Spectral Analysis of the Surface Topography of Cold Rolled Sheets Using Two Dimensional Fourier Transform

J. Zavadil[1,2], J. Valíček[1,3], M. Harničárová[4], M. Kušnerová[3], R. Grznárik[4]

[1]RMTVC, Faculty of Metallurgy and Materials Engineering,
[2]Department of Control Systems and Instrumentation,
Faculty of Mechanical Engineering,
[3] Institute of Physics, Faculty of Mining and Geology,
[4] Nanotechnology Centre,
VSB – Technical University of Ostrava, Ostrava – Poruba, Czech Republic
Email: jaromir.zavadil@vsb.cz

Abstract. *The paper provides an analysis of the surface topography of cold rolled sheets using the two-dimensional Fourier transform and methods based on digital image processing. Surface parameters of cold rolled sheets were measured using an optical profilometer and measured data were processed in MATLAB. The results from different samples have been compared and the influence of surface roughness on the calculated spectrum has been evaluated. The experiments which have been performed demonstrate the advantages of the use of two dimensional Fourier transform for the analysis of a surface topography of cold rolled sheets. Calculated spectral maps highlighted the periodicities which have not been apparent in the measured data.*

Keywords: Spectral Analysis, Fourier Transform, Surface Topography, Cold Rolling

1. Introduction

The Fourier transform is an important tool used for frequency analysis and signal filtering. Extension of the standard one dimensional Fourier transformation (1D FT) to the two dimensional Fourier transformation (2D FT) provided new possibilities of 2D data processing. When working with images, 2D FT is often used for image filtering. Contrary to the application in the field of image processing, this work uses 2D DFT for a frequency analysis of 2D data that represents a height roughness of a surface topography of cold rolled sheets. The surface analysis is an actual topic reflected in number of publications e.g. [1], [2], [3], [4]. Furthermore, between the years 2010 and 2012 first international standard for the analysis of 3D surface texture has been released. There have already been several publications focused on the spectral analysis of the surface topography. Most of the recently published works in this area end with displaying the calculated spectra as an image or in a 3D graph. In contrary, this work aims to find a relationship between the calculated spectrum and the surface quality to allow evaluation of surface topography using 2D DFT.

2. Measurement of the surface topography

Deep-drawn steel sheets KOHAL of the quality 697 were used for this experiment. The samples with dimensions 150 x 31 x 2.52 mm were rolled using a laboratory rolling mill Q110 (Fig. 1) which is placed at the VSB – Technical University of Ostrava. The surface topography of the samples was measured using optical profilometer MicroProf FRT (Fig. 2). This profilometer uses a principle of the chromatic aberration of the optical lenses (Fig. 1). Since this measurement is contactless, the measured surface is not affected.

Fig. 1. Q110 Laboratory Rolling Mill.

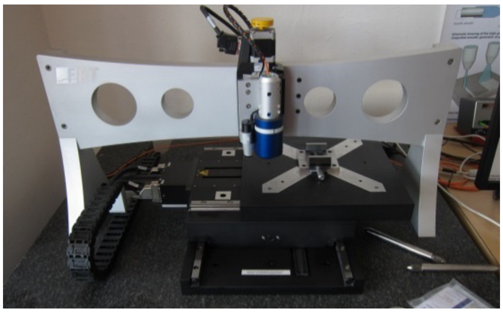


Fig. 2. MicroProf FRT.

The size of the measured surface was 5 x 5 mm and 1700 points were measured in each dimension. Data measured using this profilometer were exported and consequently processed using MATLAB. Application created in MATLAB transforms the data into a matrix consisting of height irregularities of the measured surface. These matrices are then used for spectral analysis. In the program Mark III, which is a part of the MicroProf FRT equipment, parameters *Ra*, *Rq* and *Rz* were also calculated. These parameters were compared with the results of the spectral analysis.

