DEBUNCHER DEVELOPING FOR H AND D BEAMS INJECTION INTO COSY RING

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Abstract

In case of super-conducting injector in synchrotron due to high accelerating gradient the energy spread of beam after linac exceeds the longitudinal acceptance of ring. The problem becomes even more difficult, when we need to inject two beams with different charge/ mass ratio. We consider the problem, when H^- and D^- particles are injected and ratio of mass to charge differs by a factor of two. Both beams will be injected into ring at an approximately similar energy 50 MeV. To fulfill the monochromatization requirement the momentum spread of H and D beams has to be decreased from $\Delta p / p = \pm(5 \div 8) \cdot 10^{-3}$ [1] to $\Delta p / p = \pm 1.5 \cdot 10^{-3}$, or in special case $\Delta p / p = \pm 7.5 \cdot 10^{-4}$ by the debuncher system optimized for both sorts of particle simultaneously. For this purpose the E and H debuncher types are considered.

PHASE ADVANCE ADJUSTMENT.

The first and obvious possibility is to adjust the advanced phase $\Phi \sim \sqrt{E_a \sin \varphi_s}$ in the longitudinal plane of whole linear accelerator and rotate the phase portrait to get smaller momentum spread. Definitely using this method, we should conserve the final energy of linac, what is possible in case $E_a \cos \varphi_s = const$. From Figure 1 you can see that minimum momentum spread of H beam can be reached at $\varphi_s = -25°$, when 85% of particles will be in the frame of required momentum spread. However, for D beam the optimum phase advance is another value (see figure 2). The best case is $\varphi_s = -22°$, when we can safe about 80% of particles.

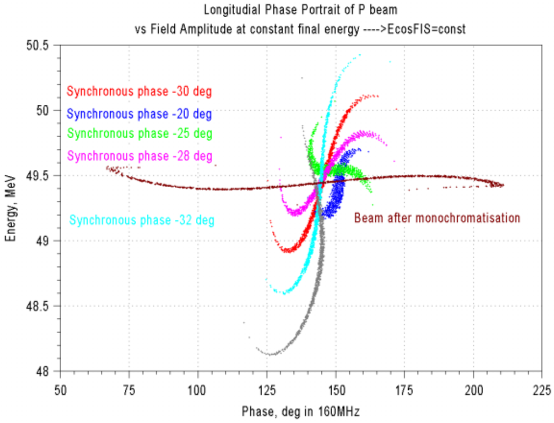

Figure1: H-beam phase portrait on linac exit vs synchronous phase

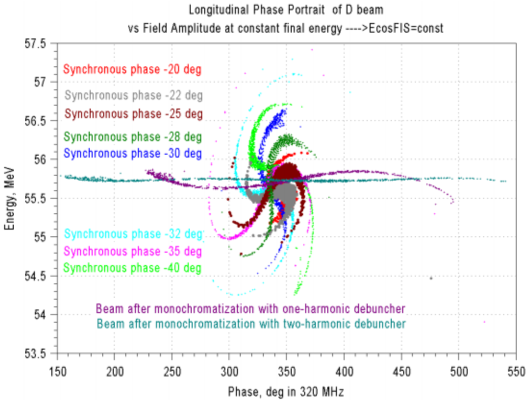

Figure 2: D-beam phase portrait on linac exit vs synchronous phase

BEAM DEBUNCHERING.

Another method of monochromatization is connected with using the debuncher for H and D beams after linac. The type and construction of debuncher is determined by required generator power. We study two options: one short (single gaps) and two long (six gaps) cavities. Both options are for 160 MHz frequency, since in case 320 MHz it is not enough large linear phase oscillation region. In second option we optimized geometry of cavity for solid-state generator ≤ 10 kW. Beam parameters have been taken for synchronous phase in linac $\varphi_s = -30°$, since for this value the separatrix is optimized. H and D-beams parameters on linac exit are placed in table 1. You can see momentum spread is very different for H and D.

Table 1

	H	D
Frequency, MHz	160	160
Beam velocity/c	0.313	0.238
Beam kinetic energy, MeV	49.4	55.7
Beam chamber aperture diameter, mm	20	20
Duty cycle	1%	1%
Beam ± Δp/p	$5.73 \cdot 10^{-3}$	$8.9 \cdot 10^{-3}$
Bunch length in 160 MHz	±19°	±7°

One single-gap debuncher

It based on conventional omega–structure. After drift of 12 m D-bunch phase length increases up to ±85° (in 160 MHz) and H-bunch up to ±30°. The beam dynamic calculation shows that in order to decrease momentum spread up to required value we need RF pulse power around 110 kW for proton and 60 kW for deuteron, and

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the peak electric field is 25 MV/m (1.9 Kilpatrick). Thus, the option of single-gap debuncher requires high power RF generator with enough high peak electric field.

