# PERFORMANCE OF AN S-BAND KLYSTRON AT AN OUTPUT POWER OF 200MW

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*Abstract*

In order to provide RF power to the accelerating sections of a future S-Band linear collider, klystrons producing 150MW of output power at a frequency of 2.998GHz are required. Two S-Band klystrons with a nominal output power of 150MW at a pulse duration of 3µs and a repetition rate of 50Hz were developed in a collaboration between SLAC, Philips, TH Darmstadt and DESY [1]. They were built and successfully tested at SLAC in 1994 and 1995 and then shipped to DESY to feed the accelerating sections of the S-Band test facility linac. In order to explore their power potential one of the klystrons was operated at an even higher output power of more than 200MW at the test facility. HV pulses up to 610kV at a current of 780A were applied to the klystron cathode. This paper reports the results of the measurements of the various parameters of the klystron at this power level (e.g. output power, efficiency, perveance). It describes the performance and the limitations of the klystron in this power range.

## 1 INTRODUCTION

A possible future S-Band linear collider would require more than 5000 klystrons, capable of an output power of 150MW at a pulse duration of 2.8µs and repetition rate of 50Hz. Until 1992 klystrons meeting these demands were not available. The well known SLAC 5045 klystron achieved 65MW at a pulse duration of 3.5µs [2]. A klystron with an output power of 150MW at 1µs pulse width was developed at SLAC in 1985 [3]. In 1992 a collaboration between SLAC, TH Darmstadt, Philips and DESY was settled to develop a klystron meeting the demands of an S-Band linear collider. Two klystrons were built and successfully tested at SLAC. The results are reported in [1]. Table 1 shows the design and the parameters of the two klystrons, which were measured during the tests at SLAC.

Later C. Bearzatto and G. Faillon of Thomson in France reported, that they had developed and tested an S-Band high power klystron with an output power of 150MW at a pulse width of 1µs [4].

Both klystrons, built at SLAC, are now in operation at the S-Band test facility at DESY. The second tube was used to investigate whether an even higher peak output power than 150MW is possible. The output waveguides of the klystron were connected to RF water loads. The klystron cathode voltage was carefully raised from 550kV to a higher voltage. In the following we describe the klystron operation at the higher power level. The results of the measurements are presented.

Table 1: Parameters of the klystrons for the S-Band test facility ( design and measured during tests at SLAC )

| | Design | Tube#1 | Tube#2 |
|---|---|---|---|
| Power Out | 150 MW | 153 MW | 150 MW |
| Pulse Duration | 3 µs | 3 µs | 3 µs |
| Repetition Rate | 60Hz | 60Hz | 60Hz |
| Beam Voltage | 535 kV | 527 kV | 508 kV |
| Beam Current | 700 A | 680 A | 652 A |
| Microperveance | 1.79 | 1.78 | 1.80 |
| Efficiency | 40 % | 43 % | 45 % |
| Gain | > 50 dB | 56 dB | 57 dB |

## 2 THE KLYSTRON

Figure 1 shows klystron #1. The total height is 2.6m, the diameter of the anode housing is 40cm and the weight is about 300kg. The cathode has a diameter of 13.3cm and a cathode loading of 6.12A/cm$^2$. The beam area convergence is 40:1. The maximum electric fields on the focus electrode and anode are 180kV/cm and 210kV/cm, respectively. Seven cavities including the input and output cavities are in the 3.2cm wide drift tube.

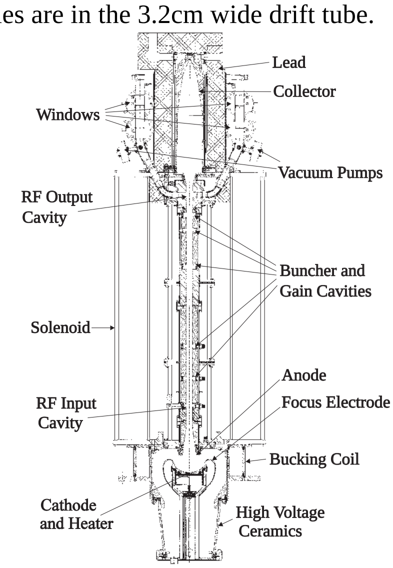



Figure 1: Layout of klystron #1

The klystron has two output waveguides, which are splitted and recombined again, so that there are two RF windows in each output waveguide. The waveguide assembly on each side is the well proven design of the SLAC 5045 klystron.

The klystron requires a solenoid with a magnetic field of 1800G and a power consumption of 14kW. A bucking coil is needed to achieve zero magnetic field on the cathode surface.

Although the two tested tubes are very similar in general, there are three major differences between tube #1 and #2. Already at the design state it was decided to use different output cavities for the two tubes. Tube #1 has one single cavity, whereas tube #2 has two coupled cavities at the output. The expectation was, that the second tube would have a slightly better efficiency than the first tube. During the tests of tube #1 an oscillation at 8.1GHz was observed depending on the beam voltage and solenoid field settings. Therefore it was decided to fabricate tube #2 with a stainless steel drift tube between the cavities 3 and 4, and 4 and 5 instead of using only copper for the drift tube as for klystron #1. This added additional losses to the disturbing oscillation. No oscillations were observed during testing of tube #2. The cathode of tube #2 was changed to a scandate cathode for tube #2, whereas tube #1 uses an osmium coated M-type cathode. More details can be found in [1].

