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TEMPERATURE UNIFORMISATION AT PLASMA NITRIDING BY USING SPECIAL PROTECTION SCREENS

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ABSTRACT

Despite some very well established advantages, during the plasma nitriding process important problems related to temperature uniformisation may occur, especially during the thermochemical treatment of metallic parts that contain areas with complex geometry. After an examination of the theoretical aspects pertaining to furnaces without auxiliary heating, the authors present an original method based on the usage of adjustable protection screens, for correcting the temperature on certain surfaces of a large-size part subjected to plasma nitriding.

Keywords: plasma nitriding, protection screens, temperature control

1. INTRODUCTION

Among the thermochemical processes for the improvement of surface proprieties of components, plasma nitriding holds an important position in industry today. Unlike processes employing conventional methods of heating, in plasma nitriding the energy is impartes directly to the work piece by ion and fast-neutron bombardment. The energy efficiency of this mechanism is quite high (70-90%) and depends on pressure and gas composition. On the other hand, under certain conditions, this form of heating may give rise to substantial and unacceptable temperature nonuniformity between different components of the load or between different areas of the same component.

The main factors which can lead to this temperature nonuniformity were analysed in a previous paper. It was found that the jigging system could be modified in order to ensure good temperature uniformity of the work piece in the treatment chamber.

In the present paper, a method of redistribution of the input energy on the surface of the load is described. Using this technique, a significant correction of the temperature in ceratin areas of large components has been achieved. As an example, some aspects of the plasma nitriding of a balancing chamber for a 700MW turbine are also presented.

2. THEORETICAL ASPECTS

During the heating process, the energy imparted to the work piece by ion bombardment and by other sources is partly used to heat up the components, the rest being dissipated by conduction, convection and radiation. This physical equilibrium may be expressed by the following equation:

$$\eta \cdot U_{disch} \cdot \int_S j \cdot dS + P_a = m \cdot c \cdot \frac{\Delta T}{\Delta t} + P_c + P_{cv} + P_r \tag{1}$$

where:

η = energy efficiency of the heating mechanism

U_{disch} = discharge voltage applied to the load

j = current density, which is often non-uniform on the surface of the components

S = surface area of the component or a part of it

m = mass of the load
c = specific heat of the load
$\Delta T / \Delta t$ = rate of the temperature rise
P_c, P_{cv}, P_r = power lost by conduction, convection and radiation
P_a = additional power, which may be resistive, radiative or conductiove from the surrounding components, etc.

When the treatment temperature is attained ($\Delta T = 0$), the whole power is dissipated to the chamber wall. The temperature of a certain area of the load is established according to equation 1 applied to that area. This equilibrium temperature can be affected by a number of factors such as local current density, pressure, distance to the anode, thermal contact with the rest of the load, etc.

At the working temperature in the range 500-550ºC, the greatest amount of the energy supplied to the work piece is dissipated by radiation according to the Stefan-Boltzmann law:

$$P_r = \varepsilon \cdot f_g \cdot \sigma \cdot (T^4 - T_w^4)(1-\rho)^n \qquad (2)$$

where:
ε = surface emissivity coefficient
f_g = geometrical factor
σ = Stefan-Boltzmann constant
T = work piece temperature
ρ = reflection coefficient of the shield
n = number of shields.

The geometrical factor f_g may cause serious problems, especially when the component presents face-to-face zones (without hollow-cathode effect). When a thermal shield is placed in front of the heated surface, at a certain distance, a share of the radiated energy is reflected back ti the surface, resulting in a reduction of the radiation losses. In some particular cases, this effect can be used to correct the temperature of the work piece.

3. SHIELDING METHOD / EXPERIMENTAL RESULTS / DISCUSSION

When small components are to be treated by plasma nitriding, they will be positioned in the treatemnt chamber so that every part will experience similar conditions (distance to the wall chamber and to the neighbouring parts). Under these circumstances, an apropiate value of the pressure may ensure good temperature uniformity.

In the case of large components, it is possible for certain areas to be subjected to different conditions compared with others. This fact may cause unacceptable temperature differences. The problem can be solved by redistribution of the input energy.

As an example of such a component, the balancing chamber of a 700MW turbine is presented in fig.1.

