LOCAL COMPENSATION-REMATCH FOR ELEMENT FAILURES IN THE LOW ENEFGY SECTION OF THE C-ADS LINAC

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Abstract

Due to the requirement of high reliability and availability for the C-ADS accelerators, a fault-tolerant design is pursued. The effects of transverse focusing element failures in different locations have been studied and the schemes of compensation by means of local compensation-rematch have been investigated. For the solenoid failures in the low energy section, a new method by using a neighbour cavity with reverse phase is used to maintain the acceleration and the focusing in both transverse and longitudinal phase planes With the help of other neighbouring elements, almost no growth in the normalized RMS emittance and modest growth in the halo emittance have been observed. For the cavity failures, the compensation on both the beam energy and phase can be performed by a self-made code.

INTRODUCTION

The extremely high reliability and availability are considered to be the most important characteristics for the C-ADS accelerators [1]. Besides all the hardware is operated with conservative performance and redundancy, it is also important to have fault-tolerant capabilities in the physics design [2, 3]. Anyway, no matter how we improve the hardware's reliability, it should be expected there is some failures of important devices, even with a much lower frequency, to happen during its operation life, and the accelerator design has to deal with these situations. Local compensation-rematch methods for major component failures at C-ADS linac were presented in Ref. [4]. Since then, the improvement of the methods has been obtained. In the following, we will mainly focus on the compensation-rematch methods in the low energy sections.

REMATCH FOR SC SOLENOID FAILURES

Solenoid failures perhaps are the most difficult situations for rematch, especially in the low energy sections. As there is only one solenoid in each cell for transverse focusing, once it fails in operation, the beam will become much mismatched and get heavy losses if nothing is done. We take the failure of a solenoid in the middle part of the Spoke021 section as an example, as shown in Fig. 1.

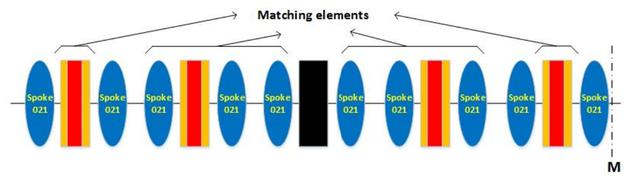

Figure 1: Rematch method for a solenoid failure in the middle part of the Spoke021 section.

The easiest way to rematch for the failure is to readjust the neighbouring solenoids. However, it was found that the emittance growth is quite large with this method. The main reason is that the transverse phase advance per period is very large at low energy and the RF defocusing in the transverse phase planes is very strong. Then we adopted a method by changing the synchronous phase of the first cavity in the same cell from negative to positive, so that it regains the focusing in the transverse plane. If the original focusing structure with solenoid is a DFD in the transverse planes and an FDF in the longitudinal plane, now it becomes an FD and a DF in the transverse and longitudinal planes, respectively.

With the help of other neighbouring solenoids and six cavities, compared with the four solenoids and four cavities rematch situation that have been done before, we can obtain a good rematch, as shown in Fig. 2. Careful optimization has been done that avoids the distortion in the bucket and the emittance in the longitudinal phase plane due to large beam phase width. The evolutions in the rms and fractional emittances are shown in Fig. 3. The parameters of the involving cavities and SC solenoids before and after the rematch for the failure are shown in Table 1.

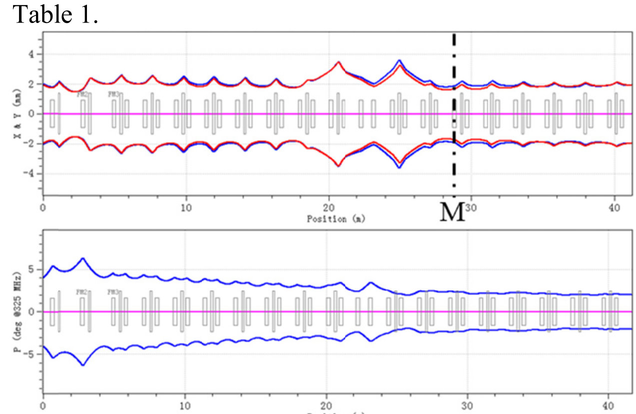

Figure 2: Envelope in the Spoke021 section in both transverse and longitudinal plates after the rematch of the solenoid failure in the low energy section

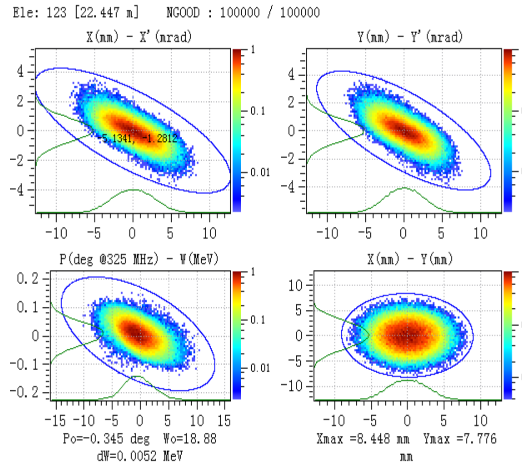

Figure 3: Phase space of the RF cavity exit with opposite synchronous phase after the rematch method has been improved

Table 1: Parameters of the Cavities and the Solenoids for the Rematch of a Solenoid Failure in the Spoke021 Section.

