Grid current and Vacuum **05.11.2018**

Grid current

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

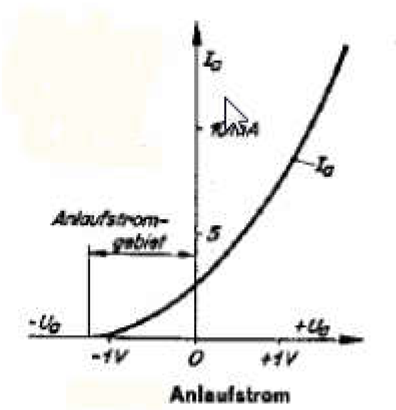
Let us take a closer look at this statement.

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 - **control grid thermal 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 used materials, the heater power, 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.

4. 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.

The different grid currents can flow in positive or negative direction:

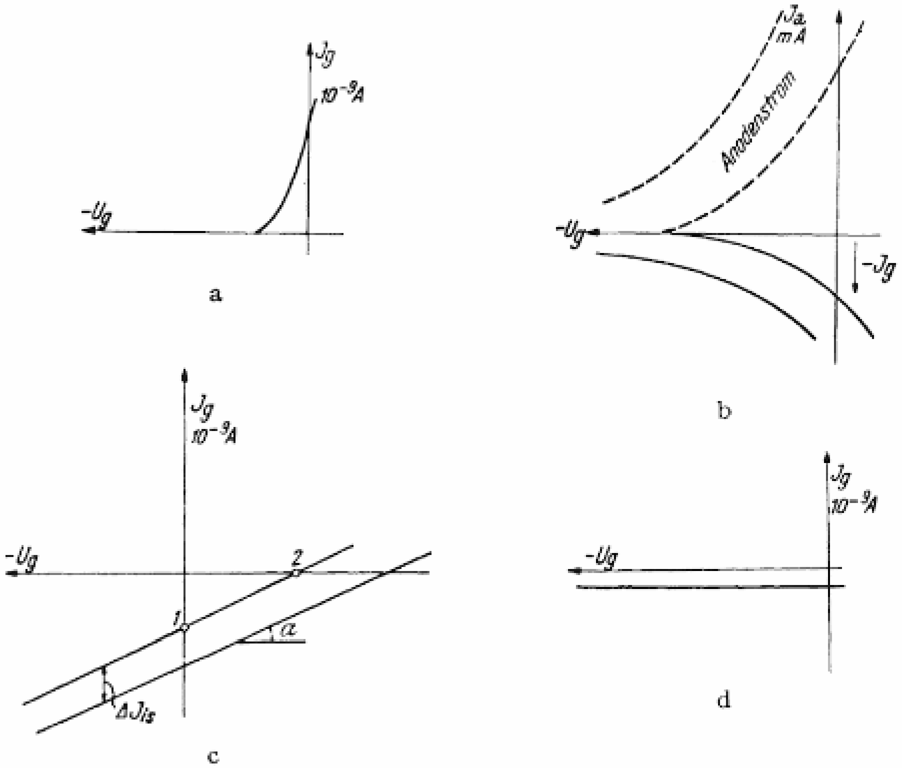


Abb. 15. Die verschiedenen Anteile des Gitterstromes.

a Der positive Gitterstrom (Elektronenstrom), b der Ionen-Gitterstrom, c der Isolationsstrom bei zwei verschiedenen Anodenspannungen, d der Reststrom (hauptsächlich Photoströme).

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.

Remark: In the 30s of the last century measurements were made for the tubes AC2, AF3, AL4 and G541 using a vacuum pump (4).

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 is 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 (Barkhausen 2).

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, especially when there are other gas molecules present additional to air, e.g. CO (carbon monoxide) that is released from metal parts and the activation of the cathode, 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.
- Vacuum degradation is mostly the result of gas eruptions especially from the anode due to overload(7).
- Tubes with two systems may have completely different grid currents. This is particularly true for tubes that have been subjected to high temperatures during operation (tube in a screen can, e.g. ECC85).
- 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.

It is crucial for this kind of vacuum test to be performed in the negative grid voltage area below the initial current threshold. The percentage of grid current change has good significance.

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":

Meldungen | Heizung | Kurzschlusstest | statische Dat

Ig (System: 1/2/3)[µA]:0,746 / 0,00347 / 0
Vakuumfaktor: 0,00007500
Änderung Ia: 0,4 [%], IgR: 7,843 mA, Ig|R: 7,813 mA

Further they are recorded in the result table:

Messwert IA [mA]		
bei UG2[V]		
Ri [KOhm]	5,2	5,5
Ig [µA]	0,746	0,00347

Of course they are also stored together with the measured data and printed on the measuring protocol. The grid current can also be output when printing labels, either in µA or nA.

The grid currents are copied to the list of measured tubes:

Liste der gemessenen Röhren

->Zwischenablage | laden (csv) | speichern unter (csv) | Tabelle löschen

tube	1: %	Ik	Ia	Ig2	S	µ	Ri	2: %	Ik	Ia	Ig2	S	µ	Ri	3: %	Ik	Ia	Ig2	S	µ	Ri	Ig[µA]	Ig[µA]	Ig
E88CC	66	9,906	9,906		7,43	36,3	5,2	52	7,806	7,806		7,21	36,3	5,5								0,746	0,00347	

Why is Grid Current undesirable?

