Electronic Control of Emitters' Operation for Infrared Welding of Plastic Details

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Abstract - **New approach for infrared welding of plastic details is proposed. Produced welding equipment is based on application of "light" infrared emitters – halogen lamps. By electronic control of their operation the power and spectral distribution of emitted energy are changed in dependence of welded detail's type. It is shown that by proper emitters' operation parameters adjustment the main disadvantages of light infrared emitters can be avoided and this type of infrared welding becomes proper for a lot of plastic materials. Variations of equipment's design, combined with electronic control of emitters' operation give possibility to choose optimal variant in dependence on the type of treated material, size of details, necessary time for welding process, etc.**

Keywords – **infrared welding, welding of plastic materials**

I. Introduction

Welding of plastic materials is wide used for production of many details in industry. This technological operation can be realized by different manners – by hot air heating; by contact heating; by infrared heating; by high frequency and microwave heating; by ultrasonic welding, etc. There is no method, suitable for all type of plastic details – the optimal method depends on properties of plastic material, size and peculiarity of the details, desirable productivity and quality.

Preferred methods of welding for production of eco – filters for automotive industry are by hot air and by infrared heating [1 - 5]. Welding by hot air may be successful for details made from polypropylene. When the details are from polyamide hot air welding is applicable for small details only. When material is polyamide filled with glass particles welding with hot air doesn't give good results. More over, at hot air welding energy consumption is too big. It is combined with big compressed air consumption. Both of them are too expensive.

Welding by infrared (IR) heating is widely used for this type of details for automotive industry and may be classified according to spectral characteristics of used radiation.

Welding of plastic details by radiation from the middle infrared spectral region (2.5µm ≤ λ ≤ 10µm) is preferred. Almost all plastic details used in industry absorb radiation from this spectral region very well independently of their colours. Many kind of infrared emitters for the middle IR region are used in industry [1-5]. Some of them possess good effectiveness to transfer electric energy (or energy from gas burning) to radiation's energy. But almost all of known infrared emitters have a big disadvantage – they are too inert. That is why it is difficult to control thermal processes, especially when they are short, like welding with duration about 10 – 40 seconds.

When the radiation used during welding process is from the near IR spectral region (λ ≤ 2.5µm) usually emitters are halogen lamps.

The disadvantages of this type of emitters are well known. The effectiveness of application of radiation from the near infrared spectral region depends on the details' colours. It's a problem to achieve uniform radiation's intensity onto large areas; control of the parameters of lamps' operation isn't simple; the life of the halogen lamps in real production conditions isn't long enough [4, 5].

In the same time halogen lamps have some considerable advantages - they allow achieving of big intensity of the radiation over the treated area; they are cheap and wide spread; their radiation's parameters can be controlled very fast (in time interval less than 1s), which is very important for welding processes with duration of 10 s – 40 s.

In this paper a method for operation control of welding equipment with halogen lamp is proposed. Its application allows avoiding the main disadvantages of light emitters and makes this equipment suitable for welding of various plastic materials.

II. Problem Statement

Generally, the problems during welding of plastic details by halogen lamps for automotive industry are connected with:

- Spectral distribution of emitted energy – the radiation is mostly from the visible and near infrared spectral region. It is well absorbed from black and grey colour plastics, but well reflected from light colour materials.
- The radiation from the visible and near infrared spectra is absorbed in a very thin surface layer and doesn't penetrate in the depth of the material. This may cause surface overheating and destruction of surface plastic layer.
- Plastics should be melted to the depth of 1 mm upon the whole area.
- The thickness of the details is between 3 mm and 4 mm; during melting of upper 1 mm layer the detail should not change the shape.
- The surface of melted plastic materials should not be overheated. If its surface temperature is raised over determined temperature for material in use the sample surface layer destructs, which worsen strongly adhesion and properties of welded joints.
- The duration of the process must be short for good productivity. On the other hand the time of the heating

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must be long enough to melt the detail to the desirable depth without preheating the surface.

To achieve good quality of the products it is necessary to have possibility for precise control of IR radiation intensity with high rate, because during this technological process conditions change fast: the heaters and details move; atmosphere in the heating volume is changed at every welding cycle; fixture accessories are with different temperatures, etc.

III. EXPERIMENTAL EQUIPMENT

A. Emitters

Light infrared emitters are widely used in industry for a lot of technological purposes [1, 2]. Usually they are halogen lamps with different shape, dimensions and power. The halogen lamps used at these investigations are produced from Sylvania Ltd; type R7s; power 1000W; 230V; Max. length 189 mm; diam. 12 mm; colour temp. 3000 K; aver. life 2000 h.

