INITIAL COMMISSIONING OF HIGH POWER, LONG PULSE KLYSTRONS FOR SSC INJECTOR LINACS

P. COLLET, J.C. TERRIEN, Ph. GUIDEE.
THOMSON TUBES ELECTRONIQUES
Bâtiment CHAVEZ - B.P. 21
78148 Vélizy Cedex - FRANCE

1 - INTRODUCTION

H^- ions are injected into the SSC boosters and main ring at a energy of 600 MeV by means of a three stage injector. It is composed of a RF quadrople, a drift tube Linac, both operated in UHF-band, and a coupled cavity Linac operated in L-band at the third harmonic of the two first stages. These Linacs are powered by two types of klystron, and their procurement contracts were awarded to THOMSON TUBES ELECTRONIQUES in October 1991. A design review held in January 1992 finalized the proposed design and fixed the final details concerning the operation and specifications of the tubes optimized for SSC requirements. Since November 1992, the commissioning of both type of klystrons has been underway and several tubes of each type have so far been accepted in accordance with the tight contractual schedule. It is expected that all deliveries will be completed by the end of 1993.

2 - MAIN FEATURES OF KLYSTRONS FOR SSC INJECTOR LINACS

RF operation of SSC injector Linacs is characterized by two main features [1] :

- The use of one Radio Frequency quadrople (RFQ) at 427.6 MHz and two successive Linacs operated at the same frequency for the drift tube Linac (DTL), at the third harmonic frequency for the coupled cavity Linac (CCL)coupled cavity Linac (CCL).
- The operation in long RF pulses, which reach a 100μs duration.

At the end of the DTL section, the beam energy is 70 MeV and the peak RF power supplied to the RFQ is estimated at 600 kW. DTL operation requires 3 MW peak power per klystron, which are designed and tested up to 4 MW to give a large margin for operation reliability. These values are consistent with performances obtained with other types of klystrons previously developed by TTE (Table I).

To accelerate H^- ions from 70 to 600 MeV in the CCL accelerating sections, the unit peak power requirements per klystron are more demanding. Each L-band klystron will have to provide 15 MW peak power in operation, and its contractual performance in acceptance test is 20 MW peak for the same reason as above. A special klystron design was necessary to provide sound tube operation at the required pulse duration.

	UNITS	SSC SPECIFICATION	TH 2134 Typical	TH 2118 Typical
OPERATING FREQUENCY	MHz	427.617	432	433.33
BANDWITH (- 1 dB)	MHz	1	1	0.75
OPERATING DUTY CYCLE	%	0.1	5	3.3
RF PULSE WIDTH	µs	100	1000	222
VIDEO PULSE WIDTH	µs	110	1100	225
REPETITION RATE	Hz	10	50	150
PEAK OUTPUT POWER	MW	4	2	6
GAIN	dB	50	46	50
EFFICIENCY	%	> 40	55	55
BEAM VOLTAGE	kV	130	95	180
BEAM CURRENT	A	80	80	75

TABLE I : COMPARATIVE SPECIFICATIONS OF SSC KLYSTRON FOR DRIFT TUBE LINAC AND TWO EXISTING TTE KLYSTRONS.

3 - TH 2140 KLYSTRON FOR RFQ AND DTL SECTIONS

3.1. GENERAL DESIGN

Based on the design already used and successfully proven with other high power klystrons produced by TTE, the TH 2140 klystron is cathode-modulated and has a built-in focusing magnet and a single window directly mounted on the output waveguide (Fig.1). It completes the already extensive family of UHF high power, long pulse klystrons produced by TTE for accelerator applications (Table II).

