CAVITY MISALIGNMENT AND OFF-AXIS FIELD EFFECTS ON TRANSVERSE BEAM DYNAMIC IN SPALLATION NEUTRON SOURCE SUPERCONDUCTING LINAC

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Abstract

For highly relativistic beams, transverse motion due to off-axis fields is not a concern because the transverse RF magnetic and electric forces for off-axis particles cancel each other. Since The Spallation Neutron Source (SNS) will accelerate moderately relativistic H- particle beam, transverse motion due to off-axis fields has to be checked. Misaligned cavities have physically the same transverse effect on particles moving on axis as off-axis particles passing through perfectly aligned cavities. The main purpose of this paper is to calculate the impact on the transverse motion of the beam from the superconducting cavity (SC) misalignment in SNS. Quadrupole misalignment is then added to obtain a more general statement for the transverse behavior of the beam under alignment errors. For this issue, we use on-axis and off-axis electromagnetic field data from Superfish to calculate beam properties of the SNS beam all along the SC linac with misaligned cavities.

1 INTRODUCTION

The SNS Superconducting Linac (SCL) is composed of thirty three low beta cavities (Beta=0.61) and forty eight high beta cavities (Beta=0.81), operating at 805 MHz. It is well known that ultra relativistic particles, passing through a symmetric accelerating gap with matched beta structure, experience no transverse forces when they pass off-axis because electric and magnetic action compensate each other. In the SNS SCL, H- are not ultra-relativistic since they are accelerated from 185 MeV (Beta=0.55) up to 1 GeV (Beta=0.88). Also the SNS cavity design includes asymmetric cavities with unmatched beta structure, not satisfying then the two other conditions mentioned above. For these reasons off-axis particles will experience effective transverse forces. Misalignment of cavities enhances this effective transverse force effect and leads also to general beam centroid kick. Of course misalignment can also have an impact on longitudinal motion since longitudinal acceleration for a particle depends on its transverse position.

Two effects have to be checked. First, how misalignment of cavities within the expected alignment tolerances could affect emittances. Second, how much the beam transverse centroid could be displaced. Tolerances for the alignment in SCL linac are; cryostat with respect to the reference line+/-1mm, each cavity with respect to cryostat +/-1mm and +/-1mrad.

2 CAVITY TRANSVERSE ACTION

The longitudinal and the transverse motions of particles with beta varying in long and complex accelerating elements are a non-trivial problem [1][2]. To realize the analysis for the SNS superconducting cavities a numerical approach using field mapping with accurate field information from SUPERFISH is used. The simulations are done without space charge effect.

An overall picture of the transverse action for the medium beta section is presented in Figure 1. This figure shows the transverse kick experienced by a single particle with different input conditions. A line in this figure corresponds to one set of transverse inputs; position and angle, used repeatedly for each cavity of the medium beta section. For each cavity the longitudinal inputs, beta and phase relative to the RF, are the same for all the different transverse input conditions.

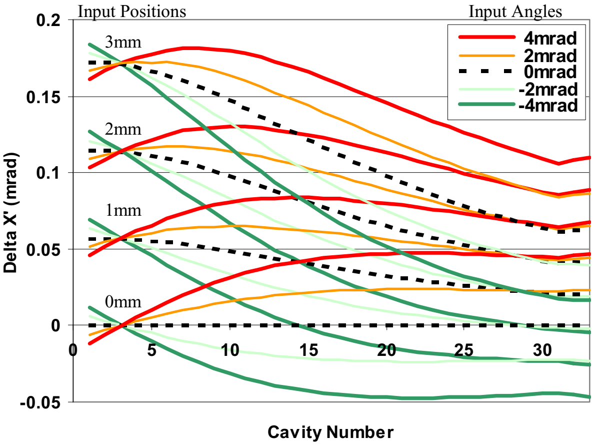

Figure 1: Transverse kick in each medium beta cavity for different set of transverse input positions and angles.

Figure 1 summarizes all the transverse dynamics occurring in SNS medium beta superconducting cavities. It combines electric and magnetic action. Important facts can be summarized. It appears that transverse kicks experienced by particles are non- negligible and that their amount depends on both input transverse position and input transverse angle. A symmetry with respect to the horizontal axis exists because of the cylindrical symmetry of the cavities. As expected, the farther from the cavity axis the bigger the kick, and the higher the beta the less efficient the kick. The transverse action depends also on the longitudinal variables such as beta and phase. In the third cavity the transverse kick is independent of the input angle of the particles because the action from the transverse fields and longitudinal accelerating field are canceling each other.

