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IMPLEMENTATION OF NITROVAC TECHNOLOGY AS ADAPTATION OF MACHINE PARK TO MARKET REQUIREMENTS

The paper presents the analysis of factors influencing the competitiveness increase. Special attention is given to innovation, which contributes to improving economic conditions. The example of pit furnace modernization shows the ability of the existing machinery adaptation to customer needs by implementation a new heat treatment process. Two possible modifications are offered and their correctness is verified through series of tests, the results of which are presented in the article.

Keywords: *modernization of machinery; competitiveness; heat treatment; nitriding.*

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ВПРОВАДЖЕННЯ ТЕХНОЛОГІЇ «НІТРОВАК» ДЛЯ АДАПТАЦІЇ ПАРКУ СТАНКІВ ДО РИНКОВИХ УМОВ

У статті проведено аналіз факторів, що впливають на підвищення конкурентоспроможності, особливу увагу приділено інноваціям, які сприяють покращенню економічних умов підприємства. Представлено приклад модернізації шахтної пічки шляхом впровадження нової технології температурної обробки без змін самого парку станків. Описано дві потенційні модифікації, детально надано результати їх тестування.

Ключові слова: *модернізація машинного парку; конкурентоздатність; температурна обробка; нітрування.*

Рис. 8. Табл. 2. Літ. 14.

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ВНЕДРЕНИЕ ТЕХНОЛОГИИ «НИТРОВАК» ДЛЯ АДАПТАЦИИ ПАРКА СТАНКОВ К РЫНОЧНЫМ УСЛОВИЯМ

В статье проведён анализ факторов, влияющих на повышение конкурентоспособности, особое внимание уделено инновациям, которым способствуют улучшению экономических условий предприятия. Представлен пример модернизации шахтной печи путём внедрения новой технологии температурной обработки без изменения самого парка станков. Описаны две потенциальные модификации, детально приведены результаты их тестирования.

Ключевые слова: *модернизация машинного парка; конкурентоспособность; температурная обработка; нитрирование.*

Introduction. Today, under global economy, enterprises are evaluated basing on the ability to compete with other companies as well as by their innovative activities (Stanislawski and Lisowska, 2012). The ability to compete at markets becomes the main development aim determining the changes that the enterprise has (Stankiewicz, 2002; Lachiewicz and Matejun, 2009). Competition takes place on many levels, which is why it is very important to identify and understand the factors influencing the competitiveness increase.

Company's potential (resources, skills and abilities) reflect the competitiveness and the ability to achieve advantage over other enterprises in the same business. Competitiveness is a feature that comes from internal characteristics of a company

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and from the ability to adapt to changes in the environment. Competitive enterprise takes actions to guarantee stable, long-term development, increase its value at the market and contribution to improve economic conditions (Banyte and Salickaite, 2008).

Figure 1 presents a model that reflects the selected key elements of the market environment influencing company's competitiveness. These factors can be divided into two groups. Some of them are connected to external environment, independent from the company, that is: national law or market regulation mechanisms etc. The second group of factors is activities connected with the company – its financial condition, resources, entrepreneurship, innovativeness etc. (Knap-Stefaniuk, 2010).

Material resources is one of the elements in Figure 1 that allows increasing competitiveness, attracting new customers and thereby improve the economic condition of a company. The company, in order to meet market demands and maintain its position in the field in which it operates, must take appropriate actions including adaptation of machinery or look for the opportunity to reduce the operation costs (Adamkiewicz-Drwillo, 2002).

The development of nitriding heat treatment technology on the basis of already owned machine park. Flexibility, new solutions, and most of all innovations are necessary to maintain and improve competitive position. Enterprise must undertake activities that improve its market position and increase revenue (Penc, 1999; Nowacki, 2010).

An example of the improvement of economic conditions is presented in the paper as a decision process regarding machine park modernization owned by the company that is a pit furnace PC-90 used for heat treatment process of tempering after hardening.

To increase the competitiveness, furnace can be modernized and adapted to nitriding process. There is no contractors at the local market offering nitriding services therefore offering nitriding will satisfy expectations and needs of customers. Launching new service offer as a new heat treatment process is an opportunity for the enterprise to attract new customers by filling the market niche. Modernization of owned machines gives an opportunity to expand the range of services, strengthen company's market position and increase revenues due to increased orders.

