X-RAY HIGH SPEED IMAGING OF ARC LENGTHENING UNDER CAPACITOR DISCHARGE

SESSION 3: ARCING PHENOMENA AND DIAGNOSTICS

ICEFA 2019 – 17/09/2019

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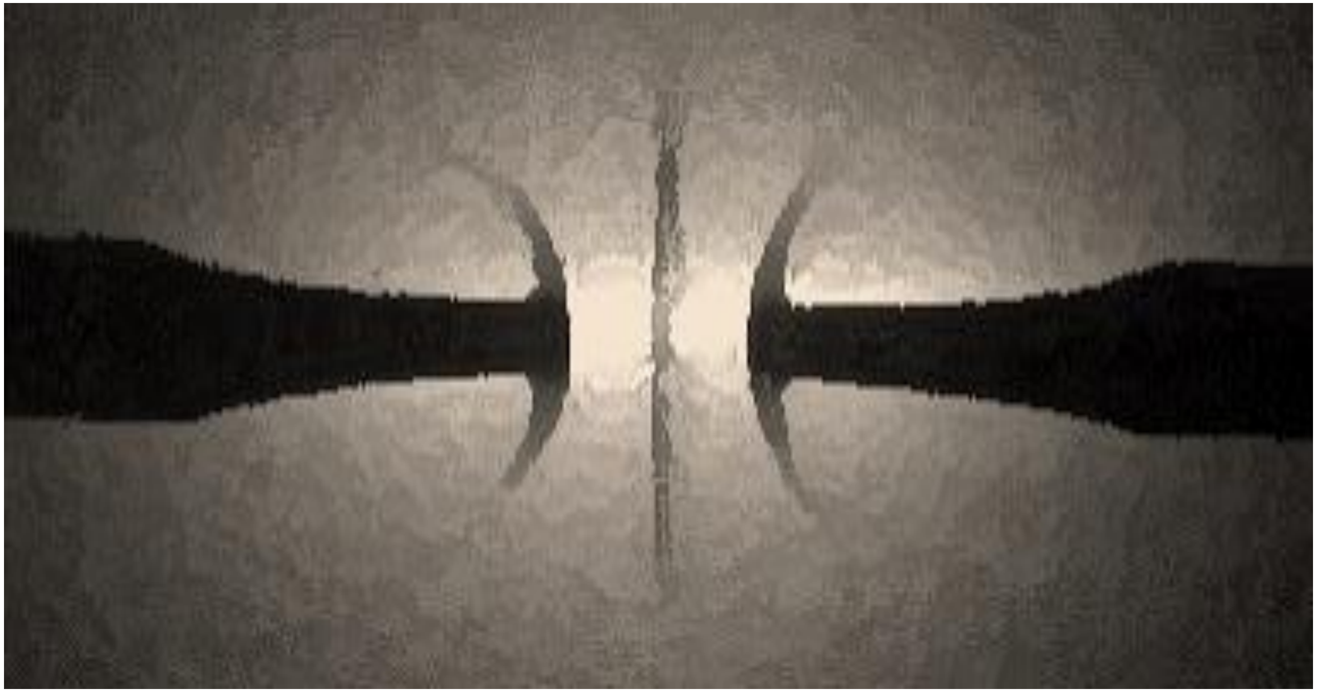


CONTEXT: ACTORS OF THE RESEARCH PROJECT

PROJECT IDEA : OBSERVE THE ARC IGNITION BY ACQUIRING X-RAY IMAGES WITH A HIGH SPEED CAMERA

MERSEN
Expertise, our source of energy

Industrial fuse expert

Project created by Jean Louis Gelet (Mersen)

