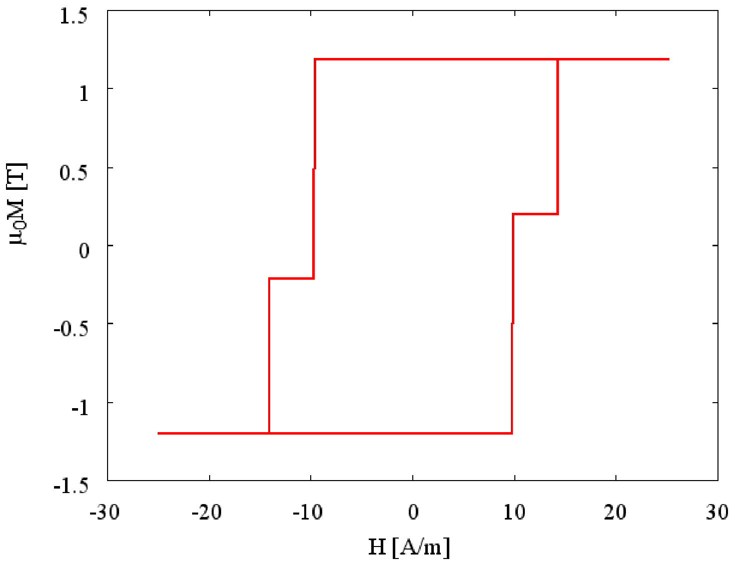
rotation

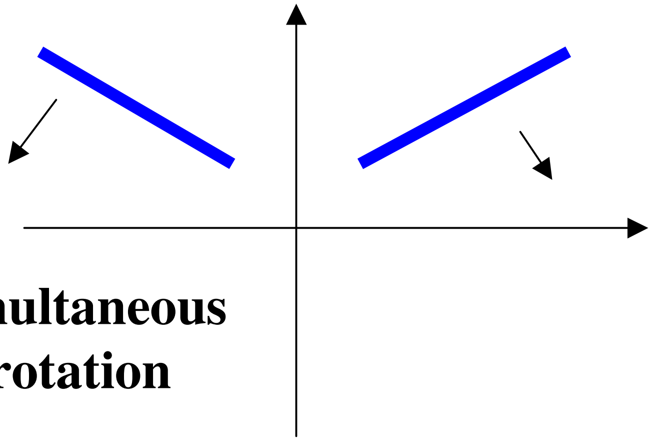
no bistability



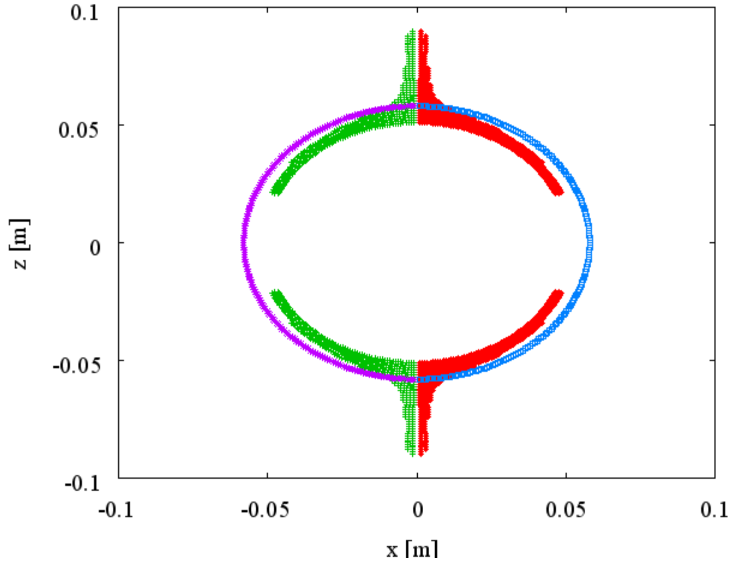
no bistability – tensile stress applied

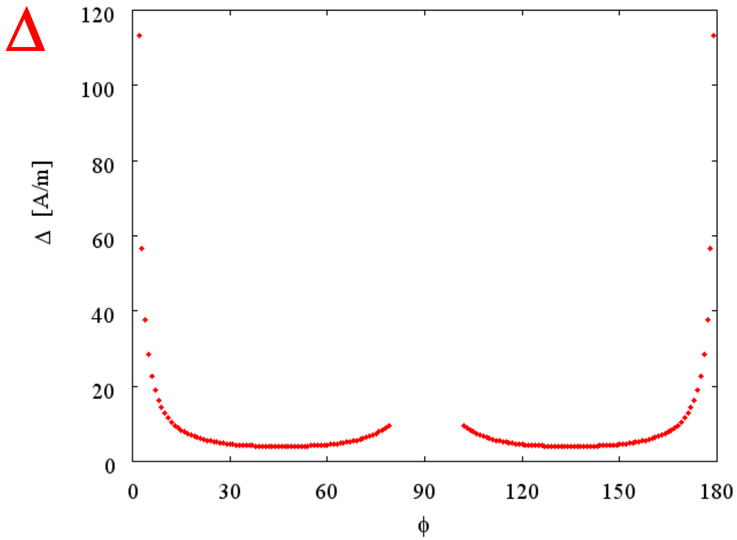




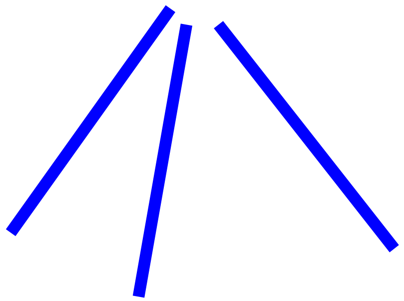


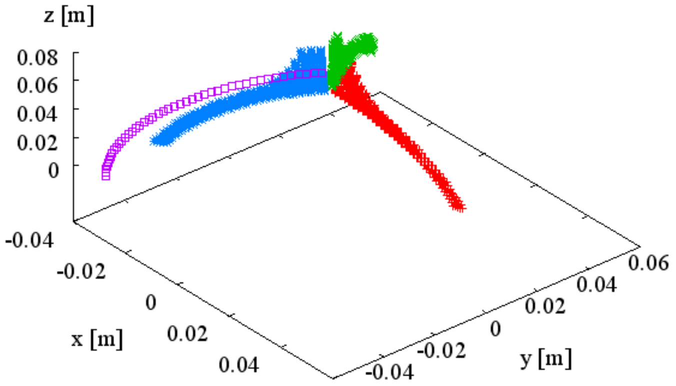
Simultaneous rotation

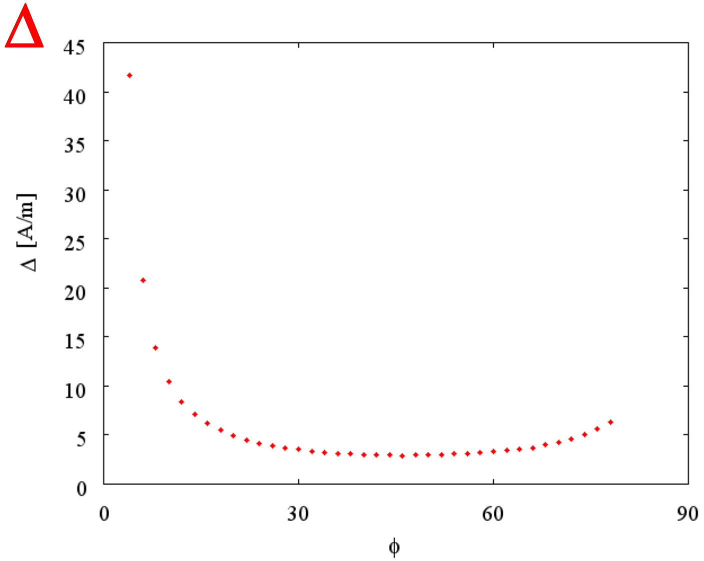


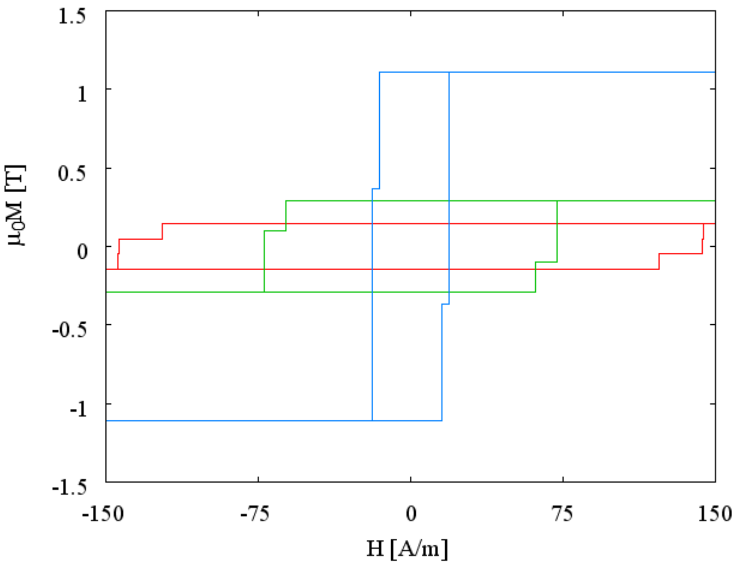


the wires – spatial structure









Conclusions:

The wire stray field can be approximated by the field created by two point magnetic charges, if the wire-wire distance is at least one order of magnitude larger than the wire diameter.

The characteristic plateau of the hysteresis loop is not only a measure of the stray field, but it also depends on the state of the wires

For some spatial configurations of the wires, the bistability is removed by the wire-wire interaction.

Variations of the mutual positions of the wires and the applied stress give a rich set of shapes of the hysteresis loops.

Thank you

bibliography

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