CHARACTERIZATION OF THE RF SYSTEM OF NSLS X-RAY RING*

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Abstract

The proper intercavity phasing is required for a storage ring with multiple RF cavities to ensure momentum acceptance and lifetime of a stored beam. In this paper we present method for simultaneous measurement of the accelerating voltage and relative phase for individual cavity at operational conditions. Theory and experimental results for NSLS X-ray synchrotron are presented.

INTRODUCTION

After winter 2005 the upgrade project was finalized and the NSLS X-ray ring is equipped with four identical RF cavities. Cavities 1, 3 and 4 are fed by the individual transmitters, while cavity 2 has two amplifiers. Combined accelerating voltage is expected to be over 1 MV to have proper RF acceptance. Phasing errors of the RF cavities reduce effective voltage and therefore beam lifetime. At low energies synchrotron losses are significantly less than accelerating voltage. In this case the synchronous phase is close to zero and relative phase between circulating electron beam and field in the cavity does not depend on the field amplitude thus making phasing of the cavities straightforward.

At high energies the synchrotron losses are comparable with accelerating voltage and change of the synchronous phase should be taken into account.

EXPERIMENTAL SET-UP

The illustrating vector diagram is shown in Fig. 1. The effective accelerating voltage is a result of the vector sum of the voltages generated by each cavity. When power fed to a cavity varies so does the amplitude of effective accelerating voltage and therefore a synchronous phase of the electron beam.

We measured phase φ between a sum signal induced by the circulating electron beam on the horizontal stripline with field pick-up from a reference cavity. Both signals are available in the control room. Variation of the accelerating voltage in one or more cavities causes change of the synchronous phase resulting in the change of the phase between the electron beam signal and the reference cavity field. The amount of the shift depends on the individual cavity power and its phase. It should be noted that in general case with mismatched cavities the phase between effective accelerating voltage and cavity field varies when cavity power changes. And such variation was taken into account in the calculations.

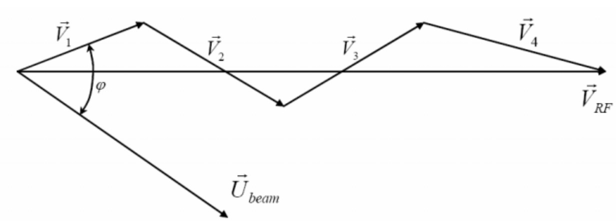

Figure 1. Vector diagram of the accelerating voltages and electron beam current.

The value of the measured phase can be found from the following formula:

$$\varphi = \varphi_{cable} \pm \varphi_{syn} \pm \varphi_{cavity}$$

where φ_{cable} is a phase shift in the connecting coaxial cables, $\varphi_{syn} = \arcsin U_{loss}/V_{RF}$ is a synchronous phase, U_{loss} are synchrotron losses, φ_{cav} is a phase of field in the reference cavity, and V_{RF} the effective accelerating voltage. Choice of sign depends on the actual experimental set-up.

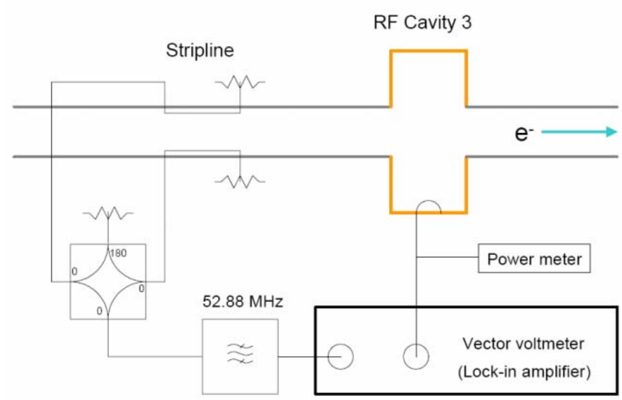

Figure 2. Experimental set-up for phasing of RF cavities of the X-ray storage ring. The change in the synchronous phase is monitored by a vector voltmeter.

The experimental set-up is shown in Fig. 2. The phase φ between the field pick-up from the reference cavity 3 and a signal induced by circulating electron beam was measured by vector voltmeter HP8508A. The available SR844 lock-in amplifier was found unsuitable for measurements due to the internal phase shift depending on the amplitude of the signal applied to the reference input. The stripline signal was additionally filtered by a bandpass filter tuned on the RF frequency (KC4-52.89M-1.M-50-7133 manufactured by TTE, Inc). The power in the cavities was monitored with Boonton 4300 RF power meter. Field pick-up signals from all four cavities were fed to four channels of 500 MHz digital oscilloscope WaveSurfer 454 manufactured by LeCroy. The cable

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delays are not known but were constant during the experiment. The levels of the intracavity power, measured by the power meter, are shown in Table 1.

Table 1: Measured cavity power levels.

