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Radiation of transient high-current arcs: energy measurements in the optical range

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Abstract. When no protection is used, the radiation emitted by a high-power electric arc can be dangerous for the eyes and the skin of a person. To ensure effective protection, it is first necessary to know the energy emitted by such arcs. The aim of our work was to experimentally determine the energy emitted by high-current (from 4 to 40 kA) transient arcs, for two different (10 cm and 2 m) lengths and for electrodes in copper or steel. These experiments enabled the radiative energy of the arcs to be quantified and also showed the influence of metal vapors in the spectral distribution of the radiation.

1. Introduction

One of the main features of electrical arcs is their radiation: the higher the current, the higher the radiation emitted. During welding or cutting operations for example, operators are efficiently protected against this radiation by protective clothing. However, undesirable transient arcs can also occur, as in maintenance operations on the electrical supply network.

To be effectively protected against radiation, it is necessary to know the precise amount of energy radiated by such arcs [1-3]. As the arcs do not radiate simply as black bodies, the radiated energy needs to be measured in several spectral bands.

The objective of this study is to go some way to answering this question by measuring the radiated energy, by spectral bands, in two arc configurations, in the field of optical radiation ranging from ultraviolet to infrared via visible radiation. However, an electrical arc creates a cloud of smoke, usually from erosion of the electrodes and of the surrounding materials, and this cloud changes the radiative transfer, so accurate measurement is very difficult to obtain.

2. Experimental setup

This section describes the two arc configurations studied. They correspond respectively to a short 10 cm arc and a long 2 m arc. The power supply used in the creation of each of these arcs is also different.

2.1. Short arc

The experimental setup consists of two opposed round copper rod electrodes 18 mm in diameter (figure 1). The distance between the electrodes is 10 cm. The electrodes are initially connected by a wire 0.2 mm in diameter in order to ignite an arc in the air at the beginning of the electric current discharge when the discharge is higher than a threshold value. The power source supplies a sinusoidal positive half-cycle current of close to 10 ms, with a 10 kA peak. The discharge current and voltage were recorded for each run, and their product was integrated on the total arc duration to estimate the input electrical power of the discharge. The total electrical energy dissipated by the arc is about 15 kJ.

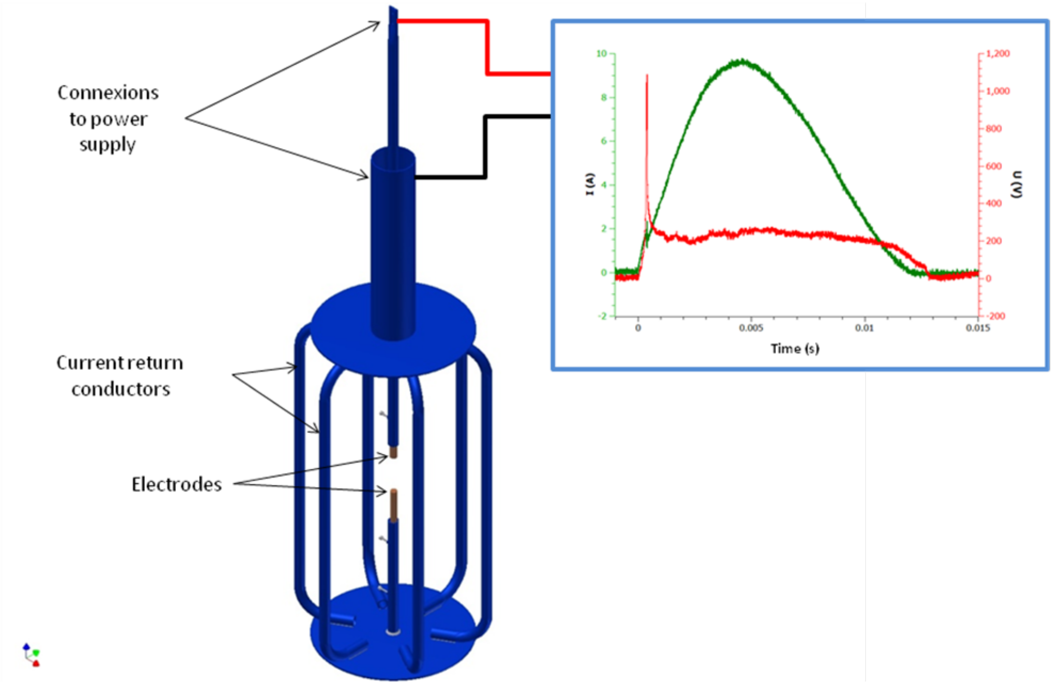

Figure 1. Device for the creation and study of the short arc. Typical electric current (green) and voltage (red) curves are shown.

