A practical approach to detect turn to turn shorts during superconductive magnet fabrication

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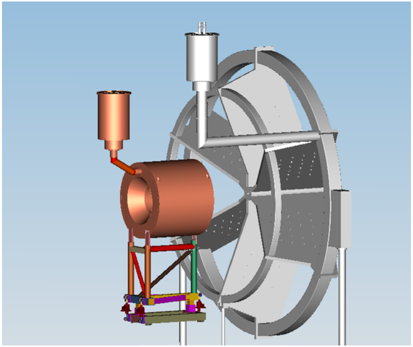
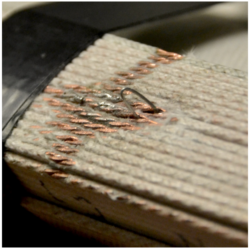
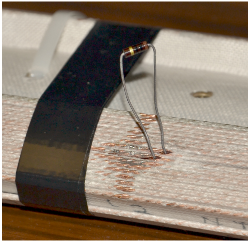
CLAS12 for Hall B experiment

Six superconductive magnets generate a toroidal magnetic field in order to deviate the debris coming from collisions between particles.
Each magnet is a double layered Nb_3Sn coil with 117 turns per layer, winded, clamped and cured in Technical Division.



Turn to turn shorts





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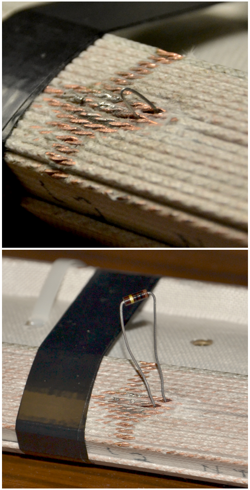

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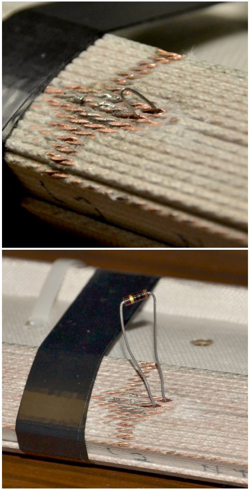

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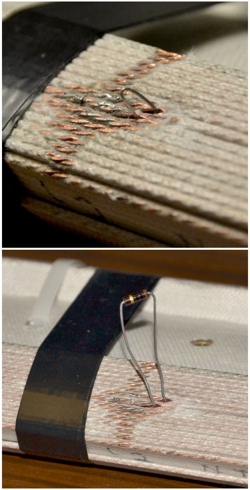

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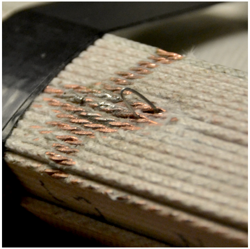

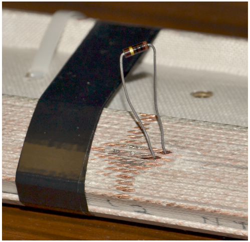

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- Simulated with resistors or wires (see pictures)

CLAS12 turn to turn short detector

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Detect turn to turn shorts, both hard and as soft as possible.

Problems:

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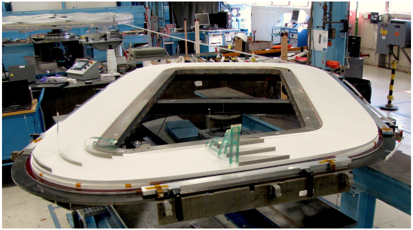

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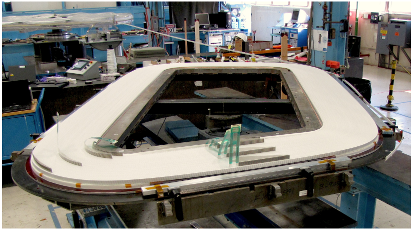

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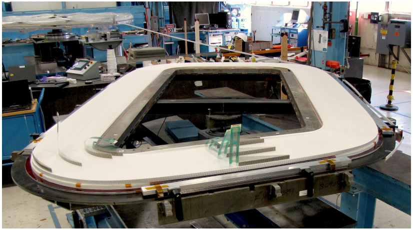

