Filtering motors and VFD combinations.

VFDs produce a lot of electrical noise which can interfere with TVs, radios and other electronic gadgets. Supply power lines to the VFD can be filtered to reduce noise being fed back into the building's wiring and reduce noise coming in to the VFD from other noise sources on the circuit.

The principal source of noise from a VFD is the fast electronic switching necessary to generate the PWM output to the motor. Modern VFDs with IGBT switches are worse in this regard than the MOSFETS etc. in older units. This is because the IGBTs switch faster creating more high frequency harmonics which can pass through the multitude of stray capacitances easier. Switching faster is good for the VFD components because internal heating is less, but the very fast voltage rise times lead to short, sharp voltage peaks several times the value of the average voltage – 220/240 V is a typical average voltage for single phase VFDs. Spike voltages will reach 1000 V or more.

These high voltage peaks can break down or gradually degrade the winding insulation of the motor. Motors older than the early 1990s are more likely to suffer from this because after that time reputable motor makers used better insulation and adopted other measures to make their motors more suitable for use with VFDs.

Another potential problem caused by the high frequency content of the motor feed is due to current flow through numerous stray capacitances in the cables and motor. Of greatest concern here is current flow through the bearings. Voltages are induced in the rotor and current flows through the capacitance of the bearings which can cause pitting and reduction of the bearing life.

The PWM carrier frequencies of between say 2 kHz and 15 kHz or more will make some motors sing. I recall one time when I was working at Segway, one of the electronics guys could get the motor to play tunes by feeding it various frequencies.

Electrical filters can help eliminate or greatly reduce the voltage peaks and lower rise times. Bearing currents can be battled in one of two ways,

1. Insulated bearing mounting or better still ceramic bearings which are not conductive.
2. Using a brush between the rotor and the motor casing, shorting out the bearings. This usually fitted to the non-drive end of the motor.

The general wisdom says that filtering and bearing protection is not worth the trouble unless you have very long cables between the VFD and the motor when reflected pulses in the cable can multiply the voltage peaks, or that you have large motors. I believe that this advice is based more on economic than technical considerations. Filters and bearing protection can add considerably to the cost in industrial situations and considering small motors as consumable items might make sense to the bean counters but not to the tree huggers.

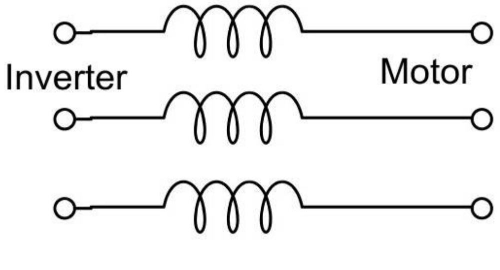
5 hp motors are not generally considered as large motors in this context. I had not taken any protective measures with either of the two 5 hp motors that I had. One on the shock dyno and one on the mill and as far as I know there have been no problems. However when I recently fitted a 5.5 hp motor to my lathe I noticed that the no load current was higher than I expected and the motor did sing. I am getting deafer by the day but I could hear it easily and it was very annoying. I wondered if some simple filtering would help and the rest of this post looks at what I did and how I made it.

Filtering.

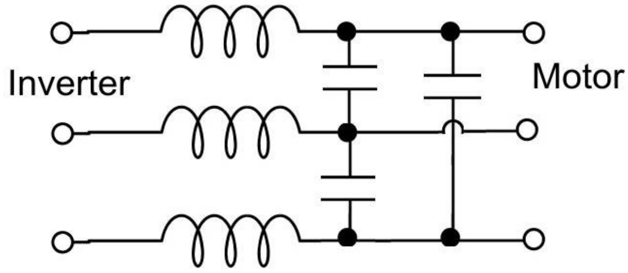
There are several filter possibilities but probably the two most widely used for VFD/motor applications are called dV/dt filter and sinewave filter. Either will be fitted as close as possible to the VFD not the motor.

dV/dt is a mathematical way of expressing the rise time of the PWM voltage pulses. We want to slow those down. That is done by adding some inductance to the 3 phase lines between VFD and motor. The inductance has to be kept relatively low or it will reduce the maximum current and hence maximum torque that the motor can deliver.

