

# Design and Development of Microcontroller Based Electromagnetic Induction Injera Mitad Prototype.

Feleke Fanta M.

**Abstract:** -Injera is flat, thin, soft, usually circular bread like staple food for most Ethiopians. Its cooking process is long and sensitive to environmental conditions. Injera baking requires temperature ranging from 150°C to 180°C. To generate this temperature, most people use biomass products, whereas those having access to grid connection use locally manufactured traditional electric injera mitad which uses Nickel–Chrome resistor as heat source. This electric clay mitad consumes at an average 3 – 3.5 KW and has low efficiency. To improve power consumption and efficiency of injera cooking mitad, the author developed Electromagnetic Induction Injera Mitad prototype. The prototype operation is based on laws of electromagnetic induction. After complete assembly of the components, a series of lab and field tests were conducted and it was observed that, for a similar injera quality, the initial heating up time was reduced to 45%, the power consumption was reduced to 50%, and the efficiency was increased around 30% compared to that of traditional electric injera mitad. .

**Key words:** - working coil, magnetic field, resonant inverter, cast iron, eddy current.

## I. INTRODUCTION

Injera mitad is Amharic name given to injera baking apparatus in Ethiopia. It is composed of two words; Injera – a flat, thin, soft, usually circular bread like staple food item of most Ethiopians, especially in central and northern parts of the country; and Mitad – a device made from clay or ceramics on which injera is directly cooked. Preparation of injera is a long process. It usually takes two to four days from mixing teff grain flour with water to cooking. Fig. 1.1 shows typical injera with bubbly eyes



Fig. 1.1 – Injera of teff grain [17]

Injera can be produced from almost any staple grain, such as teff (most preferred), sorghum, millet, and maize.

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Its unique property requires thorough understanding of the entire injera baking process like fermenting under controlled environment, proper viscosity of batter, serious control of cooking temperature etc. A good and acceptable injera has spongy texture with bubbly eyes.[10,11]

Depending on the grain type, batter viscosity and other environmental conditions, injera baking requires temperature ranging from 150°C to 180°C [10, 14]. To generate this temperature, all rural and 30% - 40% of urban dwellers use biomass products whereas the remaining urban dwellers (60% - 70%) use locally manufactured conventional electric injera mitad for decades. It uses resistive heater as heat source. Studies made by different parties showed that each locally manufactured electric mitad consumes at an average power of 3.0 – 3.5 KW [10]. It has excessive heat loss and consequently low operating efficiency.

From the field data collected from 15 locally manufactured electric injera mitad the average power consumption is indicated in table 1.1. The Initial heating up time is the time taken by the device to raise the mitad temperature from room temperature up to the working level (around 170°C).

Table 1. 1 Averaged power consumption of locally manufactured electric injera mitad [11].

S.N.	Description	Unit	Aver.value
1	Voltage	V	210
2	Current	A	16
3	Working temperature	°C	170
4	Power consumed	KW	3.36
5	Initial heating up time	min	18
6	Efficiency		45%

It was roughly estimated that, in 2007 around 530,000 [8, 10] locally manufactured electric injera mitades were in use in the country. Because of rapidly growing energy demand and shift from biomass to electricity in urban areas, in 2020 this number is roughly projected to be more than double whereas the major limitations of the device do still exist. [10] The local electric mitad is manufactured from clay which is high heat load material. In addition, due to not standardized manufacturing processes, materials used and assembling imperfections, it has excessive heat losses. Thus, it is energy intensive product and has efficiency around 45%.





Fig. 1.2. Local electric injera mitad [10]

**Statement of the problem**

Injera baking is exercised 2 - 3 times a week by each household [11]. Since the local electric injera mitad has low efficiency, it is responsible for the bulk amount of energy consumption which is around 60% – 70% [14] of the total household requirement. Thus, demand for energy efficient injera mitad with improved power consumption is a crucial question of the society and energy managing sector of the country.

**Objective of the work**

The main objective of this work was to design and develop electromagnetic induction injera mitad prototype with improved power consumption and efficiency compared to the local electric injera mitad.

