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Note

Optical inspection of punches: flat surfaces

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Abstract

Optical inspection techniques for estimation of surface roughness and surface quality of flat punches, which are used in the pharmaceutical industry for tablet compression, were studied. It was observed that a simple specular reflection technique is useful for surface roughness assessment of flat punches. A diffractive element based sensor was used for the surface quality detection, such as mirror property or flatness, with the aid of image information of a test pattern. It was observed that a new punch may have a poorer surface quality than a used one.

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

1. Introduction

A tablet compression machine usually uses two metal punches, lower and upper ones, in order to compress a powder material into tablet form. The geometry of the punches can vary depending on the desired shape of the tablet product. Whatever the geometry of the punch a common factor is the wear of the punch on industrial line. In the case of flat punches, which we study in this paper, the surfaces that are in contact with the powder material are subject to the change of the surface roughness. In addition originally bright metal surfaces can change to dull ones. As a result of the undesired changes of the flat surfaces of punches they have to be from time to time renewed e.g. by polishing. Such a surface treatment is important especially if the powder material is stuck over the compressing punch surface, which phenomenon may have a severe impact on the process of tablet making, and therefore on the quality of the tablet. We mention also that a symptom of wear of the punch is the reduction of the diameter of the cylinder. Here we study only the surface roughness and mirror quality of the flat surfaces using optical inspection techniques.

Flat punches, which are made from metal, have surface roughness. Optical measurement technology provides various methods to gain information about the surface roughness of metal. As concerns the state of art of optical surface roughness measurement techniques we refer here only to the books of Bennet and Mattson [1] and Cielo [2].

In this paper we compare the surface roughness of the flat surface and the quality of a new and a used (rejected from the process line) upper punch. By surface quality we mean here how well the surface resembles a mirror surface and also flatness. Surface quality measures how well the surface processing has succeeded. For the case of surface roughness estimation we make use of the specular reflection of laser light from the metal surface [1,2]. The surface quality in turn is inspected using a diffractive optical element [3] based sensor that was originally developed for metal surface quality assessment [4–6], but which has also turned out to be useful for surface quality inspection of porous media such as pharmaceutical tablets [7–9]. We believe that the present study gives some basic information about the surface condition of punches, and in principle some aids how to arrange an on-line optical industrial inspection of the punch quality.

2. Materials and methods

2.1. Stylus

A conventional and standardized method to measure surface roughness, such as that of pharmaceutical punches

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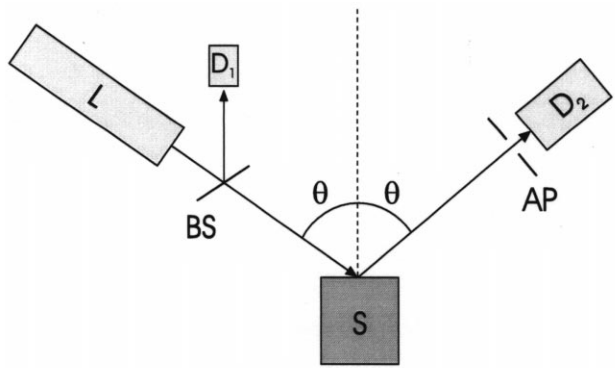

Fig. 1. Laser goniometer for specular reflection measurement. L, laser, D, detector, S, sample, BS, beam splitter and AP, aperture.

made of metal, is to use a mechanical diamond tip stylus, which is moved along the inspected surface. With this method one can obtain the average surface roughness (R_a) and the root mean square roughness (R_q) [2]. The surface roughness parameters R_a and R_q of the present study were measured by using Surftest 201 stylus apparatus.

2.2. Specular reflectance

One industrial method is based on the use of detection of specular reflection of laser light from rough metal surface [2]. Usually, the aim is to correlate the optical surface roughness R_{opt} to the average surface roughness R_a or to the root mean surface roughness R_q. One should keep in mind one advantage of an optical measurement system which is the possibility to get surface roughness information from a macroscopic area, instead of a narrow line like in the case of a mechanical stylus.

In this paper the optical surface roughness, R_{opt}, of flat punches is estimated using laser light specular reflectance technique. The analyzing of the data is based on the theory of Beckmann and Spizzichino [10], which is valid under the assumptions that the height distribution is Gaussian as well as the correlation function. Quantitative approach for the estimation of optical surface roughness can be accomplished from their theory, which gives a law for specular reflectance using a perfect surface as a reference surface. Because we can never have perfectly smooth punch surfaces, we approximate the specular reflection as follows:

$$I = I_0 \exp\left[-\left(\frac{4\pi R_{opt}\cos\theta}{\lambda}\right)^2\right] \tag{1}$$

,where I is the measured specular light intensity and I_0 is the output intensity of the laser. During the experiments, the angle of incidence (θ) and the angle of detection were synchronously changed by using a goniometer apparatus, which is shown in Fig. 1. The laser source was a semiconductor laser ($\lambda = 635$ nm). The output beam of the laser is divided into two beams by a beam splitter (BS). One of them is incident on the reference detector (D_1), which monitors the possible fluctuation of the intensity of the laser light. The other beam is incident on the sample and reflected to the aperture (AP) of the signal detector (D_2). The aperture is needed to block diffusely reflected light.