ESRF
The European Synchrotron

High speed camera

SIMaP
Grenoble INP

University laboratory

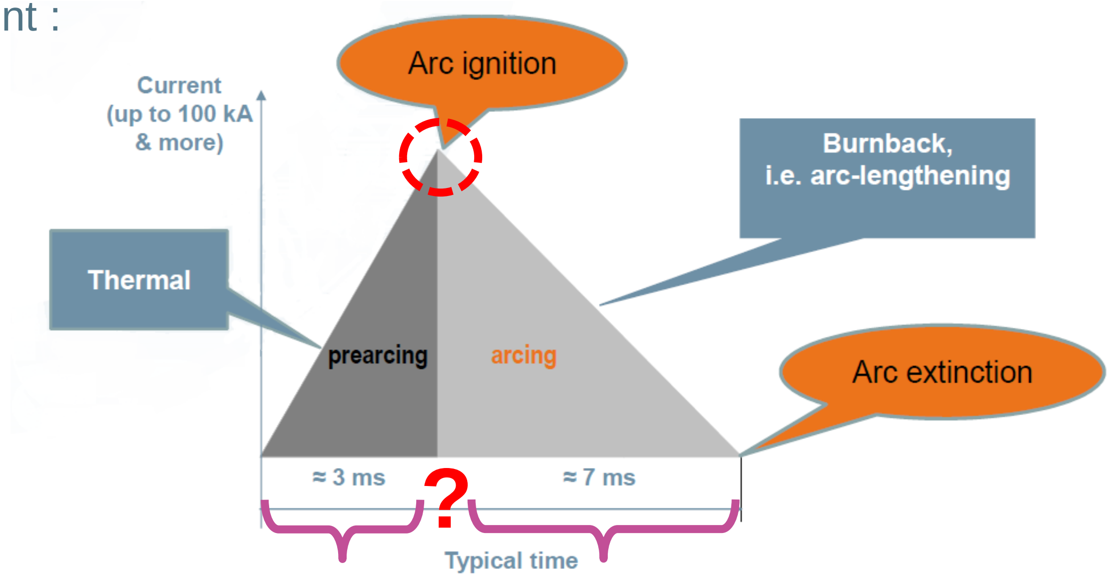
SUMMARY

- 1) STATE OF ART
- 2) EXPERIMENTAL METHOD
- 3) BREAKING TEST ANALYSIS
  - Voltage and current curves
  - X-ray imaging
  - Arc extension
  - Electrical field

CONTEXT: FUSE OPERATING

PROJECT IDEA : OBSERVE THE ARC IGNITION BY ACQUIRING X-RAY IMAGES WITH A HIGH SPEED CAMERA

Fuse operation under Max energy defect current :



Electro-physical properties of pre-arcing and arcing phase are well known

Low knowledge of the fuse behavior during extremely short times of the transition phase

STRATEGY

PROJECT IDEA : OBSERVE THE ARC IGNITION BY ACQUIRING X-RAY IMAGES WITH A HIGH SPEED CAMERA

Limits for the observation of the post pre-arcing phase

Extreme rapidity of the phenomena (µs)

Opacity of the fuse

Indirect method

- Thermodynamic principles
- Simplified mathematical models and simulation
- Current and voltage acquisition
- Post-mortem fuse state

Direct method

- X-ray images for metals observation
- Ultra fast speed acquisition → 5.10^6 frames per second

With high speed camera from ESRF

MERSEN

CONTEXT: FUSE OPERATING

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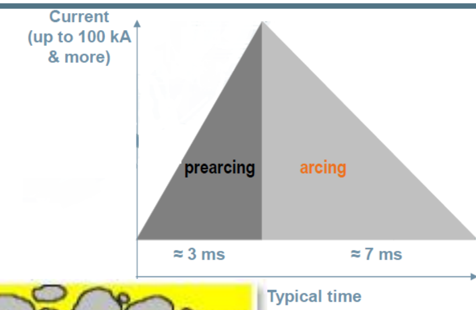
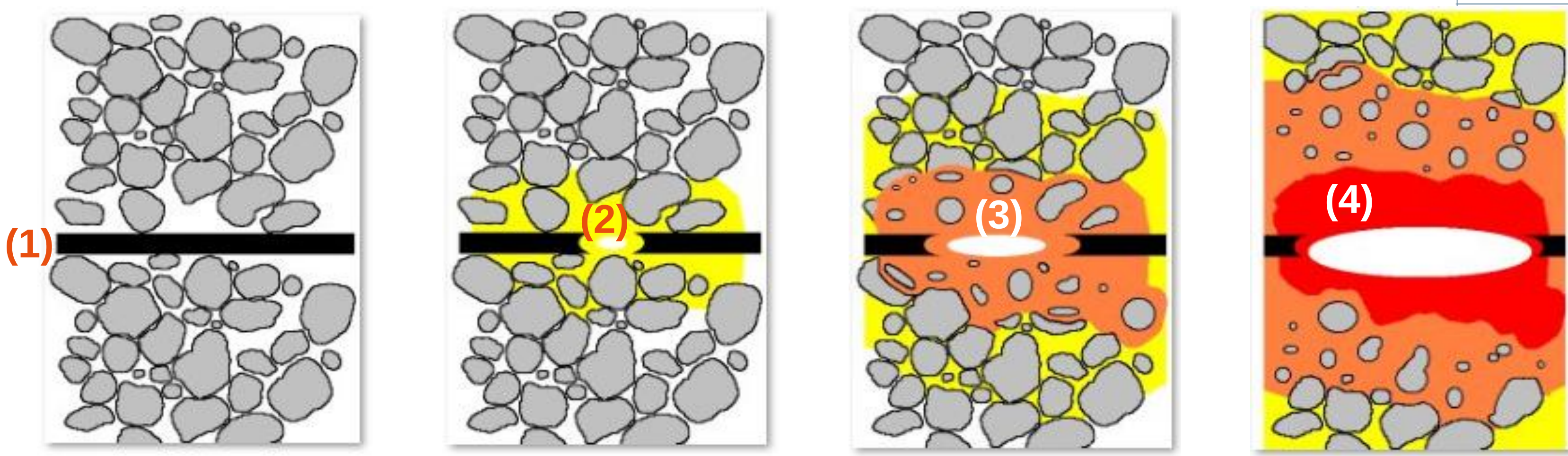


4-pictures description of the continuous phenomenon of an arc in granular system:



(1) How does the increase in temperature impact the stress of the metal strip ?

