THE LEAKAGE CURRENT INDUCED BY STRAY CAPACITANCE IN THE PULSE MAGNET SYSTEM

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Abstract

A huge amount of current must be provided during the nominal operation of the pulse magnet system in TPS (Taiwan Photon Source).It comes with all kinds of electromagnetic noises, including radiated and conducted EMI (electromagnetic interferences). The EM interferences will affect the sophisticated electronic equipments near the pulse magnets. Therefore, how to design the supporting and enclosure of the pulse magnet becomes a very far reaching issue.

The primary object of this article is to clarify the paths of conducted EMI, especially resulted from capacitance induction. Furthermore, some geometrical suggestions which had been tested are listed in this paper as the guidelines of the pulse magnet design. According to the measurement, proper distance and surface area lead to sufficient insulation and reduce the leakage current under the expected value.

INTRODUCTION

According to the basic electric principle, the Ohm's law states the behaviour of the current through two points of a conductor is directly proportional to the voltage difference across them. In case of AC circuit, the form of the current-voltage relationship is generally represented to the equation:

$$I = \frac{V}{Z}$$

In this equation, I and V stand for the root-mean-square value or the effective value of current and voltage respectively. The symbol Z stands for the impedance in AC circuit instead of R in DC case. In AC circuit, impedance is resulted from capacitance and inductance, which can be shown as the equations:

$$Z_C = \frac{1}{2\pi f C} \qquad (eq.\ 1)$$

and

$$Z_L = 2\pi f L$$

Therefore, once undesired capacitances or inductances exist, the total current in AC circuits must be reconsidered. Moreover, there are many possible paths in electronics circuit to induce capacitances. It takes lots of effort to calculate the total capacitance, including all stray capacitances, precisely

In this article, a set of kicker magnet used in booster injection section of TPS (Taiwan Photon Source) had been measured its operation current. The booster kicker operates with more than 200A current and 10kV voltage [1] (Refer to Table 1.). Because of this extreme condition, the kicker becomes an obvious source of electric noise. Some electronic devices or delicate measuring equipments lost effectiveness during the kicker fires.

Table 1: Parameters for Booster Injection Kicker and Septum of TPS

Booster Injection	Kicker	Septum
Repetition rate	3Hz	3 Hz
Electron energy (GeV)	0.15	0.15
Bend angle (mrad)	16 [30]	209.44 [314]
Length (m)	0.5	0.8
Nominal field (T)	0.016 [0.03]	0.131 [0.196]
Nominal current (A)	267 [501]	2292 [3436]
Pulse shape	Flat top	half sine
Fall time (ns) 95%-5%	<350	--
Pulse duration (µs)	1000ns-FT	300
Impedance (Ohm)	25	0.02
Inductance (µH)	1.62	1.95
Capacitance (µF)	--	4676
Drive voltage (kV)	13.4 [25.1]	0.047 [0.070]

EXPERIMENTAL METHODS AND APPARATUS
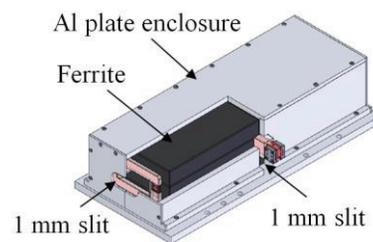
Figure 1 shows the scheme of booster kicker in TPS.

Figure 1: Booster kicker 3D drawing.

The huge amount of current passes through the cooper coil which is encircled by ferrite and aluminium enclosure. The aluminium enclosure is system grounding. Between the coil and the ferrite, there are at least eight pieces of ceramic holders as insulations. Despite of several layers of materials cover the coil, the stray capacitance exists between the coil and the enclosure. It is found that the total capacitance of the kicker is nearly 0.44nF, which leads a leakage current about 1.7 mA under 10kV.

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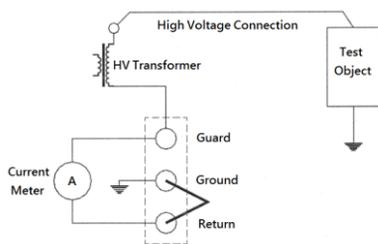
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Figure 2: AC withstand voltage test setup.

In this article, an AC withstand voltage test is proceeded and its set up is as shown in Fig. 2. The AC dielectric test sets are Model 6CP100/50-7.5 from the Phenix technologies. This portable AC high voltage test equipment is suited for use in field or in the laboratory. Its voltage output ranges from 0~50kV and 0~100kV depending on the selection of output port. The kicker system, test object in this test, is applied with an AC high voltage about 10 ~ 25kV. Total current including all stray current will be collected by the current meter. The AC current will find paths to ground as long as the impedance exists. From the leakage current read by current meter, the total capacitance can be acquired by eq. 1. The most proper arrangement will lead to the smallest stray capacitance which means the less leakage current.

In order to figure out the ratio of the leakage current comes from the edges to the parallel section. The supporting material for kicker has been changed to estimating the amount of current. (Refer to Fig. 3) There are three kinds of arrangement to verify this factor. First, the ferrites are placed on a grounding plate with three ceramic bricks in the interval. And then, these ceramic bricks are replaced with TiO_2 bricks, supposing the capacitance would change with the different dielectric constant. Thirdly, the covering area of ceramic bricks had been adjusted to simulate several cases with different dielectric constants. Finally, the supporting structure of coil had been replaced its material from ceramic to MACOR, a kind of machineable glass-ceramic. Same as above, it is supposed the leakage current should be different by altering the dielectric constant of supporting media.

