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LOCAL COMPENSATION-REMATCH FOR THE C-ADS ACCELERATOR ELEMENT FAILURES WITH SPACE CHARGE

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Abstract

In order to the requirement of high reliability and availability for the C-ADS accelerators, besides all the hardware which is operated with conservative performance and redundancy, a fault-tolerant capabilities has been proposed in the design. The effects of focusing element failures in different locations have been studied and the schemes of compensation have been investigated with the help of local compensation-rematch. 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 by means of other neighbouring elements, almost no growth in the normalized RMS emittance and modest growth in the halo emittance have been observed. However, the compensation work above is based on the TraceWin code, which has not been considered the phase compensation, a code based on MATLAB is under developing to compensate the arrival time at the matching point that the genetic algorithm has also been considered.

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.

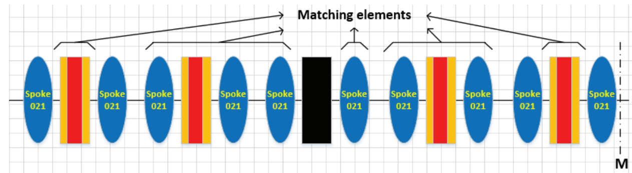

Figure 1: Rematch method for a solenoid failure in the middle part of the Spoke021 section.

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, we can obtain a good rematch after optimization [4], 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 parameters of the involving cavities and SC solenoids before and after the rematch for the failure are also shown in Table 1.

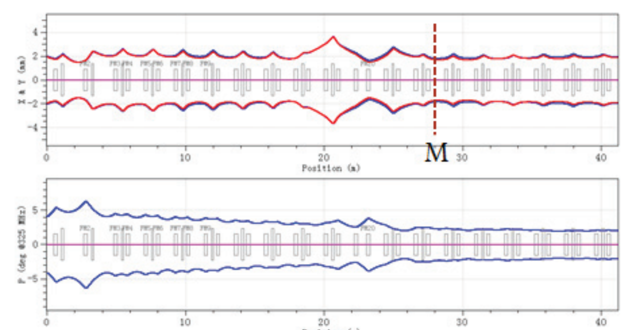

Figure 2: Envelope in the Spoke021 section in both transverse and longitudinal plates and the longitudinal phase section also been shown after the rematch of the solenoid failure in the low energy section.

After the rematch, the normalized RMS and halo emittance growths at the end of the Spoke021 section are not obvious in both transverse and longitudinal planes. Therefore, error analysis [5] has been done to check the reliability of the result which is shown in Fig. 3 and Fig. 4.

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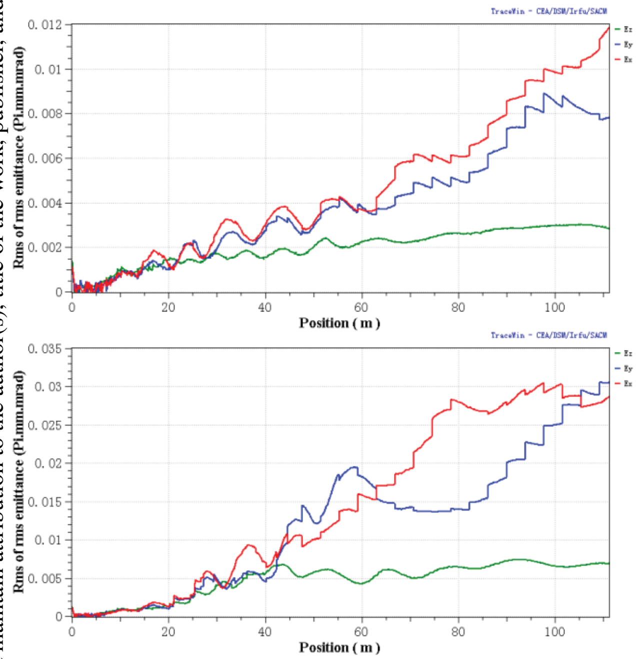

Figure 3: The nominal emittance evolution (the upper picture) and the corrected one (the lower picture) with error analysis after the solenoid failure in the middle part of the Spoke021 section.

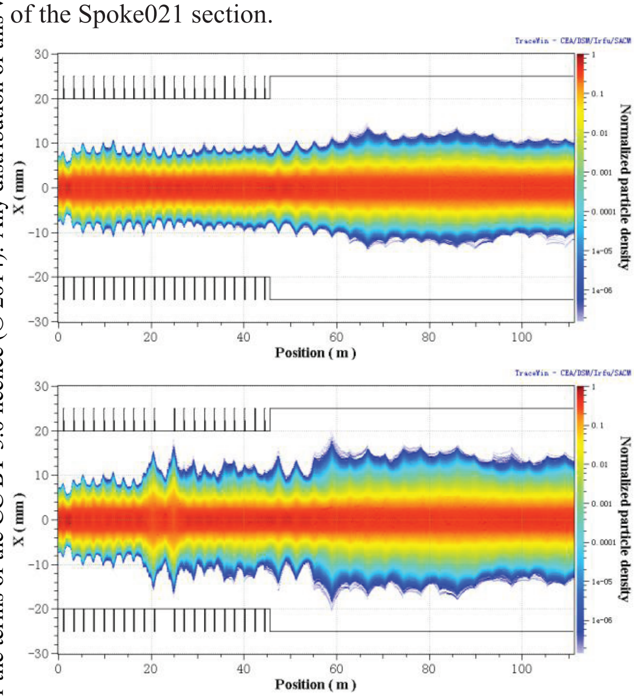

Figure 4: The nominal particle trajectory (the upper picture) and the corrected one (the lower picture) with error analysis after the solenoid failure in the middle part of the Spoke021 section.

