Development of a Magnetic Sensor for Detecting and Sizing Paraffin Deposition Inside Pipelines

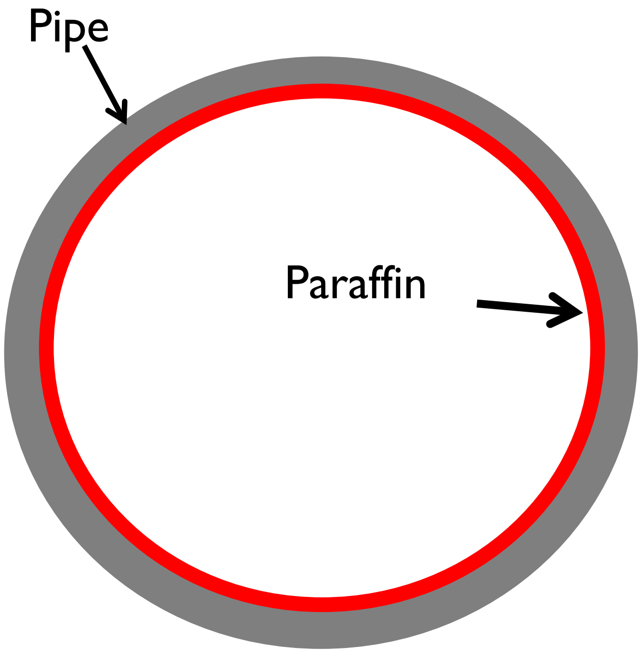
Professor Dr. João Rebello (UFRJ)
MSc. Claudio Camerini (Petrobrás)
Eng. Ivan Vicente Janvrot (Pipeway)
Dra. Maria Cristina López Areiza (LNDC/UFRJ)

UFRJ   BR PETROBRAS   PIPEWAY   LNDC PEMM/DEMM - COPPE-EP-UFRJ

ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Motivation



The paraffin deposit reduces the oil flow effiency in the pipe, by reducing its inner diameter.

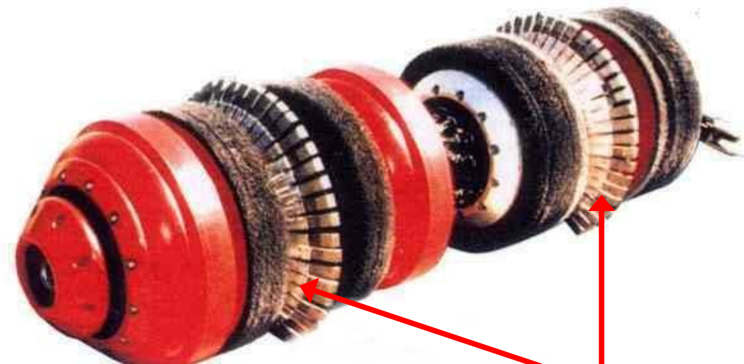
VENKATESAN, R., NAGARAJAN, N.R., PASO, K., *et al*, "*The strength of paraffin* gels formed under static and flow conditions", *Chemical Engineering Science, v.60, pp.* 3587 – 3598, 2005.

Motivation

Many companies use PIGs (Pipeline Internal Gate).

This equipment
is used in several operations: defect detection, cleaning and paraffin removal from the pipe inner wall.

These operations must be periodic to avoid flow obstruction in the pipe.



Typical distribution of sensors: called crown

Cleaning PIG

Geometrical PIG

Magnetic PIG

Objectives

Development of a magnetic based methodology for:

-detecting and sizing paraffin deposits on the pipeline inner wall and;

-detecting and sizing corrosion attack areas located underneath the paraffin deposits.

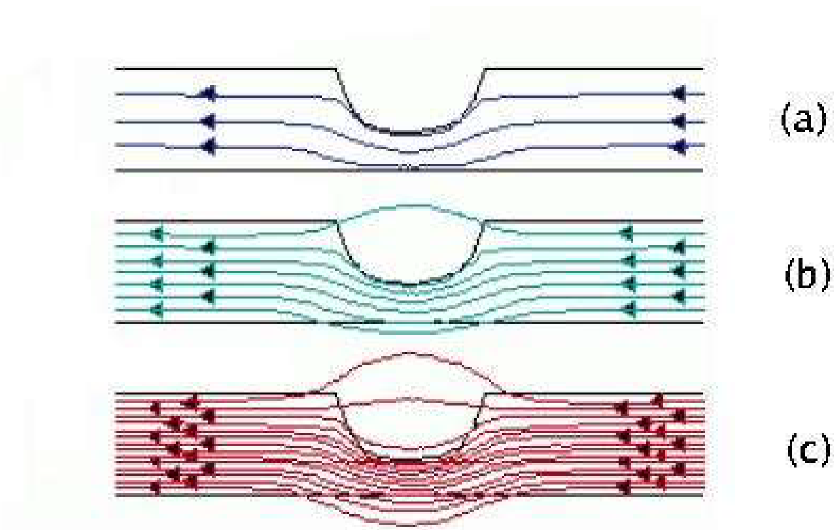
Objectives

-to develop a specific sensor to be adapted to the equipment called Pipeline Internal Gate (Pig), for detecting and sizing such paraffin deposition areas.

References

Currrently used techniques for metal loss detection due to corrosion attack based on magnetic principles:

The typical technique is Magnetic Flux Leakage (MFL)



Magnetic Flux lines during a MFL inspection :

(a) Low magnetization level, not suitable;

(b) Medium magnetization level;

(c) High magnetization level, suitable.

NESTLEROTH, B., "Technology Status Assessment for Circumferential MFL for SCC", Final Report on RESEARCH PROGRAM PR39420, 1999.

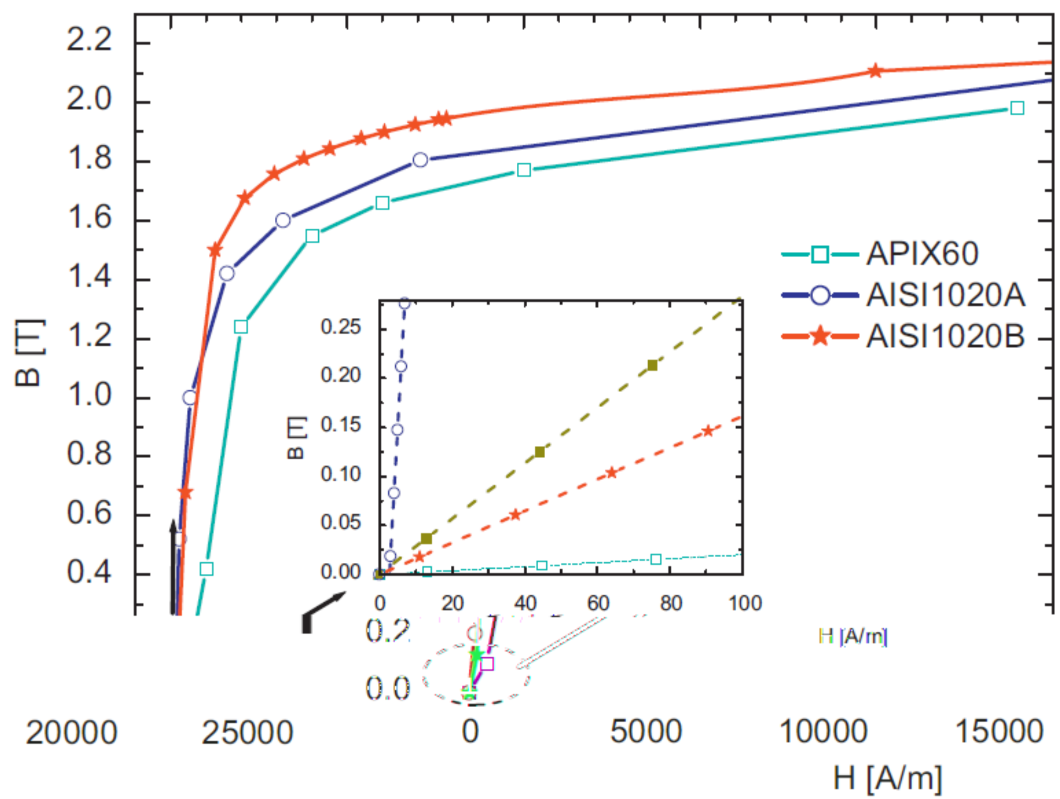
Source: www.netl.doe.gov/scng/

ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Reference

-Different carbon steels can exhibit rather different magnetic responses

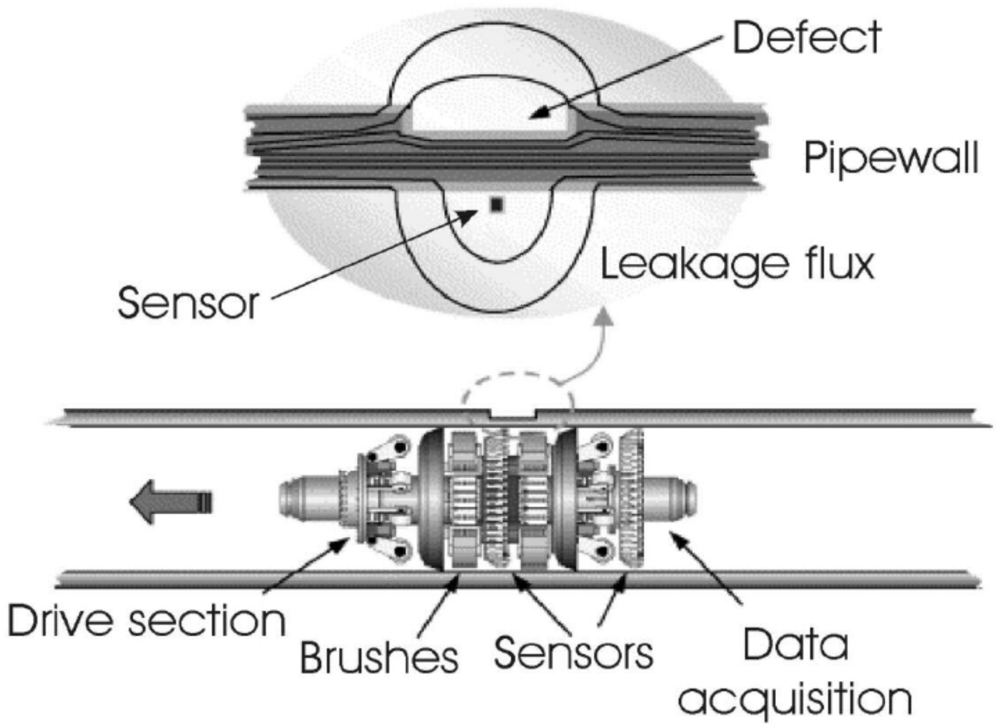


NESTLEROTH, B., "Technology Status Assessment for Circumferential MFL for SCC", Final Report on RESEARCH PROGRAM PR39420, 1999.

Source: www.netl.doe.gov/scng/

Reference

- How to detect defects and corroded areas using MFL and PIG's?



Defect detection consists in finding the areas in the pipe where there is a MFL due to metal loss.
One can see the drive section, the brushes for cleaning and magentic contact, the sensors and device for data adquisition.

NESTLEROTH, B., "Technology Status Assessment for Circumferential MFL for SCC", Final Report on RESEARCH PROGRAM PR39420, 1999.

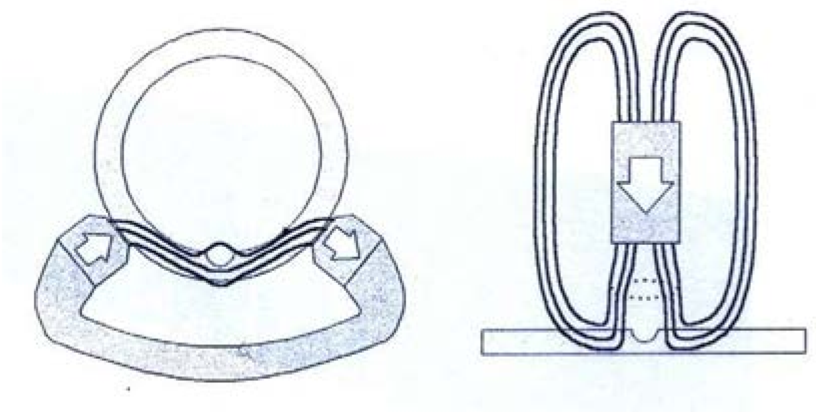
Source: www.netl.doe.gov/scng/

ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Reference

Alternative ways of magnetic induction can be considered.

