Stefan's Tesla-Pages

'The famous cylinder static gap'

and some more thoughts on one of the most critical elements in a Tesla coil System

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Some remarks on spark gaps:

- cylinder static gap (text from Richard Quick)
- statement made by Richard Hull
- the series rotary gap
- how to compare different static spark gaps
- my gaps
- 'hot adjustable' flat gap (two ideas by Toni)
- 110kV-Ableiter (The AMRAD-principle)
- breakdown voltage for series gaps

For an excellent comparison between different types of spark gaps have a look at Ritchie Burnett's website: the synchronous and asynchronous rotary gap and the static gap. But be sure to return to this website!

This is a text from Richard Quick. I found it in the funet-archives. It describes the construction of the type of static gap Richard Quick developed based on a design by Richard Hull. I only converted the ASCII-text from the archive in an HTML-version. Until I made some more experiments with different spark gaps, I recommand building such a gap for the beginner.

This cylinder static gap was designed to quench 6-8 kv running up to 1 kva in more or less continuous duty. It **will quench** 6-8 kv **up to 2.5 kva intermittent**, depending of course on your run times, three minutes being quite tolerable. These gaps are very functional and can be easily moved from coil to coil. Complex gap systems can be built up using more than one unit. These systems can provide excellent power handling flexibility and efficiencies. *It is possible to tap the gap at the center electrode creating two equal and parallel paths within a single unit. Two gap units wired in this parallel configuration may be hooked in series for quenching up to 1.2 kva continuous, or 3 kva intermittent.* ***(* look at the remark below this text!)***

These gaps can also be employed with great effectiveness when used with a rotary gap. Units wired for parallel operation may be run in series with a rotary gap. Excellent quench times can be achieved at very low cost on medium powered Tesla coils in this fashion.

The copper pipe electrodes offer a large surface area to assist in quenching. The electrodes are cooled by an air stream which also removes hot ions from the gap during operation. The air stream is provided by a 5-1/4" muffin fan mounted on top of the gap unit. The gap is remarkably quiet, and the arc is shielded by the PVC pipe eliminating the UV hazard.

Construction of a gap unit requires the following parts:

- A five inch length of 6" PVC drain pipe
- 15" length of 1-1/2 inch hard copper water pipe
- One end cap for the 6" PVC drain pipe

One 5-1/4 inch, high CFM, muffin fan
- 14 1/4" Brass machine screws with nuts and washers
- 4 #6 Brass machine screws with nuts
- 3 feet of good quality lamp cord
- 18" of thick wall vinyl tubing
- Stiff epoxy

Cut the copper water pipe into seven two inch sections and polish the pieces. Drill two holes in a line 1" apart and 1/2" from the top and bottom of each section.

Drill two corresponding holes, larger than those drilled in the copper pipe, into the PVC drain pipe. The holes in the copper pipe should be snug for a 1/4" machine screw. The holes in the PVC pipe must be loose, allowing play to properly gap the electrodes. Do not drill all of the required holes into the PVC pipe at once, work with one electrode at a time.

Mount the first electrode. Two 1/4" brass machine screws are used with the screw heads inside of the copper pipe and the threaded ends extending outside. Install a washer and nut on the screws and tighten until snug but DO NOT OVER TIGHTEN. Measure out ~2-1/2 inches and drill two holes for the second electrode. After fitting you may find it necessary to file out the holes before you can get a parallel gap. Use a feeler gauge and adjust until you can set a gap of .028 inches with the nuts snug. It is important that the gap be equal and parallel up and down the entire 2" length of the copper electrodes.

When the gap can be set, remove the first two electrodes and smear a stiff epoxy on the back sides around the screws. Reinstall the electrodes and snug the washers and nuts down, adjusting as necessary for a parallel gap. It is important that the epoxy gushes out around the nut and washer. As the gap is run over time, heating and cooling will loosen the mounting nuts unless there is sufficient epoxy on the threads to permanently affix them. Make sure to wipe away the excess and thoroughly clean the screw threads above the nut. The screws serve as the terminal posts and if the threads are fouled with epoxy you will have to fight to get your connections on and off.

