SIMULTANEOUS FOUR-HALL OPERATION FOR 12 GEV CEBAF*

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Abstract

The CEBAF accelerator at Jefferson Lab will have a new experimental hall, Hall D, added to its existing three halls as a part of the ongoing 12 GeV upgrade. Under the present CEBAF design, there is no option for sending beam to all four halls simultaneously. At least one hall has to stay down during the machine operation. A new pattern for interleaving the beam bunches is introduced that allows simultaneous operation of all four halls and provides opportunities for additional future experimental beams. The new configuration presents only a minimal change to the existing CEBAF extraction system. In fact all the lower pass extractions will stay as presently designed, and only the frequency of 5th-pass horizontal RF separator will change. In order to make room for the new Hall D beam among the existing three beams, the beam repetition rate is reduced only for the halls taking beam at the highest pass. This and other details of the new configuration and beam pattern will be presented and discussed. A separate paper in this conference will cover the implementation choices including changes to the beam source and extraction region [1].

EXISTING BEAM PATTERN

The beam bunch pattern and extraction configuration of CEBAF were designed more than 20 years ago to support simultaneous operation of its original three halls. This configuration and bunch pattern have remained unchanged since the start of the laboratory up through the last 6 GeV run, before the ongoing 12 GeV upgrade started in 2012. Figure 1 shows the layout of 6 and 12 GeV. This preliminary discussion pertains to the 6 GeV layout.

The main accelerator consists of two anti-parallel linacs that are connected with beam transport arcs on each end. The electrons start the journey from the injector and end up in one of the three halls (A, B, or C) after accelerating through the two linacs up to five passes. The operating frequency of the linacs is 1500 MHz†. In order to simultaneously supply beam to all three halls, three interleaving beams, A, B, and C, are generated in the injector each with bunches at 500 MHz, one third of the linac frequency. Therefore the bunch pattern is a simple ABCABC... (It could also be ACB but it does not alter the logic of this discussion). Together, the three beams fit in the 1500 MHz envelope of the accelerator.

At the end of each pass through the machine, one out of the three beams can be extracted from the recirculating path and directed toward one of the A, B, or C Halls. This extraction is done using RF deflecting cavities or RF separators at the end of the South Linac [3,4] (Fig. 1).

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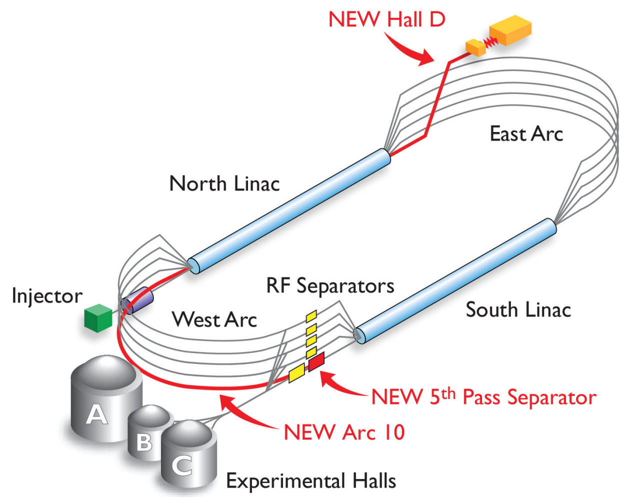

Figure 1: Layouts of 6 and 12 GeV CEBAF. The 12 GeV transport lines added to support the new experimental hall, Hall D, are shown in red.

The RF separator provides a horizontal kick to the left toward the three halls or to the right for recirculation. This kick is further amplified through optics and septa magnets (Fig. 2).

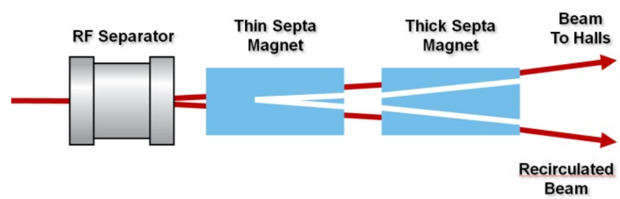

Figure 2: Separator and Septas (not to scale).

The separator frequency is 500 MHz. Figure 3 shows an example of how beam A gets a different kick than beams B and C to eventually extract beam A to go to the end station and beams B and C to recirculate for additional acceleration. The extraction of one of the beams can happen at pass 1, 2, 3, or 4. This is the basic pattern of extraction at lower passes.

