



*:Introduction*

:

.

.

.

. ( ) .

-

.

. *Work – Coil*

.

:

-

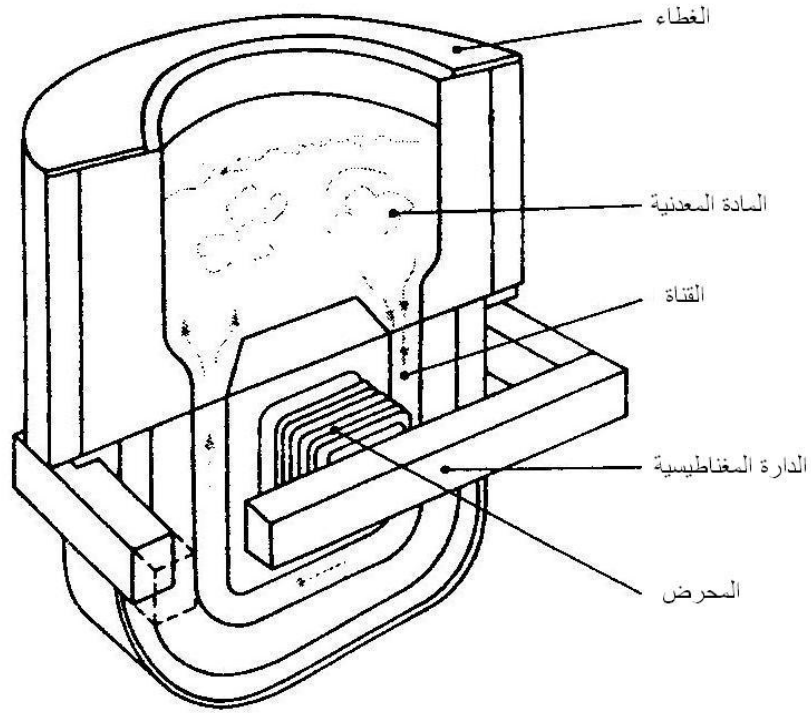
.

.

*50 Hz*

( - )

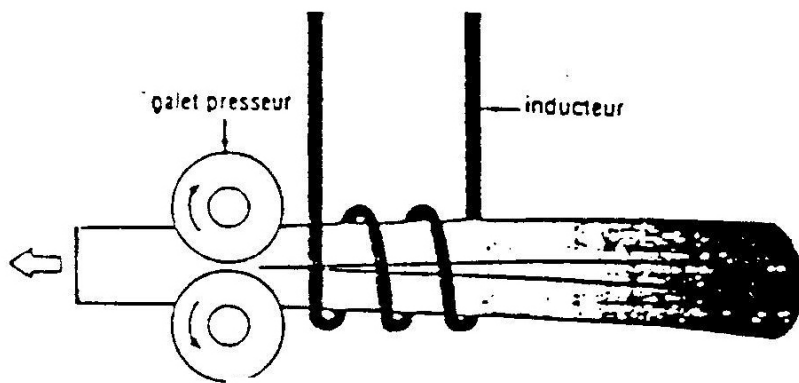
.



( - )

:

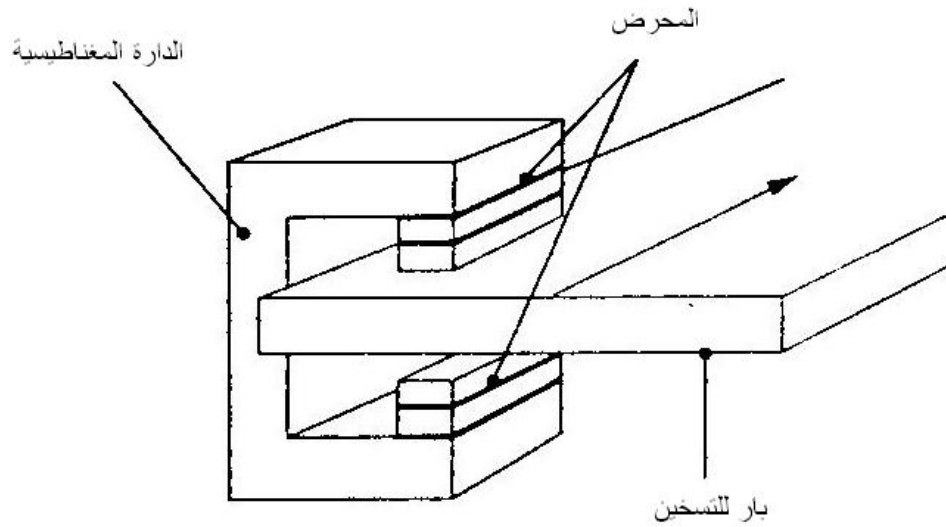
. ( 500 - Hz )