A ideal sinewave filter will filter out all frequencies other than the desired motor drive frequency, leaving a single sinewave. It is the higher frequencies that are targetted. In practice you do not get a pure sinewave but you get a much nicer signal to send down the cable to the motor which will be thankful for a much easier life. Sinewave filters are a little more complex with the addition of capacitors (and maybe resistors) to the inductors of the dV/dt style filter.



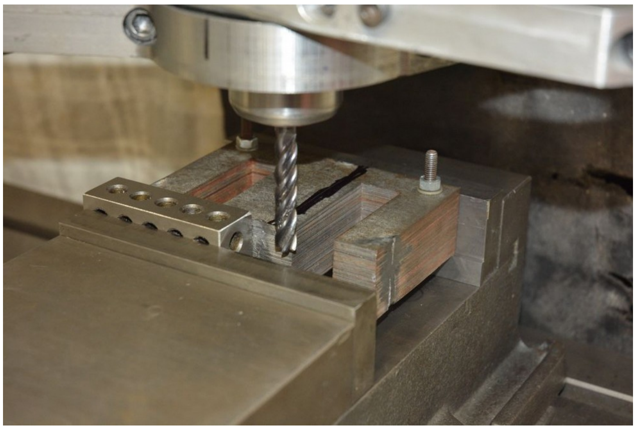
Basic dV/dt filter



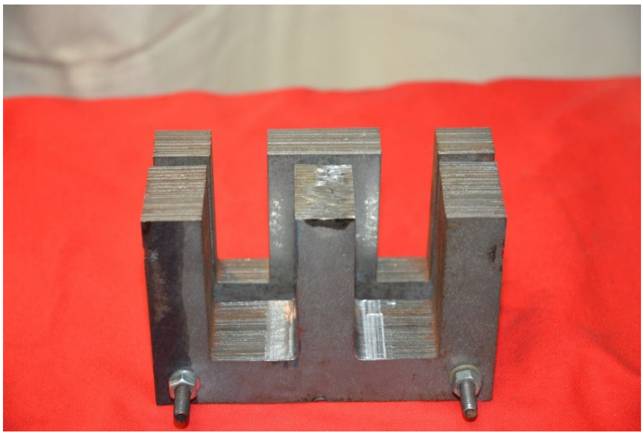
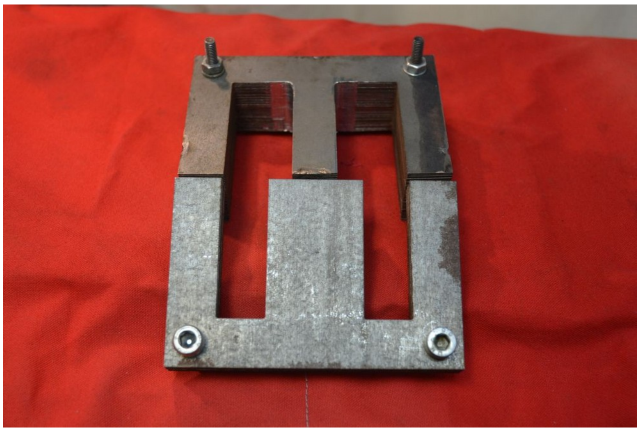
Basic sinewave filter

I had some old E-I laminations from a transformer and some 2 mm copper wire, thick enough for the motor current, but I did not have any suitable capacitors for a sinewave filter, so I decided to make a simple 3 phase dV/dt filter to check its effect. The transformer core was way too large and I used only some of the laminations to make a core which I guessed would not be driven into magnetic saturation with the maximum motor current.