Cavity Number	**1**	**2**	**3**	**4**	**5**	**6**
Initial RF phase	-33°	-33°	-33°	-33°	-33°	-33°
After rematch	-23°	-40°	33°	-45°	-22°	-22°
Initial voltage / MV	0.96	0.98	1.10	1.12	1.20	1.21
After rematch / MV	0.66	1.05	0.69	1.47	1.07	1.46
Solenoid Number	**1**	**2**	**3**	**4**	**5**	
Initial field / T	2.91	3.03	3.16	3.22	3.19	
After rematch / T	2.16	2.80	---	3.11	2.56	

The Twiss parameters at the matching point "M" after rematch are shown in Table 2.

Table 2: Twiss Parameters at the Matching Point for the Rematch of a Solenoid Failure in the Spoke021 section

Twiss parameter	**Alpha x**	**Beta x / m**	**Alpha y**
Initial	0.29	3.12	0.23
After rematch	0.26	3.15	0.32
Twiss parameter	**Beta y / m**	**Alpha z**	**Beta z / m**
Initial	2.74	0.40	2.09
After rematch	2.60	0.38	2.17

After the rematch, the normalized rms emittance growths at the end of the Spoke021 section are 6.3%, 5% in the two transverse planes and 0.4% in the longitudinal plane. But the halo emittance growths along the main linac are still evidently larger than in the nominal case, but significantly better than the results in Ref. [4], as shown in Fig. 4.

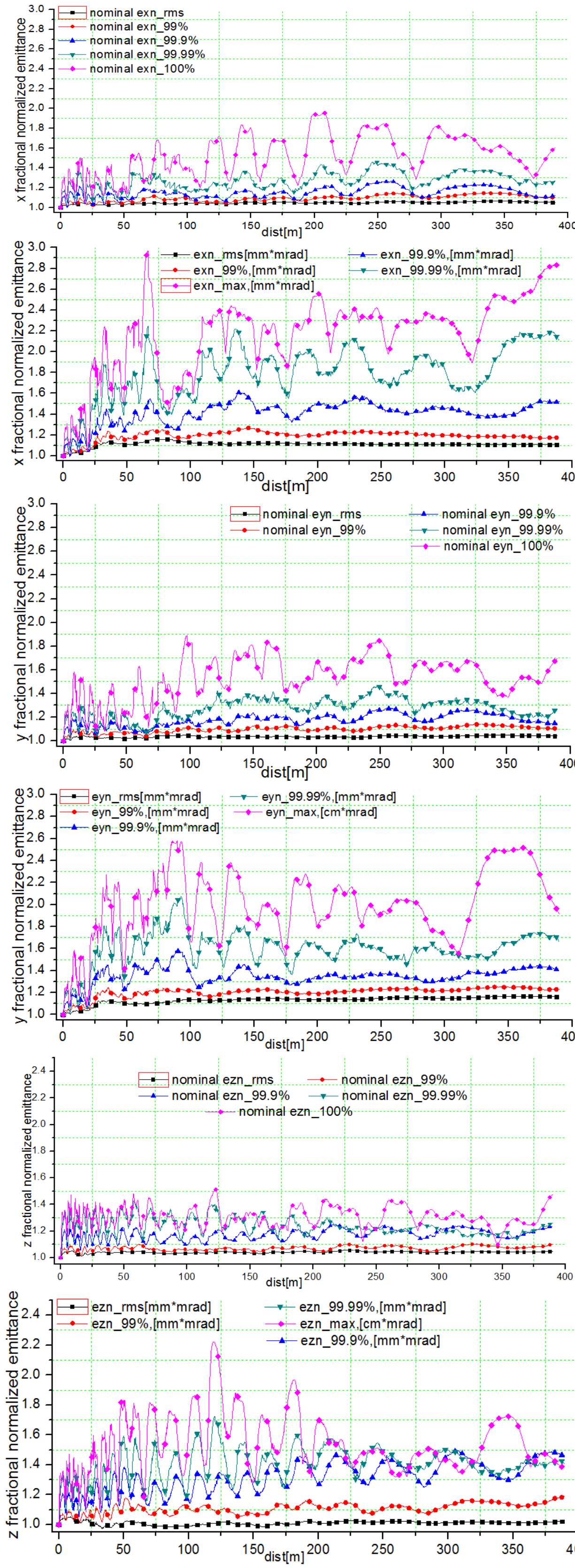

Figure 4: Halo emittance evolutions after applying the local rematch to the failure of a solenoid in the middle part of the Spoke021 section.