P/N	RF FREQUENCY (MHz)	RF OUTPUT POWER PEAK (MW)	AVGE (kW)	EFFICIENCY*	GAIN (min.) (dB)	RF PULSE LENGTH (max)	PEAK BEAM* VOLTAGE (kV)	CURRENT (A)
TH 2142*	352	2.5	100	60%	42	250 µs	120	35
TH 2140	428	4	4	50%	48	100 µs	129	70
TH 2134*	432	2	100	55%	46	1 ms	95	40
TH 2118	433	6	200	58%	50	220 µs	165	65
TH 2120	433	4	500	55%	48	10 ms	120	60
TH 2131	805	12	25	50%	50	115 µs	210	115
TH 2138*	850	1.25	75	52%	48	2 ms	87	28

* Modulation by anode

* : typical values

TABLE II MAIN CHARACTERISTICS OF HIGH POWER, LONG PULSE, LOW FREQUENCY TTE KLYSTRONS

Because of the very low duty cycle and resulting very low average power, it was possible to accept a slight reduction of the gain and efficiency. Such a trade-off allows a four-cavity design instead of the usual five, and significantly saves on length, weight and cost.

0-7803-1203-1/93$03.00 © 1993 IEEE

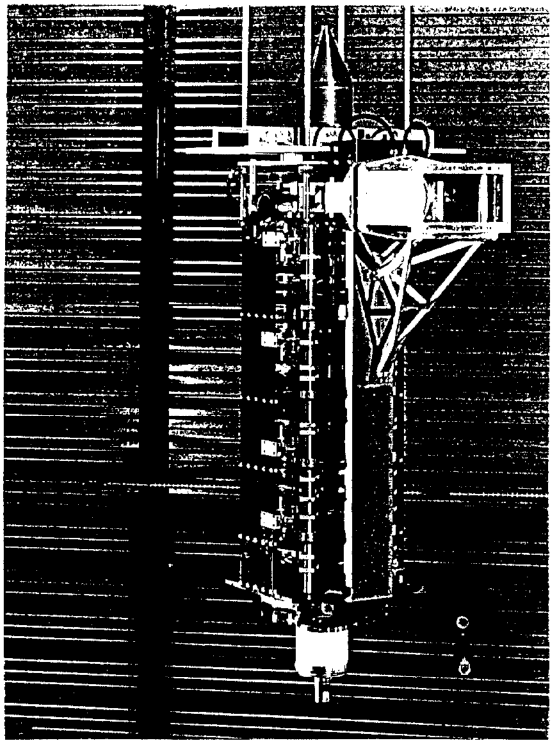

FIG. 1 : TH 2140 KLYSTRON

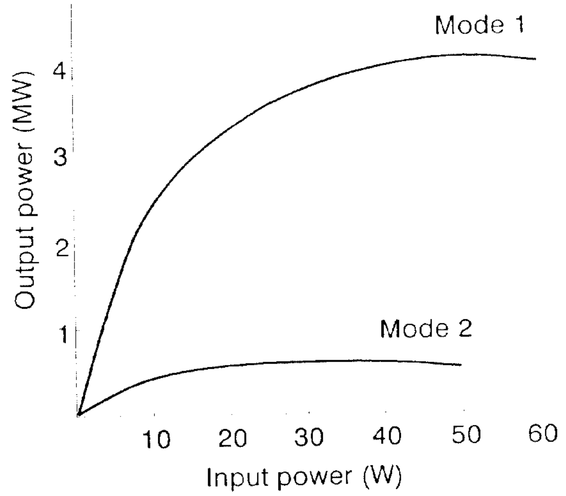

FIG. 2 : GAIN CHARACTERISTICS FOR TH 2140 KLYSTRON

3.2. EXPERIMENTAL RESULTS.

As previously mentioned, the TH 2140 klystron provides RF power to the RFQ and DTL sections and so is operated at two different modes. Table III summarizes the results obtained in these two operating conditions, as compared with SSC specifications for the 4 MW nominal mode.

