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RMS PROCESS CONTROL ALGORITHM BASED ON THE VOLTAGE METHOD

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Key words: RMS process control, voltage method, Physical Vapour Deposition.

Abstract: For the last several years, considerable progress in the use of the plasma surface engineering for the purposes of the surface layer's modification has been observed. The magnetron sputtering method is one of the most important ones. This method consists in inducing the vapours of a solid body (target) by its surface's bombardment with ions, most often the argon ones. The article presents a proposal of a control algorithm for such process. The algorithm is based on the well-known voltage control method, where a constant power of the magnetron power supply voltage on the magnetron is observed. The authors propose to modify this method based on the observation of power at a constant voltage on the magnetron. The control algorithm constructed in this way works as well as traditional means and ensures process stability.

Algorytm sterowania procesem RMS oparty na metodzie napięciowej

Słowa kluczowe: sterowanie procesem RMS, metoda napięciowa, metody fizycznego osadzania powłok z fazy gazowej.

Streszczenie: W ostatnich latach obserwuje się znaczący postęp w wykorzystaniu metod plazmowej inżynierii powierzchni do modyfikacji warstwy wierzchniej. Jedną z najważniejszych metod jest metoda rozpylania magnetronowego. Metoda ta polega na wytwarzaniu oparów ciała stałego (targetu) poprzez bombardowanie jego powierzchni jonami, najczęściej argonu. W artykule przedstawiono propozycję algorytmu sterującego takim procesem. Algorytm oparty jest na dobrze znanej metodzie napięciowej sterowania, gdzie przy stałej mocy zasilacza magnetronu obserwuje się zachowanie napięcia na magnetronie. Autorzy proponują zmodyfikowanie tej metody polegające na obserwacji mocy przy stałym napięciu na magnetronie. Tak skonstruowany algorytm sterowania działa równie dobrze jak tradycyjny i zapewnia stabilność procesu.

Introduction

Increasing the operational durability of various structural components of machines and tools is still a great challenge. In recent years, the use of different techniques of applying thin, hard and wear-resistant coatings has become more and more common [1,3]. They improve the functional properties of many products, including aesthetic properties. The most popular techniques for increasing surface hardness include the following [6]:

- Methods of chemical deposition of CVD coatings (Chemical Vapour Deposition);
- Methods of physical deposition in vapour phase PVD (Physical Vapour Deposition); and,

- Hybrid methods, combining various methods, e.g., CVD and PVD and conventional ones.

The method of the physical deposition of gas phase PVD coatings uses physical phenomena, such as the evaporation of metals or alloys or sputtering in a vacuum and ionization gases and metal vapours using various physical processes. A common feature of these methods is the crystallization of metal or plasma phase pairs. Coating may take place on the substrate cold or heated to 200–500°C [2]. This process is often carried out in the presence of a chemically inert gas (e.g., argon) [4]. This makes it possible to coat hardened substrates and tempered steels, without fear of a decrease in hardness, but it also leads to the formation very thin and poorly bounded coatings. The RMS method (Reactive

Magnetron Sputtering) involves spraying the material forming the coating substrate obtained by the gas ions generated in the region between the plasma and the charge itself. Sputtered ions pass through the plasma, where ionization and possible reactions with the ions and the atoms of a reactive gas cause the deposition of the coating. Substrates coated with magnetron sputtering systems are used for the needs of building architecture, optics, cutting tools, tools for plastic forming, injection moulds, electronic components, and others [7].

The devices based on the RMS method needs a special control system. The most commonly used methods of controlling reactive sputtering processes include the following [8]:

- An optical method, and
- A voltage method.

The optical method is based on the stabilization of the intensity of the selected spectral line, which is emitted from the discharge area. Process control is carried out by changing the reactive gas flow. This method is simple but relatively expensive due to the need to use a spectral recording device.

The voltage method is based on the detection of a voltage drop between anode and cathode. The constant parameter in this method is the discharge power. The voltage stabilization is obtained, as in the previous method, by controlling the flow of reactive gas fed into the chamber. The idea of control in the voltage method is shown in Fig. 1.

