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PHYSICAL PARAMETER IDENTIFICATION OF CROSS-COUPLED GUN AND BUNCHER CAVITY AT REGAE

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Abstract

A reasonable description of the system dynamics is one of the key elements to achieve high performance control for accelerating modules. This paper depicts the system identification of a cross-coupled pair of cavities for the Relativistic Electron Gun for Atomic Exploration - REGAE. Two normal conducting copper cavities driven by a single RF source accelerate and compress a low charge electron bunch with sub 10 fs length at a repetition rate up to 50 Hz. It is shown how the model parameters of the cavities and the attached radio frequency subsystem are identified from data generated at the REGAE facility.

INTRODUCTION

High field stability in phase and amplitude is the primary concern for the control of gun and buncher cavities at REGAE [1], a collaboration of the Center for Free-Electron Laser Science CFEL, the Max Planck Society, the University of Hamburg and DESY. Both the gun - a 1.5 cell cavity and the buncher - a 4 cell cavity are powered by the same klystron, Fig. (1).

The input to the klystron is modified through the feed forward tables. The required complex signal is implemented for the real and for the imaginary part separately. Power division after the klystron is obtained with the help of a T-shunt. It supplies the gun with 2/3 of the total power and the buncher with the remaining 1/3. It can be reasonably assumed, that the usage of one klystron for both the gun and the buncher cavity leads to cross-couplings between the two systems.

Signal detection, which is based on a MicroTCA.4 system standard [2], takes place in the gun and buncher respectively. For this the electromagnetic fields are measured by pick up antennas. The produced complex signal is then down converted to the intermediate frequency of 25 MHz and sampled with a frequency of 125 MHz. Results are then stored for the real and imaginary parts separately. The behaviour of the real and imaginary parts of the signals in the system can therefore be identified separately, though not independently, resulting in a two by two MIMO system for the gun as well as for the buncher. The frequency difference between the operating mode in each cavity, i.e. the π-mode, and the higher order modes lies between 2 MHz and 9.5 MHz. This difference is not enough to assume no influence of the higher order modes on the total field. The resulting electromagnetic field in the cavities is therefore a superposition of all the excited modes. This means that in the case of the gun one extra mode will be excited. In the case of the buncher there will be three extra modes. This behaviour is taken into consideration in the following system identification.

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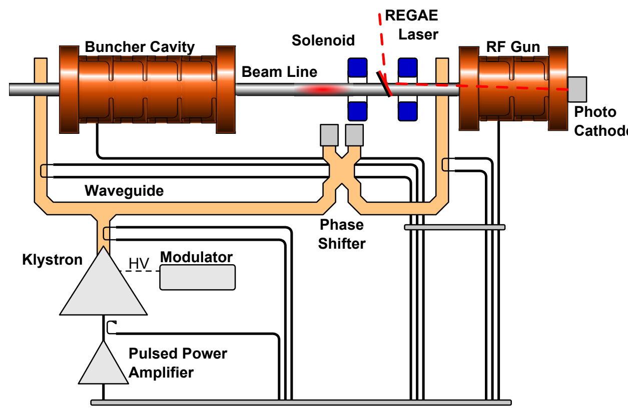

Figure 1: General cavity system set-up.

The system identification is obtained with the assumption that the cross-couplings between the gun and the buncher are negligible - case A and have to be taken into account - case B. It is shown that a consideration of the cross-couplings results in a higher accuracy of the acquired system model.

In the following the procedure of the system identification for the REGAE cavity system is explained. The used excitation signals, assumed model orders and time delays for the system are explained. Finally the results of a cross validation with the identified system model is discussed.

IDENTIFICATION

For the excitation of the system a pseudo random binary signal (PRBS) is used. This assures persistent excitation for the relevant frequency range. Two uncorrelated PRB-signals are used to excite the I and the Q channel of the input signal. The values for that are stored in the discrete time domain vector $u_I(k)$ and $u_Q(k)$ respectively. Accordingly in the frequency domain as $U_I(z)$ and $U_Q(z)$. The measured outputs are collected in the discrete time vector of $y_I(k)$ and $y_Q(k)$ and accordingly in the frequency domain as $Y_I(z)$ and $Y_Q(z)$. The general structure of the MIMO system is given by

$$\begin{bmatrix} Y_I(z) \\ Y_Q(z) \end{bmatrix} = \begin{bmatrix} G_{II}(z) & G_{IQ}(z) \\ G_{QI}(z) & G_{QQ}(z) \end{bmatrix} \begin{bmatrix} U_I(z) \\ U_Q(z) \end{bmatrix}, \qquad (1)$$

representing the dependencies between the two inputs $U_I(z), U_Q(z)$ and the resulting outputs $Y_I(z), Y_Q(z)$ of the system. The z specifies the system as discrete. The parameters in the transfer functions $G_{II}(z), G_{IQ}(z), G_{QI}(z)$ and $G_{QQ}(z)$ are the unknowns. They are determined by the system identification.

