A Search for a Better Primary – Part 3

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In Part 2, a method of simulation was investigated to determine the feasibility of evaluating a primary design for its performance and tendency to develop racing arcs. In this part a detailed evaluation of the existing primary used in my 8 inch coil is done and compared to a new and hopefully better primary design. The existing primary is located one inch below the bottom turn of the secondary and the inner radius is 5 inches (one inch clearance from the coil form). The overall coupling coefficient is **0.130**. The voltage profile measured on the existing primary (from part 2) is repeated here:

Reference for Differential Voltage Measurement

V@Seg	Gnd	Seg1	Seg2	Seg3	Seg4	Seg5	Seg6	Seg7	Seg8
9	563kv +4	515kv +4	460kv +3	397kv +3	331kv +3	266kv +3	205kv +4	144kv +4	71kv +4
8	513kv -3	468kv +3	422kv +3	359kv +3	290kv +3	224kv +3	151kv +3	73kv +4	_
7	467kv -3	418kv +4	362kv +3	300kv +3	230kv +4	161kv +3	80kv +3	_	
6	428kv -3	374kv -3	295kv -3	231kv +3	158kv +4	82kv +4	_		
5	369kv -3	315kv -3	236kv -3	162kv +3	85kv +3	_			
4	313kv -3	250kv -3	170kv -3	80kv -3	_				
3	237kv -3	174kv -3	93kv -3	_					
2	157kv -3	84kv -3	_						
1	76kv +3	_							

The voltage stress that this voltage profile results in is also repeated here:

Reference for Stress (V/inch) Calculation

Stress @Seg	**Gnd**	**Seg1**	**Seg2**	**Seg3**	**Seg4**	**Seg5**	**Seg6**	**Seg7**	**Seg8**
9	15.6kv	16.1kv	16.4kv	16.5kv	16.6kv	16.6kv	17.1kv	18.0kv	17.8kv
8	14.6kv	16.7kv	17.6kv	18.0kv	18.1kv	18.7kv	18.9kv	18.3kv	-
7	16.7kv	17.4kv	18.1kv	18.8kv	19.2kv	20.1kv	20.0kv	-	
6	17.8kv	18.7kv	18.4kv	19.3kv	19.8kv	20.5kv	-		
5	18.5kv	19.7kv	19.7kv	20.3kv	21.3kv	-			
4	19.6kv	20.8kv	21.3kv	20.0kv	-				
3	19.8kv	21.8kv	**23.3kv**	-					
2	19.6kv	21.0kv	-						
1	19.0kv	-							

The new primary, this data is compared to, is a flat primary positioned one inch above the bottom turn of the secondary, has an inner radius of 7.5 inches (3.5 inch clearance from the secondary form), has a winding pitch of ½ inch, and is auto tuned by JavaTC. This primary seems to be a better choice than the ones in part 1 that were located ½ inch above the secondary base. Of those primaries, all had voltage stress issues except the one with a 7 inch inner radius. That primary had an overall coupling of 0.137. The overall coupling of this new primary is **0.138**. The coupling coefficients from the primary to each secondary segment and between the secondary segments (as determined by JavaTC where the procedure is described in parts 1 and 2) used in the simulations are listed here:

```
K23   L2  L3  .217
K24   L2  L4  .145
K25   L2  L5  .079
K26   L2  L6  .043
K27   L2  L7  .025
K28   L2  L8  .015
K29   L2  L9  .010
K210  L2  L10 .007
K211  L2  L11 .005

K34   L3  L4  .309
K45   L4  L5  .309
K56   L5  L6  .309
K67   L6  L7  .309
K78   L7  L8  .309
K89   L8  L9  .309
K910  L9  L10 .309
K1011 L10 L11 .309

K35   L3  L5  .077
K46   L4  L6  .077
K57   L5  L7  .077
K68   L6  L8  .077
K79   L7  L9  .077
K810  L8  L10 .077
K911  L9  L11 .077

K36   L3  L6  .028
K47   L4  L7  .028
K58   L5  L8  .028
K69   L6  L9  .028
K710  L7  L10 .028
K811  L8  L11 .028

K37   L3  L7  .013
K48   L4  L8  .013
K59   L5  L9  .013
K610  L6  L10 .013
K711  L7  L11 .013

K38   L3  L8  .007
K49   L4  L9  .007
K510  L5  L10 .007
K611  L6  L11 .007

K39   L3  L9  .004
K410  L4  L10 .004
K511  L5  L11 .004

K310  L3  L10 .003
K411  L4  L11 .003

K311  L3  L11 .002
```