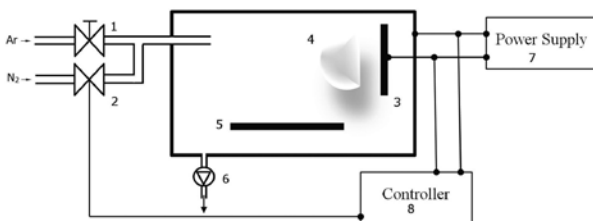


Fig. 1. The idea of control in the voltage method

The vacuum in the chamber is provided by the pump (6). A target (3) is placed in the vacuum chamber, around which the plasma (4) is made. The chamber (5) (substrate) on which the particles are deposited is also placed in the chamber. Valves (1) and (2) control the supply of inert and reactive gas, respectively. The power supply (7) supplies voltage to the magnetron while maintaining constant power. The regulator (8) controls the reactive gas flow based on the voltage observation on the power supply.

Changing the operating mode between the metallic and reactive modes is characterized by the occurrence of hysteresis [2], which is shown in Figure 2.

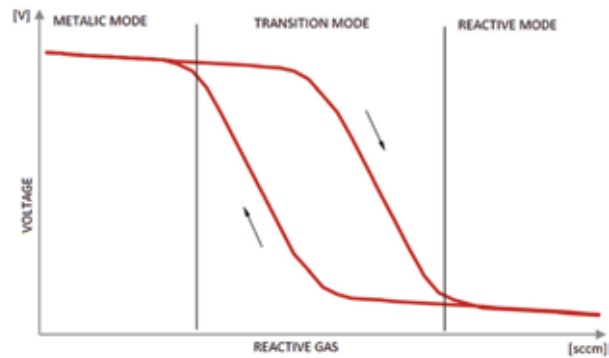


Fig. 2. Working area of magnetron

1. Measuring system

The tests were based on a laboratory chamber with a capacity of 80 l, shown in Fig. 3.

The magnetron is powered by the Huettinger TruPlasma DC 4020 power supply. This power supply has three basic operating modes:

- Current stabilization,
- Voltage stabilization, and
- Power stabilization.

It has many mechanisms for detecting and extinguishing electric arcs, which greatly facilitates process control [7] (e.g., voltage-based detector, current-base detector, cross-detector, and detection thresholds based on mean output voltage). The maximum power of the power supply used in the test is 20kW, and its maximum voltage is 1000V. The magnetron was made of titanium and the surface of the anode was 200 cm². Two vacuum pumps (PFEIFFER DUO-35 and PFEIFFER HiPace-700 dual-stage rotary vane) ensure a vacuum of 10⁻²Pa. The control system was built with use of Rockwell Automation CompactLogix controllers. Table 1 lists the parameters according to which the surface was prepared during the tests.

Table 1. Surface preparation parameters

No	Operation	Washing agent	Time (min)	Temperature (°C)
1	Degreasing	10g NaOH/dcm3H2O 10g Na3PO4.10H2O/ dcm3H2O 10g Na2CO3/ dcm3H2O 5g of wetting agent FF/ dcm3H2O	3	50
2	I rinsing	distilled water	100	80–90
3	II rinsing	distilled water	100	20–25
4	Drying	Air	10	100–110
5	III rinsing	trichlorethylene (TRI)	6	80
6	Drying	Air	5	100–110

