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Laser investigations of electrotechnical steel surface roughness

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In this paper, the results of examinations of the roughness of the electrotechnical lasered steel surface have been presented. In an experimental way, it has been shown that the parameters of narrow angle light (He-Ne laser) intensity distribution due to reflection on the lasered surface of the electrotechnical steel are correlated with the average profile height R_a (measured by a profilometer). The results obtained may be used for the on-line controlling of the parameter R_a.

1. Introduction

Nowadays, the effectivity of both transmission and distribution of electric power is of significant importance as far as electric energy economy is concerned. Due to this fact, there is observed an increasing interest in electrotechnic (silicon) steel of large oriented crystals, used to produce the transformer core of losses less than those produced of conventional fine-grain steel sheet.

Actually intensive examinations are carried out aiming at reduction of losses by diminishing the distance between the walls of magnetic domains (refinement) among others [1]–[7]. It turns out that the diminishing of the distance between the domain walls may result in an effective decrease of losses caused by the rotary currents in materials of large crystals and high degree of their orientation.

One of the contemporary methods of magnetic domain refinement consists in introduction of stretching stress in the silicon sheet by applying a series of laser radiation pulses of high power (several MW) suitably "covering" the sheet surface. Each of them causes a rapid evaporation of the external layer of the material. As a result of this an impact pressure is generated while the surface roughness changes [8]–[13] due to lessening of material. On the other hand, it is well known that the surface roughness affects the hysteresis losses. These are especially essential for the thinner sheets [14].

Thus the state of the surface becomes important in solving the problem of loss reduction for two reasons. Firstly, the parameters of the domain refinement and the magnitude of the material lessening depend on the local state of the surface before the laser treatment. Secondly, the "new" state of the surface produced by the interaction of laser radiation affects the hysteresis losses.

In this work, an attempt has been made to show in an experimental way that the parameters of the narrow-angle distribution of the light intensity (He-Ne laser) reflected from the surface of the lasered transformer sheet are correlated with the average profile height R_a [15], *i.e.*, parameters characterizing the surface roughness.

2. Experiment

2.1. Subject of examination and its features

The subjects of examination were the samples made of lasered electrotechnical steel of 0.30 mm thickness and 2.72% content of silicon.

The microtopography of the sample surfaces was observed and recorded with the aid of a scanning electron microscope (SEM) of BS 301 type. In Figures 1**a** and 1**b**, a photo of the surface being representative for the samples examined is shown. It can clearly be seen that the surface appearing during the rolling process is characterized by almost mutually parallel scratches. In contrast to this, the one-sided lasering of the sheet produces almost circular "spots". The spot diameters and the spacings between them amount to about 0.3 mm, while the distance of the laser scanning is 7 mm. On the basis of these observations, it should be noticed that the microtopography of a surface created in the rolling process is essentially different from that produced by lasering.

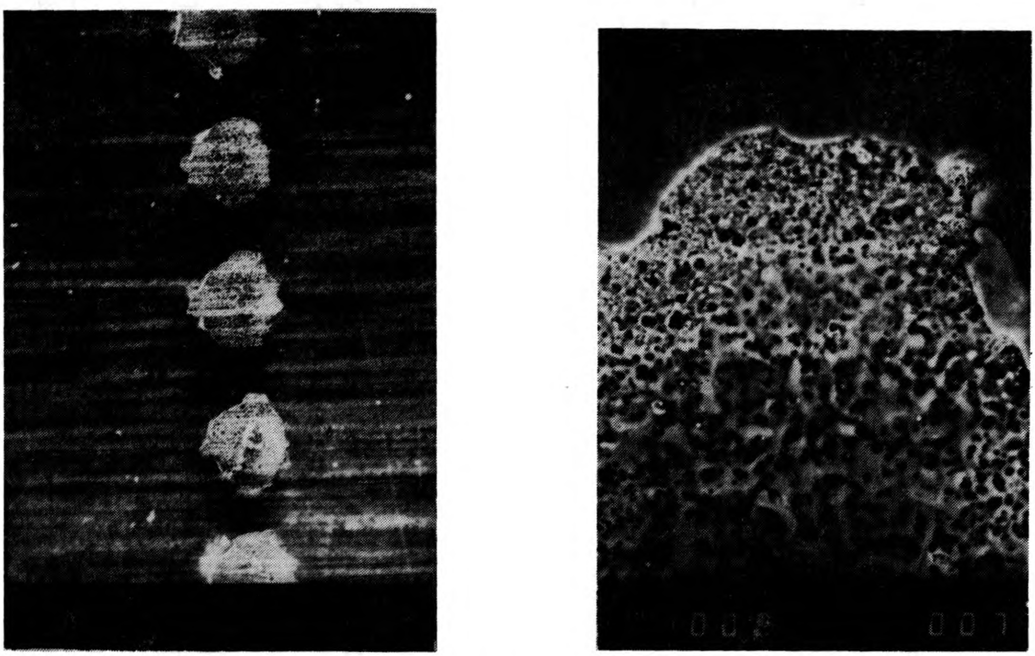


Fig. 1. Microtopography of the electrotechnical steel sheet surface (**a**). In photo **b**, a fragment of a spot appearing due to lasering is shown under a 10× greater magnification than that in photo **a**