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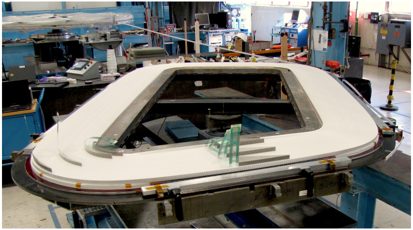

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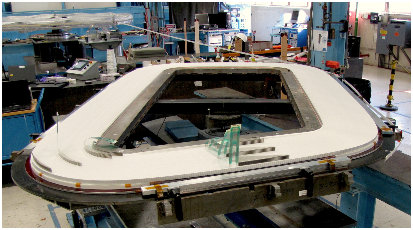

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Solution:

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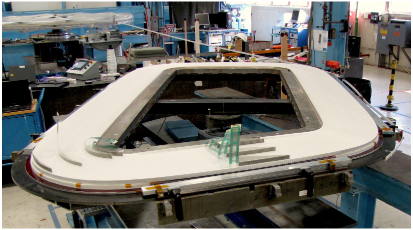
- Significant voltage drop between turns



AC impedance analysis

Setup:

- Inductive zone: $|Z| \approx \omega L$, rising with frequency

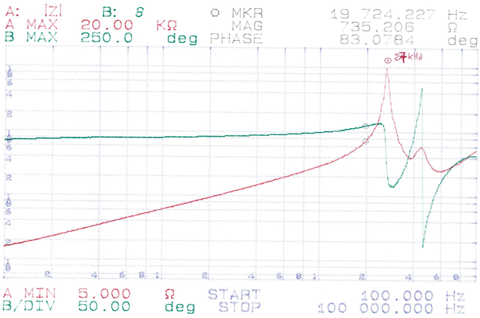


Figure: Double layered unclamped coil AC impedance

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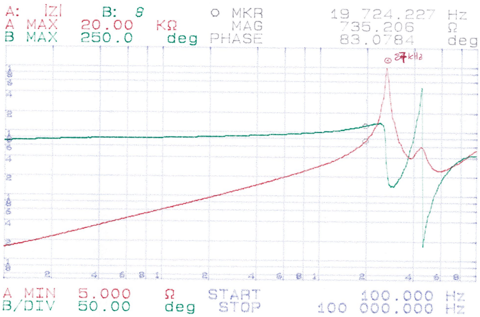

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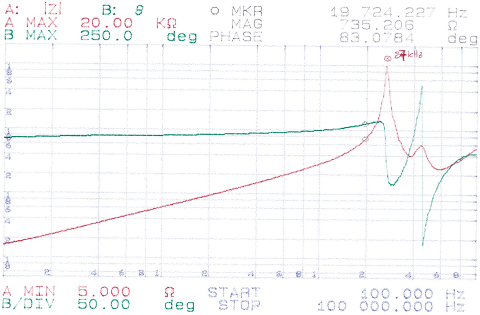

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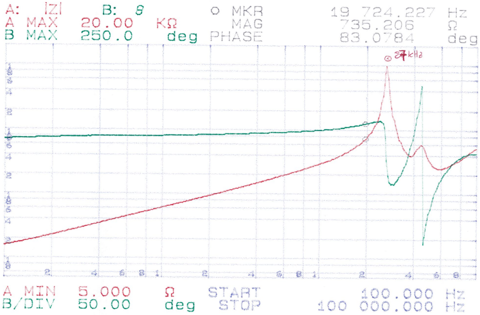