The following is the voltage profile across the coil that these coefficients result in:

Reference for Differential Voltage Measurement

V@Seg	**Gnd**	**Seg1**	**Seg2**	**Seg3**	**Seg4**	**Seg5**	**Seg6**	**Seg7**	**Seg8**
9	585kv -3	553kv -3	493kv -3	417kv -3	351kv +3	287kv +3	211kv +3	135kv +3	63kv +3
8	546kv -3	504kv -3	444kv -3	368kv -3	288kv +3	224kv +3	148kv +3	72kv +3	_
7	490kv -3	443kv -3	384kv -3	307kv -3	225kv -4	154kv -4	76kv +3	_	
6	434kv +4	383kv +4	317kv -3	241kv -3	157kv -3	79kv -4	_		
5	371kv +4	320kv +4	246kv +4	166kv +3	83kv -3	_			
4	296kv +4	242kv +4	169kv +4	86kv +4	_				
3	221kv +4	158kv -2	83kv +4	_					
2	150kv +3	80kv -2	_						
1	72kv +3	_							

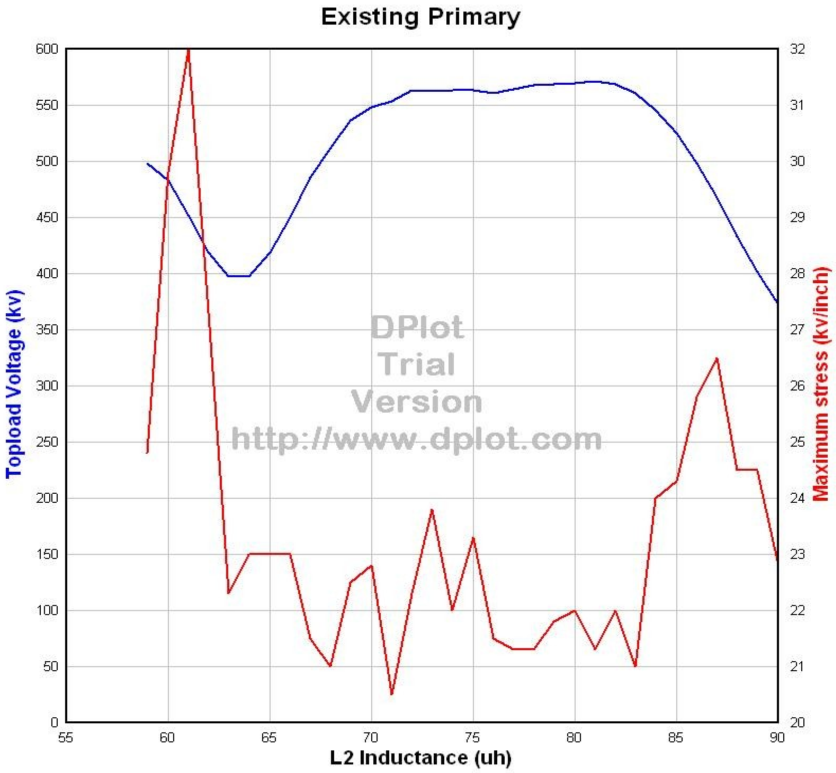
This profile results in the follow voltage stresses:

Reference for Stress (V/inch) Calculation

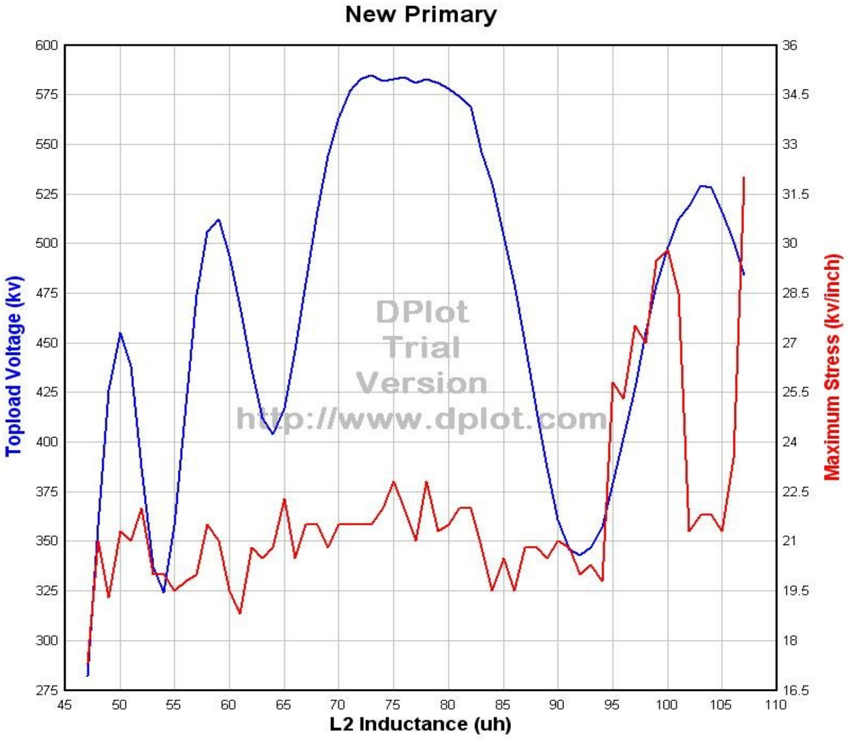
Stress @Seg	**Gnd**	**Seg1**	**Seg2**	**Seg3**	**Seg4**	**Seg5**	**Seg6**	**Seg7**	**Seg8**
9	16.3kv	17.3kv	17.6kv	17.4kv	17.6kv	17.9kv	17.6kv	16.7kv	15.8kv
8	17.1kv	18.0kv	18.5kv	18.4kv	18.0kv	18.7kv	18.5kv	18.0kv	-
7	17.5kv	18.5kv	19.2kv	19.2kv	18.8kv	19.3kv	19.0kv	-	
6	18.1kv	19.2kv	19.8kv	20.1kv	19.6kv	19.8kv	-		
5	18.6kv	20.0kv	20.5kv	20.8kv	20.8kv	-			
4	18.5kv	20.2kv	21.1kv	**21.5kv**	-				
3	18.4kv	19.8kv	20.8kv	-					
2	18.8kv	20.0kv	-						
1	18.0kv	-							

From this cursory look at this new primary, it appears that the stresses across the coil are more uniform, the maximum stress is 21.5kv between segments 4 and 3 and is lower than the existing primary's maximum stress of 23.3kv between segments 3 and 2, and the top load voltage is 22kv higher than with the existing coil. With less coupling into the lower portions of the coil, the voltage rise and corresponding stress into these areas are less. With higher coupling into the upper portions of the coil, the voltage rise and corresponding stresses into these areas are more in line with the lower portions.

A more in depth simulation was done to see what happens with the system when the primary is out of tune. The following are the maximum top load voltages and maximum stresses on the secondary resulting from the existing primary as a function of L2. This system was originally tuned with an L2 of 75 uh and L2 was changed to affect various degrees of mistuning:

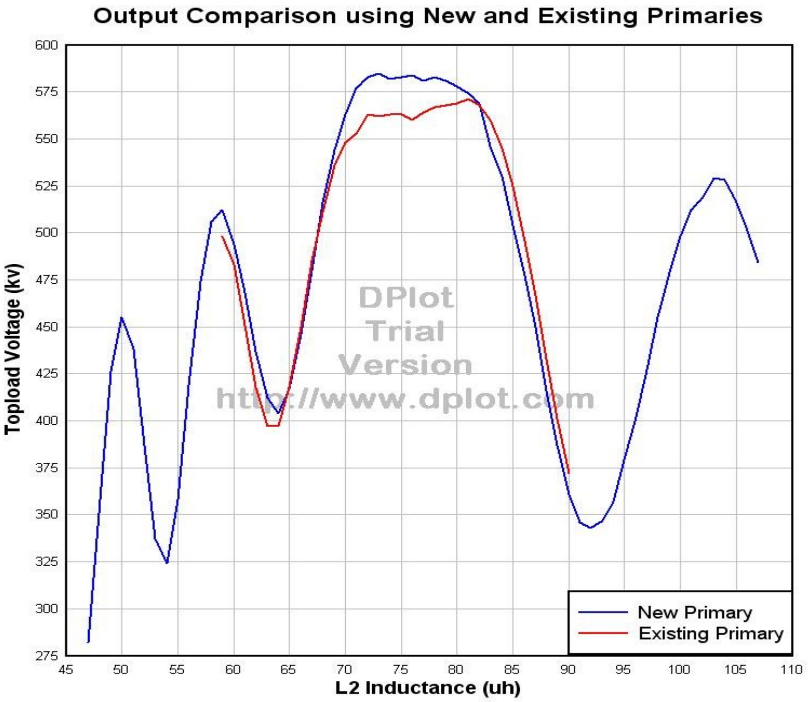


The following are the maximum top load voltages and maximum stresses resulting from using the new primary design as a function of L2. This system was originally tuned with a L2 of 73 uh and L2 was changed to affect various degrees of mistuning.



