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INDUCTION HEATING INVERTER

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1. FOREWORD

An induction heating inverter can directly heat the work. This induction heating inverter has such advantages as automation at high efficiency and simple temperature control, it is effective in improving the work environment, high safety, etc. and is widely used by industry. In the past, the thyristor type was the mainstream, but recently power devices like the power transistor. MOSFET, and IGBT have come into use and it has become possible to raise the frequency and performance so that general purpose inverters can be manufactured at a low price.

The operating characteristics, specification, and features of the low capacity induction heating inverter recently developed by Fuji Electric are described and some application examples are introduced.

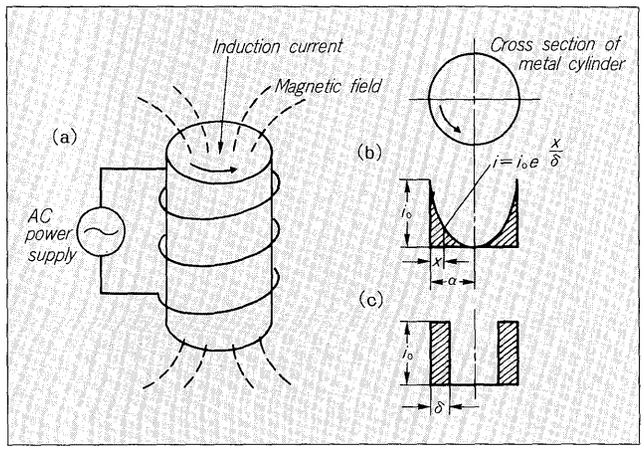
2. PRINCIPLE OF INDUCTION HEATING

2.1 Penetration depth

When an outside coil is wound around a metal cylinder and a current is passed through this coil as shown in *Fig. 1*-(a), the electromagnetic induction action causes a current to flow in metal in the opposite direction of the coil current and generate Joule heat.

The induction current flowing in the metal cylinder tends to become higher nearer the surface due to the skin effect. This tendency becomes more pronounced as the power supply frequency becomes higher. The distribution of the induction current in a cylinder is shown in *Fig. 1*(b).

Fig. 1 Principle of induction heating



Assume that all the current shown by the hatched lines in *Fig. 1*(b) flow in width δ of *Fig. 1*(c). This is called the current penetration depth and is expressed by the following equation:

$$\delta = 5.03\sqrt{\rho/(\mu_r \cdot f)}\ \text{cm} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

ρ : Resistivity of metal ($\mu\Omega \cdot$ cm)
μ_r : Relative permeability
f : Heating frequency (Hz)

2.2 Power generated inside metal

The power P generated inside a metal cylinder like that shown in *Fig. 1*(b) is expressed by the following equation:

$$P = 2.5 \cdot f \cdot H_0^2 \cdot L \cdot \mu_r \cdot A \cdot Q \cdot 10^{-8}\ \text{(W)} \ldots\ldots \quad (2)$$

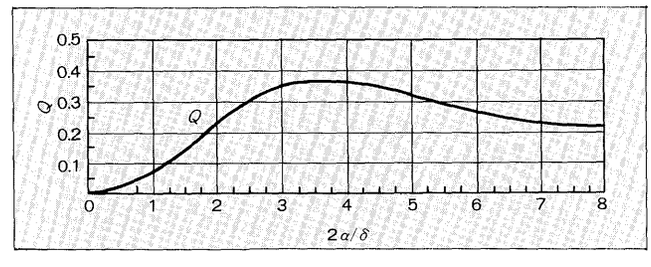
H_0 : Strength of magnetic field at surface of metal cylinder (Oe)
L : Length of metal cylinder (cm)
A : Cross section area of metal cylinder (cm^2)
Q : Function determined by $2\alpha/\delta$. shown in *Fig. 2*.

As can be seen from *Fig. 2*, the Q function becomes maximum at $2\alpha/\delta \fallingdotseq 3.5$ and selection of the heating frequency so that $2\alpha/\delta \geqq 3.5$ is a condition for efficient heating.