Radiation emitted from halogen lamps is from the visible and near infrared spectral region ($\lambda \leq 2.5\mu m$). Spectral distribution of the radiation determines its interaction with treated material and limits its application.

The part of radiation which is absorbed from the object depends on the spectral absorptivity of the treated material. This characteristic may depend strongly on the colour of the object, even if the plastic material is the same. Absorptivity of colour objects is very low for radiation from the visible and near infrared spectral regions. That is why application of light emitters for welding of this kind of objects is not effective.

The radiation from halogen lamps is absorbed in a very thin surface layer of the material (it doesn't penetrate in the depth) and heats it. The overheating of surface of plastic material during welding is very probable, as a result of this surface layer's destruction worsens strongly welded joints' quality.

Some other disadvantages of halogen lamps are connected with their electric characteristics. When they are cold at the beginning of operation the initial current through them is 4 – 5 time bigger than the nominal one. When the power of heating unit is big (over 10 – 15 kW) the start may be a problem. It is desirable to realize "soft start" of the lamps at lower voltage supply. At the same time it will increase a lot the life of lamps.

B. Solution of problems

The solution of main problems connected with welding of plastic details by radiation from halogen lamps is based on Thermal radiation's laws.

The nominal power P_1 of used lamps is 1000 W at voltage supply 230 V.

$$P_1 = U_1 . I_1 = U_1^2/R_1 = 1000 \text{ W}. \qquad (1)$$

Where R_1 is nominal resistance of lamp, I_1 = 4.34 A is the nominal current through it.

The maximum λ_m in the spectral distribution of the radiation of lamp can be calculated by Wien's law:

$$\lambda_m = 2898/T \text{ , } \mu m, \qquad (2)$$

where T is the temperature of the radiating object.

The colour temperature of these type halogen lamps is 3000 K. From (2) the calculated maximum in the spectral distribution of the radiation λ_m = 0.97 μm.

If the operating voltage supply for lamps is decreased the power will decrease too. The colour temperature of lamps will decrease and the spectral distribution of emitted energy will be moved to longer λ. Then part of radiation energy will belong to the middle infrared spectral region. This radiation penetrates in the depth of the material; the overheating of surface layer can be avoided and quality of welded joints will rise significantly.

The influence of value of voltage supply can be evaluated by Boltzmann's law. If it is supposed that the whole electric power is transferred by lamp into radiation energy:

$$P_1 = U_1.I_1 = \varepsilon\sigma S T_1^4 = 1000 \text{ W}, \qquad (3)$$

where σ is Boltzmann's constant; ε is emissivity, and S is radiating surface of lamp; T_1 is temperature of lamp at nominal voltage supply.

At other values of voltage supply U_2 the power of lamp can be expressed:

$$P_2 = U_2.I_2 = \varepsilon\sigma S T_2^4 . \qquad (4)$$

By dividing the equations (3) and (4):

$$(1000/ U_2.I_2) = (T_1/T_2)^4 = (3000/T_2)^4 . \qquad (5)$$

If the power of lamp ($U_2.I_2$) at voltage supply U_2 is known colour temperature T_2 can be calculated.

The expression $P = U^2/R$ (1) looks to be more suitable for calculations, but tungsten's thermal resistance coefficient is big (about $5.2.10^{-3}$ K^{-1}) and lamp's resistance change significantly at different temperatures (at different voltage supply). That is why for these type halogen lamps experiments are made and current's values are measured at different values of voltage supply. Some examples are shown in Table 1.

TABLE 1. Current, power, colour temperature and wavelength λ_m at maximum of spectral distribution of emitted energy at different voltage supply for halogen lamps.

U_2, V	I_2, A	P, W	T_2, K	λ_m , μm
230	4.34	1000	3000	0.97
150	3.42	513	2539	1.14
130	3.15	410	2400	1.21
110	2.91	320	2255	1.29

Spectral distributions of radiation emitted by lamps can be calculated by Plank's law (6):

$$E(\lambda,T) = \frac{C_1}{\lambda^5}\frac{1}{e^{\frac{C_2}{\lambda T}}-1} \qquad (6)$$

Here λ is the wave length, T is the heater's surface temperature, and $C_1 = 3{,}74.10^{-16}$ W.m^2 , $C_2 = 1{,}4388.10^{-2}$ m.K are first and second Plank's constants.