## 3 OPERATION OF KLYSTRON #2

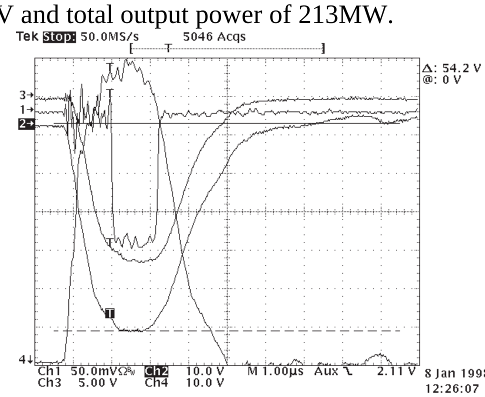
Since klystron #2 did not show disturbing oscillations up to an output power of 150MW and in addition has a slightly better efficiency than klyston #1, it was chosen to investigate the power potential of this type of klystron. Whereas klystron #1 has to provide RF power to the accelerating sections of the test facility, two sets of high power water loads, made by Nihon Koshuha, Yokohama, Japan, were installed at the two output waveguides of klystron #2. Each of the loads consists of a splitting T which devides the output power of each output waveguides. At the end of each waveguides the power is absorbed by water flowing behind a thin ceramic window. The VSWR of the loads is less than 1.10 at 2.998GHz.

Two 75dB hole coupler were installed at each output waveguide to measure the forward and reflected output power. A 2.998GHz band pass filter (30MHz bandwidth) was used to eliminate other frequency components in the measurements. In addition the output power could be determined by calorimetric measurements by measuring the water flow rate through the loads and by taking the loads water in and outlet temperatures. By taking into account these numbers, the repetition rate and the output pulse shape it was possible to calculate the klystrons peak output power. Since we were also able to measure the temperatures and flow rates in the klystron coolant circuits, e.g. the collector and body cooling circuit, we were also able to determine the power absorbed in the klystron itself. The difference between the power absorbed in the klystron at operation with and without RF power generation gives the klystron output power, too.

The high voltage pulse duration could be changed by adding or removing capacitors of the line type modulators pulse forming network. A detailed description of the modulator can be found in [5].

## 4 MEASUREMENTS

The measurements were performed at a high voltage flat top pulse duration of 1µs and a repetition rate of 12.5Hz, because both, klystron and modulator, were operated beyond their peak power specification during the tests. The cathode voltage was slowly raised from 550kV up to the maximum possible voltage of 610KV at a current of 780A. At a voltage level of 600kV it was necessary to increase the magnetic field in the solenoid by about 6%. Otherwise the RF output power would break down at the end of the 1µs long RF pulse. Later it turned out, that by adjusting the independent coils of the solenoid, operation at a beam voltage up to 610kV could be achieved even with a lower setting of the solenoid currents. Figure 2 shows the waveforms at a voltage of 610kV and total output power of 213MW.




Ch1 RF output power out of waveguide 2 107MW
Ch2 Klystron cathode voltage 610kV
Ch3 Klystron collector current 781A
Ch4 Klystron gun current 778A
Time 1 s/div

Figure 2: Waveforms at a voltage of 610kV

The measurement of the perveance of klystron #2 gives numbers lower than in the SLAC measurements. Although klystron #1 is operated at a different modulator with different devices for voltage and current measurement as klystron #2, we measure also a lower perveance than in the SLAC tests. The reason for the difference is not clear up to now. Figure 3 shows perveance and efficieny as a function of the beam voltage. The klystron efficiency increases with increasing beam voltage and reaches 47%. Figure 4 shows the output power as function of the beam voltage. At a voltage of 610kV a power of 213MW in a 1µs long pulse can be extracted from the klystron. Figure 5 shows the dependence of the output power from the drive power for different beam voltages. Four data points are included, which were taken at four different beam voltages but at fixed drive power.