Figure: Double layered unclamped coil AC impedance

General setup

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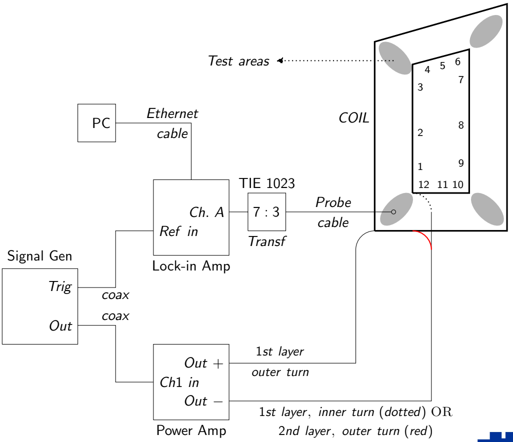
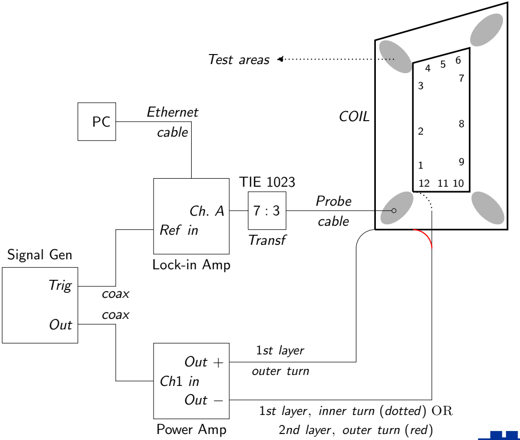


General setup

Setup:

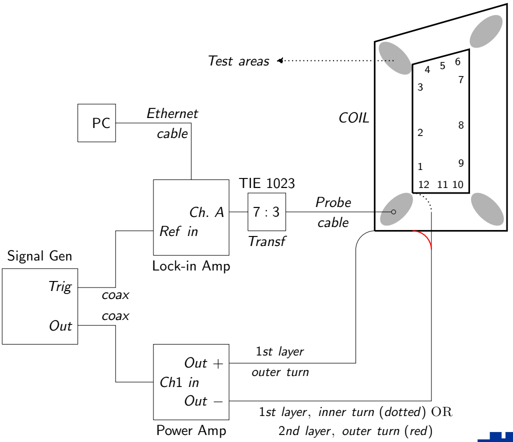
- 19.8 *kHz* sine wave



General setup

Setup:

- 19.8 kHz sine wave
- 30 V_{RMS} output



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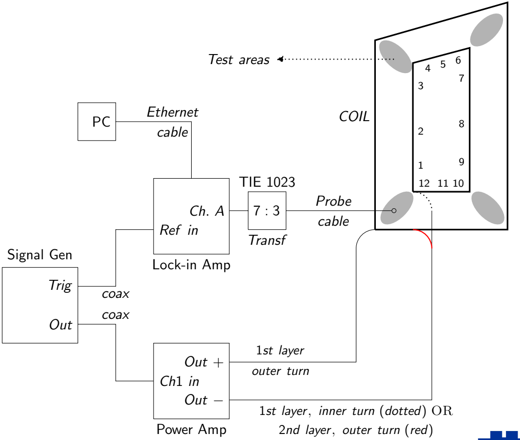

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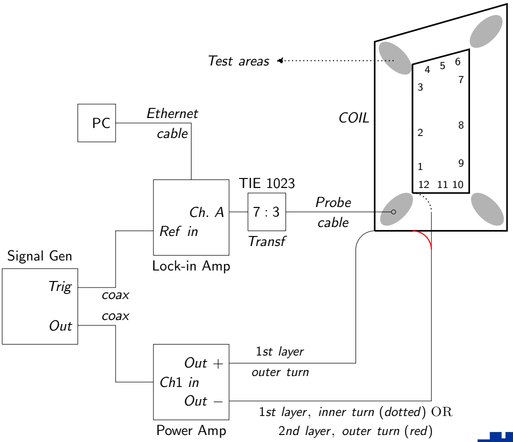
- Automatic data acquisition: LabView driver