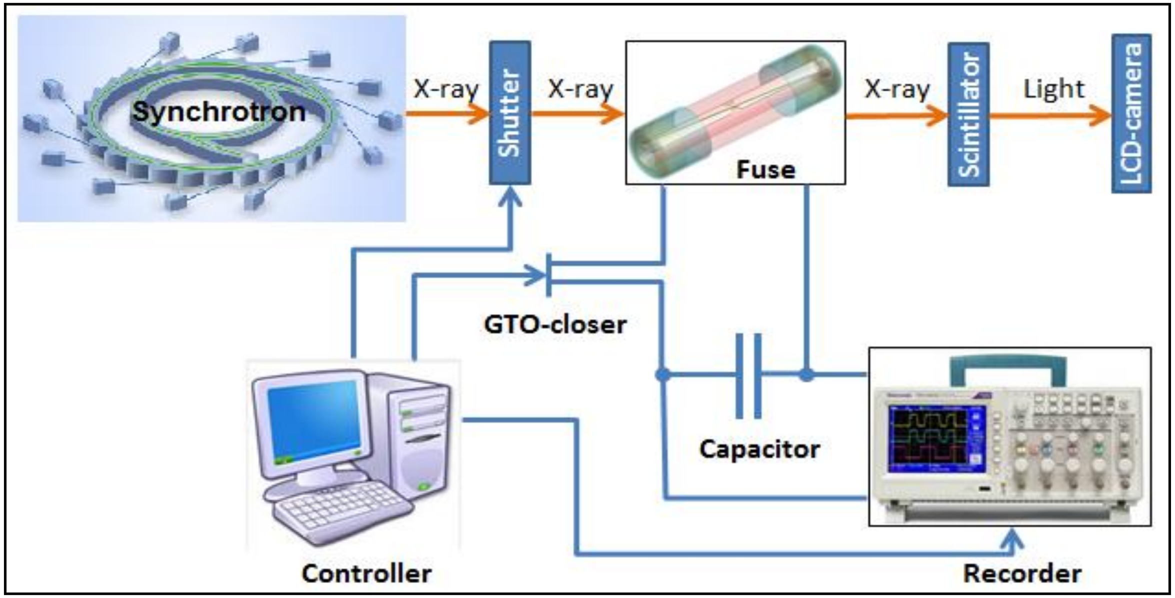
(2) What are the phenomena that occur at extremely short times during the arc ignition ?

(3) What happens when lengthening the arc ?

(4) How does the granular system react during the ignition phase ?

EQUIPMENT FOR THE DC BREAKING TEST

Experimental test bench configuration:



FIRST, SEND

- A signal for opening the shutter of the X-ray beam chamber.

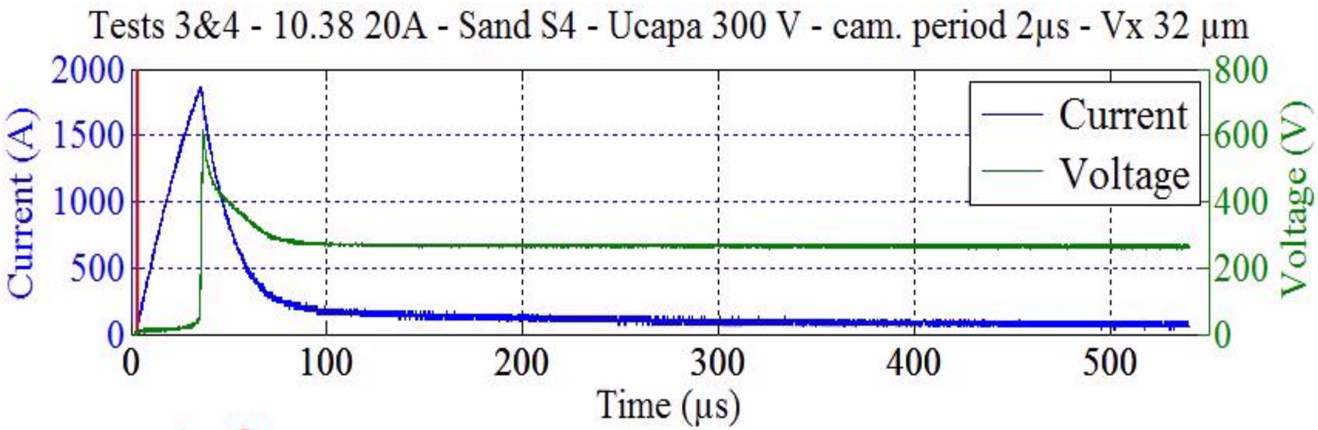
THEN, SEND A SIGNAL FOR:

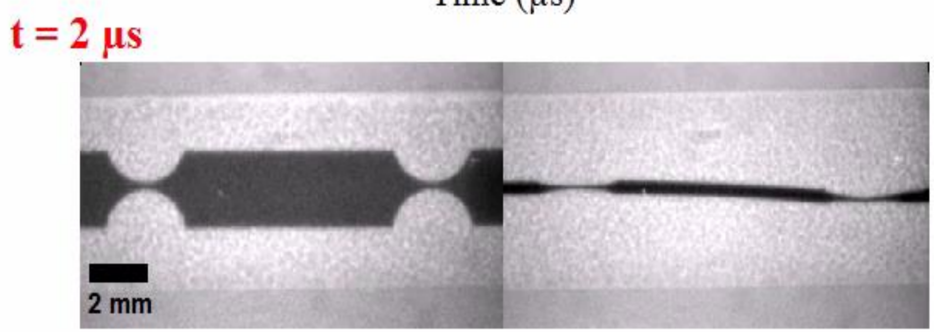
- the capacitor discharge,
- the acquisition of electrical measurements by the oscilloscope,
- the opening of the shutter of the CCD-camera and the beginning of the images acquisition.

DC BREAKING TEST AND FUSE PARAMETERS

Table of experimental parameters:

Capacitor discharge Voltage	450 V / 400 V / 300 V
Current and di/dt	Short loop / Large loop
Position of the conductor towards X-ray-beam	edge / surface
CDD camera	**Limited to recording only 128 frames** **Frequency = 5.10^6 frame/second, i.e. 1 image/ 0,2µs**
Shooting-frequency	From 1 im./0,2 µsec. to 200 im./µsec.
Mersen Fuse 10.38	**gR-class** **I_N = 20A, U_N = 690V**

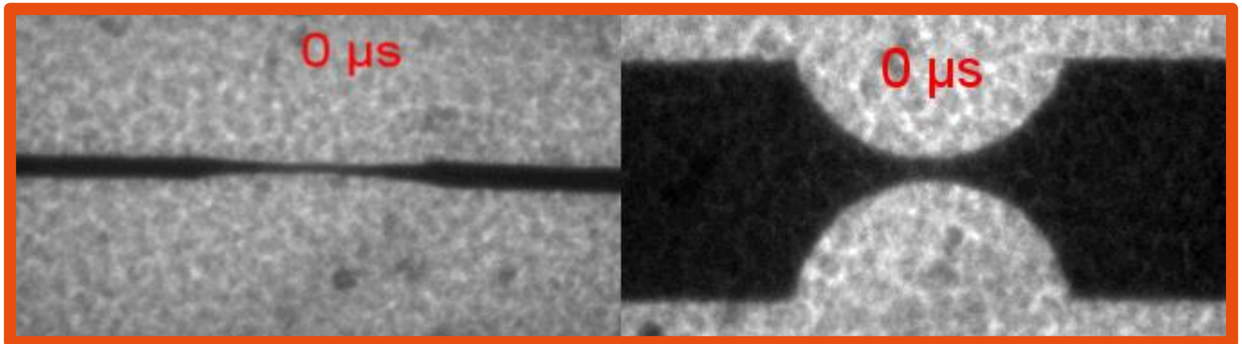




Example of fuse operation, and its corresponding X-ray images at 53µs

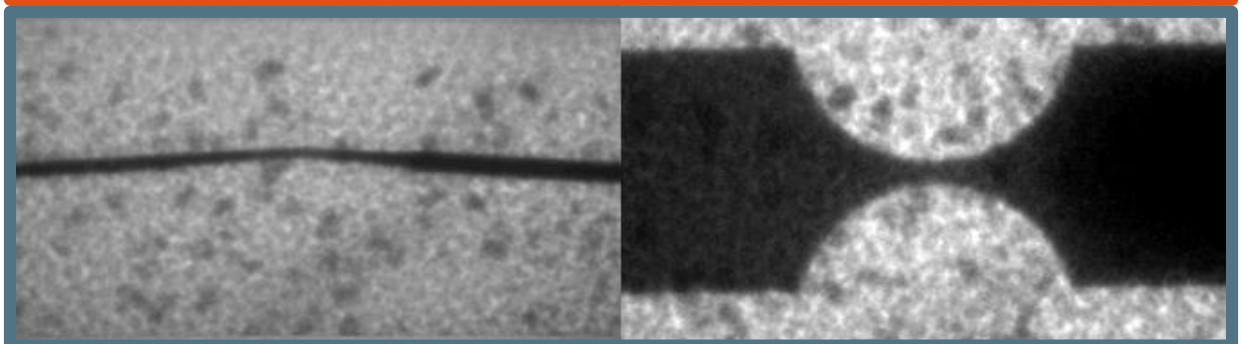
Fuse operation in function of the sand formulation

