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Data science approaches to diagnostics of metal stress-strain state using semiconductor sensor suitable for system design

Przydatne dla zbioru danych naukowych i projektowania systemowego diagnozowanie stanu naprężenia - odkształcenia w metalach za pomocą sensorów półprzewodnikowych

ABSTRACT

Article describes the data science approaches to diagnostics of metal stress-strain state using semiconductor sensor suitable for system design. It has been described the elongation curves (on permanent loading 370-450 MPa) in time of St3 (kp, sp) specimens in initial state, after treatment in He and H_2 with pressure 35 MPa and temperature 623 K during 10 hours as well as a curves of the average signal of semiconductor sensors that controls this process and spectral sensitivity of the semiconductor sensors of the visible range depending on the time of the exposure of the samples.

Keywords: *diagnostics, stress - strain state, semiconductor sensor, data science, system design*

STRESZCZENIE

W artykule pokazano możliwość diagnozowania stanu naprężenia-odkształcenia w metalach za pomocą sensorów półprzewodnikowych, przydatne dla zbioru danych naukowych i projektowania systemowego. Przedstawiono krzywe wydłużenia (przy stałym naprężeniu 370-450 MPa) w czasie próbek ze stali St3 (kp, sp) w stanie wejściowym, po obrobce w He i w H_2 z ciśnieniem 35 MPa przy temperaturze 623 K w ciągu 10 godz., a także krzywe średniego sygnału sensora półprzewodnikowego, który obserwuje ten proces i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego w zależności od czasu ekspozycji próbek.

Słowa kluczowe: *diagnostyka, stan naprężenia-odkształcenia, sensor półprzewodnikowy, zbiór danych naukowych, projektowanie systemowe*

1. Introduction

Among the well known physical registration methods of the stress-strain state of the metal in aggresive environment (for example – in hydrogen) it can be consider the method, in which used semiconductor sensors [1-3], partially – a procedure of energy release during strain and fracture [3] (is one of the wide used methods of modern investigations). Using the calorimetric infra red (IR) tests it can be directly determine the energy of formation and study the kinetics of structural defects relaxations [3]. Among the frequency ranges used in different methods of non-destructive testing [4 - 7] are UV+HUV→V→IR. A lot of sensors in visible range (V) permit more deep investigation of the physical nature of the phenomenon. Life time prediction of technological equipments large parts based on the theory of solid state physics is not sufficient due to lack of communication between quality (crystal lattice etc.) and quantity (structure of the phase-part geometry) description of the process of degradation of the metal under the influence of external forces and aggressive environments (including hydrogen). Determining the degree of degradation is possible by controlling the size of the internal energy of the metal. Measurements of the integral value of the internal energy of the metal causes a number of technical difficulties.

The proposed approach to the definition of life time large parts during the operation of the existing equipment and techniques details practically possible. Given the high level of stored energy in the metal, it can be assumed that the changes at this level under the influence of external forces and environmentas should cause a disturbance.

2. Experimental procedure and materials

To detect the changes of metal stress-strain state during the deformation were used microsamples with working part 5x2x1 mm of St-3 (kp or sp) material (C – 0,14-0,22%, Si – 0,05-0,17%, Mn – 0,4-0,65%, Ni, Cu, Cr – up to 0,3% , As up to 0,08%, P,S up to 05 and 0,04% wt.%, Fe – balance) (analogue of this materials in different country has presented in Table 1), which is subjected to a uniaxial tension (420 MPa) (with an acceptable 370-450 MPa). This materials is wide used for prodused of hydrogen tanks and demonstrated degradation after long term service [4].

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Control of the extension of the sample was carried out with an accuracy of 0.01 mm. The intervals between measurements were 1 second. For registration of stretching process has used the semiconductor "p-n" structure responsive to energy in the range of 9 to 10 degrees up to 12 Hz. Spectra sensitivity of a semiconductor sensors of visible range (with maximum of spectra characteristics 610-580, 600-480 nm with corresponding limit of red sensitivity, maximum quantum issue 25…30 %, maximum sensitivity 300 mkA/Lm and detsity of current emmision 10-15 A/cm^2) [2]. The resulting signal was taken as the voltage having the amplitude-frequency dependence (10^9…10^{12} Hz) of the metal deformation in the process of stretching. Semiconductor sensor has received the different spectral sensitivity, shielding from electromagnetic effects, including visible light (at a distance of 50-100 mm from the sample).

