SURVEY ON C.W. ELECTRON ACCELERATORS

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Introduction

For nuclear physics applications high duty cycle beams are important to allow coincidence experiments. This is especially true for experiments with electron beams because of the typically much smaller "true to accidental" ratio as compared to experiments with ion beams. Thus, for electron accelerators there is an especially strong demand for highest possible duty cycle, i.e. continuous (c.w.) operation.

During the last decade the number of proposals for c.w. electron accelerators has grown rapidly. In the following, after general discussion of the various possibilities to build such machines, brief descriptions and status reports of the current projects are given. Thereby, special emphasis is put on recent recirculating machines, since a rather detailed compilation of stretchers has recently been given elsewhere[12].

Types of C.W. Electron Accelerators

For a most global consideration of a linac the definition of the effective shunt impedance r may be rewritten to read

$$\Delta T^2 = r\ \eta\ L\ P$$

where L = linac length, P = total mains power to cover dissipation (in addition, of course, in any accelerator the beam power has to be covered), η = total dissipated r.f. power/P.

As a very rough estimate, for presently available technology the following numbers hold:
Normal conducting (NC) linac: $r \simeq 50$ MΩ/m, $\eta \simeq 0.5$, $r\eta \simeq 25$ MΩ/m
Superconducting (SC) linac: $r \simeq 6{*}10^6$ MΩ/m, $\eta \simeq 4{*}10^{-4}$, $r\eta \simeq 2500$ MΩ/m (including refrigerator for 1.8 K).

If, for example, a 1 GeV c.w. accelerator were to be realized by a c.w. linac, one could have the parameters of tab. 1 lines 1 or 2.

	ΔT^2 [MeV]^2	=	$r\eta$ [MΩ/m]	*	L [m]	*	P [MW]	*	($\hat{P}/P$ or n^2)
NC	1000^2	=	25	*	1000	*	40		
SC	1000^2	=	2500	*	200	*	2		
NC pulsed or recycled	1000^2	=	25	*	100	*			$0.4 * 10^3$

Tab. 1: Possible and impossible ways to build a 1 GeV accelerator

Thus, using NC structures, both L and P - representing roughly installation and operation costs respectively - would be uncomfortably large. In case of a SC structure at least L would be inconvenient, since accelerating gradients are limited so far to a few MeV/m by breakdown phenomena. One may, therefore, use a conventional pulsed linac, gaining something of the order of 10^3 in P*L, and feed the pulse into a storage ring ("stretcher") from which it is slowly extracted during the time interval to the next pulse. This combination is able to provide an almost (≃90 % DF) c.w. beam economically. To the best of the author's knowledge, the first really detailed proposal of a stretcher ring (ALIS) has been given by a Saclay group in 1969[21]. Helpful for such a design is the fact that electron linacs usually operate at relatively high (≃3 GHz) frequency, resulting in correspondingly short filling time. This allows economical generation of µsec beam pulses which allow a straightforward single - or few - turn injection into a storage ring of a convenient circumference. Most of the current linac-stretcher-proposals follow this philosophy.

A totally different approach makes use of the fact that electrons are highly relativistic from a few MeV on, i.e. v = const. ≃ c within narrow limits. It is thus possible to accelerate electrons of different energy simultaneously by the same linac. Thus, by recirculating a beam n times through a superconducting c.w. linac, its inconvenient and costly length of tab. 1 may be cut by a factor of n.

An even more dramatic effect occurs by recirculating a normal conducting linac. Since the total energy after n recirculations is given by $T = n\ \Delta T$ the linac equation becomes

$$T^2 = (n\ \Delta T)^2 = r\ \eta\ L\ P\ n^2.$$

Thus, recirculating 30 times saves three orders of magnitude in L*P, making a normal conducting structure a convenient and economic device also for c.w. operation.

On the other hand, with n increasing the costs of the recirculating systems become more and more significant, increasing the demand for a simple return scheme. So, for each kind of recirculation system there is a certain optimum range of n.

In fig. 1 for different ranges of n the corresponding optimum recirculation is given, keeping, as an example T = const. ≃ 1 GeV.

Recirculating a very few times is not sufficient to allow c.w. operation of a NC linac but it may be used to cut the costs of a pulsed accelerator (fig. 1). To avoid transient beam loading effects during recirculation it is a common trick to choose the pulse length (times c) equal to the orbit length of the recirculator in order to provide "head-to-tail" recirculation.

Referring to spectral response it should be remembered that in an electron linac, due to v = c, there is no stabilisation of output energy and spectral width δT due to oscillations about a reference phase angle. If n is sufficiently large such a mechanism may effectively be introduced, however, by choosing non-isochronous recirculation like a microtron scheme. Then $\delta T \sim n^{-1/2}$. The non-isochronous return implies that a resonance condition has to be fulfilled between energy gain per pass and magnetic field strength such that the path length has to increase from one linac passage to the next by an integer number of wavelengths (1 or 2, in practice).