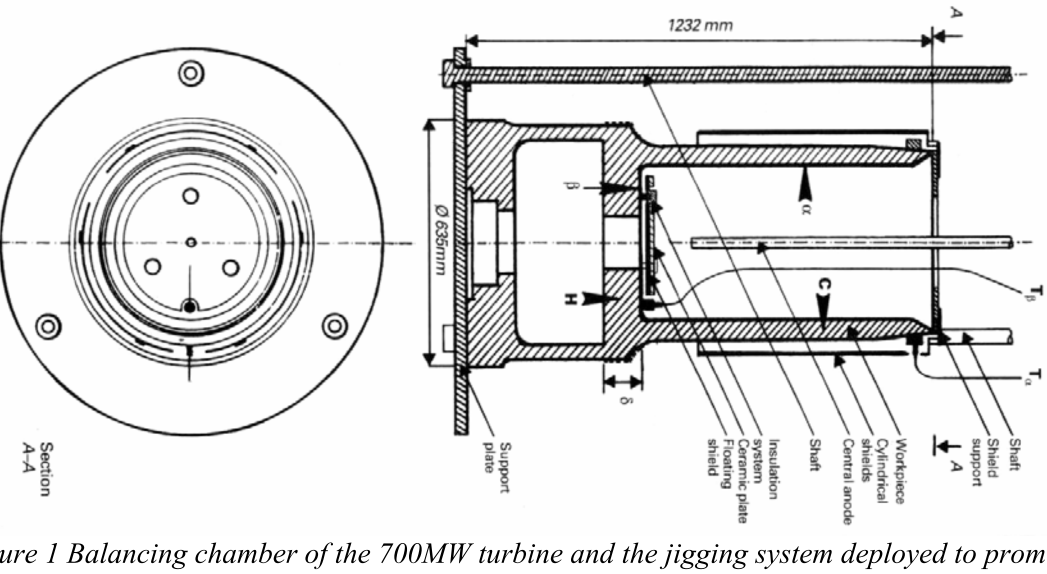

Figure 1 Balancing chamber of the 700MW turbine and the jigging system deployed to promote temperature uniformity during plasma nitriding

Weighing about 1200kg, this component is treated by plasma nitriding using a Romanian 150kW unit. The work piece is positioned on a support plate, which is hung from the top lid of the treatment chamber by means of three shafts. According to the technical documentation, only the cylindrical surface (α) is required to be treated.

Looking at the surfaces α and β, it can be seen that they experience different conditions according to the energy balance. Besides the energy supplied by the discharge, the surface β receives a large amount of energy by radiation and conduction from the cylindrial zone (C). On the other hand, the area δ presented by the horizontal zone (H) to the cooled wall of the treatment chamber is significantly smaller than that presented by the cylindrical zone, C. Considering equation 1 for the surface β, it appears that the additional power imparted by radiation from the surface α and reduction in the conductive losses are balanced by an increase in the radiation losses and, consequently, of the temperature. Experimentally, the temperature difference between surface β and α was found to be about 80ºC. If the surface α were heated up to 540ºC (nitriding temperature), the surface β would be overheated and the treatment would fail.

In order to solve this problem, two approaches are considered. One way is reducing the energy lost by the cylindrical wall, C. In order to do that, three shields, made of 1mm-thick steel sheet, have been placed around the work piece as shown in Fig.1. The distance from these shields to the external surface of the cylindrical wall is about 60mm. A central auxiliary anode has also been used. The central hole has been covered by a plate. With this arrangement the temperature difference between surface β and α has been reduced to 55ºC. The time variation of temperature and pressure during the heating process is shown in Fig.2a. Due to the energy reflected by the shield, the temperature difference T_β-T_α has been reduced by 25ºC, but it still exists.