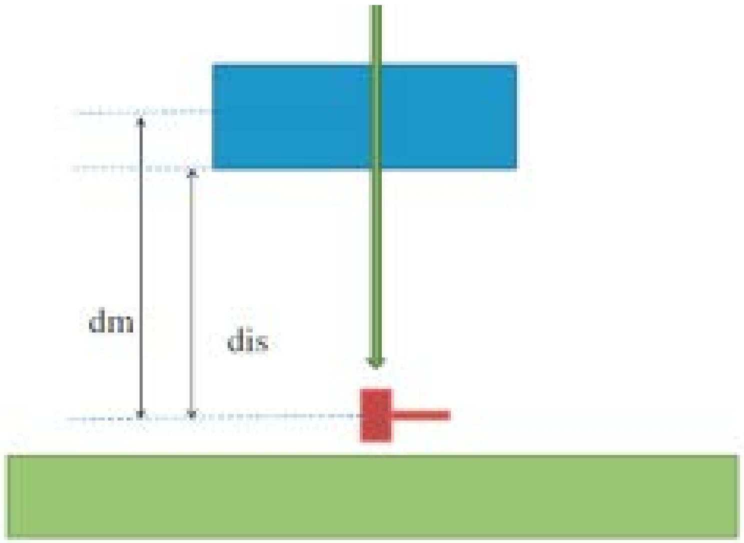


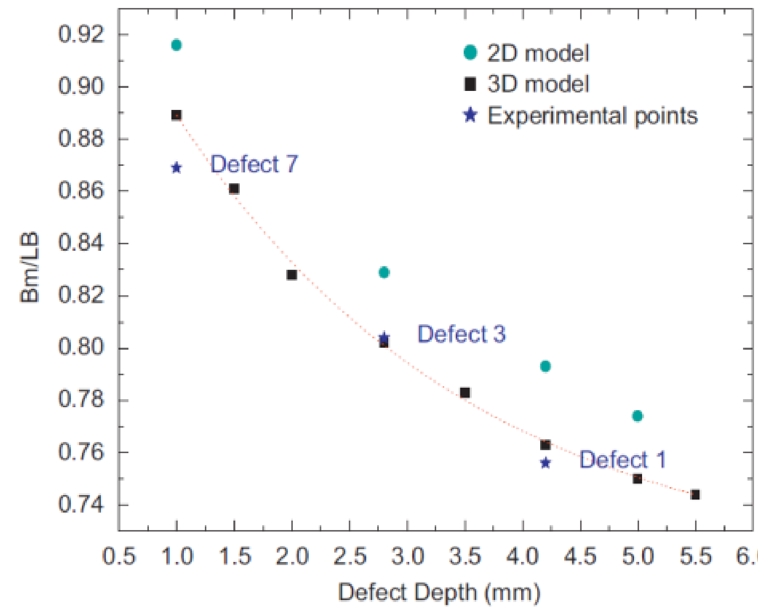
Besides the longitudinal orientation of the magnetic flux lines, it is also possible to use a perpendicular magnetic field.

GLADCHTEIN, R. S., "Solução do Problema Inverso Magnetostático Utilizando Elementos Finitos e Técnicas de Otimização", PhD Theses, PUCRio, 2002.

Reference

Perpendicular magnetic induction was succesfully used for crack detection and sizing



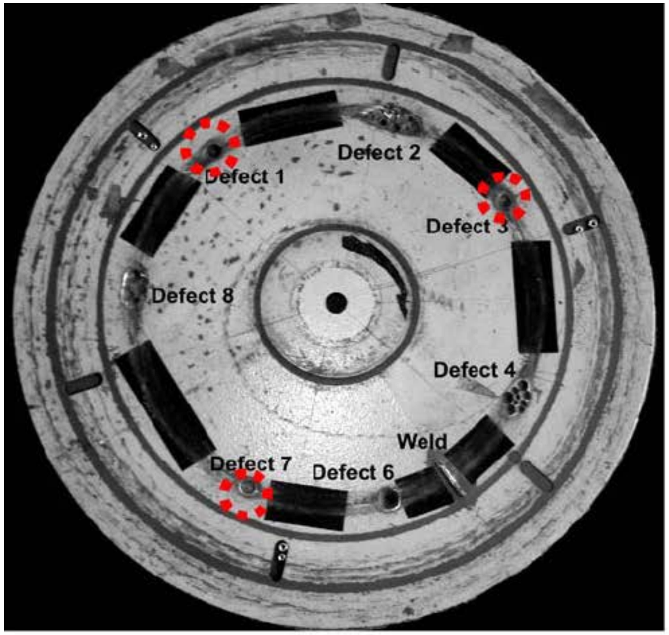


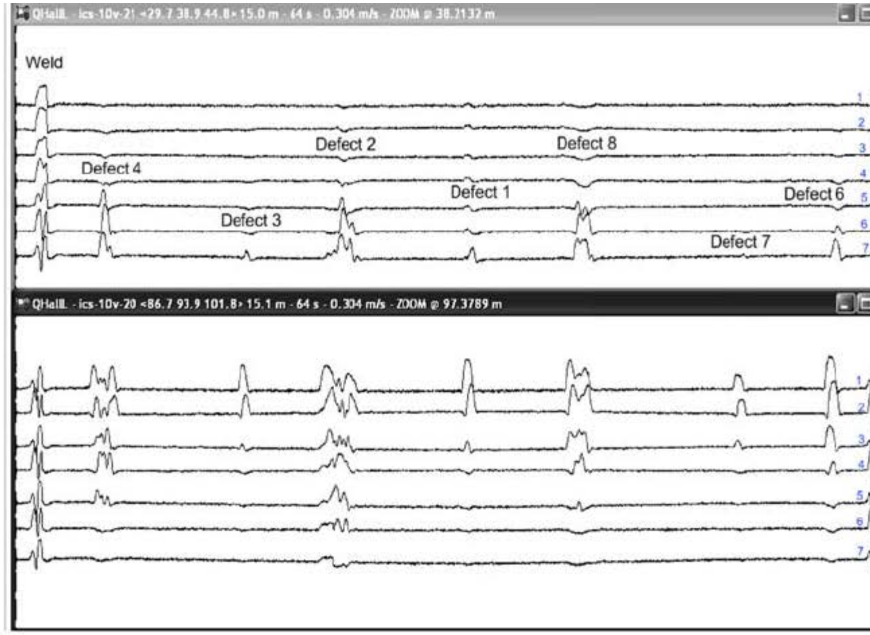
Based on Gladchtein´s work, Boechat et all (2009) developed a new magnetic sensor with perpendicular magnetic flux, called by the authors, Internal Corrosion Sensor (ICS). The focus was on the detection and sizing of small internal defects in thick walls pipelines.

BOECHAT et Al.,"Development of a magnetic sensor for detection and sizing of internal pipeline corrosion defects", NDT&E International ,Vol 42 , Pag, 669–677, 2009.

Reference

-It was confirmed the big potential of the magnetic vertical induction as technique for detection of small internal defects



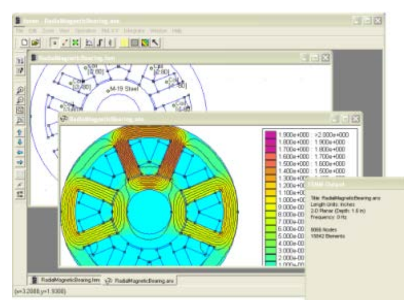


BOECHAT et Al., "Development of a magnetic sensor for detection and sizing of internal pipeline corrosion defects", NDT&E International ,Vol 42 , Pag, 669–677, 2009.

Methodology

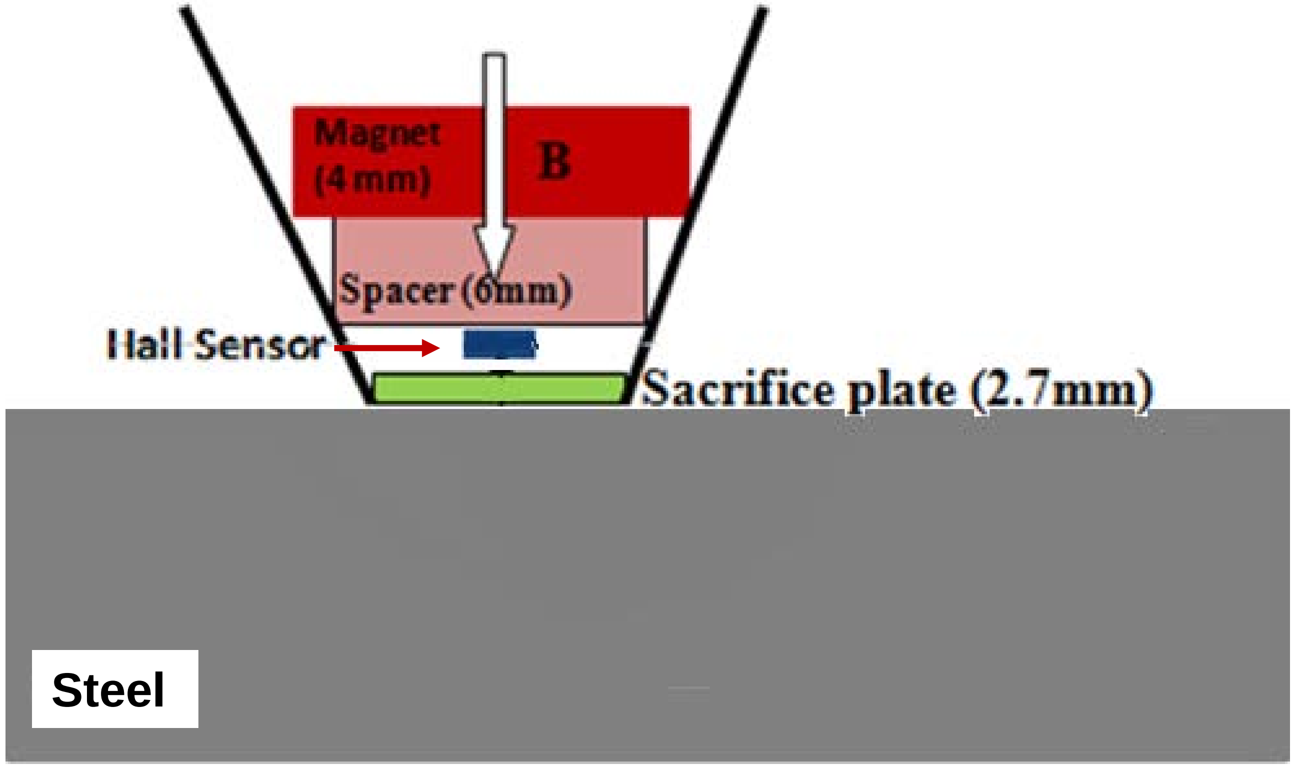
1. To develop computational models for the magnetic flux density behavior perturbation in the pipelines wall. These values were obtained by simulations with FEMM and OPERA software. The focus was to obtain the best signal contrast for the sizing of paraffin deposits.
2. To design, to build and to test a prototype probe.
3. To search for the best parameters of the probe sensor Hall aiming to attain high sensitivity.
4. To set up calibration curves for paraffin deposits sizing.

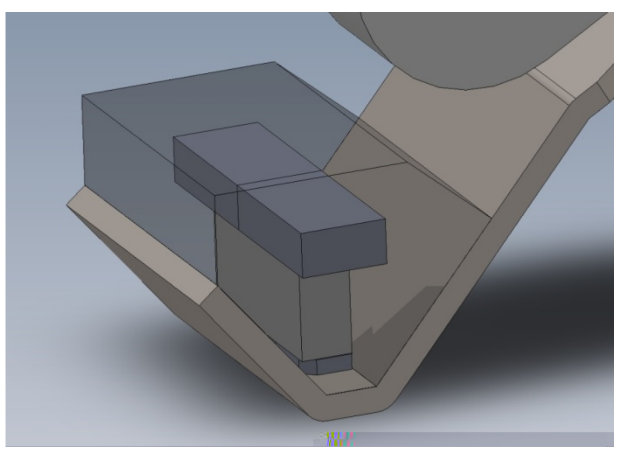
OPERA
3D
Cobham

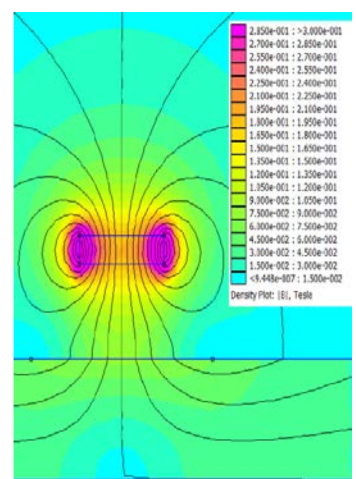


FEMM
Finite Element
Method Magnetics

Operational principle



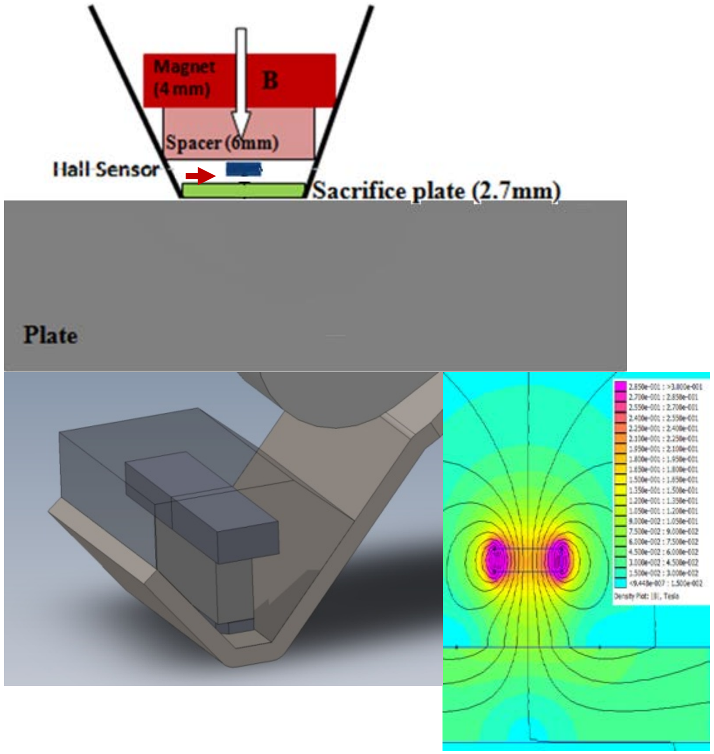




ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Operational principles



The operational principle consists in creating a constant magnetic field close to the internal wall of the pipe, using a permanent magnet.