PARAMETER	UNITS	SSC SPECIFICATIONS (FOR MODE I/DTL)	TH 2140 TYPICAL RESULTS MODE I DTL	MODE II RFQ
RF FREQUENCY	MHz	427.617	427.617	427.617
BANDWIDTH (-1dB)	MHz	1 (min)	1	1
DUTY CYCLE		0.1 %	0.1%	0.1%
RF PULSE WIDTH	μs	100 (min)	100	100
REPETITION RATE	Hz	10	10	10
PEAK OUTPUT POWER	MW	4	4.1	0.63
GAIN	dB	48 (min)	48.5	42.5
EFFICIENCY		40% (min)	54%	31%
BEAM VOLTAGE	kV	130 (max)	125	73
BEAM CURRENT	A	80 (max)	61	28
FOCUSING MAGNET POWER	kW	3.9	1.9	

TABLE III : COMPARISON BETWEEN SSC SPECIFICATIONS AND TH2140 TYPICAL EXPERIMENTAL RESULTS

Phase and amplitude stability of the RF source are very important features for accelerator designers, as well as gain curve smoothness. Special care was taken during tube tests to detect any anomaly concerning these data. Figure 2 shows typical gain curves for modes I and II and Table IV compiles the stability measurements in mode I, as witnessed with the SSC.

PARAMETERS	UNITS	SSC SPECIFICATION (maximum limits)	TH 2140 EXPERIMENTAL RESULTS
RF PHASE VARIATION			
VS-BEAM VOLTAGE	o/V	0.05	0.0023
-FILAMENT VOLTAGE	o/V	0.01	not detected
-RF DRIVE POWER	o/dB	10	3.9
RF AMPLITUDE VARIATION			
VS-BEAM VOLTAGE	dB/%	0.2	0.1
-FILAMENT VOLTAGE	dB/%	0.1	not detected
2nd HARMONIC	dB	-30	-40
3rd HARMONIC	dB	-30	-50
SPURIOUS	dB	-60	< -60

TABLE IV - STABILITY CHARACTERISTICS OF TH 2140 KLYSTRON

4 - TH 2143 KLYSTRON FOR CCL SECTIONS

4.1. GENERAL DESIGN

Stimulated by the requests issued for RF-Linac driven free electron lasers, the state of the art in high power, long pulse klystrons reached 20 MW peak power for 20 microseconds or 10 MW peak for 250 microseconds in L-band a few years ago. Table V summarizes the main data for some L-band long pulse klystrons manufactured by TTE.

PART NUMBER	RF FREQUENCY (MHz)	RF POWER PEAK (MW)	RF POWER AVGE (kW)	EFFICIENCY*	GAIN (min dB)	PULSE LENGTH (μs)	PEAK BEAM* VOLTAGE	PEAK BEAM* CURRENT	MOD ANODE
TH 2104 A	1296	5	150	45%	47	600	126	89	
TH 2115	1300	2.5	150	48%	43	1000	94	57	•
TH 2113	1300	4	500	56%	54	10 ms	120	60	
TH 2095 B	1300	7.5	50	45%	42	100	142	117	•
TH 2104	1300	15 10	50 100	43% 43%	46 44	100 200	200 168	180 138	
TH 2104 U	1300	10	250	45%	47	250	165	135	
TV 2022C	1300	20	10	40%	50	20	235	215	

* : typical values

TABLE V - MAIN CHARACTERISTICS OF HIGH POWER, LONG PULSE L-BAND TTE KLYSTRONS

After an initial request for 50μs pulse length, the SSC final demand called for 20 MW peak for 100μs. This could not be met with the standard designs implemented on existing tubes. TTE had however anticipated this evolution towards higher peak powers and longer pulses expressed by

accelerator designers, and an internally funded R&D program was initiated in 1990 to develop a new generation of high power, long pulse klystrons for both L-band and S-band applications [2].
The first application klystron to benefit from this effort is the TH 2143 (fig.3), which reuses the basic technology of other

