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Note de Sécurité

Lethal voltages from ion gauge/gas discharge interactions

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Résumé. — Tout contact entre la terre et les parties métalliques d'une chambre à vide peut être dangereux si le métal n'est pas mis à la terre, et si une jauge à ionisation est utilisée dans la chambre à une pression égale ou supérieure à 0,1 pascal (7×10^{-4} torr). Une décharge électrique mortelle peut se produire si toutes les conditions sont présentes simultanément. On peut éliminer les risques en effectuant une mise à la terre commune entre la chambre à vide et le châssis du dispositif de commande de la jauge à ionisation.

Abstract. — Human contact between ground and the metal parts of a vacuum chamber can be dangerous if the metal is not grounded, and if an ionization gauge is operating in the chamber at pressures of 0.1 pascal (7×10^{-4} torr) or higher. Lethal electrical shock can possibly occur if all of these conditions are present. Common grounding of the metal parts of the vacuum chamber and of the ionization gauge controller chassis removes this danger.

An open ground circuit plus millitorr local pressure can expose personnel to lethal voltages during ionization gauge operation, especially during degassing.

For the last 30 years I have worked with ion gauges and vacuum systems. I have looked for more ground circuits since recently making this discovery than in the previous 30 years ! I feel very fortunate to be alive, and able to tell you about this danger. It may eventually be possible to design gauges that are free of it, but presently there are hundreds of thousands of ionization gauge controllers and vacuum systems from many manufacturers around the world that could kill — if not properly grounded.

Prevent the dangerous path.

Most of us have used our ionization gauges at pressures where some visual evidence of plasma-like formation was present, i.e., there was a gentle purple glow in the tube. What interactions does this have ? Is it interfering with the gauge reading ? Is it dangerous ? If the purple glow occurs during the degas process, can this be dangerous in any way ? *Are you willing to bet your life ?*

To answer these questions, a vacuum system was arranged as shown in figure 1. This permitted us to observe the behaviour of an ionization gauge, G1, while the pressure was raised into the 10^{-3} torr range, and higher, monitored by gauge G2. By closing valve V1 totally and opening valve V3 slightly, the pressure could be made to increase linearly with time at the gauges.

Gas discharge — gauge effects.

Figure 2 shows the ionization gauge elements of primary interest, and the block diagram of the related parts of the gauge controller. The « collector » electrode and electrometer circuit are not shown because they do not enter significantly into the gas discharge interactions.

The normal operation of an ionization gauge requires the generation of ions and liberated electrons of quantities proportional to the pressure being measured. We do not usually think of this ionization as gas discharge formation because there is no visible glow such as we see in neon signs, fluorescent lights,

Fig. 1.

Fig. 2.

glow tubes, etc., which are our familiar discharge models. It seems quite normal that we might start to see some discharge glow when we get near 10^{-3} torr, for this is the pressure range of the glow discharge. The brightness and colour of the glow will depend upon the pressure and the composition of the gas, for each gaseous element has a different spectrum of light given off as its excited ions and molecules return toward normal states after being hit by accelerated electrons.

As we raise the pressure in the measurement mode of operation, the ionization gauge controller should turn off the tube filament before the glow becomes very bright. Although the plasma ⁽¹⁾ in this situation is normal, as it becomes more dense from the increasing pressure, it interferes with the gauge function, making the gauge reading a less linear indication of the pressure. At a sufficiently high pressure, the gauge reading decreases, and eventually changes sign and indicates less than zero pressure. The filament is automatically turned off by most controllers before this can happen. In some controllers the electron current from filament to grid (anode) is measured as a second safety check. If this current deviates from the value programmed, the filament is turned off. If this comparison circuitry is not used, the filament can remain on if it is accidentally turned on at any pressure sufficiently beyond the ion current reversal pressure. This can sometimes result in the burn-out of the filament, especially in those gauges with tungsten filaments.

