History of RF Division

Denki Kogyo Co., Ltd. (hereinafter referred to as DKK) has started RF induction heating business in 1952 at Haneda, Tokyo and developed vacuum tube type oscillator capable of 150kW output that was the first one in Japan.

DKK has started its business with consigned processing (job-shop business) of RF induction heat treatment (hardening/tempering). DKK had intended to accumulate relevant technology and experience 3 to 4 years to improve the heat-treating equipments before starting sales of them in 1955.

In 1965～1975, DKK had increased sales amount of both processing and machines for heat-treating backed by high growth of Japanese economy and industries associated with automobile production. DKK has built new plant specialized for the both businesses above in 1968 at Atsugi, Kanagawa prefecture and in 1981 expanded the plant for machine production and R & D of heat treatment which has become the largest one in our industry.

DKK has developed generators starting with vacuum tube type oscillators, after that electromotor generators, thyristor inverters, and transistor inverter generators one after another. The first 300kW transistor inverter in the world was developed and delivered by DKK.

Regarding hardening machine, DKK has developed and produced from manual to full automatic machine, and has applied numerical control (NC) on hardening machine for the first time in the world. DKK has introduced the technology of rotation type full automatic crankshaft hardening machine from Alfing Kessler GmbH, Germany based upon the cooperation agreement, and has been producing the machine domestically.

At the present, DKK adopts CAD in all the fields of designing RF induction heat treating equipments, which are exported to more than 20 countries, and has been becoming No.1 Company in our industry in its supplies, sales amounts and productivity.

Further, DKK has acquired the certificate of ISO 9001 for the first time in the RF induction heat-treating equipment industry on February 1997, and is proud of its technology and quality, which are acknowledged in the world.

Outline of RF Administration ATSUGI PLANT

- Site: 36,000m²
- Floor space: 18,000m²

Items of products
1. RF induction heating equipment
   - Hardening and tempering equipment
   - Iron and steel (slab) heating equipment
   - Brazing equipment
   - Forge heating equipment
   - Melting furnace
   - Pipe welding equipment
   - General heating equipment
2. RF applied products
   - RF power generator for plasma heating use and accelerator use
   - Microwave plasma CVD equipment
   - RF power generator for lighting use
3. Compact RF accelerator for electron beam irradiation
4. RF induction heat treatment trial processing
5. Vacuum furnace for metal heat treatment

Outline of RF Administration group companies

Denko Techno Heat Co., Ltd.
Sales items
1. Consigned processing (job-shop) of RF induction heat treatment
2. RF induction heat treatment trial processing
3. Manufacturing of induction heating inductor
Location
Hamamatsu, Kariya, Suzuka, Shiga

Koshuha Kogyo Co., Ltd.
Sales items
Sheet metal processing, Manufacturing of chassis
Location
in the site of ATSUGI PLANT

Denko Metallurgical Technology Co., Ltd.
Sales items
1. Vacuum furnace for metal heat treatment and associated equipment
2. Compaction press for hard metal powder
3. Precision grinding machine
Location
in the head office of DKK Co., Ltd.
The principle of induction heating by RF electric current is shown in Fig. 1. There an electric conductor such as iron or steel placed in the inductor is heated rapidly by induced eddy current caused by electromagnetic induction, and hysteretic heat loss, which is generated by vibration and friction of each molecule in magnetic material under AC magnetic flux.

As RF frequency, which is higher than that of commercial electric power, is used for induction heating, induced current flows only in the limited area near surface of heated material because of skin effect and proximity effect, and heat loss occurs only there by eddy current and hysteretic loss. The skin effect is the phenomenon, which RF electric current flows only in the limited area near surface of conductive material, and proximity effect is the phenomenon, which the primary current in the inductor and the secondary current in the conductive material pull each other because the direction of current is opposite each other, and flows in the limited area near surface where distance is nearest each other.

Fig. 2 shows the relation between frequency and depth of RF electric current flow for steel material heated by induction at 1,000 degree. The depth depends upon the frequency and as the frequency is higher, the depth becomes smaller as shown in the curves in Fig. 2.

The penetration depth is defined as the point where RF electric current decreases to about 37% (1/e =1/2.718=0.368; e is the base of natural logarithm) compared with the current at the surface and normally expressed as . In Fig. 2, the penetration depth is shown as the points, which are the cross points of line A with the current penetration curves. The penetration depth is calculated as follows.

\[ \delta = 5.03 \sqrt{f / \mu_G (cm)} \]

\( \delta = \) penetration depth (cm)
\( \mu = \) specific permeability
(magnetic material: \( \mu > 1 \), non-magnetic material: \( \mu = 1 \))
\( f = \) frequency (Hz)
\( \rho = \) specific resistance (\( \mu \cdot \Omega \cdot \text{cm} \))

This formula shows that as the frequency is higher, \( \delta \) will be smaller and the heating will be concentrated at the surface in case the materials are same. However in actual heating, the heated depth tends to become bigger because of heat conduction in the heated material. (Refer to Setting of Hardening Condition item (3) Choice of frequency)
Aims and Features of RF Heat Processing (Hardening and Tempering)

The aims of RF heat processing (hardening and tempering) are that to make harden the surface of mechanical structural parts so as to improve the wearability and to increase the mechanical property especially fatigue durability.

RF heat processing is a method to make a hardening layer on the surface of a steel material by heating the surface rapidly up to hardening temperature (generally up to 900 ℃) and after that cooling rapidly using cooling water. This method has many features.