Figure 3: Supporting structures of kicker.

EXPERIMENTAL RESULTS

The impedance distribution of a kicker is shown as Fig. 3. It is found that the impedances at two edges are bigger than in middle section. That means most leakage current passes through the parallel section even the insulators are placed to isolate the coil and the ferrite. Theoretically, there is not any material has smaller dielectric constant

than vacuity. For this reason, the less stuff filling between coil and ferrite, the less leakage current could flow out through stray capacitances from kicker system. The coil is applied with a 20kV high voltage and the leakage current is collected by a grounding terminal clamping on the metal supporting plate. It is shown that the impedance outside the ferrite is about 100MΩ, and nearly 60MΩ in the middle section. The dielectric constant of ferrite or ceramic is roughly ten times bigger than air. The contact area of coil and ceramic supporting must be designed as small as possible. The total contact area is 75cm^2 in the prototype of kicker system. The latest design will take this problem into consideration and it will be minimized to limitation. Hopefully reduces the leakage current through middle section.
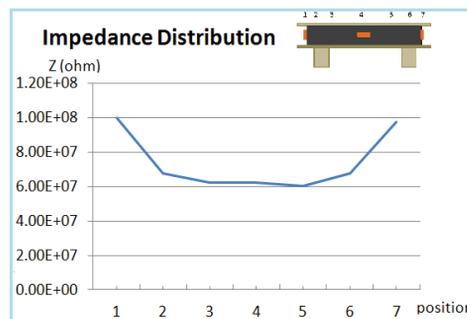

Figure 4: Impedance distribution of kicker.

Although the size of ceramic backplane could affect the total leakage current, the magnitude of total capacitance did not change dramatically with the size of ceramic backplane (see Fig. 5). In this chart, all coverage means the kicker is placed on a big sheet of ceramics assembling by several ceramic bricks. The result of smallest ceramics area is described by 7A series points. Even the ceramic area became 6 times bigger, the capacitance increased to merely 1.5 times more. Similarly, replacing the coil stand from ceramic to MACOR did not affect the total capacitance obviously. The total capacitance was slightly increased from 67pF to 71pF even the stands are machining carefully.
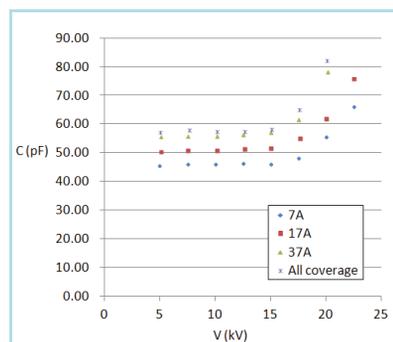

Figure 5: Relationship between backplane area and total capacitance.

In order to clarify if there is anything to do to reduce the stray capacitance, a set of TiO_2 bricks was used to replace the ceramic backplanes. The dielectric constant of TiO_2 is nearly 88. It is 10 times more than ceramic. The TiO_2 bricks were sintered in the same size with the ceramic bricks. Comparing these two cases, the difference of capacitances between them is less than 2pF. It means the effect of stand made out of different material can be ignored if the stand area is already limited to a small value. The capacitance value cannot be smaller without any major modification on the structure of kicker.

Since the original structure cannot attain a satisfying capacitance value. Some reforms on structure are needed. Area of dielectric materials and distance between two conductors are the most critical variables in geometry. Therefore, the distance between kicker backplane and ground has been increased to get more capacitance (see Fig. 6).

Figure 6: Increasing the distance between backplane and ground.

Since the interval between the backplane and the ground increases, the endurance voltage becomes bigger as well. The applied voltage can reach the maximum value 40kV without arcing if the ceramic columns are 4 cm in height (see Fig.7). It is obvious that the arc starts from the edge of coil, hits the backplane and finally ends to the ground. In former tests, the applied voltage was always less than 30kV before arcing.
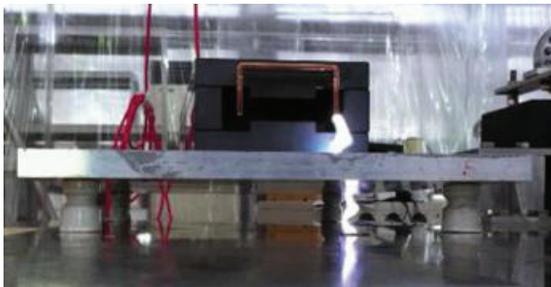

Figure 7: Arcing when a 40kV voltage applied.

Because of the normal operation voltage of kicker system is around 15kV, it is necessary to make sure that whole system can work regularly without any malfunction at least 25kV. For this reason, the minimum distance between backplane and ground must be more than 4 cm. It is better using ceramics as the material of supporting

structures. Since the structure has been built, the capacitance value is decided too.

CONCLUSIONS

In this article, some different cases have been done to verify if the capacitance value of the kicker will affect the leakage current or not. According to this paper, the arcs will appear between high voltage end and ground once the applied voltage exceeds 25kV. As long as the distance between backplane and ground increases up to 4 cm, the endurance voltage will also increase to 40kV.

Besides, the capacitance is fixed once the size of ferrite and coil is decided. Replacing with different materials does not improve the leakage current obviously.

REFERENCES

[1] Y.-H. Liu et. al., "TPS SR Kicker Prototype Installation Status.", IPAC11, 2011.