Principle of Induction Heating (Induction Heating Principle)

United Induction Heating Machine Limited

induction-heating

INDUCTION HEATING was first noted when it was found that heat was produced in transformer and motor windings, as mentioned in the Chapter "Heat Treating of Metal" in this book. Accordingly, the Principle of induction heating was studied so that motors and transformers could be built for maximum efficiency by minimizing heating losses. The develop- ment of high-frequency induction power supplies provided a means of using induction heating for surface hardening. The early use of induction involved trial and error with built-up personal knowledge of specific applications, but a lack of understanding of the basic principles. Through- out the years the understanding of the basic principles has been expanded, extending currently into computer modeling of heating applications and processes. Knowledge of these basic theories of induction heating helps to understand the application of induction heating as applied to induction heat treating. Induction heating occurs due to electromagnetic force fields producing an electrical current in a part. The parts heat due to the resis- tance to the flow of this electric current.

Resistance

All metals conduct electricity, while offering resistance to the flow of this electricity. The resistance to this flow of current causes losses in power that show up in the form of heat. This is because, according to the law of conser- vation of energy, energy is transformed from one form to another—not lost The losses produced by resistance are based upon the basic electrical formu- la: P i2R, where i is the amount of current, and R is the resistance Because the amount of loss is proportional to the square of the current, dou- bling the current significantly increases the losses (or heat) produced. Some metals, such as silver and copper, have very low resistance and, consequent-

6 / Practical Induction Heat Treating are very good conductors. Silver is expensive and is not ordinarily used

for electrical wire (although there were some induction heaters built in WorldWar II that had silver wiring because of the copper shortage). Copper wires are used to carry electricity through power lines because of the low heat losses during transmission. Other metals, such as steel, have high resis- tance to an electric current, so that when an electric current is passed through steel, substantial heat is produced. The steel heating coil on top of an electric stove is an example of heating due to the resistance to the flow of the house- hold, 60 Hz electric current. In a similar manner, the heat produced in a part in an induction coil is due to the electrical current circulating in the part.

Alternating CurrentandElectromagnetism

Induction heaters are used to provide alternating electric current to an elec-
tric coil (the induction coil). The induction coil becomes the electrical (heat) source that induces an electrical current into the metal part to be heated (called the workpiece). No contact is required between the workpiece and the induction coil as the heat source, and the heat is restricted to localized areas or surface zones immediately adjacent to the coil. This is because the alternating current (ac) in an induction coil has an invisible force field (elec-

Fig. 2.1 Induction coil with electromagneticfield. OD, outside diameter; ID, inside diameter.Source:Ref1

Theory of Heating by Induction

tromagnetic, or flux) around it.When the induction coil is placed next to or around a workpiece, the lines of force concentrate in the air gap between the coil and the workpiece. The induction coil actually functions as a trans- former primary, with the workpiece to be heated becoming the transformer secondary. The force field surrounding the induction coil induces an equal and opposing electric current in the workpiece, with the workpiece then heat- ing due to the resistance to the flow of this induced electric current. The rate of heating of the workpiece is dependent on the frequency of the induced current, the intensity of the induced current, the specific heat of the material, the magnetic permeability of the material, and the resistance of the material to the flow of current. Figure 2.1 shows an induction coil with the magnetic fields and induced currents produced by several coils. The induced currents are sometimes referred to as eddy-currents, with the highest intensity current being produced within the area of the intense magnetic fields.

Induction heat treating involves heating a workpiece from room tempera- ture to a higher temperature, such as is required for induction tempering or induction austenitizing. The rates and efficiencies of heating depend upon the physical properties of the workpieces as they are being heated. These properties are temperature dependent, and the specific heat, magnetic per- meability, and resistivity of metals change with temperature. Figure 2.2 shows the change in specific heat (ability to absorb heat) with temperature

Fig. 2.2 Changein specific heat with temperaturefor materials.Source:Ref2 for various materials. Steel has the ability to absorb more heat as temperature increases. This means that more energy is required to heat steel when it is hot than when it is cold. Table 2.1 shows the difference in resistivity at room temperature between copper and steel with steel showing about ten times higher resistance than copper. At 760 °C (1400 °F) steel exhibits an increase in resistivity of about ten times larger than when at room tempera- ture. Finally, the magnetic permeability of steel is high at room temperature, but at the Curie temperature, just above 760 °C (1400 °F), steels become nonmagnetic with the effect that the permeability becomes the same as air

induction coil design

induction Principle

induction heating theory

Physical Characteristics:

Elementary
symbol

Name

Atomic weight

Specific
weight

Melting point

Boiling point

Specific heat

Coefficientof
heat
conduction

Element
number

0.056(0')

Ag

silver

107.880

10.49

960.80

2210

0.056(0')

1.0(0'C)

47

Al

aluminum

26.97

2.699

660.2

2060

0.223

0.53

13

As

arsenic

74.91

5.73

814

610

0.082

-

33

Au

gold

197.21

9.32

1063.0

2970

0.031

0.71

79

B

boron

10.82

2.3

2300+-300

2550

0.309

-

5

Be

beryllium

9.02

1.848

1277

2770

0.52

0.038

4

Ba

barium

137.36

33.74

704+-20

1640

0.068

-

56

Bi

bismuth

209.0

9.80

271.30

1420

0.034

0.020

83

C

carbon

12.010

2.22

3700+-100

4830

0.165

0.057

6

Ca

calcium

40.8

1.55

850+-20

1440

0.149

0.30

20

Cd

cadmium

112.41

8.65

320.9

765

0.055

0.22

48

Ce

cerium

140.13

6.9

600+-50

1440

0.042

-

58

Co

cobalt

58.94

8.85

1499+-1

2900

0.099

0.165

27

Cr

chromium

52.01

77.19

1875

2500

0.11

0.16

24

Cs

cesium

132.91

1.9

28+2

690

0.052

-

55

Cu

copper

63.54

8.96

1083.0

2600

0.092

0.94

29

Fe

iron

55.85

7.896

1536.0

2740

0.11

0.18

26

Ga

gallium

69.73

5.91

29.87

2070

0.079

-

31

Ge

germanium

72.60

5.36

958+-10

2700

0.073

-

32

Hg

mercury

200.61

13.546

38.36

357

0.033

0.0201

80

In

indium

114.76

7.31

156.4

1450

0.057

0.057

49

Ir

iridium

193.1

22.5

2454+-3

5300

0.031

0.147

7

K

potassium

39.096

0.86

63.7

770

0.177

0.24

19

La

lanthaduim

138.92

6.15

826+-5

1800

0.045

-

57

Li

lithium

6.940

0.535

186+-5

1370

0.79

0.17

3

Mg

hydrogen

24.32

1.74

650+-2

1110

0.25

0.38

12

Mn

manganess

54.93

7.43

1245

2150

0.115

-

25

Mo

molybdenum

95.95

10.22

2610

3700

0.061

0.35

42

Na

sodium

22.997

0.971

92.82

892

0.295

0.32

11

Nb

niobium

92.91

8.57

2468+-10

>3300

0.065(0'C)

-

41

Ni

nickel

58.69

8.902

1453

2730

0.112

0.198

28

Os

osmium

190.2

22.5

2700+-200

5500

0.031

-

76

P

phosphorus

30.98

1.82

441

280

0.017

-

15

Pb

lead

207.21

11.36

327.4258

1740

0.031

0.08

82

Pd

palladium

106.7

12.03

1544

4000

0.058(0'C)

0.17

46

Pt

platinium

195.23

21.45

1769

4410

0.032

0.17

78

Rb

rubidium

85.48

1.53

39+-1

680

0.080

-

37

Rn

radon

102.91

12.44

1966+-3

4500

0.059

0.21

45

Ru

ruthenium

101.7

12.2

2500+-100

4900

0.057(0'C)

-

44

S

sulfer

32.066

2.07

119.0

444.6

0.175

-

16

Sb

antimony

121.76

6.62

630.5

1440

0.049

0.045

51

Se

selenium

78.96

4.81

220+-5

680

0.084

-

34

Si

selicon

28.06

2.33

1430+-20

2300

0.162(0'C)

0.20

14

Sn

tin

118.70

7.298

231.9

2270

0.054

0.16

50

Sr

strontium

87.63

2.6

770+-10

1380

0.176

-

38

Ta

tantalum

180.88

16.654

2996+-50

>4100

0.036(0'C)

