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The Effect of Pan Material in an Induction Cooker

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APPLICATION NOTE

Introduction

Induction heating is becoming more popular around the globe. It is a fast, safe, energy efficient method of cooking and is used in both residential and commercial cooking environments. In induction heating, a high frequency magnetic field is generated by a coil in the cooker and absorbed by the pan material. This is much more efficient that either gas or electric heating in which much of the heat generated rises past the surface of the pan and never contributes to the heating of the contents. The two most common topologies for induction cooking applications are the quasi−resonant boost converter, which requires 1200 V or higher, IGBT switches, and the resonant half−bridge circuit which uses 600 or 650 V IGBTs.

Both of these circuits employ an RLC tank circuit which is comprised of a capacitor (or equivalent series of capacitors), an inductor (heating coil) and a resistance (the pan). The pan acts as a core to the air core coil that it is placed on. In a normal magnetic component, the device is designed to minimize the core loss by selecting the proper material for high efficiency. In the case of induction heating, the goal is exactly the opposite and the core should be very lossy, to convert the magnetic field generated by the power converter, into heat.

This application note examines some of the common materials used in the construction of IH cookers. These include several alloys of stainless steel, iron as well as aluminum, although it is not a magnetic material.

Principles of Induction Heating

Induction heating has been used for decades to heat various metals. It began in the 1920's and saw a rapid expansion during World War 2 [1]. It has been used as a heat treating process for metallurgy processes, including case hardening for many years and more recently by the cooking industry for heating food.

Heating a metal by induction heating begins with a high−frequency power converter that generates a high ac current in an inductor, which in turn generates a high−frequency magnetic field. In the case of induction heating, a magnetic pan is placed in close proximity to the heating coil and absorbs most of the energy in the field.

There are two effects that contribute to the heating of the pan. Eddy current losses in the metal covert part of the energy into heat. This occurs in any metal pan. In addition, hysteresis losses occur in magnetic materials which improve the efficiency of the heating.

Figure 1 shows the series impedance of an aluminum and cast iron pan over a frequency range of 1 kHz to 1 MHz. It can be seen that the equivalent resistance of the cast iron pan is much higher than that of the aluminum pan. This is because the aluminum pan only has eddy current losses; however, the cast iron pan experiences both eddy current and hysteresis losses due to its magnetic properties.

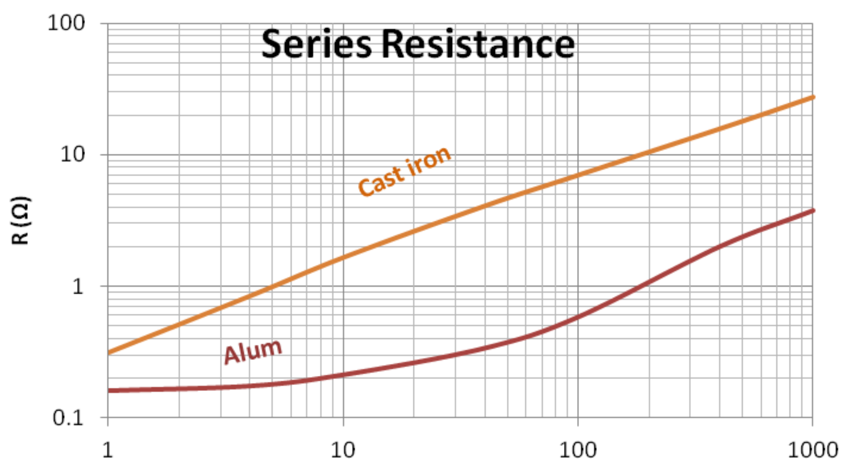


Figure 1. Equivalent Series Resistance for Aluminum and Cast Iron Pans

Induction converter circuits consist of two main topologies. The resonant half−bridge uses 600 or 650 V IGBTs and operates over a range of 20 – 70 kHz, while the quasi−resonant topology uses 1200 V or 1350 V IGBTs and typically operates at 25 – 30 kHz. At 30 kHz, the resistance is 3.2 Ω for the cast iron pan to 0.3 Ω for the aluminum pan. It can be seen that due to the higher resistance of the cast iron pan, the losses will be considerably greater and therefore, the pan will be more effective at heating.

It should also be apparent, that to reach a similar resistance for the aluminum pan, the operating frequency needs to be close to 1 MHz. This is not a practical operating frequency for today's IGBTs.

