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Scanning strategy of high speed shifted laser surface texturing

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Abstract

Laser Surface Texturing (LST) is one of the perspective ways for creating of functional surfaces: low frictional, hydrophobic or hydrophilic, photonic structures, thermal spray substrates and so on. There are several methods for laser surface texturing of large areas, but they have some physical limitations, such as heat accumulation, plasma shielding and achieving high precision at fast laser beam scanning speed. In this paper a new method called shifted Laser Surface Texturing (sLST) is presented. This sLST method is able to overcome mentioned physical limitations. The sLST method is based on formation of large array of microobjects by collecting them from short/ultrashort laser pulses, which are distant in time and processing plane. It is achieved by application of a series of laser scanning of linear raster which contains a lot of single pulses. Each single pulse in one raster belongs to different object from the textured area. The linear raster is shifted by small distance between each repetition. The high precision of the shape and position of every textured object (< 2 µm) is achieved by control of laser spots position electronically by using of constant repetition frequency of laser pulse generation. In this way the mirrors movement has no control of object position directly, but supply only continuous movement of the laser spot position. The method of sLST has great potential for polygonal, resonant or hybrid scanning system, where laser beam scanning speed reached up to 1000 m/s and high precision of microobjects formation becomes difficult task. In this paper there is described the principle of the method along with its applications on functional surfaces. In discussion there are presented physical and technical parameters of high speed sLST in comparison with classical texturing methods.

Keywords: laser surface texturing, scanning strategy, high speed, functional surfaces;

1. Introduction

Laser Surface Texturing (LST) is an actual technology which is used for formation of functional surfaces with specific characteristics: low frictional, hydrophobic or hydrophilic, bio or thermal spray adhesive, surfaces with modified optical or electrical properties (Wang, Li, Bai, Wang, & Zhao, 2016 or Zheng, Wang, Jiang, & Mei, 2016 or Cunha et al., 2016 or Kromer et al., 2015 or Vorobyev & Guo, 2015). There are a lot of laser strategies for providing of LST on materials – static, dynamic or their combination (Beiser, 2003). Static methods include interference or diffraction effects, self organization effects or surface scattering waves for formation of surface structures (Tan, Sivakumar, & Venkatakrishnan, 2005 or Höhm, Herzlieb, Rosenfeld, Krüger, & Bonse, 2015 or Zhao, Malzer, & Wang, 2007 or Gurevich & Gurevich, 2014). Dynamic strategies include moving parts, like galvanic scanners or polygon scanners for controlling laser beam movement on material surface. Dynamic laser scanning strategies have several advantages in comparison with static strategies: flexibility in surface objects addressing, wide area material processing and fast changing of texture geometry. In biggest cases the scanning strategy of LST are using pulsed mode of laser generation at high frequency, from kHz up to MHz and more. There are three basic limitations connected with it – heat accumulation from pulse to pulse in subsurface layer (Eaton et al., 2005 or Jaeggi, Neuenschwander, Meier, Zimmermann, & Hennig, 2013 or Bauer, Michalowski, Kiedrowski, & Nolte, 2015), limitation in precision of microobjects forming at higher scanning speeds (De Loor, 2013 or Moskal, Kučera, Smazalová,

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Houdková, & Kromer, 2015) and plasma shielding effect (Bulgakova et al., 2014 or Efthimiopoulos, Dogas, Palli, Gravalidis, & Campbell, 2000).

Classical strategies providing LST has two basic techniques of objects forming – scaling of every object shape and hatching trough all objects in one texture (Jaeggi et al., 2013 or Jhabvala, Boillat, Antignac, & Glardon, 2010). The scaling technique is provided by consequential laser beam scanning inside every object (Fig. 1. *a*). In this case is needed to use trepanning optic or low speed of mirror movement for high quality of microobjects geometry (Schonlau, Hebel, Pause, & Mayer, 2014 or Moskal et al., 2015). In the hatch technique the speed of laser beam moves along straight lines (Fig. 1. *b*). Hatch technique can be provided at higher speed, but for high precision of microobjects formation needs to use very strong hardware interaction between mirrors position and laser pulse generation. Limited speed of laser movement in the classical strategies and high overlapping of the laser spots initiate heat accumulation and plasma shielding effects. In this article a new shifted laser surface texturing strategy (sLST) is presented, which was designed for overcoming mentioned limitations.