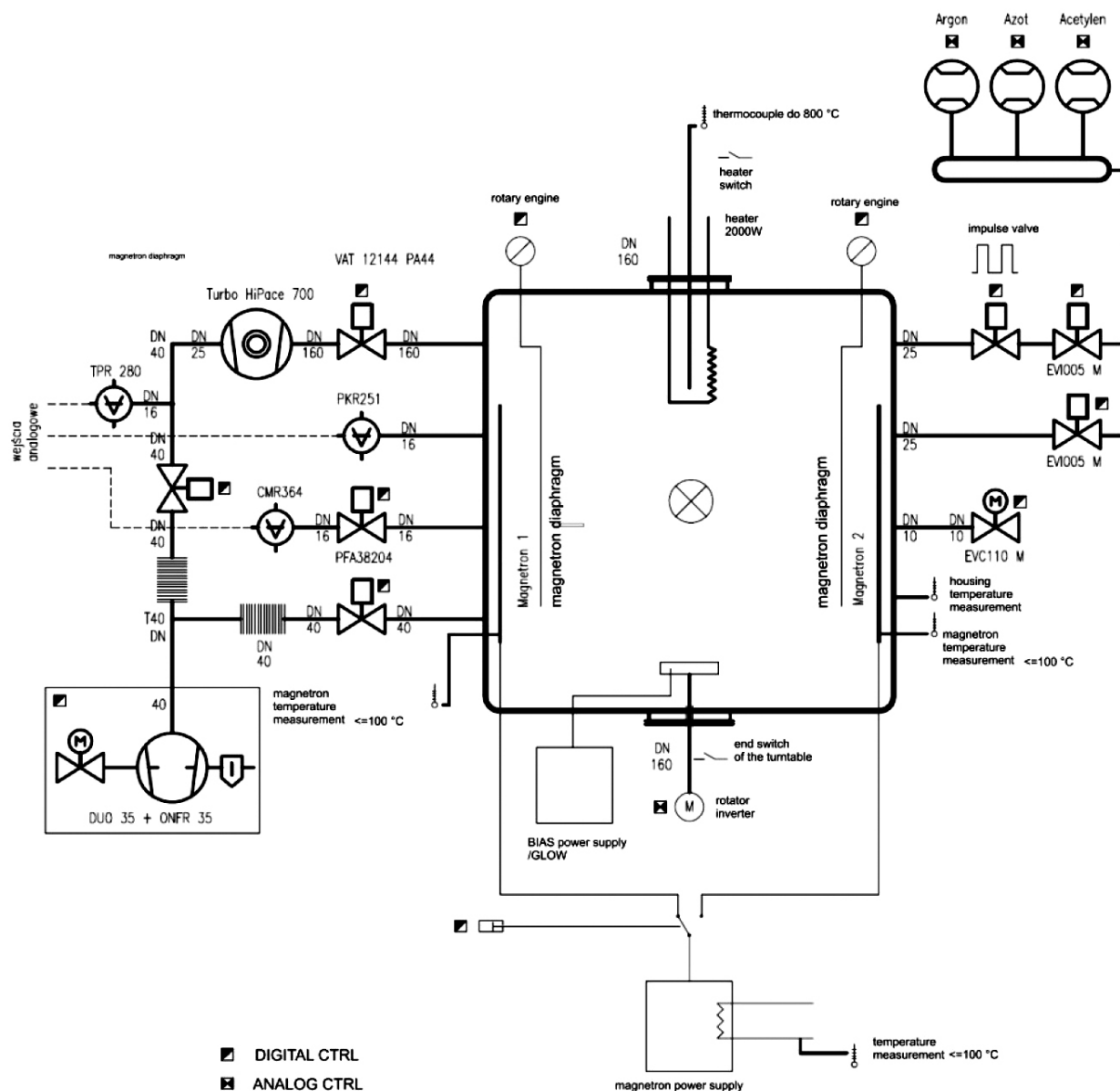


Fig. 3. Construction of the measuring element

The vacuum chamber is prepared in the following way:

- Pumping is carried out for a minimum of 1 hour after obtaining a pressure of 10^{-4} mbar;
- During the pumping, the chamber heating is switched on with the set temperature of 120°C , if the air humidity is higher than 75%.

The cleaning of the surface in the vacuum chamber is carried out as follows:

- Pressure stabilization is set at 0.15 mbar,
- Chamber heating is set to 110°C ,
- Inert gas delivery - Ar 35scm,
- The glow voltage is set at 700V and its power is set at 3KW, and
- The glow process was carried out for 1.5 hours.

