A FAST AMPLITUDE AND PHASE MODULATED RF SOURCE FOR AmPS

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Abstract
AmPS (Amsterdam Pulse Stretcher) is a 900 MeV electron stretcher and storage ring. Its installation started early 1991. To compensate for the synchrotron radiation losses and to control the injection and extraction process in the ring a CW RF source will be installed. The source will operate at 2856 MHz. This frequency has been chosen to ensure optimal beam capture of the injected beam from the linac which has a 2856 MHz bunch structure. The RF cavity in the ring is a 40 cm long slow wave structure. It is presently manufactured by Haimson Research Corporation. The filling time of the structure is 22 nsec. During the 3-turn injection and the directly consecutive extraction cycle, fast amplitude and phase modulation will be applied to obtain maximum injection and extraction efficiency. The required RF cavity input power is 30 kW for a ciculating beam of 900 MeV and 200 mA. This power will be delivered by a commercially available 50 kW CW klystron (Thomson). The source will either operate in linear- or saturated mode.

INTRODUCTION

To obtain electron beams with a high duty factor a stretcher ring will be added to the existing Medium Energy Accelerator (MEA). The ring will operate at energies between 250-900 MeV and with circulating currents up to 200 mA (ref.[1])
MEA has been upgraded for this energy range by modifying the modulators and installing new klystrons to obtain higher RF peak power (10MW) during shorter pulsewidth (3.5μs). (ref[2]). The injector is modified to deliver 2.1 μs pulses of 80 mA for the 3-turn injection.
RF related specifications of the stretcher ring:

Energy range	E	[MeV]	300-900
Circulating current	Ib	[mA]	200
Energy spread bucket	δ	[%]	±0.1
Frequency	f	[MHz]	2856
Harmonic number	h		2016
Momentum compaction	α		0.027
Bending radius magnets	ρ	[m]	3.3
Ring circumference	L	[m]	211.618
Circumference period	T	(μs)	0.7

From these numbers the RF parameters which are important for the design of the RF station are calculated.
Table 1 shows the synchrotron radiation loss per turn (Us) with the corresponding synchronous phase angle (ϕs), the total loss (Ut), including the parasitic loss per turn, with the corresponding phase angle (ϕt). Also presented are the required cavity voltage (Vrf) and the cavity input power (Prf) for the 2856 MHz travelling slow wave structure.

Table 1

Beam Energy (MeV)	Us (KeV)	Ut (KeV)	Vrf (kV)	ϕs (degr)	ϕt (degr)	Prf (kW)
300	.2	1.2	26	179.6	177.4	2
500	1.7	2.7	45	177.8	176.7	6
700	6.4	7.4	70	174.7	173.9	15
900	17.6	18.6	105	170.4	169.8	30

The synchrotron tune is approximately 0.03

RF cavity structure
This travelling slow wave structure has a natural phase slip which is optimized for the AmPS case to obtain a nearly synchronous phase orbit for the expected beamloading conditions. (ref.[3])
About 3% of the CW input power will be dissipated as copper losses, the remainder part will be dissipated in the rf load. The rf filltime of the cavity structure is 22 ns which means a very fast response to phase and amplitude changes of the input rf power and beamloading changes. Special care has been taken to damp the HOM (Higher Order Modes) in this structure.
RF injection
During the 3-turn injection at a peakcurrent of 80 mA, the increase of the beamloading in the cavity structure by the three abrupt current steps will result in a change of the desired phase orbit through the structure. Fast phase correction (<50ns) of the field will provide a safeguard against serious beam instabilities associated with this fast injection process.
RF extraction
The rf field in the cavity structure will be used to control the extraction process for maximum extraction efficiency during the time between the successive injections. The objective is a smooth, uniform and complete extracted beam at all energies. Two possible methodes of extraction are foreseen;
- Phase Modulation of the rf field in the cavity structure.
- Amplitude Modulation of the rf field in the cavity structure.

By PM a part of the electrons will be forced out of the stable rf bucket by displacing the bucket in phase by a fast phase step of the rf field in the cavity structure. This results in positioning of a small fraction of the original trapped electrons outside the bucket. These electrons slowly lose energy and migrate into the extraction zone.
By AM the bucket size will be reduced by decreasing the amplitude of the rf field. Again a part of the original trapped electrons will be positioned outside the stable bucket and slowly lose energy and enter the extraction zone. A mixture of both extraction techniques are possible, simulation calculations for the extraction methodes are started.

