Volume MMXXIII, Number 4

The Wireless

April 2023

The Garden City Amateur Radio Club

PO Box 482 • Garden City, MI 48135-9998

Next Meeting:
Tuesday, April 18, 2023, 7:00pm
Garden City Presbyterian Church
1841 Middlebelt Rd.
Garden City, MI 48135

Congratulations to our nine newly licensed Technicians and one General licensees. We look forward to hearing you on the air and seeing you in the club.

It's time to get ready for the

Dayton Hamvention, May 19-21.

Here's a fun fact:
Do you know why it is still called the ***Dayton*** Hamvention, even though it's now held in Xenia, Ohio?
The largest Ham Radio event of the year is sponsored by the Dayton Amateur Radio Association.

Field Day, 2014

SPECIAL SERVICE CLUB

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Mat-Matics # 116
Henry 2K-Classic Valve Operation
Part 2 – Inrush Current

-Mat Breton, N8TW

This is the second of four articles in a series on my studies into the behavior of my linear amplifier with respect to proper operation of the Eimac 3-500Z power tubes. In this article we will study the inrush current into the Henry 2K-Classic Linear Amplifier main switch, and also the 3-500Z tube filaments.

What is inrush current? When you power on a device, there can be a very high level of electrical current for a short amount of time. This is called inrush current or sometimes surge current. This surge can be many times higher than the normal running current. If you've ever heard a "thunk" when turning on your linear amplifier, this is an audible side effect caused by the high current surge through the transformer. In linear amplifiers, inrush current can be a problem for several reasons.

Causes of Inrush Current: In a linear amplifier there are several potential causes of inrush current. Each of these will combine together for the net effect on the mains surge current.

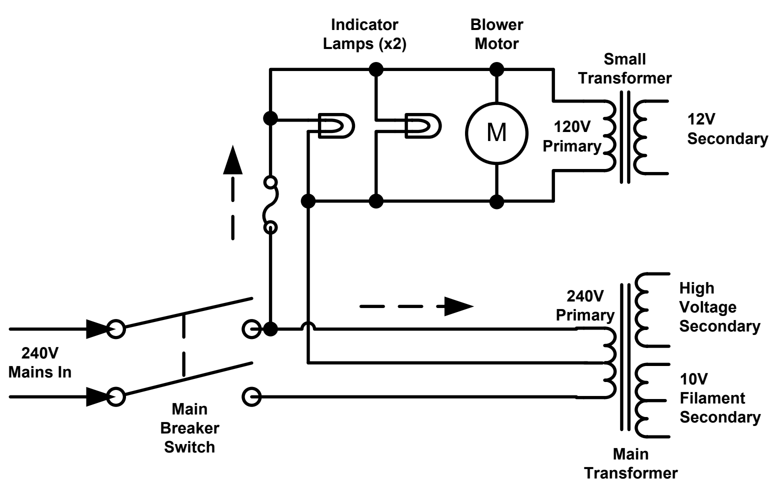
Magnetizing Inrush Current for transformers: the Henry has one large transformer, and a smaller secondary control transformer. Magnetizing inrush current occurs when the core saturates, turning the primary inductor from having a large value to a small value (when the core saturates, it effectively "disappears"). The current shoots up with its rate limited by the (now small) primary inductance. Peak current may reach the theoretical V/R value, where R is the total resistance (line, plus switch, plus transformer).

Vacuum Tube Filaments: The current through a cold filament can be up to 8-10 times the normal running current, depending on total circuit impedances.

Charging of capacitors for DC supplies: The HV (High Voltage) plate supply has a tremendous amount of stored energy. Making things more complicated, there is a rectifier bridge involved, which makes for a strange charging current waveform.

Ancillary circuits: the squirrel-cage blower motor, attached to the mains, has a stall/startup current greater than its running current. There also small lamps on this circuit.

When you turn on the mains for the 2K-Classic current will flow directly into five devices: two small illumination lamps, the blower motor, a small low-voltage secondary transformer, and the main transformer (high-voltage, filament voltage). There are additional loads on the other sides of the transformers, so they don't appear as "open windings".