Proceed with drilling the next two holes and fit the next electrode. Gap as above. When you can achieve a perfect gap, remove the electrode and bed it with epoxy. Check your gaps carefully and frequently, once the epoxy sets you will never have to worry about them again!

After all seven electrodes are installed, place the gap unit under a heat lamp to speed the epoxy cure. Then assemble the blower unit.

Center the muffin fan on the PVC end cap and scribe a circle for the fan cutout. Cut the circle out and drill four holes for the muffin fan mounts. Mount the fan with the four #6 machine screws and nuts so the air flows from the bottom of the gap unit up.

Slide the lamp cord through the vinyl tubing and solder the ends of the wire to the muffin fan terminals. The vinyl tubing is important to provide some protection from the high voltage present on the exposed gap terminals, but do not rely on it. Route your 110 volt line away from all high voltage points with nylon wire ties and provide for line filtering when using the gap.

When the epoxy has set, mount the fan assembly on top, but do not glue it into place. The top is removable for easy cleaning between the electrodes with #600 or higher sandpaper wrapped on a shaved down tongue depressor. I build a wooden or plastic tripod base to set the gap unit on. The gap base should allow at least 3" of space below the gap unit for airflow, I allow 4 inches.

The gap as sketched shows the installation of an arc shield between the two end electrodes. This is important despite the fact that the gap here is quite large. With a piece of 3/8 inch plexiglass glued in this spot, gap units can be run together in series to quench higher voltage power supplies without the arc taking the shortcuts.

When run with neons at 12 kv rms, two gap units are used and all the electrodes are run in series. If higher voltage is used (up to 25 kv) gap units may be added in straight series connection providing your kva load does not exceed the individual gap unit rating for long run times. Allow 1000 volts per gap between electrodes (.028"). ***(From my experience you need nearly double that voltage for such a gap! At least if you smooth the edges with emory cloth)***

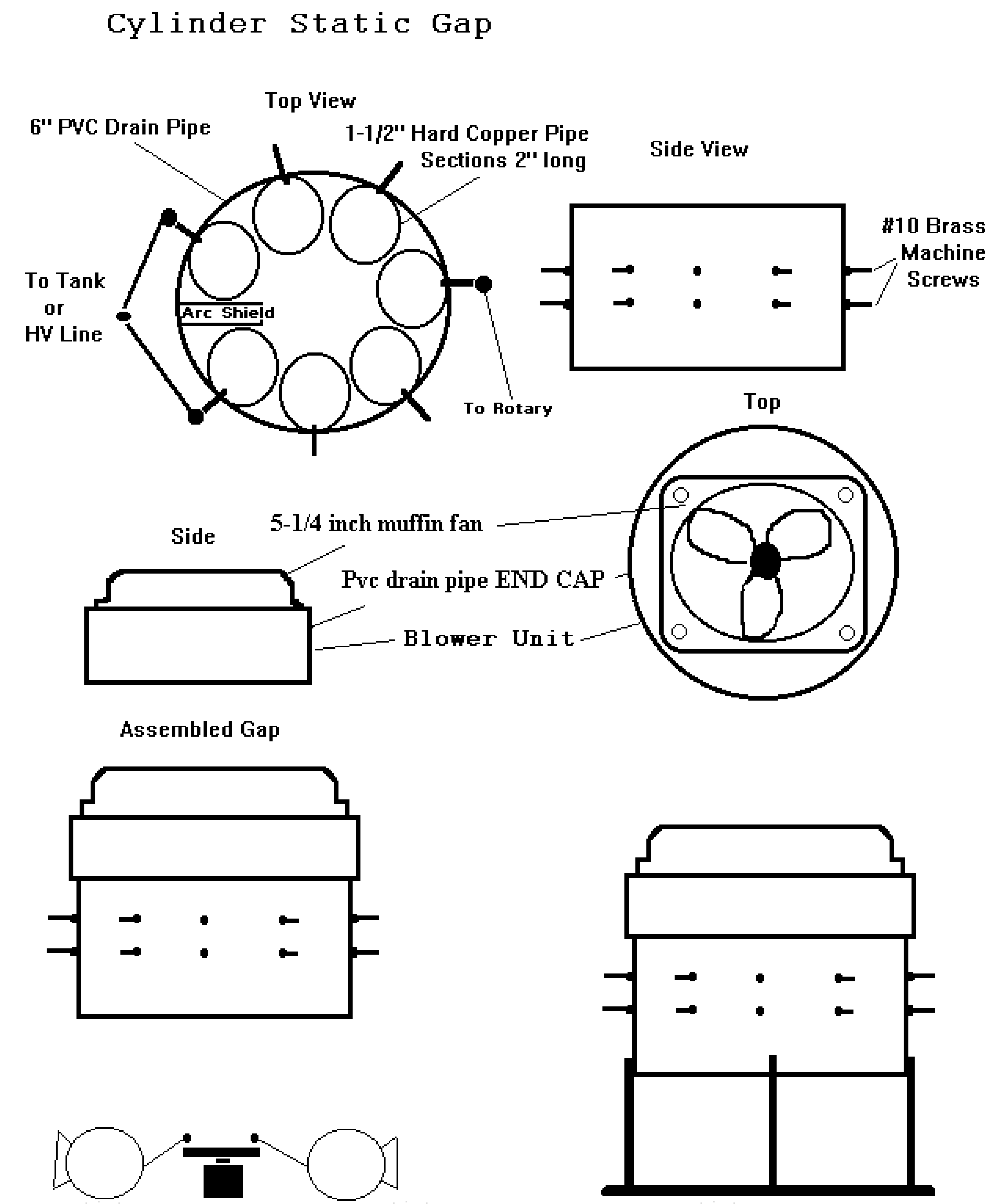
When more transformers are added to the coil, the capacitance is increased correspondingly, input voltage remains the same. Higher tank currents require that the primary arc be split into parallel paths ***(* look at the remark below this text!)*** to cool and quench. To meet this requirement additional gap units are added but all gaps are tapped at the center electrode and the two end electrodes are connected together with copper or aluminum strap. The second gap terminal is taken from this point. The gap is now wired for parallel operation, it will handle twice the current. A second unit is configured the same way and added in series with the first. The resultant gap system will handle twice the current at the same input voltage. For highest "Q" all connections should always be made using both available terminals from the tapped electrodes.