Profilometric examinations were carried out by using a Hommel Tester T1000 C profilometer. An average profile height (parameter R_a [15]) was measured in the directions both parallel and perpendicular to the direction of sheet rolling (on its both sides, also in the regions subject to the lasering). Examples of representative measurement results are contained in Table 1.

Table 1. Parameter R_a of the sheet used in the examinations

Side A		Side B			
$R_a \parallel \uparrow$ [μm]	$R_a \perp \uparrow$ [μm]	$R_a \parallel \uparrow$ [μm]	$R_a \perp \uparrow$ [μm]	$R_a \parallel \uparrow_L$ [μm]	$R_a \perp \uparrow_L$ [μm]
0.05	0.13	0.07	0.18	0.17	0.61

$R_a \parallel \uparrow$, $R_a \perp \uparrow$ – R_a measured in the directions: parallel and perpendicular to the rolling direction ($\uparrow$),

$R_a \parallel \uparrow_L$, $R_a \perp \uparrow_L$ – R_a measured in the direction: parallel and perpendicular to the rolling direction in the lasered region, respectively.

2.2. Description of the optical measuring apparatus

The optical examinations were carried out with the help of the apparatus of block scheme presented in Fig. 2. The light source was the He-Ne laser (of HNA 188-S type) of 70 mW power and linear polarization of the light beam (the polarization plane being perpendicular to the plane of incidence). The incidence angle of the laser light beam on the sample (45 °C) and the direction of the sheet rolling with respect to the plane of light incidence was determined with the help of a ZRG 3 goniometer on which the sample was fastened. For such an incidence angle, the region illuminated was approximately elliptic of axes equal to 5 and 6 mm, respectively.

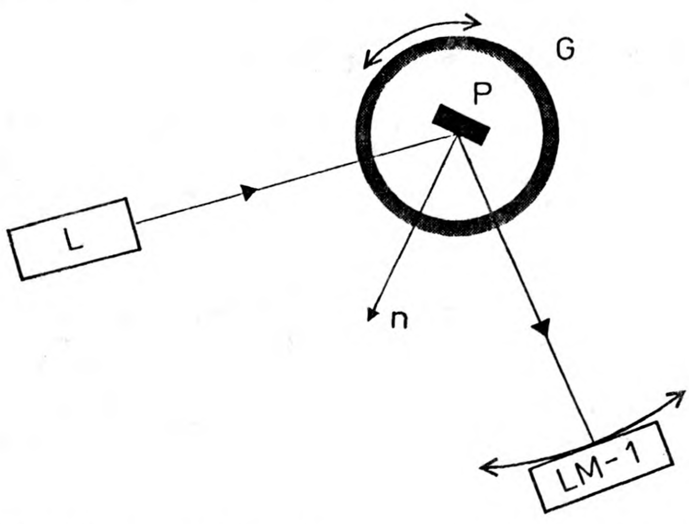
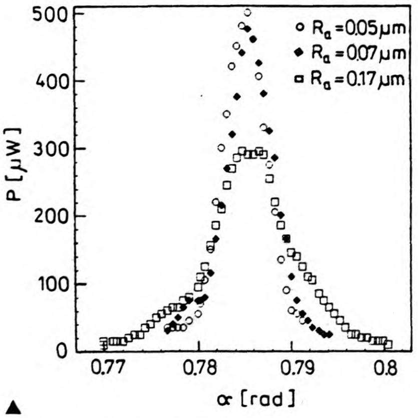


Fig. 2. Block scheme of the optical apparatus. L – He-Ne laser, LM-1 – laser power meter, G – ZRG 3 goniometer, S – sample

The angular distribution of the light intensity (in the reflection plane, close to the mirror reflection direction) was recorded by using a LM-1 laser power meter, the measuring gauge (recording the light intensity within the solid angle equal to 0.0001 srd) of which was shifted on a multi-function optical stage [16]. The measuring geometry has been chosen so that the light-sensitive area of the measuring gauge be much greater than the sizes of the single speckles.