2.3. Diffractive element based sensor

Recently, we have developed a novel sensor, which can be used for optical surface quality inspection of relatively smooth metal surfaces. The apparatus uses a diffractive optical element (DOE) based sensor. The theory related to the image formation of the sensor and quantitative metal surface roughness and flatness estimation for very smooth surfaces are described in [5,6]. Details of the fabrication of the DOE are explained in [7–9]. The output pattern of the DOE produces a 4×4 light spot matrix.

We used the set-up shown in Fig. 2, where the beam from a HeNe laser was expanded with a lens system to a plane wave and after that targeted onto the surface of the punch sample. A cubic beam splitter was used to separate the signal reflected from the inspected surface. After that the signal was guided through the DOE sensor, which was attached at the input pupil of the CCD-camera. The diffracted optical signal from the DOE was then incident directly on the chip of the CCD camera. The image of the reflected pattern was viewed on a TV monitor and grabbed into the personal computer (PC) for analysis. Due to the fact that the surface roughness of the punches is relatively high we may not use the data for surface roughness quantitative estimation as in [5]. However, the image data of DOE provides us a means for inspection of the mirror and flatness properties of the punch surface.

The system records the specularly and diffusely reflected light components at the same time. The specular component is related to the image of the 4×4 spots, whereas the diffuse reflection can be observed as a background noise. The quality of the image of the specular component depends on the surface roughness and surface curvature of the sample.

3. Results

We present the first results of stylus measurements of R_a and R_q for a new and used, rejected flat punch, which were

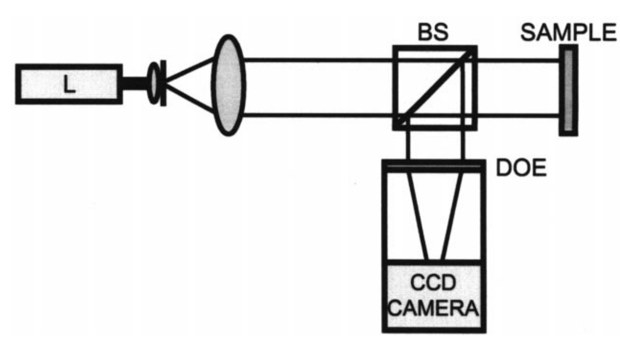

Fig. 2. Schematic diagram of diffractive element based sensor for punch surface quality inspection.

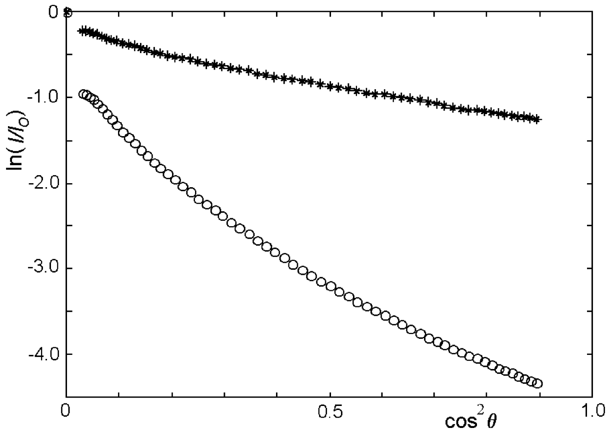

Fig. 3. Natural logarithm of the intensity ratio as a function of $\cos^2\theta$ for unused (*) and used (○) flat punches. The data were obtained by the system of Fig.1.

chosen in a random manner from a warehouse. We made ten surface scans per punch and calculated the average value and standard deviation from the results of the measurements. As a result we obtained $R_a = 0.07 \pm 0.01$ μm for unused punch and 0.16 ± 0.08 μm for used punch. The corresponding R_q values were as follows: 0.10 ± 0.01 and 0.24 ± 0.13 μm, respectively. According to the roughness data above, one may draw a conclusion that the surface roughness of a used punch is higher than that of a new punch. This is partly true because we chose a used punch where local scratches appear. Otherwise the surface is rather smooth because of the procedure of polishing of the flat surface while it was used for tablet compression.