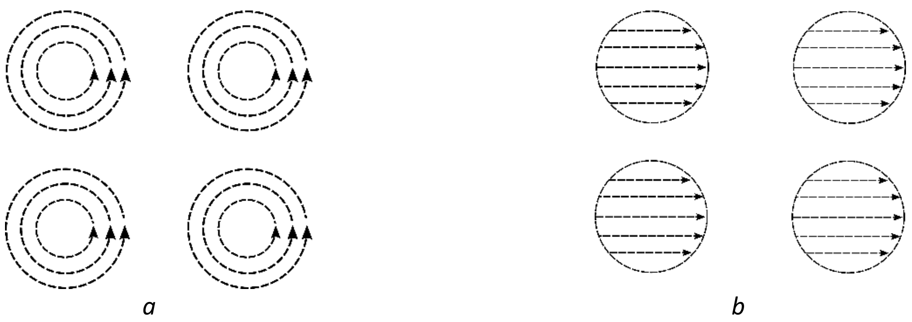
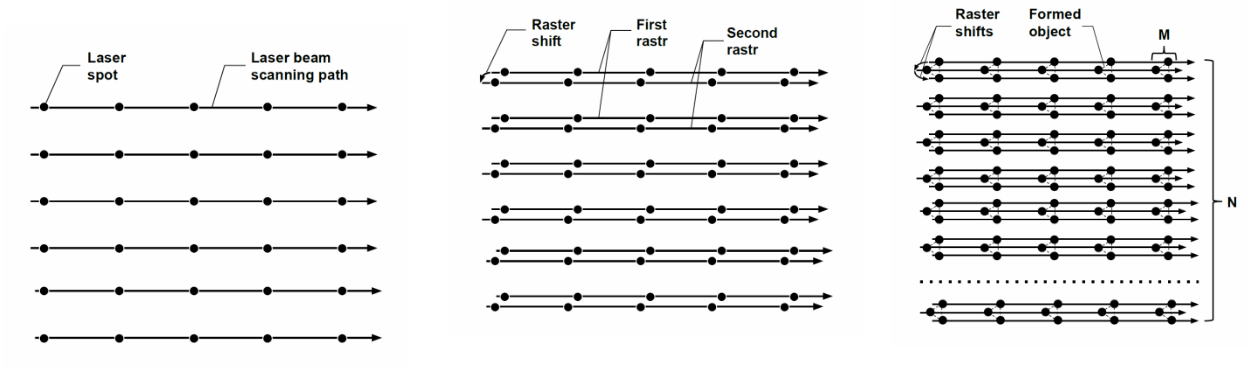


Fig. 1. a – scaling technique of microobgects filling with laser beam movement on concentric circles; b – hatch techniques of microobjects formation with scanning by laser beam through all objects. Laser switching “ON” and “OFF” should be controlled in strong connection with actual position of mirrors in scanhead.

2. Shifted laser surface texturing (sLST)

Presented sLST strategy is based on stable generation of laser pulses with continuous movement of scanning mirror. In this case inertia of the mirror play a positive role for high precision forming of microobjects for high speed of LST. It can be easily explained on one example of formation of equidistant micro objects at high mirror speed (Fig.2, *a*). The mirror is moving at high speed from the left to the right side (marked by arrows in Fig. 2, *a*). Stable pulse generation is applied independently from mirror movement (filled circles on Fig. 2, *a*). Starting moment and frequency of laser pulse generation are driven electronically and can be controlled with very high precision. The mirror movement has continuous character, because it is driven by constant force, without any breaking for correction of laser spot position. These both effects, electronically driving of laser pulse generation with stable frequency and continuous mirror movement, produce high speed formation of equidistant laser spots ordered in one line with high precision. Set of scanning lines or paths is forming linear raster with equidistant laser spots (Fig.2. *a*, all horizontal arrows). For formation of array of microobjects, where every microobject is collected from several laser spots, second scanning raster can be applied, but with short shifting of start position (Fig. 2. *b*). It means, that laser spots are applied on the positions, which are shifted from the previous positions by the vector equal to the linear raster shift. Sequence of linear raster shifts defines the form of the small objects in the array (Fig. 2. *c*, dotted triangles). In this way, every object in the whole array is composed of laser spots, which are distant on surface during the scanning process and distant in time for the case of neighbor spots. This is one solution for the two first mentioned limitations. Heat accumulation effect disappear, because overlapped spots are applied with time interval equal for one linear raster scanning process. Plasma shielding effect is decreased, because shots for formation of sequenced spots are applied on distant positions on surface.