I placed some small weld beads on the stack to hold the laminations together and then I milled the centre leg of the E down to the same width as the outer legs to provide magnetic flux symmetry. The transformer was originally single phase and the centre leg was twice the size of the other two. Milling laminations requires great care or they can be pulled up and twisted by the cutter.

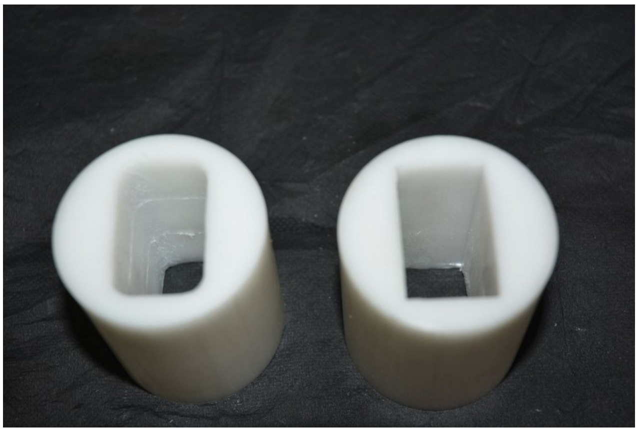



Here is a comparison of the original and reduced middle leg.

Now I needed some formers to wind the coils onto. I have used 3D printed ones in the past but did not want to waste time drawing the formers, preparing files and waiting for the printer to finish its slow work so I made some out of 50 mm Delrin bar. Firstly I parted three lengths off in the lathe and then milled rectangular slots with rounded corners to fit over the legs on the core. The inside corners needed squaring off and I did that in the lathe using a square HSS tool blank as a broach. It worked great.

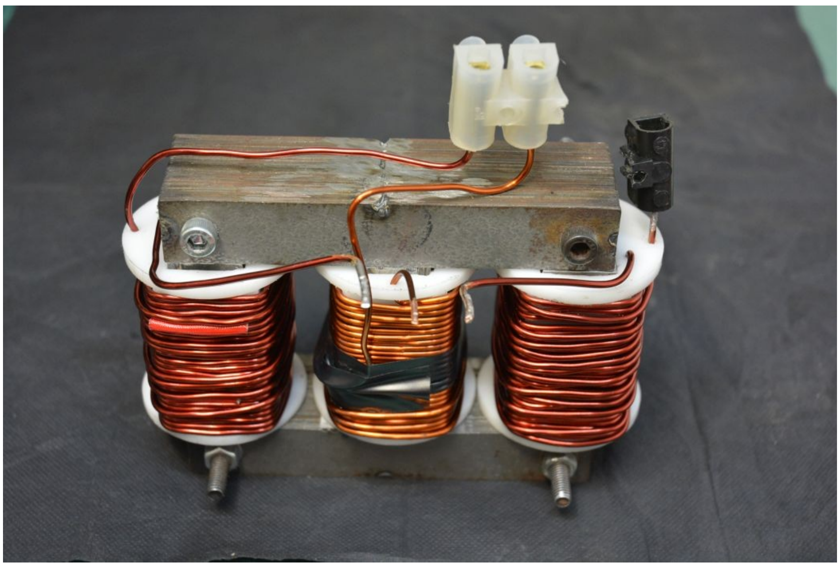
Once each former had been checked to fit on the core it was back to the mill to remove most of the material to give space for the copper coils.

Now I needed to wind the coils but what inductance do I need? I could not find any guidance on the net so I resorted to a bit of guess work guided by a bit of general electrical knowledge. I did a bit of doodling and came up with a number around 0.75 mH. I checked the VFD carrier frequency, that is programmable from 2 kHz to 15 kHz but mine defaults to 7 kHz and I use that. Then I calculated the relative reactances at 60 Hz and 7 kHz. 0.75 mH gave a fraction of an ohm at 60 Hz and several ohms at 7 kHz. So that should have little effect on a 60 Hz frequency but a significant effect on what happens at 7 kHz.