2. Problem definition and idea of control system

The basic problem when controlling a magnetron is to keep it in the transition mode. Exit from this mode to the metallic mode causes the application of a pure metallic layer to the substrate and the transition to the reactive mode applying a layer of undesirable composition. In both cases, an undesirable surface layer is produced. The authors proposed a modification of the classical voltage control. The control concept is based on stabilizing voltage and observing power changes. It is possible thanks to a specially selected power supply. The algorithm was created on the basis of empirical research.

In various environmental conditions, a working point in transition mode was sought. The working point has been determined by characteristics of voltage changes at a constant power supplied to the magnetron, which were recorded depending on the amount of reactive gas supplied at different growth rates, which is shown in Fig. 4.

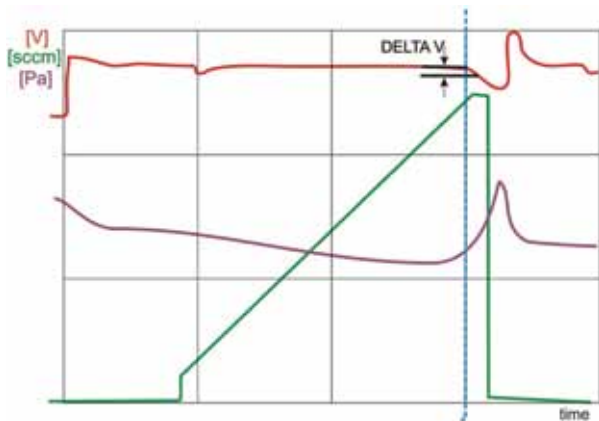


Fig. 4. Setting a work point

To assess the effect of temperature on the process, the tests are repeated for different chamber temperatures. The results obtained have shown that the change in temperature does not significantly affect the process. However, the rate of gas delivery is of great importance for the control process. With excessive gains in gas delivery per unit of time, we are not able to correctly determine the working point. A similar situation occurs when we increase the amount of gas flowing into the chamber very slowly. The best results were obtained by increasing the amount of reactive gas (in our case nitrogen N_2) by 0.1 sccm for 30 to 35 seconds.

For the needs of the tests, a PID algorithm was implemented to determine the process parameters. It made it possible to obtain satisfactory results under the condition that the process is carried out for a very long time period, i.e. below an hour. For processes that lasted three or four hours, it is noticed that the process is transitioning from the transition mode to the metallic or reactive mode, which is shown in Fig. 5. In both cases, the desired effect is not obtained, i.e. covering with a layer of titanium nitride.

An attempt is made to identify the problem, and during the process, the working point for the transition mode is again tried. It turned out that the working point is shifting, and sometimes the amount of reactive gas determined for the working point is greater than that determined at the start of the process, and sometimes lower.

