Distribution of magnetic field intensity on surface of ferromagnetic specimen with specimen getting thinner

V Yu Pivovarov and I R Kuzeyev
Process Machinery and Equipment Department, Ufa State Petroleum Technological University, Ufa, Russian Federation

Abstract. Contemporary achievements of the physics of surfaces allow to define dramatic differences between the surface layers and the underneath part of the same material. Even though there is a wide range of test methods and scientific findings, so far all the peculiarities of the surface phenomena have not been figured out. The article considers a hypothesis of the surface layer fractal structure. The hypothesis is based on the fact that the transition from a 3D plane to a 2D plane happens through a number of intermediary structures (transition or small-fraction layer). In order to check this hypothesis, we carried out an experiment aimed at studying the intensity of the magnetic field of a ferromagnetic specimen with the specimen getting thinner. The idea of the experiment was in the assumption that if the specimen has a certain thickness the surface layers will become comparable with the underneath material and this will influence the way the magnetic field intensity changes. The conducted measurements allowed to build a correlation between the magnetic field intensity components and the specimen thickness. The measurements showed that the thinner the specimen is, the ‘closer’ the correlation is. These findings display how the small fraction layer reacts to the change of the underneath material. This confirms it is possible to obtain information about the state of the structural material underneath by measuring the surface properties.

1. Introduction
For a long while the physics of surface has been an independent science thanks to fundamental researches launched as early as in the 18th century. The findings of previous and contemporary researches in this field claim that the surface and the underneath material of the same body can differ according to the organisation structure principle [1-5].

It means that solid bodies including metals have their substance atoms located in conformity with one of the 16th Bravais cells. At the same time the surface layers in the same conditions can have other structures. Studying surface structures of various materials with various crystal lattice orientation showed that there are two big groups of crystals [6].

The work’s [4] authors specify a peculiar influence and a special role of the surface layers in the entire process of macroplastic deformation of metal systems, when it comes to static brittle fracture, fatigue breakdown, creeping, recrystallizing, friction and wear related to the peculiarities of the plastic yielding in the subsurface layers.

Currently there is a huge number of various methods aimed at studying surfaces [7-8]. Despite of this, however, there is no in-depth understanding of all the peculiarities of the surface phenomena. That's why it's impossible to surely predict surface layers properties and tendencies in their change.
One of the options to describe the surface layers is to deal with their fractal structure. This hypothesis is based on the fact that the transition from the 3D structure to the 2D structure shall be carried out through a range of intermediate structures. Otherwise the surface layers won't have the associated properties.

The reason why there is a transition (small fraction) layer is provided by the findings outlined in the work [12]. The work’s authors claim that a 3-5 mcm deep metal surface layer is a traditional feature of the researched object. This layer displays where and under what conditions the object was operated, what is the wear degree, what is the remaining lifetime, etc. In other words, the surface can accumulate information about all the impacts like annual rings in the tree trunk.

It’s possible to read the information about the structural material condition without destroying the surface layer. It will take recording physical waves, for example sound waves or electromagnetic waves. There was an experiment that aimed to test the hypothesis about the metal transition layer. The experiment studied the magnetic field intensity distribution on the ferromagnetic specimen surface. This specimen was cut out of a sheet rolled metal and had an increasing thickness.

2. Experiment Procedure and Findings
The experiment was split in two stages. In the first stage the researchers studied how the surface roughness influenced the magnetic field intensity. The second stage was dedicated directly to the experiment aimed at studying the specimen’s magnetic characteristics along with the specimen getting thinner.

To implement the first stage, the researchers prepared a specimen out of a sheet ferromagnetic steel 09Г2С and divided it into 6 approximate areas. They used abrasive sheets to create various degrees of specimen surface roughness and measured it with TR200.

The magnetic field intensity was measured with IKN-2M-8. This instrument uses metal magnetic memory method. This method is based on macro-effects caused by interconnections and indirect interactions of power fields with electromagnetic fields of microparticles which subsequently form an atom, the elementary cell of the crystal lattice, domains or groups of domains, if the crystal lattice is imperfect [13].

