A HIGH POWER LONG PULSE HIGH EFFICIENCY MULTI BEAM KLYSTRON

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Abstract

THALES ELECTRON DEVICES has developed and built a new high power - long pulse - high efficiency - multi beam klystron (MBK), the TH1801. This MBK uses 7 low perveance beams in parallel and is in operation at the TESLA TEST FACILITY at DESY, where it was tested at full pulse duration of 1.5ms. It reached 10MW at 117kV and 131A with an efficiency of 65%. This paper reports on the tube and the test results obtained on the TH1801 multi beam klystrons built up to now.

1. INTRODUCTION

In the field of long pulse high power tubes, new challenges have to be taken up to go further in the increase of peak power, efficiency and reliability. This boost of performance is requested to minimize the investment and the operation costs of the entire RF system of a particle accelerator.

The peak power delivered by a long pulse single beam klystron is limited by the high voltage its gun can withstand. For instance, the regular L-band TH2104C klystron delivers 5MW peak at 2ms pulse duration. It operates at a voltage of 128kV and a current of 88A. The efficiency is 44%, in agreement with a beam perveance close to the maximum practical value of $2.10^{-6}\mathrm{A/V}^{1.5}$. To increase the current and then the power, a solution is to use several low perveance beams in parallel within the same vacuum envelope[1,2]. The advantage of this solution is the lower voltage required and the higher efficiency compared to the single beam klystron.

This multi beam concept, which is not a new one, has been applied on the tube THALES ELECTRON DEVICES has developed for the TESLA TEST FACILITY (TTF), the 10MW 1300MHz 1.5ms high efficiency multi beam klystron TH1801 (see photograph in figure 1).

About 1200 5MW TH2104C would be required to power the TESLA linear collider. Thanks to the multi beam klystron, the number of RF source is two times smaller, without increasing the high voltage and with an efficiency yield of about 20 points.

2. DESIGN ASPECTS

2.1 Main design parameters

The main design parameters are discussed in the following paragraphs and are summarized in table 1. This MBK uses 7 low perveance parallel beams which propagate in 7 drift tubes and which interact with the electric field of the common cavities they travel through.

The effective perveance of the MBK is $3.5 10^{-6}\mathrm{A/V}^{1.5}$ at the design voltage of 110 kV, with each single beam perveance being $0.5\ 10^{-6}\mathrm{A/V}^{1.5}$, that is to say 18.2A per beam. This low single beam perveance, with low space charge forces enables strong beam bunching and consequently high efficiency.

According to the empirical relation η=0.78-0.16K(μperv) (1), an efficiency of 70% is achievable with a perveance K= 0.5 10^{-6}A/$V^{1.5}$.

Table 1
Design parameters of the TH1801

Operating frequency	1300	MHz
Output peak power Output average power	10 150	MW kW
RF pulse duration	1.5	ms
Frequency repetition	10	Hz
Number of beams Nb	7	
Cathode voltage, max.	115	kV
Total beam current	130	A
Total perveance	3.5	10^{-6}A.$V^{-1.5}$
Efficiency (VSWR=1.2:1 optimized phase)	70	%
Gain (saturated), min	47	dB
Bandwidth (-1dB) Number of cavities	3 6	MHz
RF input	N type	
RF output	2xWR650	
Cathode loading, max.	5.5	A/cm²
Beam area convergence	9:1	
Electric field at 120 kV	7	kV/mm
Focussing field	1350	Gauss
Collector dissipation	full beam	
Tube height	2.5	M
Position	vertical	
Electromagnet power, goal	4	kW

Fig. 1 The TH1801 multi beam klystron

2.2 Interaction section

The interaction structure has been optimized to maximize the degree of bunching and to ensure stable operation on a mismatch of 1.2:1 at any phase. This klystron is a 6 cavities design with four intermediate cavities inductively tuned, all operating on fundamental mode TM_{010}. The simulations were carried out on one of the seven beams with an harmonic disk 1D code, and assuming that the R/Q factor is Nb (number of beams) times the R/Q factor related to a single beam. As a high efficiency operation leads to the creation of slow electrons, and in order to inhibit possible oscillations, particular attention was paid to avoid reflected electrons in the output gap and at the entrance of the collector. Related to the load, the output cavity has been slightly over coupled, so that the klystron can operate with a good stability on a mismatched load, under optimum phase condition. In addition to the large overall perveance, this results in an unusual low value of external Qx, about 10.

