IMPROVING THE PARAMETERS OF AN INDUCTIONAL SURFACE HARDENING FOR ONE FREQUENCY AND DIFFERENT SPECIFIC POWERS PER CM^2

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One of the main purposes of this article is to make a comparison among inductional heating for one working frequency of 30 kHz and different specific powers per cm^2. Another task is to make a volume analyze of the surface and the whole volume of the hardened object and at the same time to define the quality of the hardening and the one of the internal part of the dense cylindrical detail.

Keywords: hardening, specific power, working frequency, thermal losses, thermal efficiency.

For clarifying the regularities according to the heat transfer in the process of surface inductional hardening in this article a few dependencies that are typical for electrical phenomena are used.

The most useful advantage of the method described in this article is the dependence of the hardened surface in function of the working frequency. The increasing of the working frequency influences not only on the energy given to the hardened detail but improves the quality of the hardened part of it.

INDUCTANCE LAW

As we can seen by the name of the method in the heated surface flow currents caused by an induction. The heated object (detail) is placed in a magnetic field that cuts the detail in depth that depends on the frequency used. When the working frequency is high enough the field cuts the object in a small (skin) surface. The magnetic field fades rapidly in the internal volume. The depth of the penetration is given by the formula bellow:

(1) $\Delta = 503\sqrt{\frac{\rho\mu}{f}}$, where

$\boldsymbol{\rho}$ is the specific resistance, $\boldsymbol{\mu}$ - the magnetic permeance (μ=1 for temperatures above the Curie point) and $\boldsymbol{f}$ is the working frequency.
If the magnetic flux caused the field in the inductor is Φ then the energy inducted in the detail we will get (2).

(2) $e = -\frac{d\Phi}{dt}10^{-8}$

When the magnetic field is absolutely sinusoidal and it is with frequency – $\boldsymbol{f}$ for the effective value of the magnetic flux will be:

(3) $E = 4{,}44.n.f.\Phi.10^{-8}V$,where

n is the number of the windings of the inductor. Let us consider that ***n***=1.

If the two sides of the equation multiply by ***I*** – the effective value of the current that flows through the object in function of the flux F we will get (4).

(4) $P'' = E.I = 4{,}44.I.f.\Phi.10^{-8}\,VA$

Then for the power given in the heating object we can say:

(5) $P = E.I.\cos\varphi = 4{,}44.f.\Phi.I.10^{-5}\cos\varphi$ kW

For showing the distribution of the temperature in the object's volume we will examine a solid cylinder.

The main targets of the investigation will be:

1. Superheating of the surface of the hardened object ***ΔT*** – defines the deference between the needed temperature for hardening – X_k and the real temperature of the objects surface.

We can calculate the thermal efficiency that is based on the distribution of the temperature in all object's volume. This efficiency will show us what part of the energy given to the object is useful and what is the number of the thermal loses.

To define these quantities we will use the heating system equation.

(6) $\frac{d\theta}{dt} = a\frac{d^2\theta}{dx^2}$, where

$\theta = T - T_0$ is the difference between the reached temperature of the measured layer – T and T_0=20ºC is the temperature where the heating started, ***x*** is the depth of the penetration and ***a*** is a heating system coefficient $a = \frac{\lambda}{c.\gamma}$.

The heating transfer coefficient – ***λ***, the relative heating capacity – ***c*** and the relative density – ***γ*** as the coefficient ***a*** change with the temperature. We accept average values for ***a*** and ***γ*** coefficients for the temperature interval from 20ºC to 850ºC. In the common case ***a***=0,1 cm.sec and ***γ***=0,06 kcal/ºC.

We assume that the heat quantity given to a 1 cm^2 surface for one second is q_0 [kcal/cm^{2}sec]. From the dependence 1kW=239 kcal/sec, for the moment power ***p*** we can find the equation (7).

(7) $q_0 = 239.p$

The power consumed in the process of the inductional heating changes with the time. We can say that the consumed power is a function of the time and it is given by (8).

(8) $Q = \int_0^t p.dt$

The relative temperature – ***θ*** of the heated object reached in the moment ***t*** can be given by the following equation.

(9) $\theta = 239.\frac{2.p.r_0}{\lambda}\left\{\frac{\alpha.t}{r_0^{\,2}} + S\right\}$, where

r_0 is the radius of the heated detail.

(10) $$S = \frac{2.r_0}{\xi} . \frac{1-\frac{\xi}{r_0}}{2-\frac{\xi}{r_0}} \sum_{n-1}^{\infty} \frac{J_1(\nu_n.\alpha) J_0(\nu_n.\beta)(1-e^{-\nu_n^2 \tau})}{\nu_n^3 [J_0(\nu^n)]^2}$$

(11) $\alpha = 1 - \frac{\xi}{r_0}$ and $\beta = 1 - \frac{x_k}{r_0}$, where

J_0 and ***J_1*** are Bessel's functions of 0 and 1^{-st} power
ν_n are the roots of the equation $J_1(\nu_n)=0$

(12) $$\theta = 239. \frac{2.p.r_0}{\lambda} \left\{ \frac{at}{r_0^2} + S \right\}$$

