Interpretation of charge transfer measurements of brush discharges

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Abstract. In the present work, experimental results on the measurement of the total charge on a charged insulating sheet before and after a provoked brush discharge, their difference “C”, the induced charge “A” when approaching an earthed microprocessor operated hand-Coulombmeter, and the transferred charge “B” at the instance of the discharge are presented. “B” is identical with the value measured by the hand-Coulombmeter within the expected measurement uncertainty. Due to observed corona losses and multiple brush discharges independent of each other, “B” correlates better with the incendivity than “C”. The quotient B/C was closer to 1 than calculated in the literature but shows all predicted trends. The results obtained can be used for correct estimation of the incendivity of brush discharges between 10 nC and 90 nC. There is no need to change the existing threshold limits of 60 nC, 30 nC and 10 nC for the explosion groups IIA, IIB and IIC hitherto used in standards for zone 1.

1. Introduction

For the sake of safety to man and property, it is necessary to put the components or equipment for use in explosive atmospheres, which have the possibility of acquiring static electricity, through electrostatic tests under worst conditions in order to determine if the transferred charge of such discharges could ever exceed the safe threshold limits of 60 nC, 30 nC and 10 nC in order to prevent ignition of Gas Group IIA, IIB and IIC materials, respectively [1,2].

However, calculations in literature [3,4] had the result that due to charge induction only 20 % to 56 % of the actual transferred charge is expected to be recorded with a Coulombmeter. If these calculations would be true, such a significant underestimation of transferred charges may pose severe threat of fire and explosions. For example, if the actual discharge measured is 30 nC this may give the false impression to be well within the limits of 60 nC for gas group IIA.

Although brush discharges transferred from non-metallic surface such as PTFE have been found to need transferred charges measured by a Coulombmeter somewhat higher than the existing threshold limits for ignition derived from those of spark discharges from metal surfaces [5], this is clearly not sufficient if the calculated measuring efficiency would be as low as 20 %. For this reason, the transferred charges measured with a microprocessor operated Coulombmeter have been extensively investigated in a Faraday pail to know the realistic measurement errors by Coulombmeters either to revise the hitherto used threshold limits or to give sufficient experimental data to revise the calculations.

2. Experimental set-up

Charge measurements were made using a virtual earth charge measurement amplifier (JCI 178 Charge Measurement Unit from John Chubb Instrumentation, United Kingdom). The Faraday pail was JCI 247, having a 260 mm diameter 410 mm high galvanized bucket mounted on 3 insulators from the base of a converted galvanized iron dust bin, 480 mm diameter, 650 mm tall. A 260 mm diameter aperture was cut in the lid for entry and exit of samples. The pail was connected by a wire link to a BNC connector in the outer wall of the inner bucket of the bin and from this by a BNC coax cable to the charge measurement unit and a 2-channel color digital phosphor oscilloscope 300 MHz 2,5 GS/s (TDS 3032B from...
Tektronix, US). The measuring deviation between oscilloscope and JCI 178 was found to be negligible.

The transferred charges of the provoked brush discharges were additionally measured by a microprocessor operated hand-held Coulombmeter (HMG 11/02 from Schnier, Germany) with a ball probe 25 mm in diameter. It consists of a 100 nF capacitance coupled to a Voltmeter of 20 kΩ input resistance and a triggering microprocessor, measuring every 10 µsec. After a sudden increase in voltage on the capacitor exceeding a trigger level the instrument records the voltage and stops measuring if no further increase in voltage does occur in the following measurements. The display then freezes the differences of charge one measuring point before the trigger and its maximum value. The instrument was calibrated with low voltage yielding 8.5 % lower results than the factory calibration with high voltage. One measurement was made with a shielded probe 25 mm in diameter as described by Chubb [6] instead of the unshielded standard probe but showed no significant improvement.

PTFE samples were placed on a dissipative wood table outside the Faraday pail, charged by approaching and removing a corona charger, and then carefully placed on the distance pieces inside the Faraday pail. The charge measurement unit was then set to zero and the oscilloscope started in “run” mode with appropriate scales of amplification (10 – 20 nC/div) and time (2 s/div). The Coulombmeter or the earthed probe was approached towards the charged PTFE sheet. Once the crackle of a discharge was heard, the move of the probe or the Coulombmeter was stopped and, after a few seconds, taken out of the Faraday pail and the oscilloscope was put in “hold” mode and its record saved on a disk. The reading of the Coulombmeter was also noted.

This procedure was chosen because removing the sample out of the Faraday pail, discharging and replacing it yielded unpredictable charge losses of 3 nC to 90 nC whereas the disturbance of the electric field due to the walls of the Faraday pail seems negligible when comparing their distance with the distance of the discharge electrode.

3. Interpretation of the oscilloscope recordings

Fig. 1 shows a typical oscilloscope record in case of an unearthed probe hanging on a plastic cord when approaching to a charged PTFE sheet within the Faraday pail. In this kind of experiment all charge transfers are occurring in a closed system without any contact to outside. “A” is the induced charge on the approaching probe at the instance of the provoked brush discharge. “B” is the transferred charge of the brush discharge as recorded at the instance of the discharge. “C” is the lost charge on the charged sheet caused by the discharge process after the probe has been removed out of the Faraday pail while the charged sheet is still within the pail.