(1) Heating efficiency is better because of direct heating.
(2) Oxidization is less because of short time heating.
(3) Partial heating is possible and the choice of hardening depth is optional.
(4) Distortion is smaller compared to that of other methods.
(5) Improve wear ability and fatigue durability.
(6) Generally, even cheaper carbon steel substitutes for special steel.
(7) Easy to adjust hardening condition.
(8) Easy for automating.
(9) Possible for inserting into machine processing line.
(10) Harmless in working environment (No pollution).

Methods of RF Hardening

There are two methods in RF hardening.

(1) Stationary hardening (one-shot hardening) method = heating and quenching (cooling) are done at the same position

- Revolving method of hardening material (work-piece)
  - Revolve the hardening material in order to heat and cool evenly. (Always done in case the hardening material is revolvable.)
  - Ex) gear, sprocket, crankshaft, camshaft, axle-shaft, drive shaft, CVJ etc.

- Stationary method of hardening material
  - This method is adopted in case hardening material is not revolvable.
  - Ex) rocker arm, rack-steering, shift-rail etc.

- Cooling system
  - There are two methods in cooling system.
    1) Cooling is done at the same position as that of heating. Just after heating, cooling water is jetted from small holes of inductor (commonly used as cooling jacket) toward the heated portion of work-piece at the same position as heating.
    2) Cooling position differs from heating position. Just after heating, the work-piece is shifted into the cooling jacket, and then cooling water is jetted from small holes of cooling jacket toward heated portion of work-piece. Or, just after heating, the work-piece is shifted and soaked into the heating inductor (commonly used as cooling jacket) toward the heated portion. This method is adopted in case the size and weight of heating material is small and so on.
    3) Partial heating is possible and the choice of hardening depth is optional.
    4) Distortion is smaller compared to that of other methods.
    5) Improve wear ability and fatigue durability.
    6) Generally, even cheaper carbon steel substitutes for special steel.
    7) Easy to adjust hardening condition.
    8) Easy for automating.
    9) Possible for inserting into machine processing line.
    10) Harmless in working environment (No pollution).

Fig.-3: Stationary hardening system, which differs in cooling method

Fig.-4: Scanning hardening system, which differs in cooling method

(2) Scanning hardening method = heating is done partly and the heated portion is hardened, and heating inductor travels through longish direction of work-piece successively

- Scanning hardening method with revolving work-piece.
  - Used for work-pieces, which are revolvable, such as axle parts.
  - Ex) pin, bush, axle-shaft, drive shaft, ballpoint screw, piston rod etc.

- Scanning hardening method without revolving work-piece.
  - Used for work-pieces, which are not revolvable, such as plane surface of work-piece or complicated formed inside of work-piece.
  - Ex) lathe bed, direct move guide-rail, link, groove of tri-pot housing etc.

- There are two methods in scanning hardening generally.
  1) The heating inductor remains stationary and heating material travels. This method is adopted in case the size and weight of heating material is small and so on.
  2) The heating material remains stationary and heating inductor travels. This method is adopted in case the size and weight of heating material is big and so on.

- Cooling system
  - There are two methods in cooling system.
    1) Cooling water is jetted successively from small holes of inductor toward the heated portion of work-piece. Or, just after heating, the work-piece is shifted and soaked into the cooling pan, which is filled with cooling water.
    2) Cooling water is jetted from small holes of cooling jacket toward heated portion of work-piece. Or, just after heating, the work-piece is shifted and soaked into the heating inductor (commonly used as cooling jacket) toward the heated portion. This method is adopted in case the size and weight of heating material is small and so on.
    3) Partial heating is possible and the choice of hardening depth is optional.
    4) Distortion is smaller compared to that of other methods.
    5) Improve wear ability and fatigue durability.
    6) Generally, even cheaper carbon steel substitutes for special steel.
    7) Easy to adjust hardening condition.
    8) Easy for automating.
    9) Possible for inserting into machine processing line.
    10) Harmless in working environment (No pollution).
(1) Choice of frequency and electric power density

For effective RF hardening, the suitable frequency of RF power generator must be chosen. The quality of hardening layer obtained by RF hardening depends upon frequency, electric power density, heating temperature, cooling speed, pre-processed condition (e.g. cold or warm or hot temperature forging), and so on. Therefore, frequency and power density must be chosen according to the size of work-piece and hardening specifications.

The capacity of RF power generator is to be decided according to the mass, heating temperature and heating time of heating material. The calculation of heating power except heat losses in inductor and of coupling between inductor and work-piece is given as follows.

\[ P \text{ (Required power)} = P_1 + P_2 + P_3 + P_4 \]

- \( P_1 \) = Absorbed power by heating material (Net absorbed power)
- \( P_2 \) = Radiation heat loss
- \( P_3 \) = Convection heat loss
- \( P_4 \) = Conduction heat loss

\( P_1 \), \( P_2 \), \( P_3 \) and \( P_4 \) are calculated as follows.

\[ P_1 = 4.186 \times M \times C \times \Delta T \text{ (kW/sec)} \]

\[ P_2 = 5.74 \times e \times (\frac{273 + t_1 + t_2}{1000}) W/cm^2 \]

\[ t_1 = \text{Normal temperature} \]
\[ t_2 = \text{Heating temperature} \]
\[ e = \text{Radiation rate (steel:0.8)} \]

\[ P_3 = 159 \times \Delta T \text{ (W/cm^2)} \]

\[ \Delta T = \text{Surface temperature rise} \]
\[ W = \text{Micro watt} \]

\[ P_4 = 3.72 \times T \times K \times C \times S \times t \text{ (W/cm^2)} \]

- \( K \) = Heat conductivity
- \( C \) = Average specific heat
- \( S \) = Density (g/cm³)
- \( t \) = Heating time

Required electric power \( P \) is supplied from RF generator through inductor. The electric power \( P \) is calculated as shown above. The heating mass is the product of surface hardening area, hardening layer depth and specific gravity. However, accurate calculation of heat losses such as heat conduction loss and so on is difficult. So, practically it is better to calculate based on the experienced data.

