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Magnetometric new generation device for determination of the operability of metal structures

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Summary. The basic principles of creation of the magnetometric device for determination of the operability of metal structures on the basis of the definition of the level of the fatigue damages are stated. The main requirements to the device are written, the choice of all the units of the device is proved, the principle of its work is described and the flow chart is given. Preliminary results of the device usage are presented. The visualization principles of the measurement results for an operating control on the measurement results are described

Key words: fatigue damages, magnetic properties, device, knots, visualization.

INTRODUCTION

The reason for the destruction of the most metal structures is accumulation of a certain level of fatigue damages. At the initial stage these microdamages can accumulate for quite a long time, and then the destruction goes promptly. The main reason for fatigue damage is exhaustion of metal plasticity in the places where plastical deformation locally takes place. Special danger of fatigue failure is that often from the outside there are no signs of this process and the transition of a structure to the stage which is directly preceding destruction can't be determined by visual examination [1].

For the determination of operability of structures there are a number of ways and devices for detection of the various macro - and microdefects, but the definition of the fatigue damage is not discovered well [2-5]. One of the possible ways for the solution of this task is the definition of metal magnetic properties changes inthe places where there is a plastical deformation and measurements on the basis of magnetic properties changes of the deformation level and structure operability from the point of fatigue damages accumulation.

The aim of this article is to form the general requirements to the new generation magnetometric device (MD) for determination of the operability of metal structures on the basis of ideas about the fatigue damage mechanism and practice of the nondestructive control devices usage.

MATERIALS AND METHODS

It is known that ferromagnetic materials which the majority of metal structures are made of change greatly their magnetic properties under the influence of plastical deformation [6-8]. Plastical deformation leads to the decrease of magnetic capacity and to the increase of coercive forcefor various magnetic steel [9].

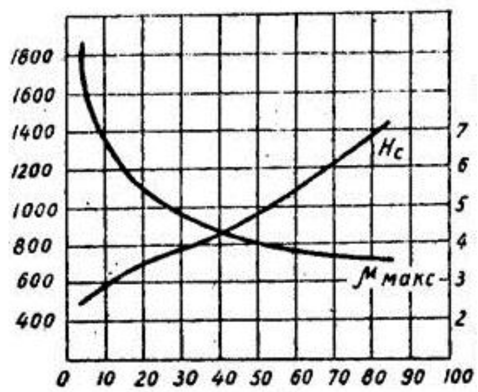

Fig. 1. Dependence of magnetic parameters of ferromagnetic material on the degree of reduction [9]

Therefore, the places with methane volumes that were deformed are magnetized by external magnetic fields worse, in comparison with metal, which is in the starting state. Existence of micro cracks, even the small ones and in small quantity also influences on the magnetization ability towards its decrease.

As the real metal structure during its production and operation is always under the influence of external magnetic fields (the Earth field, fields from electric motors, electric devices, electric wires, etc.), it receives residual magnetization and the magnetic field near a structure surface significantly differs from a background magnetic field.

The operation of the offered MD is based on the measurement of a magnetic field on a metal structure surface and further processing of the received figures. The measurement method of a magnetic field on a real structure taking into account inequality of its magnetization and a method of processing of the obtained data goes beyond this article. Here we will consider only principle basics of the creation of the MD and we will formulate the requirements to its main units.

RESULTS

Any device in general consists of a sensitive element (sensor), a signal processor, an indicator, the power supply (if necessary) and data line.

The modern trend of tool engineering development is the usage of digital sensors which are more protected from electromagnetic noise, are less in size and less energy-intensive. Besides, digital means of processing and representation of measurement results are well combined with them.

From the point of operation convenience of the MD, it is necessary to reach the smallest sizes and weight, good protection from atmospheric action, long time of autonomous work and simplicity in the device control. During the MD usage for examination of bridges, platforms, towers and other industrial facilities the work of the operator at height and in an uncomfortable position is a daily routine therefore the requirements to the size, weight and other ergonomic indicators are the most important. The aim is in the device creation which will be identical in size and weight to the modern mobile phone.