2.3 Beams generation

The tube is equipped with a multi cathode diode gun for beams generation. The electron gun mainly consists of 7 cathodes and a beam forming electrode which surrounds each cathodes (see photograph in figure 2). The cathodes are M type dispenser cathodes with a maximum loading of 5.5A/cm² at 18A and a temperature in the range 1010°Cb to 1045°Cb. This gives an expected lifetime of around 36000 hours. The cathodes are powered in parallel.

The design of the gun and the solenoid were carried out with OPTIQUE3D and ANSYS codes. The simulation results, which take into account a 3D magnetic field pattern, are shown is in figure 3. The gun produces quite laminar and low scalloping beams with a compression ratio of 9. The electric field is maximum on the radius of the focusing electrode and is kept below 7 kV/mm at a voltage of 120 kV. This value is consistent with long pulse operation.

The beams are focussed in a magnetic field more than twice the Brillouin field, which involves magnetic flux through the cathodes. The design reduces, in a large extent, the asymmetry of the magnetic field around each beam axes. Except in the compression area, the axial magnetic field is kept constant in order to limit the defocussing radial components which would lead to beam interception.

Fig. 2 The multi cathode gun

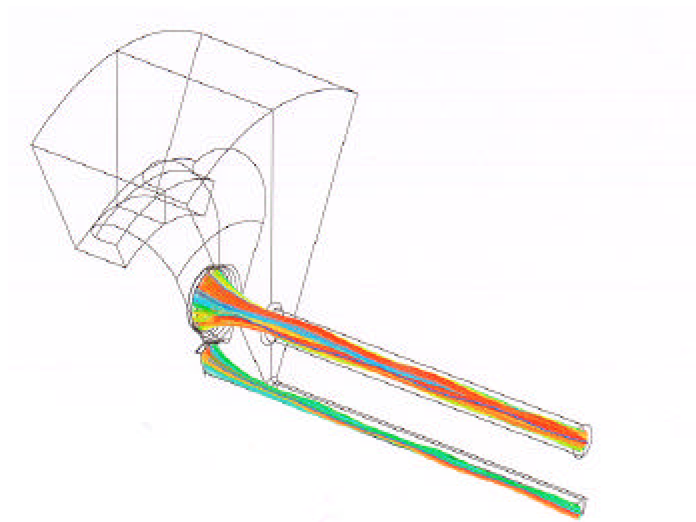

Fig. 3 Electron trajectories

2.4 RF cavities

A cross section of the cavity is represented in figure 4. The cavities are toroïdal and operate in the fundamental mode TM_{010}. The beams are packed in the center of the cavity. Due to the field shape, the center beam experiences a larger voltage across the gap than the outer beams, and the field over the cross section of the outer beam lines is not symetrical with respect to their axis. In this design the R/Q factor of the center gap is 40% higher than the one of the off axis gaps. The cavities were designed with HELMOT3D to investigate the higher order mode pattern. A study was carried out to identify and to damp the modes which could give rise to parasitic oscillations. Except for the input and output ones, the cavities are mechanically tunable, at least on the first tubes.

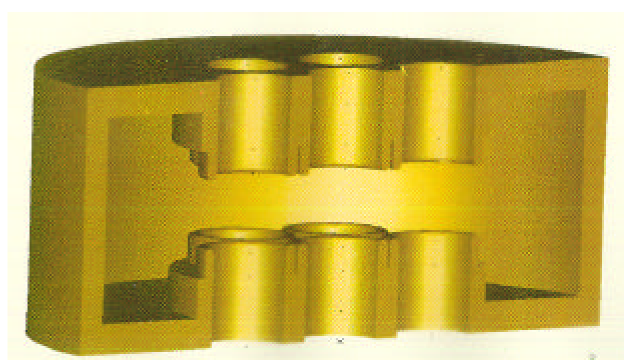

Fig. 4 Cross section of a cavity

2.5 Output circuit and collector

The RF power is fed from the cavity to two output WR650 waveguides via irises and pill box type windows used on regular L-Band klystrons.

After the RF extraction, the spent beams are absorbed in a common grounded collector. A 3D analysis of the electron beams spread allowed to limit the potential drop at the entrance of the collector in order to avoid reflected electrons. A particular attention was paid to the cooling circuit of the drift tube section comprised between the output gap and the collector.