Fig.-5 shows the relation between hardening depth of steel, frequency, power density and heating time.

Table 1 shows the relation of practical frequency to the size of hardening material and hardening layer depth.

<table>
<thead>
<tr>
<th>Hardening layer depth (mm)</th>
<th>Diameter of round bar (mm)</th>
<th>Practical frequency (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5~1.0</td>
<td>6~25</td>
<td>400•200</td>
</tr>
<tr>
<td>1.2~2.5</td>
<td>11~16</td>
<td>400•200•30</td>
</tr>
<tr>
<td>16~25</td>
<td>200•30•30</td>
<td></td>
</tr>
<tr>
<td>25~50</td>
<td>200•30•10</td>
<td></td>
</tr>
<tr>
<td>Over 50</td>
<td>30•10</td>
<td></td>
</tr>
<tr>
<td>2.5~5.0</td>
<td>19~25</td>
<td>30•10</td>
</tr>
<tr>
<td>25~100</td>
<td>3•10•30</td>
<td></td>
</tr>
<tr>
<td>Over 100</td>
<td>3•10</td>
<td></td>
</tr>
</tbody>
</table>

口 Frequency ( ) means available frequency

Table 2 shows the relation of total hardening layer depth to frequency and power density.

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Total hardening layer depth (mm)</th>
<th>Electric power density (kW/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>0.3~1.2</td>
<td>Low (3) 1 1.5 2</td>
</tr>
<tr>
<td>400</td>
<td>1.2~2.3</td>
<td>Middle (4) 0.5 0.8 1.2</td>
</tr>
<tr>
<td>10</td>
<td>1.5~2.3</td>
<td>High (5) 1.2 1.5 2.5</td>
</tr>
<tr>
<td>10</td>
<td>2.3~3.0</td>
<td>Low (3) 0.8 1.5 2.3</td>
</tr>
<tr>
<td>10</td>
<td>3.0~4.0</td>
<td>Middle (4) 0.8 1.5 2.1</td>
</tr>
<tr>
<td>3</td>
<td>2.3~3.0</td>
<td>High (5) 1.5 2.3 2.6</td>
</tr>
<tr>
<td>3</td>
<td>3.0~4.0</td>
<td>Low (3) 0.8 2.1 2.5</td>
</tr>
<tr>
<td>3</td>
<td>4.0~5.0</td>
<td>Middle (4) 0.8 1.5 2.1</td>
</tr>
<tr>
<td>3</td>
<td>5.0~6.0</td>
<td>High (5) 1.5 2.0 2.0</td>
</tr>
<tr>
<td>1</td>
<td>6.0~9.0</td>
<td>Low (3) 0.8 1.5 2.0</td>
</tr>
</tbody>
</table>

口 (1) kW is the maximum value of meter reading during heating.
口 (2) Lower frequency is used for bigger hardening depth.
口 (3) Low power density is better to be used when there is limitation in power generator.
口 (4) Histologically this can be expected the best result.
口 (5) This is adopted in order to use power capacity of generator effectively and increase productivity.
(2) Calculation of generator’s power capacity
1) Hardening depth and length: Hardening depth means total hardening layer depth.
2) Heating time: figure out from processing tact
3) Material
4) Shape and size
5) Heating temperature: change according to the temperature of material such as cold material or warm material

Decision of capacity
a) Calculate the weight of heating part
b) Calculate the net absorbed power
c) Multiply the coefficient of heat loss
d) Divide by heating time

Exercise
How much power capacity kW is required for RF generator to make harden the round bar work-piece of \( \frac{\pi}{25} \) in diameter, 50mm in length and S45C material, and to obtain 1.5 mm hardening depth (total hardening layer depth) from the surface in all the circumference along 50 mm length by heating 2 seconds?

a: Weight of heating part
\[ W = \pi r^2 h \times \text{Specific gravity} \]
\[ r = \text{Radius} \]
\[ h = \text{Length} \]

Calculation
\[ W = 3.142 \left( \left( \frac{2.5}{2} \right)^2 \times \left( \frac{2.2}{2} \right)^2 \right) \times 7.8 \]
\[ = 42.861 \text{gr} = 0.0429 \text{kg} \]

b: Net absorbing power
\[ P = 4.186 \times W \times \text{Average specific heat} \times \text{Heating temperature} \]
\[ 4.186 \text{ kW} = 1 \text{ Kcal / s} \]
\[ \text{Average specific heat (iron)} = 0.15 \]
\[ \text{Heating temperature (RF hardening)} = \text{approx. 900} \]

Substitute above figures for formula P
\[ P = 4.186 \times 0.0429 \times 0.15 \times 900 \]
\[ = 24.24 \text{ kW/s} \]

c: Heat loss
It is difficult to calculate accurately the heat losses such as radiation loss, convection loss, conduction loss, circuit loss, coupling loss between inductor and work-piece. Therefore, practically we in DKK are used to multiply approximately three times coefficient toward net absorbed power based on our experimental and experienced data. In the exercise above, the net absorbed power is 24.24 kW/s. In case of round bar heating, magnetic coupling between inductor and work-piece is excellent, so supposing as three times, the total output power of generator will be 24.24 \times 3 = 72.72 \text{ kW/s}.

d: In the above exercise, heating time is 2 sec., so the power capacity of generator will be 72.72/2 = 36.36 kW.

(3) Choice of frequency
\[ f = \frac{5.03}{\sqrt{\mu_d \cdot \sigma}} \text{ cm} \]
f = Frequency (Hz)
\[ \mu = \text{Specific permeability (iron)} = 1 \]
\[ \sigma = \text{specific resistance (cm)} \]
\[ 115 \text{ (at 900 °C)} \]
RF induction tempering is taking precedence of conventional electric furnace tempering in the next process of RF induction hardening, because of its short time heating and excellent working efficiency.