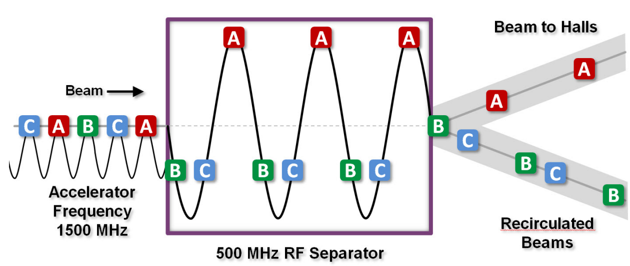

Figure 3: 500 MHz separation to kick one out and recirculate two (not to scale). This is the configuration for the first four passes.

At fifth pass, the highest pass, an RF separator with the same 500 MHz frequency but different phase provides a three-way split of the beams (Fig. 4). This three-way-separator allows the three halls to receive beam simultaneously at the highest pass (highest energy) if they choose.

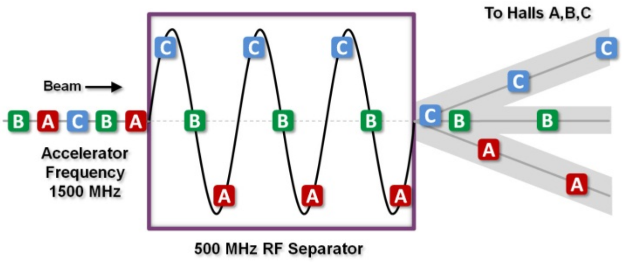

Figure 4: 500 MHz separation triple split for fifth pass (not to scale).

In summary, with the historical beam pattern and extraction system, the three original halls could select beam from different passes while the highest pass could be selected by more than one hall.

ADDITION OF HALL D

As part of the 12 GeV upgrade of CEBAF a new hall, Hall D, and a new arc, Arc10, are added to the accelerator [5] (Fig. 1). Relative to the A, B, and C halls, Hall D is at the opposite end of the accelerator. The 5^{th} pass beam traverses Arc10 to recirculate an extra pass through the North Linac before arriving in Hall D. In effect Hall D beam passes 5.5 times through the main accelerator. The design energy for Hall D is 12 GeV, and planned experiments in this end station do not want to receive beam from lower passes.

And so, for Hall D to receive beam, a part of the 5^{th} pass beam has to be separated away and directed toward Arc10 for recirculation. One way of doing this is to add another 500 MHz RF separator system in the 5^{th} pass line and separate out one of the three beams; similar to what is done in lower passes. Only this time the separated beam would go to the right for recirculation and the other two to the left to the three original halls (Fig. 5).

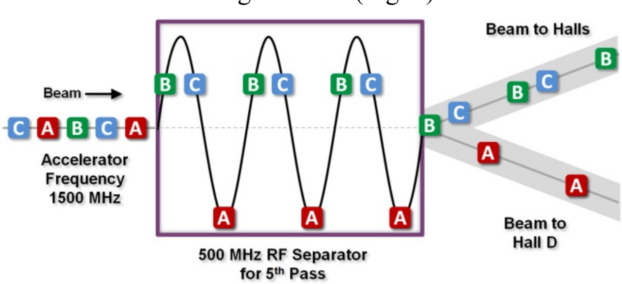

Figure 5: 500 MHz 5^{th} pass separation for three-hall operation (not to scale).

This is the solution initially adopted for the 12 GeV upgrade. It was to be implemented mainly by adding a horizontal separation in the 5^{th} pass line operating at 500 MHz, the same frequency as all other RF separators at CEBAF. However, this solution also implies that while Hall D is receiving beam, only two other halls can have beam because one of the three ABC beams would be dedicated to Hall D. For this reason this solution is called the "D+2 solution."

A FOUR HALL SOLUTION

The 500 MHz RF separator with three interleaved beams in the machine can at most supply 3 halls with beam. To add a new hall to the mix, therefore, requires a different approach. One such solution is to use a 750 MHz separator instead of the 500 MHz system for the 5^{th} pass. To explain the effect of this new separator on the beam, note that 750 MHz is one half the fundamental frequency of the machine. Therefore, if phased properly, successive bunches receive alternating kicks to the left and right as shown in Fig. 6. However, the beam is a combination of three A, B, and C beams; it is easy to see that the new separator will split each of these beams as well. For example half of the A beam will be kicked to the right (A_R) and the other half to the left (A_L).

Figure 6 shows what happens to bunches as the beam passes through the 750 MHz separator. The bunch pattern of ABCABC… will receive alternative right and left kicks which can be represented as $A_RB_LC_RA_LB_RC_L$…with bunches labelled R going to the right toward Arc 10 and Hall D and bunches labelled L going to left toward the three A, B, and C halls.