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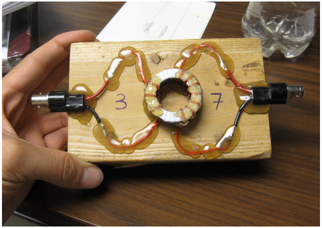
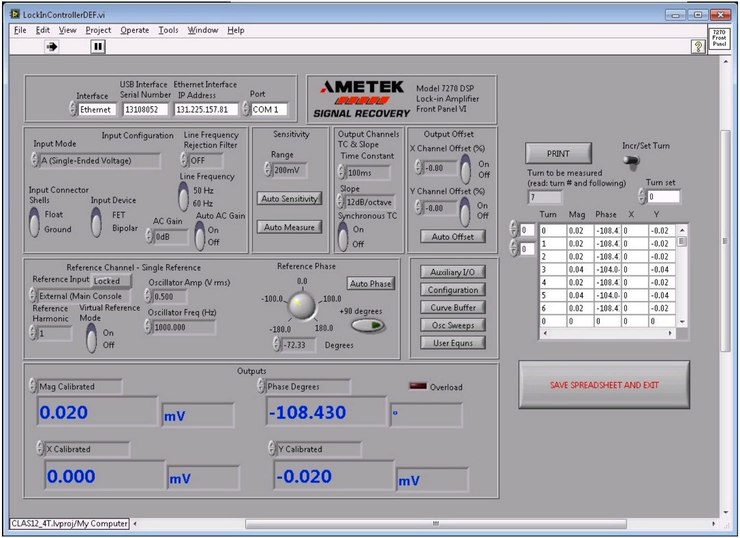
- Handmade transformer: more distant coils, high frequency wire, negligible parasitic effects

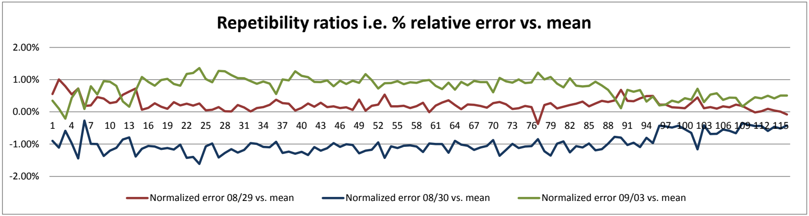


LabView Driver



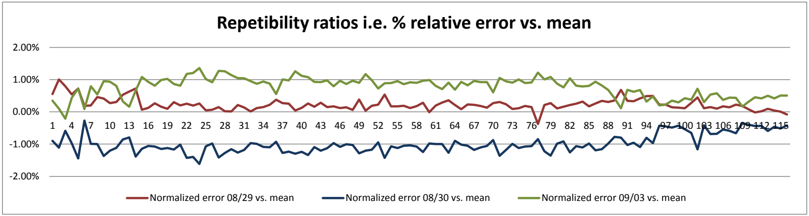
Procedure

1. A few scannings of all turns, one position (corner 1-12), to see repeatability, that is the precision of the method

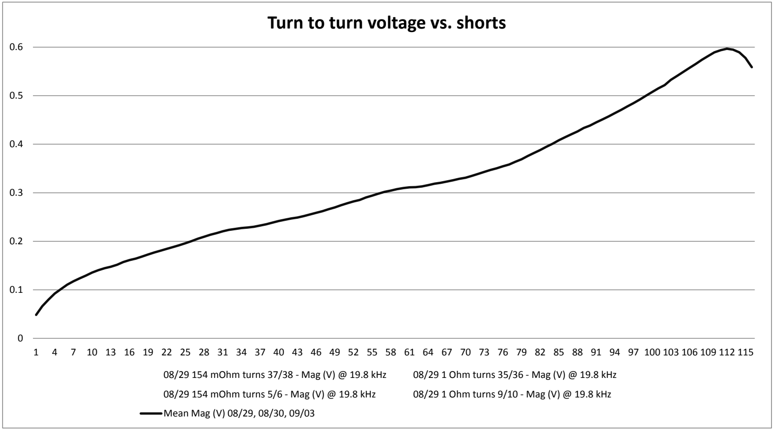


Procedure

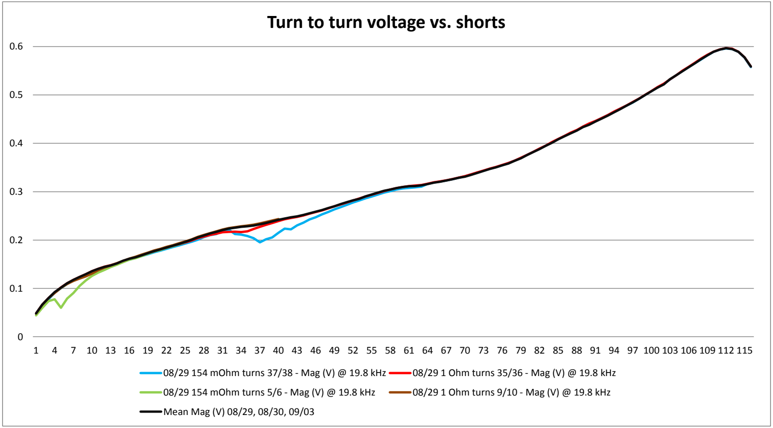
1. A few scannings of all turns, one position (corner 1-12), to see repeatability, that is the precision of the method
2. Scannings with different shorts to see position and amount of turn to turn voltage losses, that is the sensitivity and resolution of the method.