In RF induction tempering system, the RF power generator and inductor for hardening system can be used in some cases, but can not be used in other cases depending upon the shape of heating work-piece or hardening layer depth as shown below.

1. Use same generator and inductor.
2. Use different (lower frequency) generator and same inductor.
3. Use largely different (rather lower frequency) generator and completely different inductor.

**Table 4**: Choice of frequency for high temperature tempering

| Dimension (Diameter) (㎜) | Tempering temperature (℃) | Frequency
|--------------------------|---------------------------|-------------
|                         |                           | Commercial frequency 50-60Hz Transistor inverter or static generator Thyristor inverter Vacuum tube oscillator or transistor inverter kHz |
| 3-6                     | 640                       | A A A A A A |
| 6-12                    | 640                       | A A A A A A |
| 12-25                   | 370                       | A A B B B B |
| 12-25                   | 640                       | A A A A A A |
| 25-50                   | 370                       | B B A A C C |
| 25-50                   | 640                       | A A A A C C |
| 50-150                  | 370                       | A A B B B B |
| 50-150                  | 640                       | A A A A B B |
| Over 150                | 640                       | A A A B A B |

A: The best frequency  B: Suitable frequency  C: Proper frequency
Temperature range 640℃: Temperature range 426-704℃
Temperature range 370℃: Temperature range 149-426℃

This formula means that in case of tempering steel work-piece, the effect, which is obtained from the condition of temperature T₁ and time t₁, equals with that of temperature T₂ and time t₂. This formula is used to know approximate tempering temperature, therefore to know the best condition, it is required to examine accurately around the temperature obtained from the formula.

Conventionally in RF induction tempering, the method, which controls and manages heating time and output power (voltage) has been normally adopted, however these days it is making a step toward the method, which measures and manages tempering temperature directly.

**Table 5**: Electric power density required for induction tempering

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Tempering temperature range 149-426℃</th>
<th>Tempering temperature range 426-704℃</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>9.3 W/cm²</td>
<td>23 W/cm²</td>
</tr>
<tr>
<td>180</td>
<td>7.8 W/cm²</td>
<td>22 W/cm²</td>
</tr>
<tr>
<td>1,000</td>
<td>6.2 W/cm²</td>
<td>19 W/cm²</td>
</tr>
<tr>
<td>3,000</td>
<td>4.7 W/cm²</td>
<td>16 W/cm²</td>
</tr>
<tr>
<td>10,000</td>
<td>3.1 W/cm²</td>
<td>12 W/cm²</td>
</tr>
</tbody>
</table>

**Fig.-7**: Relation between tempering time and hardness
The RF induction hardening and tempering equipment is generally composed of machines and apparatus below. This is the case of Constant Velocity Joint hardening and tempering equipment in full automatic line.

**Fig. 8: Composition drawing of equipment**

1. **Power receiving panel**
   - This is the panel for receiving primary power that is composed of mainly transformer, NFB, voltmeter and ammeter etc. (Sometimes this panel and RF generator use same frame depending upon design philosophy.)

2. **Composition of RF Induction Hardening and Tempering Equipment**
   - The equipment is generally composed of the following machines and apparatus:
     - Transformer
     - Power receiving panel
     - Power supply terminal
     - Cooling tank
     - Quenching water tank (inside the pit)
     - Hardening/tempering machine
     - Conveyor
     - Scrubber
     - Air supply intake
     - Water deionizer
     - Control panel
     - 240 kW Generator
     - 50 kW Generator (for hardening shaft/groove)
     - Tempering sub-operation panel
     - Tempering machine
     - Cooling water intake 25A(2500H)
     - Cooling water intake 25A(500H)

3. **Primary power supply terminal**
   - 3φ 400V 50Hz
   - 3φ 3300V
   - 3φ 6600V

4. **Flow direction**
   - Conveyer
   - Scrubber
   - Shaft hardening
   - Groove hardening
   - Tempering
   - Hardening/tempering machine
   - Main operation panel
   - Tempering sub-operation panel
   - (Operator’s side)
(2) RF generator (Oscillator)

The RF generator is composed of generator main body, matching circuit, duct for output cable, current transformer, water deionizer. (The matching circuit is sometimes installed in generator.)

DKK manufactures various kinds of generators, which could be applied to any kinds of customer’s requirement.

DKK is prepared detailed specifications and standards for each kind of generator.

The deionizer is equipped in the main body of all the generators if they need it.

Table 6: Comparison table (of DKK generators)

<table>
<thead>
<tr>
<th>Items</th>
<th>Electric motor generator (MG)</th>
<th>Vacuum tube oscillator (VT)</th>
<th>Statistic generator (Thyristor Inverter) (SG)</th>
<th>Transistor inverter (TG, PTG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1~10kHz</td>
<td>20~500kHz</td>
<td>500Hz~1kHz</td>
<td>300Hz~3kHz</td>
</tr>
<tr>
<td>Single output power</td>
<td>10~600kW</td>
<td>2~750kW</td>
<td>500~3,000kW</td>
<td>5~1,000kW</td>
</tr>
<tr>
<td>Frequency fluctuation</td>
<td>Constant</td>
<td>Fluctuating when self-oscillation</td>
<td>(1) Constant,(2) Fluctuating</td>
<td>(1) Constant,(2) Fluctuating</td>
</tr>
<tr>
<td>Power adjustment</td>
<td>Setting voltage, Output voltage</td>
<td>Anode voltage</td>
<td>(1) DC voltage,(2) Frequency</td>
<td>(1) DC voltage,(2) DC current</td>
</tr>
<tr>
<td>Frequency conversion efficiency</td>
<td>70~83%</td>
<td>65~70%</td>
<td>75~92%</td>
<td>75~95%</td>
</tr>
<tr>
<td>Consumable parts</td>
<td>Bearing</td>
<td>Vacuum tube</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Floor space</td>
<td>Large</td>
<td>Middle</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Repair and replacement</td>
<td>Long time</td>
<td>Short time</td>
<td>Short time</td>
<td>Short time</td>
</tr>
<tr>
<td>Parallel operation</td>
<td>Available</td>
<td>Not available</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Repair and replacement</td>
<td>Much</td>
<td>Much</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Hardening depth</td>
<td>3~10mm</td>
<td>1~3mm</td>
<td>3~10mm</td>
<td>1~10mm</td>
</tr>
</tbody>
</table>