Research instruments allowing technical analysis of possibilities for adapting pit furnace to nitriding process were used as part of modernization. Analysis of final product quality requirements after such processing was conducted, primarily for hydraulic components and injection mold components. These activities were chosen for solving the problem of finding the best possible technical solution. 3D Computer Aided Design technology (CAD) as well as the analysis of similar research results (Kula, 2000; Dobrzynski, 2002) were used to analyse the feasibility of the undertaken task. As a result of the conducted research it was found that the pit furnace PC-90 can be modernized to run nitriding processes, which can be performed in two variants. The first assumes using pit furnace to perform nitriding under normal pressure, while the other allows using low-pressure nitriding.

In case of the first solution, modernization of pit furnace relates to the modernization of its control system including the replacement of the temperature control system inside the pit furnace and equipping the furnace in a hermetic retort, system of mechanical force for circulation and gas supply system. A schematic diagram of this solution is presented in Figure 2.

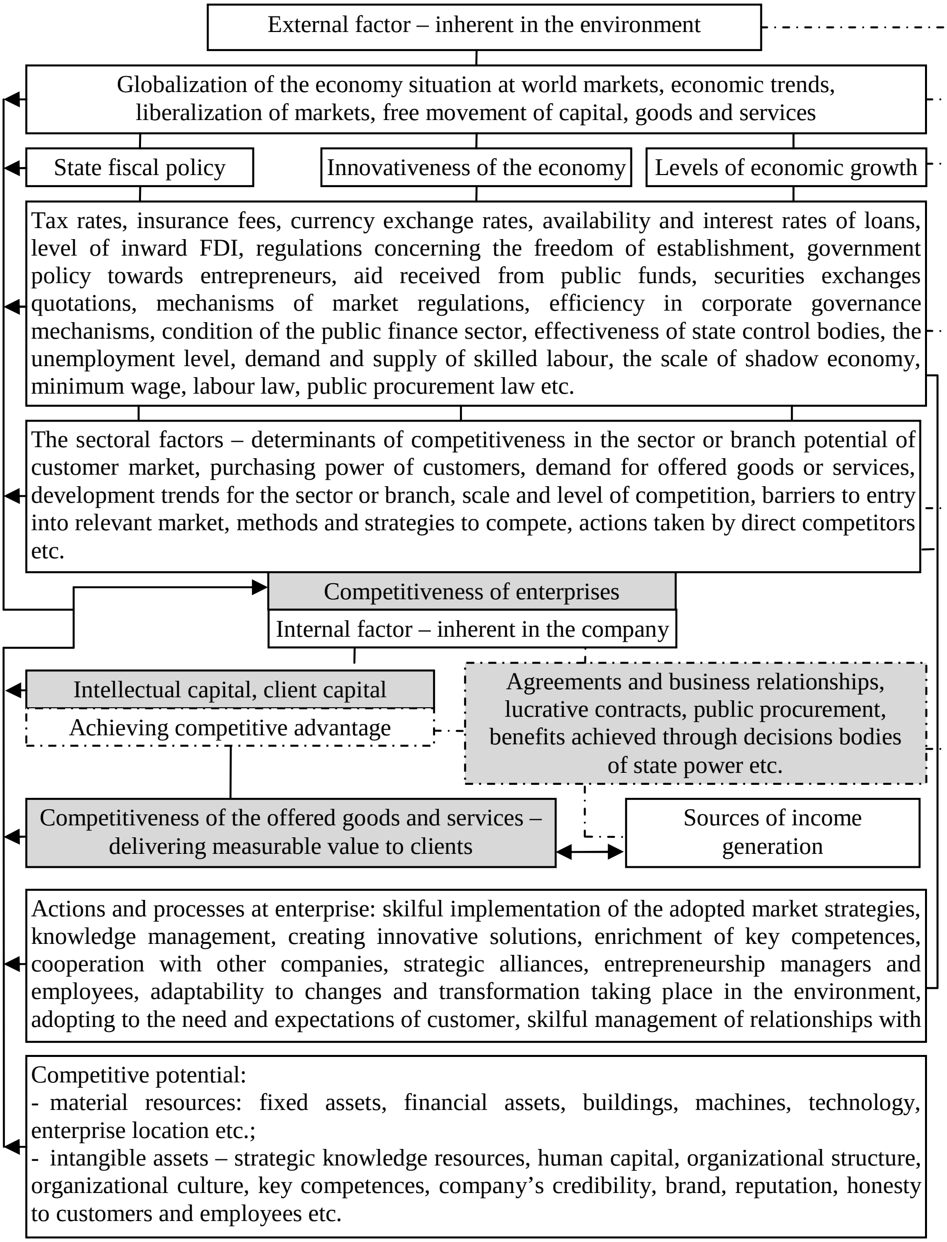
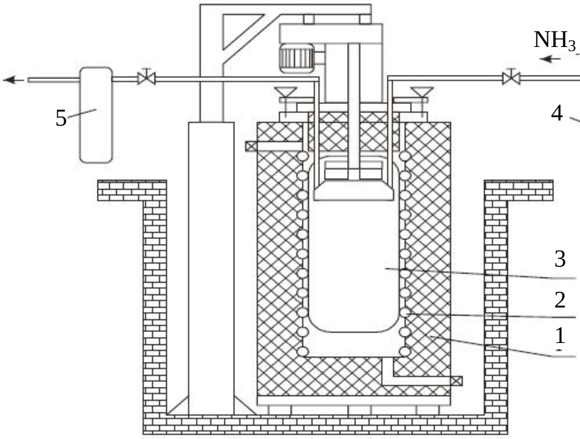