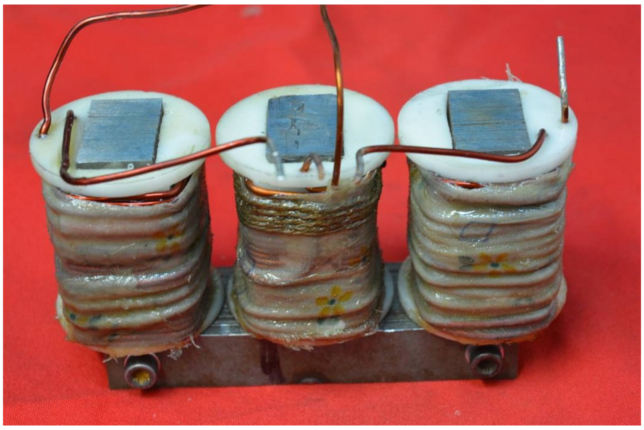
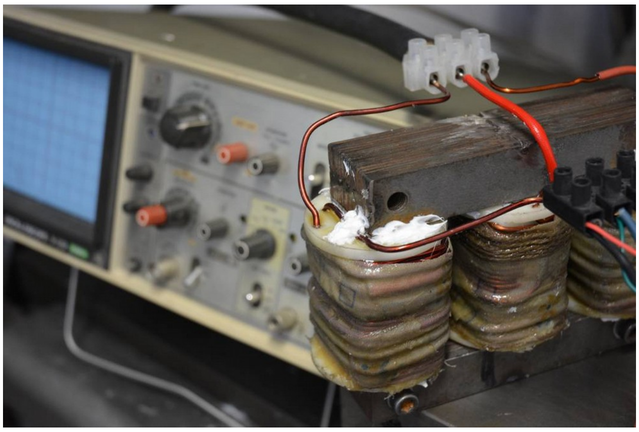
I wound a few turns on one former and measured the inductance which enabled me to calculate the number of turns needed. 0.75 mH needed 20 turns on the coils which fitted the formers nicely. Very scientific. Then I hand wound the coils which is not super easy with 2 mm wire. Assembled it all and tried it.

No whine from the motor but now the filter whines, however with the filter in a box I cannot hear that whine. There is a small reduction in max current but that is inevitable and was expected.
The 2 mm wire is about right as it only gets lukewarm at full current, however the core gets hot, a sure sign that at the switching frequency the core is quite lossy, which is fine as long as it does not get too hot. The motor appears to run a bit quieter (it should do) but that perception is corrupted due to the removal of the whine.



Once proven to have some beneficial effect, the filter needed some finishing off to make it suitable for everyday use. The coils were wrapped in strips of cotton material sourced from her indoors and dunked in varnish for an hour each.

The coils were then left several days to thoroughly dry. In an attempt at reducing the core whine I smothered each leg with silicon sealer before fitting the coils back on and the “I” piece of the core was located externally with the sealer also. It does seem to be quieter but that is purely a perception from listening to it by someone predisposed to want that result.

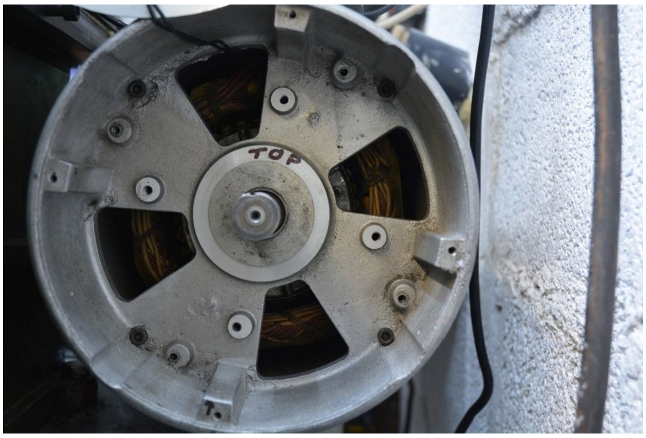
Studying the voltages with a Picoscope (an oscilloscope using a PC for storage and data manipulation) to view the voltages and currents fed into the motor it was clear that the filter presented a feed with lower voltage peaks and less “spikey” peaks. I regard it as a win.