3 EMITTANCES

A statistical approach is done assuming cavity misalignment as a random uniform distribution within the tolerances. 1000 runs of random misaligned accelerating structures are done. Each run is performed with 1000 particles. Random quadrupole misalignment within +/- 0.125mm is also included. Longitudinal and normalized transverse emittances are calculated after each element of the SCL. For each run the maximum emittance values along the SCL are compared with the ones of the perfectly aligned case. Both horizontal and vertical normalized emittances have the same behavior. Results are shown in Figure 2 and Figure 3. Under a random misalignment of the cavities emittance growths are small and are not a concern for SNS SCL.

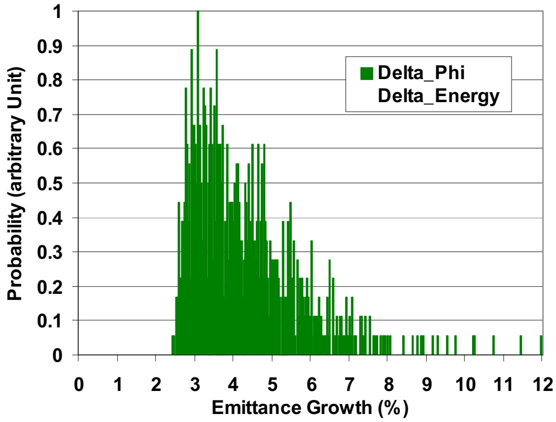

Figure 2: Longitudinal emittance growth distribution for 1000 randomly misaligned structures.

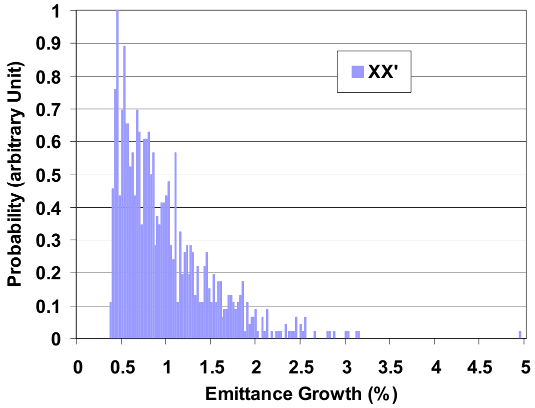

Figure 3: Normalized horizontal emittance growth distribution for 1000 randomly misaligned structures.

4 BEAM CENTROID OFFSET

The other concern is to estimate the beam centroid displacement induced by misaligned cavities. An on-axis particle with no angle passing through a perfectly aligned structure would remain on-axis. The transverse fields due to cavity misalignment give the on-axis particle or beam-centroid a transverse kick. An example of beam centroid position along a randomly misaligned case is shown in Figure4.

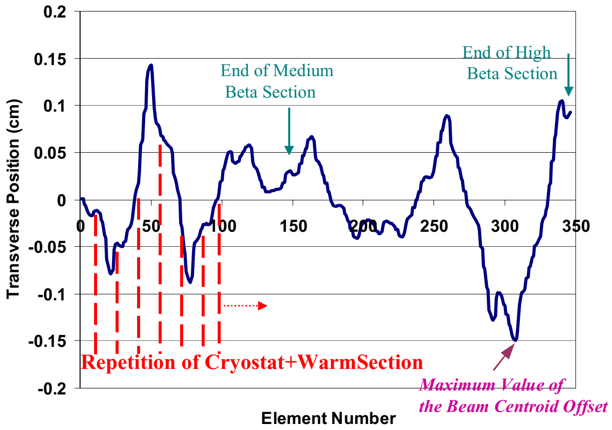

Figure 4: Beam centroid position tracking along a randomly misaligned structure. Here the maximum beam centroid offset is 1.5 mm

No very specific pattern is observed for different misaligned cases. Using the above misalignment tolerances for cavities and quadrupoles, the maximum transverse offset along the SCL is studied for 10000 random cases and plotted in Figure 5.

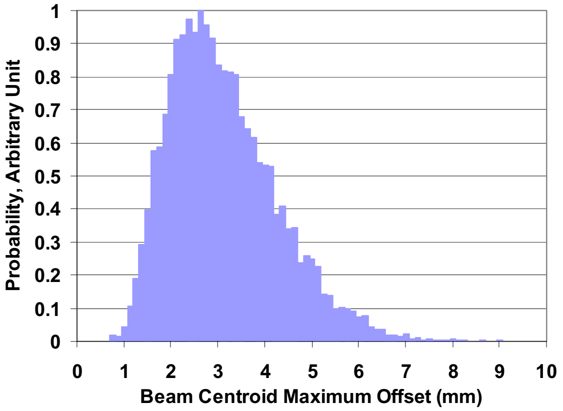

Figure 5: Beam centroid maximum offset distribution for 10000 randomly misaligned structures.

