



Understanding the Advantage In Power Magnetics

Medium Voltage Harmonic Filter Reactors



High reliability solutions for system design challenges

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Introduction to Harmonic Filter Reactors

Experts agree that there is a growing trend toward the use of medium voltage (5kV through 35kV) capacitor and filter bank applications as the use of control electronics rapidly advances. This is occurring across a wide variety of industries, including energy production, chemical processing, mining, manufacturing, and many other critical functions. The issue driving the need is the destructive nature of the harmonics on electrical and electronic components, causing higher losses, heating, accelerated end-of-life and failure, sometimes catastrophic. As has been shown by studies conducted by an international power company and verified by third party labs, harmonics can also be the source of excessive power consumption, as much as twelve to seventeen percent in some applications where electrical motors are used.



Figure 1 Single Phase Reactor

And, for many of those applications, space is at a premium, dictating the use of iron core reactors instead of the much larger physical size and surrounding area needed by air core reactors. That is true inside equipment and buildings as well as, increasingly, outside such as when harmonic capacitor banks using iron core reactors are used instead of very large air core reactors in urban areas. However, it is not just the physical space of the reactor itself that drives the space issue. This is also driven by the high level of stray magnetic fields that are inherent in air-core reactors. That dictates that a significant amount of space be provided around the air-core reactor, even greater than the size of the reactor and mounting assembly itself.

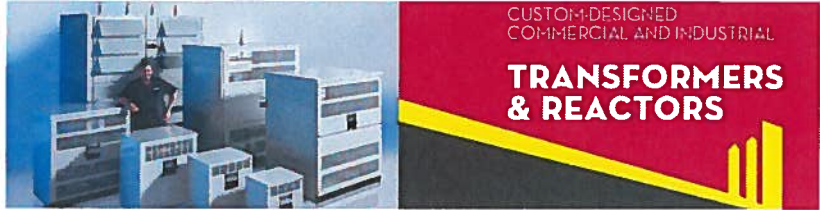


For these and other reasons, the advantages of the medium voltage harmonic filter reactor (otherwise known as medium voltage trap reactor or MVTR; we will use that shorter term henceforth), and specifically the recognized advantages of the Power Magnetics units, can best be understood by looking at five areas (specific design and construction techniques excepted as proprietary).

Those are:

1. Single phase vs. three phase
2. The role of insulation
3. Core construction
4. Coil/core design
5. Impulse voltage and insulation

We will look at each of these areas individually and then collectively to provide you with some insights to help you have a better understanding of the role of each in determining the best solution for your application.



Single vs Three Phase Reactor

Medium voltage harmonic filter reactors or trap reactors (MVTR's) are typically either (three) single phase 'Floating Core' reactors, or (one) three phase 'Grounded Core' reactor.

In the single phase 'Floating Core' reactor, the connection point between the coils (*at Power Magnetcs, our dedicated practice is to virtually always use two coil 'core type' construction for these reactors*) is tied to the core, and the core is itself mounted on insulators, which are sized by impulse rating, thus the core is 'floating' above ground potential. So in these reactors, there is virtually no voltage between the core and the coil; all the line voltage appears across the insulators, and the operating stress between the coils is the small 'developed voltage'.



Figure 2 Three Phase Reactor

The 'Grounded Core' reactor is simply what its name implies - that the entire core rests at ground potential. The direct consequence of this fact is that full line voltage appears between the winding and the core. The 'developed voltage', which is the voltage drop across the coil, is a relatively small percentage of the line voltage. Also, in the three phase reactors, (because they are sitting on the line) full line-to-line voltage appears between the adjacent coils. So, in the three phase reactors, the operating voltage stress is high between coil and core, and coil to coil, but modest within the coil itself.