In the case of the specular reflection technique, by detecting the intensity I as a function of the angle θ, it is possible to solve R_{opt} from Eq. (1). In Fig. 3 we show $\ln(I/I_o)$ as a function of $\cos^2\theta$. If the surface roughness of the punches obeys Gaussian statistics then the natural logarithm of the intensity ratio should give a straight line. Obviously the signal for unused punch is more closely related to the Gaussian statistics than that for the used one. Nevertheless, for near grazing incidence angles the Gaussian approximation is good. Next optical surface roughness was calculated and according to the calculations, $R_{opt} = 0.06$ μm for the unused punch and $R_{opt} = 0.20$ μm for the used one. Obviously there is a satisfactory agreement between the optical and mechanical surface roughness parameters. As a conclusion we can state that the optical surface roughness of flat punches can be estimated by using a laser beam reflection technique.

The surface quality of the two flat punches was inspected with the DOE sensor in a manner where the 4×4 spot matrix images were grabbed from six different areas of the punch surfaces. This was enabled with the help of a linear translation stage, where the samples were attached. Reference image was grabbed from the surface of an optical mirror. As an example we show in Fig. 4 images and corresponding intensity distributions obtained from the mirror surface, unused and used punches, respectively. The image 4b of the unused punch is blurred (the corresponding intensity distribution is a broad band in Fig. 4e) which is due to the diffuse nature of the surface. Obviously the surface quality of the unused punch is not so good. This is probably due to the finishing process of the punch. On the other hand, the surface of the used punch seems to posses a mirror property that preserves the image. The reason for the mirror property of the used punches is believed to be related to the

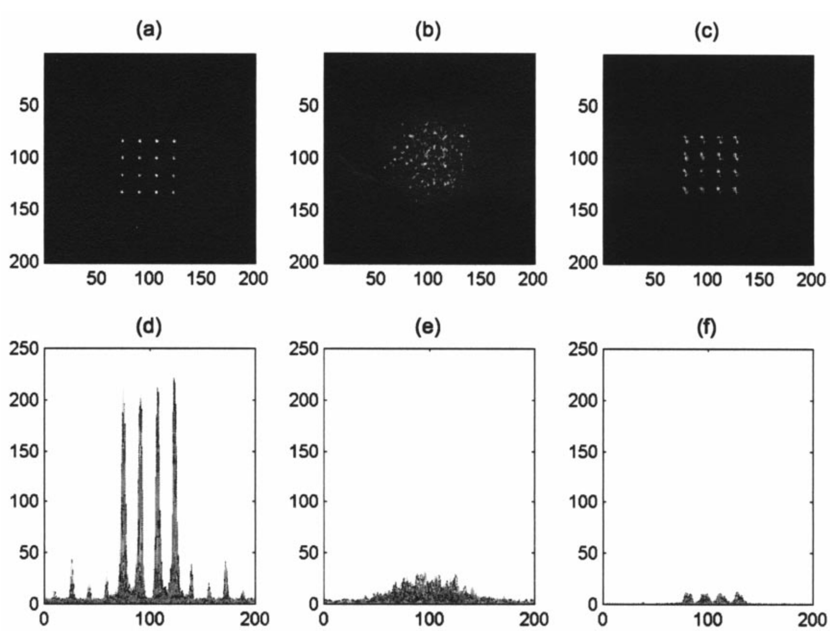

Fig. 4. (a) Image reconstructed after reflection from an optical mirror, (b) image obtained from unused punch and (c) image obtained from used punch. Bellow the images the corresponding intensity distributions (d–f) are presented. The numbers on the axes denote pixel numbers.

procedure of polishing of the flat surface from time to time while it was on use. The flatness of the used punch is relatively good. This can be deduced from the fact that the geometry of the test pattern is preserved. In the case of curvature of the punch the test pattern is distorted as described in [6]. A comparison of the intensity plots of Fig. 4e,f suggests that the reflectivity of the unused punch is somewhat higher than that of the used one.

4. Discussion

We have shown that it is possible to have a quantitative measure for the surface roughness by measuring, as a function of the angle of light incidence, the specular reflectance of laser beam from a flat punch. There are, however, some practical things that have to be taken into account. Firstly, if the inspection system is assumed to be an on-line system then a goniometric measurement is usually not possible. A better choice is e.g. a system of two lasers operating at different fixed angles. Another problem may be the change of the spectroscopic properties of the contact surface. The change may appear as dullness of the surface. This problem can be avoided by measurement of the spectral properties of dull punches and taking them into account in data analysis, which may be based on the Beckmann and Spizzichino model. In other words the apparatus has to be calibrated. It seems quite promising that the results of optical and mechanical surface roughness assessments are together in agreement

The diffractive element based sensor can be used for surface quality assessment such as mirror property or flatness inspection using image data. In addition the image data gives information about the reflectivity of the surface. Such information can be applied in the calibration of the other apparatus, which exploits specular reflectance detection of a laser beam only. The interesting result was that the quality of randomly chosen new, unused punch can be poorer than that of an old and used one. The diffractive optical element based sensor is a robust system that can be installed for off- or on-line operation.

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