Position of the every spot inside of the object is controlled by low speed and precision movement of the mirrors for short vector of shifting. At the same time, the overlapping of laser spots inside of every object can be chosen any, from micron up to distance between raster lines, because biggest value of laser spot overlapping does not involve heat accumulation for sLST technique. Distances between objects inside of every row are controlled electronically, by laser pulse generation frequency and it gives possibility to achieve high precision for microobject formation at maximal speeds. The full amount of data for sLST strategy is not equal to multiplying M and N and full number of objects in line. It is significantly smaller, because it has not direct control of objects position and their quantity. In sLST strategy the amount of data is equal to the number of lines N in one linear raster plus number of spots in one object M (Fig. 2. *c*). For demonstrated triangular object on Fig. 2. *c* the M is equal to three.



a *b* *c*

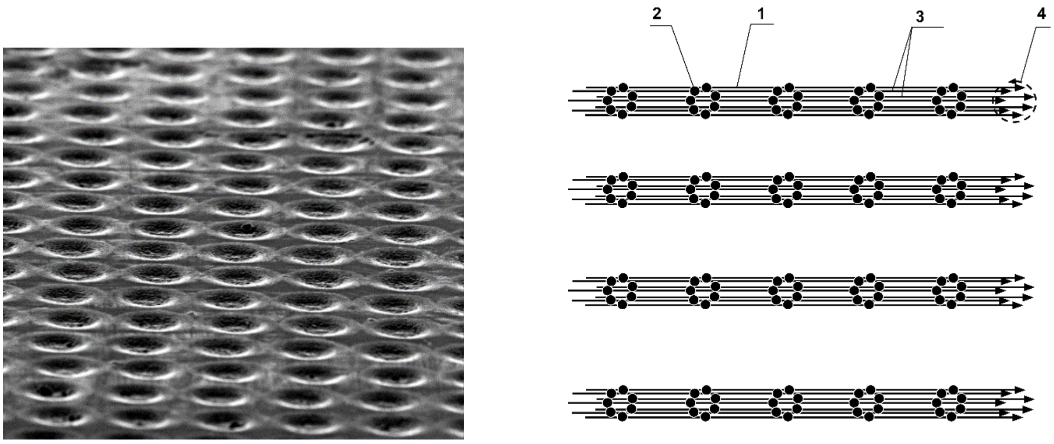
Fig. 2. Schematic representation of the shifted LST method. a - Linear raster with one shot per one laser spot. b – one small shift of the linear raster to the next position and formation of the neighbor linear raster at this position. c – formation of triangular objects in an array by two sequenced shifts of the linear raster. M - is number of spots in one object, N - is number of lines in one linear raster.

3. Experimental application of sLST strategy

In this part several examples of laser formation of big quantity of microobjects are presented. For providing sLST strategy we are using laserDesk software with RTC card from SCANLAB. Formation of microobjects was produced by application "Repeat" function for one raster in pulsed mode. In this mode the laser pulses emission is controlled independently from mirrors position by RTC card.

The structures were formed by a picosecond laser with pulse length 10 ps, wavelength 532 nm, maximum pulse energy 100 µJ and average power 12 W. The optical scheme contains galvanometric scanner with 255 mm focal length f-theta objective. In this configuration, the spot diameter is 28 µm and maximal laser beam scanning speed is equal to 8 m/s. This speed is not high enough for full use of the laser, so only certain laser pulses were picked up with frequency 5 ÷ 20 kHz.

The first example is formation of simple dimples on the surface of the bearing steel (Fig. 3. *a*) for better formation of oil film on it (Houdková, Šperka, Repka, Martan, & Moskal, 2017). Full quantity of dimples on bearing ring is more than 20000 and for sLST strategy data processing time was equal only one-two seconds.