Quenching performance can be increased by mounting an air choke on the gap base. This will act to prevent air from passing up the center of the gap where it takes up little heat and fewer ions. I use a piece of 3" or smaller PVC pipe set on the gap base and passing up into the bottom of the gap just under the electrode ring. Of course, you have to put a lid on this smaller tube to block the airflow though it. This forces the air to pass through the electrodes and between the gaps to remove heat and ions and improves the run time. Performance may also be improved by fitting finned, cylindrical heat sinks, available at the electronics surplus or many hamfests, into the center of the copper electrodes. A little heat sink paste here is helpful to assist in heat removal from the electrode and preventing corrosion from the aluminum/copper contact. Oxides formed by contact corrosion are poor heat conductors. For maximum effectiveness the heat sinks should be cleaned of any coating at the contact points. Finned heat sinks installed in this fashion will dramatically increase the surface area of the electrodes. This is especially true in gaps of this design using larger copper pipe and bigger gap rings.

When running these gap units as part of a system with a rotary, all gap adjustments are still made on the stationary electrodes of the rotary gap. Insert one .028" static gap (distance between each electrode in this unit) in series for every 2000 volts of line input to the coil, then set the rotary gap adjustment so that the coil system fires smoothly and reliably. Suppose your rotary system has a 12 kv line input: every electrode on the cylinder static gap unit is gapped at .028", and you need a total of 6 of these static gaps in series with the rotary for the system to function properly at 12000 volts. There is no limit to the number of parallel paths that can be theoretically used, but two is the practical limit with this design. Two cylinder static gaps hooked up for parallel operation, and run in series with the rotary will provide excellent quenching up to 2 kva continuous, 3.6 kva intermittent. Your rotary will require a much smaller gap, and your quench time will have dropped considerably. Your rotary will run cooler, your run times will be longer, and your secondary spark will be better.

Another benefit of gap systems with a rotary is that the wear caused by the hot arc is distributed among many gaps with a large surface area. The arc at the rotary is both cooler and shorter in duration, taking stress off of the stationary electrodes and reducing wear at these critical points.