IKN-2M-8 measuring sensor was secured on a tripod; the plate was attached to the sensor. With every measuring the plate, the sensor and the tripod had the same space orientation.

The analysis of the findings showed that the magnetic field intensity in every of the specimen’s six areas does not change drastically, if the surface roughness changes. The figure 1 shows an example of how the tangential component of the magnetic field intensity depends on the surface roughness.

![Figure 1. Tangential component of the magnetic field intensity depending on the surface roughness.](attachment:image.png)
The work [14] determined fractal characteristics of the relief at the different scale levels. When it comes to fatigue loading the relief was majorly changed at a nanoscale level with the fracture degree interval \( N_i/N_p = 0.0\div0.4 \), where \( N_i \) is the current number of cycles, \( N_p \) is the number of cycles before the breakdown. With regards to the fact that the experiment specimen material was under delivery and never experienced external impact it’s fracture degree can be considered as \( N_i/N_p = 0 \). In the work the surface roughness was measured [15] at the macrolevel according to the standard algorithm. Therefore, when the roughness changes at this level of scale, the magnetic field intensity hardly varies.

The second stage used the specimen which was a 40x40x2 mm plate cut out of the same sheet as the specimen used in the first stage. They used a layer-by-layer publishing to scrub the face of the plate. The flip side of the plate remained untouched.

One-sided impact on the specimen surface is justified with the idea of the experiment. The correlation between the surface and the underneath as the specimen gets thinner; the small fraction layers of the specimen opposite edges are getting closer. When the plate has a certain thickness, the surface layers become comparable to the underneath material, which makes it possible to define, when the transition layers start to interact directly through changing the magnetic field intensity distribution.

Each side of the plate was divided into 9 cells (figure 2). In these cells the intensity was measured in the initial condition and every time when the plate thickness was declined by 0.1 mm. The cells dimensions were chosen to make the sensor completely fit in the cell. The magnetic field intensity measuring method matched the one of the first stage.

![Figure 2. Dividing the plate into a metering points. a) face side; b) flip side.](image)

The points are marked in order to make point 1 on the one side match point 11 on the flip side, to make point 2 on one side match point 12 on the flip side. Moreover, all the points were divided into three groups:

- corner points (1-11, 3-13, 7-17, 9-19);
- edge points (2-12, 4-14, 6-16, 8-18);
- central points (5-15).

The points were divided into groups in order to detect if being on the edge influences the magnetic field intensity measuring results.

The conducted measurements allowed to build the correlation between the normal component and the tangential component. They also allowed to build the correlation between the magnetic field intensity and the plate thickness with regards to the groups of points. The figure 3 shows the correlations of the tangential component of the magnetic field.
Figure 3. The way the tangential component of the magnetic field intensity depends on the plate face side thickness with regards to the group of points (a – corner points, b – edge points, c – central point).

If you analyse the correlation in the figure 3, you can see that the range for the corner points’ field is bigger, than the one in the edge points. The same trend works for the normal component, which effects the magnetic field intensity. These findings prove that the edge conditions should be taken into account during experiments. Even though the outcomes differ in different groups of points, the magnetic field intensity values tend to align in every point of the plate along with the plate getting thinner. Based on
these findings we can conclude that the structural material becomes more homogeneous from the intensity concentration point of view [16]. The plate was thinned manually, that’s why its thickness declined from 2.0 to 0.2 mm. Further surface polishing doesn’t allow to make the plate thinner with the applied method. Electrochemical polishing may allow to thin the plate and make it reach the thickness of 10-20 mcm this will allow to assess the electromagnetic field changes, when the small fraction layers of the materials are critically close to one another from both sides of the plate. The obtained findings generally confirm the hypothesis that as long as the underneath part of the specimen material is declining, the surface layers properties start to prevail.

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