Tab. 1. The steel St-3 and its analoque in different country
Tab. 1. Stal St-3 i jej analogi w rożnych krajach

Ukraine	St-3kp (specimen serie 1)	St-3sp (specimen serie 2)
AISI, ASTM, ASME (USA)	USt 37-2, USt 37-2 G, RSt37-2	A414 Grade A, A570 Grade 36
EU	Fe37-3FN, Fe37-3FU, Fe37B1FN, Fe37B1FU, Fe37B3FN, Fe37B3FU, S235, S235J0, S235J2G3, S235JR, S235JRG2	-
PN (Polska)	St3S, St3SX, St3V, St3W	-
DIN (Germany)	USt 37-2, USt 37-2 G, RSt37-2	S235JG3/Fe360 D1, St 37-3, UZSt 37-2
JIS (Japan)	-	SS 34
GB (China)	A3, Q23A, Q23A-F, Q235A- F, Q235A-Z, Q23A-b	-
B.S. (Great Britain)	-	HS 37/23, S 235J2G3, 40C, BS4360
UNI (Italy)	-	S235J2G3

3. Results and discussions

It is well known that system design is an interdisciplinary direction and methodology for constructing intellectual environments designed to solve scientific and practical tasks of optimizing the life cycle of complex systems of various nature using resource-intensive computer technologies and expert analysis [8-10]. From this point of view General Electric Co now has developed a concept how artificial intelligence can be used in power networks and energy production. This technology will save the costs thanks to increasing energy efficiency. The technology that GE now operates will be able to optimize the flow of current in storage devices such as batteries and power consumption points. This will significantly improve the efficiency of the energy system. Digitization concerns both power stations long term exploitation and life time extantion [8-10]. On the other hand exist an algoritm for Ground plane estimation from spare LIDAR data for loader crane sensor fusion system [8]. In this paper it has ben proposed algorithm allows for accurate filtration of ground points from the cloud of points in real time [8].

The semiconductor structure responds to the energy processes occurring in the metal. The coefficient of energy conversion in the semiconductor by the above processes requires further investigation [2]. Given the spectral selectivity of the semiconductor and the wavelength emitted from the metal in the excited state, it can be assumed that in the zone of plastic deformation and cracking possible registers with the release of energy in the visible, UV, IR ranges. Deformation causes the moving dislocations, defects, and phase change has reflected in the various part of the spectrum [1]. Deformed state of metal can be described by the amplitude-frequency characteristics (AFC) depending on the chemical composition of the material and the amount of strain accumulated during operation. Dynamics of changes in the frequency response allows to predict the residual life and highlight the pre-emergency status of the items.

It has been presented the elongation curves (on permanent loading 370-450 MPa) in time of St3 (kp, sp) specimens in initial state, after treatment in He and H_2 with pressure 35 MPa and temperature 623 K during 10 hours as well as a curves of the average signal of semiconductor sensors that controls this process and spectral sensitivity of the semiconductor sensors of the visible range depending on the time of the exposure of the samples (Fig. 1-6), which demonstrated the diffferet effect of the environment (increasing from low to high aggressivity) s on the characters of average signals after accurate filtration.

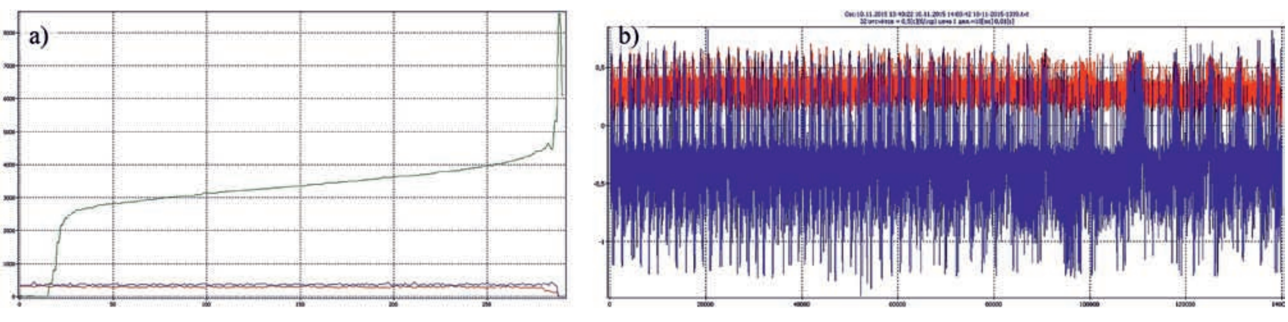

Fig. 1. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 kp specimen 15x2x1 mm in initial state. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples in the initial state under the load, realized on the sample of the series1 in the air (b).