So it was decided to build the device on the basis of a universal board Arduino Nano 3.0 having small size and weight:

Table 1. Main characteristics of Arduino Nano 3.0

Characteristics	Value
Type of microcontroller	ATmega328
Voltage supply	7 – 12 W
The number of numerical inputs/ outputs	14 (6 PWM)
Flash-memory	32 kW (2 are used by the loader)
SRAM	2 kW
EEPROM	2 kW
The type of the external interface	Mini-B USB
Clock rate	16 MHz
Board size	18,5x43x8(18) mm *
Weight	5,75 g

Note: * - from this point and onward in brackets the size is according to the bonding pads which if necessary can be removed

Table 2. Characteristics of HMC5883L

Characteristics	Value
Measurement range	± 1,3 – 8 gauss (is soft defined)
Accuracy	5 milligauss
Supply	3,3 – 3,6 W (power supply from the board stabilizer is possible)
Board size	14x13x3(13) mm
Weight (with a bonding pad)	1,1 g
Number of the used inputs	2

As the sensor HMC5883L is chosen which represents the magnetometer with measurement possibility of intensity of a magnetic field on 3 axes. The sensor uses magneto-resistive effect, gives good results in determination of constant magnetic fields, or such which slowly change.

As for signal processing the usage of powerful mathematical apparatus is planned, the personal computer, or a laptop, with the specially installed program are necessary components of the device. The task of the program is identification of the received nonuniformity of a magnetic field near a metal structure surface.

The offered board, as well as any close in the size microcontrollers, isn't capable to carry out such volume of calculations, and the volume of own memory doesn't allow to hold the necessary data volume. Therefore there is a problem of the saving on the separate carrier or results transferring on the basic computer (BC) on-line. Ideally these two processes are to happen simultaneously.

It is also necessary to transfer quickly measurement results to the indicator located in the MD for definition of failures in work, and for the preliminary estimate of research results.

Nokia 5110 LCD has the most acceptable characteristics from the point of Weight / Energy consumption / Presentation, so its module is offered to be used as an indicator.

Table 3. Main characteristics of Nokia 5110

Characteristics	Value
Supply	3,3 W (power supply from the board stabilizer is possible)
Lightning	Yes
Colour	monochromatics
Extension	84x48 px
Data-transfer rate	Up to 4Mbit/s
Size	43x45x4(14) mm
Weight	13,85 g
The number of used inputs/ outputs	5

The MD control elements consist of 1 switch, including screen lightning he and not less than 2 Switch on / Switch Off and Measurements buttons.

The possible decisions for expansion of own memory of the MD can be the module for application SD or Micro - SD - cards. The Micro module - SD - cards, was chosen as its size and weights about two thirds the size of the module for SD memory cards.

Table 4. Main characteristics of the module micro-SD-card

Characteristics	Value
Supply	3 - 5W (power supply from the board stabilizer is possible)
Card support	micro-SD/TF
Size	24x41(45)x3(6) mm
Weight	5,75 г (without a card)
The number of used inputs/ outputs	4

For the organization of a radio communication for the data transmission from the PC to the BC on-line the usage of radio - NRF24L01 modules, or all modules, realizing VirtualWire is offered. Range of operation of such modules is 100-150 m in the open space and it has to be quite enough. In the cases when distance from the MD to the BC has to be more, other modules can be used, but they demand more difficult control and more powerful supply.

Table 5. Main characteristics of the radio module NRF24L01

Characteristics	Value
Supply	1,8-3,6 B (power supply from the board stabilizer is possible)
Frequence:	2.4GHz
Data-transfer rate:	500 Kb/s, 1Mb/s, 2Mb/s
Operating range:	about 100m
Size	12x17x2,5 mm (without an external antenna)
Wight	0,55 g (without an external antenna)
The number of used inputs/ outputs	6

For comparison we will give the characteristics of the radio module of the FS1000A transmitter which realizes VirtualWire. The characteristics of the receiver are less important because it will be installed next to the BC, but not built in the MD.