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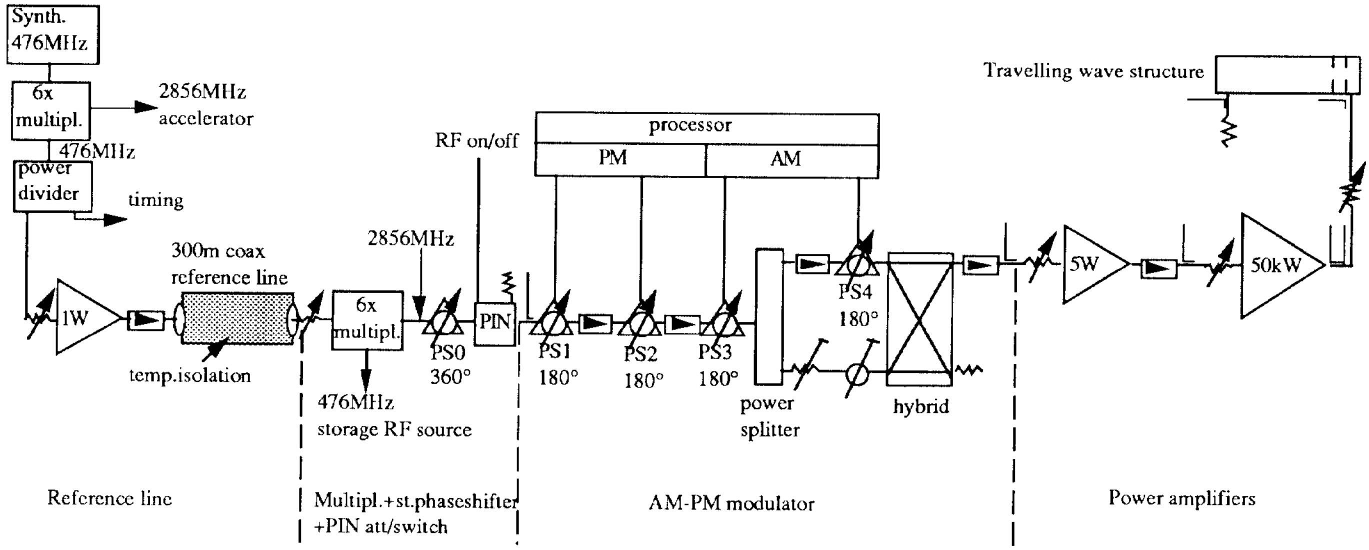

Fig.1 AmPS CW RF source

RF SOURCE DETAILS

In fig.1 The design of the stretcher source is shown. The RF system is divided in 4 parts.

- Reference line
- Multiplier x6, station phase shifter and PIN switch
- AM-PM modulator
- 50 kW power amplifier

General

In the stretcher ring there must be a perfect synchronization between the injected bunches and the rf buckets created in the cavity structure. The past has shown that MEA has a very good longterm stability and delivers high quality beams. To obtain good longterm amplitude- and phase stability in relation to the injected and circulating bunches in the cavity structure much attention is given to the temperature stabilization of the total electrical path length from the 476MHz synthesizer to and including the cavity structure

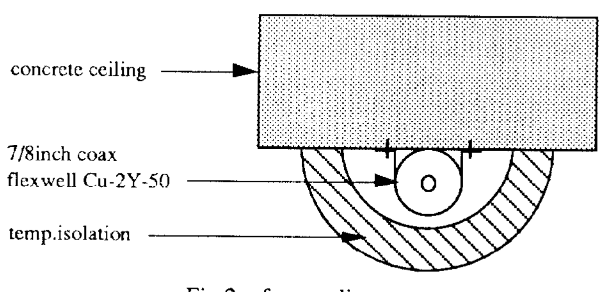

Fig.2 reference line

Reference line

This 7/8 inch phase stabilized coaxial cable (Flexwell Cu-2y-50) has a phase/temperature coëfficient of 8ppm/°C which corresponds to a phase/temp. coëff. of 1.5degr./°C for a 300m length at 476MHz. The attenuation is 2.7dB/100m. After frequency multiplying x6 the phase/temp.coëff. is 9degr./°C at 2856MHz. To obtain a long term stability within 1degr. for this case, the coaxial cable will be mounted to the 1.5m thick concrete ceiling of the accelerator tunnel with thermal isolation around it as is shown in fig.2. Temperature measurements have demonstrated a max. temp change of the concrete ceiling of .1 °C/day.

x 6 multiplier

The multiplier unit is a copy of the one used to generate the 2856MHz accelerator master source signal. The input power is 20mW and the output power is 50mW. It consists of a 476MHz amplifier followed by a passive multiplier/filter unit. The multiplier components are thermostrated for amplitude- and phase stability.(fig.3)

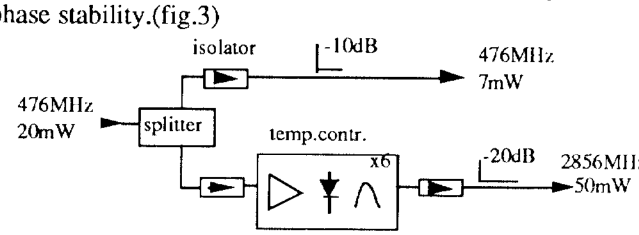

Fig. 3 x6 Multiplier

Station phase shifter and PIN switch

This slow motorized phase-shifter is to control the exact phase relation of the accelerating field in the cavity structure with respect to the bunched beam.