Of major concern is the safety of the operator and those who touch the controller and vacuum system. The generation of high plasma densities in the measurement mode of operation is not typical due to the automatic turn-off of the tube. However the failure of the ground circuit somewhere between the controller and the vacuum system can become of extreme danger in this mode, when the pressure is a millitorr, or greater. In this pressure range, *voltages of up to 160 V can give a brutal shock to the unwary one who reestablishes this ground circuit with his body. This voltage*

is sufficient to cause fibrillation of the human heart, so represents a significant danger. Maintaining proper ground circuits on both the chamber and the controller avoids this danger.

Degas — plasma interaction.

The « degas » circuits available for cleaning the ionization gauges are of two types :

1. Electron Bombardment (EB).
2. Resistance ($I^2 R$).

EB degas operation is similar to the measurement operation, except that the grid voltage is raised from 180 V to as high as 900 V. Also, the emission current is increased from 10 mA to as much as 180 mA. Now we have enough power to do some real cleaning ! It is also enough power to be dangerous if something goes wrong !

The high voltage and high emission current in the EB degas mode create much more plasma than is present in the measurement mode of operation. Thus, it is fully expected that we will see some purple glow during the early stages of degassing a dirty gauge. The degas operation may be started in the 10^{-5} torr range, or lower, but the local pressure in the tube can increase significantly as the contaminating materials evaporate from the tube elements and nearby surfaces. How far can we go ? What happens when we go too far ?

Using the equipment of figure 1, we degassed gauge G1 at low pressures, then closed valve V1 and slightly opened valve V3 with the EB degas power still applied. The pressure increased steadily, and eventually the emission or degas fuse would blow. This implied that excessive emission currents had occurred.

Using an oscilloscope, we watched the grid voltage at point A in figure 2, with respect to ground. Simultaneously, we monitored the current flowing through point A. The grid current during the moment before fuse failure was much higher than that which flows normally. We used this over-current as a trigger to take pictures of the fuse destructive half cycle.

Figure 3 shows a few cycles of conventional operation in the 10^{-6} torr range at about 40 W of degas

Fig. 3. — Normal current and voltage traces.

⁽¹⁾ The word « plasma » is used in the popular rather than full scientific sense.

power. The current was about 70 mA, except for the short time periods when the grid voltage was too low to support this current. The grid voltage peaked at 780 V in this controller. The pressure was then increased gradually into the 10^{-3} torr range where, with degas power applied, the destructive half cycle associated with blowing the emission fuse would occur.

Figure 4 illustrates the destructive half cycle. To obtain this picture, the oscilloscope scan rate was one ms/division. Note that the current sensitivity was now 5 A per division, *versus* the 50 mA used in figure 3 ! The current was as high as 140 times that in normal operation ! When we examined the grid voltage, we saw that it was very nearly constant at about 320 V over much of the cycle. This nearly constant voltage was observed as currents varied from 200 mA (the scope trigger) up to about 4 A. The behaviour was like that of the glow discharge voltage regulator tubes of yesteryear (OA3, etc.), but the current was many times higher than was permissible in those tubes. We call this the voltage regulator (VR) mode in the ionization gauge tube.

As we followed the voltage through the destructive half cycle, we saw that it suddenly dropped to almost zero, and the current increased more rapidly. This was a vacuum arc. We call this the arc mode. The arc and voltage regulator modes are violent, and not very stable. Thus the discharge changed back and forth between them. In dozens of pictures, no two patterns were totally identical.

One needs not look very hard to see that sometimes the arc had higher voltage *versus* ground than at other times. This lead us to measure current at A and B of figure 2. All of the current went through point A, but only about 10 % of the voltage regulator current went through point B. The higher voltage arcs had full current through B, the lower voltage arcs passed no current through B.

Fig. 4. — Destructive half power cycle.

Measurement of current through point C in the ground lead proved the point. *Both the VR discharge and the low voltage vacuum arcs were to ground — not to other gauge electrodes ! This required plasma contact through many inches of glass tube ! The currents involved in these ground return discharges were many amperes — inspite of 1/4 A fast blow fuses*

The fuse « blowing » was always near the end of the half cycle. The fuse appeared to melt sooner than this, but then seemed to arc across the melt until the current fell to a low value near the end of the half cycle. This still is not dangerous if good grounds are present — but here comes the beef !