Table 6. Main characteristics of the radio module FS1000A

Characteristics	Value
Supply	3-12 W (the more voltage is, the more distance of commection will be)
Frequence:	433 kHz
Operating range:	Up to 150 m
Size	19x19(25)x5(7) mm
Weight	2,42 g
The number of used inputs/ outputs	1

As we can see the first module has an advantage in weight and size, but considerably loses because of the bigger quantity of the used inputs and outputs. But the key problem is the sufficient data-transfer rate and reliability of communications which can be defined only by a complex test. Therefore the problem of a radio module which will be used in the MD is still open.

The flow chart of the device looks like this (Fig. 2).

The number of the used inputs /outputs totally makes 17 during the usage of the radio module NRF24L01 and makes 12 during the usage of the radio module FS1000A. If there are 14 outputs in the board the first variant demands the additional “extender of inputs” that will lead to decrease in information processing rate, the increase of the needed supply power, size and weight. But again it should be noted that the problem of the radio channel organization demands a separate research, as well as a power supply choice for the MD.

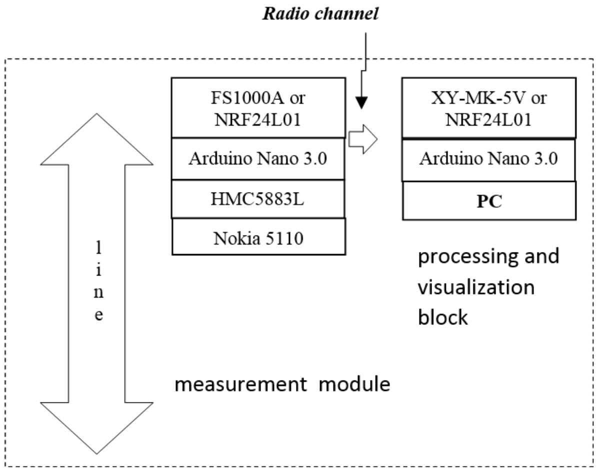

Fig. 2. Flow chart of the MD

On fig. 3, 4 there are the measuring module and the receiver of a radio channel connected to the laptop set up on the model boards.

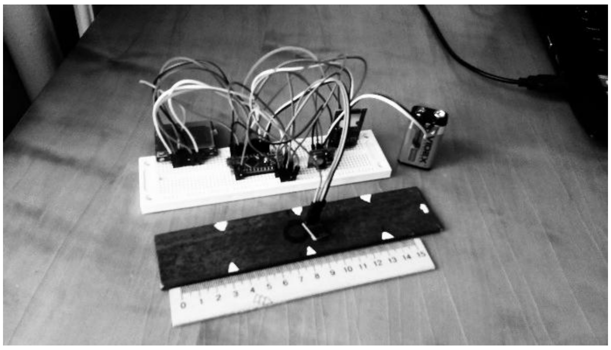

Fig. 3. The measuring block setup on the model board

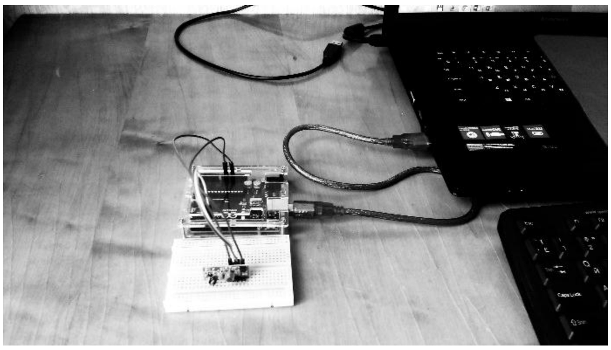

Fig. 4. The radio channel receiver connected to the laptop

Power supply of the measuring block is temporarily organized from the battery 6F22. Finally, the choice of the power supply will be made after test operation.