**Operating principle of the prototype.**

Inductive heating is a contactless technique which converts electrical energy into heat based on the principle of electromagnetic induction. It uses the heating effect of eddy current and hysteresis losses in ferromagnetic materials (work piece). When a ferromagnetic material is placed in a time varying magnetic field, an emf is induced in the ferromagnetic material. This induced emf causes eddy currents to flow in the material. According to Ampere’s law, the Magneto motive force and magnetic field are: -

$$\int Hdl = NI = F \tag{1}$$

$$\phi = \mu HA = BA \tag{2}$$

According to Faraday’s law, a time dependent magnetic field through a closed curve induces an electromotive force (emf) around the curve.

$$E_{ind} = \oint \vec{E}.d\vec{s} = \int \vec{\nabla} \times \vec{E}.d\vec{A} = -\frac{\partial}{\partial t} \int_{area} \vec{B}dA = -\frac{\partial \phi_B}{\partial t} \tag{3}$$

$$E_{ind} = -\frac{\partial \phi_B}{\partial t} = -N \frac{\partial \phi_B}{\partial t} \tag{4}$$

This induced emf causes eddy current flow in the work piece and develops ohmic losses ( $I^2R_w$  loss) which is responsible for the heating of the work piece..

$$P = \frac{E_{ind}^2}{R_w} = i_{eddy}^2 R_w \tag{5}$$

Where,  $E_{ind}$  – induced emf  
 $p$  – power loss in the work piece  
 $R_w$  – electrical resistance of the work piece  
 $i_{eddy}$  –current flowing in the work piece

The amount of heat dissipated depends on the frequency of the eddy current, magnetic field density and thickness of the cast iron work piece. In addition to eddy current loss, there is small contribution of hysteresis loss effect. The total loss in the work piece is: -

$$P = P_{loss} = P_e + P_h \tag{6}$$

Where,  $P_e = K_e f^2 B_m^2 t$  - eddy current loss  
 $P_h = K_h f B_m^x$  - hysteresis loss  
 $f$  – Operating frequency  
 $K_e$  &  $K_h$  – material constants  
 $t$  – thickness of the work piece  
 $x$  – Steimetz constant

**II. MATERIAL SELECTION AND DESIGN CONSIDERATIONS**

Considering availability of required materials in the local market, materials listed in table 2.1 and given parameters are taken.

Table 2.1 Main materials and given parameters

S/N	components	Selected material & given parameters
1	Work piece	Cast iron
2	Insulation	Ceramics
3	Working coil	Enameled copper wire
4	Working temperature	150°C – 180°C
5	Supply voltage	220 V, 50 Hz
6	Operating frequency	24 KHz – 30 KHz
7	Design power	1.5 – 1.8 KW
8	Control and protection	MCU with sensors

**Design considerations**

**Cast iron work piece** –Due to its peculiar thermal and magnetic characteristics; cast iron was selected to replace clay with embedded resistor in traditional electric injera mitad. It is the main source of the required heat.

The surface of the cast iron where injera batter is poured and cooked must be nonstick. To obtain nonstick surface a small drops of flax seed oil and PTFE (Polytetrafluoroethylene) are carefully rubbed on the smoother side surface and is kept in the electric oven having 250°C – 300oC for two hours with oven door firmly closed.



After two hours of heating the oven is switched off. Without opening the door, the work piece is left in the oven as the oven cools down to room temperature. This treatment process was repeated three to five times. By filling the microscopic cavities on the cast iron surface, the flax seed oil and the PTFE develop a protective layer where the risk of food sticking is avoided and simultaneously the work piece becomes corrosion resistant. Table 2.2 shows specification and dimensions of selected cast iron work piece.

**Table 2.2 Specifications of the cast iron**

No	Description	Parameters
1	Density ( $\gamma_w$ )	7150 kg/m <sup>3</sup>
2	Relative permeability ( $\mu_{rw}$ )	250
3	Electrical Resistivity at room temperature ( $\rho_w$ )	9.61 x 10 <sup>-8</sup> Ω.m
4	Specific heat capacity ( $c_w$ )	460 J/Kg. °C
5	Thermal conductivity ( $\lambda_w$ )	50 W/m.K
6	Diameter ( $D_w$ )	0.55 m
7	Thickness ( $h_w$ )	0.005 m

**Ceramics insulation** – Two pieces of traditional ceramics manufactured for this project are used as main insulation. One is to accommodate working coil and the second is to insulate the coil from the cast iron work piece.