3. Processing of the acquired data

When performing measurements by the MicroProf profilometer, the measured head does not follow the profile of measured surface but it moves in a parallel way with the table, so the data measured can be affected by inaccurate placing of the measured sample. For this reason, it is important to calculate the mean plane. This mean plane is also suitable for reduction of the waviness of the sample after cold rolling. The Least Squares Mean Plane was used in this work. Since the samples after the cold rolling were considerably curled, the polynomial surface was used.
The n-th order polynomial surface is defined as

$$f(x,y)=\sum_{i=1}^{n}\sum_{j=1}^{i}a_{(i-j)\,j}x^{i-j}y^{i} \tag{1}$$

The sum of the surface asperity departures from this polynomial plane is

$$\varepsilon^2=\sum_{l=1}^{N}\sum_{k=1}^{M}(z(x_k,y_l)-f(x_k,y_l))^2=\sum_{l=1}^{N}\sum_{k=1}^{M}(z(x_k,y_l)-\sum_{i=1}^{n}\sum_{j=1}^{i}a_{(i-j)\,j}x^{i-j}y^{i})^2 \tag{2}$$

Polynomial surfaces from 2. order to the 4. order were tested. The best results were achieved using the 4. order polynomial surface. From this reason and also due to adequate PC performance, the 4. order polynomial surface was used for data processing in this work. There is an example of use of the mean plane in Fig. 3.

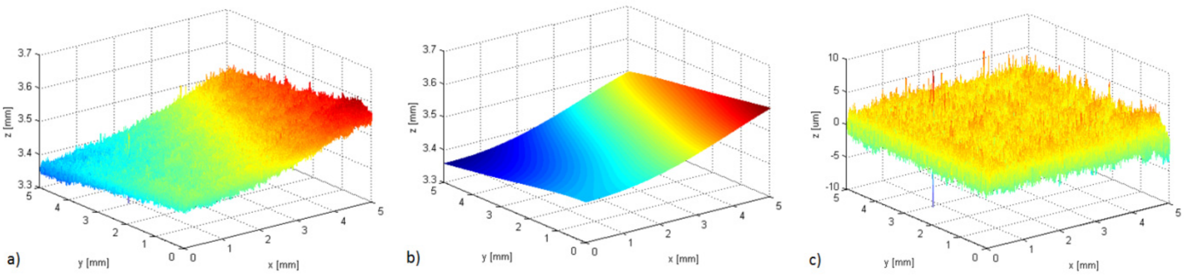


Fig. 3. An example of compensation of a surface waviness using mean plane
a) the data measured; b) 4. order polynomial mean plane; c) deviations from the mean plane

After the pre-processing of the data measured using the Least Squares Mean Plane, the frequency analysis using 2D DFT follows. The sample of data measured represented as a matrix of dimension M x N can be expressed as a function *f(x,y)* for *x* = 0,1,2,...,*M-1* a *y* = 0,1,2,..., *N-1*. 2D DFT of this function *f(x,y)* is then

$$F(u,v)=\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(u\,x/M+v\,y/N)} \tag{3}$$

for *x* = 0, 1, 2, ..., *M-1* and *y* = 0, 1, 2, ..., *N-1*. The resulting *M x N* array calculated is called a frequency rectangle. The inverse 2D DFT is given by

$$f(x,y)=\frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)e^{j2\pi(u\,x/M+v\,y/N)} \tag{4}$$

for *u* = 0, 1, 2, ..., *M-1* and *v* = 0, 1, 2, ..., *N-1*.

A result of the Fourier transform is complex even if *f(x,y)* is a real function. Therefore analysis of the result of the transform is based on computing the spectrum (magnitude of *F(u,v)*).

