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## A CRITICAL REVIEW ON DIFFERENT COIL CONFIGURATIONS USED FOR INDUCTION HEATING SYSTEM

Tejas G. Patil<sup>1</sup>, Atul A. Patil<sup>2</sup>, Vijay H. Patil<sup>3</sup>

Department of Mechanical Engineering

GF's Godavari college of Engineering, Jalgaon, INDIA

**Abstract:** Induction heating system has a number of inherent benefits compared to traditional heating systems due to a non-contact heating process. The main interesting area of the induction heating process is the efficiency of the usage of energy, choice of the plate material and different coil configurations based on application. Correctly designed, manufactured and maintained induction coils are critical to the overall efficiency of induction heating solutions. The important investment in induction heating process is in highly qualified coil technicians and advanced coil design equipment and got benefit by having coils that are customized to their specific needs and conditions, The objective of the present work reviews different coil configurations used for the induction heating Process which is based on application such as surface hardening, Casting, Rolling, welding, Brazing, Bonding, Post Heating and Water Heating.

**Keywords:** Induction Heating, Induction Coil, Helical, Pancake, Skin Effect

### I. Introduction

Induction method of heating is wide spread used in numerous technological processes for hot forming, surface hardening, annealing, etc. It is extremely effective because of its contactless energy transfer, unlimited power densities and controlled temperature field in the work piece. However, high potential of induction heating can be fully realized on the basis of numerical simulation only. All technological processes used induction method of heating is multi physical. Heating by induction it includes electromagnetic and thermal physics, which are strongly coupled because of temperature dependent properties of the work piece material. Induction heating is a process which is used to bond, harden or soften metals or other conductive materials [5]. For many modern manufacturing processes, induction heating offers an attractive combination of speed, consistency and control. Many industries have benefited from this new breakthrough by implementing induction heating for furnacing, quenching and welding.

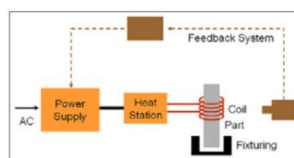


Figure 1 Basic setup of induction heating

The basic principles of induction heating have been understood and applied to manufacturing since the 1920s. During World War II, the technology developed rapidly to meet urgent wartime requirements for a fast, reliable process to harden metal engine parts. Induction heating has made it easier to set the heating parameters without the need of an additional external power source. More recently, the focus on lean manufacturing techniques and emphasis on improved quality control have led to further research in induction technology specially in precise coil design and equipment required for manufacturing of the coil which is key factor in process, along with the development of precisely controlled. In addition, it can be used special application like welding operations joining, brazing, bonding etc. Some industrial applications of the induction heating Process is shown on the Table 1.1

Induction Melting	Induction Welding	Special Applications
	<ul style="list-style-type: none"><li>- Induction Brazing</li><li>- Induction Soldering</li></ul>	
<b>Induction Heating</b> <ul style="list-style-type: none"><li>- Billet and Bar heating</li><li>- Strip and plate heating</li><li>- Wire and cable heating</li><li>- Tube and pipe heating</li></ul>	<b>Heat Treatment</b> <ul style="list-style-type: none"><li>- Hardening</li><li>- Tempering</li><li>- Annealing</li><li>- Normalizing</li><li>- Sintering</li></ul>	<ul style="list-style-type: none"><li>- Shrink Fitting</li><li>- Cap Sealing</li><li>- Banding</li><li>- Heat staking metal to plastic</li><li>- Hot material testing</li></ul>

Table 1.1 list of industrial application of induction heating

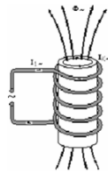
### II. Mechanism of Induction Heating System

Induction heating is contactless electrical heating. It is a costly but extremely versatile process with innumerable applications. It can be used for partial and through heating, melting, and brazing of all metallic materials. In this section, we will review the basic principles of Induction Heating System.