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Time delay The time delay between the input and the output signals of the systems are estimated a priori. This has the advantage that the time delays are not represented by the obtained model, which would lead to a higher model order. The obtained model is then independent of the time delays.

Model Order The model order of each transfer function $G_{II}(z), G_{IQ}(z), G_{QI}(z)$ and $G_{QQ}(z)$ has to reflect the general low pass behaviour, as well as the higher order modes relevant for the high frequency behaviour. Low pass behaviour can generally be represented by a model order of one. High frequency resonance modes, however are represented by a complex conjugate pole pair, i.e. an extra model order of two [3].

For case A, these assumptions lead to a model order of 3 for each transfer function of the gun. This reflects the low pass behaviour and one extra resonance mode. The model order for each transfer function of the the buncher is 7. This reflects the low pass behaviour and the three extra resonance modes.

To account for possible couplings between the gun and the buncher cavity, i.e. case B, a model order for both cavities equal to the sum of the model order of the gun and the model order of the buncher is used - a total model order of 10.

RESULTS AND DISCUSSION

The time delays between the input and the output are estimated with the help of a least squares approximation. The output signals of the identified system were compared to the real output values and the difference between the two was minimized in respect to variable time delays. Table 1 summarizes the results.

The following discussion compares the results from case A using a model order of 3 for the gun and a model order of 7 for the buncher with the results when using a model order of 10 for both - case B. The estimated time delays as well as the general model structure are the same.

Case A A validation of both obtained systems show a fit-to-estimation of 54 %. Figure 2 shows the measured data as well as the simulation results for the gun. The simulated data confirms the measurements as long as the measurements do not oscillate at high frequencies. It can be assumed that therefore a higher model order as used in case B is necessary.

Case B The fit-to-estimation when taking the cross-couplings into account and using a model order of 10 for both is 87 %. Figure 3 shows that the simulated data confirms the measurements even in the high frequency range. The higher model order reflects the high frequency behaviour more accurately.

Table 1: Time Delays given in µs

	Gun	Buncher
$t_{d,I}$	0.68	0.80
$t_{d,Q}$	0.64	0.80

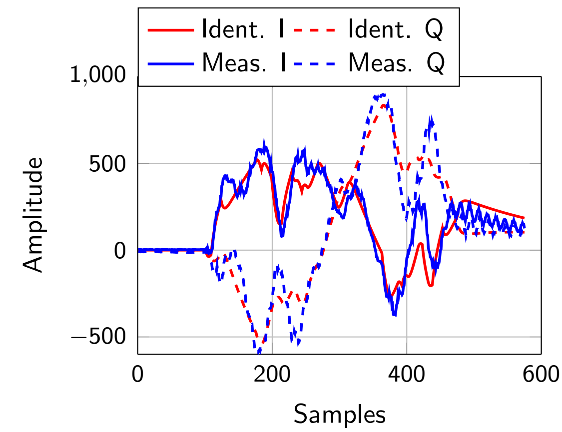

Figure 2: Comparison of measured and identified system response assuming no gun-buncher coupling.

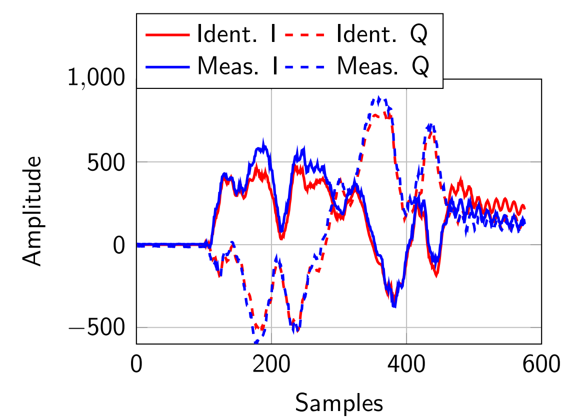

Figure 3: Comparison of measured and identified system response assuming gun-buncher coupling.