Among these schemes the race track microtron (RTM) has the simplest field geometry and beam optics. It is the most practical solution below 1 GeV. At 1 GeV and above, magnet costs become excessive in an RTM and, consequently, "higher order" microtrons like the double-sided microtron[24], the Hexatron[23] or the "Oktutron"[22] requiring much less pole face area, become attractive. Such systems might be economic in the low GeV range. The much more complex beam optics of such systems call for a small number of recirculations which perfectly matches the need for higher energy gain per turn due to the lower longitudinal dispersion of such systems (which follows immediately from the orbit geometry in the bending system). This is shown in tab. 2, where N is the number of linacs in the polygon, $\Delta R/\lambda$ the increase in bending radius per turn necessary to produce a phaseslip of one wavelength from linac to linac, and ΔT is the corresponding

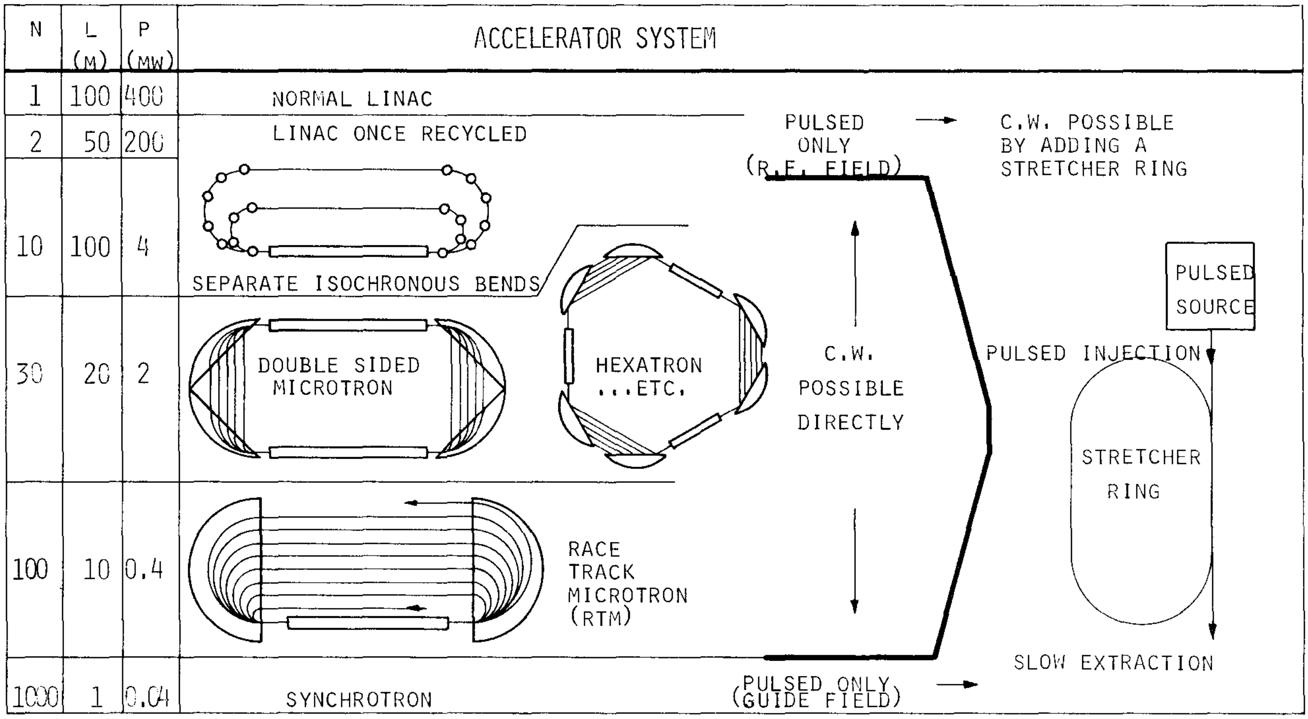

Fig. 1: Normal conducting c.w. accelerator systems

energy gain per turn with B = 1 Tesla, λ = 12.5 cm. Obviously, with N increasing, the linacs required become quickly cumbersome in length and power consumption. The recent progress with superconducting structures could, perhaps, provide an attractive solution in some future.

On the other side, if the energy gain per turn is drastically <u>decreased</u>, n becomes so large that it is no more practical to have separated return paths at all. One then uses <u>one</u> path which is matched to the instantaneous energy of the beam as it increases in time. Now, obviously, the beam output is pulsed again, due to the time varying guide field (Synchrotron), fig. 1.

Any pulsed accelerator may be supplemented more or less conveniently to a c.w. system by adding a pulse stretcher ring.