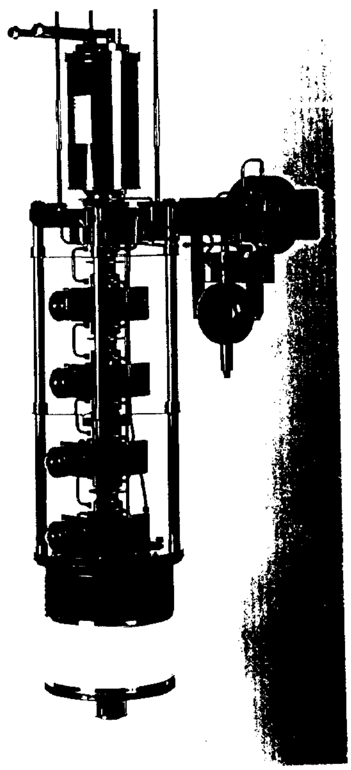

FIG. 3 : TH 2143 KLYSTRON

L-band klystrons, except for the gun. This has been redesigned to decrease inter-electrode electric fields and electrode temperatures. The resulting modifications allows the TH 2143 to withstand 230 kV HV pulses as long as 120μs.

4.2 EXPERIMENTAL RESULTS

TH 2143 klystron also has two operating modes at 20 MW and 2 MW peak. Table VI gives the results obtained in both modes, as compared with SSC specified values for the nominal operating mode. Figure 4 shows typical gain curves for both modes.
Also stability in operation has been carefully checked and measured during acceptance tests; results obtained are below the specified values.

PARAMETER	UNIT	SSC SPECIFICATION (FOR MODE I)	TH2143 TYPICAL RESULTS MODE I	MODE II
RF FREQUENCY	MHz	1282.85	1282.85	1282.85
BANDWIDTH (-1dB)	MHz	5	8	
DUTY CYCLE		0.1%	0.1%	0.1%
RF PULSE WIDTH	µs	100	100	100
VIDEO PULSE WIDTH	µs		117	
REPETITION RATE	Hz	10	10	10
PEAK OUTPUT POWER	MW	20	20	2
GAIN	dB	50 (min)	51.7	40.2
EFFICIENCY		40% (min)	43%	27.7%
BEAM VOLTAGE	kV	230 (max)	219	100
BEAM CURRENT	A	230 (max)	228	72
FOCUSING MAGNET POWER	kW	17	10.5	

TABLE VI : COMPARISON BETWEEN SSC SPECIFICATIONS AND TH 2143 TYPICAL EXPERIMENTAL RESULTS

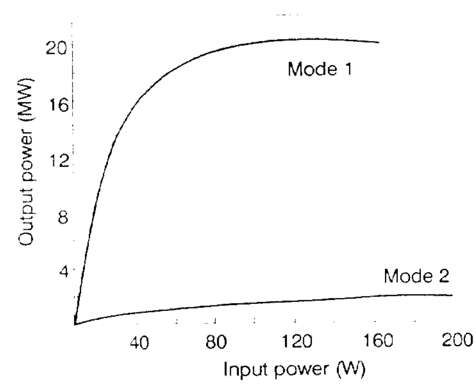

FIG. 4 : GAIN CHARACTERISTICS FOR TH 2143 KLYSTRON

5 - CONCLUSION

Two types of klystrons have been designed by THOMSON TUBES ELECTRONIQUES and are in production to equip the SSC injector Linacs. The commissioning of first tubes occurred in fall 1992 and the production is now under way in agreement with a tight delivery schedule. Design, manufacturing and test stages were carried out in a very cooperative manner between SSC and TTE to meet SSC requirements. With the successful development of the TH 2143, able to reach 20 MW peak in pulses of 100μs in L-band, extensive possibilities are now open to klystrons; a future S-band klystron with similar features is now under development, and will be an appropriate solution for long pulse S-band linear accelerators.

REFERENCES

[1] L. Warren Funk, "The SSC Linac", 1992 Linear Accelerator Conference Proceedings, EACL-10728, OTTAWA, ONTARIO, CANADA.
[2] J.C. Terrien, G. Faillon and Ph. Guidée, "RF Sources for recent linear accelerator projects", 1992 linear Accelerator Conference Proceedings, AECL-10728, OTTAWA, ONTARIO, CANADA.