Grid current and Vacuum

Grid current

Tubes are normally operated with powerless drive. For this purpose a negative voltage at the grid is required.

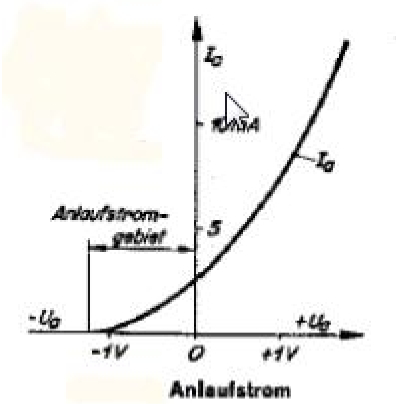
Let us take a closer look at this statement.

When will a grid current flow ?

1. Grid current flows when a positive voltage is applied to the control grid. When the grid is positive it attracts electrons. A regular grid current flows.

2. Area of initial current:

Even with a very small negative voltage at the control grid a grid current will flow. This current is referred to as „Initial current“:



The area of the initial current depends on the construction of the tube. To ensure powerless control (without grid current) the negative voltage at the control grid should be more negative than

- -0,2 V for direct heated tubes
- -1,2 V for indirect heated tubes

Only with a sufficiently high negative voltage at the grid it will reject the electrons.

3. Overload - thermal control grid emission

As the control grid is located spatially close to the cathode heating of the grid is inevitable. Caused by heating of evaporation from the oxide cathode's coating that condenses on the cooler control grid the control grid will thus emit electrons. These electrons are accelerated towards the anode and will cause a negative grid current.

The thermal grid emission primarily depends on the tube's construction, the heater voltage that indirectly controls the grid's temperature and the technical production quality.

If the tube is overloaded (and thereby excessively heated), even for only a short duration, this will frequently lead to an increase of the grid current. Some tubes have radiators attached to the control grid to reduce heating of the grid. The goal is to avoid tube overload.

5. Leakage currents – Insulation current

Bad insulation between the tube's pins may lead to leakage currents. The reason for that may be a contamination of the surface, which can easily be cleaned, or it even may be impurity of the glass or low-grade type of glass. I noticed that quite often especially with Rimlock tubes. To check for insulation problems you can measure the pin to pin insulation with a high-resistance ohmmeter or better with an insulation tester on a **cold** tube.

5. Photoelectric current

Illuminating the tube from the outside or from the filament results in a photoelectric effect. A tiny photoelectric current will flow. This effect is utilized for photocells but is undesirable for normal tubes. The photoelectric current is independent from the grid voltage. As this current is normally very small it can be neglected for the vacuum considerations.

6. Bad vacuum:

There is no grid current in an ideal vacuum. An ideal vacuum can never be achieved. There is always some residual gas in a tube. If there are too many gas particles in the tube the electrons emitted from the cathode will hit the gas particles. This can lead to split of new electrons from the electric neutral atomic union of the particles and the particles will have a positive charge excess. These positive charge carriers are called ions. The process is called „Impact ionization".

The ions are attracted by the negative charged grid and a so called „Ion current" will flow. This current is also called reverse or parasitic grid current.

Measuring the grid current, Vacuum and Vacuum factor

Direct measurement of the vacuum quality is not possible. For direct measurement the tube would have to be opened and a vacuum meter attached. But this is impossible as opening the tube would destroy the tube's vacuum.

If we exclude the above mentioned reasons 1-5 for grid current, measurement of the grid current leads to conclusions about the tube's vacuum quality. For this purpose the tube must be operated with a sufficiently high negative grid voltage and it must be checked ahead if the tube's pin insulation is sufficient.

Vacuum factor

This is the ratio of the grid current versus the anode current:

$$\text{Vakuumfaktor } V = \frac{I_g'}{I_a}$$

According to Barkhausen (who introduced the term vacuum factor) the grid current and the residual vacuum pressure are linearly dependent. A residual pressure of 10e-6 Torr corresponds to a vacuum factor of 10e-4, and a residual pressure of 10e-5 Torr to a vacuum factor of 10e-3.
During tube manufacturing the tube was evacuated to about 10e-5 Torr and then the pressure further reduced to about 10e-6 Torr by firing the getter.
Conclusion: With intact getter the tube's residual pressure should be about 10e-6 Torr and so the vacuum factor should be about 10e-4. If the getter has become inoperable the residual pressure will rise to >= 10e-5 Torr and the vacuum factor will then be >= 10e-3.

Note: Torr (mmHg) is an old measurement unit for pressure: 1 Torr = 1,33322 millibar

By measuring the grid current and calculating the vacuum factor a practical statement about the tube's vacuum quality can be made.
Good vacuum (Vacuum factor <0,0001) or bad vacuum (Vacuum factor >0,0001).

Measuring of the grid current is not easy. Each looped-in measuring instrument changes the conditions at the grid and hence the grid current and the anode current. For determining the vacuum quality an estimated measurement of the grid current will be sufficient.

The grid current also is not constant over time. During the day it can rise after powering on up to three times of the initial value. Probably from anode and screen grid absorbed residual gas is slowly emitted again by warming due to the electron bombing. The vacuum hence downgrades during the day until it finally reaches a constant value.

Some hints from experience:

- If a tube has completely lost its vacuum there will also be no anode current. Then it is also not possible to measure the grid current and the vacuum factor cannot be calculated.
- When heating tubes that have lost vacuum the heater current is higher than expected (and there is also no anode current).
- Tubes with bad vacuum quality may spark suddenly (similar to a glow lamp or a Stabilizer). In this case high currents may flow. In most cases a purple glow discharge can be observed inside the tube. Also intensive RF-radiation is generated. Measurements at the tube are not possible.
- Tubes that have lost vacuum sometimes show a milky white covering inside the tube.

The tube on the right side has lost its vacuum. You can clearly see the milky white covering

Vacuum tests implemented in older tube testers:

These tube testers usually loop-in a high-impedance resistor (1-2 MOhm) in series with the control grid. If there is a grid current flowing there will be a voltage drop across this resistor that in turn changes the voltage at the grid. This will lead to a more or less large change of the anode current. Some tube testers do that at a grid voltage of 0V so there can also be an initial grid current flowing. In this case it is difficult to interpret if the change in the anode current is due to a bad vacuum quality or not. This can only be judged by comparison to other tubes of the same type.

Vacuum test with the RoeTest:

With software version 9.7 and higher the control grid's current (Ig1) can be determined. This is also possible for older RoeTest hardware versions. Concurrently the vacuum factor is calculated. This allows a concrete statement about the vacuum quality.

Within the static tests for tubes with a control grid the measurement of the grid current is done automatically and than the vacuum factor is calculated. The results are displayed in the tab labeled "Vakuum":

In the example the vacuum factor is < 0,0001 and so the vacuum is o.k.