	N	ΔR/λ	ΔT [MeV]
RTM	1	0.159	5.96
DSM	2	0.876	32.9
Hexatron	3	2.76	103.5
Oktutron	4	6.39	240
	5	12.34	463

Tab. 2: Necessary energy gain per turn in microtrons

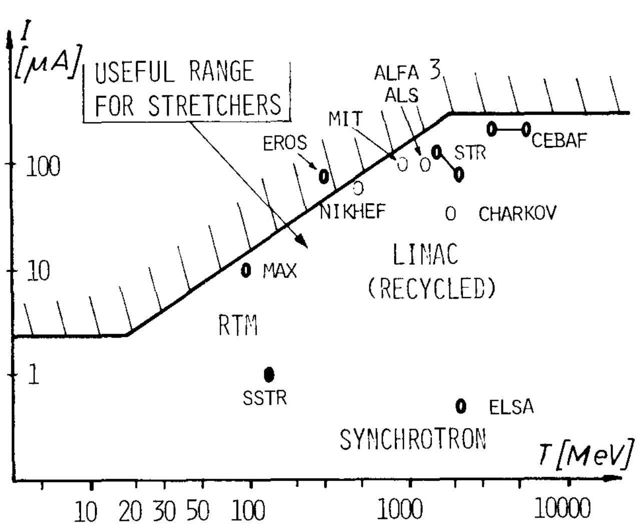

Fig. 2a: Machines using stretchers with ranges of preferable pulsed sources. For identification of abbreviations see tab. 5 and text

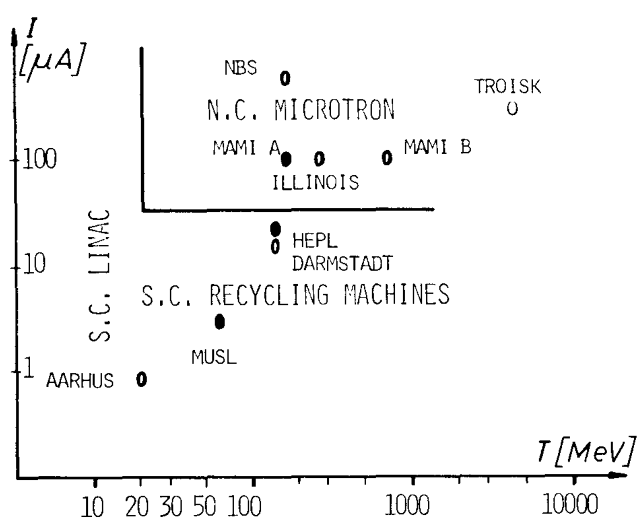

Fig. 2b: Machines achieving c.w. by recirculation directly with ranges of preferable schemes ● operating; **o** under construction; o proposed

In fig. 2 the regions of preferable types of c.w. accelerators in the I-T-plane are given.

Fig. 2a refers to machines which achieve c.w. by a stretcher. Clearly, any pulsed machine may be used to feed a stretcher ring, provided its pulse length is at least equal to the ring circumference (times c) in order to fill the ring completely, but not too long compared to the circumference in order not to need too many turns for injection. The latter condition makes it especially difficult to achieve high average current from low energy stretchers: a small ring can store a short pulse only, while the pulse repetition rate of the feeding accelerator is limited for the usual technical reasons. As a consequense, stretcher machines fill the lower right hand part of fig. 2a, and several labs owning a high duty cycle linac have, to further increase the duty cycle of their facility by a stretcher, first even to reduce the duty cycle of the linac to meet the injection requirements.

In most cases r.f. accelerating cavities are installed in a stretcher ring, be it for better control of the spill out, for improvement of the energy spectrum, for compensation of synchrotron radiation loss or for ramping up in energy before spill out (thus sacrificing some of the duty cycle for higher energy).

Generally, an important advantage of stretchers is the fact that they use only well known practice and that they may be added to an already available pulsed machine.

Fig. 2b refers to machines which achieve c.w. by recirculation. Generally, these less conventional machines fill the space that is not conveniently reached by stretchers, i.e. the upper left of the I-T-plane (with some overlap, of course, since the preferable choice also depends on local conditions). At high intensity, where the beam power is a sizeable fraction of the power dissipated in a recirculated NC-structure, normal conducting machines are preferred due to their simpler technology and less involved operation. Up to a little less than 1 GeV, the race track microtron seems to be the adequate choice; above, perhaps up to a few GeV the higher order microtrons[24,23,22] might be attractive. Quantum fluctuations of synchrotron radiation, however, spoiling the horizontal emittance[27,28], are of concern due to strong magnetic field and large β-function and they form an upper limit to the applicability of such schemes.

At very low energy recirculation is not applicable because the electrons are not sufficiently relativistic. Here a superconducting linac is the most elegant choice (though local conditions may favour other solutions).

Current Projects of C.W. Electron Accelerators

Due to the large number of proposed machines during the last few years the following compilation of c.w. electron machines will be restricted to those which are currently still "under way", between proposal and operation.

