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RF POWER SOURCE DEVELOPMENT FOR THE HIGH CURRENT LINEAR ACCELERATOR OF THE SPALLATION NEUTRON SOURCE (SNQ)

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Summary

The SNQ linear accelerator design demands a rf pulse power of 267 MW at 324 MHz with 6% duty cycle, generated by 89 klystron ampflifiers, each capable of 3,5 MW of saturated peak power. Fast analog and pulse control response to achieve the required rf field stability under heavy beam loading conditions and maximum operational efficiency are major aspects of the rf system design. The advanced technique of a grid controlled klystron which is provided as rf generator accomplishes both aspects simultaneously. Test results obtained with a preliminary industrial klystron and further development steps are reported and discussed under consideration of the requirements.

Introduction

The design of the spallation neutron source (SNQ)[1] is based on a high current (5 mA average) proton linear accelerator for a final energy of 1100 MeV. The rf accelerator consists of a 84 m long alvarez part at 108 MHz and a 384 m long disk-and-washer part at 324 MHz. The conceptual design of a new generation of klystron amplifiers as rf power sources for the disk-and-washer part has been elaborated in cooperation with industry.

Rf Power Requirements

The 324 MHz part of the linear accelerator consists of 89 modules, each with a nominal rf power requirement of 3.0 MW. Control transients and fluctuations in the beam current can be handled with a power margin of 10%. The losses along 30 m of coaxial transmission line (345 mm ⌀) connecting the klystron amplifiers and the accelerator tanks amount to < 0.2 dB. The eventual addition of circulators with < 0.3 dB insertion loss has been taken into account by the peak power rating of 3.7 MW for the klystron design.

The length of the rf pulse (fig. 1) is extended in relation to the particle pulse length of 500 μs by the rf filling time of the cavity and the control recovery time. Including an optional doubling of the particle pulse length, the rf pulse of the 324 MHz part totals 1.1 ms. The repetition rate is ≤ 100 Hz.

Klystron Modulation

The selection of the amplitude modulation methods is dominated by the coincidence of stringent control requirements (field deviations of < 0.1% in amplitude and < 0.2° in phase) and the integral efficiency optimization. The modulation requirements are:
- switching time < 5 μs
- bandwith (- 3 dB) > 5 MHz

During the particle pulse, the klystron output power is close to the nominal level (3.15 MW). An unsaturated modulation capability at this level is essential for the control system.

The modulation and efficiency requirements can be accomplished only by grid modulation of the klystron. With an integral efficiency of 54 %, this methode is preferable to the proved combination of modulation anode pulsing and rf drive modulation with an integral efficiency of 45%.

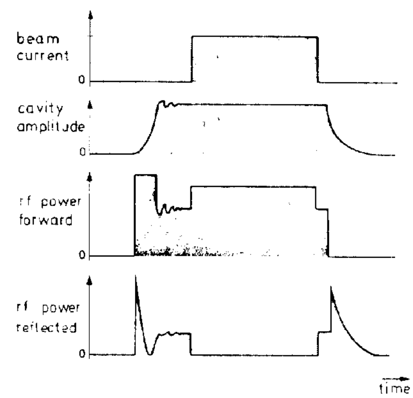

Fig. 1: Rf pulse structure

Klystron Design Concept

An important objective of the proposed 324 MHz / 3,7 MW-klystron amplifier concept is the realization of a high operational efficiency. This is achieved by combining an efficiency optimized electronic design with the advantages of a gridded gun for fast and efficient modulation of the RF-output. The concept is based on computer-aided extrapolations from existing designs of various UHF-klystron types in the power range below 1MW, on supporting experimental evidence for the feasibility of efficiency figures at and above 70 percent and on the successful incorporation of gridded gun techniques into lower power klystron

Klystron Design Parameters

A low beam perveance has been chosen for optimization of the electronic efficiency of the klystron. Empirical data of fig. 2 as well as results of computer studies of the bunching process indicate, that an efficiency of 70 to 75 percent is obtainable with a beam perveance of approximately 0.6×10^{-6} $AV^{-3/2}$ and with all other design parameters being optimized. The resulting high operating voltage of 140 kV, however, generates a number of engineering and handling problems, such as the need for heavy X-ray shielding and large overall klystron dimensions.

A 6-cavity design including one beam exited 2nd harmonic cavity was selected to provide sufficient bandwidth for fast amplitude modulation and simultaneously to permit tuning for optimum bunching efficiency. Output power is extracted through a flat coaxial window, which is designed to pass the peak RF-power of the proposed tube. Tests of this window design in a klystron

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V107SK (see below) have shown that losses are well below 5×10^{-4} of the transmitted power. Therefore, the window is not considered a critical tube element for this project.

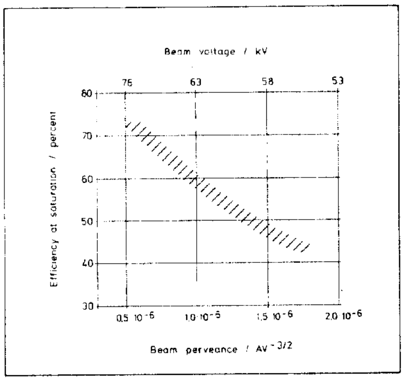

Fig. 2: Optimization of efficiency (empirical data from YK 1300)

The electron gun employs an impregnated tungsten cathode. A conservative rating of the specific loading of the cathode of less than 2 A peak per cm^2 has been chosen in the interest of long life and operating reliability. Design criteria for the control grid are low current interception, low emission, structural stability, a low grid/cathode capacity for a fast response and a characteristic suitable for beam modulation (fig. 3). Grid techniques which are adaptable to the project are being studied in lower power klystrons.