3. Results of examinations

The respective angle distributions of the light power scattered at the sheet surface in the case when the rolling direction was parallel to the light incidence plane are presented in Fig. 3. The distribution parameters (power P_z in the direction of the mirror reflection, maximal angular width α_m, angular width α_e for P_z/e) depend on R_a. Thus, the light power P_z scattered in the direction of mirror reflection recorded by a LM-1 meter (on the nonlasered side for $R_a = 0.05$ μm) amounted to



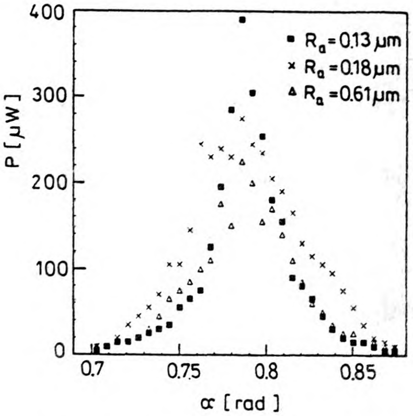


Fig. 3. Angular distribution of the light power scattered from the sheet surface (direction of rolling parallel to the plane of light incidence)

Fig. 4. Angular distributions of the light power scattered from the sheet surface (direction of rolling perpendicular to the plane of light incidence)

0.5 mW. On the other hand, the light power reflected from this surface which was subject to lasering ($R_a = 0.07$ μm) is slightly less and amounts to $P = 0.475$ mW. However, if there are "spots" ($R_a = 0.17$ μm) in the penetration region of the laser beam, the light power recorded in the mirror reflection direction diminishes significantly ($P_z = 0.295$ mW).

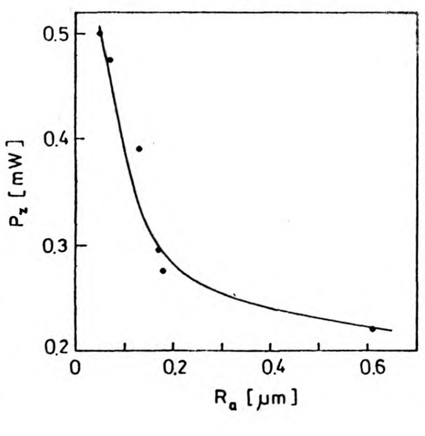


Fig. 5. Dependence $P_z(R_a)$ for the transformer sheet

Analogical angular distribution of the light power scattered in the case when the rolling direction is perpendicular to the plane of the light beam incidence is shown in Fig. 4. In Table 2, the obtained results of examinations are collected, while in Fig. 5, the dependence $P_z(R_a)$ is graphically presented.

Table 2. Parameters of the angular distribution of the light scattered from the sheet examined

Side A — nonlasered		Side B — lasered			
$R_a \parallel \uparrow$ [μm]	$R_a \perp \uparrow$ [μm]	$R_a \parallel \uparrow$ [μm]	$R_a \perp \uparrow$ [μm]	$R_a \parallel \uparrow_L$ [μm]	$R_a \perp \uparrow_L$ [μm]
0.05	0.13	0.07	0.18	0.17	0.61
Power P_z (in the direction of the mirror reflection) [μW]					
500	390	475	275	295	220
α_m (maximal angular width) [rad]					
0.016	0.17	0.018	0.17	0.03	0.17
α_e (angular width corresponding to P_z/e) [rad]					
0.008	0.055	0.009	0.080	0.012	0.065

4. Conclusions

1. The angular intensity distributions of the light scattered in a similar way as reported in papers [17]–[19] are not axially symmetric. Their parameters depend on average profile height (R_a parameter) of the illuminated surface.

2. The intensity (power P_z) of the light propagating in the mirror reflection direction is, similarly as in works [18]–[20], a monotonic function of R_a within the range of examination and may be treated as a scaling curve for a given type of material.

3. The laser processing (laser evoking of stress) results in an increase of the average height of the inequalities (parameter R_a) and thus the parameters of the angular distributions are changed.

4. The mathematical description (theoretical model) of the process of light –surface interaction, the geometric microstructure of the surface being a kind of "sum" of surfaces of single-direction roughness (rolling) [21] and two-direction roughness (laser spots) will be very complex and rather approximate [22] and has not been published yet.

5. A simple quantitative correlation between P_z and R_a allows only a relatively low accuracy when elaborating the preliminary conditions of the technological processes. They offer also advantage of possible on-line checking of parameters R_a for pure surfaces in many (only conventional) technological processes.

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