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DC TESTING AND PHASE RESOLVED PARTIAL DISCHARGE MEASUREMENTS OF THE NEW TRIGGER TRANSFORMERS FOR THE LHC BEAM DUMP KICKERS

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Abstract

During LS2, the LHC beam dump kicker pulse generators will be subject to a substantial consolidation program. One major part is the replacement of the existing GTO stack trigger transformer by a new more performant one. The transformer is assembled, moulded, and tested in-house. Part of the validation procedure are standard DC tests and subsequent discharge monitoring as well as newly introduced phase resolved partial discharge measurements. This paper briefly highlights the trigger transformer parameters and construction and outlines in detail the testing and partial discharge measurements. It concludes with a comparison and analysis of the results of the different measurement techniques.

INTRODUCTION

The LHC Beam Dump System (LBDS) [1] is one of the most critical systems for reliable and safe operation of the complete LHC. For each beam, it comprises 15 fast extraction kicker systems (MKD), 15 magnetic septa (MSD), 10 dilution kicker systems (MKB) a dump block (TDE), beam loss absorbers in front of the septa (TCDS) and the quadrupole Q4 (TCDQ). The fail-safe design must ensure correct LBDS performance also for abnormal operation such as asynchronous beam dumps or failing dilution. A crucial point for safe operation of the kicker systems are the MKD pulse generators. For reliability reasons, those have been based on semiconductor switches of the GTO thyristor type instead of usually used thyratron switches. Triggering those switches, each comprising 10 stacked GTOs, is a critical process hence special efforts have been made to ensure reliable triggering. Therefore, not only has a double branch architecture with two parallel GTO switch stacks been chosen for the MKD generators, the required trigger transformer itself has also been designed and assembled in-house to fully match the GTO trigger requirements for best triggering performance. The design was driven by optimization for a low stray inductance and high dI/dt capability [2]. One primary winding consisting of the inner stalk and is closing via the outer housing. It feeds 10 single turn secondary windings made out of two aluminium half shells each loaded with a nano-crystaline magnetic core. This assembly is then moulded with silicone for dielectric insulation purposes. In order to guarantee the reliability of the complete series of 80 trigger transformers intensive testing is needed and an improved process to assess the insulation quality has been introduced and is outlined in this paper. It needs to be highlighted that any unwanted electrical discharge in the trigger transformer can couple into the GTO stack and even if only present on one secondary, respectively one GTO, can lead to an erratic firing of the switch and subsequently leading to an asynchronous beam dump with all its potential consequences [3].

TRIGGER TRANSFORMER TESTING

General Test Procedure

After the mechanical assembly and before the moulding each transformer (Fig.1) is pulse tested. For these tests a small pulse generator has been constructed which allows to easily apply fast pulses with 1.8 kA amplitude to the transformer windings to identify any assembly issues. After moulding, the trigger transformer is DC high voltage tested. For the HV tests, all 10 secondary windings are voltage graded by resistors creating equivalent conditions as in the final installation. Eventual sparking activity is monitored and captured. In case of suspicious behaviour close to the decision criterion additional HV 50 Hz AC tests have been proposed.

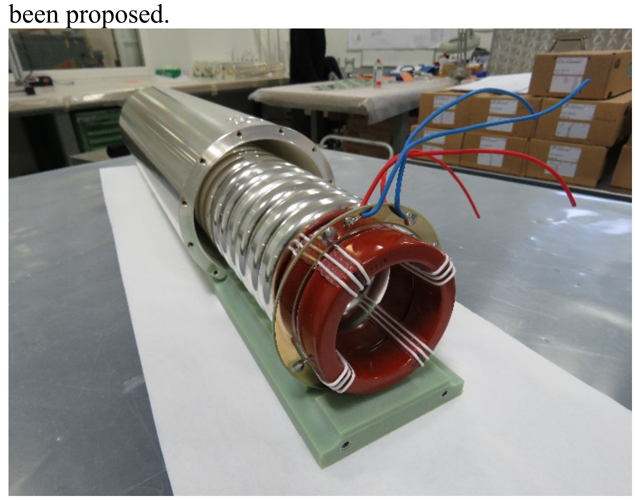

Figure 1: Trigger transformer partially out of housing and before moulding.

MEASUREMENTS AND RESULTS

Transformer Secondary Pulse Test

After the mechanical assembly and before the moulding the primary winding is connected to a 1.8 kA pulse generator and the output current on each of the 10 transformer secondaries is measured. This early testing stage ensures that the polarity for each winding is right, no short circuit exists and also good contact along the circuits is verified right before the irreversible moulding process. Approx. one out of 25 units has been found to be corrected showing the

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good quality of the assembly work but also the usefulness of the pre-moulding test.