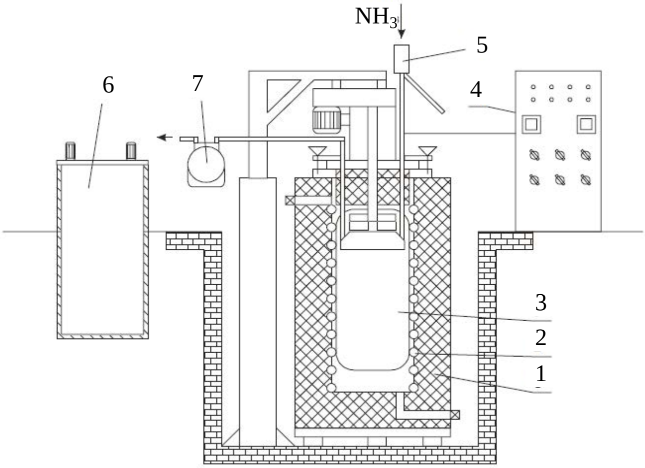
Figure 1. **Factors influencing company's competitiveness** (Walczak, 2010)

The second solution of pit furnace modernization includes upgrading the control system of the furnace including the replacement of temperature control system inside the pit furnace, equipping the furnace in a hermetic retort, system of mechanical circulation and a gas supply system is required to perform the process in vacuum. This method is called "nitrovac process" (Has and Kula, 1983). A schematic diagram of this solution is shown in Figure 3.



1 – furnace, 2 – heating elements, 3 – retort, 4 – ammonia tank, 5 – dissociation indicator

Figure 2. **Schematic diagram of gas nitriding under normal conditions,** *authors' development*



1 – thermal insulation, 2 – heating core, 3 – retort, 4 – control electrical cabinet, 5 – container with ammonia, 6 – cooling sump, 7 – rotary pump

Figure 3. **Schematic diagram of the work centre adapted to perform Nitrovac technology,** *authors' development*

Based on the analysis of customer inquiries regarding the performance of nitriding process it was found that a representative material for the determination of technological parameters of modernized furnace should be 1.8509 steel (DIN 41CrA/Mo7-10). Considering the economics of processing as well as the quality of final product, the most common aim is to produce the ozone layer, that provides hermetic surface without pores. In the case of steels alloy the minimum nitride emission forms a grid on the former austenite grain boundaries in the zone of internal nitriding. Obtaining such structure depends on the method of nitriding and the steel grade. In the conventional gas nitriding method the pore structure is obtained. Only the modern, controlled methods can prevent pores formation in the nitrided layer. While separation of nitrides in form of a grid at grain boundaries is mainly related to steel type, it is difficult to be avoided by simply setting nitriding parameters (Kula, 2000). The presented analysis allows recommending the modernization of the pit furnace based on the second considered option.

As a result of modernization the system presented in Figure 4 was created.

