DEVELOPMENT OF RF SYSTEM MODEL FOR CERN LINAC2 TANKS

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Abstract

An RF system model has been created for CERN Linac2 Tanks. RF systems in this linac have both single and double feed architectures. The main elements of these systems are: RF power amplifier, main resonator, feed-line and the amplitude and phase feedback loops. The model of the composite system is derived by suitably concatenating the models of these individual sub-systems. For computational efficiency the modeling has been carried out in the base band. The signals are expressed in in-phase - quadrature domain, where the response of the resonator is expressed using two linear differential equations, making it valid for large signal conditions. MATLAB/SIMULINK has been used for creating the model. The model has been found useful in predicting the system behaviour, especially during the transients. In the paper we present the details of the model, highlighting the methodology, which could be easily extended to multiple feed RF systems.

INTRODUCTION

The CERN Linac2 accelerates protons up to 50 MeV. The main accelerating structure is of the Alvarez DTL type, going from 750 KeV to 50 MeV in three tanks. The Linac2 RF system [1] is such that Tank2 and 3 are fed by two power amplifiers each, connected to the cavity by feed lines and coupling loops, whilst Tank 1 is simpler, being fed by only one amplifier-feed line-coupler. For the double feed systems the calculations can become quite tedious, especially for the transients during cavity filling and beam loading. In order to address this issue a model of this system, based on MATLAB/SIMULINK, has been developed. We describe the model of only the Tank2-3, the model of Tank1 being easily derived from the other by suppressing one amplifier-feed line-coupler block. To reduce the computational effort involved in simulation, base-band models of the RF system have been developed using the complex envelope concept. In the following we describe the details of the model and the results obtained with it.

DEVELOPMENT OF THE MODEL

High Power RF System

The architecture of the high power RF system of Tank2 and 3 of Linac2 is shown in Fig.1. There are three resonant circuits driven by current sources. The length of the feed-lines and their couplings with the tank circuits and the detuning of the tank circuits are the adjustable parameters. Not shown in Fig.1 but present in the actual system is a trombone to adjust the relative phase of the two drives. The tube currents are proportional to the drive available from the lower power stages, which in turn is proportional to the signal from the Low Level RF system.

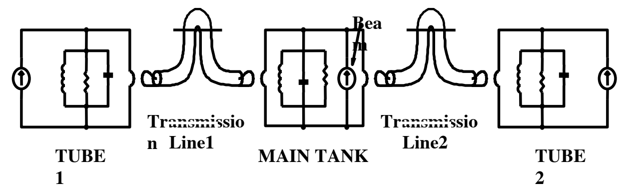

Figure 1: Architecture of the RF power system.

In order to find the dynamics of the voltage on the tank circuits, utilising the transformations offered by the two coupling loops, the complete RF power system is first transformed to the terminals of the Main Tank. Figure 2 shows the equivalent circuit of the power system after this transformation.

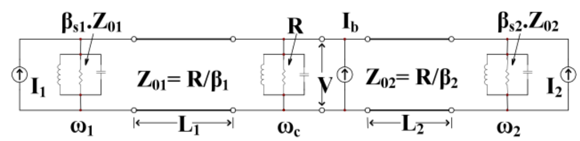

Figure 2: Equivalent circuit of the RF power system.

Under the assumption of high quality factor, the approximate differential equation describing the dynamics of the voltage on a resonator is given by [2]:

$$\tau\frac{dV}{dt} + (1 + j(\omega - \omega_c)\tau)V = V_g \qquad (1)$$

Where, V is the phasor representing the voltage across the resonator. ω and ω_c are the generator and the resonant frequency of the resonator, respectively. τ is the intrinsic decay time constant of the resonator field. V_g, the complex generator amplitude, equals the voltage across the resonator due to the drive currents when the resonator operates at resonance.

If V_{f1}, V_{f2} and V_{r1}, V_{r2} are the forward and reflected wave voltages at the Main Tank end of the two transmission lines and β_1 and β_2 the coupling coefficients of the two lines with the Main Tank, which has a shunt resistance R, then V_g for the Main Tank is given by:

$$R\left[\frac{V_{f1} - V_{r1}}{R/\beta_1} + \frac{V_{f2} - V_{r2}}{R/\beta_2} + I_b\right] \qquad (2)$$

In the transformed network:

$$V_{f1} + V_{r1} = V_{f2} + V_{r2} = V \qquad (3)$$

Using equations 2 and 3, the dynamics of the voltage on the Main Tank becomes:

$$\tau_1 \frac{dV}{dt} + (1 + j(\omega - \omega_c)\tau_1)V = \left[\frac{1}{1+\beta_1+\beta_2}\right][2\beta_1 V_{f1} + 2\beta_2 V_{f2} + R.I_b] \quad (4)$$

where, τ_l , the loaded decay time constant, is related to the intrinsic decay time constant, τ , by:

$$\tau_1 = \frac{1}{1+\beta_1+\beta_2}\tau \quad (5)$$

Expressing all the voltages and beam current, in equation (4), in terms of in-phase and quadrature (I, Q) components, two coupled first order linear differential equations, describing the model of the resonator, are obtained in the I-Q domain. The differential equations for the in-phase and quadrature components of the voltage at the output of the tubes are obtained in a similar fashion.

