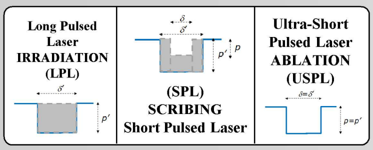
Discriminating the physical impacts of various laser pulses on the magnetic structure of oriented electrical steels

O. Maloberti[1,2,*], M. Nesser[2], J. Dupuy[3], Y. Hernandez[3], P. Dassonvalle[1,4], S. Panier[2], J. Fortin[1,2], C. Pineau[5], J-P. Birat[6]

[1]*UNILASALLE Amiens, 14 quai de la Somme, 80080 Amiens, France;* [2]*LTI Laboratory, IUT d'Amiens, Avenue des Facultés - Le Bailly 80 025 Amiens, France ;* [3]*MULTITEL, 2 rue Pierre et Marie Curie, 7000 Mons,Belgique;* [4]*MIS Laboratory, UPJV, 14 quai de la Somme, 80080 Amiens, France;* [5]*IRT-M2P, 4 rue Augustin Fresnel, 57070 Metz;* [6]*CRM Group Metal Processing, Tech Lane Ghent Science Park / Campus 1-Zone A4B, Technologiepark 922A, BE-9052 Zwijnaarde;* [6]*IF-steelman, 5 rue du gate chaux, 57280 Semecourt, France*

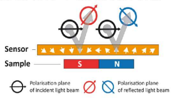
Introduction: Pulsed laser technologies with Long (LPL irradiation), Short (SPL scribing) and Ultra-Short (USPL ablation) pulse duration are used on Grain Oriented Electrical Steels (GOES) to reduce the power loss. This paper identifies separate characteristics responsible for the domains structure and the magnetization properties in a GOES sheet processed with the three lasers. Magnetic domains based properties are identified thanks to an average dynamic μ-ν_c-Λ model [1], the Tensor Magnetic Phase Theory (*TMPT*) [2], magnetic measurements/observations with the Single Sheet Tester (SST) and the Magneto-Optical Indicator Film (MOIF) technique.

Process and Models



Domains observations

MOIF technique
2D FFT technique
⇒
probability density
&
statistical average of domains' width w



$$w = \frac{1}{n.S} = \frac{1}{2k}$$

n: walls volume density
S: walls surface
k: spatial frequency

Average μ-ν_c-Λ model

Apparent permeability

$\mu_{app}(\mu, \Lambda, f)$

Internal permeability μ

Static hysteresis losses

$$P_s(\nu_c) = \nu_c \frac{B^2 f}{\gamma}$$

Coercive reluctivity ν_c

Dynamic losses

$P_d(\mu, \Lambda, f)$

B: flux density
f: frequency
γ: mass density

Domains & walls dynamic properties

$$\Lambda \propto \sqrt{\frac{w}{2\sigma J_s \eta}}$$

w: Walls
η: walls mobility
σ: electrical conductivity
J_s: saturation polarisation

TMPT model

Interactions between the surface and the magnetic structure inside the volume

Apparent permeability

$$\mu_{app} = \frac{\tanh\left(\sqrt{\kappa(1+\tau\omega)}\frac{\zeta}{2}\right)}{\sqrt{\kappa(1+\tau\omega)}\frac{\zeta}{2}(1+\sigma\Lambda_0^2\mu\omega)}\mu$$

Exchange v.s. Total anisotropy κ

ζ: sheet thickness
ω: angle velocity

Static hysteresis losses

$$P_s = real\left(-j\nu_c\frac{\tanh\left(\sqrt{\kappa}\frac{\zeta}{2}\right)}{\sqrt{\kappa}\frac{\zeta}{2}}\right)\frac{B^2\omega}{\gamma}$$

Coercive reluctivity ν_c

Dynamic losses

$$P_d = \sigma\Lambda_0^2\omega.real\left(\frac{(1+\sigma\Lambda_0^2\mu\omega)\sqrt{\kappa(1+\tau\omega)}\frac{\zeta}{2}}{\tanh\left(\sqrt{\kappa(1+\tau\omega)}\frac{\zeta}{2}\right)}\right)\frac{B^2\omega}{\gamma}$$

Surface Magnetic structure $\Lambda_0(n,S,\ldots)$

Damping time delay $\tau(\sigma,\eta,\ldots)$

Conclusion

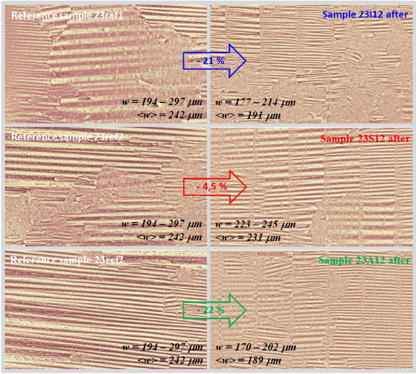
1,7T 50Hz	LPL (%)	SPL (%)	USPL 1 A12 (%)	USPL 2 A21 (%)
0,23	-17,5	-16,4	-19,3	-13,4
0,27	-15,3	-11	-15,3	-15,4