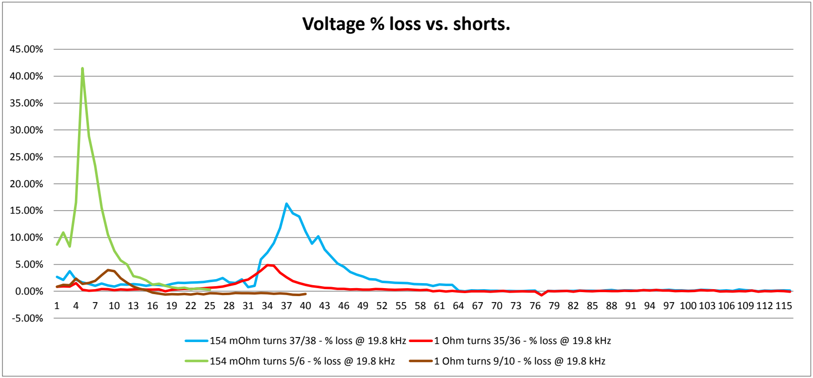
Non shorted coil voltage curve



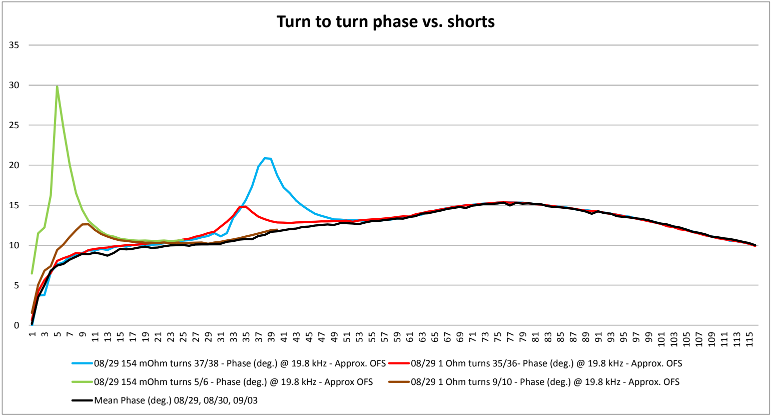
Non shorted vs. shorted coil voltage curves



Voltage losses

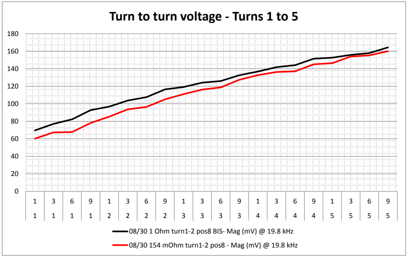


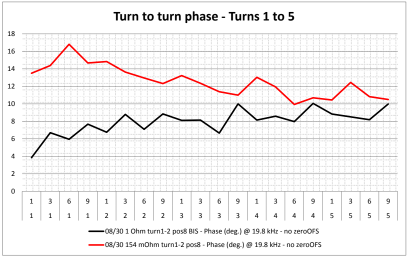
Non shorted vs. shorted coil phase curves



4 position method

In the very first turns it is harder to see a sharp loss with a smooth bending by its sides. A 4-position scanning can help increase the resolution.





NB: with low SNR, the help of the phase is fundamental.

Conclusions and problems

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2. Why should a short influence even the nearest turns?