Induction Heating Topologies

As previously mentioned, there are two common topologies used in induction heating. The Quasi−resonant, boost converter is normally used for single burner cook pads sold mainly in Asia. This topology requires that the inductor reset voltage be added to the rectified line voltage, so a 1200 V or 1350 V IGBT is required. The resonant, half−bridge is normally used in multiple burner cooktops (Hobs) sold mainly in Europe. This topology resets the inductor as a normal half−bridge circuit would so the voltage doesn't exceed the line voltage and 600 to 650 V IGBTs are normally used.

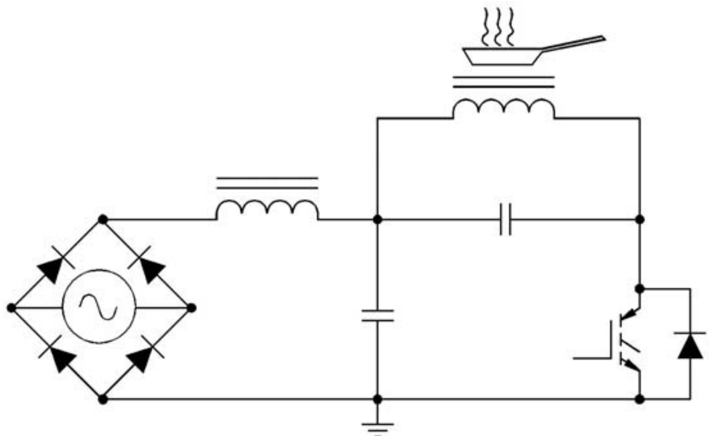


Figure 2. Quasi−resonant, Boost Converter

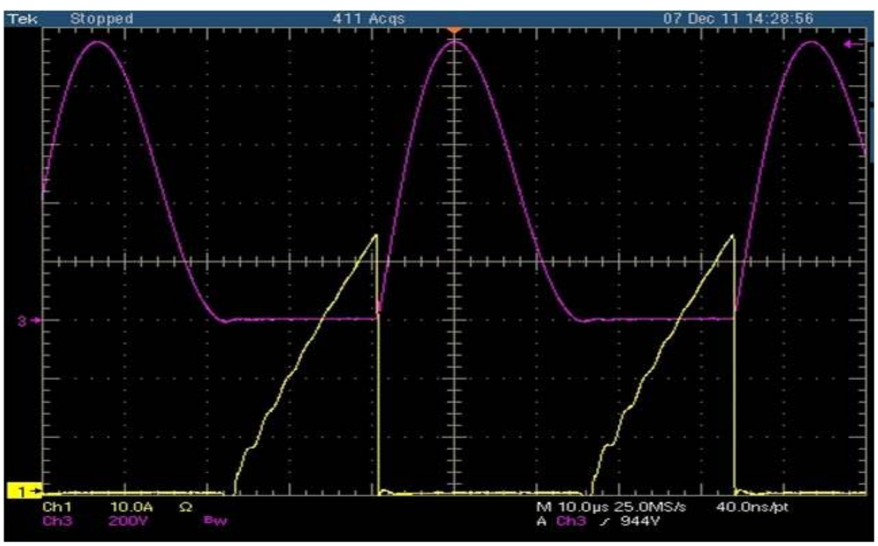


Figure 3. Quasi−resonant Voltage and Current Waveforms

Quasi−resonant circuits use a fixed on−time for the switch that is based on the power level for the cooker. A longer on−time allows a higher inductor current, so more energy is stored and more energy is delivered to the pan. The input voltage is rectified and is followed by a high frequency EMI filter so that it maintains the rectified sine waveform. The filter does not store enough energy to maintain a DC level. By allowing the input voltage to follow the sine waveform and maintaining a constant switch on−time, the average input current takes on the shape of the input voltage waveform and a high power factor is achieved.

Most of these units operate off of a 240 volt ac line, so the peak input voltage is approximately 350 V. When the reset voltage of the inductor is added to the line voltage, the peak IGBT voltage can reach 1000 volts under full load conditions as can be seen in the voltage trace of Figure 2.

For a single switching cycle, while the switch is on, the line voltage is not changing significantly so the voltage across the inductor is essentially constant and the current is a linear ramp, as can also be seen in the current waveform of Figure 3.