Results for spectral distribution of energy emitted by lamp at values of voltage supply, shown in Table 1, are presented in Fig. 1.

As it can be seen from Fig. 1 and Table 1, decreasing of voltage supply causes significant decrease of radiation's power (Table 1; the areas below the curves in Fig.1). This is not a problem – the necessary intensity of radiation for welding of plastics can be reach by proper choice of number of lamps placed over the treated object. The most important effect is displacement of spectrum of emitted radiation to longer wavelength. Part of radiation penetrates in the depth of the detail, in this way the overheating of surface plastic layer can be avoided.

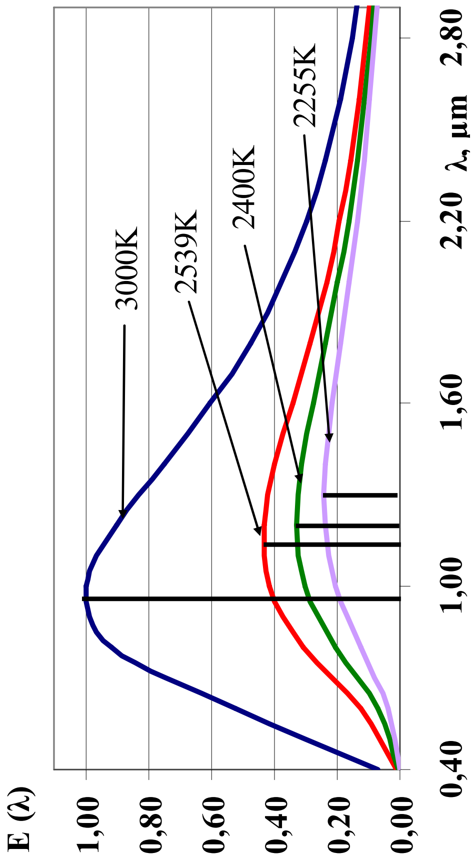

Fig.1. Spectral distribution of radiation (relative units) emitted by halogen lamps at different values of voltage supply: at (r.m.s.) 230V (3000K); at 150 V (2539K); at 130 V (2400K); at 110 V (2255K).

A scheme of experimental welding equipment is shown in Fig. 2 and photo of experimental infrared heater with halogen lamps used in it – in Fig. 3.

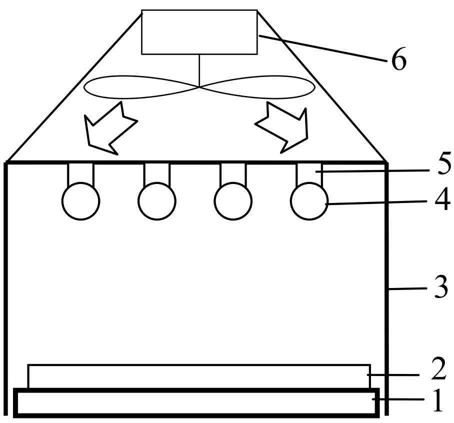

Fig.2. Scheme of experimental welding equipment for plastic details with halogen lamps. 1 – fixture accessory for the detail; 2 – plastic detail; 3 – reflectors; 4 – halogen lamps; 5 – fixture accessory for lamps; 6 – fan.

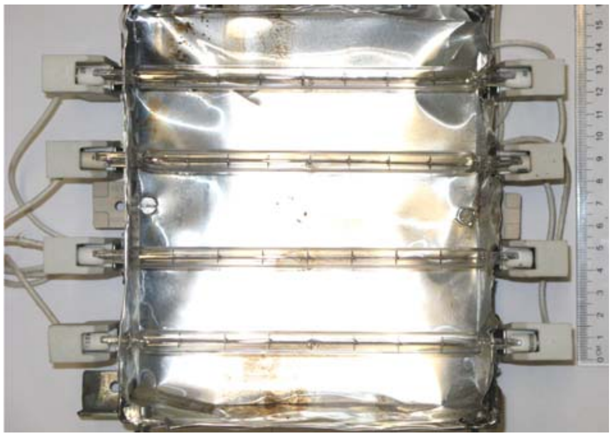

Fig.3. Photo of experimental infrared heater for welding of plastic details with halogen lamps. Nominal power 4 kW (at 230V).