0.13

73

Tc

technetium

127.61

6.235

450+-10

1390

0.047

0.014

52

Th

thorium

232.12

11.66

1750

>3000

0.126

-

22

Ti

titanium

47.90

4.507

1688+-10

>3000

0.126

-

22

Tl

thallium

204.39

11.85

300+-3

1460

0.031

0.093

81

U

uranium

238.07

19.07

1132+-5

-

0.028

0.064

92

V

vanadium

50.95

6.1

1900+25

3460

0.120

-

23

W

tungsten

183.92

19.03

3410

5930

0.032

0.48

74

Zn

zinc

65.38

7.133

419.505

906

0.0915

0.27

30

Zr

zirconium

91.22

6.489

6.489

>2900

0.066

-

Ohm's Law

Ohm's Law states that in a simple electrical circuit, the strength of a current (I) flowing through a resistance (R) is proportional to the applied voltage (E). It is expressed by the formula:

Thus, if you increase the voltage, and resistance remains the same, the current will increase proportionately.

Resistive Heating

Resistance is well named, for it opposes current flow. The lower the resistance, the higher the current flow in the curcuit, and hence the greater the power. This power (P) is the rate at which electrical energy is transformed into heat. It is expressed by the formula:

This heat can be put to good purpose and is the principle behind heating elements such as you will find in hair dryers and baseboard heaters. However, such direct production of heat is inefficient, localized, and difficult to control. For industrial purposes it is preferable to produce heat by using an induced current rather than a direct one.

Induction Heating

With induction heating, we substitute an induced current for a direct one, which is of course the principle of the transformer. It works this way. Alternating current flowing through the primary coils of the transformer creates an electromagnetic alternating field. Since the reverse is also true, by placing secondary coils within that field, we will induce a current to flow through them. And depending on the respective number of electrical turns in the primary and the secondary, we can step up or step down the voltage levels. It is the voltage in the secondary turns which, when applied to heating elements, creates the energy to heat or melt metals.