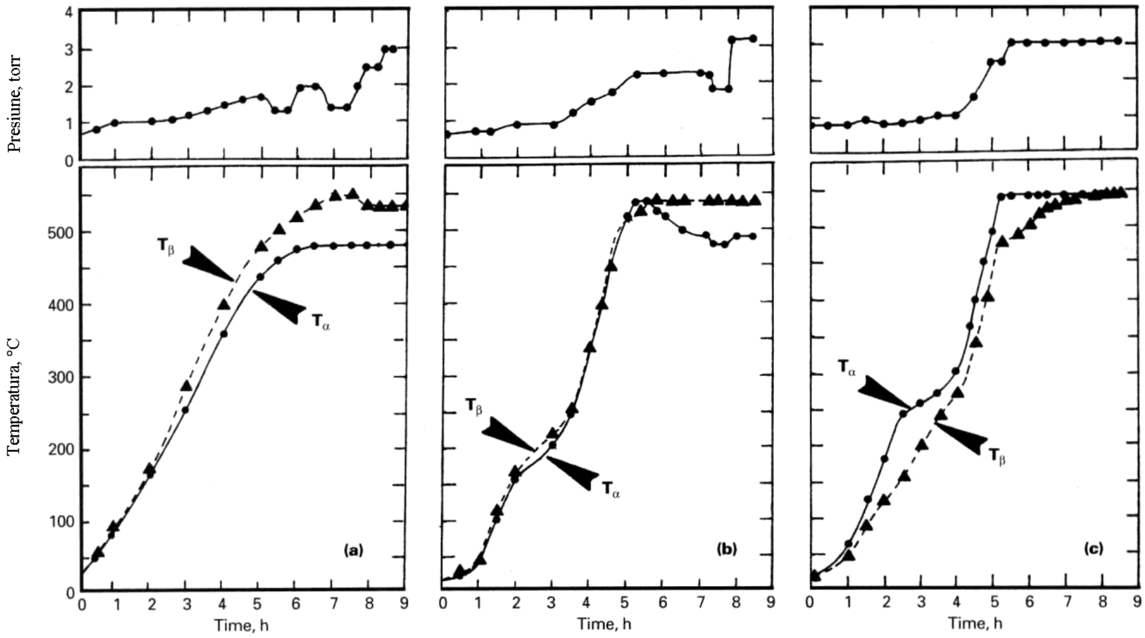

Figure 2. The relationship between temperature (T_β and T_α), pressure and plasma heating time: (a) with cylindrical shields positioned 60mm from the work piece surface; (b) with the floating shield; (c) with the floating shield and the cylindrical shields placed 30mm from the work piece surface

The other way was reducing the energy imparted to the surface β. This has been done using a floating shield insulated from the work piece by means of three special devices presented in Fig.3. The distance from the surface β to the floating shield has been adjusted to 1.5mm. during the plasma heating process, this shield is charged at floating potential and, consequently, the ion and electron current densities on it are equal. With no current on the shield, no energy is supplied by the discharge to that surface. The floating shield is heated by radiation and conduction from the cylindrical wall of the work piece. This energy is further reduced by a ceramic plate placed on the floating shield.

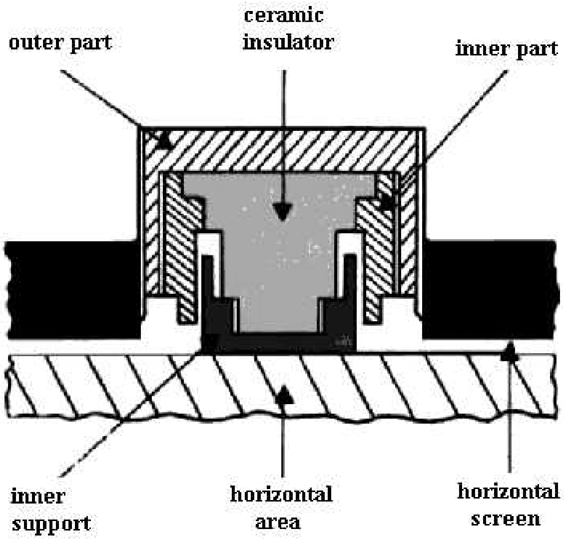

Figure 3. The insulation system of the floating shield

With this arrangement, without cylindrical shields, although there is no discharge on the surface β, T_β is 48ºC higher than T_α. The time variation of temperature and pressure is presented in Fig.2b. It is obvious that the horizontal zone (H) is mainly heated by radiation and conduction from the cylindrical wall (C), so that the direct contribution of the ischarge is not very important from the energy viewpoint. Finally, using both methods, with cylindrical shields placed at 30mm from the surface of the component, a good temperature uniformity has been obtained (Fig.2c). By adjusting the pressure, a weak hollow-cathode effect can also be produced to correct the thermal equilibrium. The appropriate pressure has been found to be 3.0torr. although during the heat-up process T_β was lower than T_α, after two hours of T_α constancy, the horizontal zone (H) has been heated to T_α temperature.

4. CONCLUSIONS

In the plasma nitriding process there are two ways to ensure the temperature uniformity of the load:

- choice of the appropriate pressure, and
- design of the jigging system, including special devices attached to the work pieces.

The shield method allows redistribution of the energy imparted to the components in order to correct the temperature for certain zones.

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