	Cavity 1 Power	Cavity 2 Power	Cavity 3 Power	Cavity 4 Power
1	38.0 kW	43.2 kW	38.1 kW	35.6 kW
2	14.3 kW	43.4 kW	38.1 kW	35.5 kW
3	38.0 kW	16.3 kW	38.2 kW	35.5 kW
4	38.0 kW	43.3 kW	12.3 kW	35.6 kW
5	38.0 kW	43.4 kW	38.2 kW	11.7 kW
6	26.8 kW	43.4 kW	38.1 kW	20.4 kW
7	26.8 kW	29.4 kW	38.1 kW	39.5 kW
8	26.8 kW	43.4 kW	21.9 kW	39.5 kW
9	38.0 kW	31.2 kW	21.9 kW	39.4 kW
10	38.0 kW	31.2 kW	38.2 kW	19.8 kW
11	38.0 kW	43.3 kW	21.9 kW	19.8 kW
12	38.0 kW	43.4 kW	38.1 kW	3.5 kW
13	6.7 kW	43.4 kW	38.1 kW	39.3 kW
14	38.0 kW	6.7 kW	38.1 kW	38.3 kW
15	38.0 kW	43.0 kW	4.6 kW	35.4 kW
16	19.0 kW	43.2 kW	17.5 kW	35.3 kW
17	18.9 kW	43.3 kW	38.1 kW	17.6 kW
18	18.9 kW	21.4 kW	38.1 kW	39.4 kW
19	38.0 kW	21.4 kW	17.4 kW	39.3 kW
20	38.0 kW	21.4 kW	38.1 kW	17.1 kW
21	38.0 kW	43.1 kW	17.5 kW	17.1 kW
22	38.0 kW	43.2 kW	13.5 kW	11.3 kW
23	14.4 kW	43.2 kW	38.2 kW	11.3 kW
24	14.3 kW	16.2 kW	38.1 kW	39.1 kW
25	14.3 kW	43.1 kW	12.3 kW	39.2 kW
26	38.0 kW	16.2 kW	12.3 kW	39.3 kW
27	38.0 kW	16.2 kW	38.2 kW	11.3 kW

The cavity field contains high order modes excited by the electron beam. These HOMs affect Boonton 4300 RF power meter, therefore, the cavity voltages were obtained from the oscilloscope traces by a least square fit with a sine wave. The following parameters were fitted: amplitude, phase and DC offset.

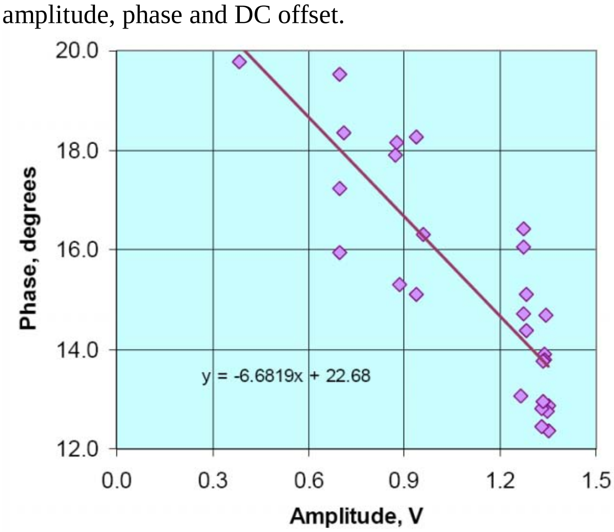

Figure 3. Dependence of phase difference between fields in the cavities 3 and 4 vs. amplitude of cavity 4 voltage.

One can expect that relative phases between cavities do not depend on the cavity power levels. However, it was found that cavity 4 has small but noticeable dependence of the field phase on the amplitude of the accelerating voltage. This dependence is shown in Fig. 3 and it was accounted for during calculations.

The amplitudes of the field pick-ups voltages, found from the oscilloscope traces, as well as phase between cavity 3 field and the electron beam signal are shown in Table 2. The observed phase jitter between cavity fields was 1.1°. It can be caused by accuracy of the fit with sine wave and/or phase modulation of the RF cavity voltages.

Table 2: Observed phase φ at different amplitudes of accelerating voltages monitored by the oscilloscope.

	Cavity 1	Cavity 2	Cavity 3	Cavity 4	φ, °
1	3.00	2.27	1.13	1.28	65.7
2	1.83	2.28	1.11	1.26	60.3
3	3.00	1.39	1.13	1.28	56.8
4	3.01	2.28	0.62	1.27	60.5
5	3.00	2.28	1.13	0.71	58.9
6	2.52	2.28	1.12	0.96	59.4
7	2.52	1.87	1.12	1.35	61.0
8	2.52	2.28	0.85	1.35	61.9
9	2.99	1.93	0.83	1.35	60.9
10	2.99	1.93	1.13	0.94	58.3
11	2.99	2.28	0.84	0.94	58.4
12	3.00	2.28	1.12	0.38	53.9
13	1.25	2.28	1.12	1.34	58.7
14	3.00	0.89	1.11	1.33	52.6
15	3.01	2.28	0.38	1.27	57.4
16	2.11	2.28	0.74	1.27	57.1
17	2.11	2.28	1.12	0.89	56.3
18	2.12	1.60	1.11	1.33	55.7
19	3.01	1.60	0.74	1.34	55.6
20	3.01	1.60	1.12	0.87	53.3
21	3.00	2.28	0.74	0.87	56.0
22	3.01	2.28	0.66	0.70	50.6
23	1.83	2.27	1.12	0.70	50.3
24	1.83	1.39	1.13	1.35	50.6
25	1.83	2.28	0.62	1.33	54.3
26	3.01	1.39	0.62	1.34	50.2
27	3.01	1.39	1.11	0.70	46.3

The eight parameters were fit to approximate the obtained dependence of the phase on the levels of the RF voltages: four individual phases for each cavity and four coupling coefficients (ratio between accelerating voltage and pick-up voltage). The results of the fit are shown in the Table 3. The absolute values for accelerating voltages were obtained assuming synchrotron losses of 790 keV per turn.

Table 3: The RF system parameters obtained from the fit.

	U, kV	φ, degrees
Cavity 1	303	5.9
Cavity 2	331	28.0
Cavity 3	311	0 (reference)
Cavity 4	258	32.6

The phase shift on cavity 2 reflects the fact that it is fed by two amplifiers and it is possible to deliver more power into the electron beam in this system. Phase shift in the cavity 4 was confirmed by independent measurements at injection energy and was corrected.

CONCLUSION

The established procedure allowed measurement of the voltages and relative phasing of multiple cavities installed on the storage ring in the operational conditions.

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