- With grid current the tube is no longer controlled with zero power. The grid port gets lower resistance and loads the preceding stage resp. voltage source. If the needed currentcan not be sourced then distortions will occur
- Unsteady current changes may cause crackling noise (these disturbances are often caused by insulation faults)
- The voltage drop across the grid resistor may lead to a shift of the operating point "Punch through"(5)P.93, especially with end tubes: These tubes get relative hot. The heating causes increase of grid current with bad tubes (thermal grid emission). The operating point shifts. Anode current rises and heats up the tube even more. This can lead up to destruction of the tube or even the device (overload of power supply or of the output transformer). Countermeasures: avoid high-resistance grid voltage supply, generate grid voltage with cathode resistor

How large may the grid current actually be?

This is a difficult question. Tube data sheets normally do not address the grid currents. Data are only occasionally available. Also the standard literature presents only hints. I collected the following facts:

Barkhausen (2) states the following:

Grid current	Grid current at Ia=10mA	Vacuum factor
bothersome	10 µA	0,001
good	5 µA	0,0005

These statements are from the early days of tubes. With modern tubes better values can be achieved.

Bergtold (5): Vacuum test due to change of the anode current: With a series resistor of 1MOhm the current change may be 20% maximum. The limit for maximum allowed grid current depends on the grid resistor and how the grid voltage is generated.

Measurements from a friend and me with a larger number of new and used preamplifier tubes (ECC and others) showed a broad spectrum of grid currents from 20nA up to and above 2µA. Zollner(1) also states in an article that the range of variation of the grid currents is quite large.

This is presumable the reason why the tube manufacturers do not provide information in the data sheets.

In the data sheet of the E83CC I found: Ig <0,2 µA, end of life: 0,5 µA.
Datasheet (Telefunken+Siemens) C3g,: Ig <= 0,5 µA

A befriended tube dealer told me the following limits that he came to know from tube manufacturers:

- Maximum Ig should be <= 1uA (this is already high).
- Good tubes <= 0,5uA
- Low tolerance tubes (E83CC, E86..) <=0,2µA or 0,3µA (Philips)

In Practice:

The permitted grid current depends on the circuit (as well as tubes with moderate emission may still work perfect in specific circuits). There is no hard limit.

Therefore I defined the following limits:

	Very good: Ig <=	Change of anode current <= at R 1,2 MOhm	Eventually still usable Ig <= (end of life)
Low tolerance tubes (E83CC ..)	0,1 µA		0,5 µA
Small signal tubes (e.g. EC, EF)	0,1 µA	5-20%	1 µA
End tubes (EL)	0,2 µA	3-8%	1 µA

Additional to the grid current in nA we can also consider the relative change of the anode current in %. However this change depends on the tube's properties (S and Ia) and should be considered individually for each tube.

One should also note that the RoeTest uses a Rg of 1,2 MOhm and fixed control grid voltage for measurement. End stages are usually built with automatic grid voltage generation with a cathode resistor Rk and also a much lower Rg; but e.g. in a high impedance AVC circuit Rg can also be several MOhm.

Practical Experiences:

To get stable measurement values for the grid current the tube must have working temperature. It is not possible to measure the grid current which the tube has during real operation with a cold tube. Practice shows that a warm up time of 180s at nominal load is reasonable.

If the tube is overloaded during the measurement (due to wrong parameters) too high (wrong) grid currents will be measured.

Common (good) measurement values for the grid current, done by measuring some hundreds of standard radio and television tubes, are normally in the lower up to medium two-digit nA range. With end stage tubes the current can sometimes also be in the upper two-digit range (varying from type to type). Grid currents in the three-digit nA range are rather rare.

Tubes (including new ones) that have been stocked for years without being operated may show bad values at the first grid current measurement. It is advisable to let the tubes cool down and measure a second time or if needed several times. Some tubes show good grid current values this way, others still show bad values; the latter are really bad tubes. I do not know what leads to the improvement of the measuring values, probably the getter absorbs harmful gas residues during the first operating minutes.

Tubes with two systems may have quite totally different grid currents. Especially noticeable are tubes that have been subjected to high temperatures during operation (tube in shield can, e.g. ECC85).

Literature List:

(1) Gitterstrom bei Trioden, Manfred Zollner, www.gitec-forum.de
(2) Lehrbuch der Elektronenröhren, 1. Band, Prof. Dr. H. Barkhausen
(3) Hochfrequenztechnik II, J. Kammerloher
(4) Vakuumbestimmung an mittelbar geheizten Empfängerröhren, G.Herrmann u. I. Runge
Zeitschrift für Technische Physik Bd19 1938 S.12
(5) Röhrenbuch, Bergtold
(6) verschiedene Röhrendatenblätter
(7) Funkschau 1943 Heft 2 S.26 Druckbestimmung an technischen Röhren durch Gitterstrommessung

I wish to thank all those people that helped me with their experience and information.