3. INDUCTION HEATING INVERTER

An induction heating inverter is usually designed and

Fig. 2 Q function which determines the size of the power generated in a metal cylinder



manufactured by selecting a frequency suitable for the work to be heated. However, the Fuji Electric induction heating inverter can be run at a wide operating frequency of 20 to 50kHz so that it can be used over a wide range of applications. A special starting operation circuit and γ control circuit are also incorporated so that it can be operated smoothly with various loads.

Its principle of operation is shown below.

3.1 Principle of operation

The circuit configuration of the induction heating inverter is shown in *Fig. 3*.

The inverter load consists of a work coil inductance (L) and resonance capacitor (C) series circuit. The inverter is operated synchronization with the resonant frequency of this load circuit.

Inverter high frequency output adjustment is performed by adjusting the inverter output voltage V_0 and output current I_0 phase angle γ.

Fig. 3 Induction heating inverter circuit block diagram

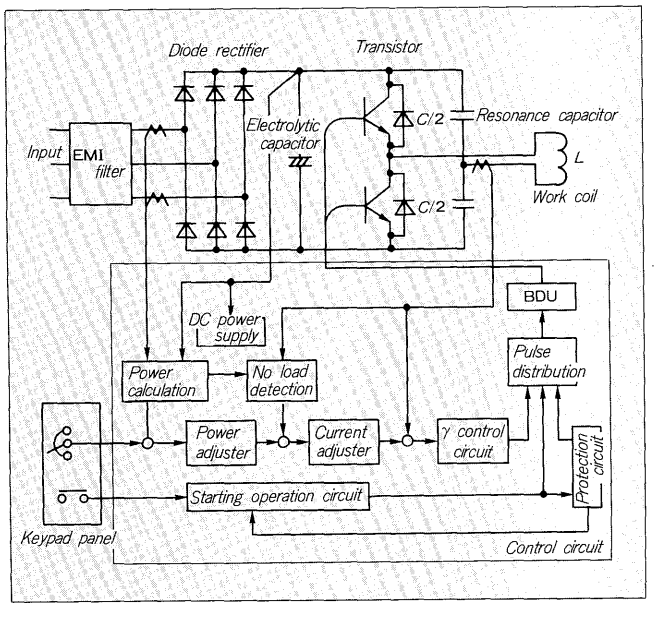
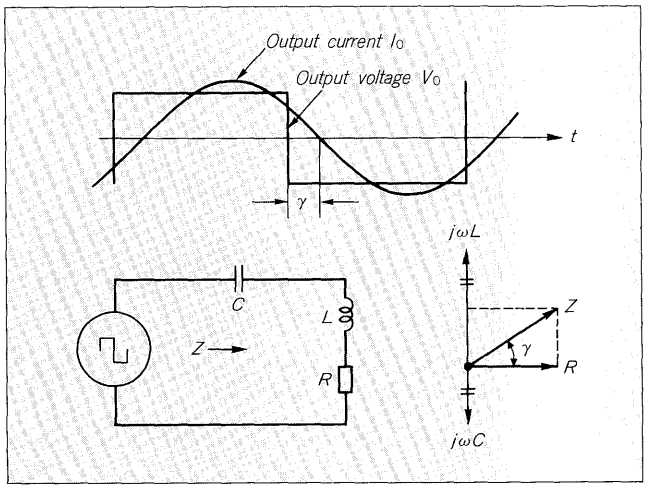


Fig. 4 Principle of operation of inverter



The principle of operation of the inverter is shown in *Fig. 4*.

The output voltage V_0 becomes a square wave and the output current I_0 becomes a sinusoidal wave. For L and R, the work coil is replaced by an equivalent inductance and equivalent resistance. C is the resonance capacitor.