C. Electronic control unit.

Important problem for successful realization of welding equipment is connected with electronic control of voltage supply necessary for halogen lamp's operation at proper voltage values, Table 1. Electronic control of voltage supply is very important because the operating conditions during welding process change significantly. One operating cycle includes next steps:

- the heating camera is empty and closed for about 15 – 20 seconds;
- then the corps 3 (Fig. 2) is lifted up, the detail on the fixture accessory comes in;
- the corps is moved down;
- the melting of the surface layer of the plastic detail passes (about 15 – 20 seconds);
- the corps 3 is lifted;
- the detail on the fixing accessory is moved out;
- the corps is moved down.

The conditions during these operations may be very different – the temperature of the ambient air, the temperature of the details and fixing accessory may vary significantly. That's why to keep the voltage supply constant is absolutely obligatory. This ensures constant colour temperature of the lamps, respectively constant irradiation intensity and allows achieving repeatability of the production conditions.

There are a lot of voltage regulators on the market, but they have essential disadvantages – they are too expensive, too big and heavy. The power of welding equipment for upper described purposes usually is big – over 8 kW (two or three heaters like the one in Fig. 3) for one machine. It turned out to be impossible to find proper voltage regulators for these purposes – if standard regulators are used, the price, dimensions and weight of the welding machine will be unacceptable. The solution of this problem is regulator [6] whose scheme is shown in Fig. 4.

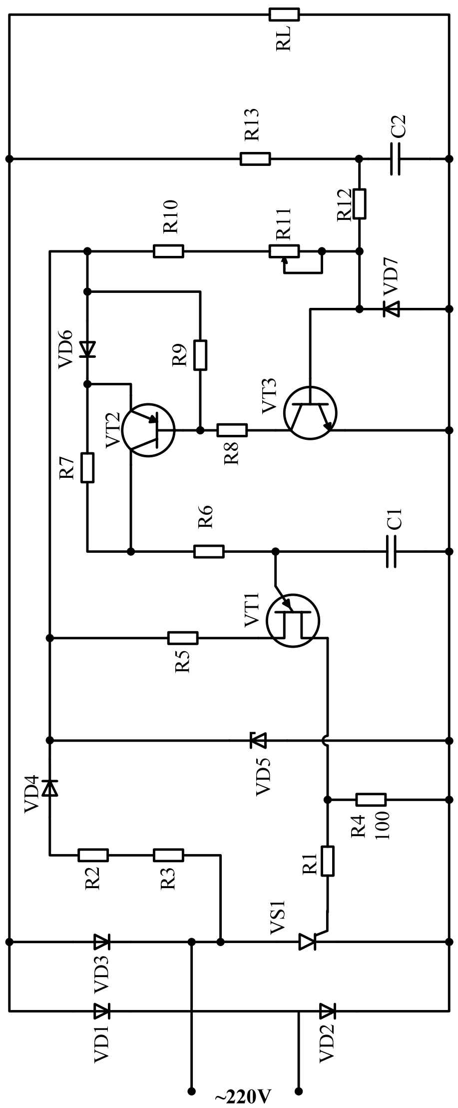

Fig.4. Voltage regulator for halogen lamps.

This regulator is simple, small size and works well. Voltage regulation factor is about ten [6], which is absolutely enough for our purposes. Voltage at its output can be adjusted by R 11 from 110 V to 210 V (r. m. s.) [6]. Voltage feedback is realised by R 13 and C 2. The power of the load RL can be big at proper choice of diodes VD1 ÷ VD3 and thyristor VS1. If they are for nominal current 80 ÷ 100 A the regulator is compact and suitable for developed welding equipment.

A welding machine is produced and operates at real production conditions according to principles presented above. The operating voltage for halogen lamps is about 120V – 130 V. The soldering process passes without overheating of surface plastic layer (polyamide, polyamide with glass) and the quality of welded joints is very good. High quality of welding joints for polyamide details filled with glass particles is combined with small duration of the process (less than 20 s), which was impossible earlier. The productivity and the quality of the production were raised.

IV. Conclusion

Welding equipment for plastic details based on halogen lamps is developed and tested at real production conditions. By electronic control of r. m. s. voltage for halogen lamps the spectral distribution of its radiation is changed and good quality and high productivity of the welding process are achieved. In comparison with other welding methods this one shows a lot of advantages:

- best quality of welding joints combined with small duration of the process (less than 20 s);
- uniformity of the welding joints onto large areas;
- possibility to weld details with complicated shapes;
- minimal deformation of details with complicated shapes in comparison with other methods;
- high accuracy of the control;
- reproducibility of the welding process' parameters.

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