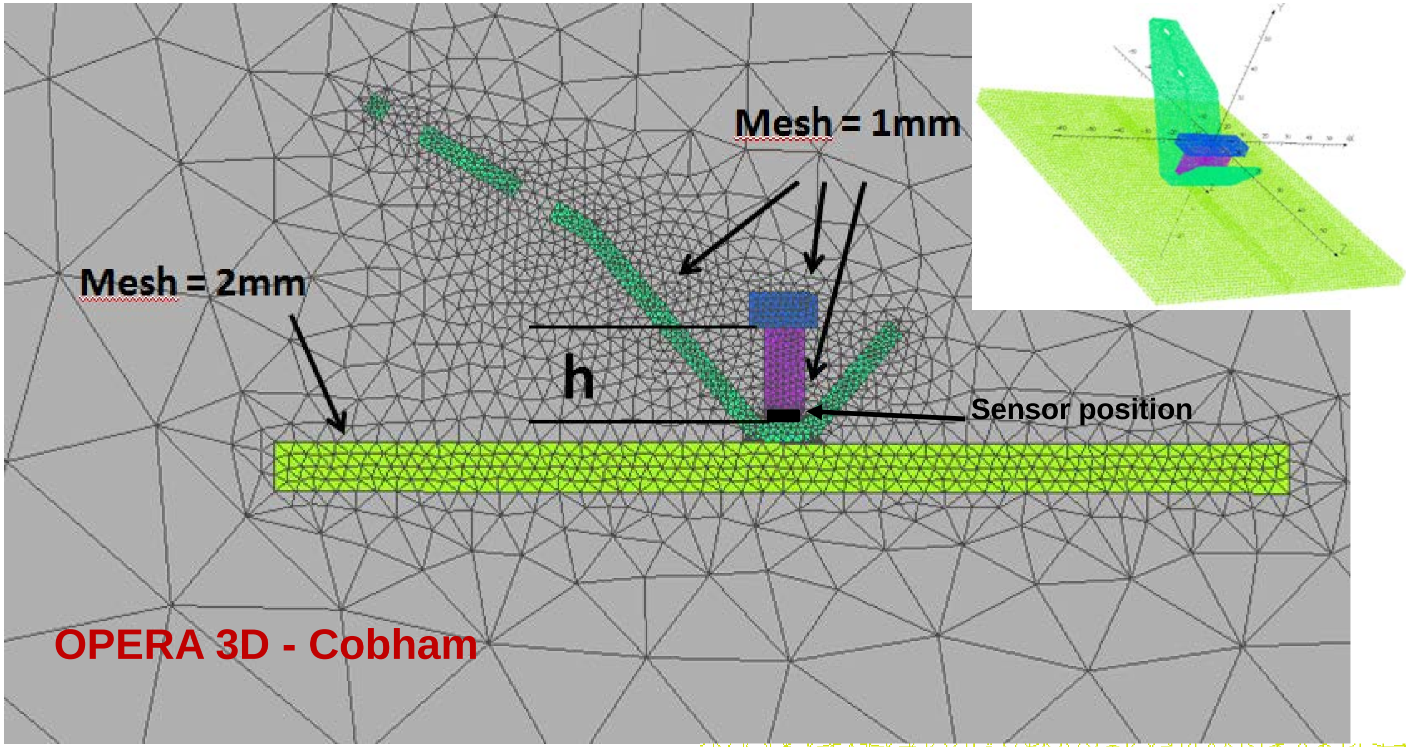
The magnetic density flow lines are measured by a Hall sensor, placed between the magnet and the internal pipe wall.

The presence of paraffin reduces the density of the magnetic flow detected by the Hall sensor.

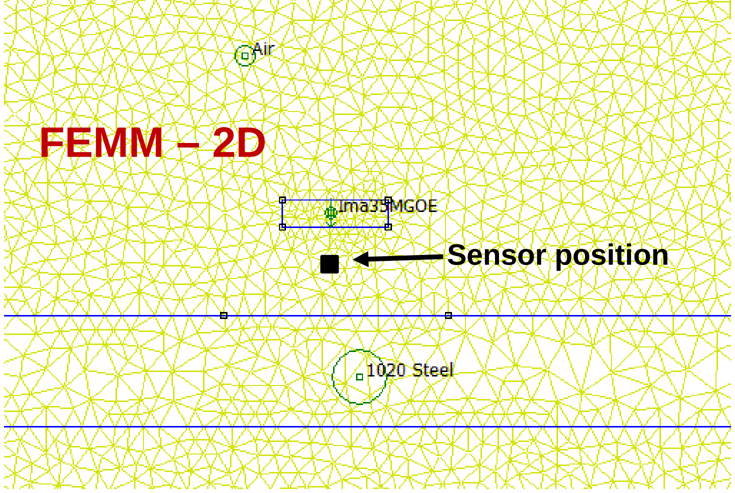
ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Computational Model



- Magnet coercivity= 35mgoe
- Isotropic and linear material settings
- Steel 1020 permeability=> μ = 760
- Steel conductivity= 5.8 MS/m
- Steel size= 100x100x5 mm
- Nodes = 71435
- Mesh elements= 216096

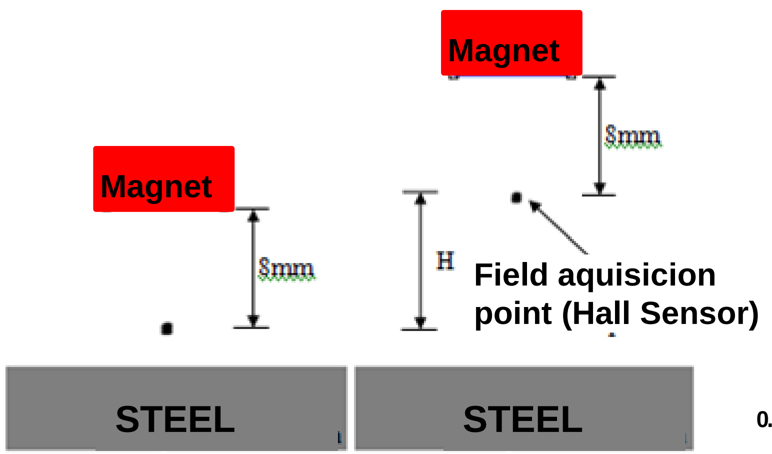


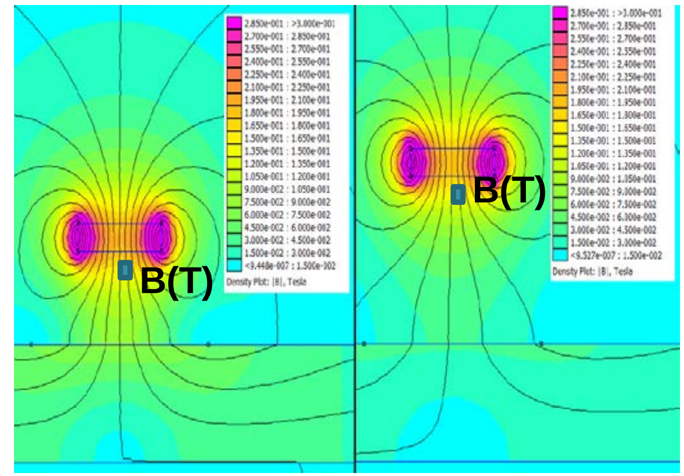
ENGINEERING OF METALLURGICAL AND MATERIALS

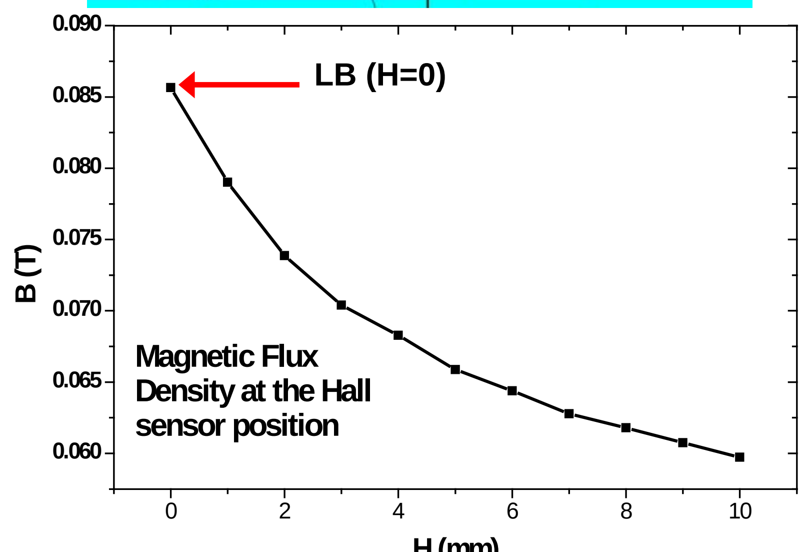
COPPE/UFRJ

Study of Magnetic Sensitivity

Sensitivity was evaluated as function of the probe sample distance







H: Distance from the pipe internal wall and the Hall sensor

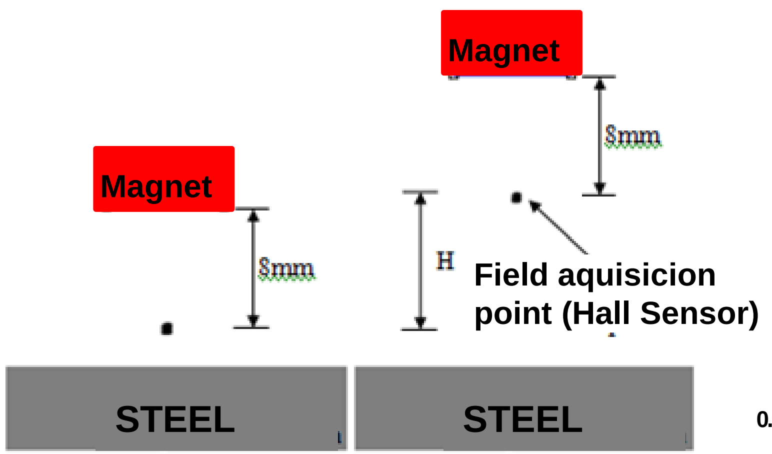
LB: Value of B(T) measured by the Hall sensor when in contact with the steel plate .

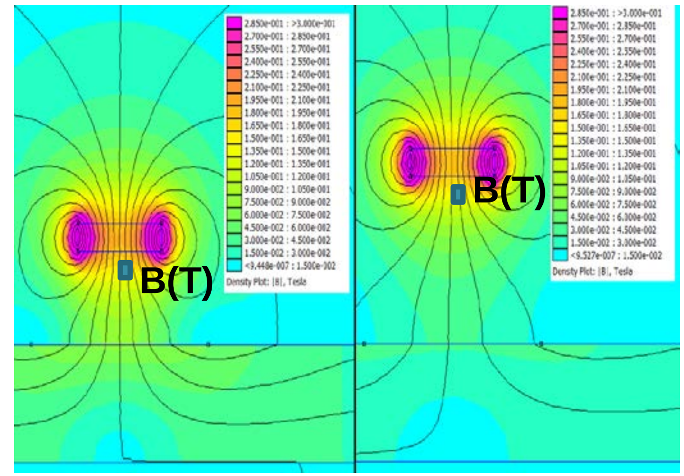
ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