This is further confirmed when looking at the frequency behaviour of the gun and buncher systems as depicted in Fig. 4 and Fig. 5. Both show the expected low pass behaviour with low cross-couplings between the I and the Q channels. Note that in the case of the buncher a phase shift of 90^o in respect to the gun has to be taken into account. Any input $u_I(k)$ which is defined before the phase shifter will actually influence the buncher on it's Q behaviour and vice versa. In Fig. 5 this can be seen by the change of dominant gains in the representation of the I-Q, Q-I dependencies. The gun has a static gain of 0 dB whereas the static gain of the buncher is −10 dB. This reflects the power division between the two cavities, 2/3 for the gun and 1/3 for the buncher.

The high frequency behaviour confirms the influence of the higher order modes on the system. The gun shows a resonance peak at 9.5 MHz with a magnitude of −4 dB. This resonance peak coincides with the measured higher order mode resonance peak for the gun at 9.5 MHz. At 2 MHz and 50 MHz less dominant peaks with magnitudes of −17 dB and −23 dB are identified. Both resonance peaks cannot

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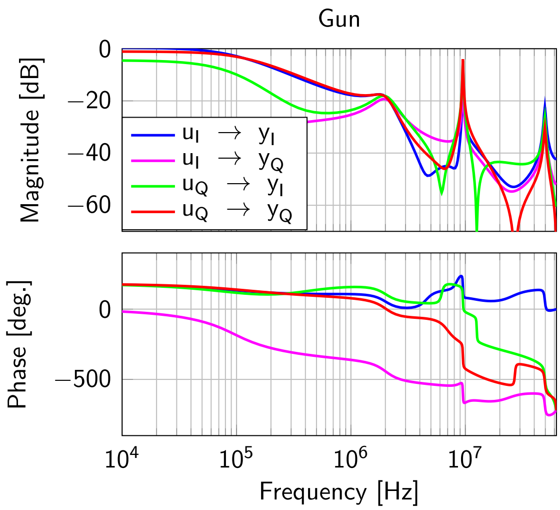

Figure 4: Identified frequency behaviour of the gun.

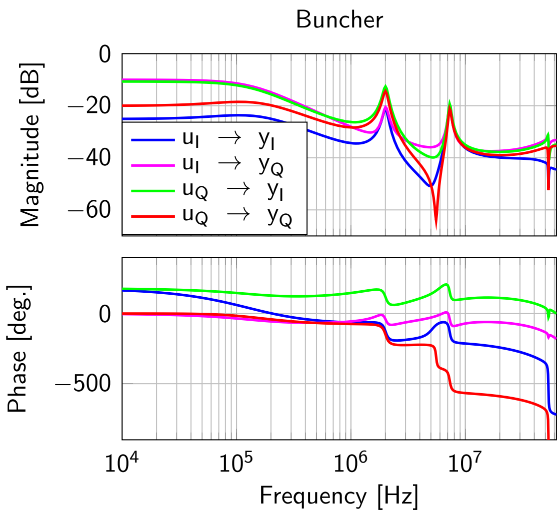

Figure 5: Identified frequency behaviour of the buncher.

be explained with the help of the system behaviour of the gun. The peak at 2 MHz, however does coincide with the measured resonance peak representing the first higher order mode of the buncher at 2 MHz. Thus confirming that the influence of the electromagnetic field of the buncher in the gun are not negligible.

The buncher shows resonance peaks at 2 MHz and 7.3 MHz with −12 dB and −19 dB of magnitude respectivly. Both coincide with the measured extra resonance peaks for the buncher at 2 MHz and 7.4 MHz. Similar to the gun a resonance peak at 53 MHz with a magnitude of −31 dB is identified which cannot be explained from previous measurements. Table 2 summarizes these results.

Table 2: Higher Order Resonance Peaks Obtained Trough Measurement [1] and System Identification

Gun			
measured resonance [MHz]	-	9.5	-
identified peaks [MHz]	2	9.5	50
identified gain [dB]	-17	-4	-23
Buncher			
measured resonance[MHz]	2	7.6	-
identified peaks [MHz]	2	7.3	52
identified gain [dB]	-12	-19	-31

CONCLUSION AND OUTLOOK

For a system identification of the Relativistic Electron Gun for Atomic Exploration (REGAE) the cross-couplings between the gun cavity and the buncher cavity are not negligible. It is shown that the excitation of higher order resonance frequencies in the buncher also reflects in the measured signals of the gun, therefore influencing the electromagnetic fields in the gun. The validation of the obtained systems for the gun and the buncher show high accuracy in low and high frequency ranges.

The time delay of the system is constant and has to be well estimated if a low model order, not reflecting the time delays, is to be identified. The dependency of a valid system identification and it's respective estimated time delays is high.

The obtained system can now be used for the design of a controller. Methods like the Smith Predictor can help take care of the time delays, which influence the system behaviour but are not represented in the obtained models.

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