The principle of induction heating is mainly based on two well-known physical phenomena:

## 1) Electromagnetic Induction:-

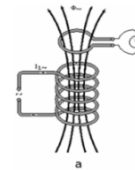
The energy transfer to the object to be heated occurs by means of electromagnetic induction. It is known that in a loop of conductive material an alternating current is induced, when this loop is placed in an alternating magnetic field (see Figure 2).



**Figure 2 Induction law of faradays**

When the loop is short-circuited, the induced voltage  $E$  will cause a current to flow that opposes its cause the alternating magnetic field. This is Faraday - Lenz's law.

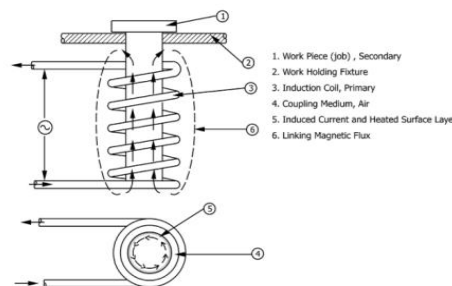
If a 'massive' conductor (e.g. a cylinder) is placed in the alternating magnetic field instead of the short-circuited loop, than eddy currents (Foucault currents) will be induced in here (see Figure 3). The eddy currents heat up the conductor according to the Joule effect.



**Figure 3 Induction of eddy currents**

## 2) The Joule effect:-

When a current  $I$  [A] flows through a conductor with resistance  $R$  [ $\Omega$ ], the power is dissipated in the Conductor. Induction heating is based on the principles of an electric transformer. The job or work-piece is the secondary while a surrounding copper coil is the primary. The two are linked or coupled by air. Thus, this is an air core transformer with a single turn secondary.



**Figure 4 Actual scenario of induction working [7]**

High frequency (HF) current (1,000–100,000 Hz) is Passed through the primary (coil) by connecting it to a suitable HF generator A similar HF current is induced in the job, i.e., secondary. This current circulates and produces heat. These are induced eddy currents and circulate circumferentially as shown in Figure 4. Eddy currents, and therefore the heating, are concentrated in a thin outer layer or skin of the work. The primary coil gets heated due to the  $I^2R$  losses in it. Some heat is also absorbed from job radiation. The coil is therefore made of copper tubing through which cooling water is circulated. The job thus gets heated by the induced current and there is no contact between the primary and secondary. Iron and other soft magnetic materials are used in ordinary transformers to act as subsectors, i.e., to concentrate the magnetic linking flux. They cannot be used in high frequency fields as they heat up excessively. Hence, air is used as the coupling medium. A few large scale induction heating processes (melting, heavy billet heating) that operate at mains or low frequencies (50–150 Hz) do use iron or alloy cores. The concentration of induced currents in the surface layer is called the "skin effect." Skin effect plays an important role in the design and operation of the induction heating process [8]. Induction heating systems works with the alternating current, as a result the induced current inside the work piece is concentrated at the outer surface with a thickness called penetration thickness (depth). This effect is also named as skin effect. The heat generation take place in this penetration part therefore material heated from surface (skin) to core. The most interesting side of the method is that heating occurs without contact and by this way locally and precise heating can be applied. The amount of heat created by induction heating is depend on the several independent parameters such as power supplied, induction heating time, work piece geometry, material properties, work piece positioning in the coil, coil structure geometry, number of turning in the coil and also induction power supply frequency .

## III. Different Coil Configuration Used in Induction Heating System

As we have discussed above heat generation rate in induction heating is depend on the several independent parameters such as power supplied, induction heating time, work piece geometry, material properties, work piece

positioning in the coil, coil structure geometry, number of turning in the coil and also induction power supply frequency; we have to review the different coil structure used for induction heating.