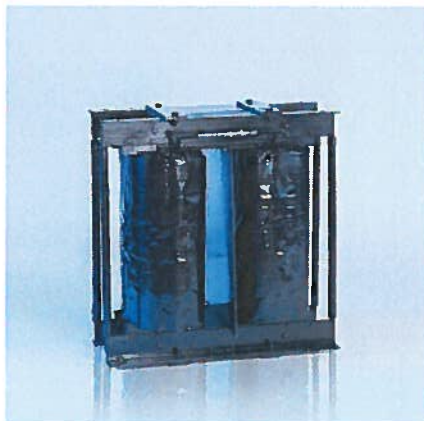
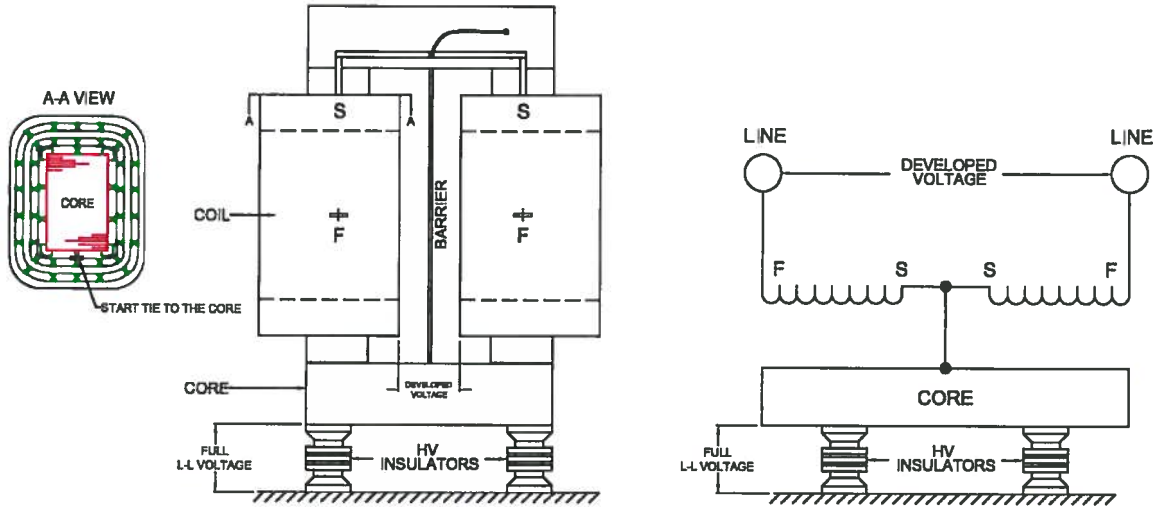


Figure 3 Single Phase Reactor

In the three phase construction there is a high operating stress in coil to core, and coil to coil. In single phase, virtually all the stress appears across the insulators, as shown in the following hybrid electrical-mechanical diagram.