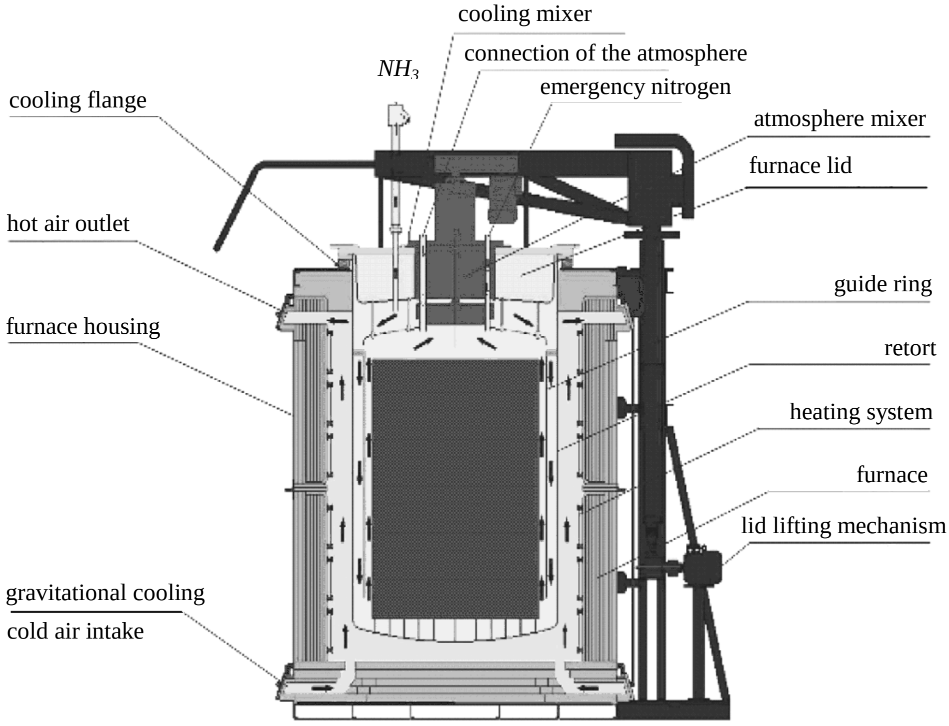


Figure 4. **Schematic diagram of pit furnace PC-90 after modernization,** *authors' development*

In order to determine the optimum parameters of the nitriding process (Alsaran, Celik and Celik, 2002), including the determination of the characteristics of the modernized machine measurements of micro-hardness distribution using micro-hardness DuraScan were conducted. Temperature control and the degree of dissociation of the ammonia inside the retort was controlled using the measuring system with data recording (Alsaran, Karakan and Celik, 2002).

Metallographic tests were conducted using microscope BX60M connected with camera OLIMPUS DP50 in order to determine the phase distribution in the layer after diffusion.

Quality parameters determination of the model after modernization. In order to determine the quality parameters of the tested model following the criteria for quality control of the nitrided layer were defined:

- surface hardness;
- cross-section hardness profile;
- layers thickness;
- structure;
- service life;
- embrittlement;
- coating density and uniformity;
- surface roughness;
- internal stresses;
- mechanical properties.

It is possible to control the following parameters during the nitriding process: duration of the process, temperature, gas pressure in the retort. Changing any of these parameters results in quality parameters change. In order to demonstrate the correctness of the pit furnace modernization process and to determine the relationship between input and output parameters (surface hardness, hardness profile cross-section, layer thickness, structure), the tests were conducted according to plan presented in Table 1. Test samples were created using a bar of 20 mm diameter and 10 mm long. Samples made of 1.8509 steel were hardened at 900°C and high temperature tempered at 600°C. The obtained hardness of the samples was 30 HRC. Samples were prepared to nitriding process by abrasive machining. 10 samples from each batch were used. The test results presented in Table 2 are the mean values of the measurements of individual parameters. It should be noted that during the presented tests process parameters were precisely controlled by the independent measurement system in order to confirm the effectiveness of the pit furnace built-in control system and devices present in the system (including a vacuum pump).

Samples for microhardness tests and metallographic examination after the nitriding process were prepared in accordance with the applicable standards.

Table 1. **Research plan,** *authors' development*

Sample	Temperature, °C	Temperature variation, °C	Process time, h
1	500	40	3
2	500	40	6
3	500	40	9
4	510	60	3
5	510	60	6
6	510	60	9
7	540	40	3
8	540	40	6
9	540	40	9
10	480	0	9
11	560	0	9

Distribution of microhardness obtained from the research is presented in Figure 5.

Figure 6 presents the results of maximum hardness.

Figure 7 presents the results of nitrided layer thickness measurements basing on the HV(500) criterion.

Figure 8 presents the results the degree of ammonia dissociation registered during the nitriding process.