The offset distributions in the horizontal and vertical directions are the same. Transverse offset is a concern at smallest aperture locations, in warm section between cryostats for SNS SCL. These apertures are 3.65 cm in radius. Maximum beam RMS extension in transverse plane is about 2 mm. Considering 7 sigma gives an overall extension of 1.4 cm. To be contained within the aperture the beam centroid should not then exceed 2 cm. Even though the beam centroid displacement shown before seems small enough to contain the entire beam within the physical aperture, minimizing the beam centroid displacement is preferable. A scheme using steering magnets present in the warm sections of the SCL has to be found to cut the tail of the beam centroid distribution and shift its center to a smaller value.

5 BEAM STEERING

The maximum beam centroid offset does not come from an accumulation of small displacements but is rather build up quickly within typically 1 or 2 cryostats and then corrected by quadrupoles. For SNS, powered dipole correcting magnets are available to steer the beam in each transverse direction every other cryostat. It seems reasonable then to try to apply a steering scheme within 2 cryostats. The maximum of the beam centroid offset distribution occurs when two consecutive cryostats tend to kick the beam in the same direction and when the beam centroid passes around the center of the focusing quadrupole between these two cryostats. Offset reaches its maximum in the center of the following warm section and is refocused from there. Beam Position Monitors (BPM) will be installed in each warm section. They can give the transverse position of the beam but not its angle. A simple idea would be to anticipate the action of the misaligned cavities and give an adequate transverse kick with the nearby upstream steering magnet. A steering scheme is applied here as explained in Figure 6. At each steering location a steering angle is applied to minimize the beam centroid position in the center of the two following warm section.

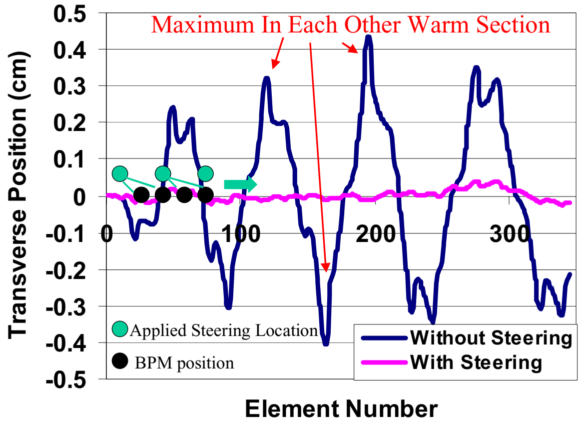

Figure 6: Proposed steering scheme. A kick is given to the beam by a steering magnet every other warm section to minimize the beam centroid position in the next two BPMs .

With this simple criteria the largest beam centroid offsets are avoided and the average beam centroid position should also been improved. Steering magnet power supplies are designed to give up to 1.9 mrad correction angle for beta=0.6 and 0.8mrad for the beta=0.88. The result of this simple steering scheme is presented in Figure 7. The width of the beam centroid offset distribution is shrunk and the most probable value of the displacement lowered by 1.5 mm. The applied correction angles do not exceed 0.4mrad keeping a 100% margin in the corrector magnets.

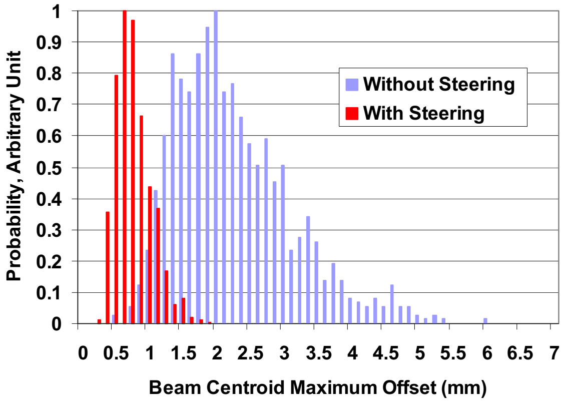

Figure 7: Beam maximum centroid displacement for 400 different randomly misaligned structures with steering and without steering.

6 CONCLUSIONS

- For random cavity misalignment distribution emittance growths are small.
- Cavity and Quadrupole misalignment effects on maximum beam centroid displacement, without steering, are quantified and the most probable value is reasonably low.
- A simple steering scheme, working with a 100% margin of the designed steering magnet capability, is proposed to lower the most probable value of the beam centroid displacement distribution and get rid of its tail.

7 ACKNOWLEDGMENT

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8 REFERENCES

[1] Pierre Lapostolle, et al, “A new method in beam dynamics computations for electrons and ions in complex accelerating elements,” Particle Accelerator, 1994, Vol 44, pp 215-255.

[2] Pierre Lapostolle, et al. “Formulae and procedures useful for the design of accelerator,” CERN-PS-2000-001, January 2000.