Zero model for currents in a shorted coil

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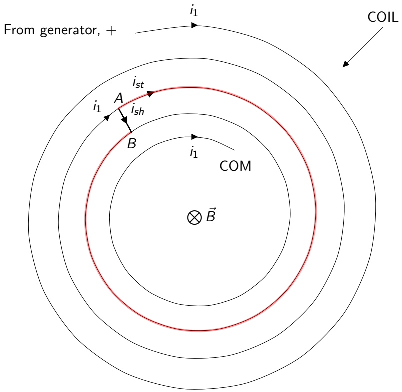

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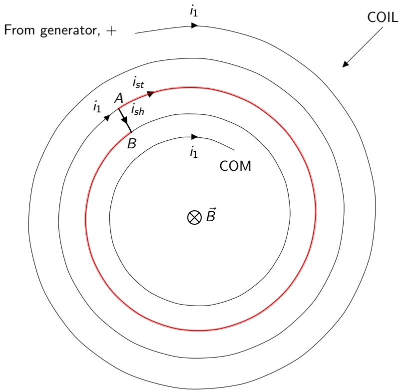

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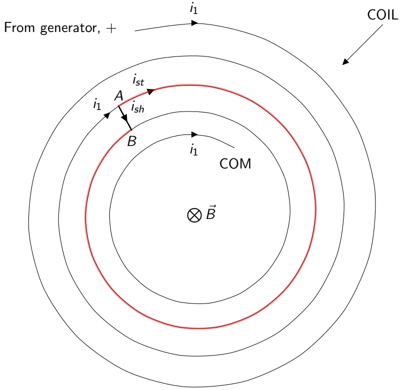

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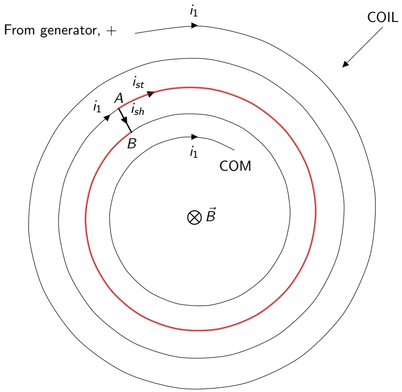

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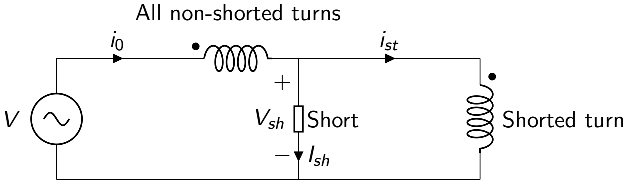

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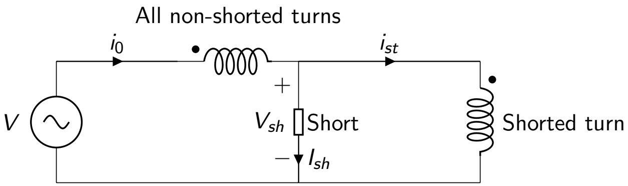

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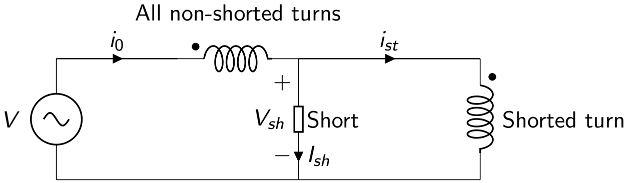

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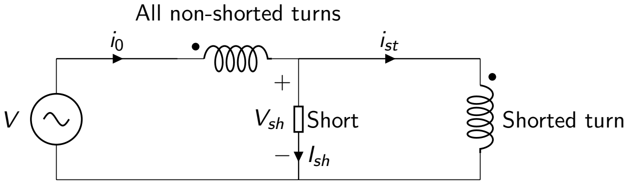

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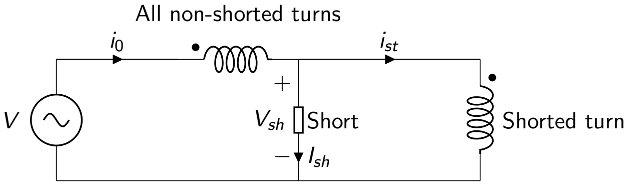

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> Despite this is a zero model, experimental data fit this theoretical result with good approximation.

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- "Enhanced 4W" needed: higher currents for very low resistances.