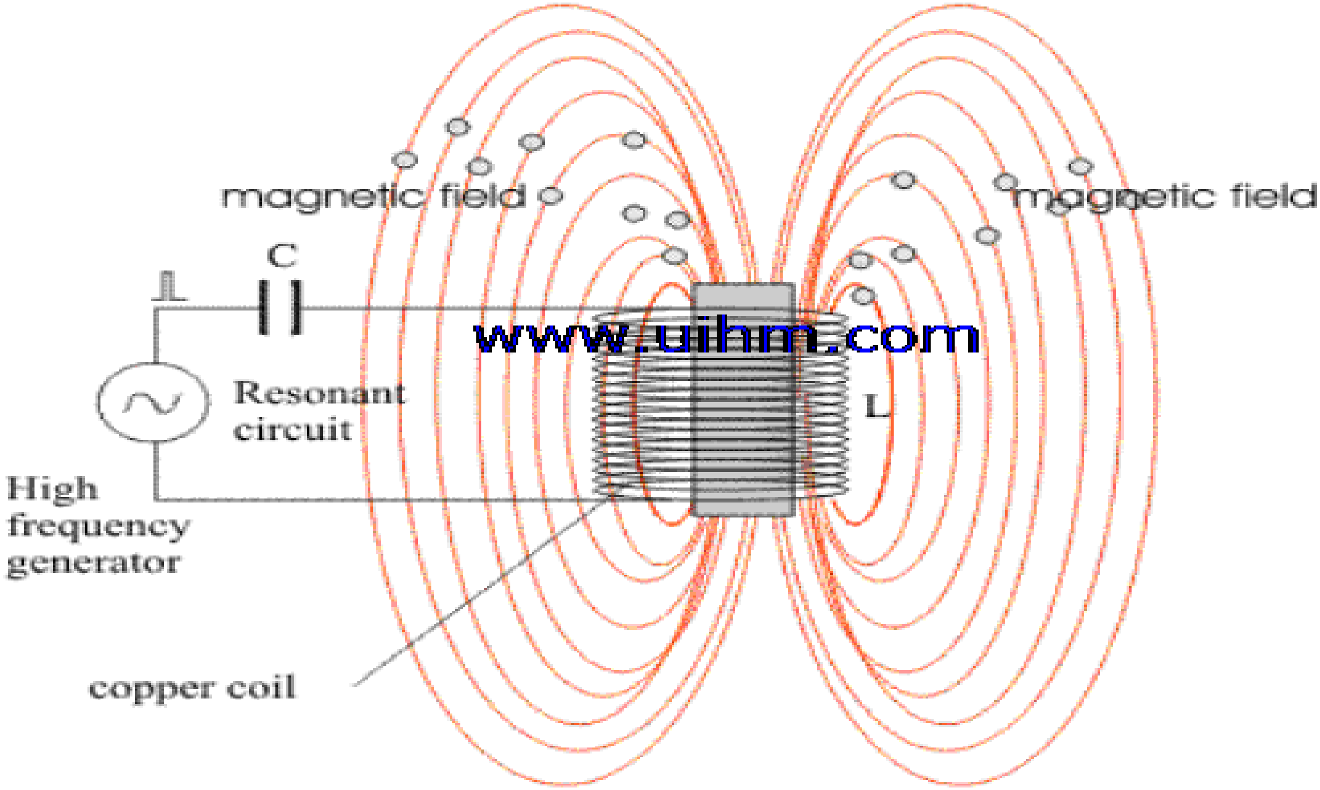
Resistive Heating Illustrated

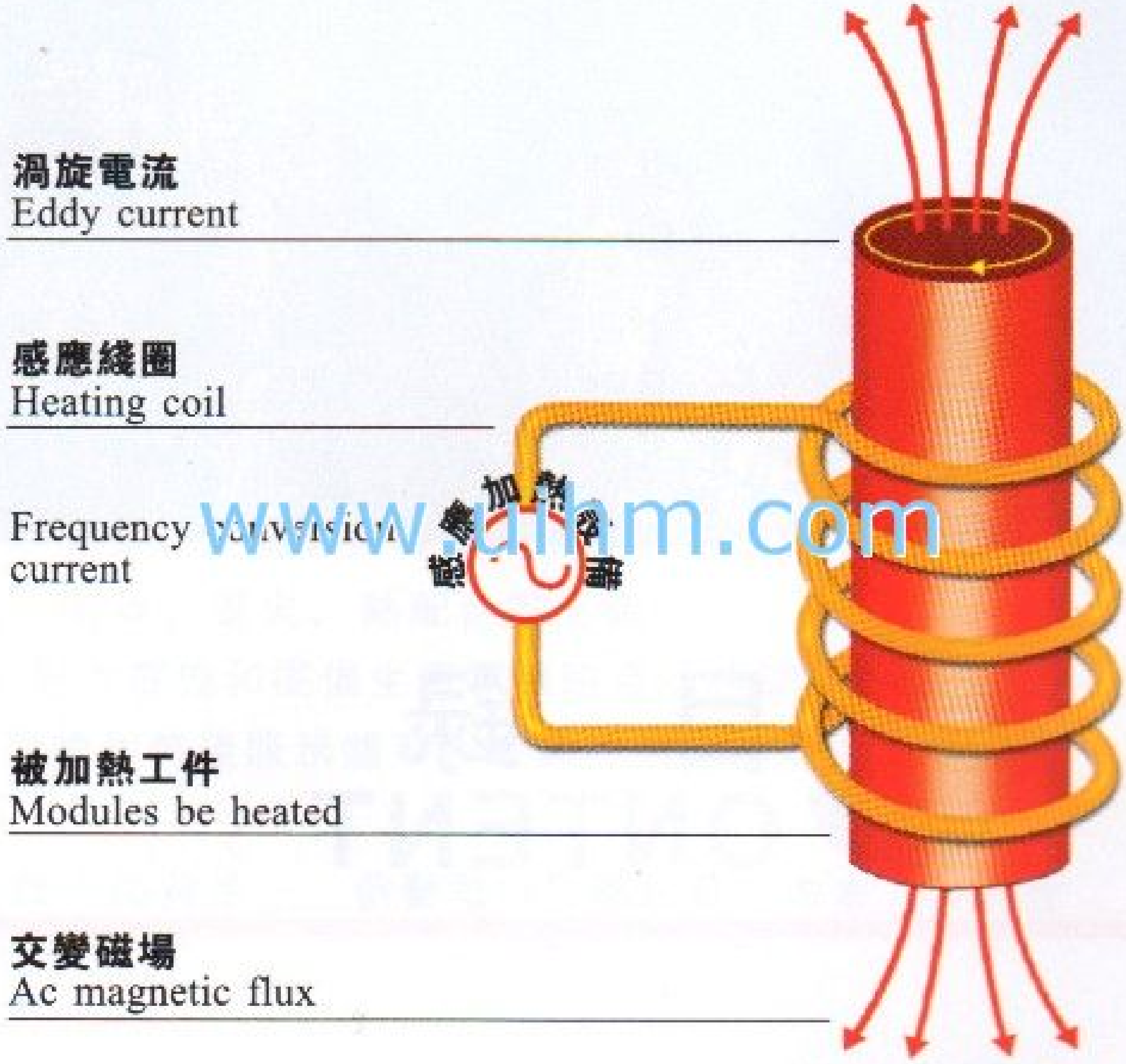
Induction Heating Illustrated

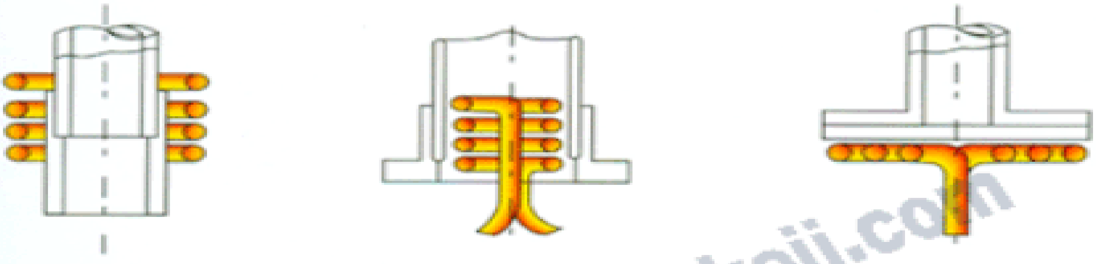
Current flow is induced in the secondary circuit by placing the secondary turns within the changing magnetic field created by the primary turns.

Induction Heating

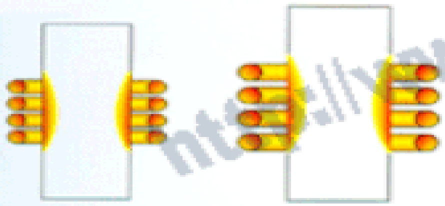
Metallic bar placed in the copper coil is rapidly heated to high temperatures by induced currents from the highly concentrated magnetic field.