Bearing protection

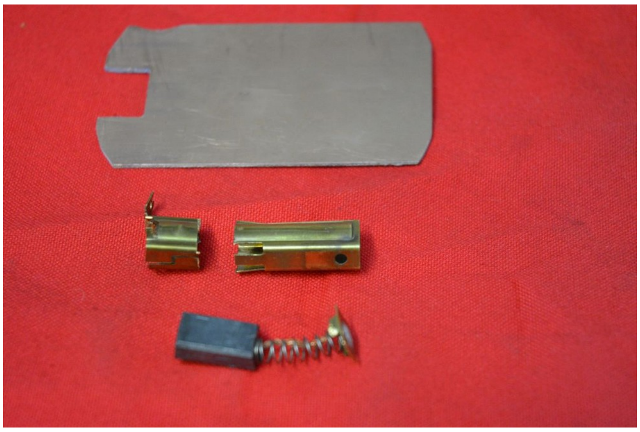
As I mentioned previously, it is generally considered that this is not worth doing for small motors and that is even more likely to be valid when the motor is fed through a dV/dt or sinewave filter. However, I saw a very easy way to add a shorting brush to the motor on my lathe. It was so simple that I just had to do it, even though I had no easy way to check its effectiveness.

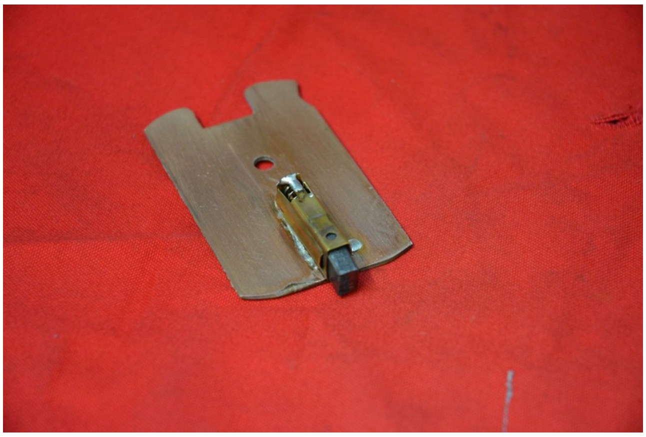
My motor came with an electromagnetic brake, but it had worn the lining down to its steel casing, in any case I did not want a motor brake because my chucks are screwed on and sudden braking could unscrew them. So although a brake at first sight seems like a safety feature it could have very dangerous side effects. So I removed the brake which opened up a lot of space at the end of the motor.


The brake on the end of the motor shaft prevented the fitting of a normal shaft mounted cooling fan so a separately powered fan was factory fitted, which is ideal for a VFD controlled motor because a motor powered fan does nor shift much air at low RPM.