ISBN 978-3-95450-122-9

We have also studied the SC solenoid failures in the Spoke040 section. As the energy increases and the phase advance per cell becomes smaller, the rematch becomes easier, and only by using the SC solenoids in the neighbouring cell as matching elements one can achieve the matching goal. The halo emittance growth is not evident in both the longitudinal and transverse planes.

The rematch method for the failures of the quadrupole magnets in the high energy section (Ellip063 and Ellip082 section) has also been studied [4]. Unlike the case of solenoid failures in the low energy section, there is no need to take the neighbouring cavities as matching elements in the rematch. After rematching, the normalized rms emittance growth keeps very small along the downstream part and the halo growths are also evident especially in the two transverse planes.

COMPENSATION- REMATCH TO CAVITY FAILURE WITH PHASE COMPENSATION

When we carry out the local compensation-rematch study for cavity failures with the TraceWin code [4], the energy loss due to cavity failure can be correctly compensated. The rematch on both cavity and transverse focusing element failures can be achieved. However, the compensation for the arrival moment at the matching point is not correct because the code fits the RF phases for the downstream cavities automatically without taking into account the energy change due to the failed cavity. This does not fully meet the requirement for the local compensation-rematch method. This means the phases for all the downstream cavities should be readjusted.

To solve this problem, we have written a dedicated code-LOCCOM based on MATLAB to search for the fully local compensation schemes. With the code, we can carry out the compensation-rematch in two steps: first, it is easy to find a good setting of the compensation cavities to achieve the matching in the beam energy and the arrival time of the reference particle at the matching point; second, the matching in all the three phase planes is performed at the matching point by using the cavities and the neighbouring transverse focusing elements while maintaining the energy and arrival time. Several iterations of Step 1 to Step 2 loop are needed to obtain a satisfactory compensation-rematch scheme. Besides, the Genetic Algorithm is adopted in the code to find the final solution.

As an example, a cavity failure in the middle part of the Spoke021 section is studied with LOCCOM. (see Fig. 5).

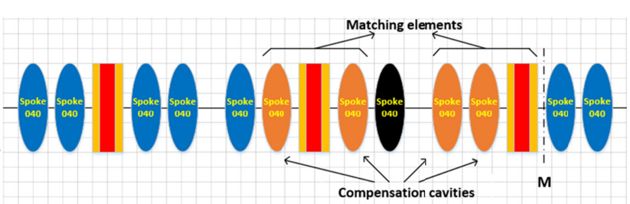

Figure 5: Local compensation method with LOCCOM

The obtained parameters for the matching elements with LOCCOM are put into TraceWin to check the compensation-rematch effect. We find that the Twiss parameters remain matched at the matching point after the compensation of both energy loss and phase difference, the envelope of both three plates are shown in Fig. 6.

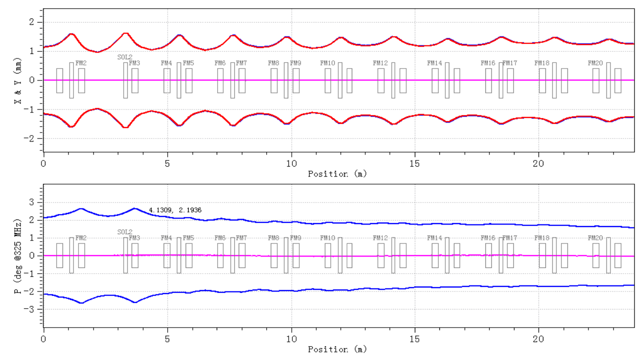

Figure 6: Envelope of spoke 021 section in both transverse and longitudinal plates after the rematch of the cavity failure in the low energy section

The results above are based on zero current which means the space charge effect has not been considered. The genetic algorithm has also been brought in for the code optimization. Further development by including the space charge is under way.

CONCLUSIONS

The local compensation-rematch method for the transverse element in the low energy section has been studied further. It is efficient to keep the good beam quality in case of failures of main elements. Though nearly no further the rms beam emittance growth happens after applying the method, the growth in the halo emittances are evident but still under control, especially in the Spoke021 section. The method that we take positive phase for one of the cavities in the same cell after the solenoid failures has been applied, and the emittance growth tells us the viability of such creative method. Besides the code-LOCCOM for the cavity failure compensation has also been optimized with the Genetic Algorithm, further work for code optimization will be done next.

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