Two multi-gaps debuncher

In this option we investigated another solution: two different multi-gaps debunchers for proton and deuteron, and both optimized for maximum power generator limited by 10 kW. One of the most appropriate structures is drift tube resonator. We considered TM and TE types. After analyzing we took the TE rectangular cavity with cross-section ~50x50 cm. The TM type has almost the same shunt impedance but 2 times bigger sizes. In multi-gaps case the main criterion is the required generator power (or shunt impedance). Peak electric field is much less then Kilpatrick limit. Different variants have been calculated on MAFIA with variation of gap coefficient $\alpha_1 = \frac{b_1}{\beta\lambda}$ for regular cells and $\alpha_2 = \frac{b_2}{\beta\lambda}$ for extremes. Here b_1 and b_2 - gaps length. Figures 3, 4 show the 3D diagram plotted to define optimal α_1 and α_2 for D and H debuncher.

Further calculations were fulfilled with optimal parameters for each case. The number of gaps in H debuncher is taken 4 and 6 in D debuncher. The stem radius of drift tube is $R_{stem} = 1cm$ and length of cavity $Z_{length} = N_{gaps} \cdot \frac{\beta\lambda}{2}$. To estimate the required power of generator the beam dynamics code was used. The real electric field distribution was obtained from MAFIA.

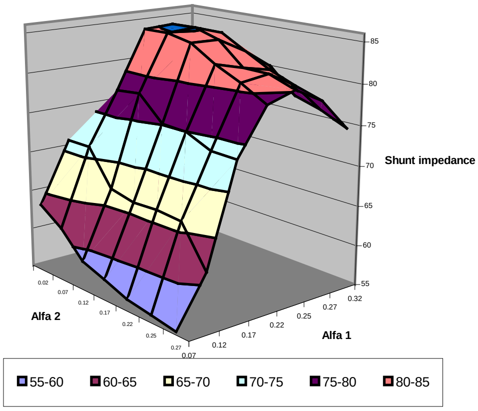

Figure 3: Shunt impedance vs gap ratio
for 6 gap debuncher, Deuterons

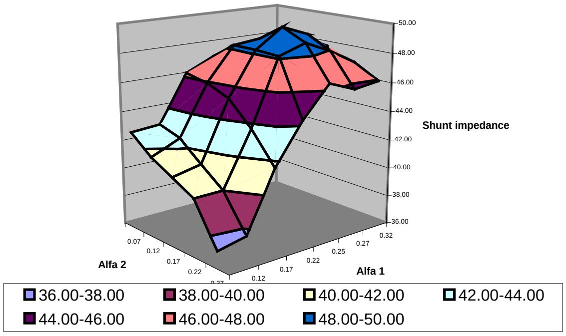

Figure 4: Shunt impedance vs gap ratio
for 4 gap debuncher, Protons

The final momentum compression depends on bunch length increasing in drift space and rotation angle in debuncher. However, in the optimized drift the bunch length has not to exceed the value, when head-tail particles appear in non-linear sin-wave region of debuncher electrical field. So, we should trade off both factors. For our bunch shape from linac the optimum drift between linac and debuncher is 9m and 20m for D and H beams accordingly. Coming in buncher, D-bunch has the phase length ±67° and H-bunch ±63° (both in 160 MHz). The final phase portrait after monochromatization is shown on figures 1 and 2. Table 2 gives the parameters of debuncher cavity for proton and deuteron calculated for aperture radius $R_a = 1cm$, outer radius of drift tube $R_{outer} = 1.5cm$, stem radius $R_{stem} = 1cm$.

Table 2

Num. Gaps	L_{cavity}, (m)	R_{sh}, (MΩ)	R_{sh}/L, (MΩ/m)	$\frac{E_{peak}}{E_{Kilpatrik}}$	Power of generator P_{gen}, kW
Protons					
2	0.58	10.2	17.5	0.78	51.1
3	0.86	28.8	33.0	0.47	16.4
4	1.15	49.8	43.3	0.36	9.5
5	1.46	67.5	46.2	0.24	7.3
Deuterons					
2	0.42	14.6	34.7	0.80	57
3	0.65	30.1	46.8	0.59	35
4	0.87	48.8	56.1	0.53	19.3
5	1.1	67.1	60.1	0.46	16.5
6	1.3	85.2	65.5	0.62	11.7
7	1.56	103	66.1	0.45	9.2

Adding second resonator with doubled frequency, we can improve momentum spread (see figure 2). Usually the second harmonic cavity is used to linearize the sin-wave field. In our case it is supposed to correct bunch shape and compensate nonlinearity of whole linear accelerator, which one allows to have on exit for single deuterons bunch $\Delta p / p = \pm 4.5 \cdot 10^{-4}$. Second resonator can be based on conventional one gap omega structure. In this case required power for second generator is 5.5kW. The drift length for deuterons should be increased up to 14 m.