Rys. 1. Krzywe wydłużenia (przy stalym naprężeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 kp 15x2x1 mm w stanie wejsciowym. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna krzywa) nm) w zaleznosci od czasu ekspozycji probki w stanie wyjsciowym pod naprezeniem, zrealizowanym na probkach serii1 na powietrzu (b).

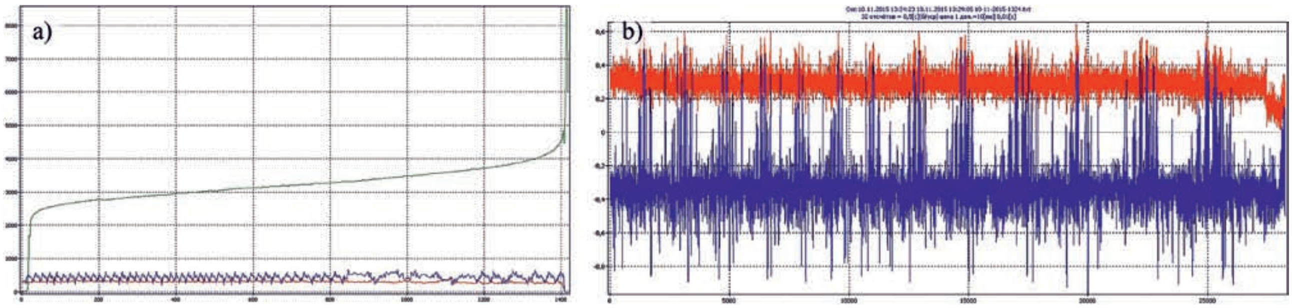

Fig. 2. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 kp specimen 15x2x1 mm after treatment in He with pressure 35 MPa and temperature 623 K during 10 hours. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples of the series1 (b).

Rys. 2. Krzywe wydłużenia (przy stalym naprezeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 kp 15x2x1 mm po obrobce w He z cisnieniem 35 MPa przy temperaturze 623 K w ciągu 10 godz. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna rrzywa) nm) w zaleznosci od czasu ekspozycji probek serii 1 (b).

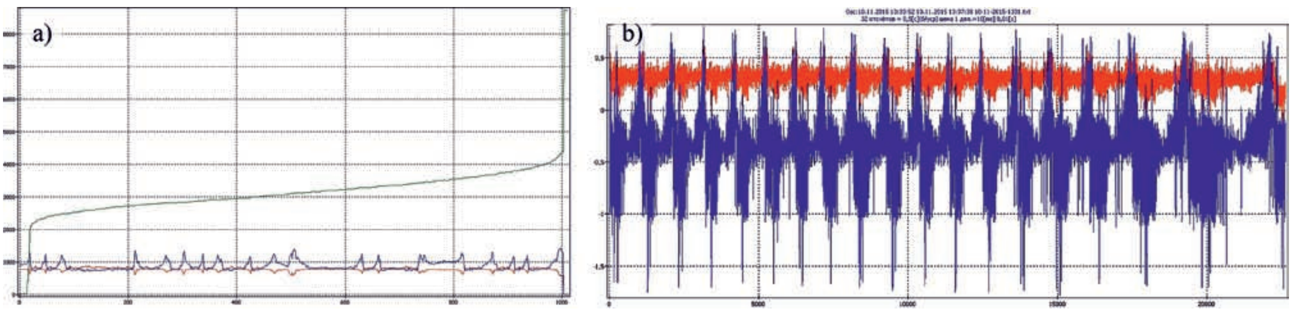

Fig. 3. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 kp specimen 15x2x1 mm after hydrogenetion in gaseous H_2 with pressure 35 MPa and temperature 623 K during 10 hours. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples of the series 1 (b).

Rys. 3. Krzywe wydłużenia (przy stalym naprezeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 kp 15x2x1 mm po nawodrorowaniu w H_2 z cisnieniem 35 MPa przy temperaturze 623 K w ciągu 10 godz. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna rrzywa) nm) w zaleznosci od czasu ekspozycji probek serii 1 (b).

