MULTPACTING IN THE PHASE BEAM MONITOR AT MMF

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Abstract

At Moscow Meson Factory linear accelerator a toroidal RF cavity was installed after fourth drift-tube accelerating cavity for beam phase monitoring. But a signal from the cavity was very weak and deteriorated and could not be used for determination of a phase of a beam. Further investigations have shown that a reason of the situation is a multipacting in the monitor cavity. The multipactor discharge arises in the RF fields generated by the proton beam in a very narrow gap of the cavity and that was its peculiarity.

This paper summarizes the calculations, experimental data and the discussion on this problem.

1 INTRODUCTION

One of the phase beam monitors for linear accelerator of Moscow meson factory is installed after fourth drift tube accelerating cavity (beam energy 94.41 MeV). It is a toroidal cavity with operating frequency 198.2 MHz. The cavity has relatively small diameter (23 cm) and to achieve the required operating frequency a very developed capacitive gap had been designed (Fig.1). A beam pulse excited the cavity, a signal is picked up by the loops and is used for phase and amplitude monitoring of accelerating field in accelerating cavities.

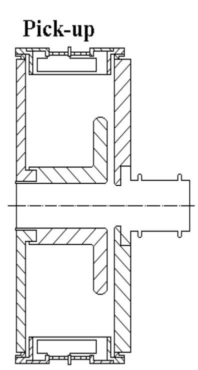

Fig. 1. Schematic view of the beam phase monitor.

After tuning and installation of the monitor there was an attempt to use it, but a signal was too weak and deteriorated and could not be used for determination of a phase of a beam. It was then found that the reason of weak signal is lowvoltage discharge in the monitor cavity and judging by all signs a multipactor one. But the gap in the cavity is rather narrow (≈ 4.5 mm), so the product $f \cdot d \leq 90$ MHz·cm, less than experimentally established edge of multipacting [1]. Also, the calculations made for the secondary electrons with zero initial velocity show, that resonance conditions are fulfilled at so low level of electric field that the electrons can not reach final energy before collision sufficient for emission coefficient $\sigma > 1$. First supposition was that the discharge is initiated and supported by the backgrounds electrons generated by the proton beam. But the measurements performed in the absence of a proton beam proved that the multipactor discharge in the gap exists independently.

In the paper we presents an analyze of multipacting process in a narrow gap, the results of calculations, experiments and discussion.

2 INFLUENCE OF INITIAL VELOCITY OF SECONDARY ELECTRONS ON RESONANT CONDITIONS

For beginning let's consider only the resonant conditions of multipacting not taking into account the final velocity of electrons needed for emission. Let's choose following parameters: f = 500 MHz, d = 1 cm and the plates made of copper. For this parameters all electrons involved in multipacting process reached necessary velocity before collision and besides we may compare the results with very reliable experiment [2] which has the same parameters.

A solution of a differential equation of electron motion in uniform electric field between two flat electrodes is expressed by following :

$$\frac{eE}{m\omega^2}[\theta\cos\varphi - \sin(\theta+\varphi) + \sin\varphi] + \frac{v_0\theta}{\omega} = d \qquad (1)$$

$$v_f = \frac{eE}{m\omega}[\cos\varphi - \cos(\varphi+\theta)] + v_0 \qquad (2)$$

where $\omega = 2\pi f$, f -frequency

- d - gap distance
- m - mass of electron
- e - charge of electron
- E - electric field gradient
- φ - initial phase of emitted electron
- θ- angle of flight
- v_0 and v_f - initial and final velocities

It is clear that influence of initial velocity increases with decreasing $\omega \cdot d$.