Gaps of this design using 1" diameter copper pipe can be constructed as above to get 12 gaps into a cylinder ring of 13 electrodes. The 1" diameter pipe sections do not sink as much heat, but if gapped at .028 -.030 inches a single unit will quench up to 15 kv rms from neon sign transformers banked up to 1.5 kva intermittent. If the unit is constructed from 1" dia. pipe and the electrodes are gapped at .056 -.06 the arc can be split down two parallel paths (center electrode tapped) for a good quench time with a neon power supply of 12 kv rms in the 1.5 kva power range, this is of course intermittent operation but will use only one gap unit. Using the flaired end of 6" pvc drain pipe will give enough room to squeeze in all of the required electrodes and the arc shield, but the result is the fan must be custom mounted, and may have to be glued into place.



static gap 1 rotary gap static gap 2
(2 parallel paths) (2 parallel paths)

Remark: Richard Quick wrote once in the text above: 'Higher tank currents require that the primary arc be split into parallel paths'. Here is snipplet from a mail of Steve Young:

Every now and then, the idea of putting spark gaps in parallel to share the high currents is proposed on this list. It seems to me in general this won't work. I think that no matter how many gaps are directly paralleled, one gap will always fire slightly before the other(s). Once this happens, the firing gap's impedance drops far below the others, the voltage therefore also immediately drops, and the other(s) will probably not fire at all. Thus only one of the paralleled

gaps will take the full current and punishment. On succeeding bangs, this one is likely to again fire first because of residual metal ions, higher temp, etc.
An analogy would be paralleled neon bulbs, with just one current limiting resistor for the two or more paralleled bulbs. I think the probability of more than one of the neon bulbs lighting is very small.
I have no practical experience with paralleled spark gaps, so I encourage other list member's wisdom for this subject.
--Steve

From my experience with paralleled spark gaps (mostly flat type) I would say that you need to match them VERY carefully to get ocasionally firing in the slightly wider gap string. This helps to cool down the other branch and the total arrangement will run a bit cooler (one branch will always run hotter than the other). Therefore I prefer longer pipes with a bigger diameter instead multiple paralleled gaps now. And not to forget a fan which blows THROUGH the gaps (not along them as Richard suggested).

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Another statement:

Richard Hull, TCBOR: "Static gaps will work great out to 5,000 watts if the builder has the experience to apply them." (posted on the TCML, 4'98)

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Good cooling will be achived with a '**series rotary gap**' a la Richard Hull (described in his 'guide to the CSN'). Such a rotary gap will have more than one set of stationary electrodes. When the gap fires, all arcs will be in series. Such a gap was also used by Greg Leyh in his BIG Electrum project.One of the advantages is the reduced thermal stress on the stationary electrodes. Newer investigations showed that it is better to use fewer gaps in series which leads to a decreased arc resistance. This will work with two gaps in an SRSG. In ASRSGs it will be a good idea to raise the minimm firing voltage with the use of a static gap in SERIES to the ASRSG.

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When somebody tries to **compare the performance of different static spark gaps**, he should be aware that each spark gap has to be set to the same breakdown voltage.This is VERY essential, because it will determine the 'energy per bang' - the energy which is stored in the tank cap before the spark gap breaks down. YOU CAN ONLY COMPARE THE GAPS WHEN THE INPUT ENERGY IS THE SAME! So the first thing to do is to hook up a cap and a HV/DC-supply to the gap. The input current has to be adjusted (via R1, R1') so that the loading time (time between each breakdown of the spark gap) is about 1 minute. This way you can monitor the voltage with a standard multimeter (of course with an HV-probe attached). To prevent damage to sensitive equipment, you should insert another big resistor (R2) in series to the spark gap for limiting the discharge current to a save value (low EMI).

```
Here is a small ASCII diagram of the circuit:

                     ______                ____
   o---|>---XXXXX---|______|--- - - --+---|____|---+--------+
     diode  choke           R1        |        R2  |        |
                                      |            o        | voltmeter
                                     ===           o test   O with
HV supply                             |C           o gap    | HV probe
            choke    ______ R1'       |            |        |
   o--------XXXXX---|______|--- - - --+------------+--------+

          charging circuit            test tank circuit
```

The gaps you want to compare with each other should then be set to the same breakdown voltage verified with the circuit above (or a similar one). MEASURING ONLY THE DISTANCE BETWEEN THE ELECTRODES WILL LEAD TO A BIG FAILURE IN BREAKDOWN VOLTAGE because of different electrode shapes, wear, non-parallelity of the electrodes and other factors.