1PH CORE TYPE CONSTRUCTION



3PH CORE TYPE CONSTRUCTION

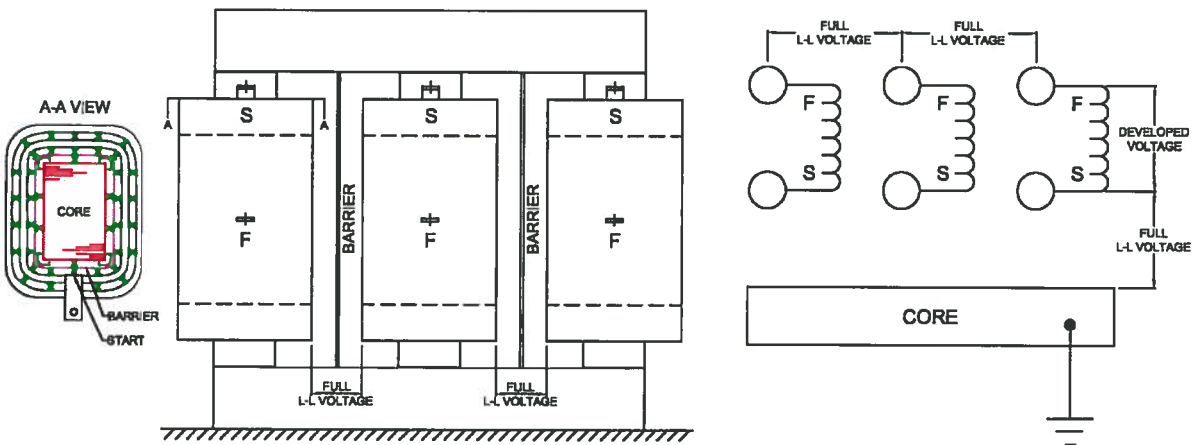


Figure 4 Single Phase vs Three Phase Construction



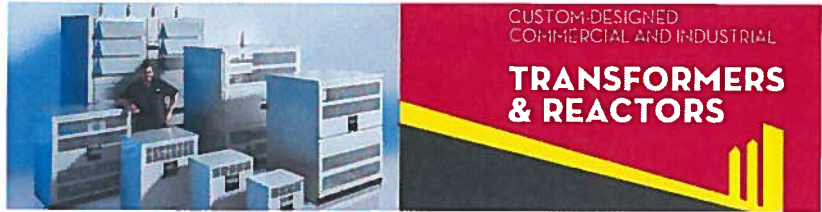
The Role of Insulation

Power Magnetix's MVTR's are designed exclusively for 115°C Rise: with a 220°C Insulation DuPont Nomex® 410 UL® Registered Insulation System. Also, all reactors receive a Vacuum Pressure Impregnation (VPI) of a high temperature varnish. Nomex® 410 (though somewhat expensive) has shown itself, through our 20+ years' experience in making MVTR's, to be an unsurpassed insulation. This is because its superior mechanical, electrical and thermal capabilities allow the reactors to endure the often incredible abuse that is inherent in day-to-day operation. The complete varnish penetration of our units achieved by the VPI system only enhances this ability. Varnish helps repel moisture; it is an incredibly strong glue (so it gives greater mechanical strength) and, as a good conductor of heat, allows the units to run cooler.

Occasionally the question of aluminum vs copper winding arises. Industry experience is that the reliability of aluminum winding (properly applied) is similar to copper. Because copper conductor cross section is smaller than aluminum for similar current, it is sometimes chosen where space is at a premium. The use of copper winding typically results in a unit that is 15-25% more expensive from the end product standpoint.

At Power Magnetix, we are constantly performing Heat Runs (full current thermal tests using thermocouples and infrared imaging) to verify that the temperature rise is consistent with what we predicted through our modeling. To date, all temperature rise measurements are at, or below the predicted levels. We also monitor core temperature to assure that the cores run cooler than our competitors, thus ensuring longer life and substantially quieter operation.

Nomex® is a registered trademark of the DuPont Corporation and UL® Underwriters Laboratory



PMI Core Construction

Reactor core elements are made of laminated blocks of electrical steel, separated by non-magnetic spacers called 'gaps'. Compared to transformer cores, which are almost always continuous sections of steel, this makes them somewhat of a unique construction challenge. The cores consist of thousands of pieces of small laminations, which makes cutting and stacking them very time consuming and tedious. The blocks must be uniformly stacked and secured in order to keep the individual laminations from vibrating. This can make them noisy and could eventually lead to failure (as they break loose).

In our more than forty five years of making reactors, we have experimented with numerous methods of reactor construction, all of which produced advances, but still came up leaving room for further improvement. Then, over a decade ago, Power Magnetics' engineering team developed an advanced solution for core construction building on previously known methods. That technology and process has now been refined with proprietary engineering and is generically known as 'wind-on-leg'. In this approach, the leg is made by stacking individual blocks and gap spacers, (which are sealed together with an adhesive using several proprietary procedures) and then held in alignment with corner angles, banded, and cured. Once the adhesive is completely set, the coil is wound on top of the prefabricated leg. See the cross section figures below.

