50μH Solarcar Inductors Construction Guide

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1 INTRODUCTION

This document describes how to build a set of 50μH 100Arms (peak) inductors suitable for use with a Prohelion WaveSculptor motor controller and a CSIRO/Marands motor.

2 OVERVIEW

The inductors are constructed on a toroid (doughnut) shaped magnetic core, winding wire through the core in several layers. The inductance is set by the magnetic permeability of the core, and the number of turns wound on it.

The wire size itself is set by how much can physically be fit through the centre of the toroid, more is better. Litz wire (having individually insulated wire strands) is required, to avoid eddy current losses that would occur with normal wire.

The complete inductor is coated in transformer varnish to lock everything together and prevent abrasion caused by vibration.

Note that no mechanical support is provided for the inductor or connections with the procedure as outlined in this document. You may wish to explore options such as moulding thermally conductive epoxy around the inductors and the connections to provide some means of restraint.

3 MATERIALS REQUIRED

Material listings are for a complete set of three inductors.

- 58908-A2 High Flux Toroid core. 26μ permeability, 79mm OD, 48mm ID, 17mm high, 37nH/T^2 AL. Quantity required: 3. Supplier: Magnetics Incorporated, http://www.mag-inc.com
- Litz wire, 30x 0.335mm diameter strands, 'single' insulation, around 2.6mm^2 total copper cross sectional area. Three of these litz wire bundles will be used in parallel, giving almost 8mm^2 total cross-sectional area. Quantity required: approximately 50 metres. Supplier: varies, see below
- Kapton or Polyester transformer insulation tape. Quantity required: a few metres. Supplier: Your local catalogue electronics supplier, eg Element14 (formerly Farnell), part number 753-014
- Transformer Varnish or low viscosity potting compound. Generic, use a local supplier. If using a vacuum chamber, a solvent-free varnish must be used to avoid boiling when the vacuum is pulled on the chamber.
- Connectors. PowerPole 75A Red or M6 bolt lug terminal. Quantity Required: 6 housings, 6 crimps. Supplier: Anderson Power Products or their local distributor, part number 5916G7 for the housing, 5900 for the crimp. Bolt lugs, if used, are available from local electrical supply shops.

The Litz wire is the most difficult component to source. It is also the component that can tolerate the largest variation in specification and does not have to be an exact match to the size given above. Finer strands give smaller eddy current losses, but also poorer fill factor (the amount of copper contained in the cable) as a bundle of very fine strands will be as much insulation as copper. Larger strands have proportionally less insulation and will give lower resistance for a given bundle diameter.

Smaller size wire strands than approximately 0.25mm diameter can be used, however this does not improve eddy current losses to any significant degree, and it will worsen the fill factor and therefore the resistance of the wire. Strands larger than 0.5mm diameter will begin to see an increase in eddy losses and are not recommended.

Multiple bundles of litz are used in parallel. This is to make construction easier, as winding three small 30 strand bundles together is easier than winding one large 90 strand bundle. However, if sourcing a different wire construction is easier, than almost any combination is OK, but may require more effort to wind on the core. The construction listed above is known to produce good results.

The wire strands are only required to be insulated to 'single' thickness insulation. Choose a 'solderable' insulation with the highest temperature grade available easily. This will usually be 155°C Polyurethane or similar.

Litz wire is available from specialised manufacturers, use a web search to find a supplier close to you, as copper wire is heavy and shipping charges will be high if not purchased reasonably locally. One example supplier in the US is the New England Wire Company.

4 EQUIPMENT REQUIRED

- Solder pot. Required to strip insulation from ends of litz wire.
- Fume hood and personal protective equipment to use with solder pot. Wire insulation fumes can be toxic, depending on the insulation material.
- Vacuum chamber. Recommended to use when applying transformer varnish or epoxy coating to inductors, to remove trapped air bubbles. It is possible to perform this step without pulling a vacuum on the inductors, but much better results will be achieved with it.
- Crimp tool. Required to crimp the PP75 connectors or M6 bolt lugs onto the ends of the wire after soldering.
- Gas torch. Required to reflow the solder into the PP75 crimps or bolt lugs after crimping. This step may be possible with a high-powered hot air gun (paint stripper), but a gas torch will be guaranteed to work properly.