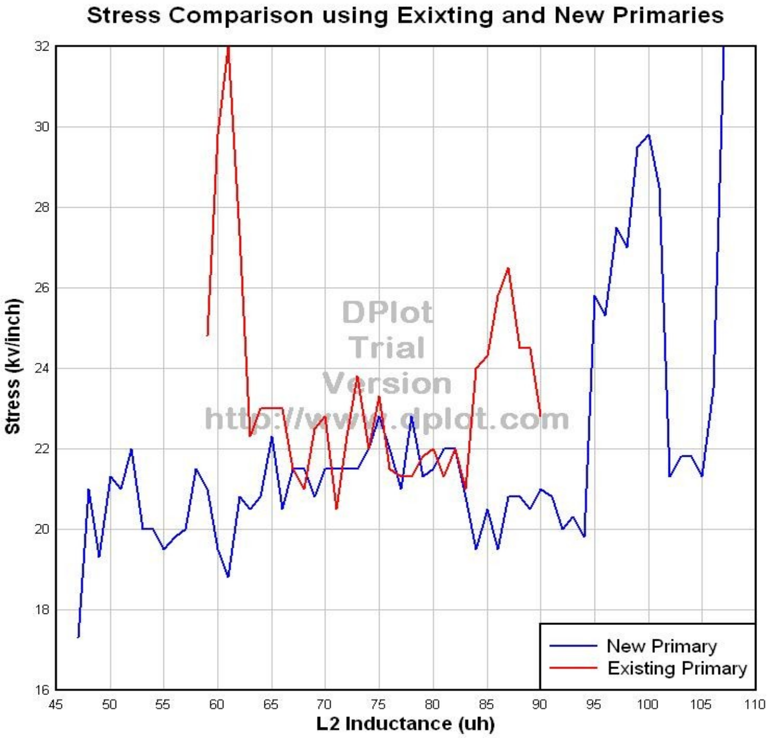
The natural responses of the secondary result from the unit step excitation when the spark gap fires. The multiple resonances on either side of peak makes me wonder if there is a beating affect with the 3rd overtone of the secondary. It is also interesting that with the existing primary, the stress gets high when out of tune on either side of resonance; where as, with the new primary, the stress only gets high when operating at a lower frequency than resonance. The important observation is probably that out of tune operation can cause much higher stresses than those from being slightly over coupled.

The following are output comparisons of the top load secondary voltage using the existing and new primaries.



It can be seen that a higher output voltage can be obtained with the higher overall coupling of the new primary.

The following are maximum stress comparisons on the secondary using the existing and new primaries:



With this graph, it can be seen that even though the overall coupling with the new primary has been increased, the stress on the secondary has been reduced in the region that can be considered tuned. Also, with the new primary, there seems to be a greater margin for mistuning than with the existing primary.

Conclusion:

The contemporary thinking is to build flat spiral primaries that are located at or below the plane formed by the bottom turn of the secondary and are spaced 1-1½ inches from the secondary form. The need to prevent racing arcs with moderate to high power coils tends to limit the maximum coupling coefficient that one can utilize in a conventional disruptive tesla coil. This need generally requires the secondary to be raised above the plane of the primary until the coupling coefficient is lowered sufficiently to eliminate the racing arcs. By implementing a flat primary that has a greater clearance from the secondary form, this paper has shown that it may be possible to raise the primary above the bottom turn of the secondary and actually increase the overall coupling without creating local voltage stresses in the secondary that can result in racing arcs

Further investigation:

1. More work needs to be done to verify the accuracy of the spice model that resulted in the conclusions mentioned above. There is always the question if the secondary has been subdivided sufficiently to yield accurate results. A common practice is to subdivide an object, simulate it, subdivide it again, and simulate it again and repeat this until the results cease to change significantly. At some point in the subdivision process, a point of diminishing returns is reached. I have subdivided that secondary to where the section represents a fraction of a waveform transition. Waveform transitions seem to take around 2us and a 4 inch section takes 2/3us to propagate across. My gut feel is the subdivision is sufficient; however, further subdividing should be done to see if the results change significantly.

2. Further investigation could be done to see what is causing the other resonant points in the frequency response of the system if they are real and not an artifact of the model.

3. Likewise, the lack of high voltage stresses when the new primary is out of tune on the high end of resonance bears some investigation.

4. Perhaps most important, a primary should be built using the simulation techniques mentioned to see if higher coupling can be achieved without causing racing arcs. This I plan on doing and will report on the results when finished.