(3) Hardening Machine and/or Tempering Machine

This machine is composed of hardening station and/or tempering station, and lift and carrier equipment, which conveys work-pieces to hardening station and/or tempering station and holds, moves and rotates work-pieces one by one. This machine is roughly divided into automatic type and manual type, and the types are chosen depending upon output, production system and production process.

DKK produces optional machines, which have picture display in NC control panel or ACC (Automatic Coil Changer) equipment depending upon customer’s request.
(4) Control Panel and Operation Panel

Control panel is normally of self-supported type and has built-in sequence controller and microcomputer. The total control of the system is done here.

Operation panel is normally attached in hardening machine, and the setting of hardening condition and each movement of the machine are operated here.

Operation panel is occasionally divided into main operation panel and auxiliary operation panel according to the necessity, and sometimes installed a graphic panel, which displays processing progress for easy monitoring and enables to communicate with PC.

(5) Heating Inductor and Inductor Holder (Cf. Fig. 14, 15)

A heating inductor is the device, which induces RF current in the heating portion of work-piece, and there are various types in heating inductor to fit various shapes of heating portion of work-piece. (Cf. Fig. 15)

An inductor holder is located between RF current transformer and heating inductor and there are bolt-clamped type and lever clamped type etc in the holder. (Cf. Construction and example of devices for RF heat processing)

(6) Cooling/Quenching Water Circulating Equipment

Cooling water is used for cooling RF generator, current transformer and heating inductor, and quenching water (liquid) is used for hardening. For quenching water tank, it is needless to say that the managing of water volume, water pressure and temperature of quenching water is required and in case of using hardening cracks preventing coolant, the managing of density is also important. Typical piping schematic diagrams of cooling and quenching water circulating equipments are shown in Fig. 10, 11, 12.

(7) Other attached Equipments

1) Hardening/Tempering Condition Setting and Supervising Display Equipment (DPL series)

On the liquid crystal touch panel display, hardening/tempering condition can be set by a touch, and upper and lower limit supervisory functions of each setting value are interlocked.

This equipment is developed by DKK for hardening/tempering equipment, and is unrivaled in operativeness.

Communication with PC is also available by request.
2) Hardening/Tempering Temperature Control Equipment
This equipment controls heating temperature of hardening or tempering, and the temperature is measured generally by radiation thermometer, which is normally attached a recorder. By interlocking RF generator with this equipment, PID control of keeping hardening/tempering temperature at a constant level is also available.

3) Automatic Coil (Inductor) Change Equipment (ACC)
This is the highest-level ACC equipment developed based upon abundant supply records in many years, and completed with high technology.
This equipment clears all the performances required for RF induction heating inductor such as reliable clamp (electrical connection and water flow) with holder, static accuracy, dynamic accuracy, repeatability and durability.

4) Heating Electric Power Amount Control Equipment
This equipment controls Electric power amount, which is the product of electric power and heating time, at a constant level.

5) Non-destructive Eddy Current Inspection Equipment
This equipment is used for the inspection of hardness/hardened-layer and hardening crack by magnetizing a work-piece, and enables to inspect all the work-pieces and to eject defective work-pieces automatically by installing this equipment in the system.
(1) Quenching water tank and cooling water tank attached with chiller unit

(1) In case of water-cooled chiller unit is used, primary cooling water and piping works are necessary.
(2) Quenching water tank and cooling water tank are sometimes installed in the pit.
(3) Control panel is attached.

(1) Water Quality Standard
In induction heating equipment, cooling water is necessary because water-cooled inductors made of copper pipe are used. The water flow section is relatively small and to prevent temperature rise of inductors, it is required to keep the inside of copper pipe in good condition for heat conduction.
Therefore, there is a certain limitation in the quality of cooling water.

DKKšt standard is as follows.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>No color</td>
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<tr>
<td>Specific resistance</td>
<td>Below 4000 ℛ cm</td>
</tr>
<tr>
<td>PH value</td>
<td>6.5~7.5</td>
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<tr>
<td>Total hardness</td>
<td>Below 40ppm</td>
</tr>
<tr>
<td>Calcium hardness</td>
<td>Below 30ppm</td>
</tr>
<tr>
<td>Magnesium hardness</td>
<td>Below 10ppm</td>
</tr>
<tr>
<td>Oxygen consumption (Acid oxidation method by KMnO4)</td>
<td>Below 2ppm</td>
</tr>
<tr>
<td>Chlorine ion (Cl)</td>
<td>Below 15ppm</td>
</tr>
<tr>
<td>Sulfuric ion (SO₄) (By gravimetric method)</td>
<td>Below 20ppm</td>
</tr>
<tr>
<td>Calcium ion (Ca²⁺)</td>
<td>Below 15ppm</td>
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<tr>
<td>Magnesium ion (Mg²⁺)</td>
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<td>Total iron</td>
<td>Below 0.3ppm</td>
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<td>Dissolved iron ion</td>
<td>Below 0.03ppm</td>
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<tr>
<td>Vaporized residue</td>
<td>Below 120ppm</td>
</tr>
<tr>
<td>Oxygen consumption (Acid oxidation method by KMnO₄)</td>
<td>Below 2ppm</td>
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</tbody>
</table>

Above shown are standard values. Almost all kinds of industrial waters are within the value. Even the case of over limitation, but small difference, there is no problem using the water.