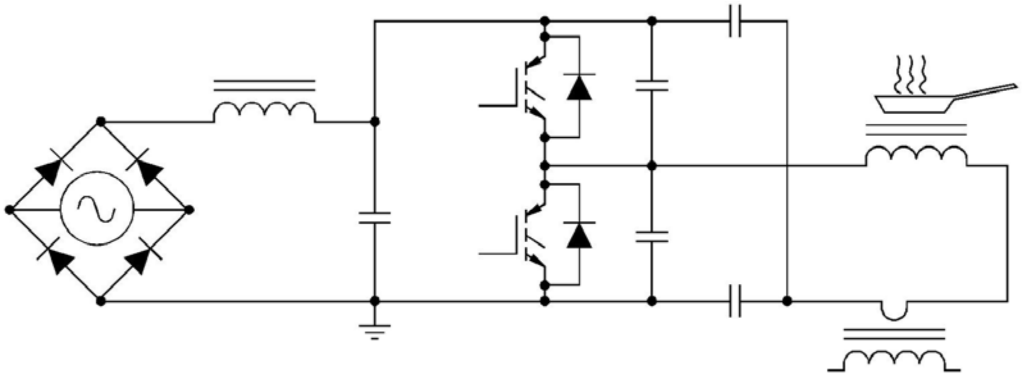


Figure 4. Half−bridge, Resonant Converter

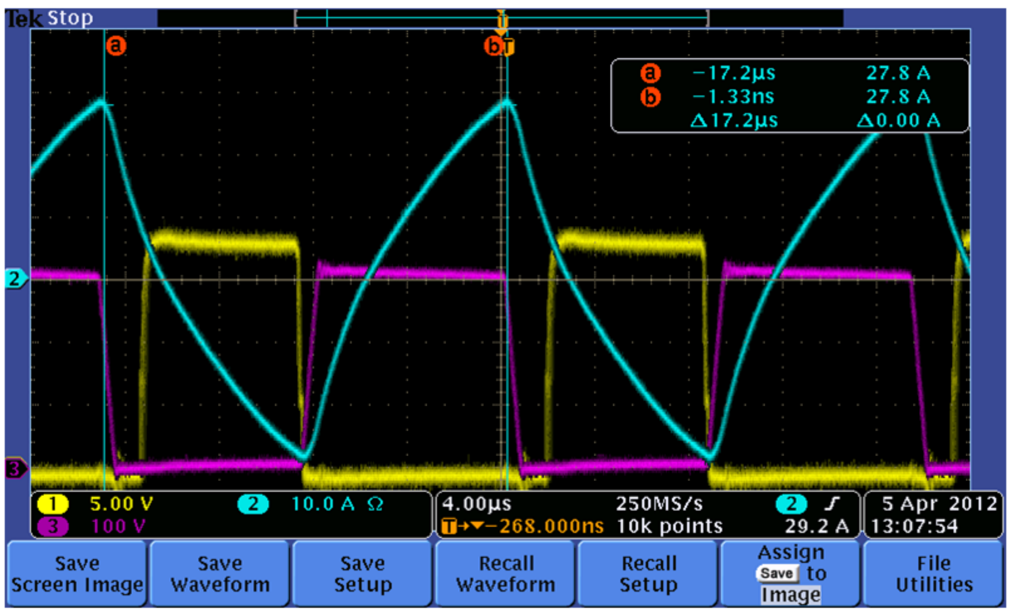


Figure 5. Half−bridge Voltage and Current Waveforms

The half−bridge resonant converter has a EMI filter on the input, similar to that in the quasi−resonant circuit. It does not filter the input voltage to a DC level. This is not a zero voltage switching topology even though it is resonant. There is a mode in which it becomes zero voltage switching, but that only occurs at the very maximum energy level, which would be the boost mode for most cookers, and not the normal operational range of the cooktop. The IGBTs normally switch when there is both voltage and current at levels other than zero. The blue waveform is the current in the inductor, the yellow is the collector voltage of the lower switch and the magenta is the gate voltage for the lower switch.

The switches in the half−bridge, resonant circuit are always conducting. Either the upper or lower switch is on at any time, other that a short off−time to avoid cross conduction. The power is varied by changing the on−time of the switches which directly affects the switching frequency. This changes the peak current level as well as the frequency as shown in Figure 6. The resonant frequency does not change, but the switching frequency varies, typically over a range of 20 to 70 kHz.