( - )

( - )

( - ) (Billettes)

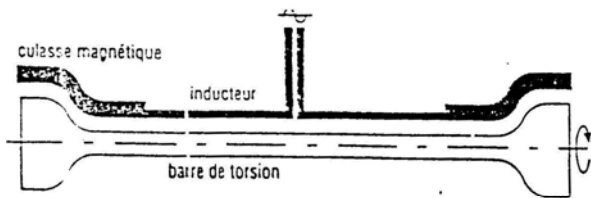


( - )

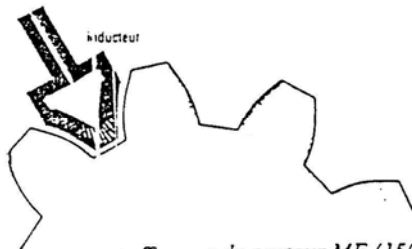
:

850 C°

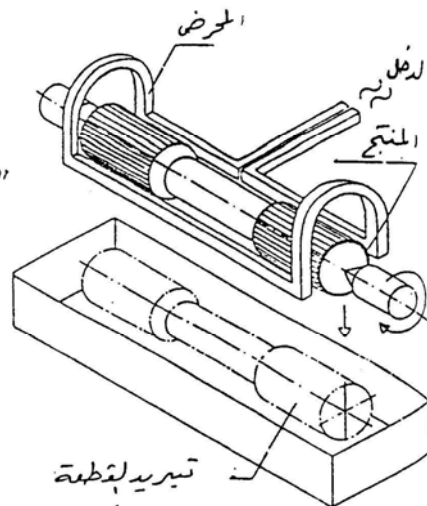
%



: Inducteur linéaire pour trempé de contour: barre de torsion



: Trempé de contour MF (150kW-8kHz)  
dent par dent de grosses couronnes dentées



( - )

*Describe the Induction Heating System :*

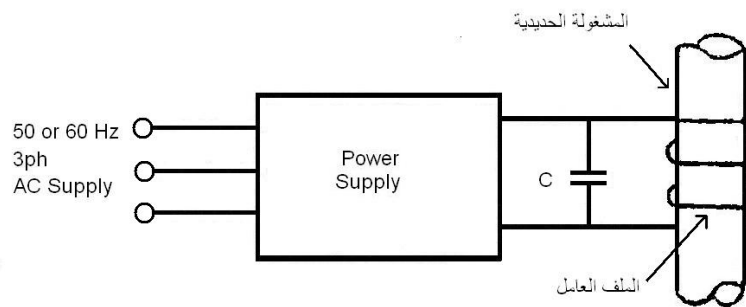
:

:

$C$

$L$

( - )



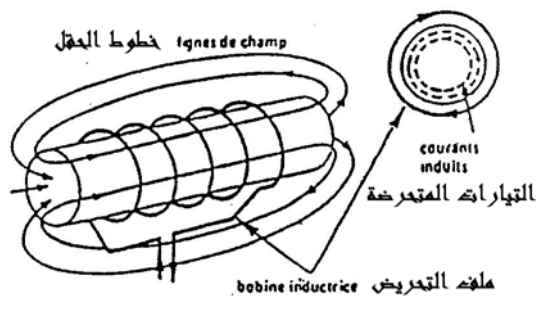
( - )