3. TEST RESULTS

Four MBK have been produced until now. The first one suffered from high beam interception, oscillations and gun arcing. The two next tubes (MBK1 and MBK2) have completed the factory acceptance tests at THALES, where they were tested to full peak and full average RF power in 0.5ms pulse duration and at 30Hz frequency repetition. The pulse duration was set at the maximum that the PFN modulator can provide. The MBK 1 was installed in May 2000 in one of the HV modulators at the TESLA TEST FACILITY at DESY and then conditioned and tested to full RF power at full pulse width of 1.5ms, but lower repetition rate of 5Hz. It is now in use for the operation of TTF. The MBK 2 will be tested at full pulse duration in one of the new HV modulators now being installed at DESY. The MBK 3 is currently under housing at factory. The results of the MBK 1 and 2 are summarized in the following table.

Table 2
Measurement results on tubes 1 and 2

parameter	unit	tube 1			tube 2	
modulator		TED		TTF	TED	
cathodes voltage	kV	117	-	117	116	-
beams current	A	132	-	131	136	-
perveance	µperv	3.3	-	3.27	3.44	-
RF pulse width	ms	0.5	-	1.5	0.5	-
repetition frequency	Hz	30	-	5	30	-
VSWR		<1.1	1.2(opt.ϕ)	1.1	<1.1	1.2(opt.ϕ)
output peak power	MW	10	10.6	10	10	10.5
output average power	kW	150	159	75	154	161
efficiency	%	64.5	68.5	65	63.4	66.6
gain	dB	48	48.5	48	48.7	48.9
body power	kW	2	2.7	1.8	3.9	3.8
heater power	W	345		360	321	
solenoid power	kW	5.7		5.7	6.25	

Figure 5 shows output power of the first MBK as a function of the input power for several beam voltages, pulse duration and operation conditions. The curves are smooth, without any discontinuities, that means without multipactor or parasitic oscillations. The RF output power was determined from calorimetric data taken from RF loads. The measurements at 0.5ms performed at THALES and at 1.5ms performed at DESY respectively are in good agreement for the same voltage. The measurements were done using water loads at THALES and cooled ferrite loads at DESY, under matched load conditions with a VSWR smaller than 1.1. These measurements are indicated as mode A. The tube 1 delivers 10MW peak and 150kW average with an efficiency close to 65% and with a voltage of 117kV. The perveance of 3.27 is slightly lower than the design value. Additional measurements on a load with a VSWR of 1.2 at optimum phase conditions were performed at THALES, indicated as mode B. Under these conditions, the efficiency increases to 68.5%. During this test the tube demonstrated good stability.

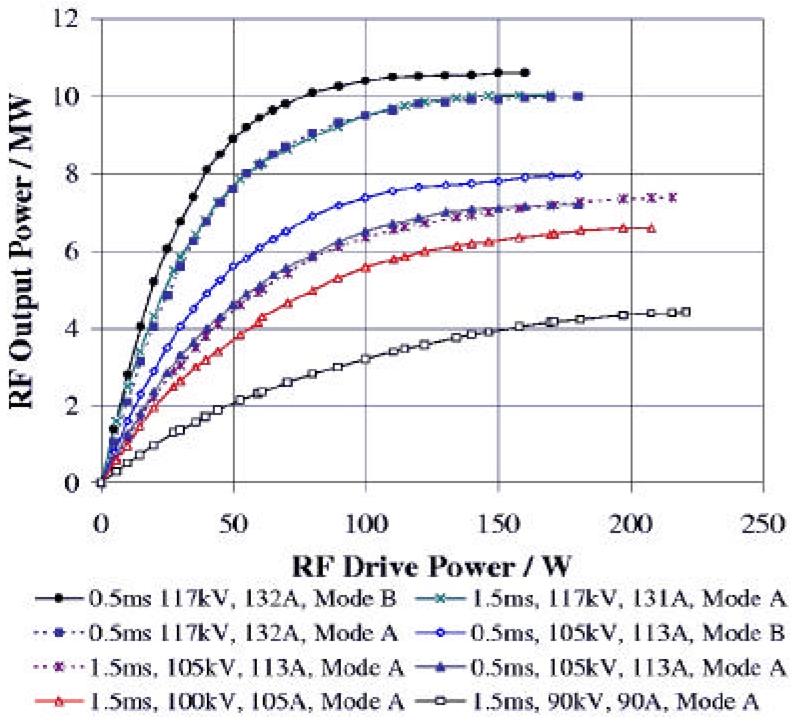

Fig5: RF output power as function of RF drive power of the MBK 1

The body losses include the RF losses in the windows and the cavities and the beam power intercepted on the drift tubes. The value measured on the THALES modulator at 150kW average power is less than 1% of the total beam power. The losses on the drift tubes located just after the output gap represent about 50% of the body power. This result confirms the design of the electron optics including the electromagnet. The greater body power measured on the DESY modulator is due to the longer high voltage rise time during which the beams are not correctly focussed. Figure 6 shows the waveforms recorded during the test at DESY.