(2) Quenching water/liquid temperature

From the figure above, it is generally effective to keep quenching water temperature 30°C ~ 40°C for preventing hardening crack.
For RF induction hardening/tempering, followings are required other than RF generator and hardening/tempering machine.

(1) Heating inductor and cooling jacket  
(2) Jig  
(3) Inductor holder  
(4) Current transformer  
(5) Output lead  

These are connected relatively as shown in Fig. 14.

(1) **Outline of Heating Inductor**

Heating inductor, which induces RF current in the heating portion of a work-piece, is a coil made of 2~10mm copper pipe in one or two turn in case of simple type, and cooled with water flow inside the pipe. Inserting a work-piece into the circular inductor, which is energized with RF current, the work-piece is heated.

In this case, the clearance between work-piece and heating inductor affects the power efficiency, and as closer the efficiency is better. Actually 1~5 mm clearance is selected considering fluctuation of steadiness by expansion and deformation of scorchingly heated work-piece, and mechanical rotation.

In actual surface hardening, the quality of hardening is affected with RF electric power, frequency and quenching liquid etc, however, the shape of inductor is the most effective one. In manufacturing inductors using copper material, silver blazing works are most important.

In the case of simple shaped work-piece, the design of inductor is easy, however, in the case of complicated shaped work-piece, to make it harden effectively, the design of inductor is done reflecting the experienced know-how.

For the purpose of giving strong heating partially, magnetizing substances such as silicon steel laminates or ferrite cores are arranged at the portion.

DKK heating inductors except for special ones are generally manufactured by machining and finished after brazing (normally silver brazing) with jig, which is prepared beforehand, and inspected with inspection jig to keep the accuracy strictly. For changing heating inductor, setting jig is available. These days, some of the inductors for scanning hardening are manufactured by only machining and not using silver brazing.
Fig. 15: Application examples of practical heating inductors

1. Heating inductor for continuous scanning
2. Heating inductor for inside scanning
3. Heating inductor for ball-stud
4. Heating inductor for traveling long plane
5. Heating inductor for saw tooth
6. Split type heating inductor for crankshaft
7. Large one gear stationary hardening heating inductor
8. Heating inductor for large one gear scanning
9. Heating inductor for small one gear scanning
(2) Classification of heating inductor
Heating inductors are generally classified as follows.

- Classification by heating method
  - Stationary heating inductor (one shot inductor): during heating, inductor and work-piece are in same position
  - Scanning heating inductor: during heating, inductor or work-piece travels
  - Direct heating inductor: direct resistance and induction heating
- Classification by copper material processing method
  - Copper plate inductor: processed with lathe, shaper etc
  - Pipe inductor: processed of round pipe, square pipe etc
- Classification by heating inductor and work-piece position
  - Outside heating inductor
  - Inside heating inductor
  - Plane heating inductor

(3) Examples of Heating inductor

- One shot heating inductor for gear/sprocket hardening: single turn inductor
- Semicircular heating inductor for crankshaft hardening
- Split type heating inductor

This is a typical one shot heating inductor and has water-splashing holes.
Pipe inductor and jacket

Scanning heating inductor for axle shaft: splash cooling water from heating inductor.

Traveling shaft heating inductor: Heated with heating inductor and quenched with cooling water from jacket.

Copper plate inductor and jacket

Pipe diameter П₀.

Hardening layer

Quenching water jacket

Heating inductor

Heating work-piece

Inside traveling heating inductor for tri-pot housing inside hardening

Water hole П₁ = 1.6~2.2

Heating work-piece

Hardening layer

Inductor cooling pipe

Brazing

Feature

This is suitable for long shaped work-pieces. Output power is smaller than that of one shot heating.

Tooth surface traveling heating inductor for single gear tooth hardening

DKK PAT.

DKK PAT.
A copper pipe inductor is manufactured using annealed round copper pipe, after filling sand in the pipe, winding around jig. (Pipe inductor)

Instead of using round pipe, another type of inductor is manufactured using copper plate or round bar, after processing the material with lathe into circular rings, connecting them to compose a multi-turn inductor. (Copper plate inductor)

### Feature
Partial heating/hardening of a work-piece is possible.

When RF electric current is supplied to the teeth side of work-piece through quenching water jacket, the current flows mainly on the surface of teeth and current density at the tips of teeth becomes bigger more than botton side. As a result of, the teeth side can be heated more than botton side.

The heating portion becomes a part of the inductor, and the portion itself can be inductively heated. And also because of edge effect (the magnetic flux is concentrated at the edge), electric current flows mainly at the edge of the teeth.
Single-shot heating inductor for shaft hardening

**Feature**
Suitable for long and uneven shaft hardening and the deformation by hardening is smaller than that of scanning. Although large RF power is required, processing tact is shorter than that of scanning.

Single-shot heating inductor and quenching water jacket

**Structure of quenching water jacket**
- Half-cylindrical (Horseshoe-shaped) type: fixed
- Box type: fixed

The material of quenching water jacket can be substituted Bakelite or vinyl chloride materials for copper plate.

By using magnetic flux concentrator such as dust core or Oken-core on the inductor, heating efficiency increases.

Protection of heating inductor
As large electric current flows in heating inductor, exothermic measures and electrical insulation measures are required for protection.