**Table 2.3 Specification of ceramics insulators**

No	Description	Parameters
1	Density ( $\gamma_c$ )	2800 kg/m <sup>3</sup>
2	Relative permeability ( $\mu_{rc}$ )	1
3	Electrical Resistivity at room temperature ( $\rho_c$ )	1x10 <sup>12</sup> Ω.cm
4	Specific heat capacity ( $c_c$ )	0.80 J/Kg °C
5	Thermal conductivity ( $\lambda_c$ )	3 W/m.K
6	Diameter ( $D_c$ )	0.57 m
7	Thickness ( $h_c$ ), Max	≈ 0.008 m & 0.006m

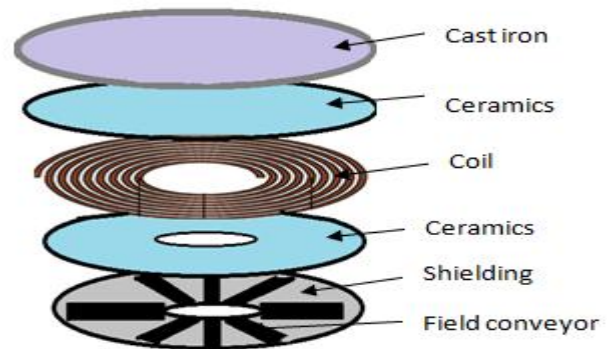
**Working coil** - It is a flat planar coil wound from multi stranded enameled and twisted copper wires. Coil parameters are shown in Table 2.4.

**Table 2.4 Specification of working coil**

No.	Description	value
1	Cross-section of the bundle	8.0 mm <sup>2</sup>
2	Diameter of a strand	0.72 mm
3	Cross-sectional area of a strand	0.41 mm <sup>2</sup>
4	Number of stands in parallel	20 strands
5	Actual diameter of the bundle	4 mm
6	Number of turns	41 turns
7	Total length of the coil	36 m
8	Outer diameter of the	0.55m

	coil	
9	Inner diameter of the coil	0.030 m
10	Inter-turn space (uniform)	2.5 mm
11	Height of the coil	4 mm

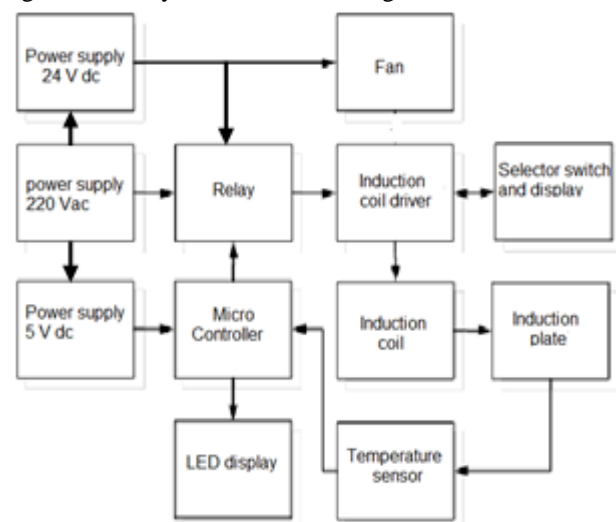
**Structural arrangement of main components**



Arrangement of main component [11]

### III. CONTROL AND PROTECTION SYSTEM

The basic parameter to be controlled is temperature of injera mitad. The microcontroller gets the signal from the temperature sensor embedded in the cast iron. It is programmed to make OFF the induction coil driver circuit when the temperature reaches 180°C (max.) and to make it ON when it falls to 150°C (min.) for teff grain injera. Block diagram of the system is shown in Fig. 3.1.

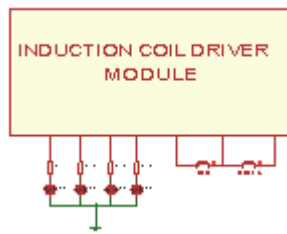


**Fig. 3.1 Block diagram of the system**

**Power supplies (220 V, 50 Hz; 24 V dc; 5 V dc)** - The mains power supply is 220 V, 50 Hz. The 24 V dc power supply module is to power the fan and the relay. The 5 V dc is to power the microcontroller and the amplifier.

