ATTACHMENT F PRESSURES DEVELOPED BY AC ELECTRIC ARCS

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INTRODUCTION

As well as flash burns from electric arcs [1], nearby personnel are propelled away from such arcs by pressure developed by the arcs. This can cause falls and other injuries, as well as damage to nearby structures. A relationship is developed between arc current and pressure for an applicable range of distance.

For familiarization with some units used for pressures used in the SI (metric) the following table may be useful:

Standard International	
1 Newton (N)	= 0.2248 pound force (lbf)
1 Newton/m^2	= 0.0209 lb/ft^2
1 Atmosphere	= 2116 lb/ft^2
	= 1.0125 x 10^5 N/m^2

BACKGROUND

Reports of the consequences of electrical power arcs in air include descriptions of the rearward propulsion of personnel who were close to the arc. In many cases, the affected people do not remember being propelled away from the arc, even some not remembering the arc occurrence itself. The relative infrequency of power arcs has tended to minimise interest in determining the nature and magnitude of this pressure. Not only that, but the heat and molten metal droplet emanation from the arc cause serious burns to nearby personnel [1], which also tended to reduce interest in the rearward propulsion and pressures generated.

Another consequence of arcs is structural damage. One power arc in a substation of the Quebec Hydroelectric system caused collapse of a nearby substation wall. To determine the magnitude of pressure generated by the arcing fault, M.G. Drouet and F. Nadeu, of the Institute de Recherche de I'Hydro-Quebec were assigned to develop theoretical and practical bases for this phenomenon. The results of their work are described in a 1979 paper, "Pressure Waves due to Arcing Faults in a Substation." [2] Drouet and Nadeau's work showed a disparity of somewhat greater than one order of magnitude between the theoretical and actual measured pressures, a phenomenon attributed by a discusser, Dr. Nettleton, as due to a very high frequency component of pressure not recorded by measuring apparatus. Regardless of this, they measured amplitudes of pressure from 100 kA, 10 kV arc that reached about 400 lb/ft^2 (2 x 10^4 N/m^2) at a distance of 3.3 ft. (1m). This pressure is about ten times the value of wind resistance which walls are normally built to withstand. Factory Mutual guidelines indicate that overpressures in the range of 300 to 450 lb/ft^2 (1.4 x 10^4 N/m^2 to 2.2 x 10^4 N/m^2) are sufficient to shatter non-reinforced concrete or cinder block walls.

Pressures on projected areas of individuals at 2 ft. (0.6m) from a 25 kA arc would be about 160 lb/ft^2 (7.7 x 10^4 N/m^2). This is sufficient to place a total pressure on the front of an individual of 480 lbs or 2100 N. Pressures in the 350 lb/ft^2 (1.6 x 10^4 N/m^2) are damaging to human ears. Where anticipated overpressure exposures exceed 200 lb/ft^2 (1 x 10^4 N/m^2), the use of ear protection is indicated. The protection should preserve audible communications, i.e., through the use of electronic communication head-sets or their equivalent.

DEVELOPMENT

The pressures from an arc are developed from two sources, the expansion of the metal in boiling, and the heating of the air by passage of the arc through it. Copper expands by a factor of 67,000 in vaporizing, much as water expands about 1670 times in becoming steam.[3] This accounts for the expulsion of near-vaporized droplets of molten metal from an arc; these are propelled for distances of about 10 ft. (3m). Expanding metal also generates plasma (ionized vapor) outward from the arc for distances proportional to the arc power. With copper, 53 J will vaporze 0.05 in^3 (0.328 cm^3)[4], producing 3350 in^3 (54,907 cm^3) of vapor. A single cubic inch (16.39 cm^3) of copper vaporizes into a volume of 1.44 yd^3 (1.098m^3). The air in the arc stream expands in warming up from its ambient temperature to that of the arc, or about 35,000°F (20,000°K). This heating of the air is related to the generation of thunder by passage of lightning currents through it.

Dr. RD. Hill [5] developed theoretical pressures at distances of 0.75 to 4 cm. (0.295 to 1.575 in.) from a 30 kA peak lightning stroke. These pressures ranged from 40 atmospheres down to 9 atmospheres. Dr. Hill's data were plotted on Figure 1, on log-log scale and the straight line of his points extrapolated to 100 cm (39.37 in.) distance, at which distance the pressure would have been 0.45 atmospheres. Multiply this 0.45 by the ratio of 200/30, to match the peak power of the Drouet-Nadeau (D-N) tests, the Hill data becomes 3 atmospheres, rather close to the D-N theoretical value of 2.7 atmospheres.