DC Sparking Test

After the moulding the trigger transformer is placed in an HV test box to undergo a 48 h DC sparking test. For this test 27 kV is continuously applied, representing a situation and voltage level equivalent to the normal operating conditions in the generator. The high voltage is supplied by a standard HV power supply with low ripple and any sparking is monitored by a standard oscilloscope via a current transformer in the supply leads. Figure 2 shows an exemplary screenshot for an electrical discharge as seen during the sparking tests. The test criterion is that only two sparks in 24 h are allowed. The number of sparks and their magnitude is used to assess the transformer quality. Bad moulding processes or pollution during assembly can result in several hundred sparks per hour up to complete breakdown.

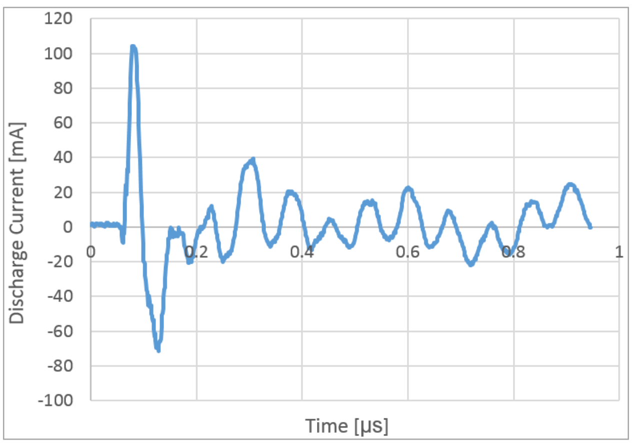

Figure 2: High spark signal monitored with Oscilloscope during DC sparking tests.

Depending on the discharge amplitude and the spark count over 48 h the transformers can be directly validated and installed in the generators or must undergo an additional 50 Hz AC partial discharge measurement to be able to trace the origin of smaller discharges. In total only one transformer failed the DC-test and in average three out of 25 showed increased sparking activities and were subsequently PD tested.

50 Hz AC Partial Discharge Test

The 50 Hz sinusoidal high voltage is generated by a standard PD free supply. The partial discharges are recorded by a sensitive current transformer and an oscilloscope. The oscilloscope is controlled by its development kit, to quickly pre-process the data inside the oscilloscope. The read out, plotting and analysis is done with Python. This low cost setup was already used to test coaxial cables [4], [5] and since has been slightly improved.

Table 1 shows the measurement results of a pre-series transformer. Each secondary was measured and the PD inception voltage (PDIV) recorded. At the lower potential taps 1 to 4 (Fig. 1 in the front) no PDs up to the nominal voltage have been measured. The taps from 4 up to the highest potential have PDIVs between 11 kV and 12 kV peak.

Table 1: Inception Voltages per Tap for LBDS Pre-series Trigger Transformer

Tap #	Unominal [kVp]	PDIV [kVp]
1	3	-
2	5	-
3	8	-
4	11	-
5	14	11.92
6	16	11.16
7	19	10.9
8	22	11.14
9	25	12.15
10	27	12.15

The following measurements were conducted at the high potential secondary at the maximum peak operation voltage of 27 kV. The rest of the taps have been voltage graded by resistors. In Fig. 3, the PDs are correlated to the voltage phase of the sinusoidal HV excitation. The Phase Resolved Partial Discharge (PRPD) pattern of the pre-series trigger transformer (Fig. 3) shows signs of surface discharges by comparing to reference patterns [6], [7] and [8].

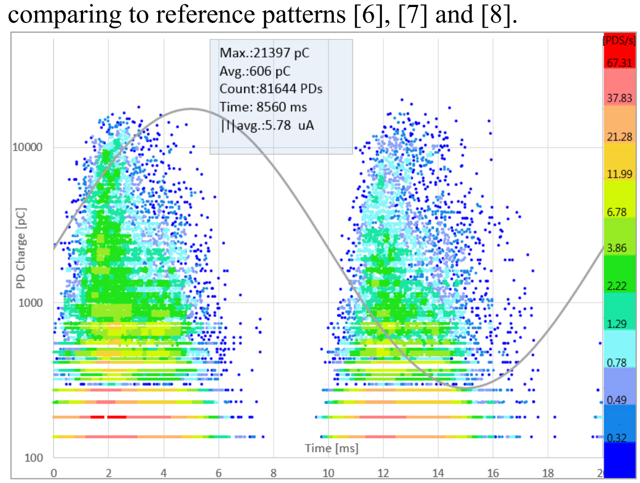

Figure 3: PRPD of pre-series trigger transformer with signs of surface discharge at 27 kV.