With all the nominal static and dynamic errors, one can control the residual orbit error quite well with the correction scheme, the emittance growths in both transverse and longitudinal plates are not evident and particle trajectories in the transverse planes with correction can also been controlled.

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	-20°	-39°	33°	-42°	-22°	-11.5°
Initial voltage / MV	0.96	0.98	1.10	1.12	1.20	1.21
After rematch / MV	0.65	0.98	0.88	1.47	1.13	1.2
Solenoid Number	**1**	**2**	**3**	**4**	**5**	
Initial field / T	2.91	3.03	3.16	3.22	3.19	
After rematch / T	2.07	2.82	---	3.01	2.88	

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	0.366	3.18	0.31
After rematch	0.356	3.23	0.42
Twiss parameter	**Beta y / m**	**Alpha z**	**Beta z / m**
Initial	2.81	0.50	2.20
After rematch	2.92	0.50	2.25

We have also optimize the section of 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. Besides, the rematch method for the failures of the quadrupole magnets in the high energy section (Ellip063 and Ellip082 section) has also been studied before [6]. 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. However, the results will also been checked by error analysis.

COMPENSATION- REMATCH TO CAVITY FAILURE WITH PHASE COMPENSATION

When we carry out the local compensation-rematch study for cavity failures with the TraceWin code [6], 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

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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 [6] and the Genetic Algorithm has been 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). With local compensation, four cavities and two solenoids are recommended, the thought of code based on Genetic Algorithm has been shown: first, each field and synchronous phase of four cavities will decide the energy gain which acts as a function one. Second, the arrival time of the reference particle at the matching point will act as function two. Third, Twiss parameters at the matching point will act as function three and four. Fourth, quadratic sum of all the four functions above convert the final objective function, ultimate goal is to find the optimal value of the function. The result will been decided by each field and synchronous phase of cavities taking part in the compensation.

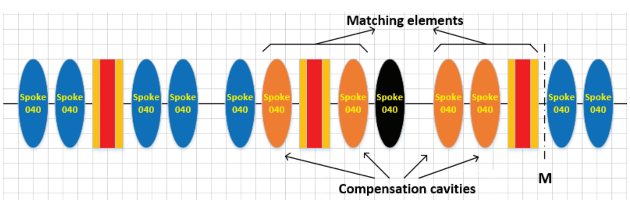

Figure 5: Local compensation method with LOCCOM.

With the code based on MATLAB, the result has been shown in Fig. 6.

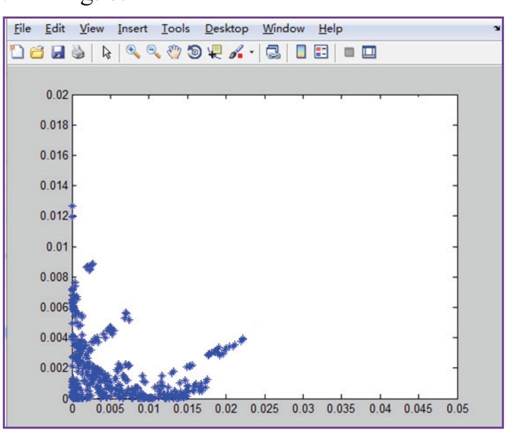

Figure 6: the result for 600 generations based on the method of Genetic Algorithm.

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 very well [5,6].

The genetic algorithm results above are based on zero current, after the Space charge has been considered, a new thought called modularization has been introduced which is shown in Fig. 7.

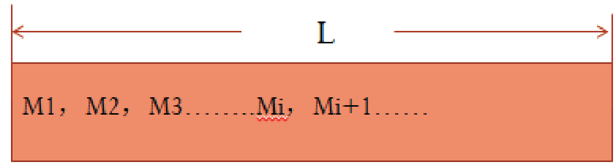

Figure 7: equivalent diagram of modularization thought.

Each element will be cut into slices, the space charge is Equivalent into a matrix in each slice. With the matrix, the output Twiss parameter can been calculated as the input of the next one, after one by one, the space charge in the whole element will be got and the compensation work can been solved. The work for such thought has being done, further development is under way.

CONCLUSIONS

The local compensation-rematch method for the transverse element in the low energy section has been optimized. 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. After the study of error analysis, we are confident of our result and method. Besides the code-LOCCOM for the cavity failure compensation has also been optimized with the Genetic Algorithm, and the modularization thought has also been proposed to consider the space charge, further work for code optimization will be done next.

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