Coil design is one of the most important aspects of an induction system. A well-designed coil provides easy part handling, maintains the proper heating pattern and maximizes the efficiency of the induction heating power supply. Inductor coil for high frequency induction heating usually referred to as heating coils and it can be made in a large variety of types and styles which depends on the shape of the metal surface to be heated. Heating of metal parts is the result of internal energy losses within the material being treated, which causes the temperature to rise. Their design must follow certain principles to achieve maximum efficiency. Some of them which are mostly used in induction heating process are shown as follows:



### 1) Round Coil:-

The most common is a cylindrical or Round coil which is suited for short length of work piece. The copper conductor is wound or formed either symmetrical in contour or shaped to suit the outline of the part to be heated. This Round coil is especially use for surface heating of shafts and round parts

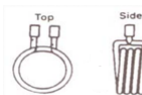


Figure 5 Round coil

### 2) Helical and Spiral Helical coil:-

A helical coil is generally used for the part or area to be heated located within the coil and, thus, in the area of greatest magnetic flux. In general, helical coils used to heat round work pieces have the highest values of coil efficiency and internal coils have lowest values. The copper conductor is wound or formed either symmetrical in contour or shaped to suit the outline of the part to be heated [3]. This type is suited to surface heating of shafts and bars. The shape of helical coil mainly depends on the shape of work piece [1]. So, the coil may be in the shape of round, rectangular, formed, spiral helical and others. Spiral coils are generally used for heating bevel gears or tapered punches.

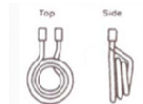


Figure 6 Spiral helical coil

### 3) Pancake Coil:-

A pancake induction coil usually multi-turn. It heats a ring on surface; central zone may be heated by heat conduction or coil part movement such as eccentric part rotation. Concentrator is strongly desirable to improve coil parameters and reduce under heated central zone. Concentrator is strongly recommended for this coil. A pancake coil is used for heating flat surfaces and so flux from only one surface intersects the work piece. Pancake coils are generally utilized when it is necessary to heat from one side only or when it is not possible to surround the part.



Figure 7 Pancake coil

### 4) Irregular Shape coil:-

The use of the coil is solely depends upon the size of the work piece and most of cost spending in induction heating is design of precise coil and manufacturing of the same. This irregular shape coil is used for work piece with irregular shape. One of the irregular shape coils is shown in figure 8 which is used for Induction Hardening.

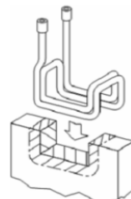


Figure 8 Irregular coil

### 5) Single Turn Coil:-

The use of single-turn coil and the use of multi-turn coil are based on usually the area of the zone to be heated; Single-turn coils are preferred when the heated area is narrow or restricted. Single-turn coils are more practical

where the height does not exceed the diameter. Single-turn coils are also effective for heating bands that are narrow with respect to the part diameter. Depending upon the application, it is a single-turn, single-place coil or a multi-turn, single-place coil. Both coils are used for heating a single part at a time. And it is a single-turn, multi-place coil or a multi-turn, multi-place coil for heating the multi parts at a time [2].

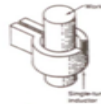


Figure 9 Single turn coil

#### 6) Internal coil:-

Tubing for internal coils should be made as thin as possible, and the bore should be located as close to the surface of the coil as is feasible. Because the current in the coil travels on the in-side of the inductor, the true coupling of the maximum flux is from the ID of the coil to the bore of the part. Thus, the conductor cross section should be minimal, and the distance from the coil OD to the part (at 450 kHz) should approach 0.062-inch (0.16-cm). The coil tubing has been flattened to reduce the coupling distance, and the coil OD has been increased to reduce the spacing from coil to work [4]. An internal coil is used for heating inner surfaces of holes.



