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Summary

In the PETRA storage ring of the DESY laboratory at Hamburg, a new generation of 600 kW, 60 % efficiency, modulating anode equipped cw high power 500 MHz klystrons has successfully passed its first two-year period of routine operation. Based on this experience, a development program is under way at Valvo Hamburg trying to push the state of the art to the 1 MW cw 70 % efficiency level. In addition to 500 MHz, the program includes klystrons with other frequencies in the 300 to 1000 MHz range.

Introduction

In addition to military applications and UHF-television, the needs of particle accelerators have significantly motivated the development of high power klystrons. In the beginning, there was the request of linear electron accelerators for L-band and S-band pulse tubes with several megawatts of peak output power per unit for pulse lengths of a few microseconds. In the more recent years, the construction of large electron synchrotrons and storage rings required long pulse and cw tubes in the UHF-region. The power range of these tubes between 0.1 and 1.0 MW cw or average is by more than one order of magnitude higher than that of UHF-television klystrons. Until the mid-seventies, 200 - 300 KW cw per unit with efficiencies slightly above 40 % were achieved both in Europe and in the US. Then the PEP and PETRA projects at Stanford and Hamburg requested even higher powers which, in turn, necessitated higher efficiency tubes in order to cut down the operating costs because in these machines the rf-systems became the dominating constituents of the laboratories' power bills. The total rf-power for PEP is around 6 MW, for PETRA 4 - 5 MW (first stage) or 8 - 10 MW (second stage). For the CERN future project LEP¹, up to 96 MW of rf-power are in discussion. In order to simplify both the rf-transmitter systems themselves, and the routine operation of these systems, the number of tubes necessary to generate the total power has to be as small as possible, or, respectively, the output power per unit as large as possible. Consequently, at Stanford a 500 kW cw tube at 353 MHz with 70 % maximum efficiency was developed for PEP, based on the experience with the 75 kW/40 % SPEAR klystron. At DESY in Hamburg 250 kW cw/500 kW pulse tubes for 500 MHz with efficiencies around 40 % had been in operation in the synchrotron and in the DORIS storage ring, developed and manufactured by Thomson-CSF in Paris and Varian Ass. in Palo Alto, Ca.

PETRA-Klystrons

For PETRA, the rf-transmitters (see figures 1 and 2) were developed and constructed at DESY^{2,3}, whereas the new generation of klystrons necessary for these transmitters was designed and manufactured by Valvo, Hamburg according to the DESY design objectives. The main features were

- 500 MHz with respect to the DESY synchrotron radio-frequency,
- high efficiency because of the power cost for the

- generation of 4 MW (minimum) of rf-power,
- 500 kW cw minimum output power per unit in order to restrict the number of sockets to 8 for the 19 GeV first stage of PETRA,
- "modulating" or "accelerator" anode, and air insulation for the gun, providing easy control of the output power level.

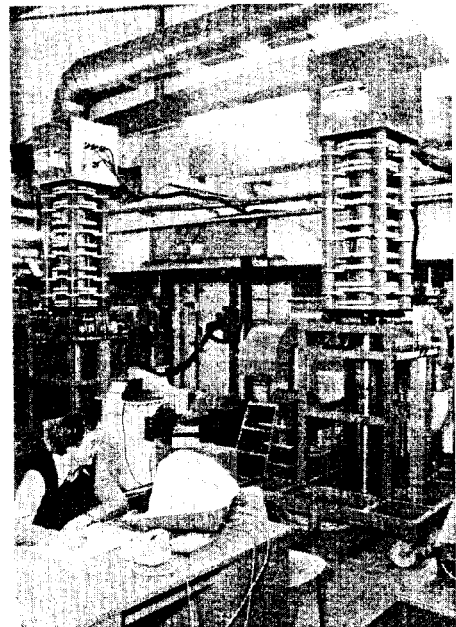


Fig. 1 PETRA "double" transmitter equipped with 2 YK 1300 klystrons

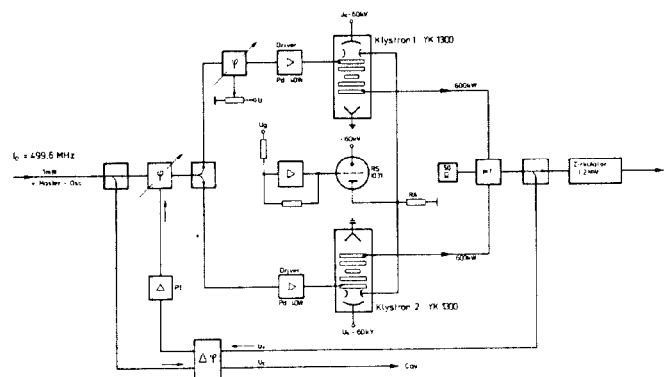


Fig. 2 Block diagram of PETRA double transmitter

Figure 3 shows a table containing a comparison of data of 500 MHz high power klystrons now operating at DESY. For the Valvo tube there are two sets of data, one presenting the optimization for maximum efficiency, the other for maximum output power.