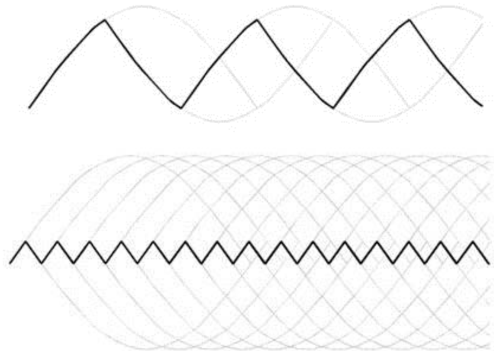


Figure 6. Power Control for a Half−bridge Resonant Converter

Impedance Test Results

Five pans were tested. The alloys or materials are shown in Table 1. Results were taken in both the time and frequency domains.

The time domain waveforms show the resonance. A short period of ringing means that there are high losses (low resistance) for that pan which is good for heating purposes. A long ringing period means that the losses are low and not much heat will be delivered to the pan.

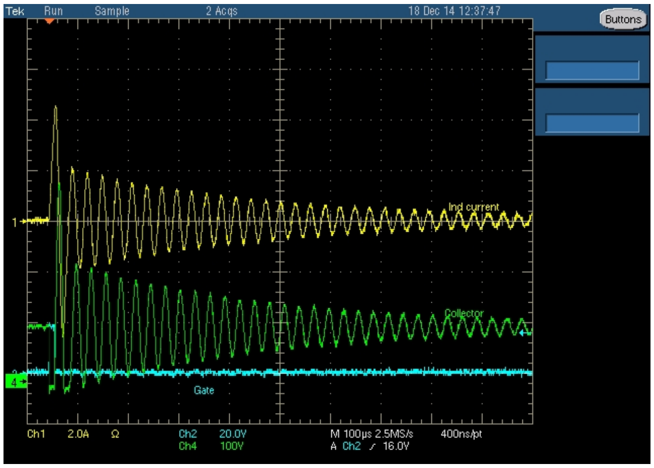
The frequency domain data show the inductance and resistance for each type of pan. These data were taken on an HP inductance bridge for both equivalent series and resonant circuits.

Table 1. PAN MATERIALS

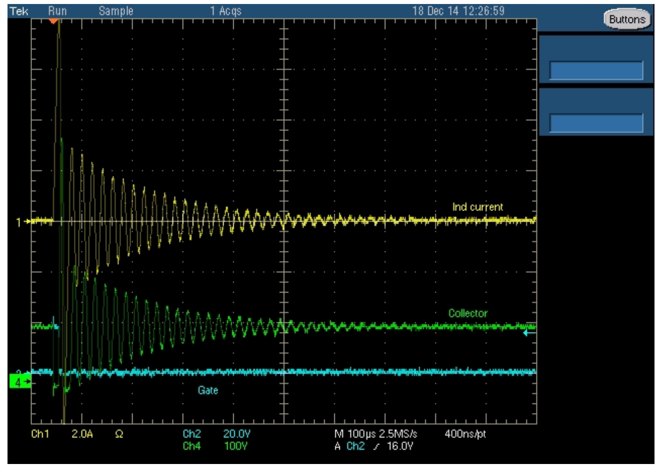
Pan	Material
Duxtop 5.5 Qt Sauté Pan	304 (18/10) Stainless Steel
8 1/4” skillet (5 ply) Cookware Wholesale Superstore	1. Ultra AISI 430 Stainless Steel 2. Aluminum Alloy: bonding agent, heat transfer 3. Pure Aluminum: fast, even heat distribution 4. Aluminum Alloy: bonding agent, heat transfer 5. 304 Surgical Stainless Steel Bottom is approximately 1/4” (6 mm) thick.
Midea cooker	430 Stainless Steel
Cast Iron Pan	Iron
Aluminum Pan	Aluminum