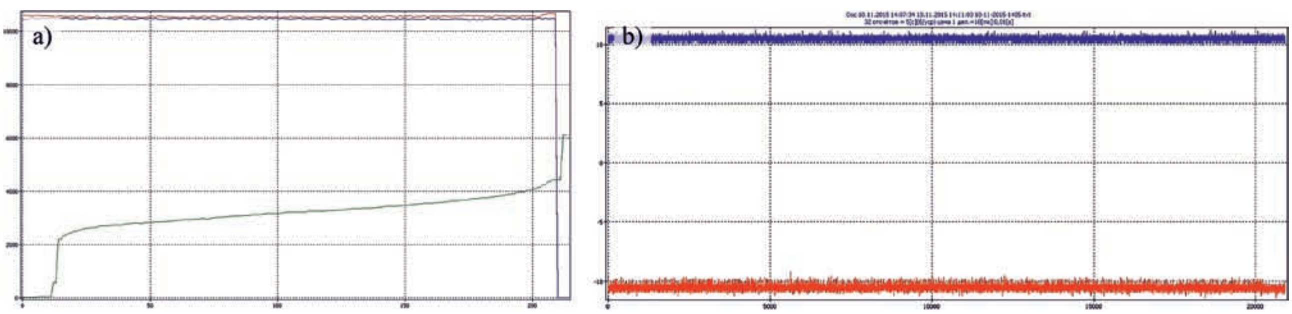

Fig. 4. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 sp specimen 15x2x1 mm in initial state. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples in the initial state under the load, realized on the sample of the series2 in the air (b).

Rys. 4. Krzywe wydłużenia (przy stalym naprezeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 sp 15x2x1 mm w stanie wejsciowym. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna rrzywa) nm) w zaleznosci od czasu ekspozycji probki w stanie wyjsciowym pod naprezeniem, zrealizowanym na probkach serii 2 na powietrzu (b).

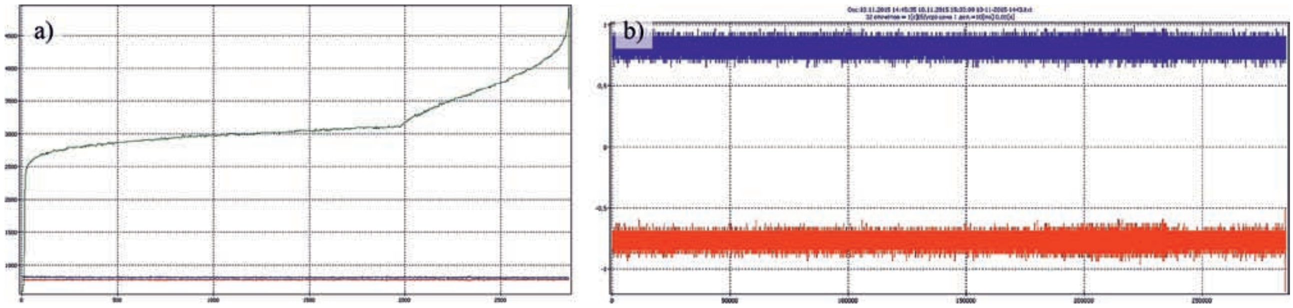

Fig. 5. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 sp specimen 15x2x1 mm after treatment in He with pressure 35 MPa and temperature 623 K during 10 hours. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples of the series 2 (b)

Rys. 5. Krzywe wydłużenia (przy stalym naprezeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 sp 15x2x1 mm po obrobce w He z cisnieniem 35 MPa przy temperaturze 623 K w ciągu 10 godz. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna rrzywa) nm) w zaleznosci od czasu ekspozycji probek serii 2 (b)