**Exothermic measures**
1. Make sufficient flow of cooling water to heating inductor.
2. Keep cooling water temperature below 35°C.

**Insulation measures**
Practical measures are shown below. Each measure has both merits and demerits and is applied on a case-by-case basis.

**Examples**
1. Wrap with glass tape or vinyl tape etc.
2. Treat with alumina coating etc.
3. Mould with epoxy resin etc.
5. Treat with Teflon coating etc.

**Electric measures**
1. Detect a touch of inductor with work-piece
(4) Examples of Quenching water Jacket

- Box type quenching water jacket
- Ring type quenching water jacket
- Jacket and inductor integrated type for scanning hardening

(5) Inductor not using current transformer

- Multi-turn inductors such as for RF induction tempering etc
- Tempering inductor

(6) Jigs

(Role of jig)
It is used for holding a work-piece, usually for a work-piece rotation.

(Material)
- Bras: It is easy to be processed but also easy to be worn out.
- SS material: It is easy to be processed but also easy to be rusted and worn out.
- Stainless: Austenite stainless is less RF induced and free from rusting.
- Silicon nitride: It is not RF induced but hardly processed and expensive.
- Copper: Easy to be worn out but because of its high heat conductivity, it is better for heat absorber.
(7) Inductor-holder
(Role of inductor-holder)

This is used to connect inductor with current transformer. Various types of holders are prepared to conform to the types of inductors and current transformers. Each holder is designed so as to set up inductor easily. The shorter holder in length is better in efficiency.
RF Hardening Adopting Manual

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<th>Steel kind + Symbol</th>
<th>A(Water)</th>
<th>Hardening hardness</th>
<th>B(Oil)</th>
<th>Hardening depth mm</th>
<th>Maximum hardening depth (Water)</th>
<th>Preprocess</th>
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<td>HS</td>
<td>HRC</td>
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</tbody>
</table>

A is for simple shaped work-pieces such as shaft, pin etc.
B is for complicated shaped work-pieces such as housing, shift-fork etc.
The figures in the table above are for the desirable hardening, which the microstructures on the surface are even and wearability is excellent.
The suitable hardening depth \( D \) for the desirable fatigue limitation is calculated as, assuming the diameter of work-piece \( D \), \( d = 0.15D \).

**Fig.-16: General confirmation for RF hardening**
<table>
<thead>
<tr>
<th>Rockwell C scale hardness</th>
<th>Vickers hardness</th>
<th>Brinell hardness 10mm ball/3000kg load</th>
<th>Rockwell hardness</th>
<th>Rockwell superficial hardness special Brale penetrator</th>
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<td>62.5</td>
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</table>
Trial processing and Experiment

In induction hardening/tempering, various kinds of parts such as automobile parts, construction machine parts, machine tool parts etc. are processed. We described how to decide output power and frequency of generator in the preceding clause, however in general, the shape of each kind of parts is different, and so the method of processing is individually different. Therefore, the best way to decide output power and frequency of generator is to be done based upon the data of trial hardening process using RF generator for the purpose. DKK prepares trial testing equipment and inspection equipment listed in the tables below to meet to any kinds of customer requirements. Please refer to tables 10 and 11.

In case we have tested upon request, we will submit the result in a report of testing method and inspection data.

For ordering a trial processing of parts, please inform us the purpose of parts used for, shape and size with drawing and processing tact.

After ordering, we need a couple of weeks for preparing heating inductor etc. We will submit the report in about one week after finishing heating inductor etc.

Table 10: Testing equipment

<table>
<thead>
<tr>
<th>Oscillators type</th>
<th>Device Type</th>
<th>Output (kW)</th>
<th>Frequency(kHz)</th>
<th>Hardening machine</th>
<th>Drive</th>
<th>Heating method</th>
<th>Stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 MLL-250STR type VT</td>
<td>250</td>
<td>30 • 60 • 200</td>
<td>DMH-800S special type hardening machine</td>
<td>Motor (Pulse)</td>
<td>Work traveling and stationary heating</td>
<td>800m/m</td>
<td></td>
</tr>
<tr>
<td>No. 2 M-40TR type VT</td>
<td>40</td>
<td>300</td>
<td>DOH-800 type hardening machine</td>
<td>Oil pressure</td>
<td>Work traveling and stationary heating</td>
<td>800m/m</td>
<td></td>
</tr>
<tr>
<td>No. 3 MLL-120TR type VT</td>
<td>120</td>
<td>30 • 60 • 200</td>
<td>DMH-800S type hardening machine</td>
<td>Motor (Pulse)</td>
<td>Work traveling and stationary heating</td>
<td>800m/m</td>
<td></td>
</tr>
<tr>
<td>No. 4 PG-3/10-350 type SG</td>
<td>350</td>
<td>3 • 10</td>
<td>DMH-1000S type hardening machine</td>
<td>Motor (Pulse)</td>
<td>Inductor traveling and stationary heating</td>
<td>1000m/m</td>
<td></td>
</tr>
<tr>
<td>No. 5 PTG-10-20-200 type TG</td>
<td>200</td>
<td>10 • 20</td>
<td>Full-automatic crankshaft hardening machine</td>
<td>Hydraulic pressure</td>
<td>Single-shot</td>
<td>Total length 1500m/m</td>
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</tr>
<tr>
<td>No. 6 PG-3/10-600 type SG</td>
<td>600</td>
<td>3 • 10</td>
<td>DMH-500 special type hardening machine</td>
<td>Motor (Pulse)</td>
<td>Work traveling and stationary heating</td>
<td>500m/m</td>
<td></td>
</tr>
<tr>
<td>No. 7 ML-750STR type VT</td>
<td>750</td>
<td>6 • 200</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table-11: Inspection equipment