Pan Photos

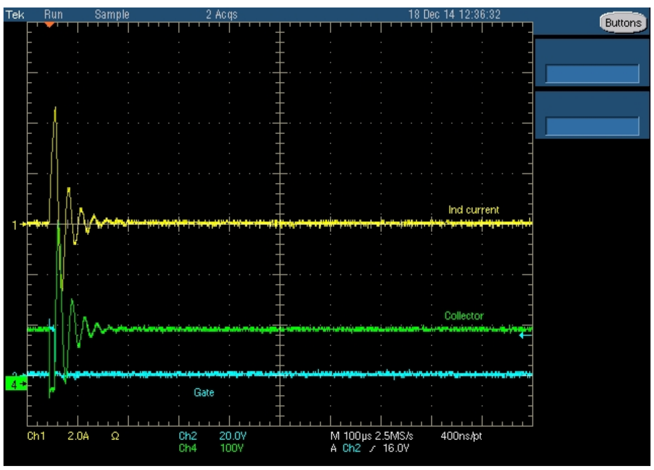
Figure 7. Pans Used for Testing



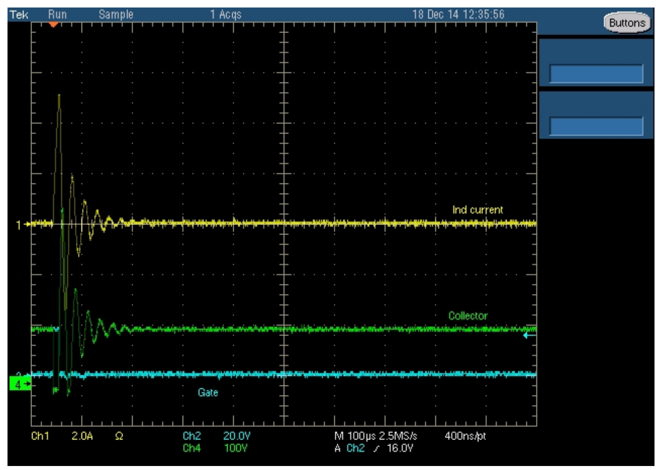
No Pan – Bare Coil



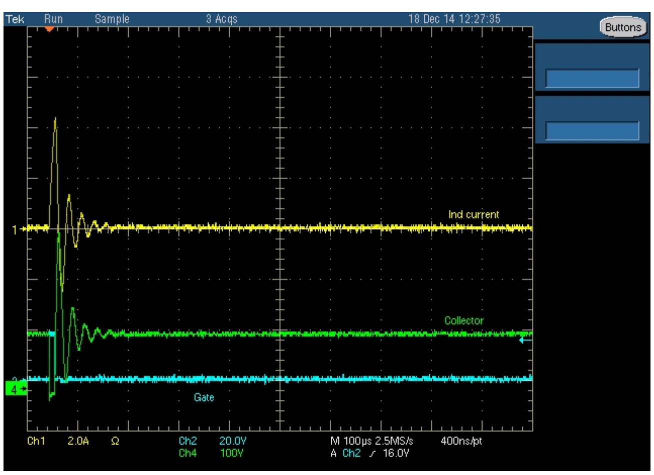
Aluminum Pan



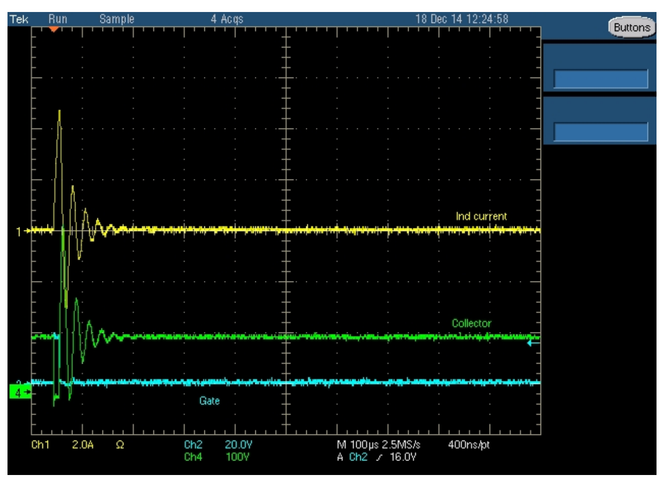
Duxtop 304 SS



5−Ply Pan



Midea 430 SS



Cast Iron Pan

Figure 8. Time Domain Waveforms

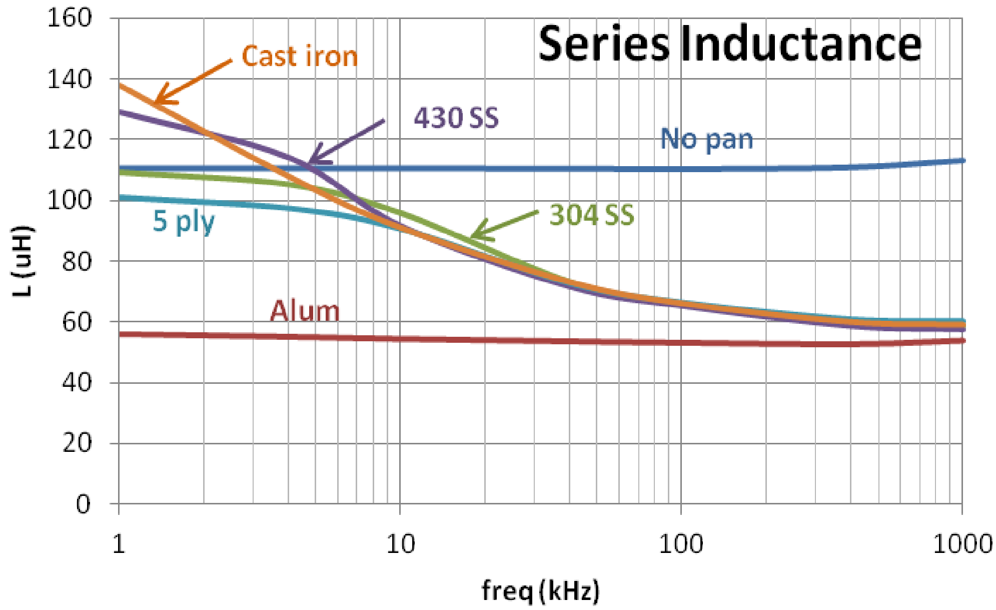


Figure 9. Frequency Domain Series Inductance

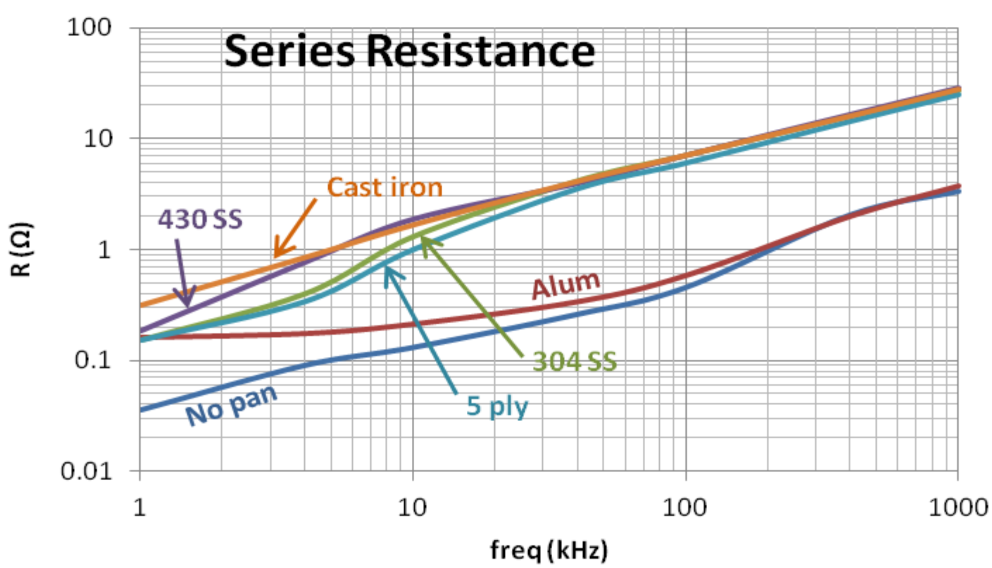


Figure 10. Frequency Domain Series Resistance

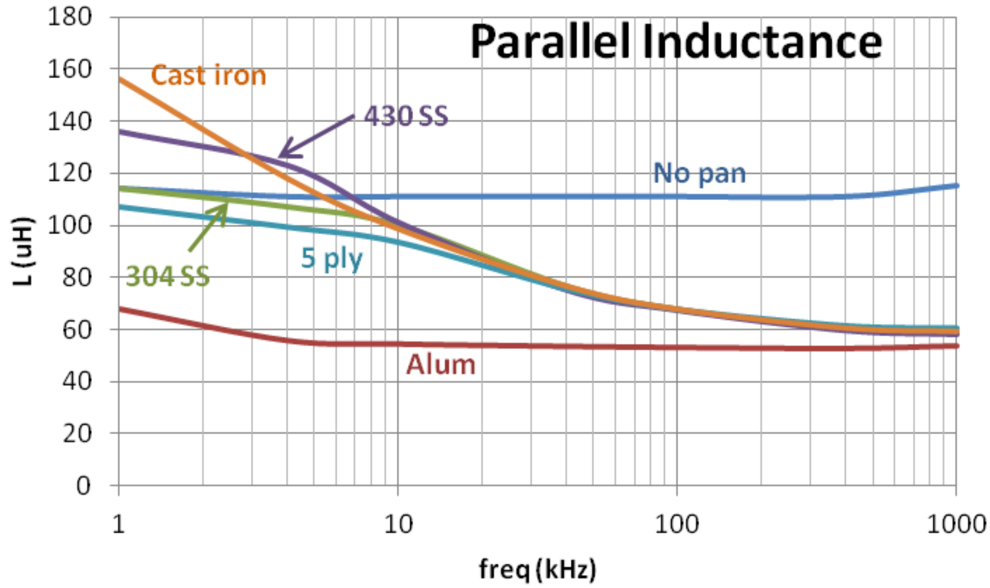


Figure 11. Frequency Domain Parallel Inductance