The Current Paths for the Henry 2K-Classic

The lamps have a small inrush current, but it is very minor compared to the other devices, and can be ignored. Likewise, the small secondary transformer also will have an inrush current, but it will be so much smaller than the blower motor and main transformer that we don't have to spend much time on its study.

Blower Motor: The AC induction motor used in the blower will appear to be a transformer with a shorted secondary (at least until the blower starts moving). This "stall current" will contribute to the inrush current the main switch will see.

Main Transformer: When the Henry amplifier is turned on current flows through the primary winding of the main/big transformer. Unlike many other amplifiers, the Henry 2K uses a single transformer for both the HV and the filament supplies. Most of the primary side inrush current goes towards a magnetizing effort and the and peak primary current is affected by when in the 60Hz cycle the switch is turned on (which will determine the length of time the core is saturated). This magnetizing inrush current is not actually transferred to the secondary side. In addition, another smaller portion of the primary side inrush current is busy energizing the HV secondary winding and load (capacitors).

The high-voltage secondary load will appear as a short circuit due to the large bank of HV capacitors on this winding.

The filament secondary load will vary as the primary resistance is the tungsten filaments, whose resistivity varies greatly with temperature.

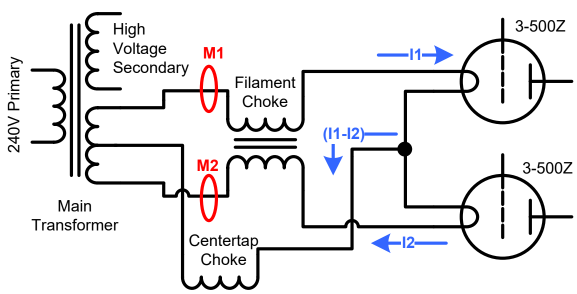
Inrush Concerns: There is a lot of chatter around about various potential issues of high inrush current, but the two that I am concerned with in this application are 1) exceeding the 3-500Z tube filament current ratings, and 2) exceeding the mains power-switch limitations.

Steve Sageman (WQ8T) has explained to me how Drake L4B's have an issue with main power switch failure due to high inrush current and how the switch is difficult to source. In the Henry, the switch (P&B W92X11-1-20) is actually a dual-pole hydraulic-magnetic circuit breaker, rated for 20Amps continuous. It still manufactured and can still be purchased at around $45 USD. This switch is good for about 5KW. In addition, the overload current capacity is 600% for 750mS (or about 120Amps). Of more interest to me is the "breaking" of the highly reactive (inductive) mains transformer current (especially if switched at a zero-voltage crossing threshold) … but this would be the subject of a different article.

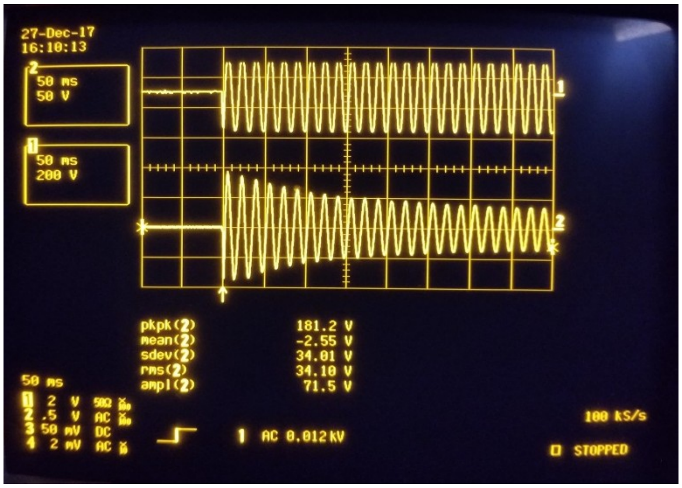
Eimac states for the 5-300z that the "For best tube life the inrush current should be limited to two times normal current during turn on." The maximum current at 5.0Vrms is 15.0Arms: this would put the maximum recommended inrush current at 30Arms.