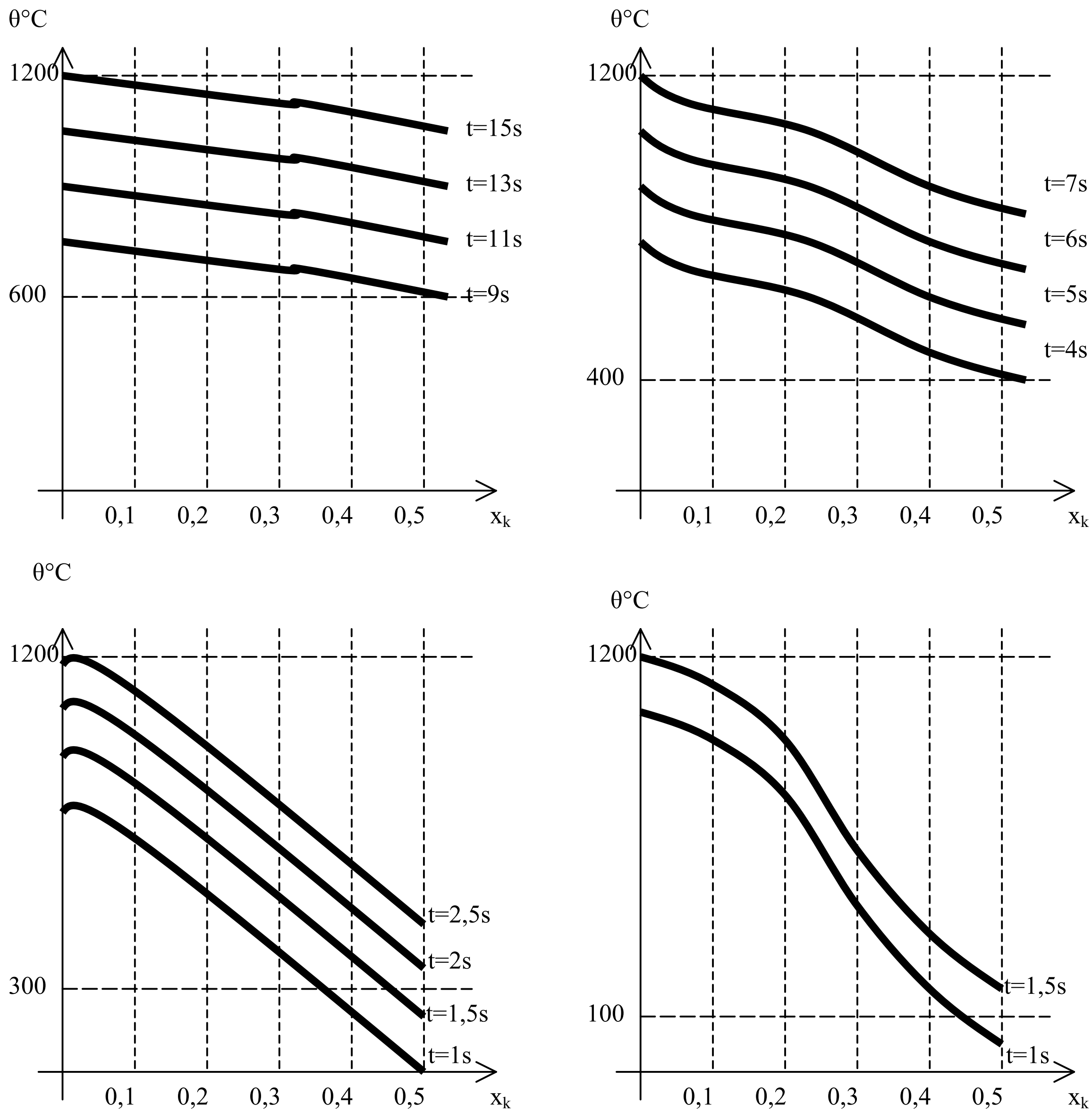

Figure 1. The dependence between the inside temperature and the different specific power [kW/cm²] used for induction heating.

Figure 1 shows the distribution of the temperature inside of the hardened cylindrical object. It is based on the equation (12) considering that $\boldsymbol{x=x_k}$, $\boldsymbol{t=t_k}$ and $\boldsymbol{\theta=\theta_k}$.. Here the depth of the penetration – $\boldsymbol{x_k}$ is variable (depend on the frequency) and the radius of the object $\boldsymbol{r_0}$ is 10 mm. Different times for heating and different powers are presented in one figure to clear the differences between them.

As you can see from figure 1 the thermal efficiency can be calculated using the equation (13).

$$(13) \quad \eta = \frac{1}{239}.\frac{\lambda}{a}.\frac{\theta_k}{p}.\frac{x_k}{t_k}(1-\frac{\xi}{2.r_0})$$

We can find the value of t_k using equation (12).

CONCLUSION

From the formulas, text and figures given above we can say that to increase the power applied to a cm^2 for approximately one frequency $\boldsymbol{f}$ and the same $\boldsymbol{\cos\varphi}$ of the system inductor-heated object ($\boldsymbol{\cos\varphi}\approx 0,8$ for $\mu=1$) we have to increase the voltage – $\boldsymbol{E}$ and as follows the current $\boldsymbol{I}$ inducted in the detail.

1. This is the way for decreasing the thermal losses in the heated detail and at the same time for increasing the thermal efficiency.
2. From the calculations made and the figures that were plotted on them we can see that increasing the specific power given to the surface of the heating object the overheating of the detail's surface decreases. When the specific power $\boldsymbol{P}$ reaches values more than 2 kW/cm^2 the overheating of the surface becomes approximately zero.
3. When the specific power increases the heating time decrease, therefore the productivity increases too.
4. The quality of the hardened surface improves if the conditions of cooling are kept. The whole volume except the hardened surface keeps its basic characteristics.
5. The disadvantages of this hardening device are its big mounted power, that increases the device's sizes and cost.

The calculations made are for frequency $\boldsymbol{f=30kHz}$.

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