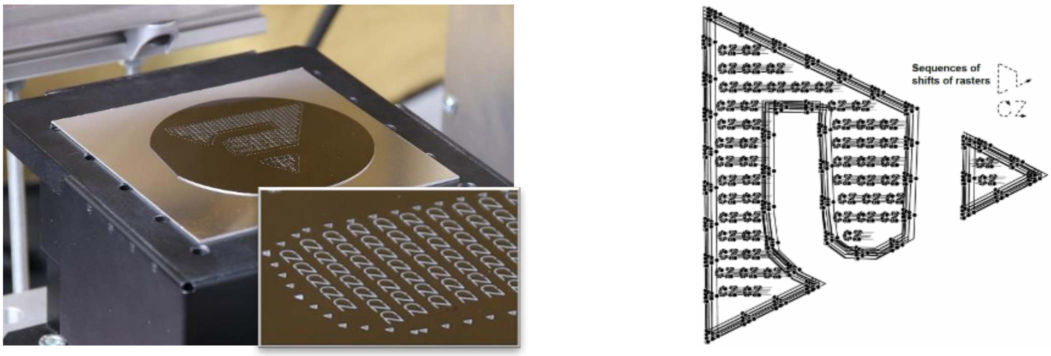
a *b*

Fig. 3. a - surface of bearing steel, processed by sLST with dimples for better formation of oil film under rotation of shaft. b - sLST formation of one ring by collection of several rasters: 1) a path of laser beam scanning in the linear raster with equidistant laser spots; 2) a laser spot that contains one laser shot (one shot mode); 3) lines in the consequential linear rasters; 4) shifting trajectory of linear raster;

Every object contains 71 laser spots with 28 µm, which are collected in three rounds with 10 µm, 15 µm and 30 µm diameters. Scanning speed is 2 m/s, laser frequency 400 kHz and pulse switcher was set to 20 kHz and 10 kHz. Every laser spot from neighbor dimples is divided from consequence laser spot by 100 µm and 200 µm distance, correspondingly to pulse switcher frequency (20 kHz and 10 kHz). Example of sLST formation of an array of simple rings is presented on Fig. 3, *b*. At this process all raster is shifted by small shifting vectors along small circle (Fig. 3, *b*).

For this array of ring only seven positions of shifting vectors need to be known. The resulting structures were used for providing tribological tests and show decrease of torque force for sLST processed surfaces by Houdková et al., 2017. In actual time we are performing tests with IR detection of heat accumulation on textured surfaces. As preliminary result it can be presented, that the maximum of detected temperature for shifted LST is about 15÷20 % in comparison with classical method.

The next example is sLST on silicon plate with more complicated structure of textured field. It contains UWB logo with letters CZ inside of it (Fig. 4. *a*). The sLST strategy was provided by repetition of two independent rasters with different trajectories of shifting (Fig. 4. *b*). Scanning speed was set up to maximal value 8 m/s, laser frequency was equal to 303 kHz and pulsed switcher was set to 5 kHz, for different shifted vectors. This example illustrates possibility of collecting microobjects into macrostructures by sLST.



a *b*

Fig. 4. a – silicon plate with textured UWB logo which was provided by sLST with two independent rasters. b – formation of two sLST arrays by different trajectories.

4. Results and discussion

The sLST strategy overcomes two physical limitations - heat accumulation and plasma shielding effect. Reduction or elimination of heat accumulation effect was detected by comparison of classical method with sLST method. There are two possible mechanisms of heat accumulation for classical methods – collection of residual heat in subsurface layer of processed material and pumping up plasma cloud by consequential laser pulses with secondary transfer of heat to the processed surface.

In the shifted method of LST the laser shots are divided in time by one scanning period and in space by distance between textured objects. This laser shots division gives time for heat transfer from surface to the deeper layers of material and plasma cloud disappearing before next laser pulse in the same area of on textured surface.

The precision error in the sLST strategy has no major decrease at high speeds and in our tests it was smaller than 10% for the highest possible speed of 8 m/s of the used scan head (< 2 µm for biggest casses). This value of precision error was detected already at speed of 2 m/s for the hatch classical method of material processing. Such difference can be explained by positive influence of mirrors inertia for sLST strategy in contrast with classical strategy, especial for scale method of objects filling, then this speed have to be reduced to 0.3 m/s. Additional advantage of sLST strategy is stable electronic control of every microobject position in the textured field. As disadvantages of sLST strategy can be mentioned difficult application of it for textures with no periodical structures or on complicated 3D surfaces.

5. Conclusion

In this paper the new sLST strategy for material processing was presented. As advantages of this method of large area surfaces laser processing were presented: overcoming of heat accumulation, high precision of textured microobjects at higher speeds and major decrease of data amount for microobjects addressing. Such strategy can be applied as useful method for material processing with hybrid polygon or resonant scanning systems, when laser beam movement speed has great value, equal to thousand meters per second.

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