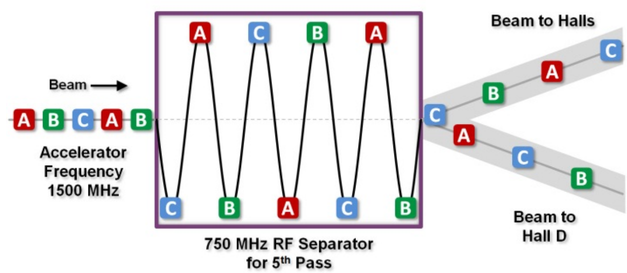

Figure 6: 750 MHz separation with all buckets filled (not to scale).

Now let us first consider the part of the beam which goes to the left. First notice that half of bunches are kicked out of the beam. Therefore what remains is A_L, B_L, and C_L beams each with 250 MHz bunch structure, one half the original 500 MHz. Second, since the timing of the individual bunches has not changed, the beams can go through the same beam line and the same three way split separator described above and end up in their respected halls.

On the other hand, Hall D will receive the A_R, B_R, and C_R beams, again each with 250 MHz bunch structure. With this arrangement, it is not hard to setup four-hall operation. If the injector produces three 250 MHz beams A_L, B_L, and C_L, for the Halls A, B, and C and produces a fourth beam, for example A_R, also at 250 MHz, then all four halls can receive beam simultaneously. It would be Hall D plus the three original halls or the "D+3 solution". Figure 7 shows the scenario described above graphically.

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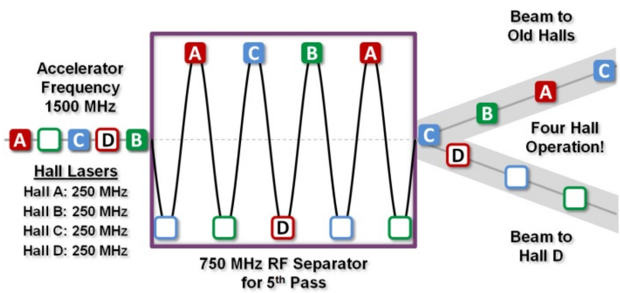

Figure 7: Proposed 750 MHz separation for four hall operation (not to scale).

IMPLICATIONS

In order for all four halls to receive beam simultaneously, the halls have to share the 5th pass beam. Therefore the new system will have two trade-offs when Hall D is on:

1) all other halls using 5th pass beam must run at 250 MHz, half of the original repetition rate.
2) at least one of the other halls has to take beam at the 5th pass and share beam with Hall D or alternatively remain off.

On the other hand, sharing beam and running at lower rep rate does not mean that the average current to any hall has to be lowered! It only means that the charge per bunch has to increase. The CEBAF injector and linacs are capable of handling this higher charge per bunch. For example, at 12 GeV the maximum average current for Hall A or Hall C is 85 uA. That is 0.34 pC per bunch for a 250 MHz beam. The accelerator has run at higher charge per bunch levels in the past [6]. Also, Hall D requires only a few microamperes of beam, so it will not have much impact on the total beam current through the linacs. However, the impact of doubling the charge/bunch on physics experiments limited by accidental rates should be evaluated.

With the proposed 750 MHz separation scheme, there are still several scenarios where halls can receive 500 MHz beams:

1) Any of Halls A, B, and C may have 500 MHz beam if either Hall D is off , or they are taking beam at passes one through four.
2) Hall D may have 500 MHz beam if less than four halls are running and Hall D is the only one using the 5th pass beam.

At present, the injector only provides 500 MHz beam. It must be upgraded to also provide 250 MHz beam on demand [1].

FUTURE USES

The 750 MHz system essentially makes six interleaving beams, $A_R B_L C_R A_L B_R C_L$, out of the original three ABC beams. In the example shown in Fig. 7, Hall D beam is in fact A_R beam. Also in that example the beams B_R and C_R are empty. It is possible to fill these buckets with beam and separate them later at the end of the North Linac before going to Hall D. These beams could provide 12 GeV electron beams to other applications or feed future accelerators. They may also just go to Hall D to increase the beam repetition rate to that hall.

CONCLUSION

The existing 500 MHz separators have been serving the three-hall 6 GeV machine well for the past twenty years. When a fourth experimental hall was added to CEBAF, a new separator system was planned for the 5th pass to branch out part of the beam for the new hall. This paper shows that a new separator operating at 750 MHz instead of 500 MHz can support beam delivery to all four halls simultaneously. The other separators for lower passes and the three-way separator before the A, B, and C halls are unchanged and remain at 500 MHz. A fourth laser system is needed to control the beams to four halls independently. The impact of this change to the laser system on the physics program would not be on a hall's average current but on its charge per bunch whenever the hall receives beam at half the original rep rate. That will be only for experiments taking beam at the highest pass. Engineering details of the new separation system including the RF separator design and changes to the electron gun laser system are covered in a separate paper [1].

ACKNOWLEDGEMENTS

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REFERENCES

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