Preliminary testing results of the HMC5883L sensor together with Arduino Uno board and magnetic field measurements per samples allowed to reveal the following features. At the installation of the maximum sensitivity sensor “overswing” on the much magnetized places is possible. But such places on real structures can be only single ones and their demagnetization and magnetic reversal are carried out very easily.

The distance from a structure surface significantly influences on the sensor sensitivity. At the distance of 1 mm from a surface the sensor registers anomalies of a magnetic field as a result of deformation on a reverse side of a plate 4 mm thick. It allows to draw a conclusion that oxidizing films and paint coatings which don't contain ferromagnetic parts significantly won't influence on the research results.

Because of the high sensor sensitivity, and dependence of the research results on the distance to a surface, it is desirable to keep a constant tilt angle of the sensor and the minimum distance from a structure surface during the testing. It was decided by creation of a mounting pad. The board of the sensor was filled in with epoxy for the best isolation from undesirable influences of the atmosphere (moisture, dust, mechanical influences). A model sample which is used for preliminary testing of the MD is on Fig. 5.

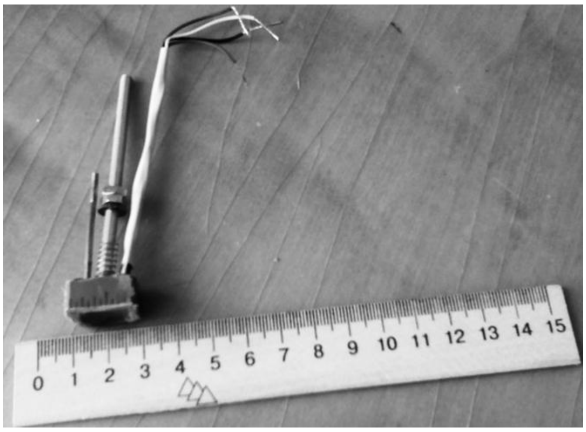

Fig. 5. A mounting pad of the sensor with clamping devices

It is offered to add the research directed sensor axis X along a longitudinal axis of the structure element, or other axis, which is easily defined for “correlation” of the research results to a concrete structure point. The testing is conducted, leaning with a pad on a surface and smoothly with a constant speed moving it along the studied place. During testing of the plane the lines pitch has to be 5 mm that provides reliable overlapping of all the places.

The minimum time between sensors' scanning is 60 ms that gives the chance to receive 16 values of a magnetic field in a second. At motion speed about 5 mm /s we receive too high accuracy of the research because the single defect influences on a magnetic field in a radius of 1-2 mm. So, it is potentially possible either to reduce the frequency of sensors scanning, or to have more data for statistical processing.

As a result of data readout from the sensor we receive a number of values of conditional intensity of a magnetic field on axes X, Y, Z. The format of values is integer and it demands 16 bits = 2 bytes for storage, so 6 bytes are necessary for research results fixing. If we examine the sensor with the maximum frequency data-transfer rate has to be not less than 32 bytes / s. The radio channel and record on the SD card rate practically much exceeds these values. Capacity of modern SD cards allows to store hours of continuous measurements, even taking into account that additional information for identification of files, zones of testing, date, testing time and so forth will be necessary.

Therefore it is possible to consider that at the chosen configuration neither the line nor the processor, neither a radio channel, nor the ROM isn't “a weak link” of the MD. And in general the MD parameters are optimum.

Another important problem is the MD interface and information displayed for the user during the work.

Critical for the user is data about necessary supply characteristics, normal operation of the sensor, the radio channel and the ROM. It can be shown on the display in the form of text messages, or in the form of pictograms pressing the corresponding button. In this article we won't consider various service functions, and we will concentrate only on the information from the sensor, that has to be shown on the display of the measuring module.

For convenient operation the user has to have at least superficial idea about the characteristics which he is measuring now. As it was described above the information from the sensor represents a set of the integers characterizing a magnetic field near a structure surface. At a measuring rate of 16 figures / s it is impossible to trace visually the changes of absolute values. Even if we take values with a smaller frequency, there is a problem of a figure choice for output (one figure per second, so 1 of 16 or the average value of some period, or mathematical expectation, etc.). The choice is rather unevident. Besides, data presentation in a graphic form is more informative.