The load circuit impedance Z is expressed by Eq. (3).

$$|Z| = \sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2} \quad \cdots\cdots\cdots\cdots\cdots (3)$$

For the real part of Z, R becomes

$$R = |Z| \cdot \cos\gamma \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

Because $V_0 = |Z| \cdot I_0$, from Eq. (4),

$$I_0 = V_0/R \cdot \cos\gamma \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

and the inverter high frequency output P_0 is expressed by Eq. (6).

$$P_0 = V_0^2/R \cdot \cos\gamma \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (6)$$

That is, P_0 can be coatrolled by changing γ.

3.2 Features

(1) Stable operation against load fluctuations

Since it is a self-controlled inverter which operates in synchronization with the resonant frequency of the load, the frequency and γ angle is changed automatically and stable operation is possible even when the material, temperature, shape, etc. of the work changes and the load constant changes.

(2) Wide range output adjustment possible

Output adjustment of 0 to 100% is possible by stable γ control.

(3) High efficiency

An efficiency of 95% or greater is obtained by unique main circuit configuration and power transistor high-speed switching technology.

(4) Positive protection circuit

When an output overcurrent flows, γ control makes the load impedance high and limits the current and at the same time, turns the pulse off and protects the inverter.

(5) EMI (Electro Magnetic Interference) filter

An EMI filter is built into the inverter. This filter suppresses the higher harmonics current radiated from the inverter and reduces the mains terminal interference voltage. This suppresses the space noise and realizes a level below the level specified by the Electromagnetic Law. Especially, in the radio broadcast band which is effected easily by it, the noise is attenuated to 50% or less.

(6) Compact fully enclosed construction

Since the cooling fan uses a diecast frame and has a fully enclosed construction, it is compact and can be used in poor environments.

(7) Enhanced operation and display functions

Since the operation keypad panel can be connected with standard cable, when housed in a cabinet, the layout is free and diversification of design, etc. is easy.

Separate temperature controller and operation status display can also be connected.

Table 1 Standard specifications of induction heating inverter

Model		HFR030C5K-2	HFR050C5K-2
Input	Voltage	200/220V ±10%	
	Frequency	50/60Hz	
	Number of phases	3-phase or single-phase	3-phase
	Capacity	4.5kVA (5.5kVA)	7.0kVA
Output		3kW	5kW
Output adjustment range		0~100%	
Control method	Output	Power control	
	Frequency	Self-control	
Construction	Construction cooling	Fully enclosed cooling system	
	Dimensions	350x400x245 (mm)	350x400x245 (mm)
	Weight	21kg	22kg
Environment	Temperature	0~50°C	
	Humidity	90% max.	

Fig. 5 Induction heating inverter unit

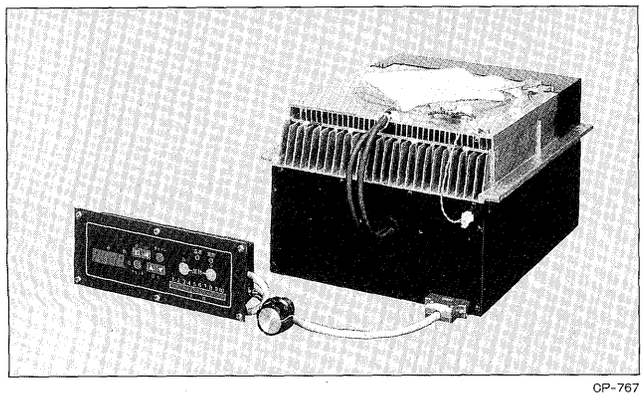


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Fig. 6 High output electromagnetic range for commercial use