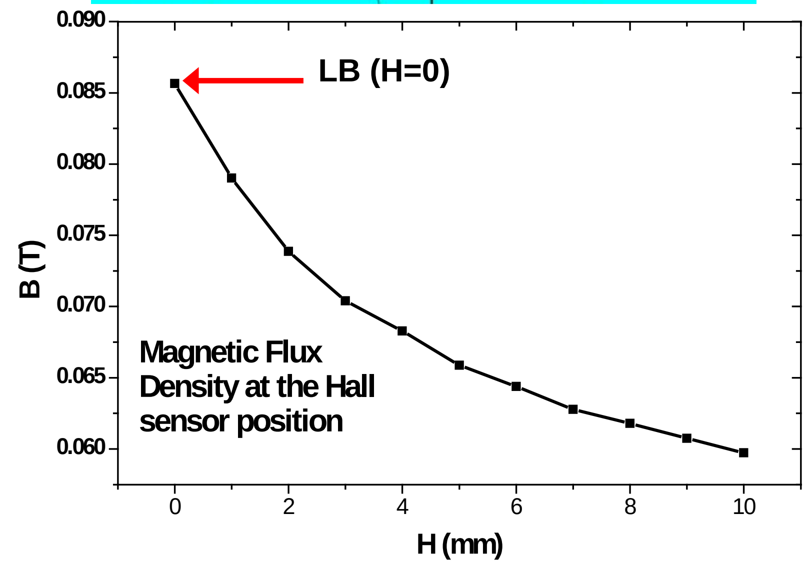
Study of Magnetic Sensitivity

Sensitivity was evaluated as function of the probe sample distance



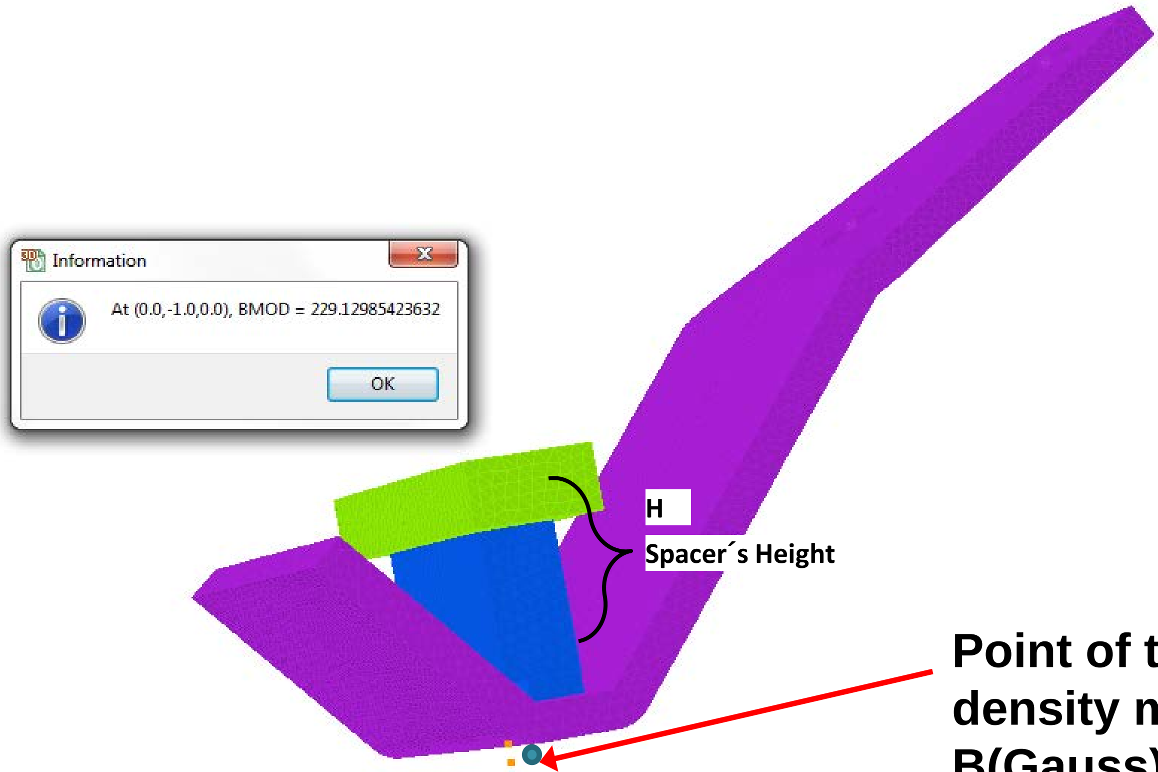


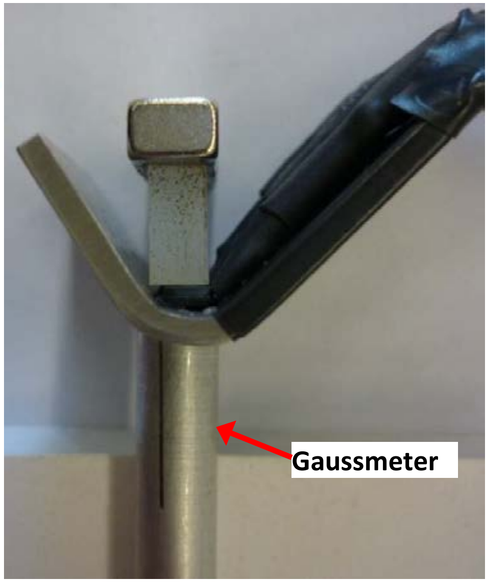
Even for big distance (8 to 10 mm) the magnetic flux density is high enough. This means that the parameters selected are appropriate. The figure shows that the Hall sensor is not in a magnetic saturated condition.



Level of magnetism

Magnetic flux was measured B(Gauss) experimentally and compared with OPERA 3D simulation results.





Point of the magnetic flux density measurement, B(Gauss).

Simulation Validation

Comparison of B (Gauss) for different spacer´s values (H).

H Spacer´s Height (mm)	B (G) (Experimental)	B (G) (OPERA3D) to 2mm	Δ (Error)
8	185	198	6,5%
7	220	230	4,3%
6	246	270	8,8%
5	295	319	7,5%

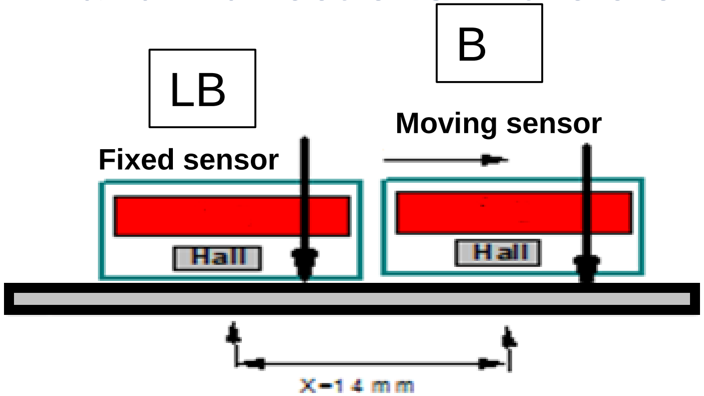
There is a good correspondance between the experimental and simulated results for the magnet initially chosen (35 MGOe). The maximum error in the table is lower than 10 %.

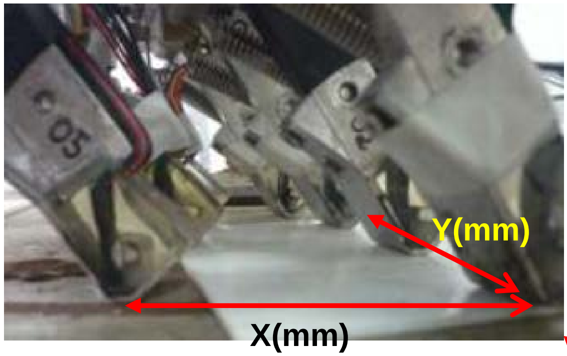
ENGINEERING OF METALLURGICAL AND MATERIALS

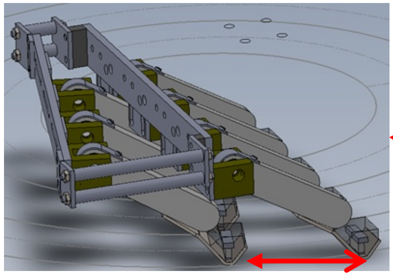
COPPE/UFRJ

Interference Among Probes

The interference between the sensors signals was evaluated in the X and Y directions in the crowns.

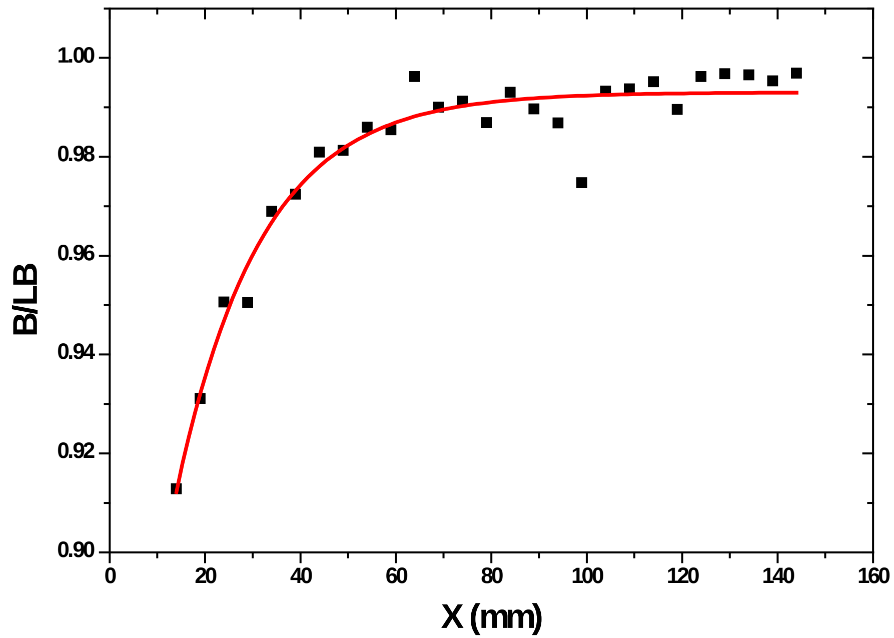






The crowns

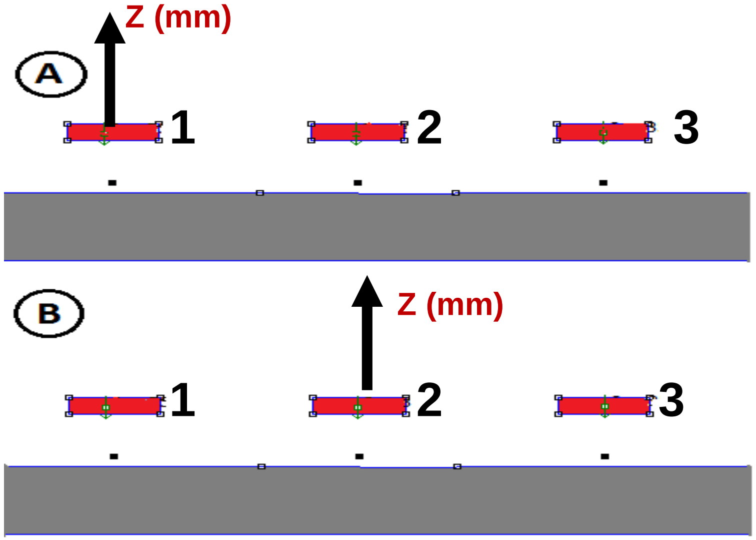
X direction

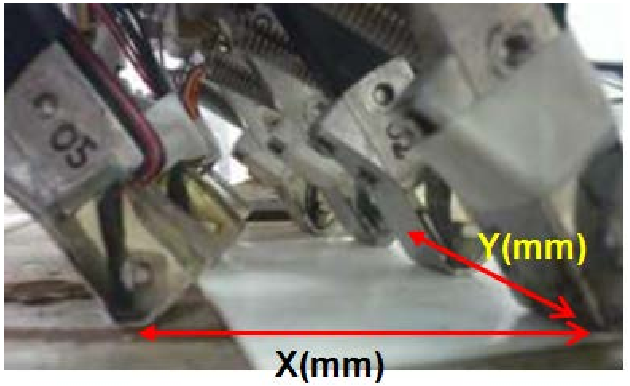


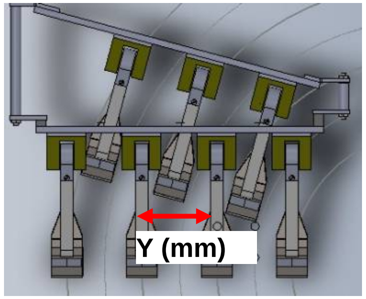
The influence can be neglected for X greater than 70mm

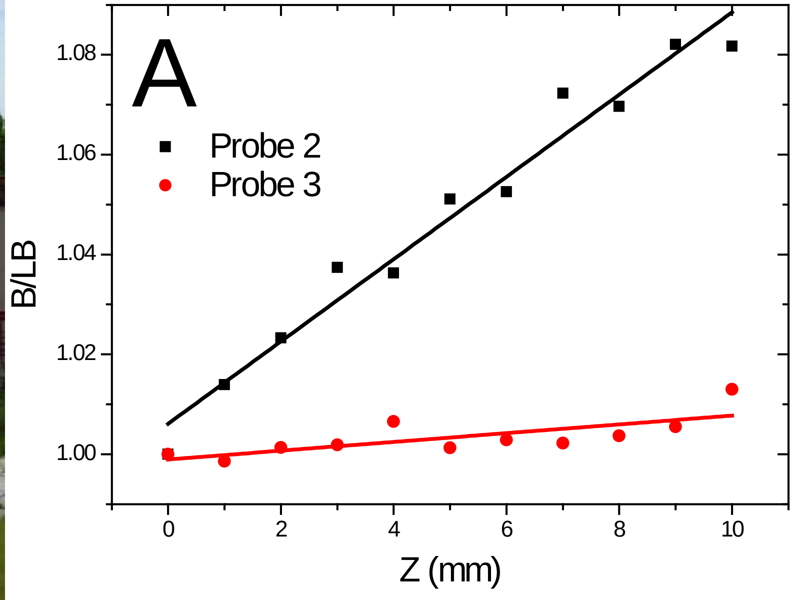
Interference Among Probes

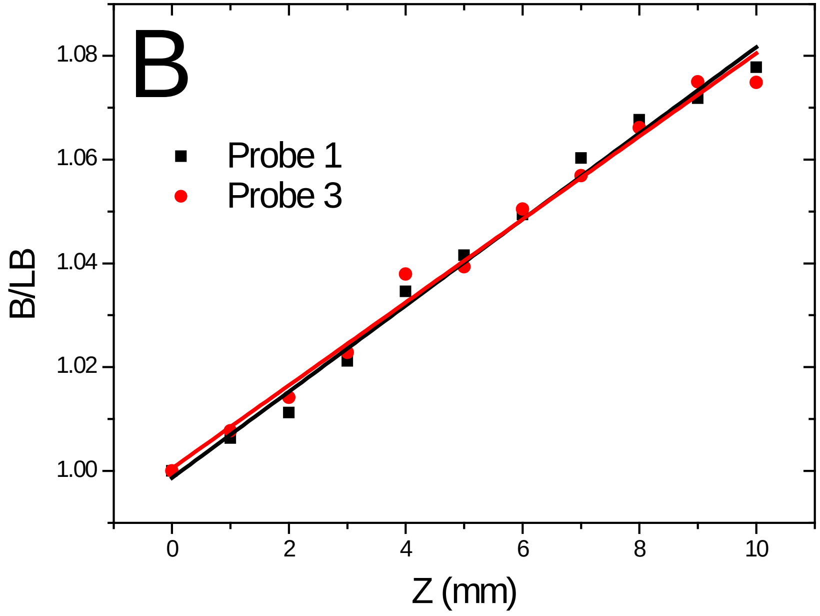
- Vertical interference among sensors.