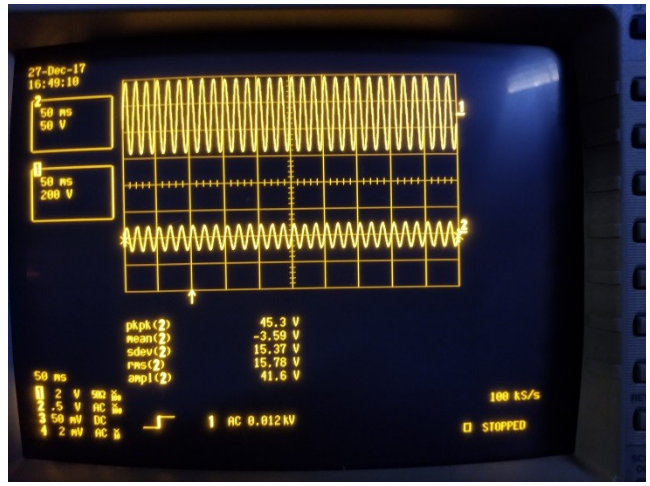
Filament Inrush Current Measurement: I wanted to verify that the inrush current into the filaments was less than the 30Arms limit from the Eimac 3-500Z datasheet. To make matters difficult, the Henry amplifier uses a non-typical series filament setup with a centertap from the transformer going to the point between the two tube filaments. The original Henry 2K amplifier had series tube filaments, but no centertap (equal currents, but not necessary tube voltage). Most other amplifiers have the tubes wired in parallel. This centertap provides voltage balancing (but not current balancing). It is possible that during warm up one of the tubes draws more current than the other, with the extra current circulating back through the center tap.

Filament Current Path



Since I only had a single AC current sensor, I eliminated the pesky issue of the centertap current leakage path by disconnecting it for this test. This could result in some small skewing of the test results, but the normal current “leakage” through this centertap is < 1% total current (I checked). To measure the filament current I put the AC current sensor (basically a fancy loop of wire and a transimpedance converter to change current to voltage) around the filament supply lead (see point M1 in the figure above). This was plugged into an oscilloscope set to trigger and capture the inrush waveform. The results are shown below:

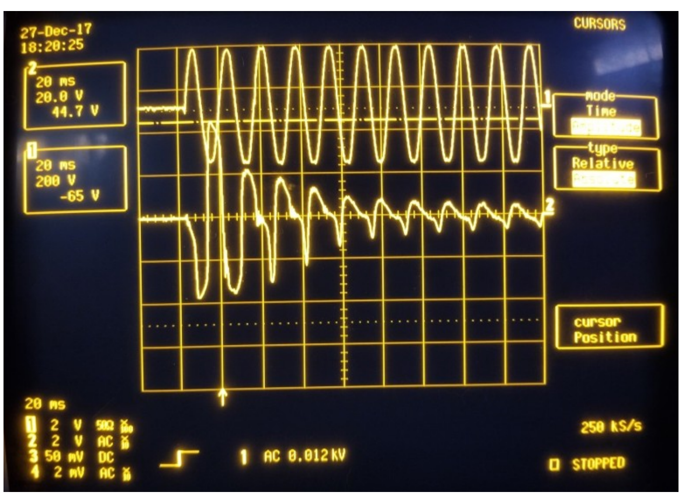




Filament Inrush Current (left), steady-state (right)

You can see from the graph that maximum inrush current is achieved when the unit is switched on near the voltage peak. The top trace is the “mains” voltage and the lower trace is the filament current (w/ 1A = 1V). The peak Vrms is approximately 64Arms, well beyond the allowed 2X = 29.4Arms Eimac max specification.

