BEAM BREAKUP STUDIES FOR NEW CRYO-UNIT*

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Abstract

In this paper, we report the numerical simulations of cumulative beam breakup studies for a new cryo-unit for injector design at Jefferson lab. The system consists of two 1-cell and one 7-cell superconducting RF cavities. The study has been performed using a 2-dimensional time-domain code TDBBU developed in-house. The stability has been confirmed for the present setup of beamline elements with different initial offsets and currents ranging 1 mA - 100 mA.

INTRODUCTION

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson lab is on the way of 12 GeV upgrade. Among other activities, installation of new cryo-modules for RF injector is one. In this paper, we report the cumulative beam breakup (BBU) simulation study. In linear accelerators, cumulative BBU results when a beam traverses the accelerating structures off axis and thus couples to the dipole modes of the structure. This can occur when the beam enters the accelerator with a lateral offset or angular divergence. The coupling between beam and dipole modes can also occur when the structures themselves or the focusing elements are displaced from the nominal accelerator beam line. Such displacements occur in a random fashion and the displacement of the beam along the accelerator will exhibit a random behavior [1]-[2].

The layout of the system considered in this study is shown in Fig. 1. It consists of two 1-cell (6.35 cm long) and one 7-cell (70 cm long) suprconducting RF cavities with an energy gain of 351 keV, 198 keV and 3.87 MeV from the first, second and third unit respectively. The basic parameters of our study are shown in Table 1.

Table 1: Basic Parameters of Study

Initial beam energy	200 keV
Energy gain from Ist Unit	351 keV
Energy gain from 2nd Unit	198 keV
Energy gain from 3rd Unit	3.87 MeV
Required Beam Current	1 mA, 10 mA, 100 mA

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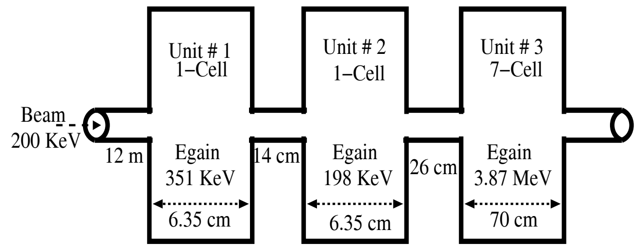

Figure 1: Schematic layout of the system considered in the simulations.

SIMULATION PROCEDURE

In this study, we have used a two-dimensional time-domain beam breakup computer program developed at Jefferson lab [3, 4]. This code is based on impulse approximation, i.e. the kicking time of the higher-order modes (HOMs) to the beam is infinitely short. This means that the cavity model follows the thin lens approximation. The HOM voltage is in general a complex quantity, having the real part (V_r) proportional to the electric HOM field and the imaginary part (V_i) proportional to the magnetic HOM field. A bunch of charged particles passing through an RF cavity modifies the real component of the HOM field according to [5]

$$dV_r = \frac{q\omega_{\mathrm{h}}^2}{2c}\left(\frac{R}{Q}\right)_{\mathrm{h}}(x\cos\alpha + y\sin\alpha) \tag{1}$$

where the subscript 'h' represents the parameters corresponding to the HOMs, q is the charge of a beam particle, c is the velocity of light in free space, ω_{h} is the angular frequency of HOMs, x and y are the displacements along the respective directions, and α is the HOM polarization angle in the xy-plane ($\alpha = 0^{\mathrm{o}}$ and 90^{o} correspond to the horizontal and the vertical polarization). The imaginary part of the HOM voltage causes deflections along the x and y directions as [5]

$$x' = \frac{V_i\cos\alpha}{V_b}, \quad y' = \frac{V_i\sin\alpha}{V_b} \tag{2}$$

where $V_b = pc/q$ is the beam voltage. Let us define the HOM damping time as $\tau_h = 2Q_h/\omega_h$ and phase at each time step Δt as $\phi_h = \omega_h\Delta t$. The time update ($t' = t + \Delta t$) of the HOM voltage is given by [5]

$$\begin{bmatrix} V_r \\ V_i \end{bmatrix}_{t'} = \exp\left(-\frac{\Delta t}{\tau_h}\right)\begin{bmatrix} \cos(\phi_h) & -\sin(\phi_h) \\ \sin(\phi_h) & \cos(\phi_h) \end{bmatrix}\begin{bmatrix} V_r \\ V_i \end{bmatrix}_{t} \tag{3}$$

where $\Delta t = 1/f_{\mathrm{rep}}$ is the step-size for time update, which is dictated by the beam repetition rate f_{rep}. To propagate particles between HOMs the code uses 4x4 transfer matrices. In these simulations, each cavity was split into two equal halves. The matrix of each half was calculated according to the procedure described above. All the HOMs were situated in the middle of each cavity. To simulate beam breakup, the beam starts with a finite initial offset in x and y and enters into the cavities. The details of the studies are discussed in the following section.