Once all the spark gaps you want to compare are set to the same breakdown voltage, you can insert one after each other in your Tesla coil system and tune (tapping the primary coil) for maximum discharge. Then repeat with all the other spark gaps and check which one gives the best performance.

One last hint: you can't compare an internal spark gap (totally integrated in a sophisticated Tesla coil system with optimized wire lengths) to an external gap! An external gap will usually be connected with longer wires during testing. This will lead to more off-axis inductance in the primary circuit (unused inductance, more losses). So you should dismount the internal gap and connect it with the same wires during the testing as the other external gaps.

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Here is a list of the **gaps I have** (or plan to build) and I'll compare in the future:

- Vitamini gap (the oldest one, consisting of 7 gaps made out of 8 heavy steel rings (modified set collars) on a wooden rod), set to 9kVAC
- 2"-system gap (flat, 6 pieces of 22mm x 5cm copper pipes lying next to each other in a distance of approx. ***0.5mm***, total gap width for 10kV$_{eff}$ supply is therefore about *2.5mm*)
- 4"-system gap ('RQ cylinder static gap' with fan, 22mm x 10cm copper pipes spaced approx. ***0.7mm*** in a 4" PPS drain pipe, I use a series/parallel combination of 2 times 4 gaps in series for a total gap with of around *2.8mm* for 8kV$_{eff}$ supply) should bridge every second gap with wire for better cooling
- new gap for vitamini: about 10 pieces of 15mm x 3cm pipe, flat, spacing **0.63mm (ceramic spacer)**, planned, design data for 10kV$_{eff}$ with 20% safety margin and one adjustable gap (to compensate corrosion)
- folded flat gap with lots (up to 28) of 15mm x 6cm pipes spaced **0.11mm** (like the one described on Terry Fritz' website, planned, design data for 10kV$_{eff}$ with 30% safety margin)
- two-gap spark gap (3 pipes, 22mm x 15cm each, adjustable, planned)
- optimized vacuum gap (35mm pipe, planned) for my high power 8" Tesla coil system (perhaps used in series with a rotary gap)
- 'hot adjustable' flat gap (V2 made like Toni, a fellow coiler, suggested), see below for a detailed description

It will be a good idea to add one adjustable gap to the series gap. This way you can set the breakdown voltage in steps ('rough tuning') of one gap and you'll also have the possibility for 'fine tuning' (to compensate corrosion).

It seems as if a high number of individual gaps results in excellent quenching. Some experienced coilers say that in the low power range 2 gaps are enough. If the gap between two pipes is to small, corrosion will make it even more narrow over the time and therfore decrease the breakdown voltage by a significant amount. As said in the comment to Richard Hulle series rotary gap, fewer gaps result in less resistance and this will (over-)compensate quenching at a later notch

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'hot adjustable' flat gap, V.1

ASCII-scheme of the gap (basic idea by Toni, additional features by STK):

```
               safety gap (max. voltage)
  +~~~~~~~~~~~~~~O     O~~~~~~~~~~~~~~~~~~~~~~~~~+
  |                                              |
  |    variable gap   fixed gap (min. voltage)   |
  |      1 2 3 4 5     A  B  C                   |
o~+~~~~~~O*O*O*O*O~~~~~O**O**O~~~~~~~~~~~~~~~~~~~+~~o
    _____|_|_|_|_|_____|__|__|__
    XX       |       XXXXXXXXXXX   ( * = spark )
    XX       M       XXXXXXXXXXX
    XXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Most of the electrodes (O1 to O5) are mounted on a flexible part of the cover (-) of the rigid box (X). Inside the box, a remote controlled mechanism (M) is used to bend the cover of the box outwards. Therefore, these (initially touching) electrodes can be moved apart, rising the breakdown voltage. When buildt with the proper materials and parts, this can be done while the coil is running. On the other side of the arrangement, some fixed gaps (OA, OB, OC) are connected via a short piece of wire (~) to the adjustable gaps. This arrangement defines a minimum breakdown voltage. Always use a properly spaced safety gap across this type of gap, otherwise some of your components could die by overvolting them.

'hot adjustable' flat gap, V.2 (basic idea again by Toni)

Toni wrote on the GTL that he thought of making a new gap out of aluminium angles screwed to pieces of PVC. The end of the PVC strips are screwed (twistable) to strips of wood (or any other material). If the two long strips of wood are moved against each other, the distance between the electroden on the PVC strips will decrease. A motorized version is poosible also.

ASCII-scheme of the gap:

```
                 safety gap (max. voltage)
   +~~~~~~~~~~~~~~~O     O~~~~~~~~~~~~~~~~~~~~~~~~~+
   |                                               |
   |   variable gap    fixed gap (min. voltage)    |
   |      .-.-.-.-.- ->  A  B  C                   |
 o~+~~~~~~|*|*|*|*|~~~~~~O**O**O~~~~~~~~~~~~~~~~~~~+~~o
          '-'-'-'-'- <-
                     'twist'        ( * = spark )

 So you can achieve any desired setting between these two extremes:

     ~~~~/*/*/*/*/~~~~~~~~  gap closed
         '-'-'-'-'-

          .-.-.-.-.-
     ~~~~~|*|*|*|*|~~~~~~~ gap wide open
          '-'-'-'-'-

 The safety gap is not necessary if the number and spacing of the
 gaps is set to the maximum allowed voltage.
```

Things you can do with this gap:
It can be used to adjust the input power to the Tesla coil from min. to max. like using a variac. But you can start at lower energies, allowing a smoother start than possible with a variac and a fixed gap (of course, a similar behaviour can be achieved with a 'series rotary gap' adjusting the BPS).

BUT - this only will work if the toroid allows breakout at such low power levels! Any ideas about a 'hot adjustable bump' (like a remote controlled needle) for a toroid??
Achims idea: a servo controlled flexible rod (perhaps guided inside a flexible tube) with a metallic top, the drive located at the lower end of the coil (gnd potential) and the rod going through the coil up inside the toroid.
I (STK) thought of doing this with a pneumatic driven cylinder (smaller bending radius possible). A high tech version of a variable bump will be a servo driven needle, remote controlled via IR or glass fiber (but this will be a bit 'overengeneered', I think).

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AMRAD spark gap principle still used in modern powerline equipment:

The "110kV-Ableiter" (overvoltage protection)

In December 2000 there was a thread about the AMRAD spark gap on the TCML. On 27.04.99, a fellow coiler and I had the chance to get our hands on some "modern" (about 30 years old) powerline equipment. We actually could dismantle parts of a switching station which means some nice insulators and such things. In a barrel we found parts of a broken overvoltage protection device. It was buildt like the described AMRAD spark gap!

Ok, let me describe what we have found: The thing was housed in a ceramic insulator and looked EXACTLY like a very standard insulator. The only difference was inside: there were some ceramic hockey puck shaped disks, perhaps something like a VDR (=MOV) or such thing at the lower end. In series to them there were LOTS of small copper plates with insulating spacers inbetween. They were placed in a tube of something like pertinax or plastic (see photograph#1) to hold them in place. The insulating spacers were something like oil paper (waxy kraft paper). There was only one kind of copper plate which was placed alternating flipped upside down:

The copper plates looked like this (view from the side):

```
Fig. A:
  )
 (    3
 _)   2
(_    1
  )   2
 (    3
  )
```

The numbers represent the possible circular "arcing surfaces" as depicted in photograph#2 above.

There were two kinds of spacers | between the copper plates (), one had a bigger inner diameter than the other. To make things clearer, I added the sparks * between the areas#1 and areas#2 in the next picture:

```
Fig. B:
     )|(  |  )|(  |  )|(  |  )|(
    (   ) | (   ) | (   ) | (   )
    _)*(_   _)*(_   _)*(_   _)*(_
~~~(_   _)*(_   _)*(_   _)*(_   _)~~~
     )*(     )*(     )*(     )*(
    (   ) | (   ) | (   ) | (   )
     )|(  |  )|(  |  )|(  |  )|(
```

As said, the whole thing was housed in the big ceramic insulator and therefore airtight as the described AMRAD spark gap! The ones we found were in service for 30years and we couldn't see any big sign of wear besides a very little buildup of black copperoxide on some of the copper plates in the arcing area. Obviously the principle behind the AMRAD spark gap is working perfectly.