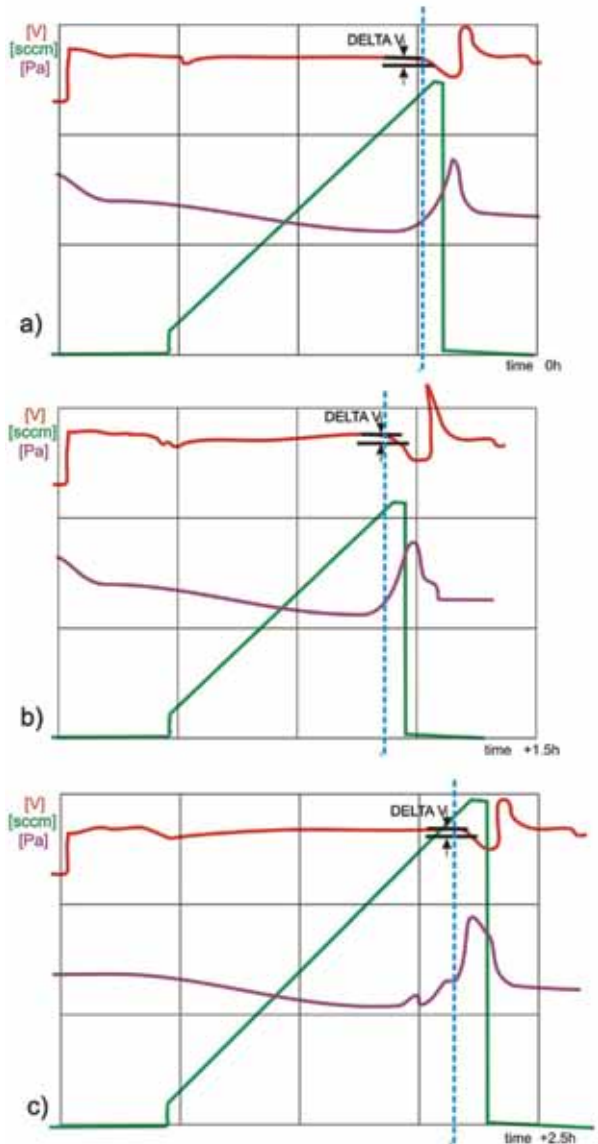


Fig. 5. Drift of work point a) start of process, b) after 1.5 hours, c) after 2.5 hours

3. Results

In order to determine the possibility of conducting the process successfully over a longer period of time, a simple control algorithm that allows tracking parameter changes was developed.

As in the case of the standard method, at the beginning, a working point is determined at the set power supply operation mode with power stabilization. The voltage and pressure behaviour in the chamber is observed. Under normal conditions, the voltage increased to a certain limit as the amount of reactive gas feed into the chamber increased. The amount of inert gas feed into the chamber is constant and is