Another way of analysing the measurements is the Pulse Sequence Analysis (PSA) where several correlations can be made. The correlation of the normalized excitation voltage level between two consecutive PDs (ΔV_n / ΔV_{n-1}) is shown in Fig. 4 and the PSA plot of the phase correlation between two consecutive PDs ($\Delta\Phi_n$ / $\Delta\Phi_{n-1}$) is shown in Fig. 5.

By comparison, of the PRPD and PSA results the different sources of the discharges (corona, surface, void, floating potential, etc.) can be distinguished more easily. All 3 figures indicate surface discharges [6], [9].

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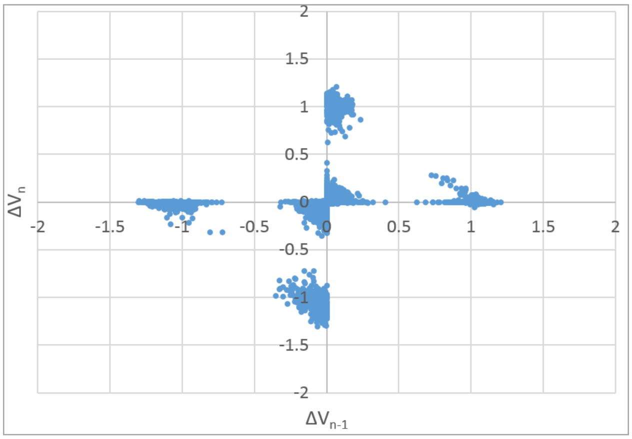

Figure 4: PSA Pattern ΔV_n / ΔV_{n-1} of pre-series trigger transformer with signs of surface discharge at 27 kV.

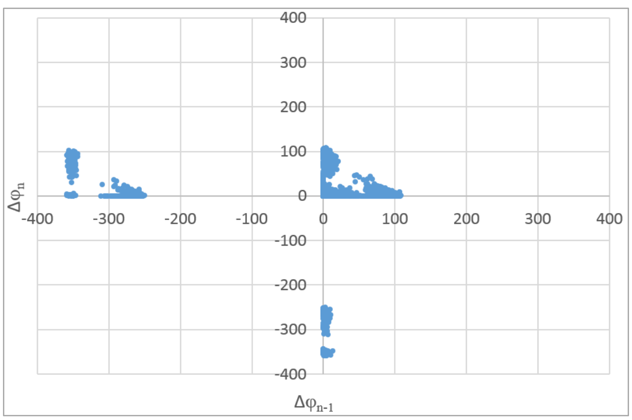

Figure 5: PSA Pattern $\Delta\Phi_n$ / $\Delta\Phi_{n-1}$ of pre-series trigger transformer with signs of surface discharge at 27 kV.

By comparing (Table 2) the PDIV, the number of PDs per second (PD/s), the maximum and average PD charge magnitude together with the PRPD and PSA pattern the quality of the different trigger transformers can be validated.

Table 2 shows 4 transformers of the final series. Transformer 13 and 16 showed suspicious behaviour (Fig. 2) during the DC HV test with high amplitude discharges.

Table 2: Comparison of Series Trigger Transformers

#	PD/s 17.5kV	PDIV [kVp]	Possible Cause
11	0	N/A	no PDs
12	0	N/A	no PDs
13	35	14.7	void, internal corona
16	66	16.9	void, internal corona

During the AC HV tests these behaviour was confirmed by a relatively high PD/s rate and compared to the reference transformers (#11 and #12) with a low PDIV. The PSA and PRPD indicate possible problems with voids in the insulation and internal corona. In the next step, these transformers will be opened and inspected.

CONCLUSIONS

The improved test procedures for the safety and reliability relevant LBDS trigger transformer have been outlined in this paper. The advantage of a pulse test prior moulding and an extensive DC testing under operational conditions have been described. To validate and assess transformer units with questionable DC test results a new powerful test tool has been introduced: phase resolved PD measurements. Those measurements allow to capture discharge pattern which can be used to better identify and understand the source of electrical discharges and consequently minimize the risk of a bad moulding quality which could otherwise lead to eventual sparking activity or even breakdown during operation. A new low cost in house constructed PD test bench and analysis tool has been presented and the results of the so far tested trigger transformers were given. All test activities not only guarantee and contribute to a reliable LBDS but already showed their benefits in early failure detection and hence reduction of expensive production rejects during final product acceptance.

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