Of course, the purpose of this whole setup was overvoltage protection which means the gap will fire only once in a while without significant heat buildup. To use the copper plates (yes, I took some of them with me! ;-)) in a TC, one has to find a way to let the gap run cool, at least not too hot. The first thing to consider is the spacer because of its organic nature. I plan to replace them by thin ceramic plates for higher temperature stability and smear some silicon on the outside to make it airtight. I'll place a thin (0.38-0.63mm) ceramic plate after every second copper plate in the middle of the plate. It will look like this:

```
Fig. C:
     )(     )(     )(     )(
    (  )***(  )***(  )***(  )
    _)(_ | _)(_ | _)(_ | _)(_
~~~(_  _)|(_  _)|(_  _)|(_  _)~~~
     )(  |  )(  |  )(  |  )(
    (  )***(  )***(  )***(  )
     )(     )(     )(     )(
```

Originally, every plate acted as two electrodes (one spark at each side, see Fig.B), so I doubled the mass here. The big disadvantage is that one can't smear silicon on the outside without smearing it into the arc path! Please compare Fig.B and Fig.C, you will see that in my configuration the arcing will take place more on the outer side of the plate (area#3), resulting in a wider surface on which the arc will play. This should help to quench the arc because it could run a bit cooler (at least before the whole thing is very hot...).

First results with 9.54kV_{AC} (at 200W) and simple gap design as depicted in fig. C (only stacked, not glued or clamped):

Test #1 (small gap distance):

a) Spacer on the inner and outer face: 8*380µm+15*254µm, measured value 7.15mm, this works out to 1.334 $^{kV}/_{mm}$.

b) Spacer only on the inner face: 9*254µm gaps, measured value 2.5mm.
So we have an offset of (7.15mm-2.5mm)/9=0.517mm between the inner and the outer face (rim?) of one gap or with other words the inner surface is 0.258mm above the outer rim.

Test #2 (Verification with higher gap distance):

thickness of the ceramics 630µm: 6 gaps needed = 3.78mm+6*0.517mm=6.88mm, this works out to 1.386 $^{kVAC}/_{mm}$

which is pretty close to the value above.

All in all, this works out to approx. **1.36 $^{kV}/_{mm}$** for this type (read geometry) of gap.

Theses results are NOT conform to those of Terry Fritz's achieved with the copper pipe flat gap mentioned above (he found approx. 4.6 $^{kV}/_{mm}$). *A possible explanation could be that his gap distance was not even over the width of the gaps and some narrow spots (nonparallelity of the individual copper pipes) changed the result towards a higher voltage than really would be needed.*

I used two different thicknesses of the ceramics and got the following working designs:

thickness of the ceramic spacer	**# of gaps**	**individual gap width**	total gap width	applied voltage (rms)
254µm	**9**	.254+.517 = **0.77mm**	6.94mm	9.54kV
630µm	**6**	.630+.517 = **1.15mm**	6.88mm	9.54kV

Without the airtight sealing, the gap oxidized quickly in this test because it got very hot (the copper plates only have 2.5 inches diameter). So I tried to find some better arrangements.

Obviously, the ceramic spacers have to be placed on the outside so that the arcing is more centered. This will allow a sealing of the individual pairs of electrodes without affecting the arc path:

```
Fig. D:
     )|(     )|(     )|(     )|(
    (   )   (   )   (   )   (   )
    _)*(_   _)*(_   _)*(_   _)*(_
~~~(_   _)(_   _)(_   _)(_   _)~~~
     )*(     )*(     )*(     )*(
    (   )   (   )   (   )   (   )
     )|(     )|(     )|(     )|(
```

