MULTIPACTORING STUDIES IN ACCELERATING STRUCTURES

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Abstract

A multipactor discharge takes place in the accelerating tanks of the the Moscow meson factory linac. The RF-power level, the place and the characteristics of the discharge were determined basing on the experimental results and the computer simulation. The results of the investigation are given.

1 INTRODUCTION

The multipactor discharge, which occurs at certain levels of the RF electric field, is the frequent problem in the RF cavities and accelerating structures. The influence of the discharge may be so strong that it becomes impossible to reach a desired level of accelerating field. Accelerating system of the Moscow meson factory (MMF) linac consists of 5 drift tube cavities (intial part of linac, 0.75÷100 MeV) and 27 tanks of high energy part of linac (100÷600 MeV). Every high energy part tank consists of four accelerating disk and washer cavities connected with three bridge couplers. In the begining of high power testing of the tanks the multipactor discharge takes place in the tanks and electromagnetic field pulses break down. When the discharge begins the vacuum in the tanks deteriorates and the attempts "to jump" over the discharge diapason are not successful because of vacuum blocking system. In the process of surface conditioning the intensity of the discharge decreases, the vacuum becomes better and the level of RF power may be gradualy increased. After this increasing the discharge begins again. Also there was supposition that the multipactor discharge occurs in the cavities of the initial part of linac. The question of a place and a character of the discharge is intresting for design of accelerating systems analogous with MMF one.

2 BASIC RELATIONS

For the discharge parameter determination we used the analytical relations. The analytical estimations were then checked by computer simulation and compared with experimental data.

Let us consider a system of two flat electrodes with a distance d between them. An equation of electron motion in uniform electric field is

$$\frac{dx}{dt} = \frac{eU}{md}\sin(\omega t + \phi), \qquad (1)$$

where x - an electron coordinate, e and m - its charge and mass, U - an amplitude of applied alternative voltage, ω - frequency of the voltage, ϕ - an initial fase of electron motion from a surface of an electrod. Further in our consideration we will mean a "mean" electron with the most probable initial velocity V_0.

When the certain relations between the initial fase ϕ, the distance d, the amplitude U and frequency of oscillation ω are fulfiled, the primary electron reaches the opposite elctrod after n halfperiods of RF field oscillations with the velocity V_k, which is sufficient for the secondary electron generation. If the coefficient of secondary emission is greater than 1, the periodical repetition of this process creates a stationary electron bunch, which oscillates between the electrodes synchronously with the RF electric field [1].

From the decision of equation (1) we can obtain a condition for periodical motion of the "mean" electron:

$$U = \frac{1-(2n-1)\pi V_0/\omega d}{(2n-1)\pi\cos\phi + 2\sin\phi}U_0, \qquad (2)$$

where U_0 [V] $= 2.26\cdot 10^2(f\cdot d)^2$ $[MHz\cdot cm]^2$, and also a finite velocity of the electron at the drift angle $(2n-1)\pi$:

$$V_k = \frac{2U\omega d\cos\phi}{U_0} + V_0, \qquad (3)$$

Experimental investigations of the multipactor discharge shows [1, 2], that at the value of $fd > 300$ (that is truth in our case) we may neglect the initial velocity V_0 in formula (2). Taking into acccount that the initial fase may be equal to $0 \div \phi_{max}$ at $V_0 = 0$, we may obtain from (2) the estimations of the boundaries of the dinamic diapason of the electric field strength in which the drift angle is equal to $(2n-1)\pi$:

$$\begin{aligned} E^D_{\max} &= \frac{U_0}{(2n-1)\pi d} \\ E^D_{\min} &= \frac{U_0}{[(2n-1)\pi\cos\phi_{max} + 2\sin\phi_{max}]d}, \end{aligned} \qquad (4)$$

Electron gets a maximal finite velosity - velosity of collision - at zero initial fase. Let the most probable initial velosity of secondary electrons is $0.13\cdot 10^7$ m/s (5 eV) and let the diapason of finite velocities, in wnich the coefficient of secondary emission for copper is greater than 1, is $0.42 \cdot 10^7 \div 5.89 \cdot 10^7$ m/s (50 eV $\div$ 10 keV) [3]. Then we can obtain from (3) the diapason of the electric field strength in which the electron gets required velosity:

$$\begin{aligned} E^v_{\max}\,[V/cm] &= 3.26\pi f\,[MHz \cdot cm] \\ E^v_{\min}\,[V/cm] &= 0.164\pi f\,[MHz \cdot cm]. \end{aligned} \qquad (5)$$

It is clear that these diapasons (4) and (5) must overlap for the multipactoring discharge can exist.