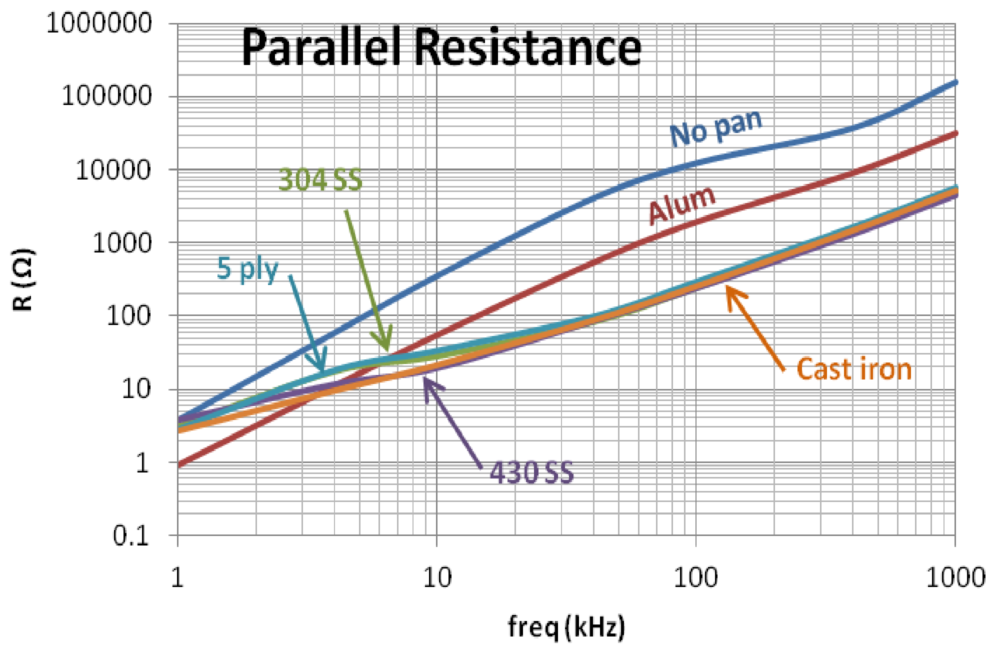


Figure 12. Frequency Domain Parallel Resistance

Conclusion

Induction heating is a well established method of generating heat in metal goods and has been used for decades. The induction cooking market is well established, but little has been written regarding the properties and interactions of the induction coil when a pan is placed on it. It can be seen that any metal pan will have losses due to eddy currents; however, those losses are small compared to those in pans with magnetic properties.

The type of magnetic material does not have an appreciable impact on the losses; however, the losses increase with frequency for all pans. Pushing switching frequencies higher will reduce the cost of the coil, resonant capacitor, and increase the efficiency of the unit. As switching devices advance in switching speeds, frequencies for these types of cookers with also increase to take advantage of these improvements.

Note [1]: United Induction Heating Machine, “Induction Heating Technology”, http://www.uihm.com/en/Induction−Heating−Technology/History−of−induction−heating−1020.html#.VJheZf9W5Q. (accessed 22 Dec 2014)

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