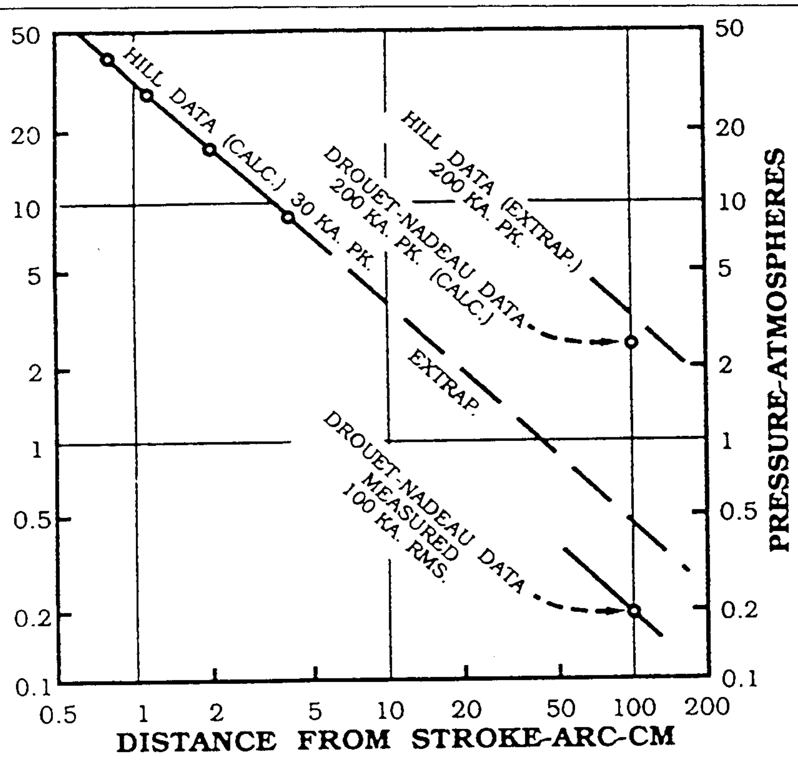

FIGURE 1
PRESSURE VS DISTANCE
FROM STROKE OR ARC

HILL DATA (CALC)
DROUET & NADEAU
DATA (CALC & MEAS)

The actual measured pressure, by D-N from a 200 kA peak, 100 kArms current, was 0.19 atmospheres, or 0.07 times the calculated theoretical pressure. Since this is the only available measured pressure level, it will be used to generate a family of lines, shown herein as Figure 2. In Figure 2 pressures are shown for arc currents ranging from 1 kA to 100 kArms, for a range of distances of 0.5 ft. to 100 ft., (15 cm to 30 M) from the arc center to the point of interest. From this, the pressure may be determined for a 25 kA arc at a distance of 2 ft. (60 cm) to be 160 lb/ft^2 (7656 N/m^2), etc. This pressure has at least one useful aspect; the individuals close to an arc are propelled rapidly away from the heat source, substantially reducing the degree of burn that they are exposed to.

The hot vapor emanating from the arc starts to cool immediately. While hot , however, it combines with the oxygen in the air, forming an oxide of the metal in the arc. These products continue to cool and solidify, and become minute particles in the air, appearing as smoke, black for copper and iron, and grey for aluminum. The particles are still quite hot and will cling to any surface they touch, actually melting into many insulating surfaces they may contact. This is believed by many to be carbon particles. The oxide particles are most difficult to remove, as surface rubbing is not effective. Abrasive cleaning is necessary for plastic insulations, and a new surfacing compound must be applied, or leakage will be severe and would likely cause termination or splice failure within a few days.

Persons exposed to severe pressure from proximity to the arc are likely to suffer short-time memory loss, and not remember the intense explosion of the arc itself. This is a consequence of a brief concussion which interferes with the transfer from short-time to long-time memory. This phenomenon has been found true even for high-level electric shocks.