The phasor V_o representing the output of the transmission line is related to that at the input V_i by the following transformation:

$$V_0(t) = e^{-(\alpha + \frac{j\omega}{c})L} V_i(t - \tfrac{L}{c}) \quad (6)$$

where, L is length of the line, α is the attenuation constant and c is the electromagnetic wave velocity.

A very basic model has been employed for the RF power amplifiers. These are assumed to have constant output impedance. Their gain variation with drive power approximates the maximum gain curve as provided by the supplier. The power output of the amplifiers is converted into current source by assuming matched condition at the Main Tank end of the transmission lines. Obviously there is a lot of scope for refinement in this part of the model.

The model of the complete RF system is obtained by suitably concatenating the models of the RF power amplifiers, transmission lines and resonant circuits [3] as shown in Fig. 3.

The model described up to now calculates the voltages and currents in the transformed network. In order to obtain actual voltages and currents appropriate transformation ratios are applied. There are two types of transformation ratios.

a) Transmission line to the Main Tank:

Let this transformation ratio be 1:N_1. Then the defining relation for N_1 is:

$$N_1^2 Z_0 \beta = R \quad (7)$$

where, Z_0 is the characteristic impedance of the transmission line. In order to compute the voltage/current on transmission line we have to divide/multiply the voltage/current on the transformed network by N_1.

b) Tube output tank circuit to the transmission line:

Let this transformation ratio be N_2:1. Then the defining relation for N_2 is:

$$N_2^2 Z_0 \beta_s = R_t \quad (8)$$

where, R_t is the equivalent shunt resistance of the tank circuit of the tube. In order to get tube voltage/current we have to multiply/divide the voltage/current on the transformed network by N_2/ N_1.

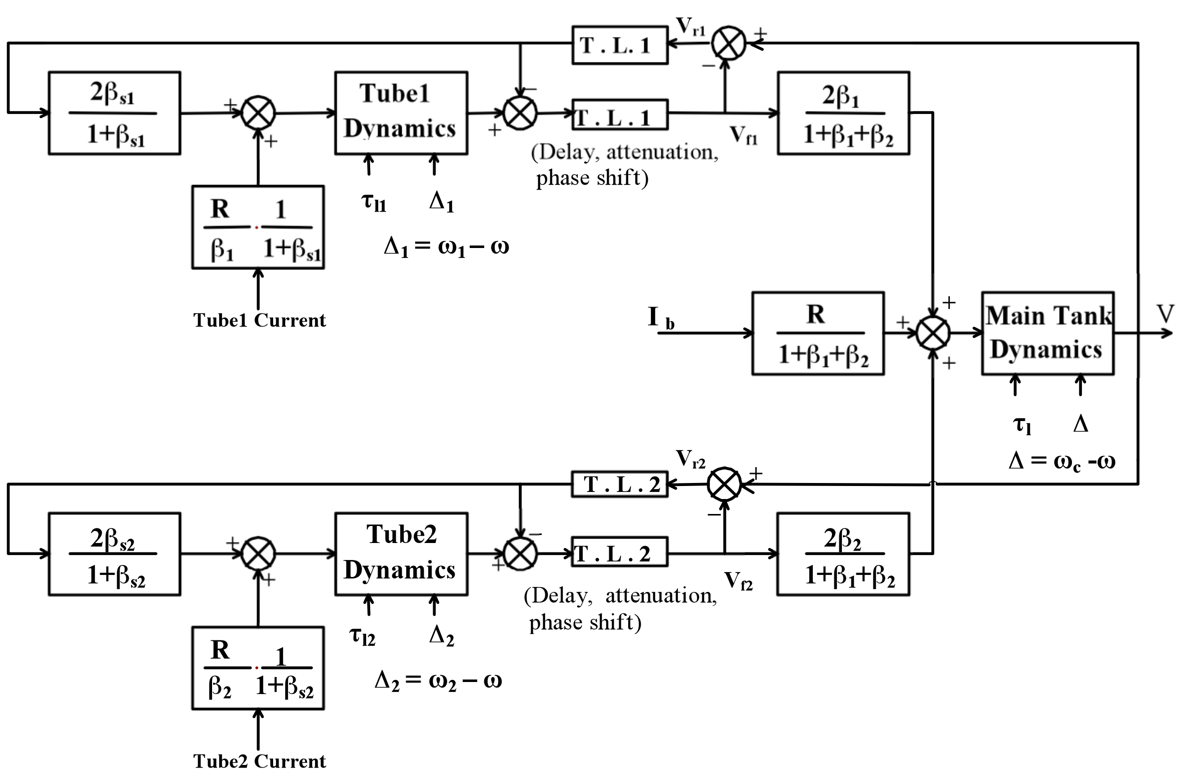

Figure 3: Calculations in the transformed network.