5 CONSTRUCTION PROCEDURE

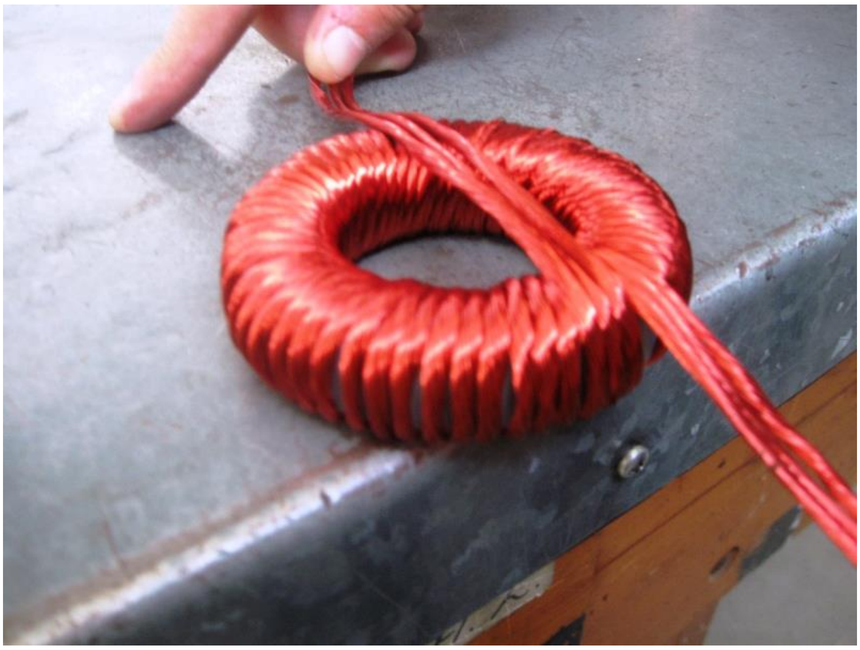
1. Cut three 5m lengths of litz wire to wind in parallel. If a different type of litz wire from that specified is being used, then more or less bundles in parallel may be required. Some experimentation may be necessary to work out how much wire can be physically wound through the toroid. 36 turns in total are necessary to achieve the specified inductance.
2. Hold the three bundles together in a flat group, three bundles wide. Leave a 20cm tail of wire to start, and wind 19 turns onto the toroid. This should fill up one layer of wire, with no overlaps. There is no need to twist the bundles together but pay attention to keeping the tension of the wires reasonably constant, so that each bundle remains the same length as the others.
3. Wrap the winding so far with Kapton or Polyester tape, to hold the wire in place. Pay attention around where the tail exits the bundle, as this is the most likely place for vibration and abrasion to occur, and also where the highest voltage difference will be across the inductor. Before placing all the tape, consider using a marker pen to draw an arrow on top of the tape to indicate which direction the windings were wound.
4. Wind another 17 turns in a second layer, continuing to wind in the same direction as the first layer. It is important to have 36 turns in total when finished, and all turns in the same direction. Leave another 20cm tail where the winding exits the inductor.
5. Wrap the complete winding in another layer of tape. As before, pay attention to the exit tail area.
6. Dip the inductor in a container of transformer varnish or low viscosity potting compound. Much improved results will be achieved if this process is done in a vacuum chamber, as the varnish will then penetrate into the inner layer and will completely lock all the windings and the core together.
7. Cut the tails to the required length if necessary and use the solder pot to strip the insulation from the ends of each tail. Using pliers or some method to hold the wire (it will get hot!) dip each tail into the solder pot to a depth of 15 to 20mm. Hold it in the pot until the insulation stops bubbling up – this usually takes around 30 seconds. Warning: the fumes produced by this process can be toxic, take appropriate cautions with personal protective equipment or

use a fume hood in a laboratory.

8. Insert the soldered wire end into the PP75 crimp or bolt lug, and crimp it with the appropriate tool. This will usually be a hex crimp tool capable of generating quite high forces.
9. If left at this stage, a good electrical contact will be in place, but over time the solder will 'flow' under the mechanical pressure of the crimp, and a loose and high-resistance joint will result. This can be fixed by using a gas torch (or possibly a hot-air gun or paint stripper) to heat the crimp past the solder reflow point so that the solder around the wire flows onto the inside of the crimp and forms a soldered connection. More solder can be added to the joint if necessary during this process.

6 PHOTOS

Inductor after completely winding the first layer, ready for taping.



Inductor after taping first layer and beginning second layer.

Inductor after spraying with transformer varnish. It is recommended to use a dip procedure for this step instead of spraying.

Photos courtesy of Erdem Guven, SAU Solarcar

7 PERFORMANCE

Calculation:

$L = N^2 \times A_L = 36^2$turns x 37nH/turn = 48μH

Testing:

50A step response

L = 118V / (23.4A / 10 μS) = 50μH

100A step response:

Start of step (10A)	L = 118V / (45.3A / 19.2μS) = 50μH
End of step (115A)	L = 118V / (35.9A / 12.4μS) = 40μH

120A step response:

Start of step (10A)	L = 118V / (54.7A / 23.8μS) = 50μH
End of step (150A)	L = 118V / (54.7A / 13.8μS) = 30μH

The decay of inductance with increasing current is gradual and continuous, unlike the ferrite cored CSIRO inductors. This gradual decay presents no major problems for the Wavesculptor current control loop maintaining control of the motor phase current.

8 REVISION RECORD

REV	*DATE*	*CHANGE*
1	13 August 2021	Document creation (AJP)