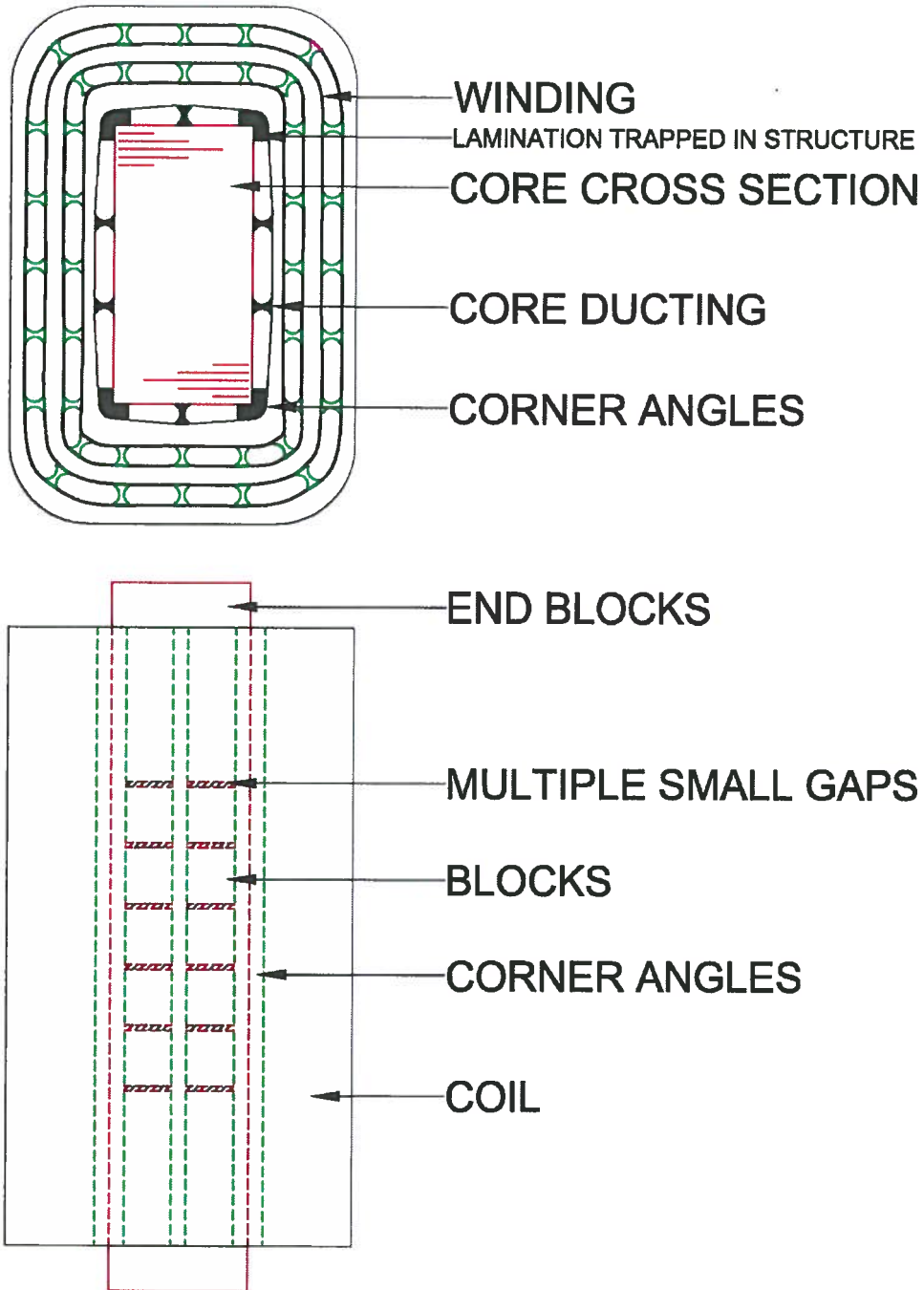


Figure 5 Cross Section of Core



Thus, the blocks are held in perfect alignment by the corner angles. In addition, individual laminations are 'trapped in the structure of the leg', where it is *virtually impossible* for them to vibrate, or even worse, break loose. What this means is that we have developed a unique and (practically) 'fool-proof' method of reactor manufacture. In addition, we use a number of proprietary techniques to secure the blocks and spacers that combine to deliver maximum strength and reliability to the leg.

This method also has several important side benefits. One is that it makes it practical to break the total gap down into smaller individual thickness, separated by shorter blocks. (See above figure.)

Also, reducing the amount of fringing flux (and the heating it causes) our cores run at significantly cooler temperatures than alternative technologies. As in almost any engineering undertaking, eliminating unwanted effects helps to improve the quality of the end product. And in this case, the cooler the reactor runs, the quieter it will be, the longer life it will have, and the more economic value it will offer (high operational value maximized and cost of ownership per year is minimized).

It is a reality, at the same time, that by increasing the number of blocks (and laminations) as well as gap spacers, the manufacturing cost is increased. Ongoing testing confirms that our reactors are significantly cooler and quieter than any competing technology. And while it costs more to make them, our customers acknowledge that the money is well spent.

Finally, with the coil tightly wound onto the leg, the mechanical strength of the winding itself is much higher, reducing the chance of any deformation under a short circuit condition our reactors have passed short circuit tests up to 200 kilo amperes.



Coil/Core Design Insights

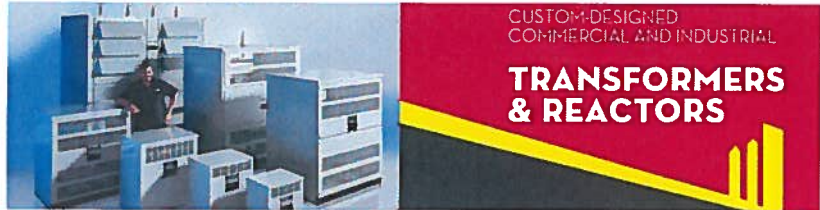
If current is circulated through a gapped Iron Core Reactor, a linear relationship between voltage and current would be noticed initially. ($X=V/I$) As current is further increased, a point is reached at which voltage begins to fall off the linear relationship. This is called 'saturation' and all iron core devices exhibit this effect. From a core design standpoint, the saturation starts at a maximum magnetic flux density (usually 15 to 16 kGauss) which is directly related to the peak current (I_p).

$$I_p \sum s = F + H_1 + H_2 + H_3$$

For harmonic filter reactors, the peak current is calculated by adding the fundamental current and all the harmonic components (the 'Arithmetic Sum') for the maximum coincidental current. It is important that the reactor not saturate under this peak current condition in order to function properly.