Low Level RF

Model for this part has been derived from the low level RF schematics. All the RF systems in Linac2 employ Generator Driven Resonator scheme. The amplitude and phase control is performed using amplitude and phase modulators placed in the drive path of the power amplifiers. Various features of these pulsed RF systems are easily modelled using building blocks available in SIMULINK. Both amplitude and phase control loops employ phase lag compensation, realized using operational amplifiers. One of the challenging aspects has been the modelling of the saturation effect in the operational amplifiers which perform the phase-lag compensation. To address this issue the operational amplifier has been modelled as a nonlinear first order system as shown in the Fig. 4. In this figure R equals the DC gain and 1/C the gain-bandwidth product of the operational amplifier. The limiter decides the slew-rate (MAX/C). The diodes represent voltage-dependent current sources which take away the current from the R-C filter once the voltage at the filter exceeds the limiting values.

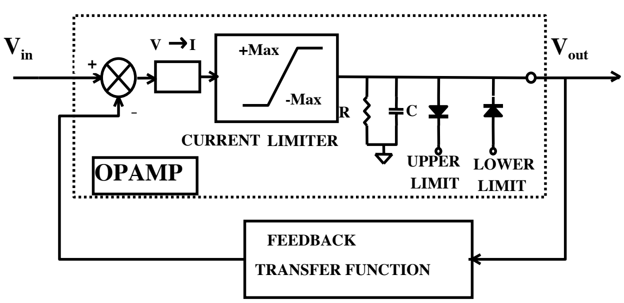

Figure 4: Filter with saturation.

DISCUSSION

With the help of the model, which has thirty-six settable parameters for the double-feed systems, a large number of operating scenarios can be easily created and 'virtual experiments' performed. This not only helps as a learning aid but also can be useful in fault diagnosis. Fig. 5 shows one such result when the various parameters are properly adjusted. The RF pulse lasts for 500 microseconds with beam entering the resonator 200 microseconds after the start of cavity filling for a period of 100 microseconds. The dotted line shows the reflected wave voltage. Figure 6 shows the same waveforms when the Main Tank side couplings are made 75% of their optimal values. Though the cavity voltage is still well regulated there is an appearance of reflected power at the expense of forward power. These results tally well with what is observed with the real system.

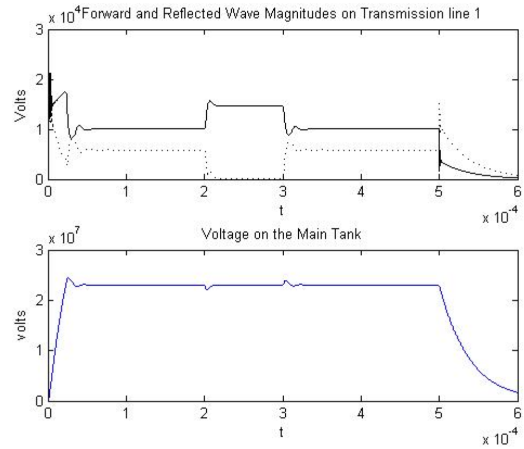

Figure 5: Properly Adjusted RF System

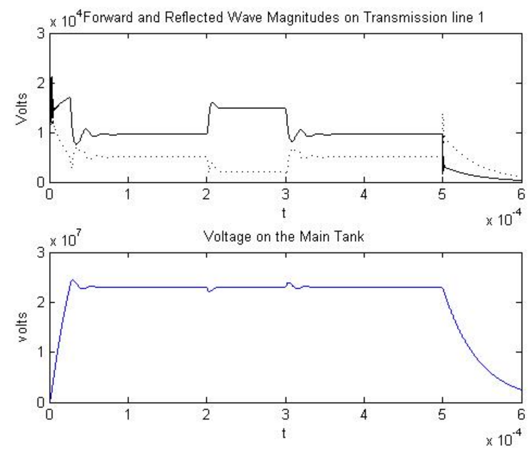

Figure 6: RF System - weak couplings to the main tank.

The procedure followed in developing the model of the high power system is generic in nature. Its extension to multiple-feed system is quite straight forward as simple additions are needed in equation 2-5 and Fig. 3.

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