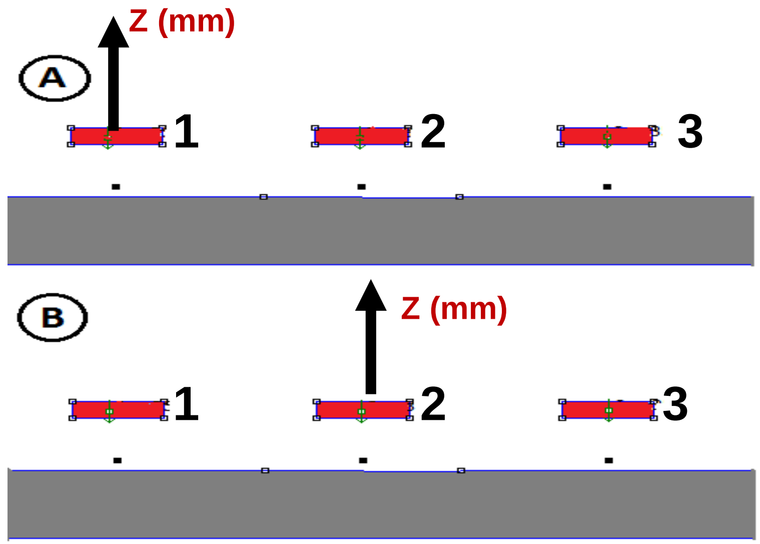




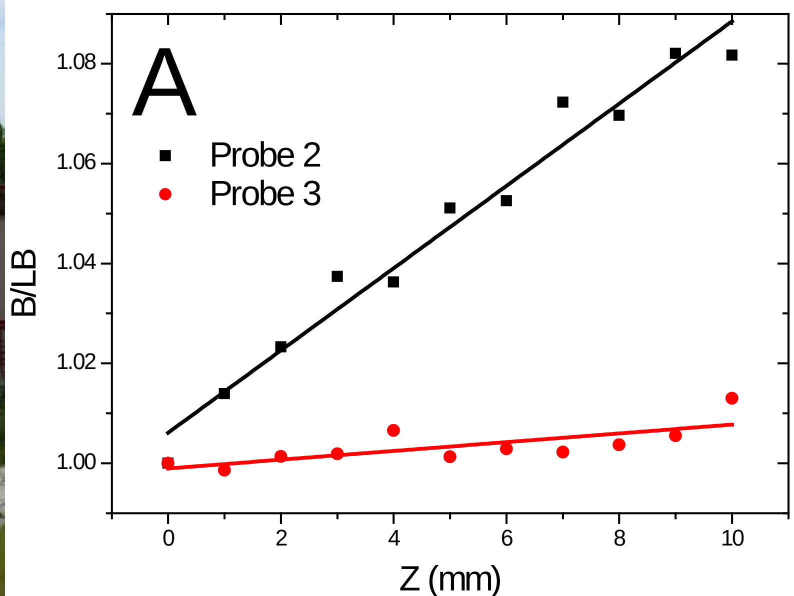


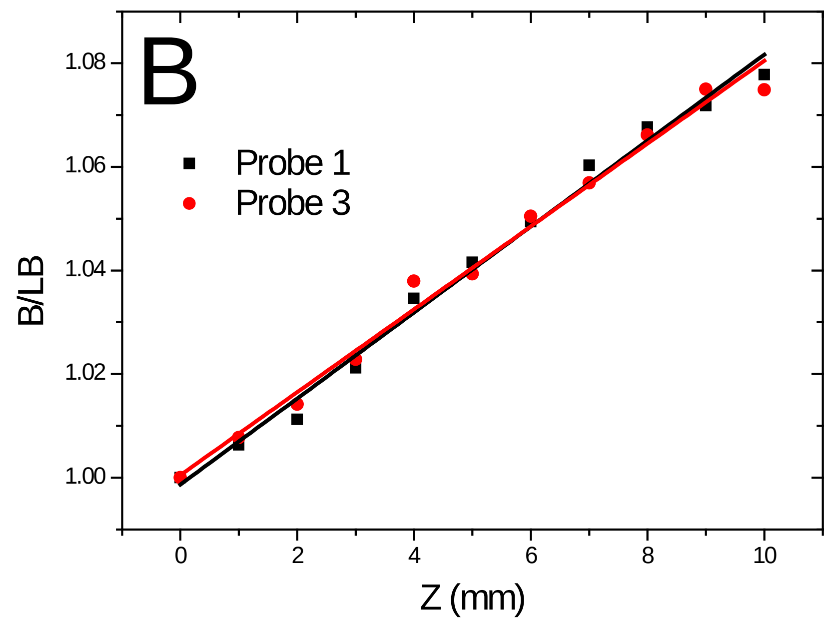
Interference Among Probes

- Vertical interference among sensors.



From figure A the moving sensor is placed at the extremity of the crown. There is a clear interference on sensors 1 and 2, but not for the sensor 3. When the moving sensor is in a middle position in the crown, figure B, the moving sensor does interfere on the signal sensors 1 and 3 but in the same way. This is the real case in the PIG crown.

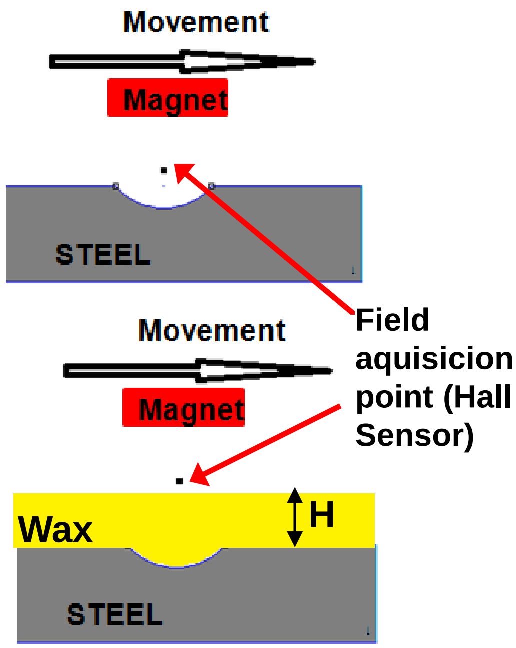


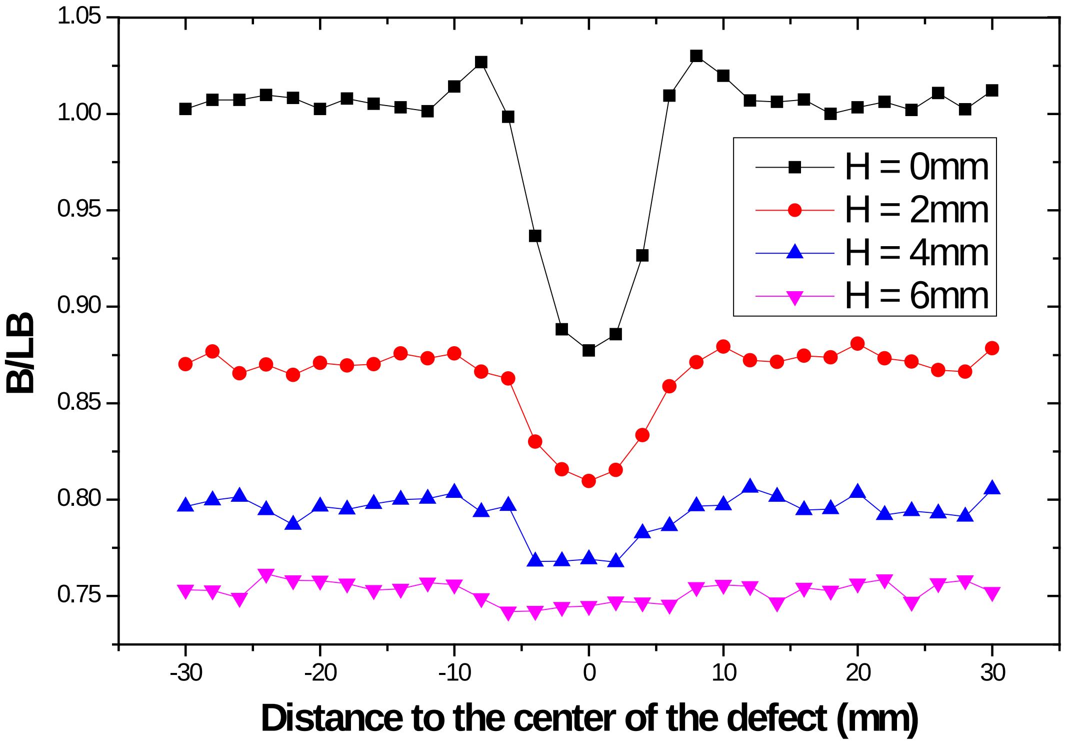


Material Loss

Is it possible to detect defects beneath the paraffin layer?

From the simulated results below it is possible to define 4 mm as the maximum paraffin thickness enabling crack detection.





B : Magnetic flux density

Defect depth = 3 mm

B and LB Magnetic flux density of the sensor WITH and WITHOUT paraffin layer

ENGINEERING OF METALLURGICAL AND MATERIALS
COPPE/UFRJ

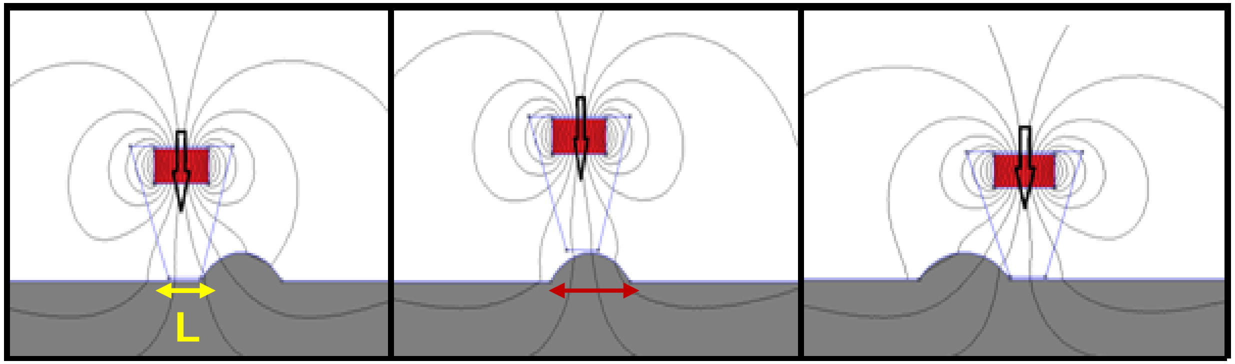
ENGINEERING OF METALLURGICAL AND MATERIALS

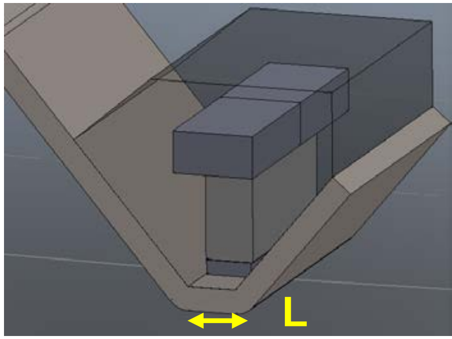
COPPE/UFRJ

Excessive Material

A weld bead could represent what is called “excessive material” or a bump on the pipe inner surface.

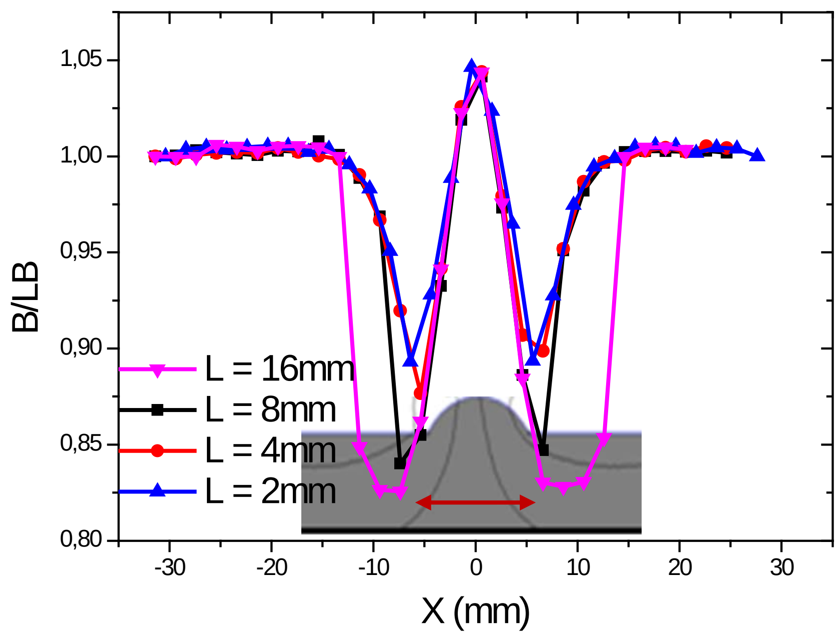
FEMM – 2D





What is the effect of the size of the probe tip on the sensor response when it moves over a weld bead?