X-ray movie reconstituted at 50.10^6 frame/s, total of 615µs:



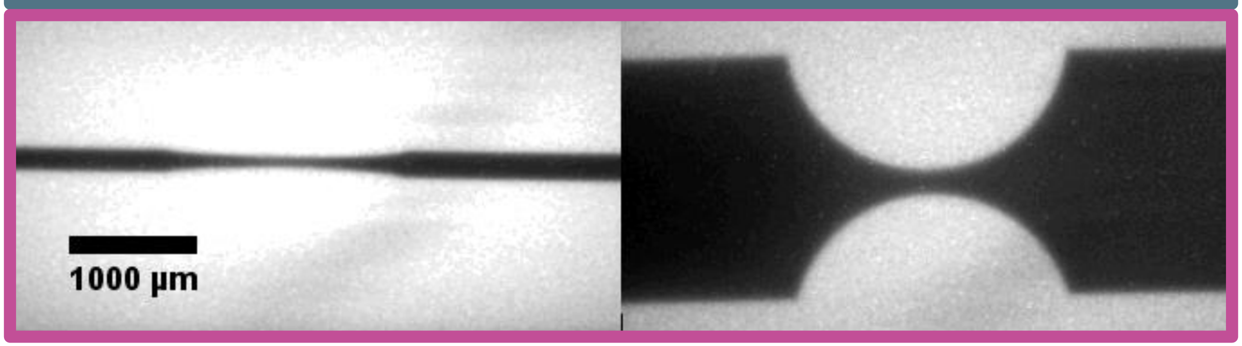
Sand silicated

Very fast burn-back during 20µs : $v_{bb} \approx 60\ m.s^{-1}$
And then slowly decreases below $v_{bb} < 10\ m.s^{-1}$



Sand non silicated

Rise of internal pressure: sand movement during 10 µs



Without sand

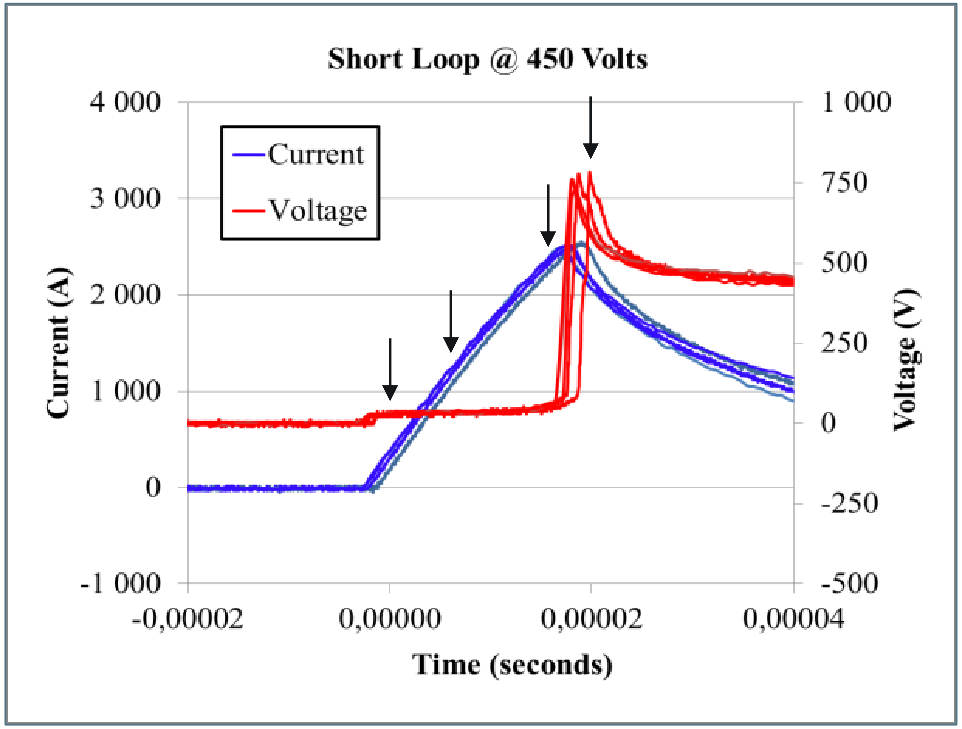
Very fast burn-back with full silver fuse element melting
Fuse terminal explosion

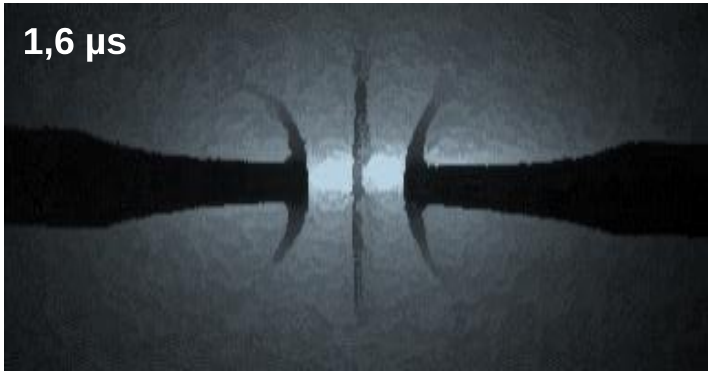
Importance of the arc energy absorbed by the sand, it can modify:

- **The operating time and the arc phase**
- **The dynamic of the arc energy**
- **The arc extension**

DC BREAKING TEST – X-RAYS IMAGES AT SHORT TIMES

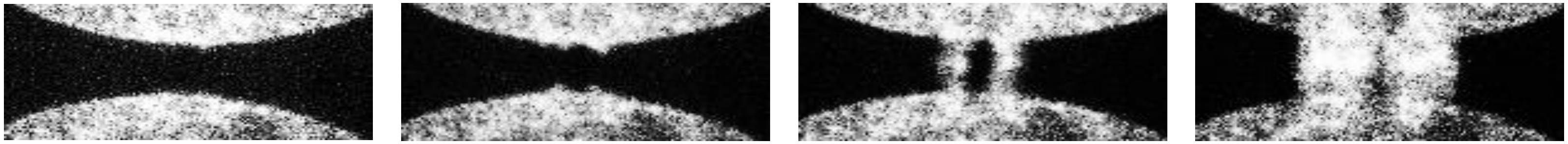
Voltage and current waveform during the pre-arcing and transition phases:





- Reproducibility of the experiment → reconstitution of a X-ray film with several identical tests.
- During the pre-arcing phase, the reduced section inflates.
- Then a separation of the metals appears in accordance with the arc ignition.

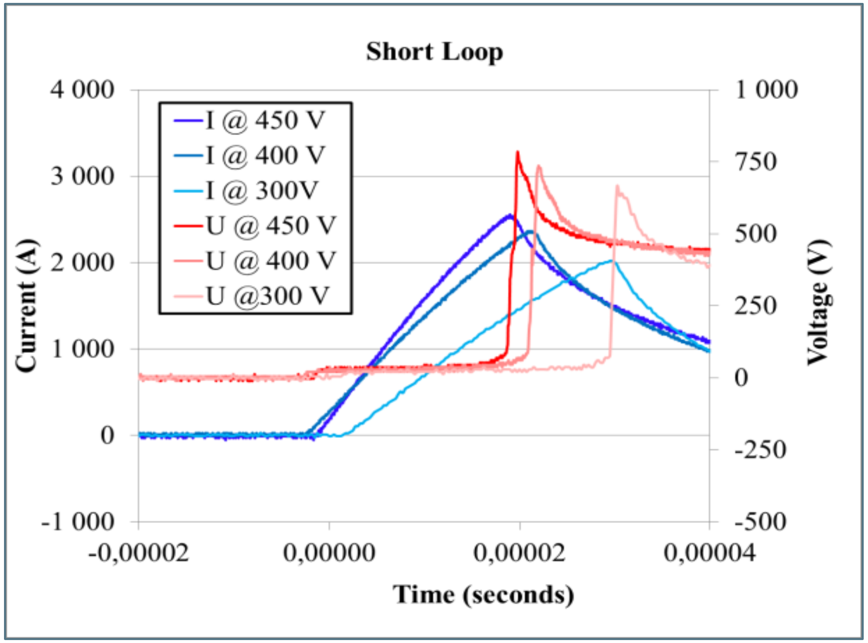
Top view at 5.10^{-6} frame/second:



t = 0   t = 0,6 µsec.   t = 1,4 µsec.   t = 2 µsec.

DC BREAKING TEST UNDER 300, 400 AND 450V

Voltage and current waveform
under 300, 400 and 450V DC:

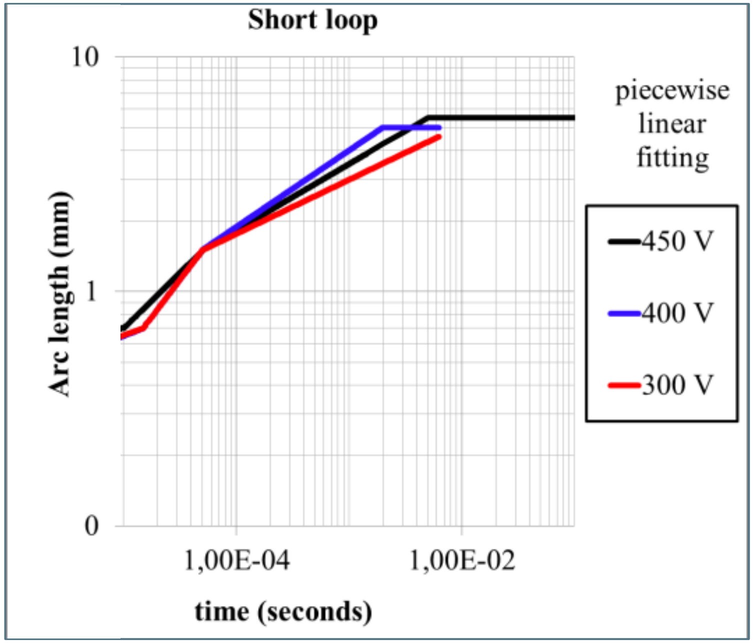


If the applied voltage decreases:

- Lower max current value, di/dt and power
- Longer pre-arcing time
- But stable I^2t

Representation of the electrical field in function of the current

Arc extension
under 300, 400 and 500V DC:

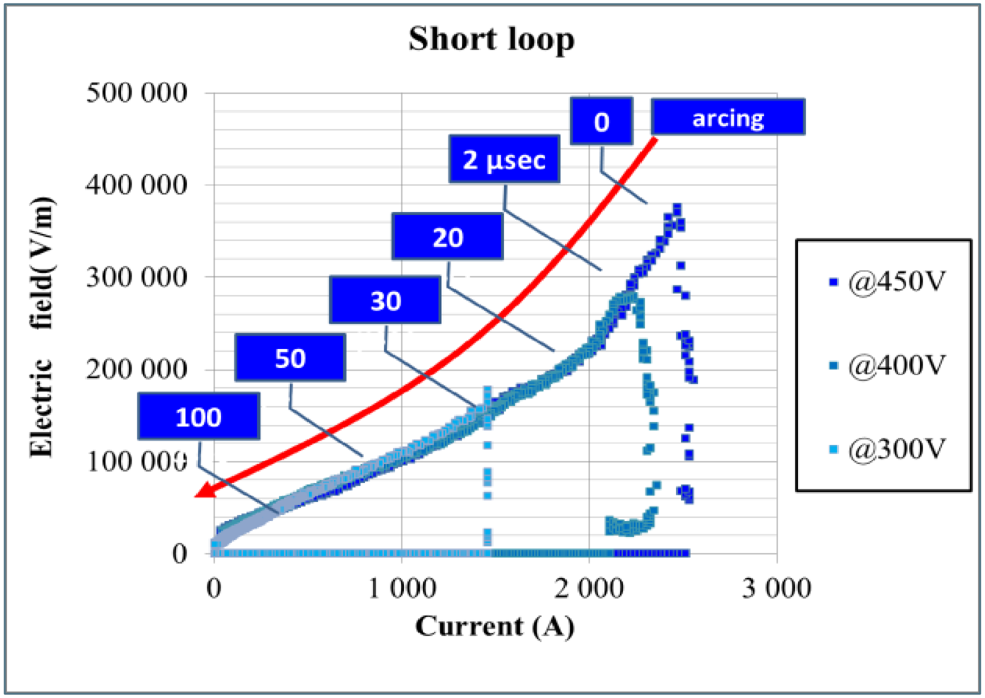


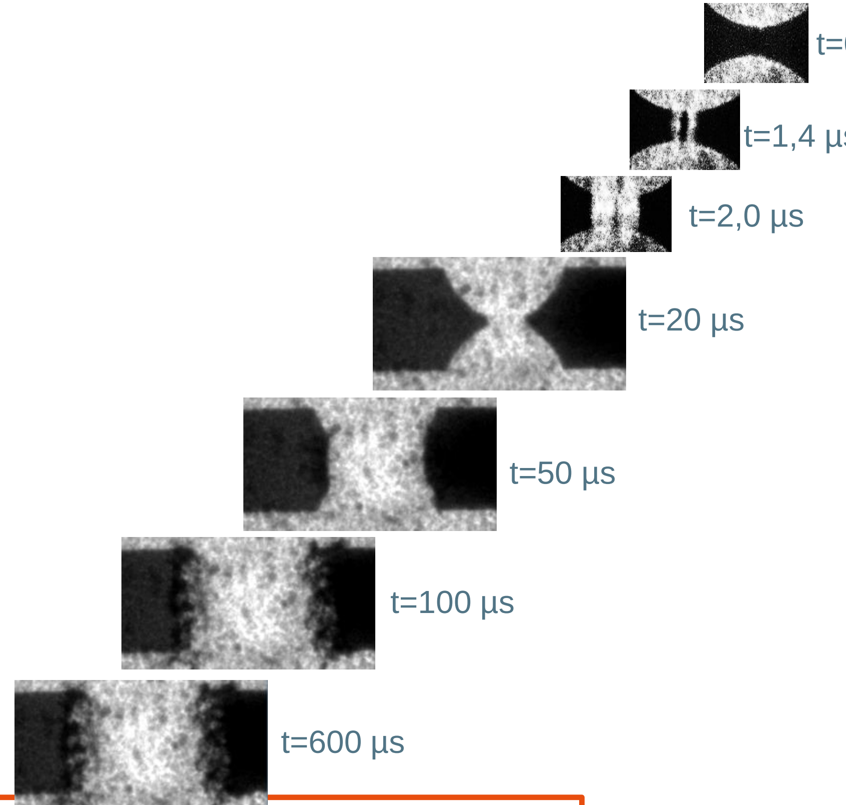
Different speed of arc extension depending of arc phase:

- Fast during the arc ignition and with the reduced section melting (<100 µs)
- Slower during the arc phase and the melting of large silver strip (>100µs)
- Correlated to evolution of the arc voltage and current

ELECTRIC FIELDS

Representation of the electric field in function of the current:





Three profiles of decline of the electric field:

- **0 to 20 µs: strong decrease of the electric field due to the decrease of the tension → ignition and arc transition phase**
- **20 to 100 µs: the electric field decreases more slowly → fast arc extension phase and strong decrease of the current and voltage**
- **100 µs to extinction: slow evolution of the current and voltage → arc and plasma are in stable conditions**

ELECTRIC FIELDS VS MATHEMATICAL MODELS

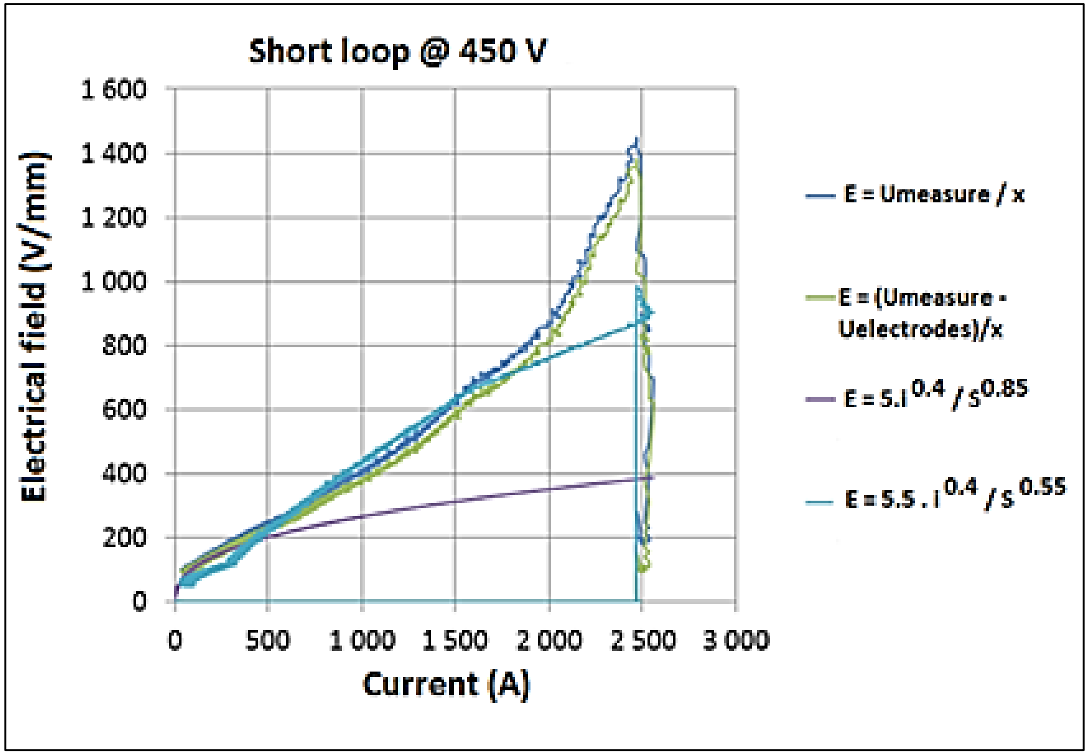
Example based on Wheeler model:

$$E = \frac{K.i(t)^{0.4}}{S^{\gamma}}$$

Where,

K ≈ 3.5 to 5.6 and $\gamma = 0.85$

for plane geometry



Bad fitting of the models on short time during the transition phase

C.B. Wheeler, "The high-power constricted plasma discharge column – 1. Theoretical analysis, *J. Phys. D. 3. pp 1374-1380,* 1970

Conclusion and perspectives

(1) How does the increase in temperature impact the stress of the metal strip ?

→ **At the end of pre-arcing phase, the metal strip is deformed and swells**

(2) What are the phenomena that occur at extremely short times during the arc ignition ?

→ **There seems to be a strong mechanical stress that induces a beam explosion with a strong energy**

(3) What happens when lengthening the arc ?

→ **During the arc phase, the arc extension have different profiles of extension : Fast in short time, then low evolution until its extinction.**

(4) How does the granular system react during the ignition phase ?

→ **Granular system is blow by energy of the arc ignition**

Next step :

New experimental tests with a higher speed camera of 0.5×10^6 frame/s

Develop new mathematical models or simulation programs

CONCLUSION AND PERSPECTIVES

Thank you
for
your attention

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