Measuring the shunts

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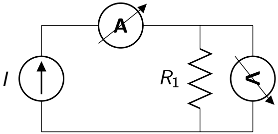

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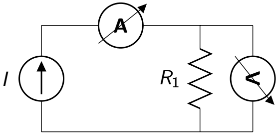

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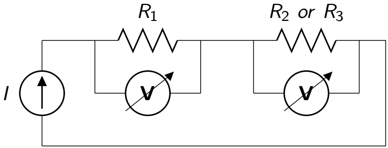

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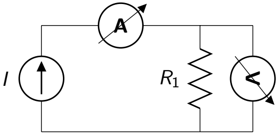

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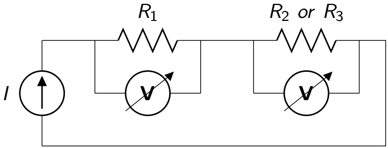
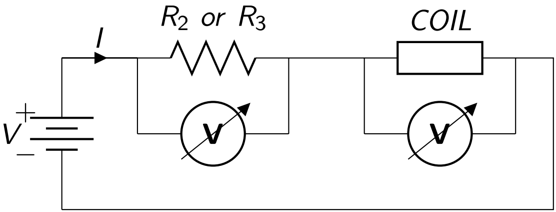


3. The same way with just R_2 and R_3 to double check their ratio at higher currents.

Measuring the coil

4. Coil as load, R_2 and R_3 as shunts, currents from 1 to 10 A. Measured R_{coil} with no less than 3 significant digits. NB: Voltage source used because current source did not work with reactive loads.



Shunts

Im avg	Va avg	Vb avg	Vc avg	Ra avg	Rb avg	Rc avg
1.00538	1.00577	10.02065	0.9955	***1.000387913***	***9.967027393***	***0.99017287***
0.901365	0.90175	8.9885	0.8928	1.00042713	9.972097874	0.990497745
0.8944	0.89479	8.909	0.885	1.000436047	9.960867621	0.989490161
0.89587		8.9345	0.8884		9.972987152	0.991661737
			Average:	**1.00041703**	**9.967839188**	**0.99066020**
			St. Dev.	**0.00002091**	**0.003986671**	**0.00074192**
			% St. Dev.	**0.002090%**	**0.039995%**	**0.074891%**
			Final values:	***1.0004***	***9.968***	***0.991***

Small test coil

Vshunt (mV)	Rshunt (mOhms)	I meas (A)	Vcoil (mV)	R coil (mOhms)
10.325	9.968	1.035814607	26.919	25.98824136
20.831	9.968	2.089787319	54.315	25.99068312
40.791	9.968	4.092195024	106.33	25.98361011
70.705	9.968	7.093198234	184.3	25.98263772
102.76	9.968	10.30898876	267.95	25.99188011
1.025	0.991	1.034308779	26.876	25.98450341
2.0755	0.991	2.094349142	54.397	25.97322428
4.062	0.991	4.09889001	106.46	25.97288528
7.045	0.991	7.108980827	184.65	25.97418737
10.224	0.991	10.31685166	268.1	25.98660994

Average:	**25.98284627**
St. Dev.	**0.00675612**
% St.Dev.	**0.0260%**

R: ***25.98***

4 significant digits.

CLAS12 coil

Vshunt (mV)	Rshunt (mOhms)	I meas (A)	Vcoil (V)	R coil (mOhms)
10.767	9.968	1.080156501	0.9124	844.692412
26.497	9.968	2.65820626	2.2447	844.4416198
65.198	9.968	6.540730337	5.5207	844.0494739
102.34	9.968	10.26685393	8.664	843.8807114
1.113	0.991	1.123107972	0.9484	844.4424079
2.589	0.991	2.612512614	2.205	844.0150637
6.211	0.991	6.26740666	5.2891	843.9056674
10.355	0.991	10.44904137	8.8176	843.8668856

Average:	**844.1617802**
St. Dev.	**0.2967168**
% St.Dev.	**0.0351%**
R:	***844***

3 significant digits, but St. Dev is much less than half of the last digit.

A practical approach to detect turn to turn shorts during superconductive magnet fabrication

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