Superconducting machines

The first attempt towards c.w. machines has been undertaken in the 60's by HEPL, Stanford, on the basis of superconducting r.f structures. This effort finally resulted in a 3 to 4 pass recirculator which is still in operation. Its highest beam energy is reported to be 232 MeV at a duty cycle of 20 %[1] and 5 μA average current. Its c.w. data may be extrapolated from ref. [1] to be around 140 MeV at 20 μA. (It should be noted that ref. [1] is of 1981. The author did not succeed in getting more recent information).

At the University of Illinois the scheme of a race track microtron had been chosen for recirculating a SC linac. In its present form (MUSL II) it accelerates by 6 passes to a maximum of 67 MeV. Its beam intensity, being limited for years to $\lesssim$1 μA at full energy by beam blowup, was recently increased to 3 μA by installation of a new HEPL linac section which is equipped with probes for damping the breakup modes. It is expected that this intensity which was limited by the power of the r.f. source will be increased to 5 to 10 μA by use of a most recently installed, more powerful r.f. source. It is planned to use the magnets of the planned normal conducting cascaded microtron (see below) in a preliminary setup in connection with the SC linac to produce 100 MeV by 9 traversals[2].

The most recent attempt to use r.f. superconductivity for c.w. electron acceleration is presently undertaken by a Darmstadt-Wuppertal cooperation. Under the perspective of the recent progress in the use of SC cavities in storage rings at CERN and DESY there is realistic hope that the new generation of S-band SC structures developed by H. Piel and coworkers at Wuppertal might provide satisfactory performance. The Darmstadt project is shown schematically in Fig. 3 containing all essential data.

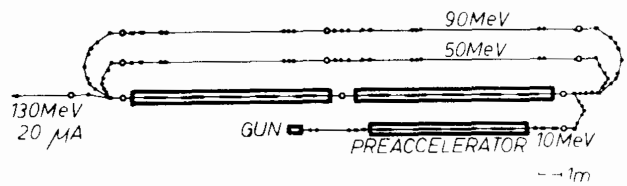

Fig. 3: The Darmstadt superconducting recyclotron

The project is funded and presently under construction. A new hall for housing of the machine is essentially completed. A five cell structure, to be used as a capture section, has been beam tested successfully up to an accelerating field strength of 5.7 MeV/m [3]. A detailed description of the present state of the art of superconducting structures will be given in a separate paper by H. Piel. Therefore I will not go into further detail here.

Normal Conducting C.W. Machines

The pertinent difficulties concerning breakdown phenomena and blowup properties with the first generation of SC structures suggested the use of multiply recirculated NC structure as a c.w. accelerator. Serious considerations on such a machine started in Mainz in 1974 and led, after several tests on crucial components, to a detailed proposal of a cascade of three NC race track microtrons for 100 μA c.w. operation, called MAMI (Mainz Microtron)[4].

An updated parameter list of the machine is given in tab. 3. The 14 MeV-stage is in operation since spring 1979. During numerous runs both for machine tests and users experiments it has demonstrated stable operation over many hours up to full design beam intensity.

The second stage has been in operation since Feb. 1983. It has been operated so far at a maximum energy of 187 MeV and a maximum beam intensity of 63 μA, limited by insufficient performance of the present r.f. control system. It is now being run routinely around the clock for users experiments at 183 MeV, maximum demanded beam intensity being 30 μA up to now. Beam transmission is 100 % within reading errors. Estimation of beam emittance from beam spot sizes is compatible with the design values. The output energy may be decreased by putting the extraction magnet (see Fig. 4) over one of the lower return paths. A more detailed description of this machine (MAMI A) is given in ref. [5].

MAMI B, comprising MAMI A, the 840 MeV-stage and an injector linac, (to replace the v.d. Graaff in order to ease the installation of a polarized source), has been funded by early 1984. Excavation of the new accelerator hall is expected by early 1985, completion

		"MAMI B"		
		"MAMI A"		
	stage	I	II	III
General				
input energy	[MeV]	2.1	14	180
output energy	[MeV]	14	180	840
number of traversals		20	51	74
total power consumpt.	[kW]	280		900
Magnet System				
magnet distance	[m]	1.66	5.59	11.83
magnetic field	[T]	0.1	0.56	1.54
magnet weight (each)	[t]	1.3	43	500
RF-System				
number of klystrons		2		5
linac length	[m]	0.8	3.55	10.4
dissipated rf-power	[kW]	8	51	130
energy gain per turn	[MeV]	0.59	3.25	9.0
Beam performance design, at 100 μA)				
energy width	[keV]	±9	±18	±60
emittance vert.	mm*mrad	0.17 π	0.04 π	0.01 π
hor.	mm*mrad	0.17 π	0.09 π	0.14 π

Injector: at present van de Graaff, Typ AS 2500 High Voltage Corp., later on: injector-linac optionally with polarized source