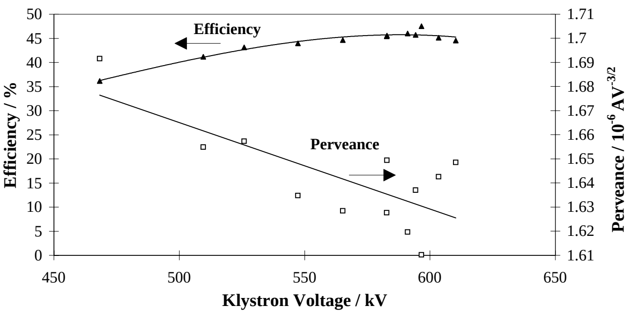



Figure 3: Efficiency and perveance as function of beam voltage

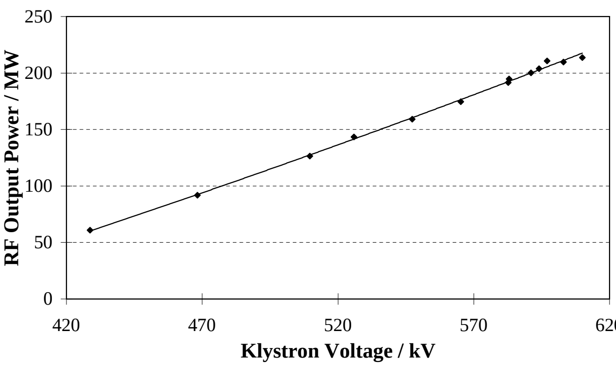



Figure 4: Output power versus beam voltage

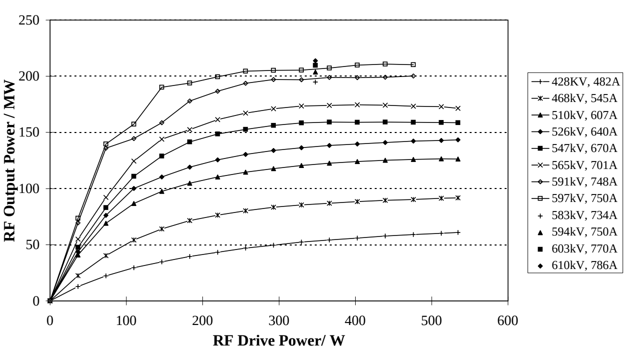



Figure 5: RF output power versus RF drive power for different klystron voltages and currents at an RF pulse duration of 1µs

At a drive power of 300W the output power is saturated. The saturated gain at this point is 58dB for an output power of more than 200MW. For beam voltages above 550kV the curves start to show a strange behavior on the rising part of the curve, where bumps appear. This can be seen more easily in figure 6, which shows the gain at a beam voltage of 583kV. The gain, which usually decreases with increasing drive power, shows a bump at 95W of forward drive power. Since the reflected drive power increases almost linearly as function of the forward drive power and shows no distinct bump, the drive power absorbed by the klystron should show a similar behavior. The vacuum pressure in the tube was not conspicuous in any way. A variation of the solenoid filed affected the bumps. The bumps could be shifted to other points or could be made more or less distinct. It is even possible to find curves which show two or three of these bumps on the gain curve. The reason for this behavior is not clear up to now. It might be, that it indicates multipacting in the tube.

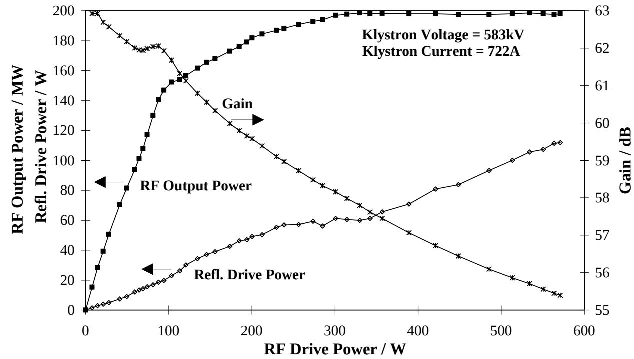



Figure 6: RF output power, gain and reflected drive power at 583kV and 722A

# 5 CONCLUSION

It is possible to operate an S-Band klystron at a pulse duration of 1µs at more than 200MW of output power. Even longer RF pulses at this power level might be achievable. Since we wanted to use the klystron to provide RF power for the test facility, we refrained from trying to reach more than 200MW at longer pulse duration. Both, the klystron and the modulator, were operated beyond their original specification. The e-beam needs careful focussing when the beam voltage is in the 600kV range. The reason for the bumps on the gain curves is not clear. Since these can be affected by varying the magnetic field, this might indicate multipacting in the tube.

# 6 REFERENCES

[1] D. Sprehn, G. Caryotakis, R.M. Phillips, “150-MW S-Band Klystron Program at the Stanford Linear Accelerator Center”, Proceedings of the RF96, Kanagawa, Japan, April 8-12, 1996, P 91-99

[2] T.G. Lee, J.V. Lebacqs, G.T. Konrad, “A Fifty Megawatt Klystron for the Stanford Linear Collider”, SLAC-Pub-3214, September 1983

[3] T.G. Lee, G.T. Konrad, Y. Okazaki, M. Watanabe, H.Yonezawa, “The Design and Performance of a 150MW Klystron at S-Band”, SLAC-Pub-3619, April 1985

[4] C. Bearzatto, G. Faillon, “Short Presentation of High Peak Power TH 2153 Klystrons”, Proceedings of the RF96, Kanagawa, Japan, April 8-12, 1996, P 116-122

[5] S. Choroba, M. Bieler, J. Hameister, Y. Chi, “A 375MW Modulator for a 150MW Klystron at the S-Band Linear Collider Test Facility at DESY”, Proceedings of the XVIII International Linear Accelerator Conference, Linac 96, Geneva, Switzerland, 26 -30 August, 1996, P 785-787