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Research paper

Diffractive optical element based sensor for surface quality inspection of concave punches

Ville Hyvärinen[a,1], Raimo Silvennoinen[a,*], Kai-Erik Peiponen[a], Tapani Niskanen[b]

[a]Department of Physics, University of Joensuu, Joensuu, Finland
[b]Orion Pharma R&D, Orion Corporation, Espoo, Finland

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Abstract

Optical surface quality of concave shaped punches was investigated with a diffractive optical element based sensor. Image information of the present sensor was studied for the purpose of surface roughness and reflectance inspection. The robust sensor is proposed for off-line optical inspection of concave punches.

Keywords: Concave punches; Tablet; Surface roughness; Surface quality; Optical inspection

1. Introduction

A tabletting machine uses flat or non-flat punches for the compression of pharmaceutical tablets. Unfortunately, due to the wear of the metal punches they are subject to surface treatment in order to improve the surface quality e.g. to prevent sticking of the powder material on the metal surface. Off-line surface roughness inspection of the flat punches is relatively easy and can be realized either by mechanical or optical stylus or using laser reflectometer [1]. As concerns the state of art of industrial surface roughness measurements by the above mentioned techniques we refer here only to the books of Cielo [2] and Bennett and Mattson [3]. The surface quality inspection of curved metal surfaces such as concave punches is a more complicated matter than the inspection of flat punches. Firstly the mechanical stylus is designed for the measurement of relatively flat surfaces along a line, which means that the stylus should be at normal incidence on the surface. Such a procedure may be problematic in the case of strong and complex curvature of the metal surface. In addition the simple laser beam specular reflectance technique, which has found applications in the estimation of the surface roughness in basic metal process industry [4] and that of pharmaceutical compacts [5] fails in the case of concave punches. Fortunately, there is another novel technique, which we initially developed for the surface roughness inspection of flat metal surfaces [6,7]. This technique is based on the use of a diffractive optical element based sensor (DOES). We have shown the applicability of the sensor to detect simultaneously the surface roughness and curvature when the flat metal surface has only a minor deviation from flatness, and constructed an off-line scanning device for that purpose [8]. Later we have extended such a metrology for surface quality inspection of different pharmaceutical compacts [9–11] and paper [12].

In this paper we describe the applicability of DOES for optical inspection of the surface quality of concave shaped punches that were obtained from pharmaceutical industry. The aim was to detect possible wearing marks of the punch surface caused by normal mechanical erosion in industrial production process. It is obvious that in use, the surface of a punch may turn to be darker or there may occur some changes in the surface roughness. Due to the changes of the surfaces, the punches will have to be renewed from time to time to make sure that the quality of the tablets remains good. In this study we propose that information of the surface quality of concave shaped punches can be achieved by using DOES.

2. Experimental and results

In this study the detection of the surface quality was carried out based on the set up shown in Fig. 1. This is

* Corresponding author. Department of Physics, University of Joensuu, P.O. Box 111, FIN-80101 Joensuu, Finland. Tel.: + 358-13-251-3205; fax: + 358-13-251-3290.

E-mail address: raimo.silvennoinen@joensuu.fi (R. Silvennoinen)

[1] Present address: Measurement and Sensor Laboratory, University of Oulu, Technology Park 127, FIN-87400 Kajaani, Finland.

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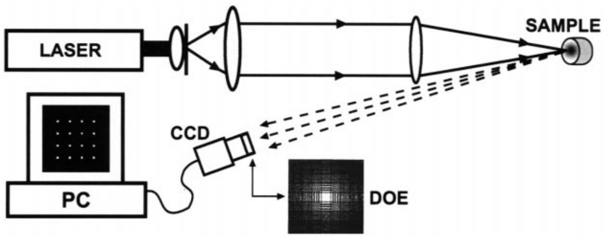

Fig. 1. Schematic diagram of the DOES. Visual appearance of the DOE located at the aperture of the CCD camera and its image on the display of a PC are shown.

the first time, in the case of a strongly curved metal surface, that we have applied technique where the laser beam is focused on the surface of a metal. The advantage of laser beam focusing is that local information about surface quality can be obtained contrary to the previous studies, where the plane wave gives information of the average quality of a macroscopic surface area [6–8].

The light source we used was a HeNe laser ($\lambda = 633$ nm). The laser beam was expanded and collimated and after that focused towards the sample under test. The focusing of the beam is also necessary because of the curved geometry of the sample surface, which actually prevents the use of the plane wave front. The spot size of the focused beam was calculated to be 10 μm. Reflected light was incident on the DOE sensor (details and somewhat lengthy theory of the system function of the sensor can be found from the paper [7]), which produced a 4×4 light spot matrix in its focal plane ($f = 100$ mm). The DOE is a computer-generated hologram, which was calculated using the Rayleigh–Sommerfelt diffraction integral [13]. It was fabricated using an electron beam writer, which gives the best imaging quality for such a diffractive element. The spot matrix image was then detected with a CCD-camera and grabbed to the memory of a personal computer. An optical mirror was used as a reference surface.