To calculate the current from an effective heating standpoint, it is best to use the RSS- Root of the Sum of the Squares ('Geometric Sum') calculation, $RSS = \sqrt{F^2 + H_1^2 + H_2^2 + H_3^2}$. Additional heating is caused by high frequency skin effect and proximity effect. In general, thinner conductors tend to minimize high frequency heating, as does the transposition of the individual strands.

The alternating flux in the core, caused by the alternating currents, generates heating in the core. As we alluded to earlier, the result is a minimized stray core loss by using multiple small gaps in the core. It is equally important to make sound choices of proven core materials and low flux densities to further minimize core temperature for cool operating temperatures, long life and high efficiency.



Impulse Voltage and Insulation

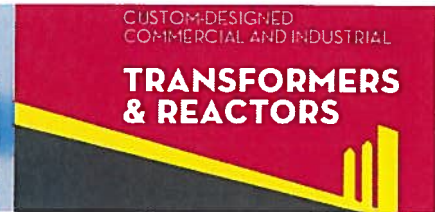
Impulse wave forms have rise times in the microsecond range. Because of this, the capacitance of inductive devices (i.e. transformer and reactors) controls the initial voltage distribution. At Power Magnetics, we pay strict attention to coil capacitance to even out impulse voltage distribution. In single phase reactors, the impulse voltage is split between the two coils, though the full voltage appears between the outside of the coils (which is why a barrier is used). The stress between the outside of the coil (and the core and frame) is at $\frac{1}{2}$ of the impulse level. This is advantageous because of the greater spacing between the finish of the coil, and the core and frame.

In three phase reactors, the impulse voltage appears across a single phase, and between phases (hence the phase barrier). The start lead must be rated for full impulse voltage, necessitating additional insulation because of proximity to the core. In both single and three phase reactors, the layer insulation must be increased beyond what is needed for the relatively modest developed voltage, though more so in three phase reactors because the impulse stress is concentrated in one coil.

In 2013, Power Magnetics had reactors impulse tested at KEMA LABS to the 95kV, 125kV and 150kV BIL level. We keep the test reports on file, and make them readily available as reference material supporting these specifications. The tests had the effect of confirming our standard design, which we have practiced consistently for many years. During the 150kv BIL test, our reactor was hit repeatedly with a level of 169kV, due to a software fault at KEMA's lab while attempting to calibrate the 'CHOP'. Even with that, the reactor passed, indicating that it would withstand impulse testing at much higher levels.



Figure 6 KEMA Lab Impulse (BIL) Test



The PMI Advantage for OEM's

The net result of Power Magnetics' design and construction techniques is that our medium voltage harmonic filter reactors are discernably smaller, cooler, quieter and more efficient. They are sought out by our customers because of their extraordinarily high reliability. And that's not just self-serving hyperbole. It is, instead, independent and unsolicited feedback from our customers. We routinely build replacements for reactors originally supplied by other vendors, even those under warranty.

The Power Magnetics engineering, design and manufacturing philosophy is summed up in its motto: "Built Like the Brooklyn Bridge™", an engineering marvel from 1883 that has outlived its



Figure 7 Power Magnetics, Inc. products are "Built like the Brooklyn Bridge"

design life by three times. Our approach to a customer's design is similarly conservative; the end result is unmatched reliability (think MTBF – meantime between failures – in decades, not years).

When reliability of the reactors in the most demanding applications is a primary consideration, OEM's choose Power Magnetics Inc. Power Magnetics' reactors are in the remotest and harshest regions of the world – polar, desert and extreme altitude installations where a reactor failure is not an option. So our goal, and our

commitment, is to continue to deliver an unsurpassed level of reliability, the lowest total cost of ownership (TCO) over the life of the OEM equipment, and remain a leader in design and engineering elegant solutions for the most demanding applications in the industry.

You simply cannot buy a more economical, higher quality, iron core reactor. Period.



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About the Author

Carl A. Bannwart, otherwise known as “Docta Reacta™” in the industry, is President of Power Magnetics, Inc. He has been full time with Power Magnetics since 1973 after graduating magna cum laude from Tufts University with a BS in Electrical Engineering. In 1978, after working in every position in the company, he became president, when his father who founded the company unexpectedly passed away. Carl and his wife are both accomplished vocalists and have traveled the world with a variety of choral groups performing before audiences. He and his wife have one son and live in the beautiful area and tourist destination of Bucks County, PA.