The rf PIN mod./switch has two functions,

1-it will be used as an analog attenuator to control the amplitude of the RF field in the cavity to real zero level during the last part of the extraction cycle in the case of AM extraction, if the AM control network is not able to come into the few watts power level.

2-it will be used to switch off the RF for safety reasons.

AM and PM modulator

This part consists of four commercially available fast electronic analog phase shifters which are shown in fig. 1 and 4. The Amplitude Modulator consists of phase shifters PS3 and PS4. The voltage behind the hybrid will be modulated by PS4 according to the relation $V\cos(\phi/2)$ and PS3 will compensate for the $\phi/2$ phase shift introduced by PS4. This network introduces AM without phase change over more than 30dB with a resolution of 12 bit. In the case of AM, PS1 and PS2 have constant values.

The Phase Modulator consists, in the first place, of PS1 and PS2. Each Phase shifter has a resolution of 12 bit. Over the 360degr. phase range the insertion loss of both phase shifters together will change about 2dB. The AM part of the circuit will be used for insertion loss compensation. The four phase shifter network introduces PM without amplitude change with 12 bit resolution.

Modulation processor

Pure AM and pure PM are both defined by two, four 4Kx12bit look up tables with corresponds to exact phase shifter settings. Each phase- or amplitude step is defined by 4 phase shifter settings from the two tables. The data for these tables will be obtained by a measurement procedure with a network analyzer. The max. puls rep. rate of the injection will be 400 pps. The max. extraction time is chosen to be 20ms. If we take four 8Kx12bit memories for the phase shifters then we can give a phase- or amplitude step every 2.5 μs, which means every 3 turns. The 2.5 μs is defined by a clock in the processor.

Extraction simulations will define what AM, PM or mixed Modulation curves will be required during the extraction time. The four 8Kx12bit memories will be filled with phase shifter settings according to the calculated extraction modulation curves. The earlier mentioned look up tables act as source tables. A possibility will be built in to change the modulation curves on line to obtain optimized extraction. The memory

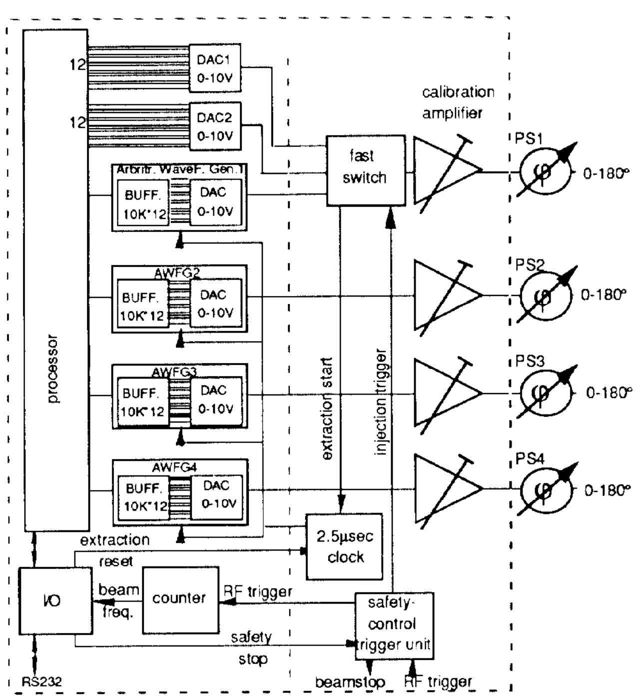

Fig. 4 AM-PM processor

speed is100ns and is fast enough to control the extraction.

During the 3-turn injection, phase correction due to beamloading phase shift will be accomplished by fast switching (20 ns) of the correct voltage levels to PS1.

50kW Power amplifier

The pre-amplifier is a commercially available 37dB, 5W classA linear amplifier used for driving the CW klystron in linear or saturated mode. The bandwidth is more than 100MHz. AM and PM step speed will be limited by the klystron bandwidth (15MHz) only.

The 50kW amplifier tube is the newly developed TH 2110 CW klystron from Thomson. In table 3 the typical specs are given.

Table 3. TH 2110 specifications(typical)

Pout saturated	kW	15	30	50
Beam voltage	kV	17.3	20.8	25.3
Beam current	A	1.9	2.5	3.3
Pdrive sat.	W	4	2	.7
Bandwidth(-1dB)	MHz	5	7	7
Phase sensivity	degr/%V	18	16	14.5
Efficiency	%	45	56	60
Pout(1dB compr.)	kW	6	18	30
Pdrive(1dB compr)	W	.5	.34	0.14

For PM the tube can be used in saturated mode and for AM the tube will be used below the 1dB compression level. For operation at lower levels than specified in the 15kW list and for accurate power control an attenuator is implemented in the RF output of the klystron.

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