RF field errors

All above stated calculations consider bunch after ideal linear accelerator. In reality due to RF field amplitude and phase instabilities (~1%, 1°) the effective bunch has larger sizes. Figure 5 shows the effective bunch portrait after linac for the different instability value. Obviously, the optimised debuncher system has to take into account this circumstance.

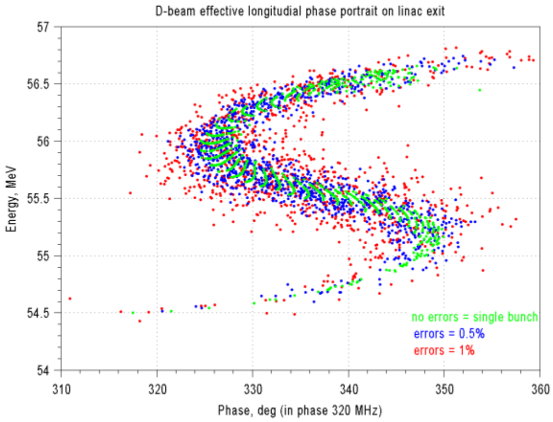

Figure 5: D-beam effective phase portrait on linac exit vs errors.

Tabel 3 shows the percentage of accepted particles and the required power of generator in case of 5 gaps cavity for proton and 6 gaps cavity for deuterons with various drift length.

Table 3

Drift length, m	Percentage of particles in region $\Delta p / p = \pm 1.5 \cdot 10^{-3}$ consider errors=1%	Percentage of particles in region $\Delta p / p = \pm 1.5 \cdot 10^{-3}$ consider errors=0.5%	P, kW
Protons			
16	98.38	99.64	10.2
17	99.01	99.73	9.7
18	99.19	99.73	8.2
19	99.19	99.82	7.3
20	99.37	99.82	6.8
21	99.55	99.91	6.5
Deuterns			
5	88.95	95.96	27.3
6	92.45	97.66	20.9
7	94.07	98.11	16.6
8	95.6	98.47	14.1
9	95.6	98.11	11.7
10	95.6	97.66	10.1
11	95.24	97.3	8.6
12	95.23	97.3	8.2
13	95.15	97.39	7.7
14	94.7	97.21	7.2

The percentage of accepted particles depends on drift length weakly, but the required power grows with drift significantly. From table we can see 9 m drift space gives the best captures of D-particle, but the power little bit exceeds 10 kW. Therefore 12 m drift space option is more preferable.

Two harmonic debuncher

Almost the same estimations have been done in case of two-harmonic debuncher. Two-harmonic debuncher consists of two cavity – cavity with normal frequency (160MHz) and cavity with doubled frequency (320MHz). First cavity is 5 gaps cavity for protons and 6 gaps cavity for deuterons. Second harmonic cavity is based on conventional one-gap omega structure. Due to larger linear region in two-harmonic debuncher, the optimized drift space has another value. Table 4 shows percentage of accepted D-beam and required power of generator for first (P_1) and second (P_2) cavity in case of two-harmonic debuncher.

Table 4

drift	Percentage of particles in region $\Delta p / p = \pm 1.5 \cdot 10^{-3}$ consider errors=1%	Percentage of particles in region $\Delta p / p = \pm 1.5 \cdot 10^{-3}$ consider errors=0.5%	P_1, kW	P_2, kW
12	95.69	97.66	9.6	1.4
13	96.41	98.56	9.6	3.1
14	97.21	99.28	9.6	4.5
15	97.12	99.01	9.1	5.5
16	96.68	98.29	8.5	5
17	95.87	97.84	7.5	5

You can see actually H-beam does not need the second harmonic cavity. However, for special requirements, when we need $\Delta p / p = \pm 7.5 \cdot 10^{-4}$ the second harmonic cavity is needed for H beam as well, and the capture efficiency will be 95% for RF errors 1% and 97.5% for errors 0.5%.

CONCLUSIONS.

So, we analyzed: 4 possibilities of H and D beams monochromatization simultaneously:

1. Phase advance adjustment: it has the momentum spread reduction limitation.
2. One single-gap debuncher: it specifies high peak electric field and high power RF generator.
3. Two multi-gaps debunchers: the solid-state generator can be used.
4. Two-harmonic debuncher: it improves monochromatization and allows to get the effective momentum spread $\sim 7.5 \cdot 10^{-4}$

REFERENCES

[1] Yu.Senichev, et al., SOME FEATURES of BEAM dynamics in super-conducting linac based on quarter- and half-wave cavities, EPAC 2002.