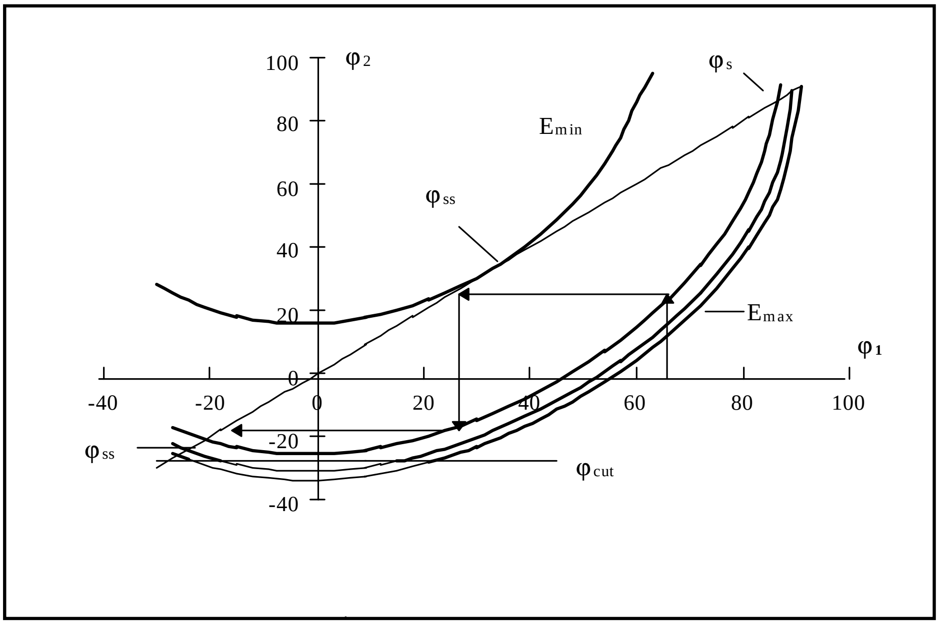

Fig. 2. Initial phase of electron emitted from electrode 2 in dependence on initial phase of electron from electrode 1 at different values of electric field gradient.

Let an electron live electrode 1 at phase φ_1, fly time θ and strike electrode 2. Secondary electron is emitted from electrode 2 at phase $\varphi_2 = \varphi_1 + \theta - \pi$. (We will consider a multipucting of order n = 1) Solving the equation (1) at different values of electric field gradient one may plot a function $\varphi_2(\varphi_1)$. And let an initial velocity for all secondary electrons $\mathbf{v_0} = 1.163 \cdot 10^6$ m/s (close to the most probable velocity for the secondary electrons [3,4]. This function is presented in Fig.2 together with a line of equal phases.

At some value of electric field gradient $\mathbf{E}_{min}$ the curve has one common point with the line of the equal phases: $\varphi_s = \varphi_1 = \varphi_2 = 32.5°$ and $\theta = \pi$. This phase is synchronous and stable. From collision to collision the secondary electrons have an initial phase closer to φ_e, i.e. an autophasing takes place. With farther increasing of **E** the curve $\varphi_1(\varphi_2)$ goes down and gets two synchronous phases φ_s and φ_{ss}, but it is easy to check that only φ_{ss} is stable one. The concentration of electrons and multiplication of their number take place around stable phase φ_{ss}.

With increasing of **E** the stable phase φ_{ss} becomes negative. But at certain value of **E** some electrons in their way to φ_{ss} have initial phase $\varphi < \varphi_{cut}$, can not leave an electrode and are lost. And the stable motion is completely terminated when $\varphi_{ss} \leq \varphi_{cut}$ .So, we may determine the boundaries of stable resonant motion of electrons as:

$$E_{min} = \frac{m\omega(\omega d - v_0\pi)}{e[\pi\cos(32.5^0) - 2\sin(32.5^0)]} \quad (3)$$

$$E_{max} = \frac{m\omega(\omega d - v_0\pi)}{e(\pi\cos\varphi_{cut} - 2\sin\varphi_{cut})}$$

It is clear that in fact the boundaries are not so sharp because of spread of initial velocities of secondary electrons. In the beginning the fastest electrons begin to move in resonance, then slower ones are involved in the process. With increasing of **E** the inverse process is observed: the slowest electrons come out of the game first. The exact moments when the multipucting starts or terminates depend very strongly on the particular value of σ, which can be changed even during an experiment because the multipactor discharge provides a conditioning of a surface.

Graphic in Fig.2 is useful to consider phase motion of the electrons. To determine a range of multipacting a diagram shown in Fig.3 is more convinient. Here we plot φ_s , φ_{ss} and φ_{cut} against electric field gradient. From this graphic we see that formally the resonant conditions for multipacting are fulfilled from E_{min} = 1338 V/cm to E_{max} = 2564.5 V/cm, but for the electrons with initial velocity close to zero these figures changes to 1515 V/cm and 1800 V/cm respectively. In this range all electrons are included in the process. So, we may say when a mulipacting may begin and may stop and at what values of electric field gradient it is the most probable.

In the Table 1 the calculation values of the multipacting range for chosen example and experimental ones for copper electrodes [1] are presented.

Table 1. Calculated and experimental boundaries of muiltipacting.