At DESY, the MBK1 was operated at 5Hz repetition rate to full power. The -1dB bandwidth is more than 10MHz and the high gain of 48dB allows the use of semiconductor drive amplifiers. At 10Hz, measurements were restricted to 105kV or 7MW output power, because of main power limitations. At this power level, the efficiency is 60.5%.

The second tube also delivers the required RF power. The test results at 0.5ms pulse duration are shown in figure 7. The maximum efficiency of 63% for mode A, and 66% for mode B at 116kV is slightly lower than for the first tube. The reason is a 4 MHz detuning of the output cavity which occurred during the bakeout together with a too low Qx. The MBK 3 does not present this fault. The perveance of 3.44 $10^{-6}A/V^{1.5}$ is close to the design value. However, the body losses are two times larger than for the first tube. It could be due to a too large magnetic radial component of the solenoid.

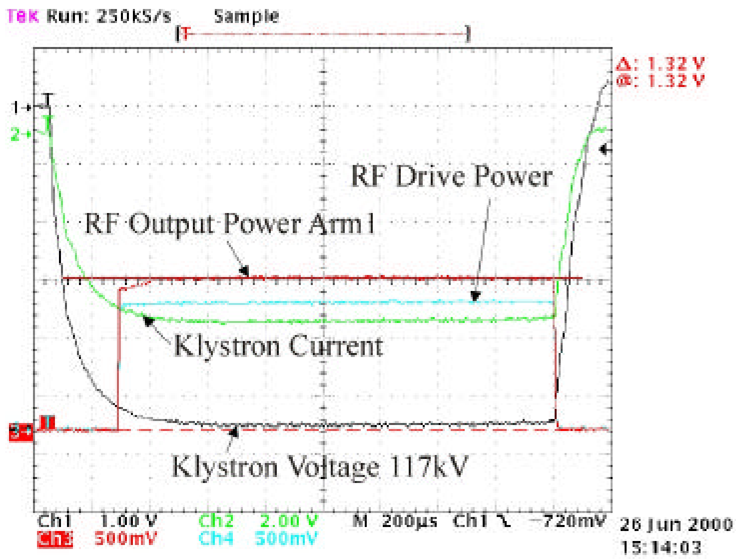

Fig 6:Waveforms at 10MW output recorded on MBK1

The MBK 1 is now used for TTF operation where it operates at low power, typically 3 to 4 MW, since only 16 superconducting are connected.

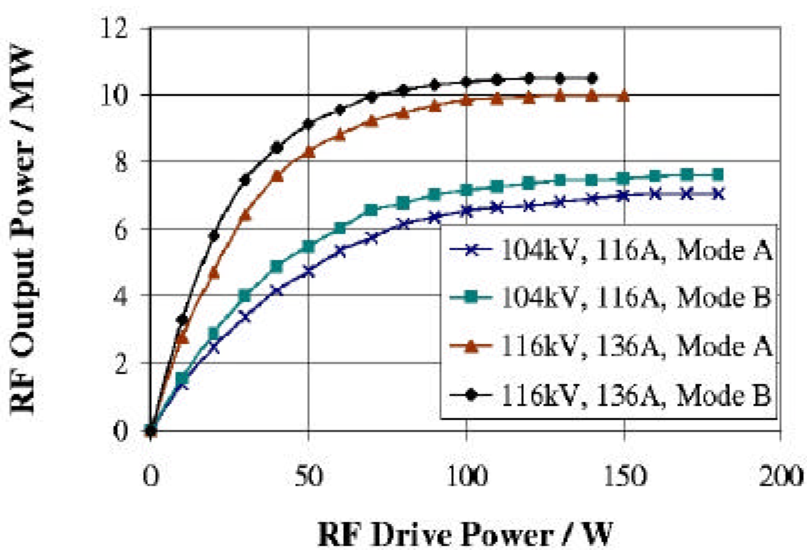

Fig.7 : RF output power as function of RF drive power of the MBK 2 at 0.5 ms pulse duration

4. CONCLUSION

THALES electron devices has successfully developed and built a long pulse high efficiency multi beam klystron. The two first tubes are close to the design goals.

For the TESLA linear collider, additional modifications are required in order to meet the infrastructure requirements of the tunnel installation, for instance the horizontal mounting position

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