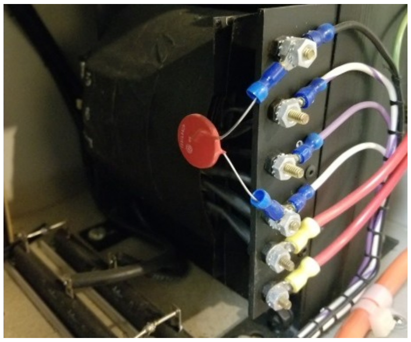
Mains Inrush Current Measurement: We know that the worst-time to switch on the Henry is when the mains 240V is at zero-volts (due to the highly inductive load when the core is not saturated). Fortunately for real-life use that will rarely occur, as a sine-wave naturally spends very little time at/near the zero crossing point. Unfortunately for measurement purposes it is therefore very hard to capture that worst-case event naturally. If you are randomly turning on the switch, you might have to measure and repeat many times to ensure you have captured a true worst-case scenario. I used an easier method, and put a “Zero-Voltage Turn-On Solid-State Relay” in series with my mains: this device is designed to switch on resistive or capacitive devices at the zero-crossing point … perfect for what I was trying to measure.



Mains Inrush Current (left), P&B W66 Series Switch (right)

While there is a significant inrush, it is well within the Potter & Brumfield W92X11-2-20 industrial 2-pole switch Henry used. They did not go cheap on the on/off switch.

Mains Disconnect Arcing: When a switch or relay with an inductive load is turned off arcing will occur: you can't instantly change the current through an inductor, and the voltage across the switch will increase until you get an arc. If big enough and often enough, this arc will damage and eventually destroy the contacts. Henry Radio planned for that by placing a MOV across the transformer primary winding. This MOV clamps the voltage and recirculates the current so that an arc doesn't occur across the switch contacts. It is a simple but effective solution that also has the added benefit of squelching fuse arcs, or in this case allowing the mains breaker to trip out faster. GE V250LA40A. Only rated for 354V (250Vrms), probably good enough when the line voltage was 230VAC nominal, but not high enough when my mains occasionally exceed this for short periods of time.



Picture showing the Henry MOV

Mitigation for Filament Surge Current: There were a number of possible options (although not all are available for the design of my particular amplifier).

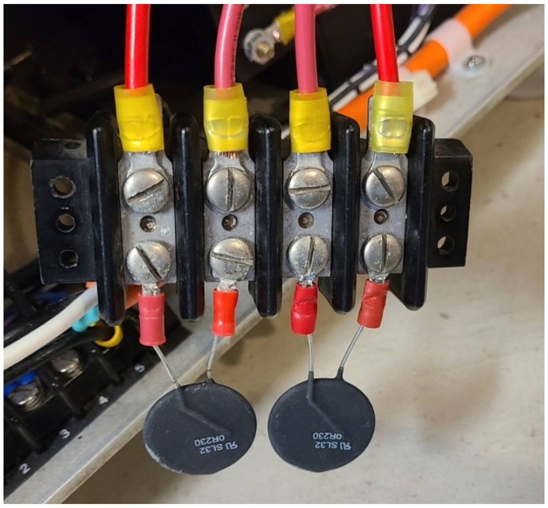
If my amplifier had a separate filament transformer (which it doesn't), I could place a limiting device in the primary side (where the current is much lower). NTC (Negative Temperature Coefficient) thermistors are often used in this case. These devices have a higher resistance when cold and a very low resistance once they warm up. This solution is actually "standard" on a number of modern linear amplifiers. Unfortunately with a common plate/filament transformer (like my Henry), non-linearities are introduced due to change in plate current, and the resulting effect on both plate and filament voltages.

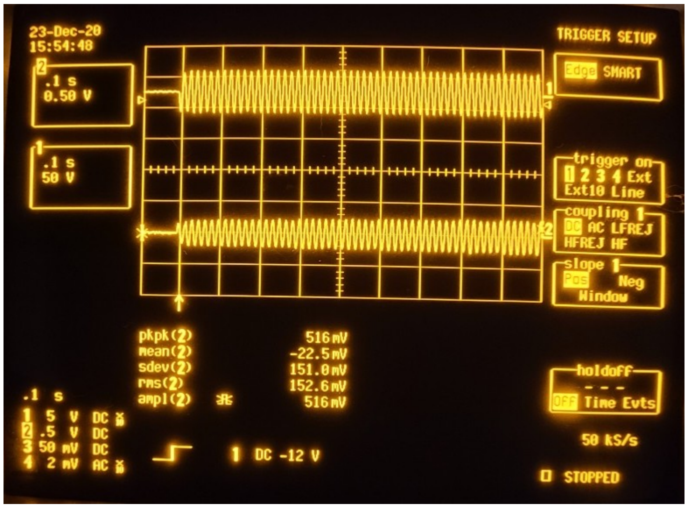
A "two-step" resistive solution could be done by putting a resistive element in parallel with a bypass relay in the primary side of the transformer. This adds complexity and cost, but could be done on my amplifier.