**Induction coil driver module** - This module is commercially available and is a load resonant converter type in which the working coil is a part of the resonant circuit. The power flow to the coil is controlled by the converter switching frequency.

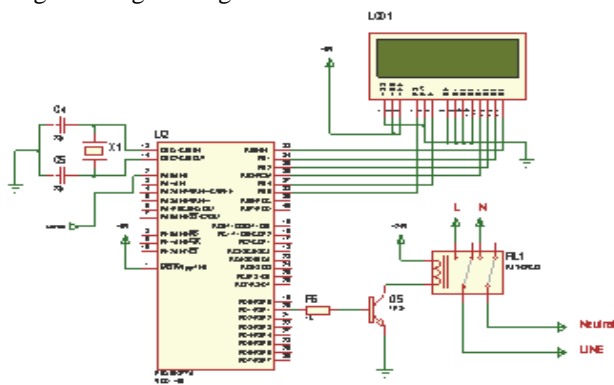




**Fig.3.2 Driver module and selector switches with indicator LEDs.**

The three LEDs D2, D3, and D4 indicate the different power selection options for cooking injera. The fourth LED indicator (D5) indicates the readiness of the system to switch ON the module. The higher the power, the faster the heat generation across the work piece. The driver module varies the operating frequency from 24 kHz to 30 kHz.

**Microcontroller circuit** - The heart of the circuit is the PIC16F877A microcontroller in which required program is installed. The LCD is used to display information regarding the actual temperature that is processed by the microcontroller. The relay also is used to isolate the low voltage and high voltage in the circuit.



**Fig.3.3 .The microcontroller circuit**

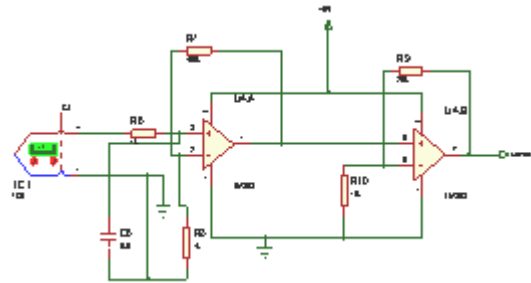
A 24 V dc voltage was applied to the relay coil via transistor as the driver of the relay. The microcontroller converts the analog voltages coming from the temperature sensor to digital signal. These conversions are made in order to make the microcontroller process the signal. At 520 ADC value in the microcontroller (representing maximum work piece temperature), the relay is activated and turns OFF the induction driver module. When a 505 ADC value in the microcontroller is detected (representing minimum work piece temperature), it switches ON back the induction coil driver module. The ADC value is dependent on the work piece temperature sensed by temperature sensor. Thus, the microcontroller controls the maximum and minimum injera baking temperature. The microcontroller circuit uses 4 MHz clock operating frequency.

**Temperature sensor** - The circuit uses thermocouple as a sensor for the temperature across the induction work piece plate. The said sensor converts the heat into a voltage. This voltage is very small enough for the microcontroller to process. The microcontroller needs at least 1 mV in order to process effectively. The output of the thermocouple was found out to be 10 micro volts per degree centigrade. Thus, it needs to be amplified in order to be processed by the microcontroller. The output of the thermocouple was connected to the input of the voltage amplifier as shown in

fig. 3.3. The circuit uses LM358 operational amplifier. The amplifier has two stages for amplifying the voltage coming from the thermocouple. The first stage uses a voltage gain of 10 and the second stage uses a gain of 2. The configuration used in the circuit was non-inverting amplifier configuration.

$$Gain = \frac{R_f}{R_{in}}$$

Where,  $R_f$  = the feedback resistor,  
 $R_{in}$  = the input resistor.



**Fig.3.3 Thermocouple with amplifier**

**Protection system** – The following devices are implemented as protection system in the prototype development.

- Main circuit breaker and fuse for overload and short circuit protection
- Auto power off if the work piece is overheated (above 180°C).
- Auto Power off if the work piece is not on place.
- Over current protection
- IGBT overheat protection.

**Experimental results and the prototype performance**

All components of the prototype are properly assembled and a series of laboratory and field tests were conducted to verify the performance of the developed prototype with the set objectives.