Klystrons: Thomson-CSF TH 2075, 50 kW c.w., η=60%

Frequency: 2449.3 MHz

Structure: "on axis" coupled biperiodic structure, essentially CRNL design

Tab. 3: Main parameters of MAMI

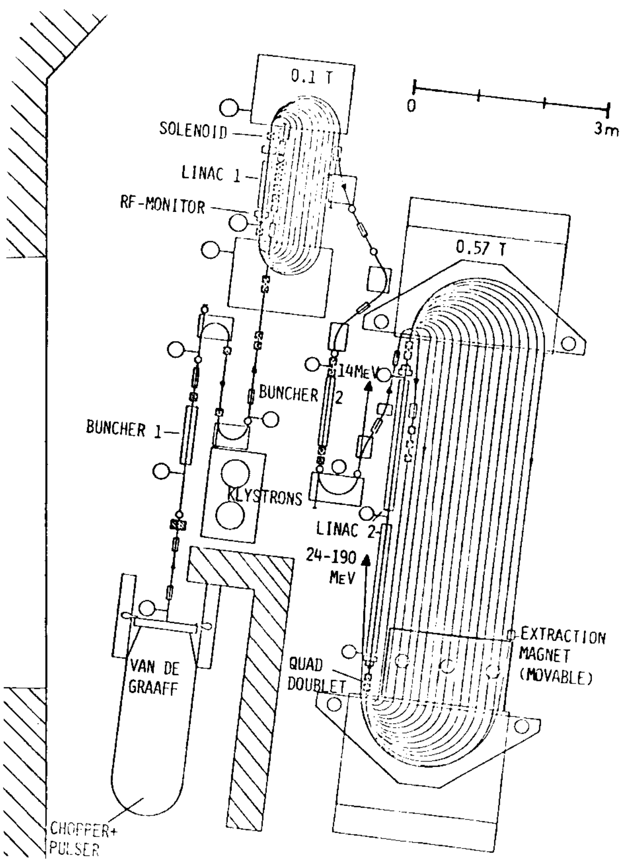

Fig. 4: Scaled scheme of MAMI A

by fall 1986. First beam is scheduled for 1988. The whole setup of MAMI B is shown in fig. 5.

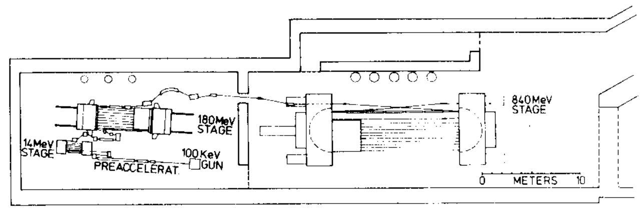

Fig. 5: Scaled scheme of MAMI B

A similar design philosophy is followed by two other projects: the NBS-LASL-collaboration and the new Illinois accelerator proposal.

The NBS-LASL-collaboration originally planned a cascade of two RTM's going up to 1 GeV. Its second stage, however, was not approved. Its first stage is presently under construction at NBS, Washington, D.C. The layout of this machine together with its main parameters is shown roughly to scale in fig. 6. Maximum design energy is 185 MeV (15 passes) or 197 MeV (16 passes), max. design current is 550 μA. As accelerating structure originally a DAW structure was planned. Due to appearence of a deflecting mode close to the operating frequency (2380 MHz) a side coupled structure is to be used now. It will be powered by one 500 kW klystron (Varian VKS - 8270).

Of this machine, gun and preaccelerator are essentially completed and tested. The end magnets should be installed in May and August 1984, respectively. First 185 MeV beam is scheduled for October 1985[25,26].

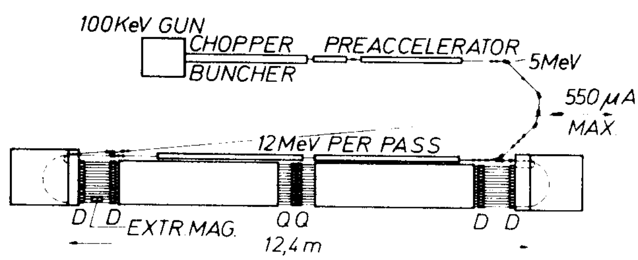

Fig. 6: Scaled scheme of the NBS-LASL-RTM

A normal conducting RTM cascade is also planned at the University of Illinois to replace the present superconducting machine. Originally a 3 stage cascade was proposed, similar to MAMI, for a maximum energy of 750 MeV. For this project funds are available for accelerator research and development and there is great confidence that at least stage one and two will be funded. This version is shown in fig. 7. The present work is concentrated on the installation of the 100 keV gun and, in collaboration with ANL, a prototype klystron power supply. Further, studies are undertaken in collaboration with LASL for optimisation of the coaxial coupled biperiodic structure for use with c.w. RTMs[2].