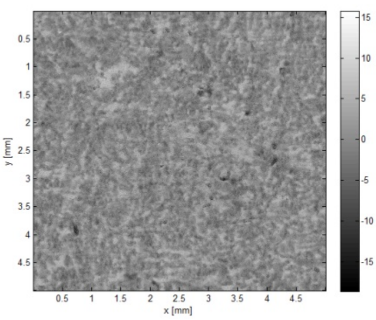
$$\left|F(u,v)\right|=\sqrt{R^2(u,v)+I^2(u,v)} \tag{5}$$

An important mathematical property of DFT is that the result of this transform is infinitely periodic. However, DFT computes only one period (array of size MxN). Fourier spectrum is symmetrical about the origin

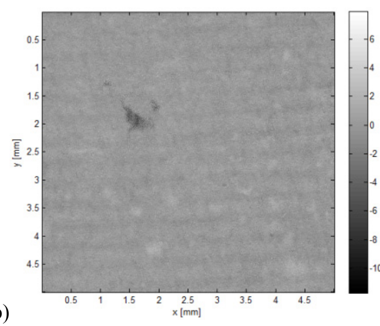
$$\left|F(u,v)\right|=\left|F(-u,-v)\right| \tag{6}$$

4. Results

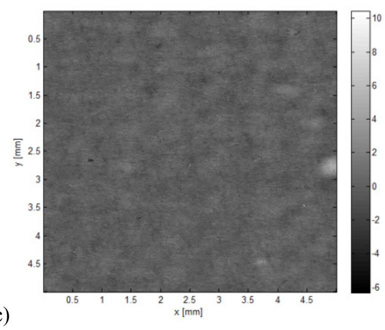
In the calculated spectra, it is possible to examine the changes in the surface topography caused by cold rolling (Fig. 4), first capture shows an image of the original surface of the sample before rolling (Fig. 4a). From the result of the Fourier transform of this data homogeneity of the surface is apparent which led to the homogeneous spectral map (Fig. 4d). In the next figure (Fig. 4b) it is possible to see a thin horizontal stripes created by rolling of the material. These periodic stripes cause stripes in the calculated spectral map (Fig. 4e). The stripes in the calculated spectral map are orthogonal to the stripes in the original image. In the spectral map periodicities in the surface topography are highlighted. Also in the Fig. 4f the change in the spectrum can be seen.



a)



b)



c)

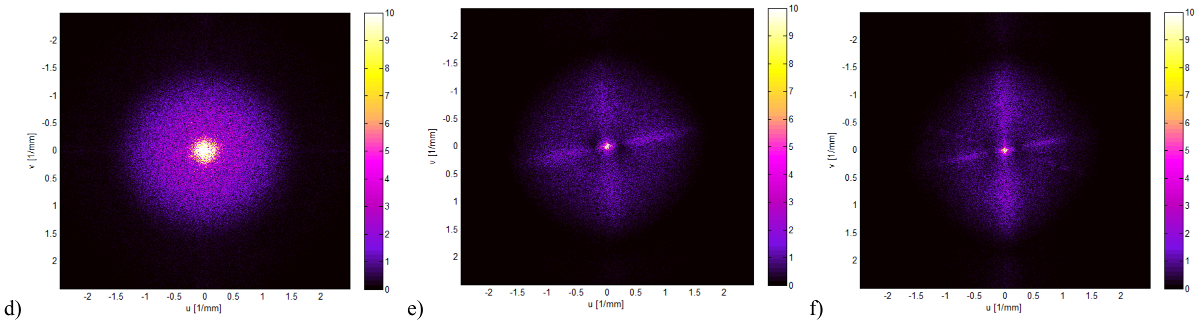


Fig. 4. An example of images of surfaces and the spectral maps calculated
a) an image of the original surface of the sample before rolling; b) the image of the surface of the sample after rolling with absolute drafting 1.2mm; c) the image of the surface of the sample after rolling with absolute drafting 1.98mm; d) the calculated spectral map of the original surface of the sample before rolling; e) the calculated spectral map of the surface of the sample after rolling with absolute drafting 1.2mm; f) the calculated spectral map of the surface of the sample after rolling with absolute drafting 1.98mm;

5. Conclusions

Experiments performed demonstrate the advantages of use of two dimensional Fourier transform for the analysis of a surface topography of cold rolled sheets. Calculated spectral maps highlighted the periodicities which were not so apparent in the measured data. Cold rolling creates marks on the surface of the material, which represent periodicities that can be effectively detected by 2D Fourier transform. Design of an algorithm for automatic evaluation of the surface quality of cold rolled sheets is the subject of the next research.

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