**Table 3.1 shows summary of the test results.**

No	Parameters description	value (Average)
1	Average Room temperature	20°C
2	Input voltage (regulated)	220 V
3	Input current	9.35 A
4	Input power	1.70 KW
5	Injera baking work piece surface temperature range	140°C – 170°C
6	Heating up time of work piece up to 150°C	9.5 min



**Table 3.2 Parameters of the prototype and local Electric Mitad compared.**

No.	Indicators	Local Electric Mitad	prototype	Remarks
1	Average Initial heating up time	16 - 18 min	8 – 10 min	45% improved
2	Average consumed Power at full load	3.2 – 4.00 KW	1.70 KW	50% improved
3	Efficiency	45% – 55 %	75.30%	20% improved
5	Injera texture	V. good	V. good	Comparable

#### IV. CONCLUSION

From the laboratory and field test results we observed that, since the surface of the cast iron was carefully seasoned the baked injera did not stick to the surface of the cast iron and was easily removed from it. The Mitad temperature was carefully controlled by microcontroller within  $\pm 10\%$  of working temperature. The initial heating up time is improved practically about 45% compared with local electric mitad. The Power consumption and efficiency of the prototype are also improved as seen in table 4.2. Therefore, the prototype can replace the traditional electric injera mitad.



**Fig 3.4 Injera cooked on the prototype**

#### REFERENCES

1. Me Me Khaing , Soe Sandar Aung, Design and comparison of conductor size for induction cooker coil, IJSETR, Vol.03, Issue.07, May-2014,
2. Robert Van Buskirk, Haile Teclai, Ezana Negusse, “The Effect of Clay and Iron Cooking Plates on Mogogo Efficiency and Energy Use: Experimental Results” Energy Research and Training Center, Asmara, Eritrea. 1996
3. Cindy S. Cheung, “Shielding Effectiveness of Superalloy, Aluminum, and Mumetal Shielding Tapes”, California Polytechnic State University April 2009
4. Umar Shami, Design and development of an efficient coil for a resonant high frequency inverter for induction heating. University of Engineering and Technology, Lahore. Pakistan.
5. Clementine Viellard, Albert Romann, Urs Lott, and Niels Kuster - B-Field exposure from induction cooking appliances, Zurich, July 2006
6. Laszilo Koller, Balazs Novak, “Improving the energy efficiency of induction cooking”. Budapest university of Technology and economics. Department of Electric power engineering, 2017, Hungary.
7. Ole Witt-Hansen, “The physics of induction stoves” 2009(2017). [www.olewithubansen.dk](http://www.olewithubansen.dk)

8. J. Acero, R. Alonso, J.M. Burdío, L.A. Barragán, and C. Carretero, “A model of losses in twisted-multistranded wires for planar windings used in domestic induction heating appliances”, in Proc. IEEE Appl. Power Electron. Conf. (APEC), 2007, pp. 1247-1253.
9. Jones, R., Diehl, J.-C., Simons, L., & Verwaal, M. , The Development of an Energy, Efficient Electric Mitad for Baking injera in Ethiopia”. 2017 DOI: 10.23919/DUE.2017.7931827.
10. Danas Electrical Engineering - Energy Efficiency Standards and Labeling. Project document on Electric Injera Mitad. May, 2015.
11. Feleke Fanta, Dr. Vinyl Ho Oquiño - Design and development of Electromagnetic Induction Injera Mitad, IRJET, Volume: 06 Issue: 05, May 2019.
12. Materials data book; Cambridge University of Eng. Dept. 2003 edition.
13. AND9166/D Application note - Induction cooking everything you need to know.
14. Awash Tekle “Experimental investigation on performance characteristics and efficiency of electric injera baking pans („mitad”)”, MSc thesis, 2011, AA University
15. F. Bordry, Power converters: definitions, classification and converter topologies, CERN, Geneva, Switzerland.
16. Garede Ambaw Tsige, “Performance analysis and reliability testing of a ceramic bake ware for an electric injera baking stove.” Addis Ababa University, 2015.
17. Dave Sood – Consultant, Great Falls, Virginia 22066 USA, May 10, 2010; “Injera electric baking: Energy use impacts in Addis Ababa Ethiopia”. (A World Bank-funded Study)

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