The smaller the probe tip the higher the possibility of surface scractching.
L= 4mm is the ideal probe tip dimension.



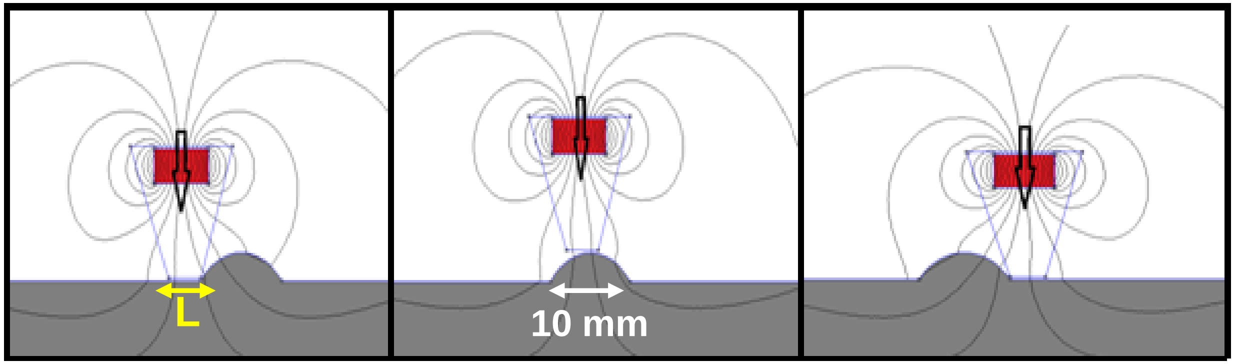
ENGINEERING OF
METALLURGICAL
AND MATERIALS

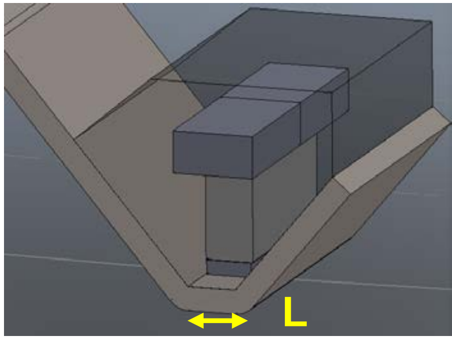
COPPE/UFRJ

Study of excessive material

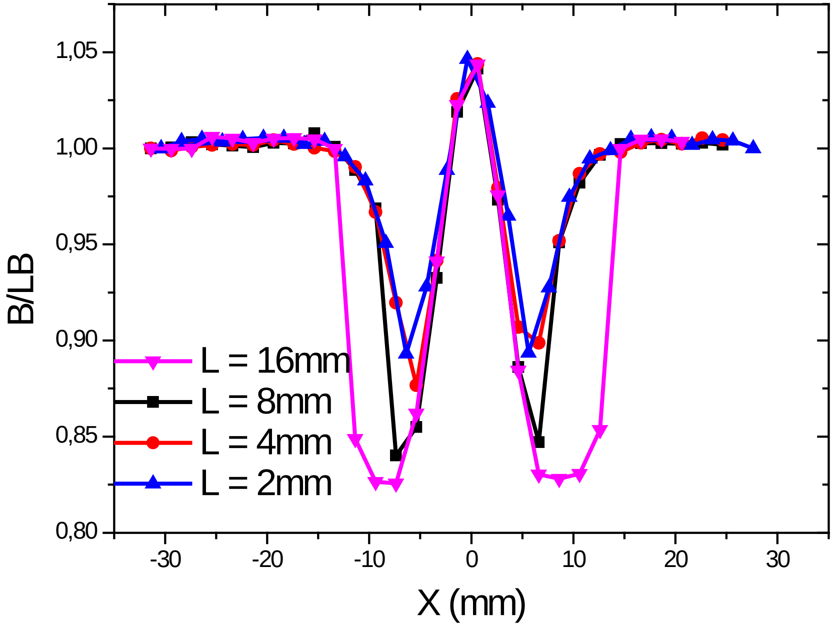
The excessive material could be interpreted as a weld.

FEMM – 2D

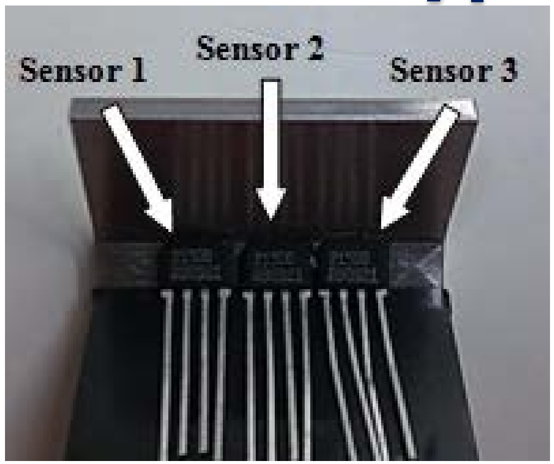


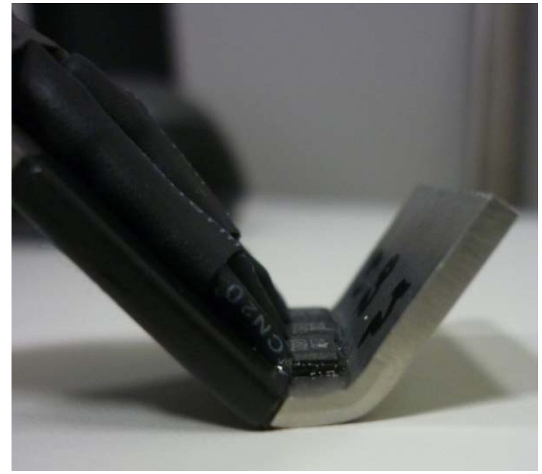


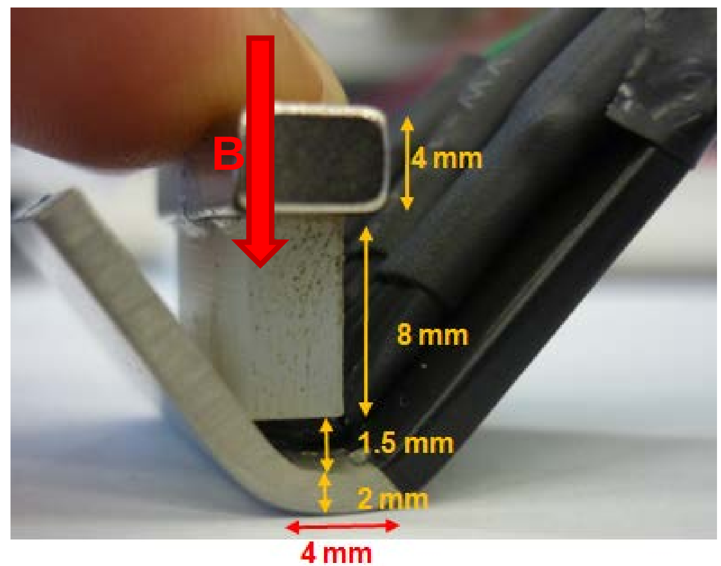
It was studied the effect of the size of the base of the sensor in the response when passing through an excessive material metal area.



Prototype Probe Construction





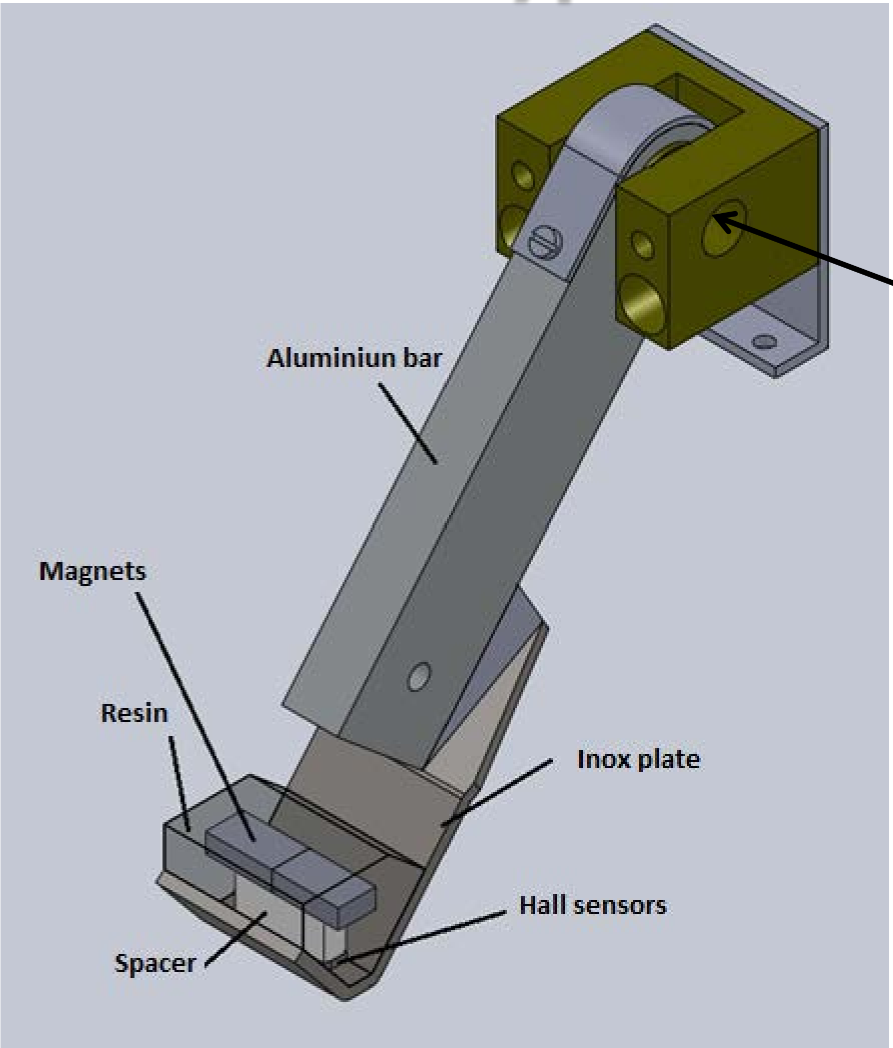


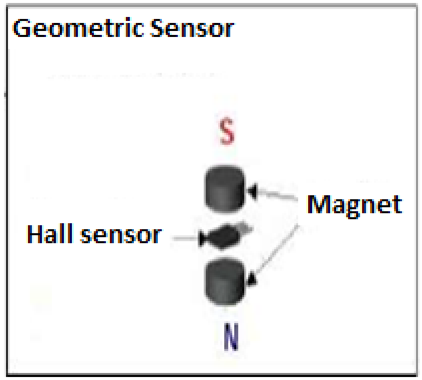
MLX90242: Linear Hall Effect Sensor
NdFeB magnets:grade N35
Material of the Structure: Stainless Steel (non magnetic)

ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Prototype Probe Construction



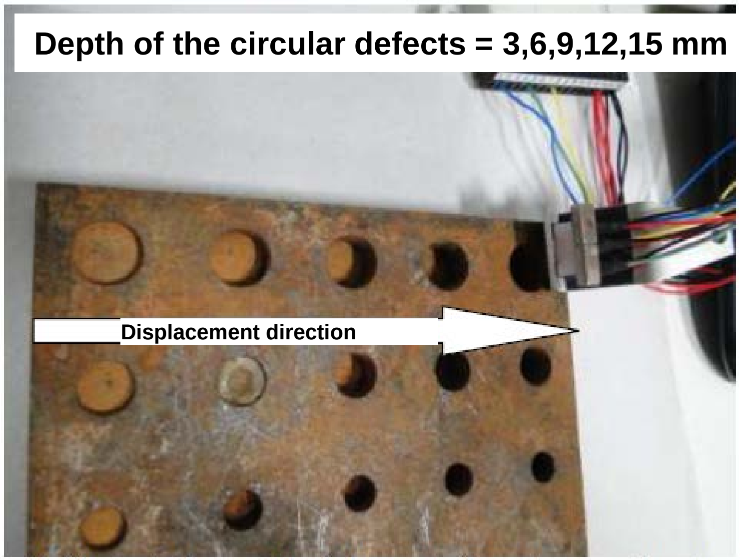


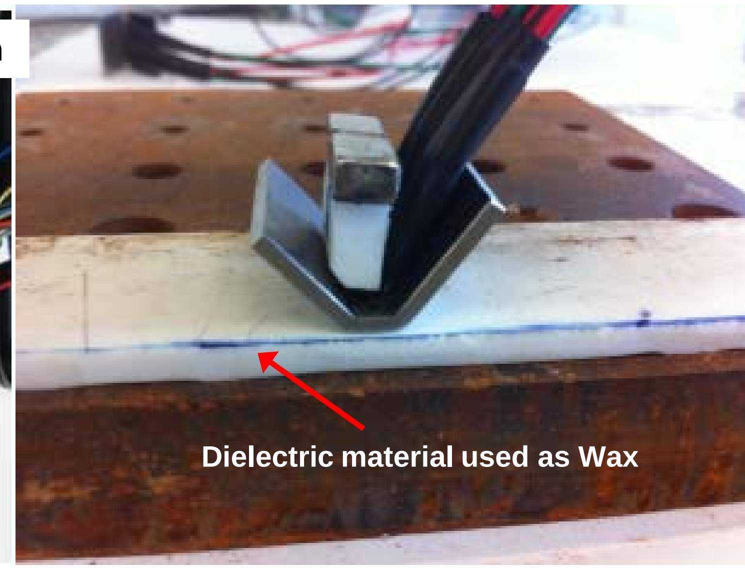
ENGINEERING OF METALLURGICAL AND MATERIALS