Table 2. **Summary of test results,** *authors' development*

Sample	Temperature, °C	Process time, h	Surface hardness, $HV_{0,1}$	Effective layer thickness (HV500), μm	Nitride layer thickness, μm	Dissociation of ammonia, %	Pressure, hPa
1	500	3	1140	70	0	2,3	50
2	500	6	1176	90	0	2,1	50
3	500	9	1010	90	0	2,4	50
4	510	3	990	70	0	2,3	50
5	510	6	1180	120	0	3,8	50
6	510	9	1150	150	10	3,2	50
7	540	3	955	90	7	9,1	50
8	540	6	978	130	8	9,0	50
9	540	9	1002	200	9	9,0	50
12	480	9	780	50	0	0,5	50
15	560	9	1050	250	17	10,5	50

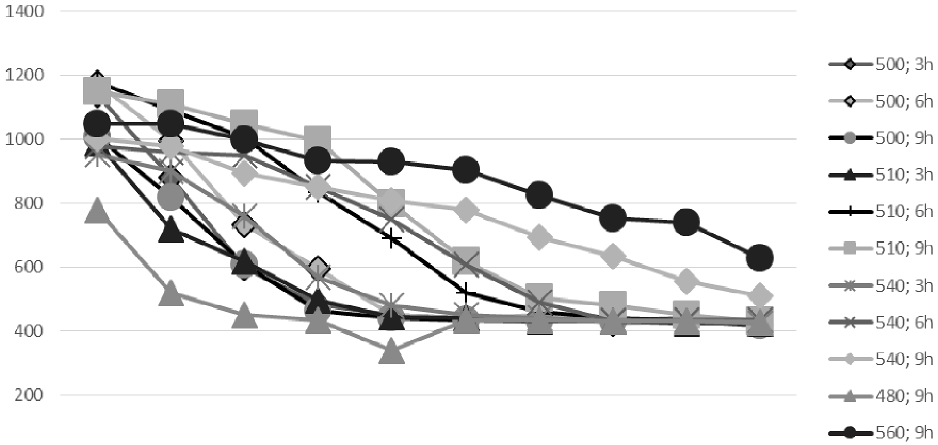


Figure 5. **Distribution of microhardness of the nitrided layer depending on the temperature and time of a process performed at 50 hPa pressure,** *authors' development*

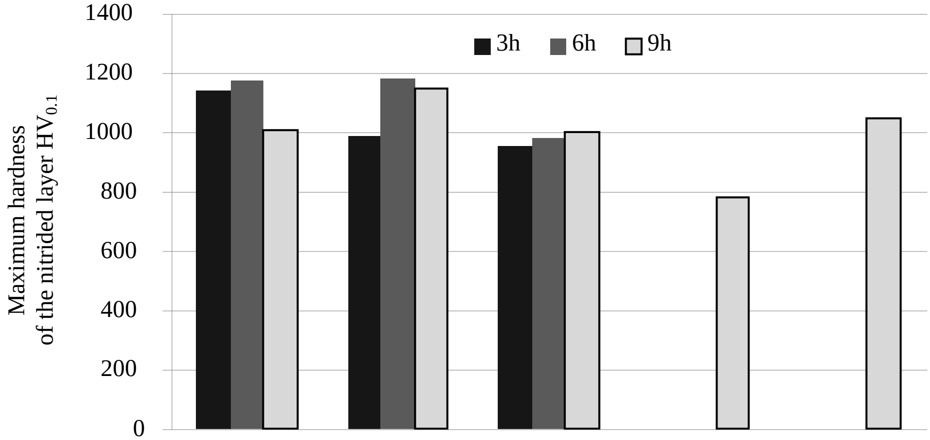


Figure 6. **Dependence between the maximum hardness and the nitriding temperature and time at 50 hPa constant pressure,** *authors' development*