Specimens and Experiments

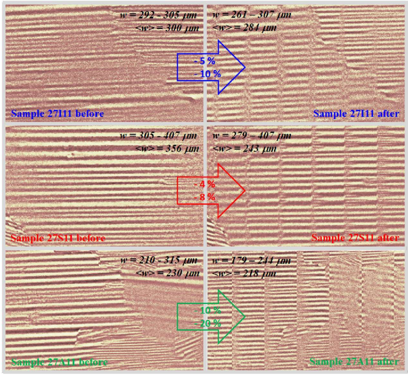
		Std GOES
23I11, 23I12	LPL IRRADIATION, 1 or 2 sides	23MXX
23S11, 23S12	SPL SCRIBING, 1 or 2 sides	
23A11, 23A12	USPL ABLATION 1, 1 or 2 sides	0,23 mm
23A21	USPL ABLATION 2, 1 side	

Std GOES		
R120-27	27I11, 27I12	LPL IRRADIATION, 1 or 2 sides
	27S11, 27S12	SPL SCRIBING, 1 or 2 sides
0,27 mm	27A11, 27A12	USPL ABLATION 1, 1 or 2 sides
	27A21	USPL ABLATION 2, 1 side

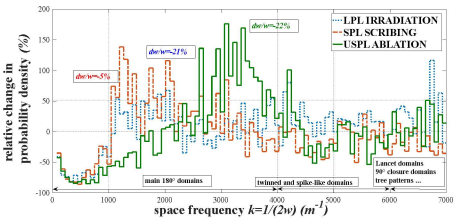
Magnetic domains imaging for LPL, SPL and USPL on 23MXX



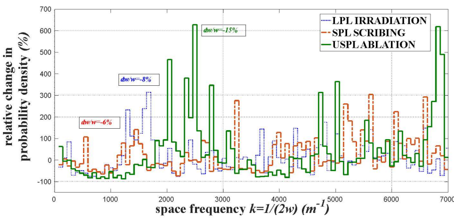
Magnetic domains imaging for LPL, SPL and USPL on R120-27



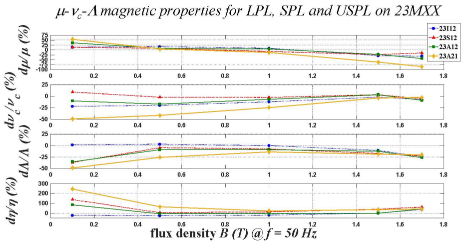
Domains refinement distribution for LPL, SPL and USPL (average of more than 16 images per process v.s. reference samples).



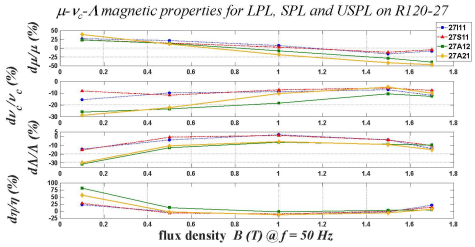
Domains refinement distribution for LPL, SPL and USPL (average of more than 16 images per process, comparisons before/after).



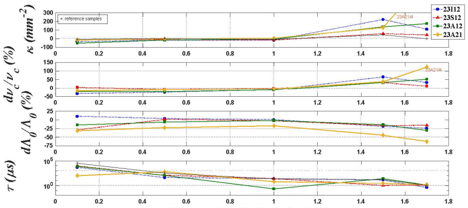
μ-ν_c-Λ magnetic properties for LPL, SPL and USPL on 23MXX



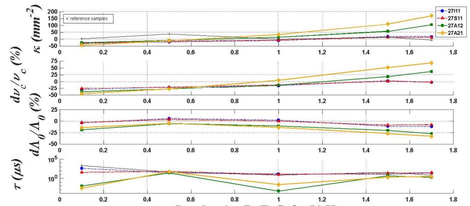
μ-ν_c-Λ magnetic properties for LPL, SPL and USPL on R120-27

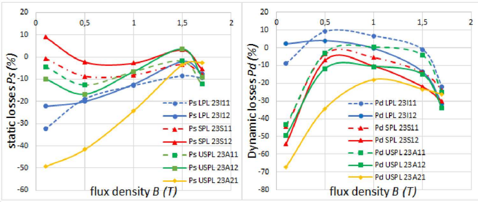


TMPT magnetic properties for LPL, SPL and USPL on 23MXX

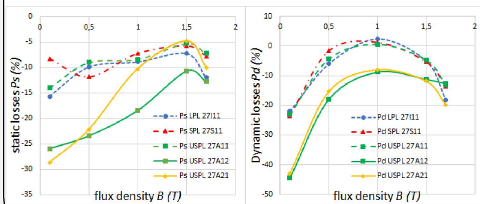


TMPT magnetic properties for LPL, SPL and USPL on R120-27





Loss reduction properties for LPL, SPL and USPL on 23MXX



Loss reduction properties for LPL, SPL and USPL on R120-27

*: olivier.maloberti@unilasalle.fr / olivie.maloberti@gmail.com; [1] Maloberti O. et al., JMMM, vol. 304, issue 2, Sept. 2006, Pages e507-e509; [2] Maloberti O. et al., JMMM, vol. 502, (2020), 166403.
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