1. X-ray stress measuring equipment: Output 30kW □ 10mA, Parallel beam
2. Scanning electron microscope: Magnification: 30—70000, Accelerating voltage: 20kV, Resolution: 80A
3. Automatic Vickers hardness meter: Load 1 • 5 • 20 • 30 • 50kgf, 100-power measuring microscope
5. Optical microscope: 50—400-power
6. Magnetic flaw meter: Voltage 200—220V, Magnetizing current 3000A
7. Sample inlay machine
8. Sample grinder (3 sets)
9. Sample dryer
10. Automatic cutter (2 sets)
11. Electric furnace
12. Carbon analyzer
13. Gear accuracy measuring equipment
14. Heating temperature measuring equipment (various kinds)
15. Charpy impact testing machine
Inquiry and Ordering Information

The manufacturing and installation process of DKK’s hardening/tempering equipment after receiving an order is generally as follows.

- Meeting on ordering specification
- Meeting on approval drawing
- Submit final approval drawing
- Factory inspection
- Installation
- Trial operation
- Commissioning

- Parts ordering
- Manufacturing
- Submit hardening/tempering data
- Submit instruction manual

Please inform us following requirements on the occasion of inquiry or ordering DKK’s RF hardening/tempering equipment.

1. **Purpose (Ex. Hardening or Tempering)**
2. **Power supply Voltage/Frequency**
3. **Environment of plant**
4. **Specification of heat processing (Please show us with drawings.)**
   - Name and size of work-piece
   - Material and composition
   - Pre-heat processing
   - Hardness of material
   - Portion of hardening
   - Hardening hardness
   - Hardening depth layer
   - Distortion before and after hardening
   - Processing tact and processing amount
   - In case there are many kinds of work-pieces, please inform us the pertinent ones, which shall be the estimation standard of generator's output power. (The pertinent ones mean the work-pieces, which are maximum, minimum size and largest in processing/production number.)
5. **Specification of equipment**
   - RF generator (Vacuum tube type/Thyristor type/Transistor type)
     - Output kW
     - Frequency kHz
   - Number of processing stages
   - Hardening machine
     - Standard machine
     - Vertical type scanning hardening machine (500mm, 800mm, 1000mm, 1500mm, 2000mm)
   - One-shot hardening machine
   - Exclusive use machine
     - Manual machine
     - Automatic machine
       - Pre-process and post process
       - Supplying equipment (Stock amount)
       - Discharging equipment (Stock amount)
       - Carrier equipment (Conveyor type, Turn-table type, Lift and carrier type, etc.)
     - Drive
       - Hydraulic pressure
       - Pneumatic pressure
       - Motor
     - Etc.
   - Control panel and operation panel
     - Sequence controller type (Manufacturer name)
     - Display equipment
     - Etc.
   - Cooling water circulation equipment
     - Air-cooling/water-cooling chiller (refrigerator)
     - Quenching water circulating equipment
     - Cooling water circulating equipment for machine
   - Other attached equipments (Magnetic separator, Oil/water separator, Flow meter)
   - Heating inductor and jig
     - Number
   - Other attached equipments

**DKK’s RF Induction Heating Equipments Manufacturing/Sales Items**

- DKK accepts orders of equipments below and RF generators for semi-conductor production use etc besides the RF hardening/tempering equipment

- Melting
- Heat processing (Job-shop)
- Billet heating
- Soldering Brazing
- Pipe welding

- Adapting material and parts
- Seel
- Stainless
- Copper
- Gold/Silver
- Titanium
- Electronic material
- Automobile parts
- Motorcycle parts
- Parts for construction machine
- Parts for industrial machine
- Parts for machine tool
Head Office: RF Application Equip. Sales Dep.
Shin Tokyo Bldg., 3-3-1 Marunouchi, Chiyoda-ku, Tokyo 100-0005, Japan
Tel 03-3216-9433—4, Fax 03-3216-1669

Osaka Office
18-38, Toyotsu-cho, Suita-shi 564-0051
Tel 06-6378-0162, Fax 06-6378-0163

Atsugi Plant (RF Administration)
4052-1, Nakatsu, Aikawa-machi, Aiko-gun, Kanagawa 243-0303, Japan
Tel 046-285-1411, Fax 046-285-5302

RF Division Group Companies
Denko Techno Heat Co., Ltd
Head Office, Hamamatsu Plant: 170 Tsumori-cho Hamamatsu-City Shizuoka-Pref. 430-0815 Japan
Head Office: Tel 053-441-8451, Fax 053-441-8896
Hamamatsu Plant: Tel 053-441-8517, Fax 053-441-8896

Kariya Plant: 1 Yamanota Kariya-City Aichi-Pref. 448-0812 Japan
Tel 0566-27-0750, Fax 0566-27-6394

Suzuka Plant: 1820-39 Nakanoke Mikkaichi-machi Suzuka-City Mie-Pref. 513-0803 Japan
Tel 0593-82-1829, Fax 0593-82-1419

Shiga Plant: 10 Satsukigaoka Minakuchi-Chou Kouga-Gun Shiga-Pref. 528-0062 Japan
Tel 0748-63-3831, Fax 0748-63-3833

Koshuha Kogyo Co., Ltd. (in DKK Atsugi Plant)
4052-1 Nakatsu Aikawa-machi Aiko-gun Kanagawa-Pref. 243-0303 Japan
Tel 046-286-1065

Denko Metallurgical Technology Co., Ltd. (in DKK Head Office)
Shin Tokyo Bldg., 3-3-1 Marunouchi, Chiyoda-ku, Tokyo 100-0005, Japan
Tel 03-3286-5233, Fax 03-3286-5270