2.2. Long arc

The device for the creation of the 2 m arc is more or less the same as the previous one (opposite electrodes, current return, etc.) but with larger dimensions. The power supply is different, since it allows the creation of alternating currents during 5 periods of 50 Hz and intensities ranging from 4kA to 40 kA rms.

The electrical energies are respectively about 0.75, 0.7, 3.1 and 5.5 MJ. In comparison with the previous configuration, the electrical energies are much higher, because of the duration of the discharge, the current intensities and the size of the arc.

2.3. Energy measurements

The radiated energy was measured with two joulemeters XPLF12, from Gentec Electro-Optics®.

In the short arc configuration, they were positioned 178 cm from the axis of the electrodes on the horizontal plane defined by the middle of the inter-electrode gap, and directed towards the center of the arc. In the second configuration, the joulemeters were positioned 9.4 m from the arc.

To obtain the energy distribution of spectral radiation, these detectors were equipped with filters in order to determine radiation in the UV, visible and IR bands for the two configurations. For the short arc configuration, it was possible to obtain more precise information on 6 spectral bands (2 UV, visible and 3 IR). Table 1 lists the standard boundaries of the spectral bands in the optical field of electromagnetic waves.

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Table 1. The 7 standard spectral bands of the optical range.

Spectral band	Lower wavelength (nm)	Upper wavelength (nm)
UVC	100	280
UVB	280	315
UVA	315	400
Visible	380	780
IRA	780	1400
IRB	1400	3000
IRC	3000	10^6

Note that the radiation below 190 nm cannot reach the sensor and that the spectral sensitivity of the sensor above 20000 nm is negligible. Thus in the results the spectral bands UVC and IRC are not completely measured.

3. Results and discussion

The contribution of each spectral UV, visible and IR band is shown in figure 2. UV is in the range 190-400 nm, visible in the range of 400 (in our case) to 780 nm, and the IR from 780 to 20000 nm. Whatever the nature of the electrodes, the largest proportion of radiation is UV and the lowest is visible radiation. As the arcs are created in air with fuse wire of the same nature as the electrodes, this radiation seems governed by metallic vapors coming from the electrodes rather than by the ambient gas.

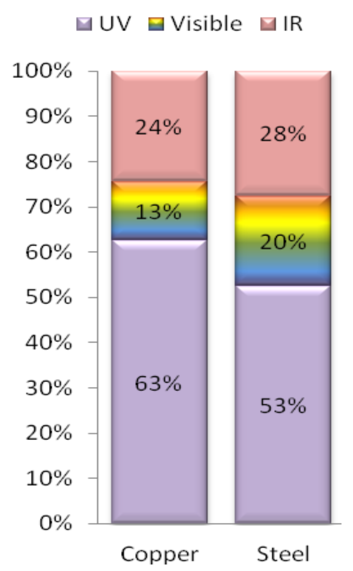


Figure 2. Spectral distribution of the measured radiated energy vs the type of electrodes, for the short arc.

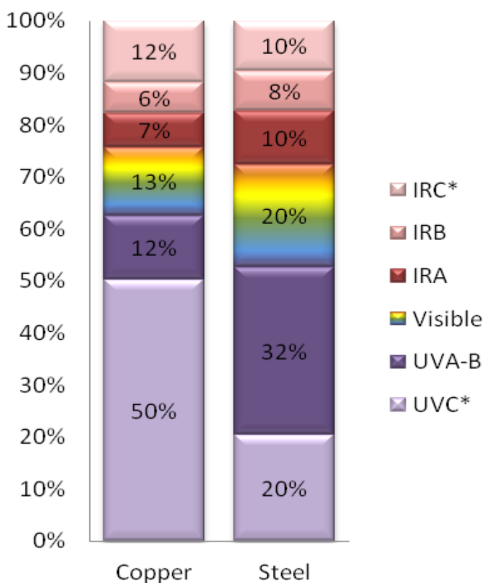
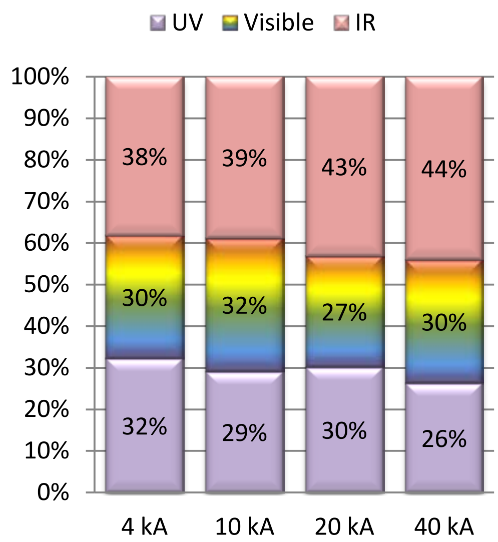