Therefore we made the decision to visualize the research results for a certain period in the form of the diagram / line chart on the measuring block display.

We made the decision to reorganize the chart line every 5 seconds that will allow to receive data about the last 80 measurements, or at the rate of 5 mm / with 25 mm from the surface.

Preliminary data processing for their bigger visualization is also expedient.

For example, the value from the sensor on axes X and Y is given on Fig. 6 are not really informative. Even the addition of the line, which illustrates the position of average value, doesnot help. The different size of the measured value must be also considered that places inconveniently all three line charts on the axes.

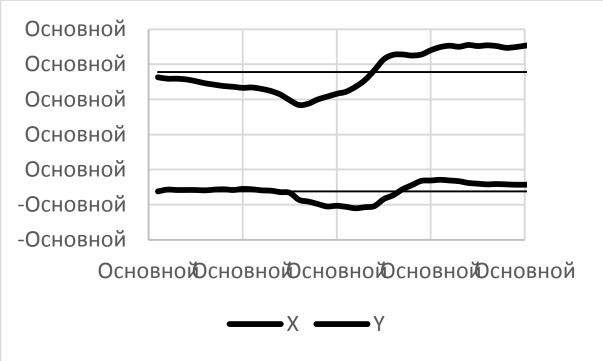

Fig. 6.The line chart of magnetic field change in the strain-hardening range

Therefore we decided to use rated values (Fig. 7) for displaying because usually we are interested in a deviation from the average value, but not an absolute value of the magnetic field intensity.

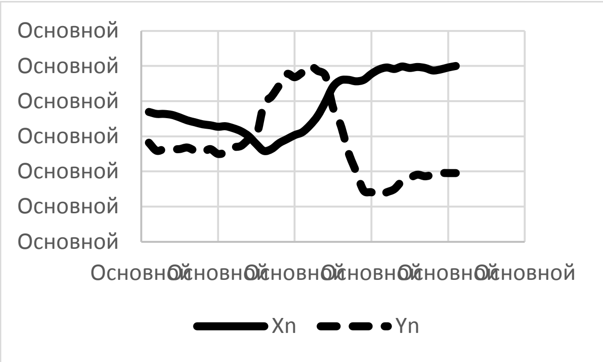

Fig. 7.Reflection of the rated values with the same data, as in Fig. 6

As we can see, anomalies are shown more visually. It should be noted that all these transformations demand computing resources which significantly depend on the chosen processing algorithms, but are a priori limited with controller opportunities. Therefore a final conclusion about application of the chosen way of visualization will be made according to the results of the device testing on samples and real structures.

CONCLUSIONS

The main requirements to the magnetometric device for determination of the operability of metal structures are established. The configuration and blocks which are its part are chosen. It is defined that the chosen structure and device components fit the research requirements, blocks are compatible and the system has no “weak links”. According to the test results of a device model sample, the display way, optimum in informational content, of the research results of metal structures, on the measuring block is established. The problem of parameters of a radio channel, power supplies and service functions demand additional research.

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МАГНИТОМЕТРИЧЕСКИЙ ПРИБОР НОВОГО ПОКОЛЕНИЯ ДЛЯ ОПРЕДЕЛЕНИЯ РАБОТОСПОСОБНОСТИ МЕТАЛЛОКОНСТРУКЦИЙ

Д. Марченко, А. Жидков

Аннотация. Сформулированы основные принципы создания магнитометрического прибора для определения работоспособности металлоконструкций на основе измерения уровня усталостных повреждений. Определены основные требования к прибору, обоснован выбор всех его блоков, описан принцип его работы и устройство. Представлены предварительные результаты использования прибора. Описаны принципы визуализации результатов измерений для оперативного управления на основе испытаний.

Ключевые слова: усталостные повреждения, магнитные свойства, устройство, узлы, визуализация.