RESULTS AND DISCUSSION

To see the cumulative effect, we first run the simulation for beam with 200 keV initial energy, 100 mA beam current, beam repetition frequency f_{rep} = 1497 MHz and a 2 cm initial offset. To see the effect of Q values, we start with Q = 5 x 10^6 and go as high as Q = 5 x 10^{13}. The sub-figures shown in Fig. 2 are displacement versus time for different Q-values. We see the buildup phase of instability which is the signature of cumulative beam breakup followed by a falling time where the beam recovers and becomes stable. Increasing Q-value increases the instability build-up time and the recovery time from the maximum displacement up to Q = 1 x 10^8. The saturation is reached for higher values starting at Q = 2 x 10^8 beyond which we do not observe significant difference. The above observations are consistent with the results reported in [6]. This is also expected from the exponential term exp($-\Delta t/\tau_h$) of the equation (3). The characteristic decay time τ_h is significant only when Q is small for a given ω_h and becomes insensitive to any higher Q.

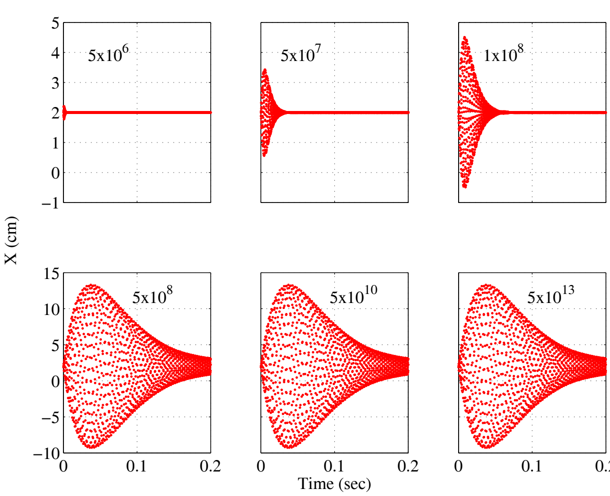

Figure 2: Transverse displacement versus time monitored at the exit of the final beamline element. Subplots correspond to different Q-values as shown. The beam has initial offset of 20 mm and 100 mA current.

Figure 3 shows the comparison of 10 mA with 1 mA beam current for the same initial condition. The noteworthy points are as follows. First, the general feature of the graph is almost the same as seen earlier. Second, the maximum displacement has a quadratic dependence on beam current. Third, the stability has been observed.

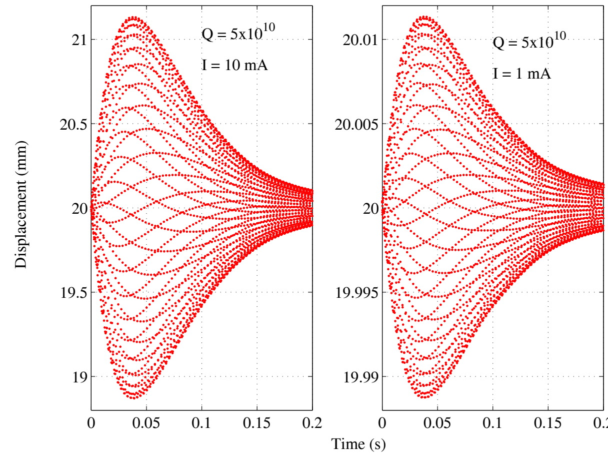

Figure 3: Transverse displacement versus time for 1 mA and 10 mA beam current with Q = 5 $\times$ 10^{10} and 20 mm initial beam offset at the exit of final beamline element.

Effect of Initial Offset

The effects of beam initial offset have been illustrated in Fig. 4. To perform this study, we have chosen 1 mA beam current and Q = 5 x 10^{10}. In this study we observe that the results are consistent with the earlier studies. The important conclusion is that the maximum displacement is proportional to the initial offset as expected.

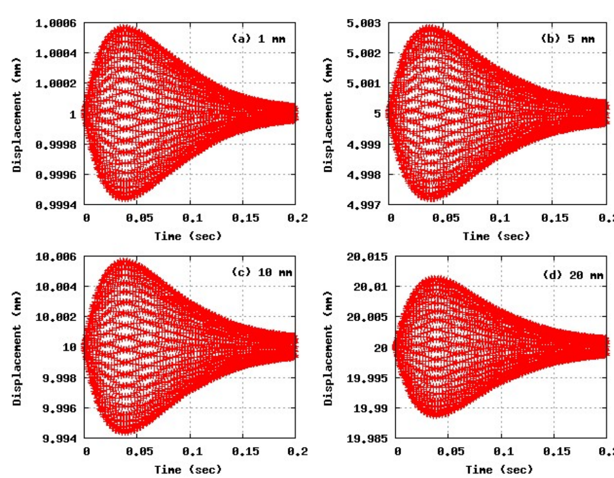

Figure 4: Transverse displacement versus time for different beam initial offsets monitored at the exit of final beamline element. Q = 5 $\times$ 10^{10} and initial current = 1 mA.

CONCLUSIONS

In this paper we report the cumulative BBU studies for new cryo unit for injector upgrade at Jefferson Lab. The simulations have been performed using a 2-dimensional time-domain computer program, which reveal the transient behaviour with the onset of beam blowup which settles down with the damping time of HOMs. The results are consistent with the typical signature of cumulative beam breakup. We have observed the linear increase of peak amplitude of displacement with the increase of initial offset. However, the peak amplitude of beam blowup varies quadratically with the current. The beam stability has been confirmed by the simulations for the wide range of current 1-100 mA with Q = 5×10^{10}. The detailed study with various combinations of beamline arrangements are in progress.

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