Figure 3. Detailed spectral distribution of the measured radiated energy vs the type of electrodes, for the short arc

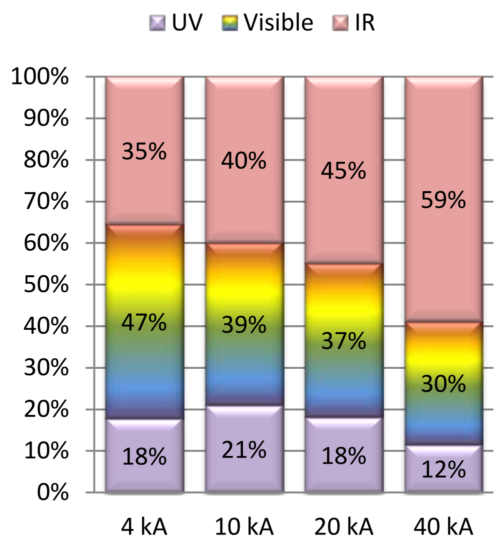
Calculations [4] have shown that radiation from a plasma in air is mostly in the visible and the IRA spectral bands for a fairly wide temperature range. This confirms the important role of the metal vapors in our results.

The steel electrodes consist more than 97% of iron. In figure 3, which gives a more precise spectral distribution of radiation from the arc, we see that the essential difference between the two radiations is in the UVA-B and UVC* bands. * Remember that the 100-190 nm part of the UVC band is not measured, because this radiation is very quickly absorbed in air. The observed difference between the two types of plasma (copper and iron) comes from the spectral characteristics of the two elements, but also depends on their concentration in the plasma and on its temperature. The two parameters are linked since the plasma temperature tends to decrease when the proportion of metallic fumes increases.

It is admitted that the radiation of metallic vapors in a plasma is mostly in the UV range and that the contribution of UVC is substantial since the plasma is hot. This is in good agreement with our measurements in the case of copper electrodes. In the case of the steel electrodes the low proportion of UV and especially UVC is surprising. We can observe these trends provided that the proportion of iron in the plasma is significant (several %) and that the temperature is low enough (between 10 and 15 kK). However in this case the proportion of visible and IR should be lower. We observed [5] that the arc creates a cloud of smoke, composed of metallic vapor and droplets of molten metal. This cloud is dense and changes the radiative transfer around the arc. It is possible that part of the UV radiation is absorbed by this cloud. As the temperature of the latter does not exceed 1000 or 2000 K, its radiation will be rather in the near-infrared, which might explain our results.



(a) Copper



(b) Steel

Figure 4. Spectral distribution of the measured radiated energy vs the type of electrodes and the current, for the long arc.

Figures 4 shows the same kind of results as figure 2, but for the long arc configuration. The first trend that emerges is the high proportion of visible and infrared radiation. These proportions are more characteristic of air. One might think that in this configuration, the proportion of metal vapors in the plasma would be lower than in the short arc configuration. Given the high currents, erosion is greater but the volume provided by the plasma is significantly broader.

It can also be seen that UV radiation is greater for copper and visible radiation for iron. As the current increases, the UV radiation decreases while the visible and infrared ranges increase. When the current increases, the electrode erosion also increases, and with it, the proportion of metallic vapors. Radiative losses due to these fumes tend to cool the plasma so that the temperature of the plasma does not necessarily increase with the current. Here also the cloud of smoke certainly plays an important role, especially in this configuration. Indeed, the arc lasts 10 times longer than in the short arc configuration. The expansion of the cloud is greater; it occupies a larger volume, thus promoting the absorption of part of the arc radiation and the retransmission in a spectral domain closer to the visible and infrared spectral ranges.

4. Conclusion

In this study, we measured the energy emitted by strong current transitional arcs in two different configurations: one for a short arc and short duration, one for a long arc with longer-lasting and stronger currents, for two electrode materials: copper and steel.

We have demonstrated that this radiation does not depend only on the nature of the initial gas, namely air. Metallic vapors generated by the erosion of electrodes play an important role in the radiative transfer, both when it comes from metallic atoms in the plasma, and from the fact that the droplets form a cloud that modifies the radiative transfer around the arc.

As the erosion of these electrodes differs depending on the material used, we cannot ignore a dynamic effect of this cloud, which is more or less hot depending on the case, and is evacuated differently. This feature was verified using fast videos. We also plan to conduct these experiments for aluminum electrodes. They will not only confirm the hypotheses advanced, but will also be of practical interest, as arcs are increasingly created with aluminum electrodes.

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