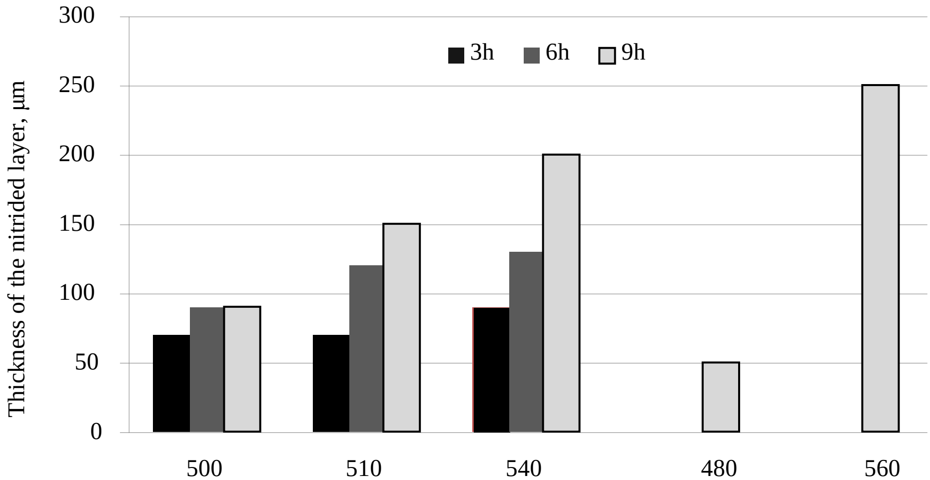


Figure 7. **Dependence between the nitrided layer thickness and the nitriding temperature and time at 50 hPa constant pressure,** *authors' development*

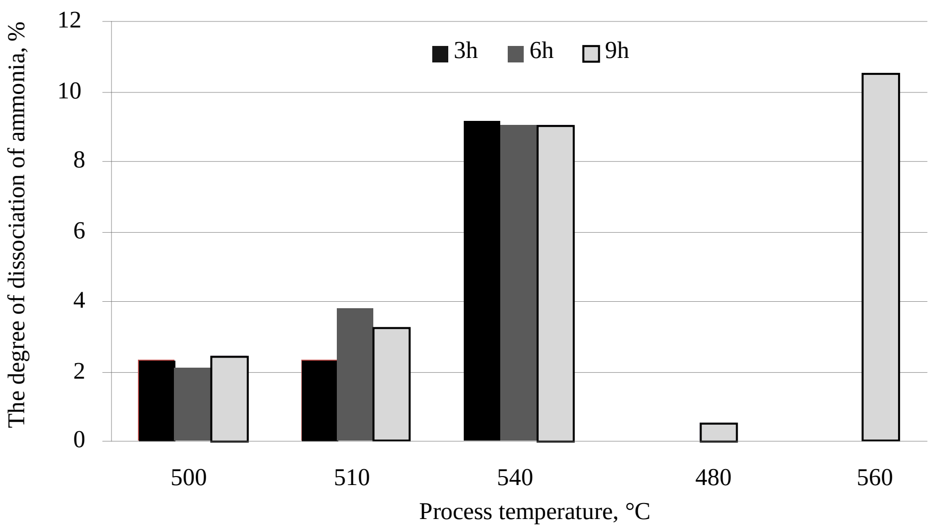


Figure 8. **Dependence between the ammonia dissociation degree and the nitriding temperature and time at 50 hPa constant pressure,** *authors' development*

Analysis of the graphs in Figures 5 and 6 proves that the processes performed in 3h, and carried out at different temperature allowed obtaining the highest hardness of the nitrided layer – around 1140 $HV_{0,1}$. This hardness of layer can be already obtained at the lowest temperature of 500°C.

For higher temperatures the decrease of hardness was observed, for 510°C the hardness is 990 $HV_{0,1}$, and for 540°C it drops to 955 $HV_{0,1}$. It should be noted that for the highest temperature of 540°C the amount of nitrogen provided to the surface is greater than the amount of nitrogen diffused into the material which then forms a white area of nitride compounds on the surface. Appearance of white area in the nitrided samples at the temperature of 540°C occurred for all variants, regardless the nitriding time. Decrease of surface layers hardness is the unwanted result of the process.

Data presented in Figure 8 prove that nitriding time has the greatest impact on the thickness of the formed layer of nitrogen. Increasing nitriding time results in deeper diffusion of nitrogen into the substrate material, however, increasing the concentration of nitrogen leads to formation of the white nitride compounds zone. Increasing the time of nitriding leads to reduction of maximum hardness in the surface layer due to the loss of coherence between nitride and the surface layer of material and significantly decreases surface hardness.