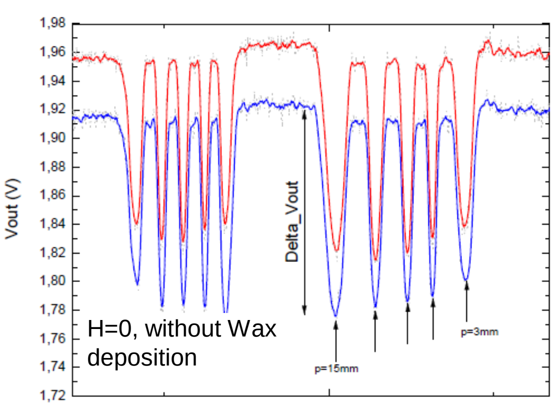
COPPE/UFRJ

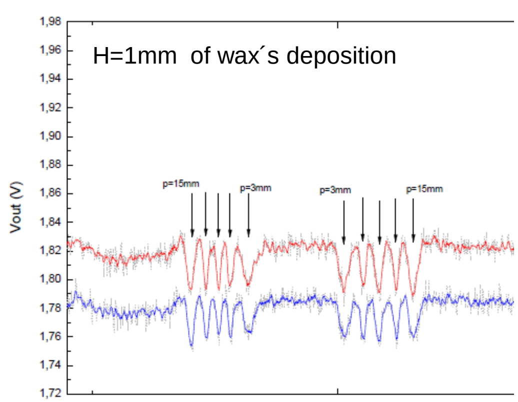
Prototype Testing

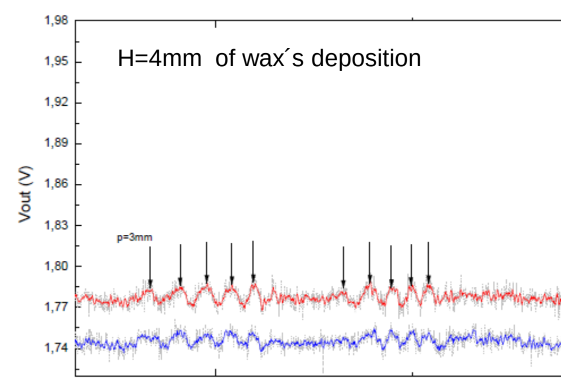
A carbon steel plate with known defects was used.
The focus was not to reconstruct the shape of the defect but to evaluate the ability of the sensor to detect the different defect depths.





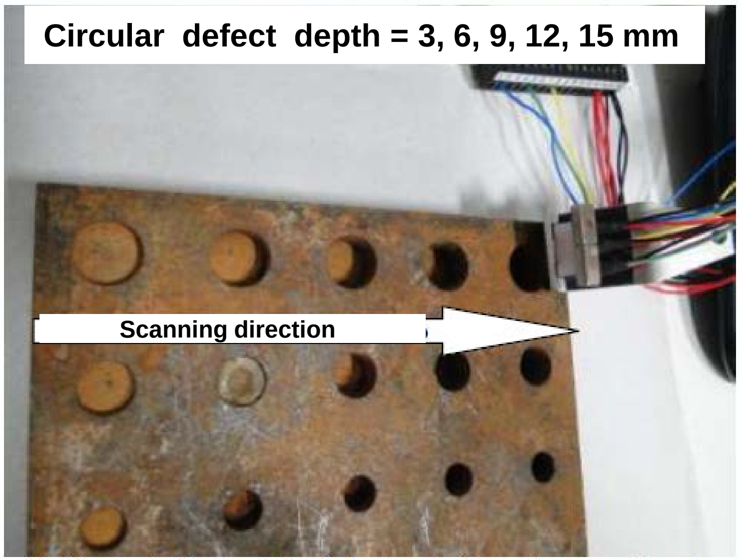


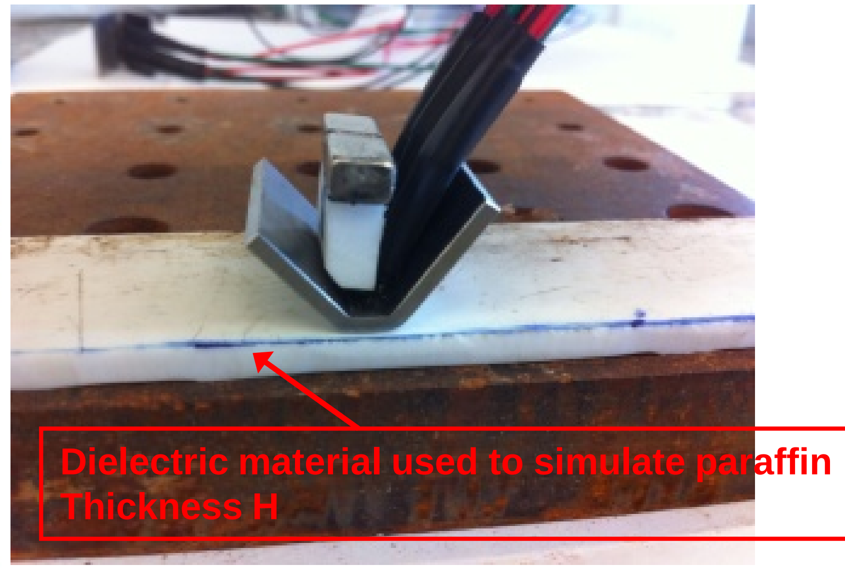


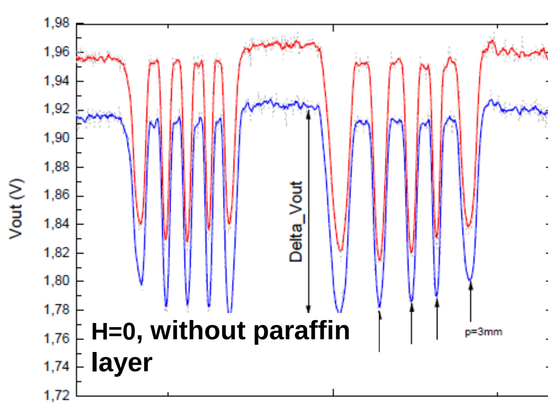


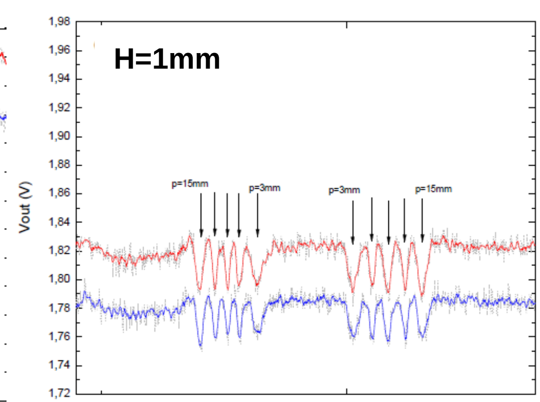
Prototype Probe Test

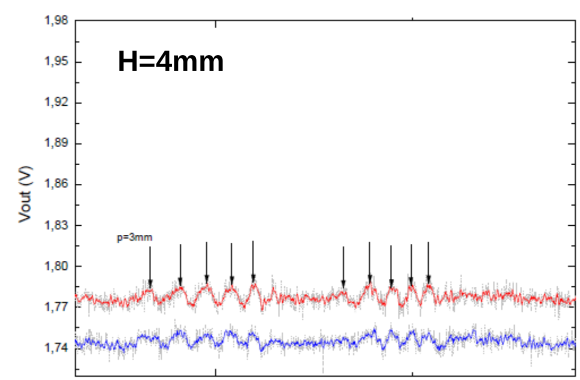
A carbon steel plate with defects was used. The focus was to assess the ability of the sensor to detect defect at different depths.

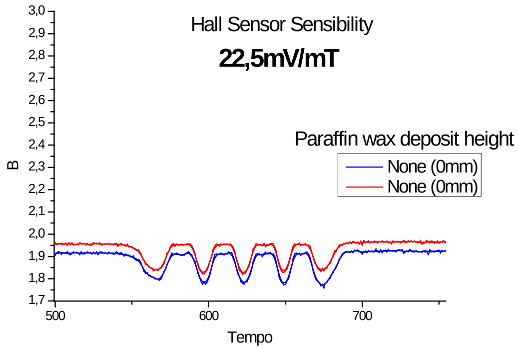


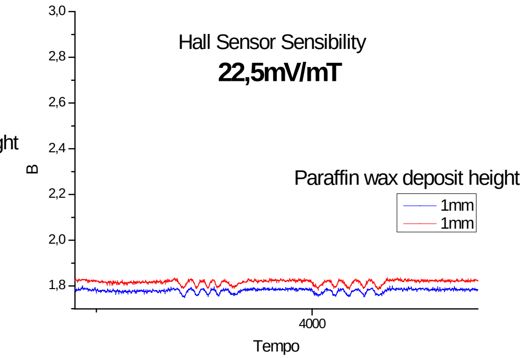


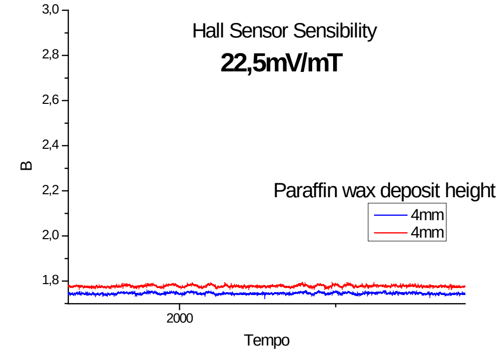


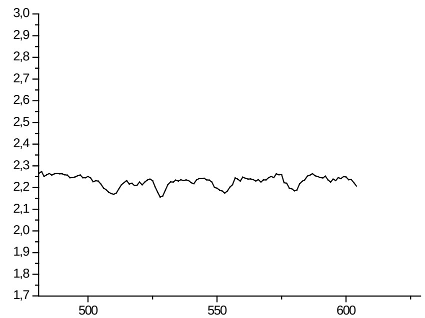





Hall Sensor Sensibility
22,5mV/mT
Paraffin wax deposit height
None (0mm)
None (0mm)
B
Tempo
3,0
2,9
2,8
2,7
2,6
2,5
2,4
2,3
2,2
2,1
2,0
1,9
1,8
1,7
500
600
700


Hall Sensor Sensibility
22,5mV/mT
Paraffin wax deposit height
1mm
1mm
B
Tempo
3,0
2,8
2,6
2,4
2,2
2,0
1,8
4000

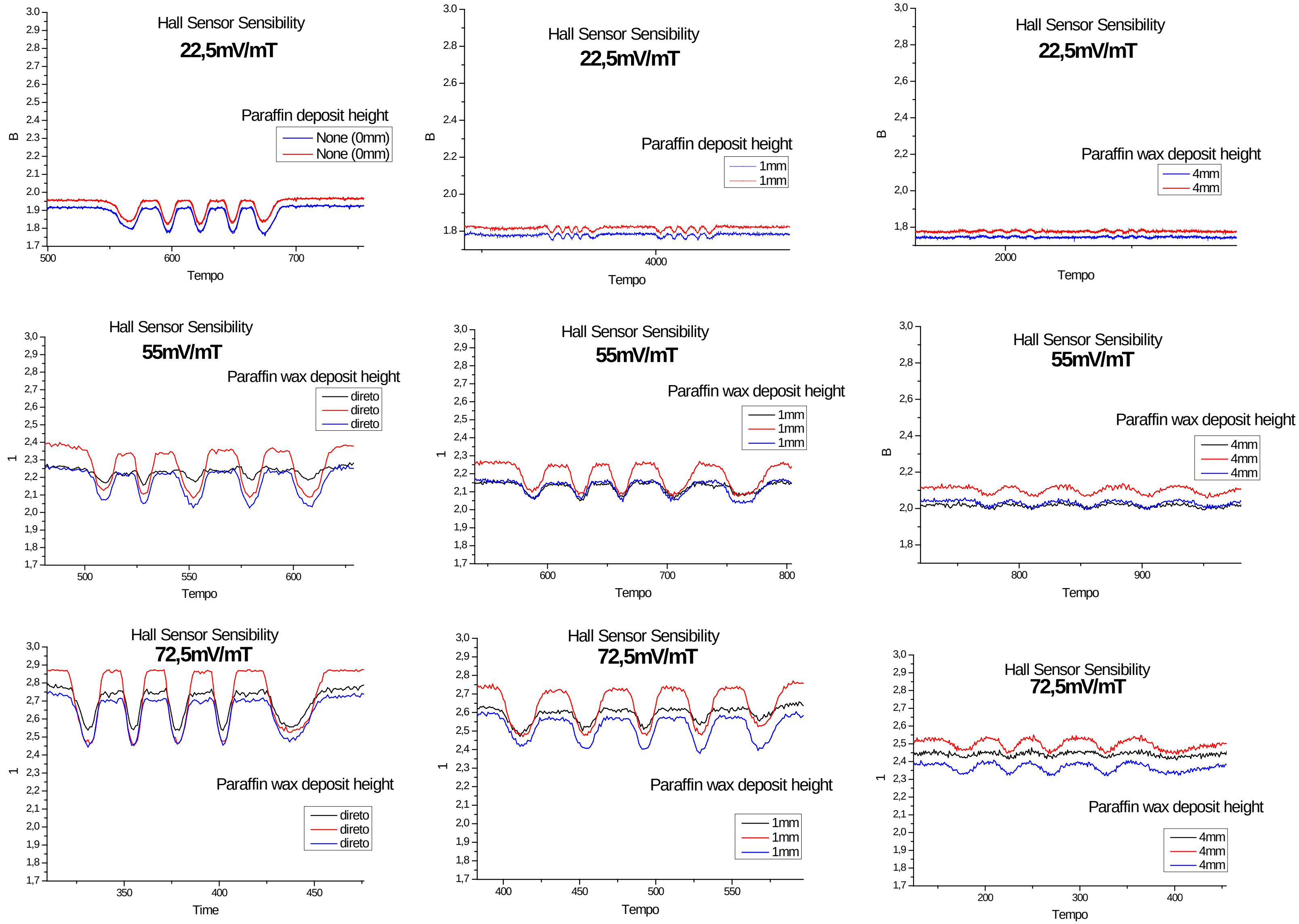

Hall Sensor Sensibility
22,5mV/mT
Paraffin wax deposit height
4mm
4mm
B
Tempo
3,0
2,8
2,6
2,4
2,2
2,0
1,8
2000