:

*The Affect Factories through the working of the Induction Heating:*

( )

( )



( )

( )

Joll Effect ( )

$$p_2 = E_2 I_2 \cos(E_2 \cdot I_2)$$

(2-1)

:  
 $E_2$   
 $I_2$   
 $E_2 \cdot I_2$

$$E_2 = \omega \phi_\omega$$

(2-2)

:  
 $\phi_\omega$  :  $\omega$

$$I_2 = \frac{E_2}{\sqrt{R_2^2 + L_2^2 \omega^2}}, \quad \cos(E_2, I_2) = \frac{R_2}{\sqrt{R_2^2 + L_2^2 \omega^2}} \quad ( - )$$

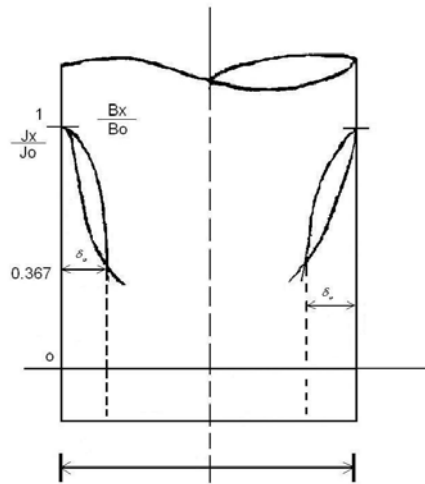
$$P_2 = E_2 \frac{E_2}{\sqrt{R_2^2 + L_2^2 \omega^2}} \frac{R_2}{\sqrt{R_2^2 + L_2^2 \omega^2}} = \phi_\omega^2 \omega^2 \frac{R_2}{R_2^2 + L_2^2 \omega^2}$$

$\phi_\omega, R_2, L_2$

:Skin - depth

( - )

$$\delta_\omega \quad ( - ) \quad [S] \quad 0.367$$



( - )

:  $\delta_\omega$

$$\delta_\omega = \sqrt{\frac{\rho}{\pi \mu_0 \mu_r f}} \quad (2-4)$$

:  $\delta_\omega$

$$.4\pi \times 10^{-7} H/m$$

:  $\mu_0$

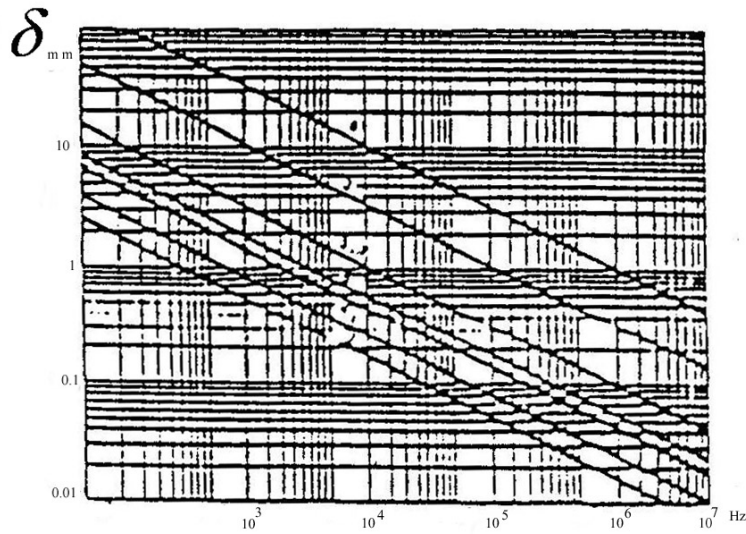
:  $\mu_r$

.Hz :  $f$

. $\Omega m$  :  $\rho$

%

. $\delta_\omega$   
( - )



( - )