Figure 10 Internal coil

#### 7) Split Coil:-

Split coils are generally utilized as a last resort for applications in which it is difficult to provide a high enough power density to the area to be heated without very close coupling, and where part insertion or removal would then become impossible. One such situation is the hardening of journals and shoulders in crank-shafts. In this case, the split-coil design would also include the ability to quench through the face of the inductor. It should be noted that with a split inductor, good surface-to-surface contact must be made between the faces of the hinged and fixed portions of the coil. Generally, these surfaces are faced with silver or special alloy contacts that are matched to provide good surface contact. Clamps are used to ensure closure during heating [2].

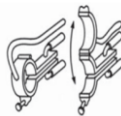


Figure 11 Split coil

### IV. Factor consider for different coil geometries required for induction heating system

According to the geometry of work piece surface the shape of work coil is varied and the size of work coil is governed by the length of work piece. Basic points to consider for efficient working of Induction heating process [6]:

1. Work coil for induction hardening is made in a wide variety of styles, shapes and sizes. Depending upon the natures of work piece the styles of work coil are changed
2. The inductor coil itself is only a part of the generator output system and Success is directly dependent on proper design of the Inductors (work coils).
3. The same principles of design must be applied to the leads which connect the coil to the output terminals of the generator or remote heating station [8].

Following factors have been considered for construction of heating coil required for induction heating system [8]:

- **Type of wire:** It may be solid wire or multi stranded litz wire. At high frequency, the skin effect loss will be more in case of solid wire. Thus for energy efficient induction cooker, the heating coil may be made by multi stranded litz wire.
- **Work piece Shape:** It governs the important factor for design of induction coil because shape of induction coil design according to shape of the work piece
- **Shape of wire:** It can be round or rectangular cross sectional wire or it may be foil coil. At round cross-sectional wire the current flows uniformly through the whole cross section. But in case of rectangular or foil coil current density is more at the corner or edge section.
- **Size of strand:** From the litz wire manufacturer's manual at the frequency range of 20 to 50 kHz, the strand size lies between 30 to 36 AWG. Three different strand sizes, such as 30, 33 and 36 AWG have been use for special applications.

- **Number of turns of spiral coil or Pitch:** It depends on the size of the heating coil. It is varied from 30 to 60 in the present study and optimal value is chosen.
- **Heating Time:** The time values necessary to reach the prefixed final temperature affect the parameters of coil design.
- **Number of twist per feet or lead:** The stranded litz wire is twisted so that each strand can possess both azimuthal and radial transposition. For thick wire number of twist can be 12 twists per feet and for thinner wire it may be up to 200 twists per feet.
- **Lead:** It is desirable to keep them as close together as possible in order to avoid inductance losses between the leads
- **Operating frequency:** Induction cooker operates at the frequency range of 4 kHz to 50 kHz. For different strand size and number of strands suitable operating frequency will be different and it is to be determined in an optimal sense.
- **Coil efficiency:** Coil efficiency is that part of the energy delivered to the coil that is transferred to the work piece which is mainly depends upon frequency and geometry shape of induction coil.
- **Heating pattern:** It depends upon the shape of the work piece to be heated and the coil is to be design for specific work
- **Part motion relative to the coil:** The motion of the work piece decides the turns of the coil and increase in geometry [8].

## V. Conclusion

The review indicates that Induction heating (IH) is a contactless energy-efficient method of heating. In this process for the efficient working key factor is induction coil design for particular application because it governs other factor of induction heating system; so we have studied the different type of induction coils used in industry especially based on geometry like Helical, Round, Pancake coil etc.. The Heat generated in the conductors is depends upon the shape and distance of the coil from work piece placed inside the induction coil. It was observed that the multi-turns are preferred to be effective as compared single turn induction coils due to large variety of irregular shapes of work piece. Also design of induction coil some of factors consider plays important role like Frequency, Size of wire, Pitch and Lead etc. it is observed that Lead will affect magnetic field and increase inductance loss. Finally this paper reviewed the understanding the basic concepts of induction heating and overall mechanism of the Induction Heating process, Different coil geometries used and common factors required for proper design of induction coil for specific application.

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