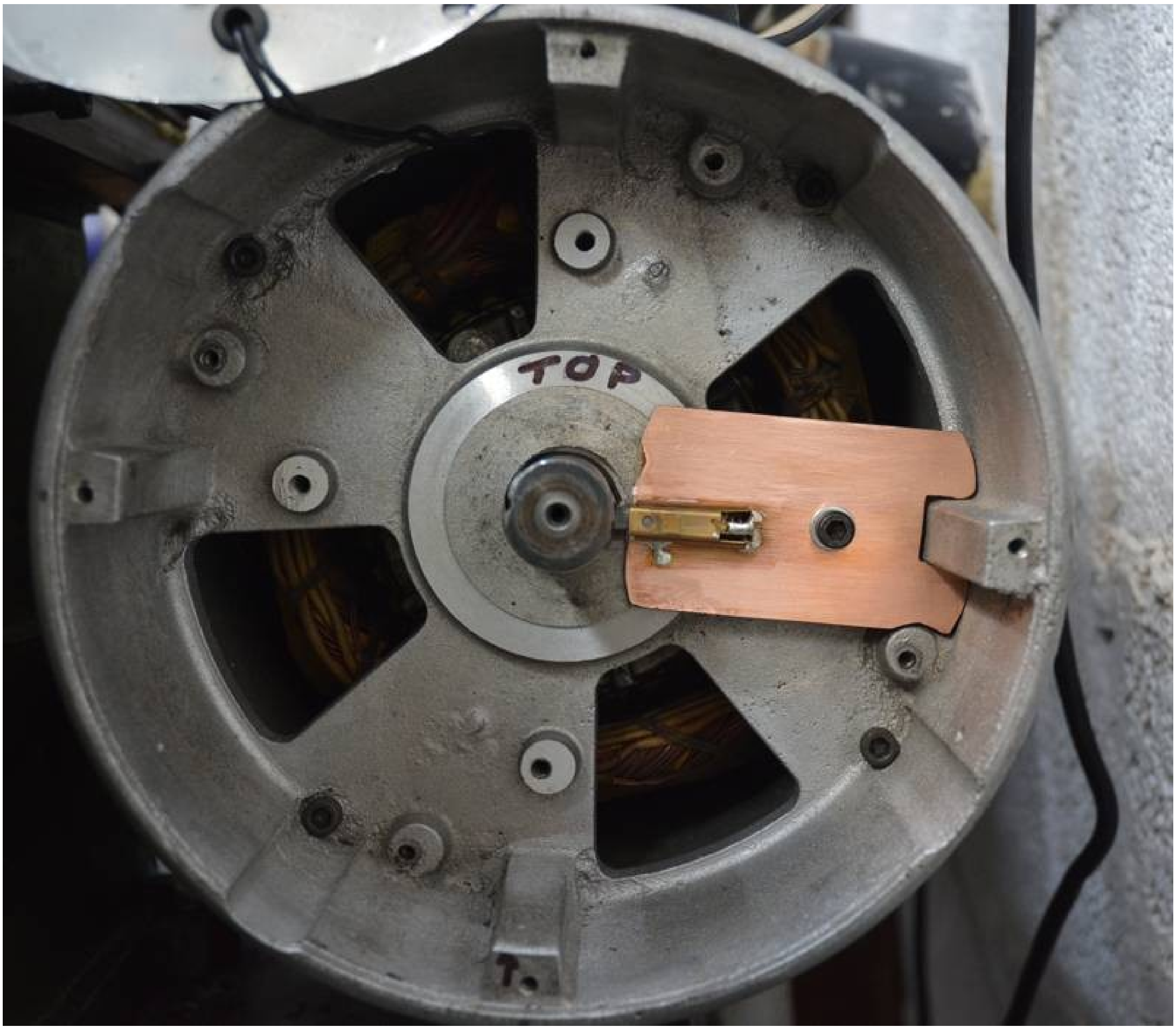


The missing brake gave me plenty of space in which to fit my brush idea. In my brushes and brush holders scrap box I found a suitable brass brush holder but no brushes that were meant for it, but I did have some with the right cross section but a short cable. The easy solution to this was to cut the brush holder to make it shorter. I used a piece of printed circuit board for mounting the brush holder because it was easy to solder the brass brush holder to it.





There were four machined and tapped holes in a great place to bolt the brush assembly. I shaped the printed circuit board so that it would fit against a cast in boss to prevent rotation with a single mounting bolt.



The brush runs directly on the motor shaft and shorts any potential bearing currents through the holder and PCB to the casing. If I had had a suitable piece of brass or copper I would have made a sleeve to fit on the shaft for the brush to run on, but I did not have that piece. I have no worries about running it on the shaft though and will check it from time to time.

Well, that is it. There is plenty more to know about motors and VFDs but there is only so much that is reasonable to put in a single document.