Because of the charge maintenance law one would expect that within an ideal Faraday pail the induced charge “A” and the charge “B” lost during the charge transfer from sheet to probe electrode are both zero. However, as the used Faraday pail had an opening on its top a significant part of the charge may get undetected when shifted closer to the opening as a consequence of charge movement.

In the experiments performed with unearthed probes “B” was always 5 % of “C”. As “A” is reversible this attributes the used Faraday pail a charge collecting efficiency of maximal 95 %. This value was supported by experiments with a normal Coulombmeter as a probe which usually displayed 95 % of the value of “C” after its removal out of the Faraday pail (e.g. 60 nC in Fig. 1).

Figure 2 reproduces a typical actual oscilloscope recording when approaching an earthed object to a charged sheet within the Faraday pail. As in the case of the unearthed probe “A” is the induced charge on the approaching probe, “B” is the value of the transferred charge as recorded at the instance of the discharge and “C” is the lost charge on the charged sheet
caused by the discharge process after the probe has been removed out of the Faraday pail. Note that this type of system is no closed system as charges may move out of the system via the earth line between the Coulombmeter, which is within the Faraday pail, and earth.

Figure 1: Oscilloscope record of the charge losses “C” of 62 nC (10 nC/div) when approaching an ungrounded probe 25 mm in diameter to a charged sheet provoking a brush discharge (microprocessor operated hand-Coulombmeters don’t work correctly under these conditions).

Figure 2: Oscilloscope record of the charge losses “C” of 44 nC (20 nC/div) when approaching an grounded probe 25 mm in diameter to a charged sheet provoking a brush discharge “B” of 40 nC (hand-Coulombmeter displays 38 nC).

All experimental results obtained show that “B” is in between 20 nC and 70 nC equal within +1 nC to -6 nC (± 3 nC when factory calibrated) with the reading of the microprocessor based Coulombmeter after the discharge has occurred to its input sphere. “C” should be zero if the probe is removed from the Faraday pail without any discharge having occurred. Nevertheless we often observed a lost charge “C” without any notable discharge occurring. We interpret this result that a significant part of the charge may get undetected due to corona from the charged sheet to the approaching earthed electrode independent from any brush discharge. In fact, when approaching an earthed sharp needle to the charged sheet very strong charge lost “C” can be observed without any brush discharge being provoked (Fig. 3).

Figure 3. Oscilloscope record of the charge losses “C” of 170 nC (50 nC/div) when approaching and removing an earthed needle to a charged PTFE sheet without any brush discharge occurring (no hand-Coulombmeter present).

Figure 4. Oscilloscope record of the charge losses “C” of 42 nC (20 nC/div) when approaching an earthed needle 25 mm in diameter to a charged sheet provoking a double brush discharge “B1+B2” of 40 nC (hand-Coulombmeter displays 20 nC corresponding to “B1”).

Additionally we sometimes observed the occurrence of double brush discharges B1 and B2 (Fig. 4). Due to observed time intervals of about 10 ms between both discharges when expanding the x-axis of the oscilloscope record only the stronger brush, in most cases the first
of both, contributes to the incendivity. Our microprocessor based Coulombmeter was found to always record the first one B1 which seems appropriate in most cases.

4 Conclusions

As charge remains constant in a closed system it may be said that “B” represents the recorded transferred charge at the instance of the brush discharge, while “C” represents the lost charge caused by the whole discharge process. The value of “C” is always somewhat higher than that of “B”. The difference of both values is often called the “absolute underestimation”, while the ratio of “B” to “C” has been termed as “collection efficiency” in the literature although “C” may contain charge lost by non-incendive secondary discharges (Figs. 3,4).

Already a short glance on Figures 2 and 4 shows that the difference between measured transferred charge “B” and lost charge “C” caused by the discharge process is not as high as expected from literature calculations [3,4]. As additional experiments prove that a probe of 25 mm in diameter behaves like an average human thumb or knuckle, such a probe dimension is, therefore, suitable for discharge simulations [7]. For such a probe the measured transferred charge “B” was found to be in average about 70% of the lost charge “C” after provoked brush discharges in the case of 60 nC transferred charge and more than 50% in the case of 10 nC [7]. These values are significantly higher than those obtained from calculations in the literature [3,4].

One possible reason for this may be an underestimation of the induced charge after the brush discharge to simplify the calculations (typical assumption: homogeneous circular charge distribution after discharge). Experiments with Bürkers charge powder show, however, distinct discharge channels on the discharged surface leading to a centre [7]. This center and the mid of the discharge channels may contain opposite charge. The discharged surface may be circular symmetric or only a half circle and usually contains extended not discharged areas [7]. This is contrary to the assumptions made for the calculations. Against to the expectations shielded probes did not show a significant improvement concerning charge collection efficiency of microprocessor operated Coulombmeters (see [7] for more details).

As ignition experiments with brush discharges in 22% hydrogen, 8% ethylene and 5.2% propane yielded minimum transferred charges “B” of 23 nC, 32 nC and 93 nC for ignition measured with the used microprocessor operated Coulombmeter [5] there is no need to change the existing threshold limits for transferred charges of 10 nC, 30 nC and 60 nC for zone 1. Due to the small safety gap for ethylene it is, however, reasonable to change the values to 0 nC, 10 nC and 30 nC for zone 0 as it is already proposed in the latest IEC DTS 60079-32 [8].

References

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