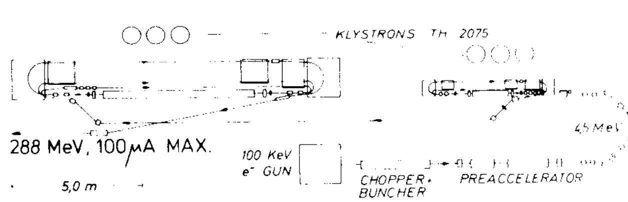

Fig. 7: Scaled scheme of the Illinois microtron cascade

At Aarhus University, Denmark, there is another c.w. RTM being under construction which is remarkable for two reasons: it is going to use the DAW structure and it is to be built practically for no money. This small machine, an "afterburner" of a 4 MeV van de Graaff, to be used for channeling experiments, is designed for 15 MeV, 1 µA. Its DAW structure, to be driven by a 5 kW magnetron (!) at 2450 MHz, will consist of a normal conducting, 13 cells DAW cavity of 80 cm length. The washers are suspended by means of three pipes, going through the cavity parallel to the axis. Its shunt impedance, as measured on an aluminum model and scaled for copper, is 99 MΩ/m. Provision is taken by large tuners to match its resonant frequency to the magnetron used[6]. This highly individual little machine will presumably be completed in 1985.

Further more it should be noticed that in ref. [22] a 140 MeV, 100 µA c.w. RTM is briefly mentioned to be under construction by a collaboration of the Moscow State University, the Physics Institute of Academy of Science and some other institute.

Finally, there is a recent, not yet very detailed proposal of the Lebedev Institute, Moscow, on a three stage 4.5 GeV microtron cascade consisting of an RTM, a DSM and an "Oktutron"[22] (fig. 8). Design current is 300 µA, including the option of multiple beam extraction in a similar way as previously proposed by ANL[23]. Some of the design parameters are compiled in Tab. 4. The machine is proposed to be built at the site of the Physics Institute of the Academy of Science at Troizk. The project seems to be in a rather early state of investigation.

		RTM	DSM	Oktutron
input energy	[MeV]	7	200	1000
output energy	[MeV]	200	1000	4500
energy gain per turn	[MeV]	12	2*25	4*90
magnetic field	[Tesla]	1.0	1.5	1.5
ν(λ=12.5 cm)		2	1	1
linac length	[m]	8.5	2*20	4*77
r.f. power	[MW]	0.2	1.0	7.2
number of klystrons (300 KW each)			4	24

Tab. 4: Main parameters of 4.5 GeV microtron cascade

Machines Using Stretcher Rings

There are two machines which do not follow the general recipe of a linac-stretcher combination: MAX and ELSA.

MAX, at the University of Lund in Sweden, uses a pulsed RTM as accelerator. The microtron has been in operation for several years already, whereas the installation of the ring has been delayed time and again. The RTM delivers 100 MeV in pulses of 1 µsec duration. Its design peak beam current is 25 µA, maximum p.r.f. 750 Hz. It has been moved recently to a new hall in which the stretcher is presently being installed (May 1984). First operation of the ring is scheduled for fall 1984[7]. The latter consists of four 90^o bends and four straight sections; its circumference of 18.75 m requires multiturn injection. A 10 µA, close to c.w. beam is expected by slow extraction by horizontal third resonance from the ring. Optionally, the stored beam can be ramped up within 1 sec to 500 MeV by a 400 MHz r.f. system to feed an internal tagging device for about 20 sec[29].

ELSA, at the University of Bonn, is presently under construction. It is designed to optionally merely stretch the beam of the Bonn 2.5 GeV synchrotron or to ramp it up to 3.5 GeV before slow spill out. Its beam intensity is limited by the synchrotron to 0.5 µA in stretching mode and considerably less in ramping mode. Since the circumference of the stretcher (164 m) is 2.35 times larger than the circumference of the synchrotron, a multiturn extraction from the synchrotron has to be chosen to fill the stretcher smoothly. Extraction from the stretcher will presumably be done by a third resonance[8]. The cavities of the 500 MHz r.f. system are identical to the ones used in DORIS and PETRA and will be supplied by DESY. The new buildings for this machine are essentialy completed. First operation in stretcher mode is scheduled for late 1985, first operation in the ramping mode expected for late 1986[9] (fig. 9).