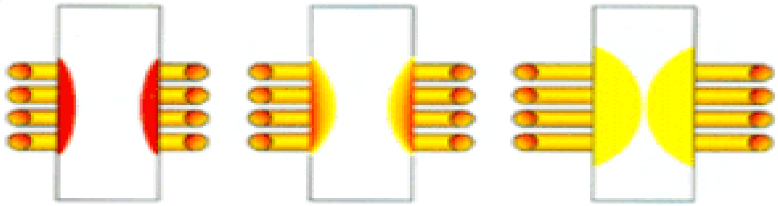

渦旋電流
Eddy current
感應綫圈
Heating coil
Frequency conversion
current
www.uihm.com
被加熱工件
Modules be heated
交變磁場
Ac magnetic flux



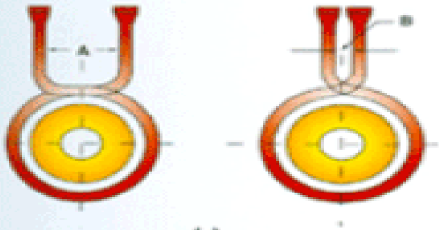
(a) (b) (c)



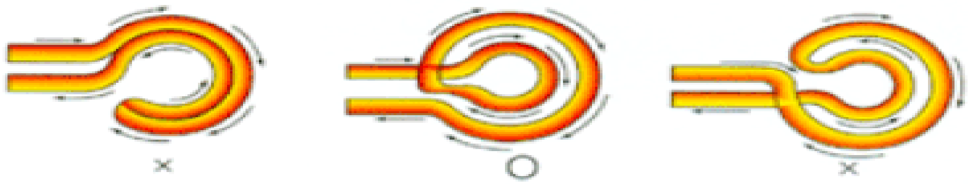
(d)
Effect of distance between turns on heating pattern



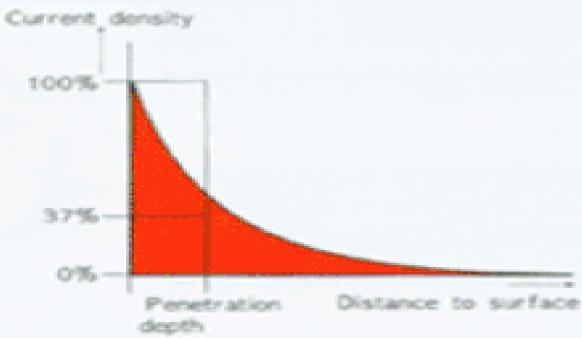
(e)
Effect of coupling on heating pattern