Criticality of grounding.

If these large currents pass through the common ground, what happens if this connection is missing, or unable to handle these large currents ?

To test this we broke the ground connection to the vacuum system, but left the controller in the rack with a proper ground. A voltmeter was placed between the vacuum chamber and ground. The controller operated the ion gauge in the measurement mode, and in degas mode to full power (80 W) with no more than about 20 V of AC or DC appearing between the ungrounded vacuum chamber and ground. Then the pressure was increased.

EB Degas. In the degas mode, at pressures of approximately 1×10^{-3} torr for all gases tested, the voltmeter jumped to 740 V (peak). *The vacuum chamber was + 740 V relative to ground, and the fuse did not blow nor the circuit turn off.* After the pressure was increased to the mid 10^{-3} torr range this controller would automatically turn off due to its emission current comparison circuit. If the pressure stabilized slightly below this, however, the chamber would remain at + 740 V until the degas circuit was manually turned off. *Contact between ground and the vacuum system during this time could very possibly have been fatal !*

This was a typical Bayard-Alpert (BA) ion gauge and controller — both in good operating condition. *The only fault was the missing ground wire to the vacuum system. The gauge tube pressure was no higher than might occur in your system when degassing the tube. But this could have killed you, or anyone else who made contact between the vacuum system and ground.*

The test was repeated with the same controller with its chassis isolated, and the vacuum system grounded. In this configuration the controller was driven to - 740 V by this overpressure reaction. Contact between the controller and ground could then have been fatal, also. *All tubes and controllers tested gave very similar results.*

I² R Degas. The resistance type of degas circuit drives current through the wire of the grid, or through an auxiliary heating element. This is usually about 10 A, at low voltage. The heated element typically

glows orange. The gauge filament is not functional during this $I^2 R$ degas operation in some controllers, but the grid voltage remains on in most of them. Although we have not observed a dangerous interaction between plasma and BA tubes while degassing using this type of controller, however, *when the filament and grid are both operational during $I^2 R$ degassing, a plasma coupling problem can again occur.* This involves the same situation of current flow to ground as discussed before, even though the full VR mode voltage has not been applied. The filament emission seems to play a critical role in establishing and maintaining this auxiliary discharge. The voltage involved is typically 150 V at a few milliamperes. This will not blow the fuses, nor readily provide other evidence of its presence. Such a discharge may seem very mild in comparison with the EB degas case, but it is still potentially lethal in the absence of correct grounding, for it can fibrillate the human heart.

Conclusions. All of these ion gauge controller types are generally safe when correctly grounded. It is only the failure to have an available current path between the controller chassis and the exposed metal parts of your vacuum system that provides danger. The danger is that your body could then provide such a pathway at any time while the gauge is encountering conditions that could couple power into that pathway. The result could cost you your life

All manufacturers insist on good grounding for their equipment. We, in the laboratory and production areas, however, have been spoiled by excellent equipment that very seldom fails either (1) in a way that involves the safety grounds that are provided, or (2)

in a manner that makes it obvious to us that the safety ground was involved. It is perhaps even more unexpected to recognize a natural phenomenon that leads to large currents through the safety ground circuits — especially one that is easily achieved in normal practice, and can involve voltages and currents of lethal significance.

Please check and test your vacuum chamber/ionization gauge controller chassis grounding system. Is it complete and capable of supporting at least 10 A ?

The placement of a second ground wire (dashed line in Fig. 5) between the vacuum chamber and the gauge controller chassis *is not a safe answer*, for large continuous currents could flow through it. Professional help is recommended.

My asking you to check your vacuum system and controller grounds may seem a little like your mother reminding you to button your jacket. However, the implications are human life — yours, and that of your associates.

Fig. 5. — Correct system/controller grounding.