Additional resistance could be added to the secondary side (the lines to the tube sockets). This could be done with a slightly smaller gauge of wire, or longer lengths of wire. This would have the side effect of also reducing filament voltage, which would have to be taken into account to ensure we don't operate the filaments at too low a voltage.

Adding an NTC inrush limiter to the filament secondary. This would need to be a large device as the currents are pretty high. Additionally, I would need two devices for the Henry due to the center-tapped design.

I decided to put two NTC inrush-limiters in. When picking a part you need to know the inrush current, the inrush energy, the voltage, the steady state current, and the ambient operating temperature. I found a part with a nominal cold resistance of 0.25Ohms a hot (50% of peak current) resistance of 0.02Ohms, and an energy capability of 100J: the . When two were added into the circuit (one in each of the side of the filament winding) the inrush current increase was effectily eliminated: the current now increases from about 8Arms initially to about 15Arms steady state in approximately 1 second.





NTCs Installed (left), and New Filament Inrush Current (right)

Filament Inrush Current Measurements			
	Eimac Spec	Before - Unloaded	After - Unloaded
Line Voltage		242.9 Vrms	241.7 Vrms
Transformer In		242.5 Vrms	241.2 Vrms
Inrush Current	30.0 Arms	**64.1 Arms**	**15.2 Arms**
SS Filament Current	15.3 Arms	**16.0 Arms**	**15.2 Arms**

Table of Results

Remember that this method will drop the filament voltage: you should ensure that this voltage does not drop out of spec for your tube or RF distortion and/or negative tube lifetime effects may occur. We will address filament voltages in a later article in this series.

Summary: I did not need to add any mitigation for the mains switch (which had a high enough rating for the inrush, and Henry already had a MOV installed for turn off). I did add two NTC inrush limiters to the tube filament supply to bring the inrush current within the Eimac spec without dropping the filament voltage out of spec. Total cost for this mod was $4.92 for the two NTC inrush limiters … much less than a new set of 3-500Z tubes. ***Caution: these measurements involved working on near live 220V mains … lethal voltages/currents: do not do attempt this if you don't have the proper equipment and experience.***

Sunday Night Net:

We still need more people to help with the net. Serving as a net control operator is a great way to get more involved in the club and to get to know more of our members. If you'd be willing to help, please contact any of the Net Control Operators or Club Officers for more details.

Join us on Sundays at 9:00pm, 146.86 MHz, -600Hz offset, 100Hz PL tone

This is a purely social net, all licensed hams are welcome to join in.

Upcoming Sunday Night Net Control Operator Schedule:

Apr. 02 N8TW
Apr. 09 W8ROY
APR. 16 KC8VCX
Apr. 23 N8TW
Apr. 30 W8ROY
May 07 KC8VCX

*Can we add **your** name to the schedule?*

UPCOMING SWAPS:

04/22/2023 - St. Joseph County Michigan Amateur Radio Club Ham Fest
Centreville, MI

05/06/2023 - Wexaukee ARC Swap & Shop
Cadillac, MI

06/03/2023 - IRA Hudsonville Hamfest
Hudsonville, MI

06/04/2023 - Chelsea Amateur Radio Club Swap Meet Partnering w/Michigan Electronics Expo
Chelsea, MI

06/17/2023 - Midland Amateur Radio Club Hamfest
Midland, MI

06/18/2023 - Monroe Hamfest
Monroe, MI