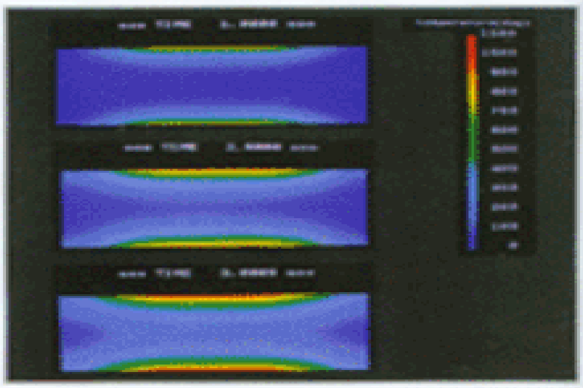


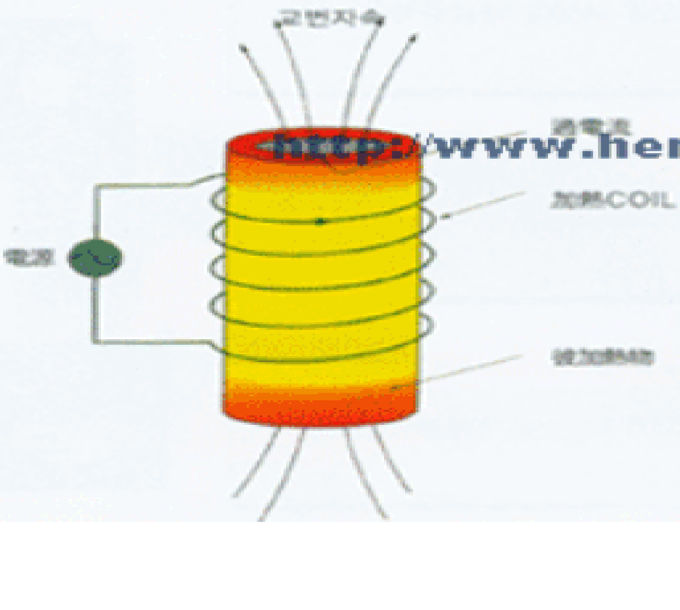
(f)