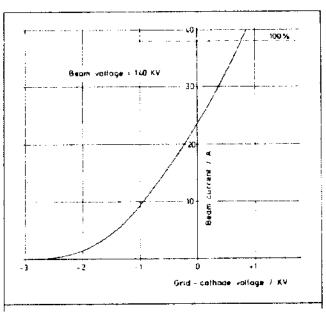

Fig. 3: Grid characteristic of V116SK gun (computed)

The operational efficiency of the proposed grid-modulated klystron amplifier is shown in fig. 4 as a function of the instantaneous RF-output power level. Constant drive power is assumed for curve A whereas for curve B the drive is adjusted to saturated operation at each modulation level. RF-phase shift for grid modulation is given in fig. 5 and compared to that for cathode voltage and RF-drive modulation.

Feasibility Tests

A standard klystron YK 1300 [2] with a modulation anode for current (perveance) control was used to obtain the efficiency data of fig. 2. Nominal data for this tube are 500 MHz/600 kW-CW power, with an efficiency of 60 percent. With reduced beam perveance and simultaneously optimized output loading and beam focusing improved efficiency figures up to 72 percent could be achieved.

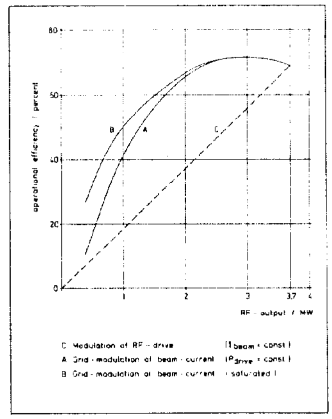

Fig. 4: Operational efficiency of klystron amplifier V116SK for various methods of power modulation

On the basis of the above results an experimental 6-cavity klystron V107SK for 324 MHz was designed, built and tested. Because of present limitations of the test facilities with regard to maximum available voltage (see table 1), the tube design was optimized for a voltage range of 65 to 85 kV.

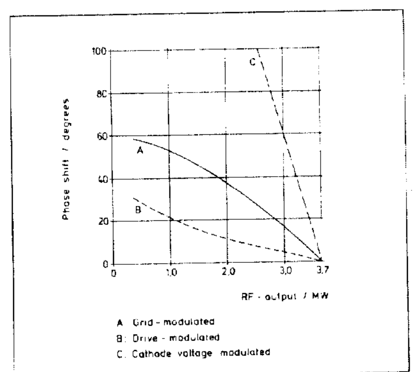

Fig. 5: RF-phase shift of klystron amplifier V116SK

The gun is equipped with a modulation anode to adjust the beam perveance up to 1.2×10^{-6} $AV^{-3/2}$. Electrical design and technology of the RF-section were chosen to test basic features of the proposed V116SK-project. All cavities are tunable by means of deformable membranes acting on the gap spacing to permit optimization of the tuning scheme.

Results of intensive factory tests are in good agreement with the design specifications of table 1. Efficiency data of fig. 6 were obtained using a coaxial transformer section between klystron output and waterload to adjust for various degrees of output loading. Other data obtained from these tests related to the signal transfer characteristics and to dissipative loading of exposed klystron elements such as the window, the output coupling loop, tuners etc. The results have contributed to confidence in the chosen design approach and to reducing development risks for the proposed klystron project V116SK.

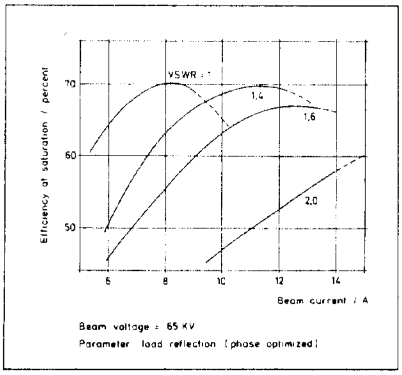

Fig. 6: Efficiency of experimental 324 MHz-klystron V 107 SK as function of beam current and output loading

References

1 J. Vetter, High Intensity Proton Linear Accelerator for the German Spallation Neutron Source (SNQ) these proceedings

2 H. Musfeldt, H. Kumpfert, W. Schmidt, A New Generation of High Power CW-Klystron for Accelerator and Storage Ring Application, Practical Experience and Aspects for Future Development, these proceedings.

TABLE 1
Design data for the proposed klystron V116SK and the present feasibility study klystron V107SK

	V107SK	V116SK	
Frequency	324	324	MHz
RF-output			
pulse	≥ 0.6	3.7	MW
average	≥ 300 *	410	kW
pulselength		1.1	ms
beam voltage	≥ 70 **	~ 140	kV
beam current	≥ 18 **	~ 38	A
collector dissipation average	≥ 800	≥ 400	kW
efficiency at saturation	~ 70	~ 75	%
gain at saturation	~ 40	~ 40	dB
modulation	anode	grid	
grid/cathode capacity	-	~ 50	pF
length of klystron	4	~ 5	

* limited by power rating of available water load.
** limited by available high voltage supply.