Now we can arrange the pairs of plates with e.g. springs (conductive, of course!) between them for improved cooling:

```
Fig. E:
     )|(       )|(       )|(       )|(
    (   )/\/\/(   )/\/\/(   )/\/\/(   )
    _)*(_     _)*(_     _)*(_     _)*(_
~~~(_   _)   (_   _)   (_   _)   (_   _)~~~
     )*(       )*(       )*(       )*(
    (   )/\/\/(   )/\/\/(   )/\/\/(   )
     )|(       )|(       )|(       )|(
```

If we place this whole setup in the pertinax tubing where it was located originally, we only have to make some slits into the sides and blow some air for cooling through them.

Still have to try this but I thought I tell you my thoughts here after I've read about the original AMRAD gap...

Let's compare the measured breakdown field strength with other values I found in the web:

In Jim Lux' HV-book it is written:
Paschen's Law (for a single gap!)
... For air, and gaps on the order of a millimeter, the breakdown is roughly a linear function of the gap length: V = 30pd + 1.35 kV, where d is in centimeters, and p is in atmospheres. If we compare this with my geometry (total gap width 7.15mm), I should have needed a voltage of V=30kV/(cm*atm)*1atm*0.715cm+1.35kV = 22.8kV !!! With other words the field strength should have been 22.8kV/7.15mm = 3.2kV/mm.

In the old archive files concerning the cylinder static gap, Richard Quick wrote: "*Allow 1000 volts per gap between electrodes (.028")*". With other words he suggested 1.41 kV/mm.

Finn wrote on the GTL: *Mit 28 Teilfunkenstrecken, jede 0,6 mm lang= 16.8 mm Funkenstrecke, Durchbruch bei ungefähr 20000 V. 20000/16,8=1190 V/mm Ich habe nicht Vsec. gemessen, aber nur Position des Variac ungefähr auf*

400 Vout. angeschaut, deshalb glaube ich, das es auf 10% genau ist.

Summary:

Finn	1.19 kV/mm (voltage not directly measured)	28 gaps
STK:	1.36 kV/mm (voltage and distance measured)	6-23 gaps
RQ:	1.41 kV/mm *(suggested)*	5-10 gaps
Paschen:	*3.2 kV/mm (formula for ONE gap)*	*1 gap only*
TF (see next paragraph):	3.48 kV /mm (voltage directly measured) 4.2 kV/mm (voltage directly measured) 5 kV/mm (voltage directly measured)	2 gaps 16 gaps ('TF-gap') 4 gaps

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breakdown voltage (measurements done by Terry Fritz)**:**

- 2 gaps spaced ~0.040 inches apart, the primary firing voltage (peak) is approximately 5000 volts (from his paper 'A Comparison Study of Multi-Gap and Static Tesla Coil Spark Gaps with Various Primary to Secondary Coupling Coefficients', sgap.htm on his website). Transferring this into rms-values leads us to $4.9kV_{peak}$/mm = **$3.48kV_{eff}$ /mm** .
- 0.028" = 0.71mm total = 5kV (peak voltage!) for 4 gaps of $^1/_2$" x 2" copper pipe => 7kV/mm (peak voltage!) (from his paper 'A Comparison Study of Multi-Gap and Static Tesla Coil Spark Gaps with Various Primary to Secondary Coupling Coefficients', sgap.htm on his website). Transferring this into rms-values leads us to $7kV_{peak}$/mm = **$5kV_{eff}$ /mm** .
- 0.004" = 0.10mm each = 0.59kV per gap (peak voltage!) for 16 gaps of $^1/_2$" x 2" copper pipe => 5.9kV/mm (peak voltage!) (from his image describing the 'Terry Fritz Gap' with up to 30 series gaps). Transferring this into rms-values leads us to $5.9kV_{peak}$/mm = **$4.2kV_{eff}$ /mm** .

The voltage was measured with an O'scope, but I think there is a great amount of failure in measuring the distances as the paper he used to set the distance is somewhat compressible.

From Terry's results, it seems that it is better to use lots of gaps with small spacing. The disadvantage here is corrosion on the copper pipes which will reduce the spacing over time and therefore will lead to a decreased breakdown voltage (and spark length). So there will be a compromise in using not too small gaps. Or you can simply lay the pipe sections in kind of grooves in a rigid base. So you can rotate them after a while or take them out for cleaning (Bert Pool did this with his BIG 2" dia copper pipe gap).

A description of selfmade HV-probe can be found here: http://fribble.cie.rpi.edu/~repairfaq/REPAIR/F_hvprobe.html (link not tested up to now!)

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