Five images with 10 μm steps were taken from five different places on the surface of a used punch under examination. For the present purpose we chose, in a random manner, short discrete line segments along which the measurements were performed. The reason for such a procedure of choosing of nearby points was to find out the surface quality of a punch at microscopic level. The positioning was possible by using

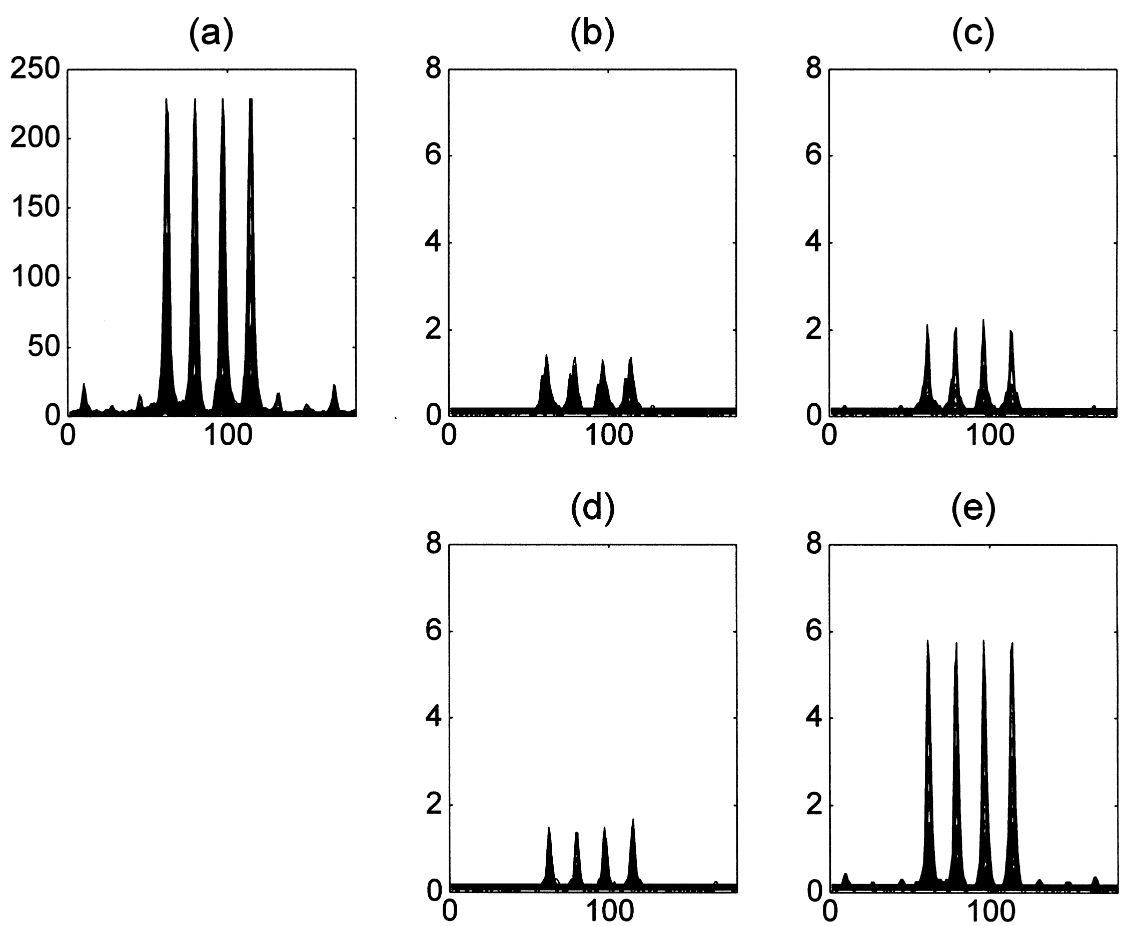

Fig. 2. Intensity projections of the 4×4 spot matrix onto plane. (a) Mirror surface, corresponding plots for different location on the concave punch (b–e). In (b,c) increased local surface roughness causes the decrease and the broadening of the peaks. In (d,e) reflectance of the investigated areas has changed. The numbers shown on the axes are the pixel numbers of the digital device (in x-direction for location and in y-direction for intensity).

a linear *xyz*-translation device. Some intensity plots of the projections of the spot matrix images are shown in Fig. 2 for one investigated punch sample. In Fig. 2a the intensity plot for the optical mirror is shown. In Fig. 2b,c we present intensity plots for two locations at the concave punch separated by 10 microns. We observe that the peaks are broad, which is an indication of the local surface roughness in the inspected punch locations of Fig. 2b,c. The broadening and lowering of the intensity distribution as a result of surface roughness is a well-known fact in context of metal surfaces [14,15]. Linear translation of 20 and 30 microns with respect to the position of Fig. 2c gives completely different surface quality as shown in Fig. 2d,e. Indeed, now the surface is rather smooth but the strength of specular reflectance varies because of the dullness of the surface. As a conclusion we can state that by DOES it is possible to observe in a relatively small inspected area variations of the quality of the used punches. Such an information, which can be related to local surface roughness or microscopic scratches may help tablet makers to estimate condition of the punch.

3. Conclusion

We have demonstrated that DOES can provide a tool for off-line surface quality inspection of concave punches. The basic idea is to observe the height and the width (at half maximum) of the intensity spikes of the image information provided by DOES. The sensor can provide e.g. useful information when the surface processing of a used punch has reached satisfactory level. In addition DOES can be used to estimate when the punch should be rejected. Of course the tablet makers set the decision limits for quality.

Quantitative measure for surface roughness could be estimated if we assume for instance that the height distribution of the surface roughness obeys normal distribution. Unfortunately, most of the metal surfaces that have undertaken a surface machining process obey an asymmetric distribution because of ‘wiping off the mountains and preserving the valleys’. Therefore the quantitative estimation of surface roughness needs further measurements and also theoretical work. At the moment it is possible to take a new punch as a reference and compare the image data of used punch with that of the new one. Then, surface roughness and spectroscopic data by DOES is available. Usually the information about the surface roughness is more important as concerns the punches.

In principle the method at the present stage provides means for off-line inspection of used concave punches. The measuring head can be constructed into a small size and compact unit. So, it is possible to construct a computer driven mechanical and optical system. This, however, requires a great deal of design and development.

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