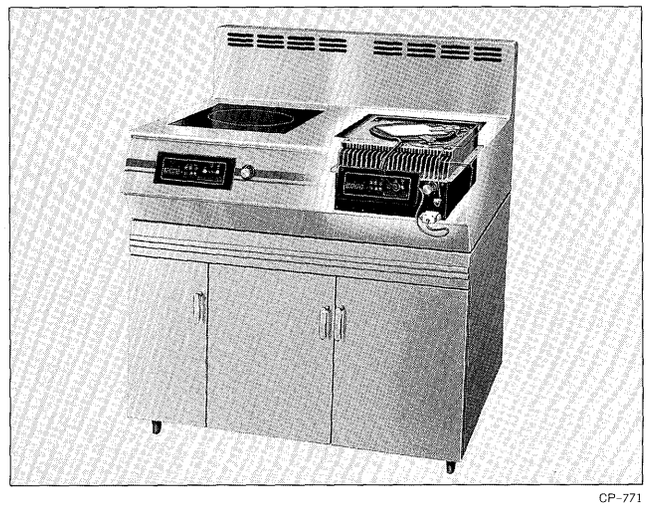

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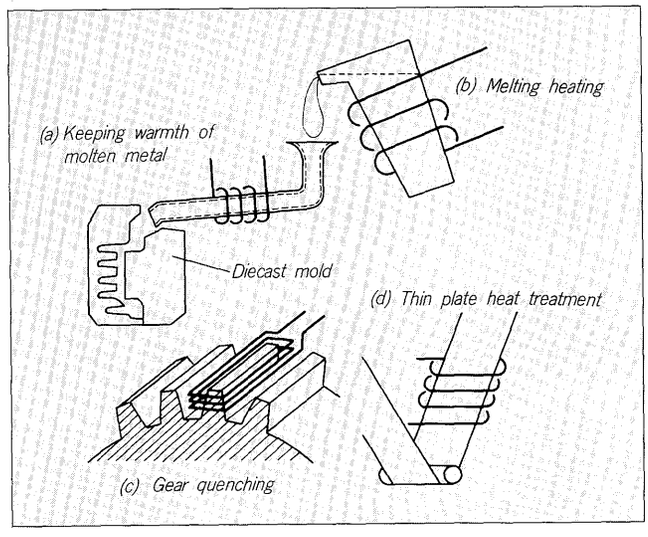
Fig. 7 Heating application example for general industry



3.3 Specifications

The standard specifications of the induction heating inverter are shown in *Table 1*. The inverter unit is shown in *Fig. 5*.

4. APPLICATION EXAMPLES

Induction heating inverter application examples are given below.

4.1 High output electromagnetic range for commercial use

The high output electromagnetic stove for incorporates an induction heating inverter unit integrating an induction heating inverter and flat work coil into a range or stove. It is shown in *Fig. 6*.

The high output electromagnetic range for commercial use is used as the main heating source of the kitchen of restaurants, etc. It features high output, safety, cleanliness, environment improvement, etc. and is high evaluated.

An actual example of installation in a restaurant kitchen is reported below.

(1) An air conditioner capacity and exhaust amount of 50% or less of that for gas heating are sufficient.
(2) Dirtying of the kitchen is small and the amount of water used in cleaning, etc. is 50% or less than gas heating.
(3) Carbon dioxide gas is not generated and it is healthy from the standpoint of cooking work.

4.2 Heating equipment for general industry

The induction heating inverter has the features previously describes and can be used in metal heating, temperature maintenance, heat treatment, automated heating line, and various other applications.

Specific examples are given below.

(1) Heating of drying drum for printed matter, film, etc.
(2) Cylinder heating of injection machine for plastic molded products
(3) Mounting and dismounting of frame and press fitting of bearing of small motor
(4) Keeping warmth of aluminum diecast and molten metal

(5) Melting of aluminum
(6) Partial quenching of small parts
(7) Partial heating of thin steel sheet

The concept of application examples (4) to (7) above is shown in *Fig. 7*.

5. CONCLUSION

The induction heating inverter introduced here is a low capacity induction heating inverter manufactured to be highly reliable, small, compact, and low priced based on Fuji Electric's induction heating know-how and achievements accumulated over many years.

Many units have been supplied to the market, including commercial ranges, and its many advantages not only for kitchen use, but also in heating applications for facilities with heavy oil as their heat source and general industry which depend on a heater are acclaimed and we are confident that it is widely used.

In the future, we will aim out efforts toward advanced functions and low price and request the further guidance and cooperation of the concerned parties.