: Curie Point

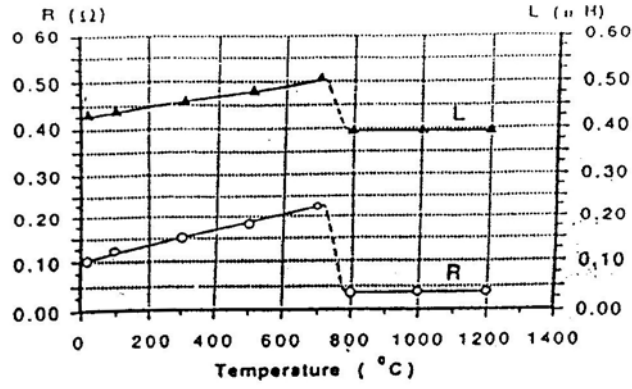
740C°

$f_o$

(R, L)

(R, L)

( - )



( - )

.L

$R_2$

( - )

$R_2$

$r$

$h$

:

$$P_2 = I_2^2 R_2$$

(2-5)

$I_2$

$R_2$

:

$$R_2 = \rho \frac{2\pi r}{\delta_\omega h} = \frac{2\pi r}{503h} \sqrt{\rho \mu_r f}$$

(2-6)

$\mu_r$

$R_2$

$\rho$

:

*Distribution of the Magnetic Field inside the Work – Piece*

$$\nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t} \quad (2-7)$$

$$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t} = -\mu \frac{\partial \bar{H}}{\partial t} \quad (2-8)$$

$$\frac{\partial \bar{D}}{\partial t} \quad ( - )$$

$$\nabla \times \bar{H} = \bar{J} = \sigma \bar{E} \quad (2-9)$$

$$\nabla \times \nabla \times \bar{H} = \nabla \times \bar{J} = \sigma \cdot \nabla \times \bar{E} \quad (2-10)$$

$$: \quad ( )$$

$$\nabla \times \nabla \times \bar{H} = -\mu \frac{\partial \bar{H}}{\partial t} j \omega \mu \sigma \underline{H} \quad (2-11)$$

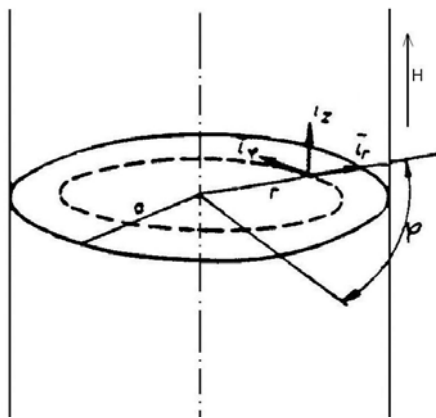
$$\nabla \times \nabla \times \bar{H} = \nabla(\nabla \cdot \bar{H}) - \nabla^2 \bar{H} \quad (2-12)$$

$$\nabla \times \bar{H} = 0 \quad (2-13)$$

$$\nabla^2 \bar{H} = \mu \sigma \frac{\partial \bar{H}}{\partial t} = j \omega \mu \underline{H} \quad (2-14)$$

Z

$$( - )$$



$$( - )$$

$$\bar{H} = H_z \bar{l}_z \quad Z$$

$$\nabla \times \nabla \times \bar{H}$$

( ) r Z H

$$\nabla \times \bar{H} = -\frac{\partial H_z}{\partial r} \bar{i}_\varphi \quad (2-15)$$

$$\underline{H}_z = \underline{H}_{za} \frac{J_0[(j-1)r/\delta_\omega]}{J_0[(j-1)a/\delta_\omega]} \quad (2-16)$$

$$\underline{J}_\varphi = \frac{\underline{H}_{za}}{\delta_\omega} (j-1) \frac{J_1[(j-1)r/\delta_\omega]}{J_0[(j-1)a/\delta_\omega]} \quad (2-17)$$

$$\underline{E}_\varphi = \frac{\underline{H}_{za}}{\sigma \delta_\omega} (j-1) \frac{J_1[(j-1)r/\delta_\omega]}{J_0[(j-1)a/\delta_\omega]} \quad (2-18)$$