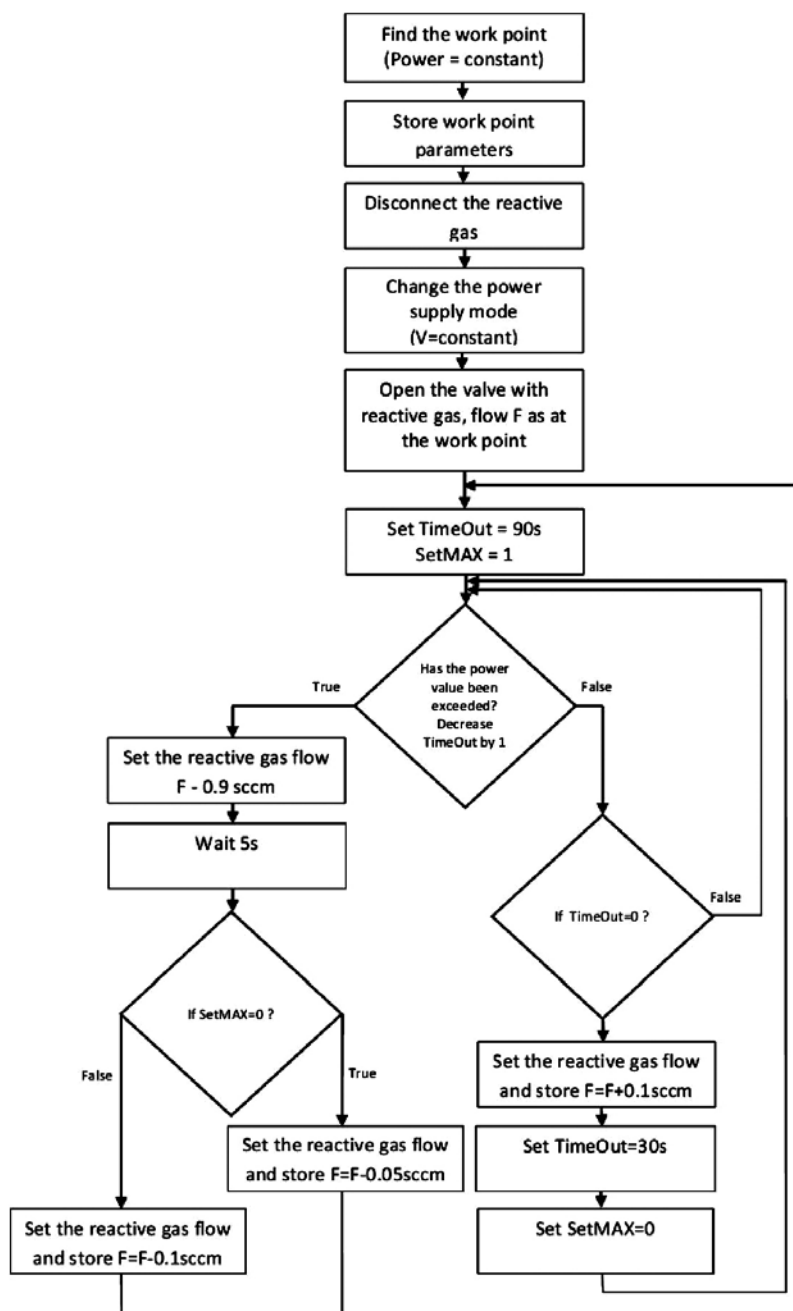


Fig. 6. Control process algorithm

7.5 sccm Ar (argon). After a while in which the voltage reached the limit value, there is a sudden voltage drop and pressure increase in the chamber with unchanged amounts of gas supplied to the chamber. The amount of gas from before reaching the maximum voltage the operating point. The supply of reactive gas to the chamber is switched off, and the PSU mode is changed from power stabilization to voltage stabilization with the set voltage determined in the previous stage. Reactive gas is introduced to the level determined in the

previous stage. The power supplied to the magnetrons is constantly monitored. The meter measuring the time of this stage is also started. If the power starts to grow and exceeds the threshold at which the working point is determined, some reactive gas is subtracted from the given time interval. The amount of gas by which the inflow is reduced is the amount that does not allow the transition from metallic mode to transition mode. After the preset period of time, the amount of gas is restored to a level of 0.05 sccm less than before the reduction, if the reaction to adding a portion of gas occurred after

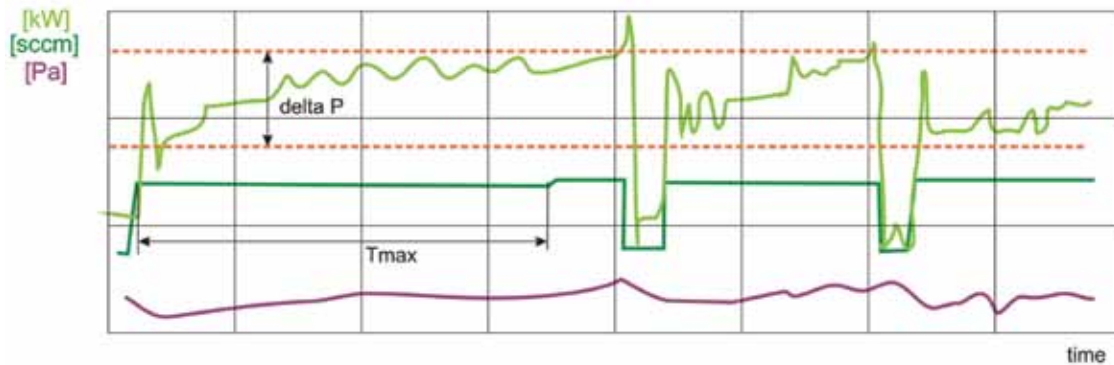


Fig. 7. Process parameters using the proposed algorithm

more than 60 seconds since the last gas reduction. If the change is faster, the amount of gas is restored to the level of 0.1 sccm less than the previous one. In the case when in the given time period (the maximum time during the tests is set to 90 sec) no change in the power delivered to the magnetron is noticed, the amount of reactive gas increases by 0.1 sccm every 30–40 seconds. The result of the algorithm's work is presented in Figure 7.

Conclusions

The carried out tests allowed us to draw the following conclusions:

- The proposed algorithm provides equally good magnetron control as the known voltage method.
- Conducting the process should be carried out with the amount of reactive gas such that the process is still active and the power does not exceed the set level designated at the start.
- Both the voltage and pressure in the chamber should be observed.
- Significant difficulties appear when a significant amount of arcs appear during the process, which are extinguished by the power supply, but have an effect on the read out parameters of the power supply: power, voltage, and current.

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