Klystron Parameter for operating conditions	Synchrontron	DORIS-St-Ring	PETRA-St-Ring	
			A	B
Frequency	MHz 4 99.6	4 99.6	4 99.6	4 99.6
Saturation Bandwidth 1dB	MHz 5	5	3	3
Beam - Voltage	kV 50	44	60	60
Beam - Current	A 24	13.5	15	17.5
Microperveance	$\mu\text{AV}^{3/2}$ 2.15	1.46	1.02	1.19
Accelerator-Anode-Voltage	kV -2	-8	-15	-10
RF - Output - Power	kW Puls 500	cw 250	cw 540	cw 610
Saturation Gain	dB 40	37	43	45
Efficiency	% 40	42	60	58
Number of Cavities	4	4	4+1	4+1
Klystron Type	F 2055 VKP 8259 Thomson CSF Varian	F 2055 VKP 8259 Thomson CSF Varian	YK 1300	YK 1300
Manufacturer			Valvo	Valvo

Fig. 3 Comparison of characteristic data of klystrons now operating at DESY

Special Features of the PETRA Klystron

Gun

Impregnated tungsten cathode, 40 cm^2 , 0.5 A/cm^{-2} ; filament power 625 W. Control of effective perveance and output power by means of a modulating or accelerator anode which can be set to any potential between cathode and collector potentials, air insulation for beam voltages up to 75 kV, special measures for suppression of thermal and field emission from the internal electrodes.

Output window

Low loss (less than 0.1 % of transmitted power) $6 \frac{1}{8}$ " coaxial alumina with forced air cooling; the coaxial section is part of a transformer/transition system delivering the output power through an 1800" waveguide.

RF-section

4 cavities for the fundamental, one cavity for the second harmonic, optimized for high efficiency both by computer simulation and experiments with the actual tubes, perveance as low as possible for the given maximal beam voltage and power output ratings (see figure 4).

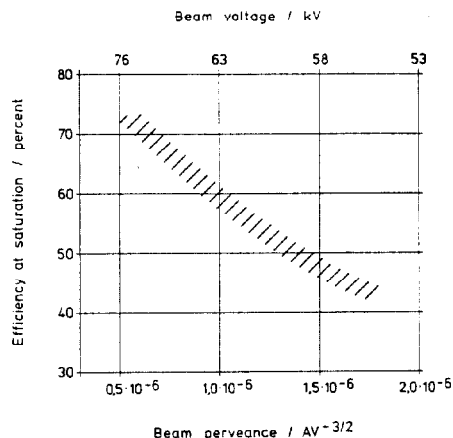


Fig. 4 Optimization of efficiency (empirical data from YK 1300)

Collector

Water cooled copper for full beam power (850 kW) with zero rf drive, average power absorption less than 200 W cm^{-2} .

Operating Experience with the PETRA Klystron

For the time being, there are 8 klystron sockets in the 4 PETRA double transmitters. In each transmitter, the power out of two tubes is combined by means of a "magic tee" and, after passing through a 1 MW circulator providing more than 20 dB isolation for reverse waves, is split up again for feeding the PETRA first generation 5 cell accelerating cavities. In the years from 1978 to 1980, 20 klystrons were delivered which contributed to a total of approximately 100 000 klystron high voltage operating hours. Quite a few tubes have achieved more than 10 000 hours individual life time without showing any signs for "end of life". The main reason for tube failures was vacuum leaks in the region between the output circuit and the collector entrance due to local overheating. In the meantime, this problem was successfully cured by modifying the geometry. As part of a DESY/VALVO joint program, many experimental data have been taken from the tubes operating at DESY. These data were not only used for comparison with computer model predictions, but primarily for supplying information on those klystron data which cannot be included in computer simulations, e.g.

- evidence for internal breakdowns in the gun area,
- difference in amplitude and phase characteristics for a large number of tubes including life time behaviour of the individual tubes,
- evidence for electronic instabilities in the rf-parts of the tubes like ion oscillations, multipactor, beam instabilities for extreme setting of the beam parameters, temperature of critical tube parts, etc.

Figures 5 and 6 present examples from the above mentioned klystron studies.