In the 9-hour process, white zone of nitride was formed at 510°C and above. The lowest hardness (780 $HV_{0,1}$) was observed for a layer nitrided at the constant temperature of 480°C. Saturation processes run very slowly at this temperature. The layer also has the smallest thickness of about 50 microns (Figure 7). This happens due to insufficient amount of nitrogen provided to the surface. The degree of dissociation of ammonia for this temperature is 0.5% (Table 2). At such low degree of dissociation a very small area is affected. By oscillated increasing the temperature to the value of 500°C, the degree of ammonia dissociation increases several times, from 0.5 to 2.4%. Larger amount of nitrogen provided this way to the surface diffuses into the material increasing its thickness and hardness. It significantly reduces the time of nitriding, because after just 3h of nitriding at 500°C, layer has a thickness of 70 microns and an effective high-hardness of 1140 $HV_{0,1}$. Pressure changes during the nitriding processes increase the dissociation degree of ammonia.

Increasing the temperature of the process and its duration causes the precipitation of γ' nitrides grid to the former austenite grain boundaries. This can be observed in the photographs of the structural nitrided layer in the processes carried out at 540°C and time of 9 hours and in the process carried out at the constant temperature of 560°C.

Maximum hardness of nitrided layers has slight changes with temperature when nitriding for 6 hours. Its decrease occurs for higher temperatures, i.e. 540°C. Nitrided layer obtains the highest hardness when nitrogen concentration within is large enough, it appears on the surface in clearly visible white area of nitride compounds.

Beginning of the formation of nitride compounds white area was observed for temperatures of 540°C, at pressure of 50 hPa. These parameters seem to be optimal due to relatively short time for nitriding and high hardness obtained (1180 $HV_{0,1}$) and layer thickness of 120 microns.

Metallographic examination carried out on the samples nitrided at constant and variable temperature confirm the increasing of small precipitates of γ' phase for the samples processed at variable temperature.

Conclusions. The investigation of the effect of variable nitriding temperature on the properties of nitrided layers allow drawing the following conclusions:

- variable temperature vacuum nitriding processes within the limits recommended for the material hardly affects the thickness and hardness of the layers of nitride, while increasing the amount of dispersion nitride precipitates γ' in the zone of internal nitriding does not increase the tendency to form γ' nitrides grid at the former austenite grain boundaries and does not increase layer brittleness;

- lowering process temperature reduces the rate of nitriding processes, including the diffusion rate and catalytic breakdown of ammonia, which is important considering the effective use of the modernized pit furnace;
- longer time of nitriding results in increasing thickness of the nitrided layer and creating the white area of nitride compounds, wherein the tendency to form the white area on the surface is rising together with the temperature. Therefore, the process time should be selected taking into account the functional characteristics of nitrided element;
- higher process temperature leads to the loss of coherence between the forming nitride precipitates and matrix what consequently reduces the hardness of the nitrided layer;
- changes in retort pressure together with temperature changes are expected to result in the increase in the degree of ammonia dissociation, consequently in increase of the nitrogen layers thickness and even in greater fragmentation of γ' nitride precipitates in the internal nitriding zone. This allows controling the process as the function of temperature and pressure to obtain the expected functional characteristics of the elements surface;
- proper activation of the sample before nitriding largely affects the nitrogen saturation of the elements surface layer;
- for the objects tested at higher temperatures, the process of nitrogen diffusion saturation of the surface layer runs more intensified, and this allows achieving larger thickness of nitrided layers. Unfortunately, it happens at the expense of reducing hardness. The optimal solution is a compromise between hardness resulting under low temperature and layer thickness increasing while increasing temperature or extending the nitriding time.

Summary. Development and implementation of nitriding technology based on PC-90 pit furnace owned by a company resulted in improved performance and competitiveness by widening the range of highly specialized services especially the surface layer processing, not only for local contractors. This would help developing an effective technology and its implementation is organizational, process, marketing and product innovations. Due to the complexity of nitriding processes it was necessary to carry out a number of qualitative research and on basis of such analysis – to determine the recommended parameters of technological processes for the modernized furnace.

An alternative solution in relation to the use of an innovative process for the enterprise utilizing existing machines is to use the method of traditional gas nitriding method. As it was found during the analysis, such solution compared to the one that was chosen, does not guarantee achieving significant benefits in terms of competitiveness. Simpler option would be purchasing new equipment, generating higher costs, but over time this allows expanding the market share, finding new customers and improving the economic situation overall. The proposed solution to upgrade the existing devices is advantageous from the financial point of view – it's cheaper in terms of total cost. Investment costs on modernization will pay off quicker and the company will make profits faster than in the case of purchasing new equipment.

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Стаття надійшла до редакції 20.05.2015.