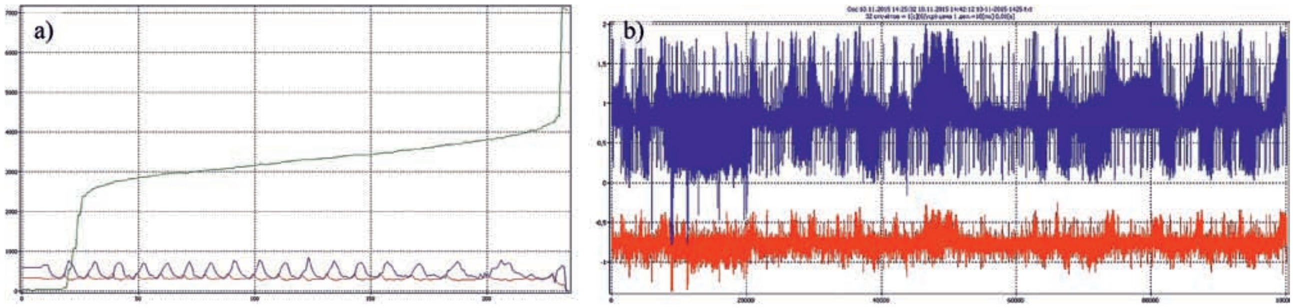

Fig. 6. Elongation curves (on permanent loading 370-450 MPa) in time (on verticall axis – Δl with step 0,01 mm, on horisontal axis – time in sec) of St3 sp specimen 15x2x1 mm after hydrogenetion in gaseous H_2 with pressure 35 MPa and temperature 623 K during 10 hours. Lower curve – the average signal of semiconductor sensors that controls this process (a) and spectral sensitivity of the semiconductor sensors of the visible range (610-580 (upper curve) i 600-480 (lower curve) nm) depending on the time of the exposure of the samples of the series 2 (b)

Rys. 6. Krzywe wydłużenia (przy stalym naprezeniu 370-450 MPa) w czasie (w prostopadlym kierunku – Δl z krokiem 0,01 mm, w poziomym – czas, sek.) probek ze stali St3 sp 15x2x1 mm po nawodrorowaniu w H_2 z cisnieniem 35 MPa przy temperaturze 623 K w ciągu 10 godz. Dolna krzywa – sredni sygnal sensora półprzewodnikowego, ktory obserwuje ten proces (a) i czujność spektralna sensorów półprzewodnikowych diapazonu widocznego (610-580 (gorna krzywa) i 600-480 (dolna krzywa) nm) w zaleznosci od czasu ekspozycji probek serii 2(b)

It is well known, that the analysis of large data helps engineering companies improve the team's productivity [8-10]. Even small changes in the formation of working groups can produce tremendous changes, increasing productivity by more than 22% [9]. Since the last time, the process of active commercialization of technology has taken place, several companies are building their business entirely on the creation of Hadoop commercial distributions and ecosystem services, and virtually all major information technology providers for organizations in one form or another include Hadoop in product strategies and line of solutions. In Big Data, the neurons of the network has built and to calculate the array of received information, the neural network was used (Fig. 7).

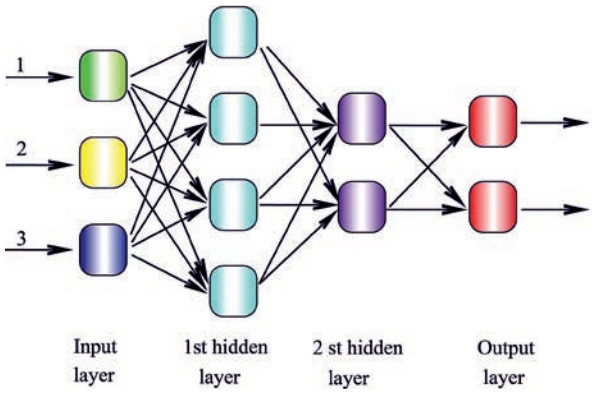

Fig. 7. Diagram of the neural network: 1 – elongation curves, 2 – load, 3 – spectral sensitivity of the semiconductor sensors of the visible range

Rys. 7. Schemat sieci neuronowej: 1 – krzywe wydłużenia, 2 – obciążenie, 3 – czujność spektralna sensorów półprzewodnikowych diapazonu widocznego

As input data we used: 1 – elongation curves, 2 – load, 3 – spectral sensitivity of semiconductor sensors of the visible range. Mathematically, an artificial neuron transforms the vector of input signals (influences) X into the vector of output signals Y using a function called the activation function. In the framework of the connection (artificial neural network – INS) there are three types of neurons: the input (receiving information from the outside world – the values of interest to us variables), output (return the desired variables – for example, predictions, or control signals), as well as intermediate – neurons that perform some internal ("hidden") functions. Classical INS, thus, consists of three or more layers of neurons, with the second and subsequent layers ("hidden" and output), each element is connected to all elements of the previous layer. It is important to keep in mind the notion of feedback, which defines the kind of structure of the INS: the direct transmission of the signal (the signals go consecutively from the input layer through the hidden and entering the output layer) and the recurrence structure, when the network contains links going back, from distant to nearer neurons). All these concepts constitute the necessary minimum of information for the transition to the next level of understanding of the INS – teaching the neural network, the classification of its methods and understanding the principles of each of them.