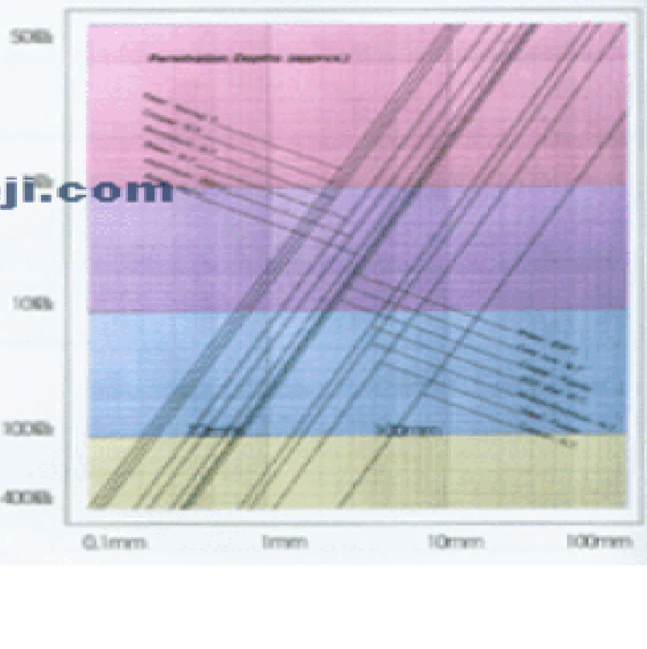


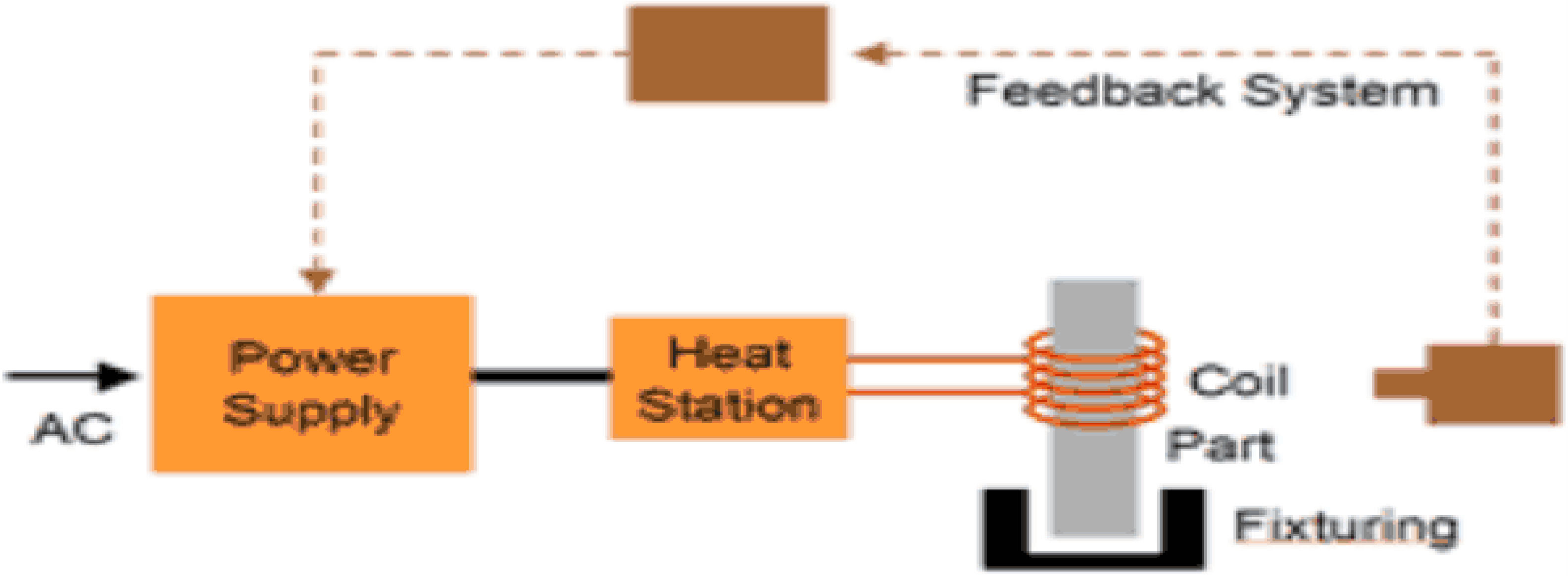
(g)











$$I = \frac{E}{R}$$

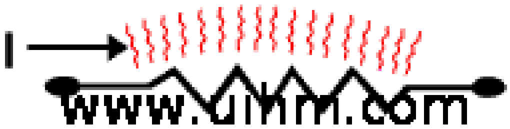
where
I=Current in amps
E=Voltage in volts
R=Resistance in ohms

$$P = I^2R$$

where
P=Power in watts
I=Current in amps
R=Resistance in ohms

POWER CONSUMED

$$P = I^2R$$

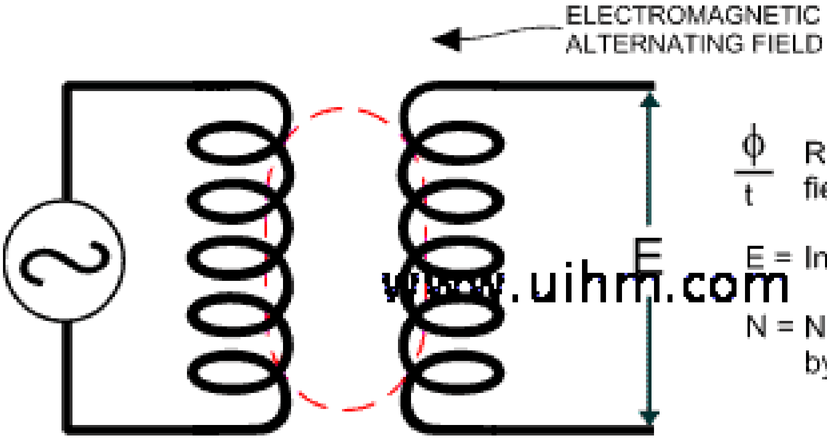


R

P = Power in Watts
I = Current in Amps
R = Resistance in Ohms

service@uihm.com
United Induction Heating Machine Limited

VOLTAGE INDUCED



$\frac{\phi}{t}$ Rate of change of magnetic field in lines per second.

E = Induced voltage in volts.

N = Number of turns affected by the field.

$$E = N\frac{\phi}{t} \times 10^{-8}$$