3,0
2,9
2,8
2,7
2,6
2,5
2,4
2,3
2,2
2,1
2,0
1,9
1,8
1,7
500
550
600

ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Sensitivity Analysis

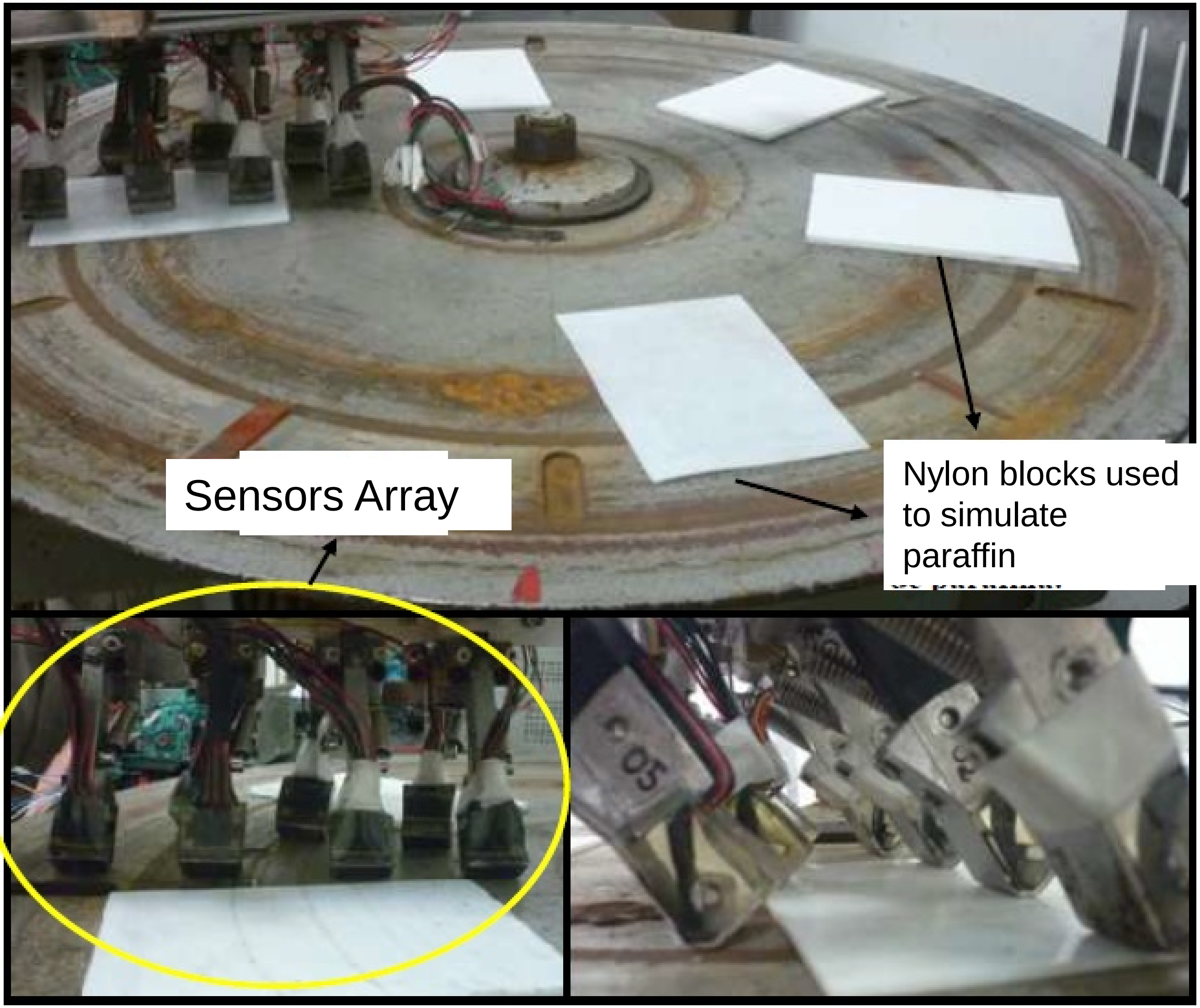


ENGINEERING OF
METALLURGICAL
AND MATERIALS

COPPE/UFRJ

First tests with array system

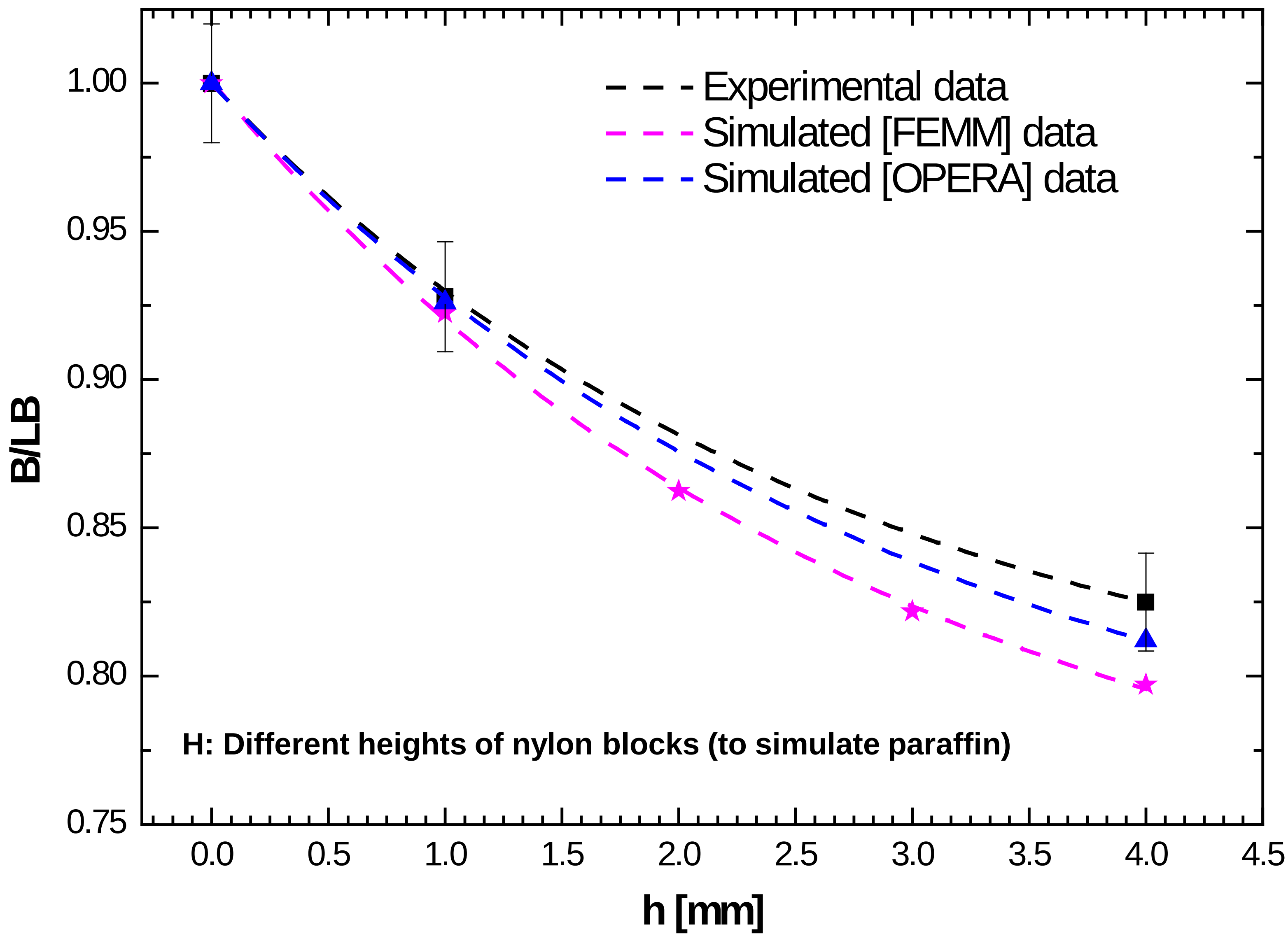
Setup ready at Pipeway Company.



ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Results



Conclusions

A prototype probe for detection and sizing paraffin height at the inner surface of steel pipelines was designed.

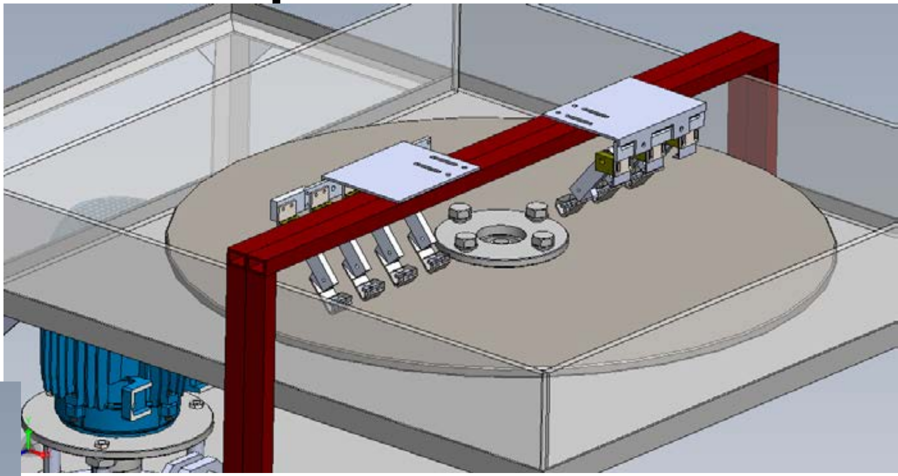
It also showed to be able to detect defects on the pipeline located beneath the paraffin layer.

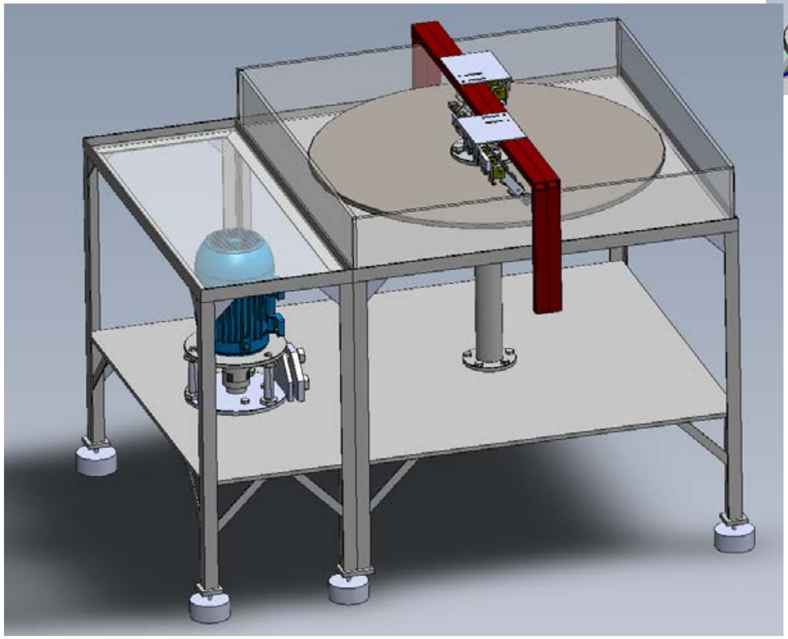
ENGINEERING OF METALLURGICAL AND MATERIALS

COPPE/UFRJ

Future works

- To evaluate the answer of an array of sensors in a precision setup.





Questions?

Professor João M. A. Rebello

jmarcos@metalmat.ufrj.br

LNDC - Laboratory of Nondestructive Testing, Corrosion and Welding

Department of Metallurgical and Materials Engineering, Federal University of Rio of Janeiro, Rua Pedro Calmon SN, Cidade Universitária. CEP 21941-596, Rio de Janeiro, Brazil.