In general, the training of the INS is as follows: input neurons accept variables ("stimuli") from the external environment; according to the received information, the free parameters of the NA change (the intermediate layers of the neurons work). As a result of changes in the structure of the NC, the network "reacts" to information in another way. It is clear that the universal learning algorithm does not exist and, most likely, can not exist. Conceptually approaches to algorithm assumes that for each input ("learner") of a vector there is a necessary value of the original ("target") vector – thus, these two values form the learning pair, and the whole set of such pairs is an educational set. Thus system design and data sience is an interdisciplinary direction and methodology for building intellectual environments designed to solve scientific and practical tasks of optimizing the life cycle of complex systems of various nature using resource-intensive computer technologies and expert analysis.

4. Conclusions

The semiconductor structure responds to investigations of the energy processes occurring in the metal during long term service. The stress-strain state of metal can be investigated by the amplitude-frequency characteristics (AFC) depending on the chemical composition of the material and the amount of defects accumulated during operation. Dynamics of changes in the frequency response allows to predict the pre-emergency status of the items. Data science methodology is suitable for building intellectual environments designed to solve scientific and practical tasks of optimizing the life cycle of complex systems of various nature using resource-intensive computer technologies and expert analysis.

5. References/Literatura

[1] T. Chady, K. Schabowicz, "Nieniszczące badania płyt włóknistocementowych z wykorzystaniem terahercowej spektroskopii w dziedzinie czasu, Badania Nieniszczące i Diagnostyka, vol. 1, no. 1-2, pp. 62-66, 2016.

[2] E. Ballik, "Area and wavelength sensitivity of a photomultiplier", Applied Optics, vol. 10, no. 3, pp. 689-691, 1971. DOI 10.1364/AO.10.000689

[3] A. Balitskii, V. Pokhmurskii, Y. Dzioba, "Heat Irradiation of Mono- and Polycrystalline Materials During Deformation and Destruction Process. Fracture Mechanics: Successes and Problems", presented at the 8th International Conference on Fracture, ICF-8, Kiev, Ukraine, Jun. 8-14, 1993, pp. 619-620.

[4] A. Balitskii, M. Semerak, V. Balitska, A. Subota, O. Wus, "Hydrogen degradation of the pressure gas tanks materials after long-term service", Solid State Phenomena, vol. 225, pp. 39-44, 2015. DOI 10.4028/www.scientific.net/SSP.225.39

[5] O. I. Balits'kyi, "Two methods of investigation of the influence of hydrogen on the propagation rate of a crack and behaviour of fracture of high-strength steels", Materials Science, vol. 34, no. 4, pp. 574-583, 1999. DOI 10.1007/BF02360710

[6] A. Balitskii, O. Makhnenko, O. Balitskii, V. Grabovskii, D. Zaverbnyi, B. Timofeev, "Strength of materials and durability of structural elements of nuclear power plants" in Fracture mechanics and strength of materials: Reference book, vol. 8, Kiev, Ukraine, Publishing House of NASU "Akademperiodyka", 2005, p. 544.

[7] O. Loshak, A. Balitskii, L. Pulkas, S. Lizunov, I. Ripey, O. Gurina, "Methodological recommendations of technical state diagnostic and evaluation of life time of steam turbine cast vessel details", Decision of Minister of fuel and energetic of Ukraine No 124, 1.03.2007, Kyiv: GRIFRE, p. 39.

[8] K. Miadlicki, M. Pajor, M. Sakow, "Ground plane estimation from sparse LIDAR data for loader crane sensor fusion system", in Proc. 22nd International Conference on Methods and Models in Automation and Robotics, Miedzyzdroje, Poland, Aug. 28-31, 2017, pp. 717-722. DOI 10.1109/MMAR.2017.8046916.

[9] T. Alhart, "A Date with Data: Taking Stock of the Emerging Digital Industrial Economy - GE Reports", GE Reports, 2018. [Online]. Available: http://www.ge.com/reports/a-date-with-data-taking-stock-emerging-digital-industrial-economy-2/. [Accessed: 1- Mar- 2018].

[10] "Materials Science and Engineering Data Challenge | Challenge.gov", Challenge.gov, 2018. [Online]. Available: https://www.challenge.gov/challenge/materials-science-and-engineering-data-challenge/. [Accessed: 1- Mar- 2018].

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