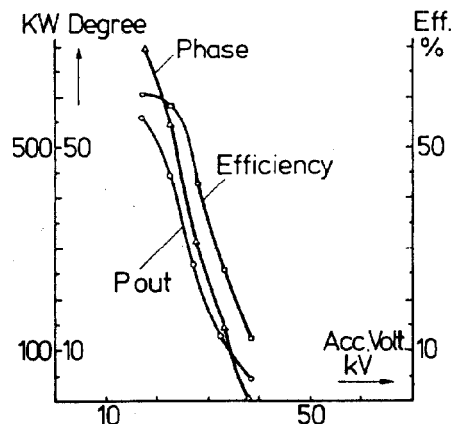


Fig. 5 Variation of output power, efficiency and relative phase as a function of accelerator (or modulating) anode voltage for constant beam voltage

Future Aspects

At DESY as well as in other accelerator laboratories there is a strong interest in further improvements for high power klystrons. This applies to higher efficiency and higher output power for 500 MHz tubes as well as to klystrons for 1 GHz and around 0.3 GHz. For DESY, aside from 0.5 GHz, 1 GHz is of particular interest for application to a second harmonic rf system in PETRA for bunch length control. For 500 MHz

the number of klystron sockets in PETRA is now being doubled in order to push the PETRA beam energy in several steps (depending on the number of additional "second generation" 7 cell accelerating cavities) from 19 GeV towards 23 GeV.

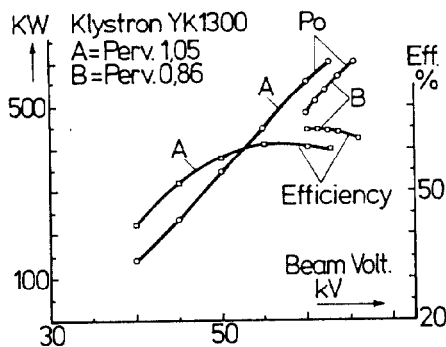


Fig. 6 Output power and efficiency as a function of beam voltage for different perveance

Based on the DESY experience with the now operating standard YK 1300 klystron, further computer studies at Valvo, and several experimental klystrons now under construction, an improvement program is under way, the steps of which are shown in figure 7.

Klystron Parameter (operating conditions)	Second Generation for PETRA				
		I	II	III	IV (DEV Target)
Frequency	MHz	499,6	499,6	499,6	499,6
Saturation Bandwidth 1dB	MHz	1	1	2	2
Beam - Voltage	kV	64 - 65	75	75	≥85
Beam - Current	A	13,9	12	16,4	15,7
Microperveance	$\Delta AV^{-3/2}$	—	0,6	0,8	0,6
Accelerator-Anode-Voltage	kV	-24	-36	-28	—
RF-Output - Power	kW	570	650	800	>750
Saturation Gain	dB	46	36	42	40
Efficiency	%	64	72	65	75
Number of Cavities		4+1	4+1	4+1	4+1
Klystron Type		YK1300	V114 SK	V113 SK	V113 SK
Manufacturer		Valvo	Valvo	Valvo	Valvo

Fig. 7 Data of improved 0.5 GHz - klystrons now under development

The data at 64 kV were taken from an actual tube of YK 1300 type which was operating at lower perveance and with modified output transformation. The data for 75 kV and 85 kV are computer predictions (at 85 kV, the gun will be under oil instead of air). Test klystrons for 75 kV beam voltage will be available starting from March 1981.

Klystron Parameter Second Generation		CERN DEV Target	PETRA Pro. Type	PETRA 2.Pro. Type	PETRA DEV Target
Frequency	MHz	358,8	999,3	999,3	999,3
Saturation Bandwidth 1dB	MHz	≈ 1	4	4	4
Beam - Voltage	kV	85 - 90	44	55	55
Beam - Current	A	14 - 16	7	7	10
Microperveance	$\Delta AV^{-3/2}$	0,6	0,75	0,54	1,3
Accelerator-Anode-Voltage	kV	≈ 35 kV	-20	-17	-15-20
RF-Output - Power	kW	1000	14,0	22,0	30,0
Saturation Gain	dB	37-40	37	37	40
Efficiency	%	75	45	57	55
Number of Cavities		5+1	4+1	4+1	4+1
Klystron Type		V103 SK	V109 SK1	V109 SK2	V109 SK3
Manufacturer		Valvo	Valvo	Valvo	Valvo

Fig. 8 Experimental klystron data, and design objectives for 0.3 GHz and 1 GHz tubes

The table in figure 8 compiles data of klystrons for frequencies different from 0.5 GHz. For both 1 GHz and 0.3 GHz first data from existing "test vehicles" were available; for 1 GHz, a second experimental klystron will be ready by March 1981. Furthermore, design objectives for a third 1 GHz test klystron are incorporated in figure 8.

Conclusion

Based on the experience with the PETRA 500 kW cw/500 MHz standard klystron YK 1300, the next klystron generation with output powers up to 1 MW and efficiencies up to 75 % is under development for frequencies between 0.3 GHz and 1 GHz. The program includes the construction of experimental klystrons, the first data of which now become available.

Acknowledgement

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