So it is evident that persons working in conditions where power arcing is possible should be protected not only against arc burns but against falling (as from ladders and scaffolds) and against ear damage.

A simple equation was developed to define the family of curves shown in Figure 2 and is defined as follows:

$$P = 11.65 \times \frac{(kA)}{R^{0.9}} \qquad \text{(Eq. F1)}$$

Where P = Pressure developed by arc in $lbs./ft.^2$

kA = Short circuit current$_{rms}$ in kiloamps

R = Distance in feet from arc center to area of interest

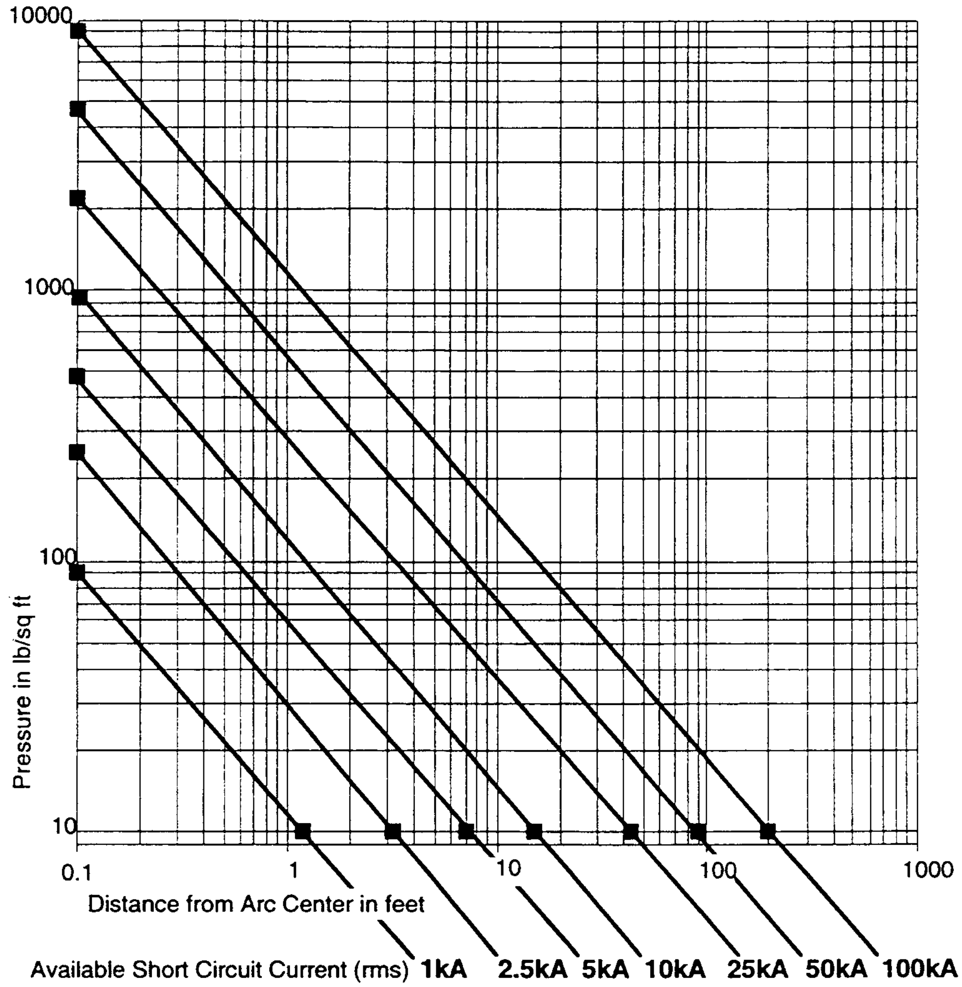

Figure 2
Short Circuit Overpressure
Pressure (lb/sq ft) vs Distance from
Arc (ft)
Current in Kiloamperes rms

REFERENCES

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[3] W. R. Wilson: "High Current Arc Erosion of Electric Contact Materials." AIEE TP 55-215

[4] R. R. Conrad & D. Dalasta: "A New Ground Fault Protection System for Electrical Distribution Circuits." I&CP Conference, May 22-25, 1967 and published in 1967 IGA Transactions

[5] R. D. Hill: "Channel Heating in Return Stroke Lightning." Journal of Geophysical Research, Jan 20, 1971