$a/\delta_\omega$

:

$$\underline{H}_z (r \rightarrow 0) \cong \frac{\underline{H}_{za}}{J_0 \left[ (j-1) \frac{a}{\delta_\omega} \right]} \quad (2-19)$$

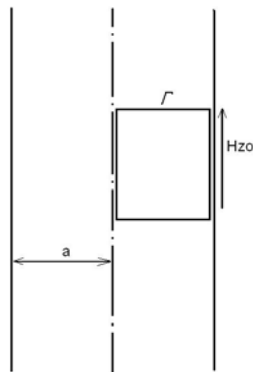
$r$   $h$

$\Gamma$

: ( - )

$$\int \underline{H} \cdot d\bar{l} = \underline{H}_{za} h = \iint_S \bar{J} \cdot d\bar{s} = I \quad (2-20)$$

: I . : h



( - )

$$H_{za} = I / h \quad (2-21)$$

:

### Distribution the heat in the work Piece

$r$

$:r = a$

$$\bar{S} = \bar{E}_{ef} \times \bar{H}_{ef} = \frac{H_{zaef}^2}{\sigma \delta_\omega} (j-1) \frac{J_1[(j-1)a / \delta_\omega]}{J_0[(j-1)a / \delta_\omega]} \bar{i}_r \quad (2-22)$$

$:[S]$

$$P_2 = \text{Re} \left\{ - \int \bar{S} d\bar{s} = \int \frac{H_{zaef}^2}{\sigma \delta_\omega} (j-1) \frac{J_1[(j-1)a / \delta_\omega]}{J_0[(j-1)a / \delta_\omega]} h a d\varphi \right\} \quad (2-23)$$

$$P_2 = \frac{2\pi a}{h \delta_\omega \sigma} \text{Re} \left\{ (j-1) \frac{J_1[(j-1)a / \delta_\omega]}{J_0[(j-1)a / \delta_\omega]} \right\} I_{2ef}^2$$

: ( - )

$$P_2 = \frac{2\pi a}{h \delta_\omega} PF \left( \frac{a}{\delta_\omega} \right) I_{2ef}^2 \quad (2-24)$$

:

$$\frac{a}{\delta_\omega} \quad F \left( \frac{a}{\delta_\omega} \right) \quad p$$

$h$

$.I$

$\delta_\omega$

$h$

:

$$d = 2a \quad ( - )$$

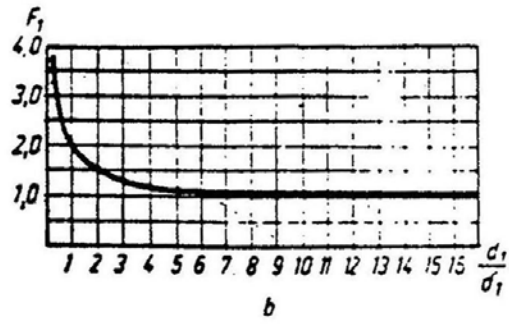
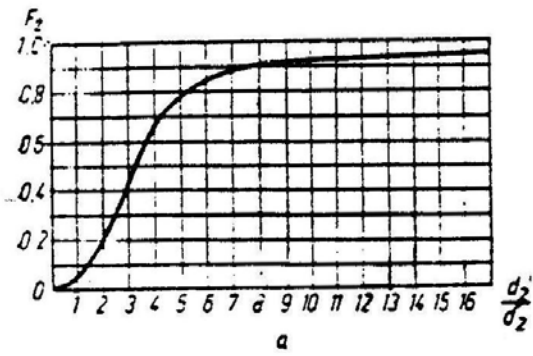
$$F \left( \frac{a}{\delta_\omega} \right)$$

.

$$F1 \left( \frac{d_1}{\delta_\omega} \right)$$

.

$$F2 \left( \frac{d_2}{\delta_\omega} \right)$$



( - )

:

Calculate Efficiency of Induction heating

$\eta$

$P_2$

:

$$\eta = \frac{P_2}{P_1 + P_2} \quad (2-25)$$

$:P_2$

$:P_1$

$:I_2$

$:I_1$

$$K = \frac{I_2}{I_1} \quad :K$$

$:R_1$

$:R_2$

$$P_1 = R_1 I_1^2 \quad (2-26)$$

$$P_2 = R_2 I_2^2 = R_2 K^2 I_1^2 \quad (2-27)$$

:

$$\eta = \frac{1}{1 + \frac{P_1}{P_2}} = \frac{1}{1 + \frac{1}{K^2} \frac{R_1}{R_2}} \quad (2-28)$$

:  $\delta_1 \quad \delta_c \quad \delta_2 \quad \delta_\omega \quad ( - )$

$$R_2 = \frac{\pi d_2}{h_2 \delta_2} \rho_2 F_2 \left( \frac{d_2}{\delta_2} \right) \quad (2-29)$$

$$R_1 = \frac{\pi d_1}{\frac{h_1}{N} \delta_1} \rho_1 N F_1 \left( \frac{d_1}{\delta_1} \right) = \frac{\pi d_1}{h_1 \delta_1} \rho_1 N^2 F_1 \left( \frac{d_1}{\delta_1} \right) \quad (2-30)$$

( - ) ( - ) ( - ) ( - )

:

$$\eta = \frac{1}{1 + \left( \frac{N}{K} \right)^2 \frac{\delta_2 \rho_1 d_1 h_2 F_1(d_1 / \delta_1)}{\delta_1 \rho_2 d_2 h_1 F_2(d_2 / \delta_2)}} = \frac{1}{1 + \left( \frac{N}{K} \right)^2 \sqrt{\frac{\rho_1}{\rho_2 \mu_{r2}} \frac{d_1 h_2 F_1(d_1 / \delta_1)}{d_2 h_1 F_2(d_2 / \delta_2)}}} \quad (2-31)$$

( - )

(d/δ)4

F<sub>1</sub>(d<sub>1</sub>/δ<sub>1</sub>)/F<sub>2</sub>(d<sub>2</sub>/δ<sub>2</sub>)

F<sub>1</sub>/F<sub>2</sub> ≅ 1

. d / δ ≅ 4

:

d<sub>1</sub>h<sub>2</sub> = d<sub>2</sub>h<sub>1</sub>

$$\eta = \frac{1}{1 + \left( \frac{N}{K} \right)^2 \sqrt{\frac{\rho_1}{\rho_2 \mu_{r2}}}} \quad (2-32)$$

:

(μ<sub>r2</sub> = 1)

$$\eta = \frac{1}{1 + \left( \frac{N}{K} \right)^2 \sqrt{\frac{\rho_1}{\rho_2}}} \quad (2-33)$$

50%

(ρ<sub>1</sub> = ρ<sub>2</sub>)

. (ρ<sub>1</sub> > ρ<sub>2</sub>)

:

*Calculate the Electricital Amount for the Induction Heating*

:

$$U = (R_1 + k^2 R_2) I_1 + j \omega (L_1 - k^2 L_2) I_1 \quad (2-34)$$

:U

:R<sub>1</sub>, R<sub>2</sub>

:L<sub>1</sub>, L<sub>2</sub>

:K

:ω

*Calculate the Inductive Factor and Mutual Factor for the Induction Heating*

:

$$L = \frac{1}{2} N^2 d_1 F_1' \cdot 10^{-9} H \quad (2-35)$$

$$M = \frac{1}{2} \pi^2 d_2 N_1 \frac{d_2}{h_2} \sqrt{F''} \cdot 10^{-9} H \quad (2-36)$$

:

:N

:μ

:A

:h

:D

.(d/h)

:C<sub>L</sub>

.( - )

F'

:h<sub>1</sub>, h<sub>2</sub>

:d<sub>1</sub>, d<sub>2</sub>

.(N<sub>2</sub> = 1)