3 MULTIPACTORING IN THE MMF ACCELERATING SYSTEM

The discharges occured in the cavities with drift tubes during RF power conditioning. There was supposition that these discharges are multipactoring. In fact, the conditions for existing of a multipactor discharge with n=1 between drift tubes are fulfiled in the cavities #1 and #2 and with n = 2$\div$5 in all five cavities of the initial part of the linac. The discharge with n=1 is the most probable, because a current density of discharge decreases as n^2 and the discharges with $n > 5$ are not practically observed [4]. But the character of the experimentally observed disharges does not prove this supposition.

Differing from the drift tube cavities the picture of the multipactor discharge in the high energy part tanks is very typical and stable. The discharges take place in the continuous diapason of RF pulse power which changes from time to time even for the same tank, but the average diapason is 40$\div$200 kW for all tanks. The equality of the RF pulse power diapason of multipactoring for all tanks and its continuity are important features.

The supposition that the multipactoring arises inside the cells of the DAW (in accelerating gaps in the first place) contradicts to three facts :

1. At the operating frequency of high energy part of linac 991 MHz the upper boundary of a multipactoring is E^v_{max} = 10 kV/cm. The dinamic conditions of the discharges with $n \geq 2$ satysfy this boundary : for example, E^D_{min} = 6.4 kV/cm for n = 2 and the first accelerating gap d = 2.6 cm of the first tank. But the gap in the fifth tank is larger by factor 2 and the multipactoring could not be observed beginning from this tank, because $E^o \sim d$.

2. Pulse power in a tank is P $=\alpha \overline{E}^2$, where $\overline{E}$ is an average electric field strength in a tank, $\alpha = 1.33 \cdot 10^7$ Wm^2/V^2 for the first tank. So, the upper level of RF power at which $\overline{E} = E^v_{max}$ is equal to 14 kW. No multipactor discharge with any n can arise above this level. This level is much less than the experimental upper power level of multipactoring.

3. The computer simulation of an electron motion in a accelerating gap with a real distributon of electric field [5] shows that the existence of radial components of field leads to an instability of the motion. The initial fases of the electrons correspond to defocusing direction of the radial components. The curvature radii of the drift tube "noses" are small (about 3 mm) and the electrons because their displacement miss the "noses" and strike the conical surfaces of the drift tubes in the best case or travel inside them in the worse one. In result : a) the electrons get aditional shift of fase and go out from the stable fase interval $0 \div \phi_{max}$; b) the most probable direction of the secondary electron motion is perpendicular to the conical surface of the drift tube and the displacement of the electron is increased. After two-three oscillations an electron with any initial conditions leaves the accelerating gap.

These facts forced to search for more suitable places in the tanks for multipactoring. It was found that such places are the transitions between halfcells of DAW cavities and the bridge couplers. The transitions are the same for all tanks and represent approximately the parts of rectangular waveguide with the sizes 2.5x170x210 cm. The standing wave H_{101} is exited in the transitions, so a longitudinal-uniform electric field exists in the gaps with d=2.5 cm.

The electric filed strength amplitude in the transitions is approximately equal to the average electric field on the axis of the tanks. This relation gives a simple expression for estimation of RF pulse power level at which the multipactoring can arise in the transition:

$$P = (E^D_{max}/\overline{E}_{nom})^2 P_{nom}, \qquad (6)$$

where $\overline{E}_{nom}$ and P_{nom} - nominal calculated values.

Basing on this formula the multipactor discharges with $n = 2 \div 4$ can exist at pulse power diapason 10$\div$70 kW. But the diapason for every n is very narrow - not more than 3 kW. The only explanation of the very broad and continuos experimental multipactor diapason $(40 \div 200kW)$ is the drift of multipactoring area during the increasing of power level from the center of the transition to its periphery, where the multipactoring conditions begin to be fulfiled due to sinusoidal distribution of the electric field. For example, at the power level in the tank of 70 kW the conditions for discharge with n = 2 are fulfilled in the center of the transition; at the power level of 200 kW the conditions for n = 2 exist on a kind of circle, where the equality $\sin(\pi x/l)\sin(\pi y/\lambda) = (70/200)^{1/2}$ is truth (l is a width of transition, λ - a wave length). This is about 4-5 cm from the wall of transition. The drift of the discharge area also explains the renewal of multipactoring after increasing of RF power level - the discharge begins on a new place, where a surface is not conditioned yet. The equality of the multipactoring RF power diapasons for all tanks are in agreement with the identity of the transitions.

The low current density of the discharges with $n \geq 2$ is compensated obviously by the big area, where the discharge takes place.

4 CONCLUSION

On the base of analytical estimations, computer simulation and experimental data it was concluded that the multipactor discharge does not take place in the DAW cavities of the high energy part of MMF linac. It was found that the multipactoring takes place in the transitions between the DAW cavities and the bridge couplers. In this case the broad and continuos experimental RF power diapason of multipactoring is explained by the drift of the multipactoring area from center to periphery of the transitions during the RF power level increasing and the equality of the multipactoring RF power diapasons for all tanks is in agreement with the identity of the transitions.

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