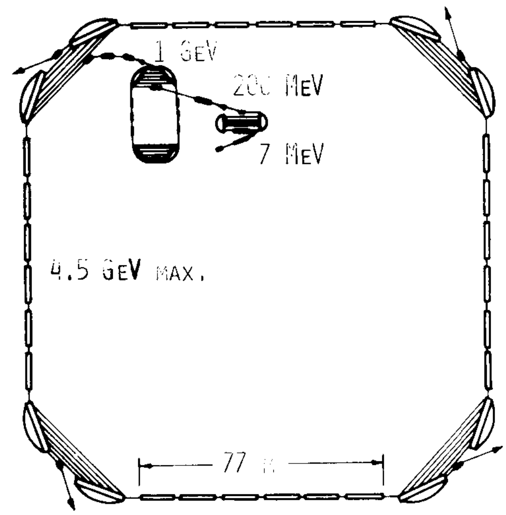

Fig. 8: Scheme of the 4.5 GeV machine, roughly to scale

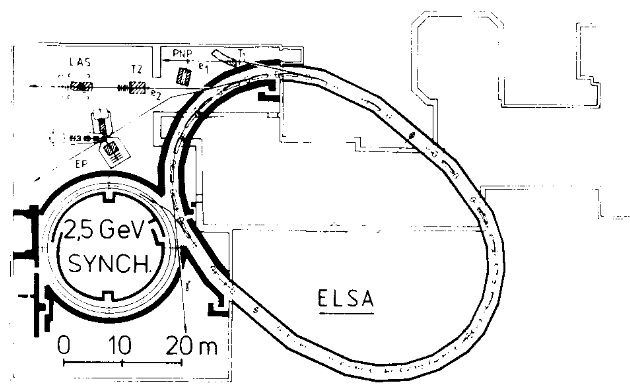

Fig. 9: Scaled scheme of ELSA

An excellent compilation of the current linac-stretcher-projects with many figures has recently been given by G. Loew[12]. So I will confine myself here to give brief verbal descriptions of the various projects. The main parameters of these machines are compiled in Tab. 5, which is essentialy an updated brief version from ref. [12]. Common to all projects is an S-band linac as a pulsed source (sometimes optionally once recycled) and a design duty cycle of the stretcher of at least 80 %.

So far the first and only stretcher ring in operation is the 150 MeV stretcher at Tohoku University, Sendai[10,11]. It has 15.5 m circumference. A three turn injection is used to store about 150 nsec of a 70 mA linac beam pulse at a repetition frequency of 300 Hz. Extraction is done by slow energy loss due to synchrotron radiation which drives the stored beam slowly into a chromatic 1/3 resonance. Thereby the energy spread of 1.4 % of the injected beam is reduced to 0.2 % after extraction. In tab. 5, this kind of extraction is referred to as "monochromatic". As typical

PLACE NAME		Tohoku SSTR	Saskatoon EROS	NIKHEF (Amsterdam)	MIT	Frascati ALFA 3	Saclay	Charkov	Tohoku STR	SURA CEBAF
Energy max.	(GeV)	0.15	0.3	0.7	1.0	1.1	1.7	2	3.9	4(6)
Max.extracted current	(μA)	1	72	50	100	100	100	30	70/140	240
LINAC										
Peak energy (one pass)	(GeV)	0.38	0.3	0.7	0.54	1.1	1.75		2.0	2.2
Peak current	(mA)	140	200	80		160	200		200	200
Beam pulse length	(μsec)	0.2	0.3; 1	1.2	2.6	3.1	1		1.2	1.2
RF pulse length	(μsec)	3.5	2.5		(40)	4.2	2.4		≤ 4.2	3.2
Repetition rate	(pps)	100-300	360		1000	200	500		300	1000
Overall length	(m)	54	≈30	≈200	160	>110	174		238	179
Number of sections		21	7	24	23	24	24		32	40
Number of klystrons		5	6	12	12	12	24		28	40
Klystron peak power	(MW)	20	20	4; 25	5.4	30	25		40	40
Number of passes through linac		1	1	1	2	1	1,possibly 2 later		possibly 2	possibly 2
ΔE/E	(%)	0.1 - 2	0.2 - 1		0.2	0.1 - 2	0.1 - 1		0.1 - 2	0.2
Energy compressing system (ECS)		yes	yes	probably	yes	probably	yes		yes	yes
STRETCHER										
Circumference	(m)	15.47	108	120	390	460.77	300		362.8	362.7
Magnetic radius	(m)	0.8	1		9.1	22.3	15		16.7	26.85
Number of bending magnets		8	8		16	48	64		32	32+12
Number of quadrupoles		1	26+10		137	204	100		?	30+20+14
Number of sextupoles		1+1	10+2		16	6	?		?	16
Betatron tunes	ν_x	1.22,1.28	4.26		10.46	17.33	8.5		9.5	8.5
	ν_y	1.3, 1.2	4.8		10.6	7.25	8.6		9.4	8.8(var.)
RF System				yes	yes					
Frequency	(MHz)	-	714			-	600		476	714
Voltage	(MeV)		0.09				0.5			4.5 var. 1.5 cont.
Turns for injection		2 and multi	1 or 3	3	2	2	1		1	1
Extraction resonance		1/3 monochromatic	1/2 achromatic, 1/3 monochromatic	1/3 or 1/2 monochromatic	1/2 monochromatic	1/3 monochromatic	1/2 achromatic		1/2 achromatic	1/2 achromatic
Emittance	(π mm mrad)									
x		5	1	not yet defined	0.01	4	0.5		0.5	0.3
y		3	1		0.01	4	0.1		1.0	0.1
ΔE/E	(%)	0.2	0.1		0.02	0.02	0.1		0.1	0.2

Tab. 5: Compilation of parameters of current linac-stretcher combinations

results of test operation are given: duty factor 80 %, average current 0.5 μA, emittance 5 π mm mrad horizontally and 3 π mm mrad vertically. This machine is in operation now for about 2 years and is currently used for photonuclear and (e,e'p) coincidence experiments. Needless to say that the operation experience gained will be very useful for any further stretcher project.