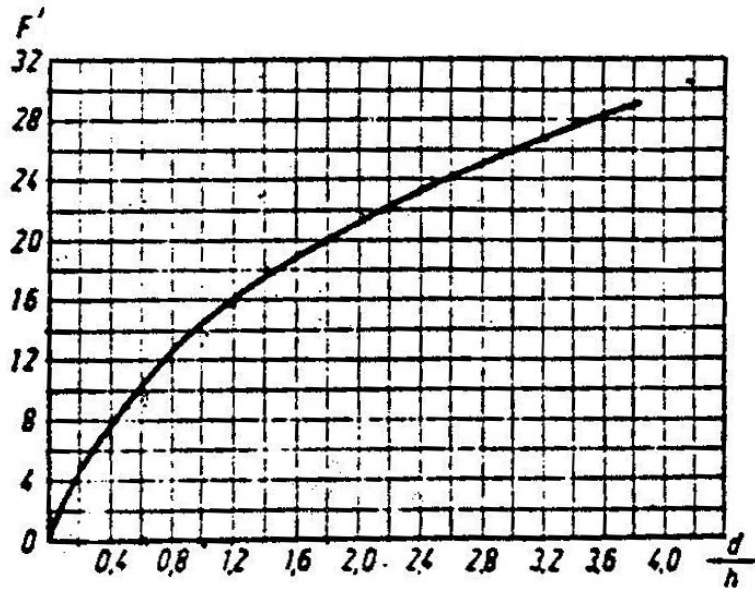
:N<sub>1</sub>

. ( )

$F''$

:

$(h, A)$



( - )

$h_1/h_2$ $d_1/h_1$										
	,	,	,	,	,	,	,	,	,	,
	,	2,37	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,
	,	,	,	,	,	,	,	,	,	,

( )

Calculate the Amper – Turn of Induction Heating

$$K^2 \cong \frac{M^2}{L_2^2} = \pi^4 N^2 \left( \frac{d_2}{h_2} \right) \frac{F''}{F_2'^2} \quad (2-37)$$

$$X = \omega(L_1 - K^2 L_2) = 2\pi f \left[ \frac{1}{2} d_1 N_1^2 F_1' \cdot 10^{-9} - \pi^4 N_1^2 \left( \frac{d_2}{h_2} \right) \frac{F''}{F_2'^2} \frac{1}{2} d_2 F_2' \cdot 10^{-9} \right] \Rightarrow$$

$$X = \pi f N_1^2 \left[ d_1 F_1' - \pi^4 d_2 \left( \frac{d_2}{h_2} \right)^2 \frac{F''}{F_2'^2} \right] 10^{-9} \quad (2-38)$$

(X)

$$U = I_1 X = 2\pi f N_1 \left[ d_1 F_1' - \pi^4 d_2 \left( \frac{d_2}{h_2} \right)^2 \frac{F''}{F_2'^2} \right] (I_1 N_1 \cdot 10^{-9}) \quad (2-39)$$

$$P_2 = R_2 K^2 I_1^2 = \frac{\pi d_2}{h_2 \delta_2} \rho_2 F_2 \pi^4 N_1^2 \left( \frac{d_2}{h_2} \right) \frac{F''}{F_2'^2} I_1^2 \quad (2-40)$$

( $\rho_2$ )

$$\mu_0 = 4\pi \cdot 10^{-7}, F'' = \left( \frac{d_2}{h_2} \right)^3 \frac{10^3}{F_2'^2}$$

$$P_2 = 6.1 \sqrt{\rho_2 \mu_{re} f} F'' F_2 (I_1 N_1)^2 10^{-8} KW \quad (2-41)$$

Calculate the Power Circuit Data for the Induction Heating

$$Q = C_m m (\theta_2 - \theta_1) \quad (2-42)$$

$$1 \text{ cal} = 4.186 \text{ J} \quad (\text{cal}) \quad : Q$$

$$\text{cal/gc} \quad : C_m$$

$$\text{.g} \quad : M$$

$$\text{.c} \quad : \theta_2 - \theta_1$$

$$P_2$$

$$P_2 \quad . P_2 = \frac{Q}{t}$$

$$1200C$$

$$\mu_r$$

$$. ( )$$