Calculations	1338-1515 V/cm	1800-2564 V/cm
Experiment	1321 V/cm	1884 V/cm

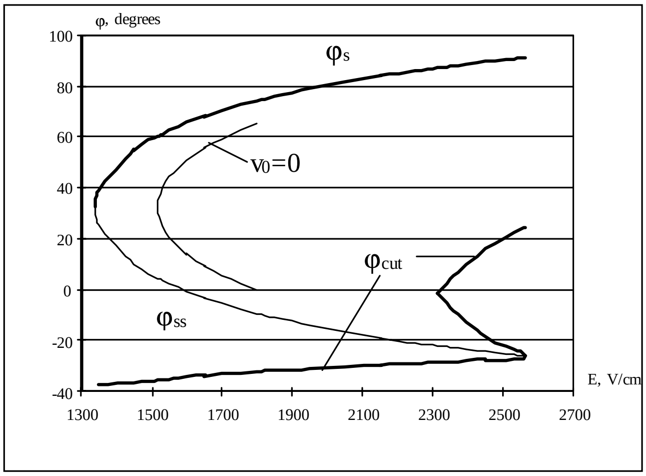

Fig. 3. Phase lines against electric field gradient.

3 MULTIPACTING IN A NARROW GAP

In a narrow gap an electric field gradient necessary for resonant motion of electrons is so low that a part of electrons can not get the energy which provides $\sigma > 1$. To compensate this losses emission coefficient must be rather high. We used the experimental values of σ from [5] where the authors tested a copper sample without any special cleaning and degassing (that is close to real life) and got σ =1 at energy of collision of 33 eV and maximal value of σ = 3.27.

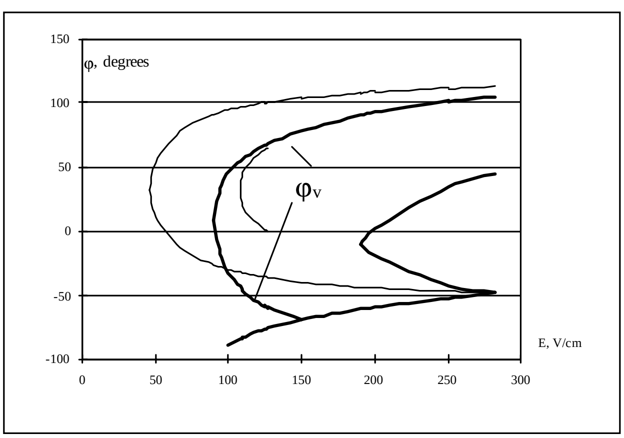

Fig.4. Phase lines against electric field gradient.

In our calculation for a narrow gap of beam phase monitor we added new line of phases $\varphi_v(E)$: the phases at which the electrons with given initial velocity $v_0 = 1{\cdot}10^6$ m/s get energy 33 eV. As we expected and as it is seen from Fig.4 this line reduced the range of valid phases. The electrons with zero initial velocity get energy 33 eV only in a small region around $\varphi_{ss} = 0$ and are almost completely excluded from multiplication process.

The range of E, where the dynamic conditions are fulfilled for given initial velocity $v_0 = 1{\cdot}10^6$ m/s begins at a point where lines φ_{ss} and φ_v cross each other and ends at a point where $\varphi_{ss} = \varphi_{cut}$ .The exact calculated figures and experimental result are given in Table 2.

Table 2. Calculated and experimental boundaries of muiltipacting in phase beam monitor.

Calculations	100 V/cm	282 V/cm
Experiment	129 V/cm	169 V/cm

It should be mentioned that the experiment values have been measured after some conditioning of the cavity. The original range of multipacting was larger and the discharge itslef was more intensive.

3 DISCUSSION

The calculations have shown that the resonant conditions for multipacting in the monitor cavity exists due to the spread of initial velocities of secondary electrons. But the real base for multipacting we should consider a high emission of not very “clean” copper and the big surfaces of the electrodes. This compensates the losses of the electrons with low initial velocities. Just after installation of the monitor the discharge level was broad and the discharge itself was very intensive. During the accelerators runs the monitor was being conditioned by the RF fields generated by proton beam. After this conditioning multipacting became so nonintensive and narrow that the signal from beam can overcome its level. Multipacting increases after short exposition of the cavity under bad vacuum between accelerating runs, but can be easy conditioned again during 10-15 minuts with the use of RF generator with power ≈ 1 W.

REFERENCES

[1] B.S.Fraiman, “Secondary electron emission”. “Nauka”, Moscow, 1969, (in Russian)

[2] D.Proch, D.Einfeld, R.Onken, N.Steinhauser, “Measurement of Multipacting Currents of Metal Surfaces in RF Fields”, PAC95, Dallas, 1995.

[3] I.N.Slivkov, “The Processes at High Voltage in Vacuum”, “Energoatomizdat”, Moscow, 1986 (in Russian).

[4] V.P.Kovalev, “The Secondary Electrons”, “Energoatomizdat”,Moscow, 1987, (in Russian).

[5] L.V.Grishin et al. “An Investigation of Secondary Emission RF Discharge at the Big Angles of Electron Flight”. Proceedings of Lebedev Physical Institute, Vol.92, pp.82-131, 1977 (in Russian).