EROS (Electron Ring of Sakatoon), originally proposed as early as 1971[13], was one of the earliest proposals of stretcher rings at all. It has finally been funded in spring of '83 in the revised version SORE (Son of Resurrected Eros) which fits into the present facility without major changes of existing buildings: it surrounds rather closely the existing linac[14,15].

The NIKHEF plans have changed significantly during the last few months[16] in that the present high duty cycle linac is to be modified stepwise to higher energy (700 MeV, finally perhaps 1.2 GeV) and lower (0.1 %) duty cycle by replacing the present 4 MW, 10 % D.F. klystrons stepwise by 25 MW, 0.1 %D.F. ones. The geometry of the 700 MeV stretcher is chosen compatible with later upgrade to 1.2 GeV. An official proposal will be presented before summer 1984.

Also brandnew is the MIT proposal for upgrading the Bates facility[17]: the present linac will be upgraded by two additional klystrons from 410 MeV to 540 MeV unloaded energy. The present linac recirculator, which recently has demonstrated head-to-tail operation at 40 mA will be extended by 200 m in length in order to increase the present head-to-tail pulse length of 1.3 μsec to 2.6 μsec, thus doubling the maximum average beam current. An energy compressing system will be provided which is expected to reduce the energy spread to ± 0.02 %. Finally, a stretcher ring of 390 m circumference will be added which will store the 2.6 μsec pulse by a two-turn injection. Thus, the overall performance expected is a beam of 300 to 1060 MeV (unloaded), max. current of 100 μA at a D.F. in excess of 80 %. A detailed proposal of this project has just been completed in a draft version (April 1984).

The present status of the Frascati project ALFA 3 is not known to the author. The data given in the table are of 1981[12]; the author did not succeed in getting more recent information.

The ALS (Saclay) upgrade to the performance shown in the table is proposed to be done in three steps[18]: at first the stretcher will be installed, which would immediately allow to produce a close to c.w. beam of around 10 μA at a maximum energy of 600 MeV. In a second step, by partial upgrading of the present linac and installation of an energy-compressing system, the energy will be raised to 700 MeV and the maximum c.w. current to 100 μA.

The third phase provides an essential upgrade of the linac energy to 1.7 GeV (unloaded) by replacing the present high duty cycle klystrons (and modulators) by 0.15 %, 25 MW ones. By this a loaded energy of 1.3 GeV at 100 μA should be achieved.

Finally the option is kept open to increase the maximum energy to 3.25 GeV by recirculating the linac once. The ring elements will be designed for this energy from the beginning. ALS hopes to get funds for this program by the end of 1985. In this case the 1.7 GeV version should be operational in 1990[19].

Another stretcher project for 2 GeV, 30 μA, is proposed at Charkov[22]. The author did not succeed, however, in getting closer information.

The Tohoku University STR project[12,11] is in an advanced state of design. In contrast to most of the other stretcher projects it will require an entirely new linac and new high power klystrons (40 MW, 3.4 µsec, 300 pps). Without recirculation of the linac its maximum energy at full load (200 mA) will be 1.75 GeV, 140 µA average. This version has recently been recommended for funding[11]. To reach the ultimate energy of 3.3 GeV (loaded) the linac will require a recirculation system. The resulting average current will then be reduced to 70 µA due to the shorter pulse length of the head-to-tail recycled beam.

Finally the SURA project[20], since recently called CEBAF (Continuous Electron Beam Accelerator Facility) is shown in the last column of Table 5. In its first stage, it is designed for 4 GeV but it is kept expandable to 6 GeV at a later time. The project has been approved by the U.S. Department of Energy and is expected to receive its major construction funds in F.Y. 1986, with a completion schedule of five years. At the present time the linac design assumes 40 klystrons and sections and a recirculation system for two passes of ≅ 2 GeV each. An alternate design with 61 klystrons and 122 sections would achieve the same total energy of 4 GeV without recirculation. This scheme would result in a shorter r.f. pulse length (2.2 µsec instead of 3.2 µsec), thereby reducing the power demands placed on the klystrons, modulators, cooling systems, etc. It would also simplify the focusing and operation of the linac. On the other hand it would lengthen the linac from 179 m to about 438 m. The size of the ring is chosen so that an expansion to 6 GeV could be obtained later without difficulty.

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