FEASIBILITY STUDY OF A HOM IOT FOR TESLA

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Abstract

For the TESLA linear collider 1.3 GHz RF sources with 10 MW peak power and about 70% efficiency are needed. As an alternative to the development of a Multibeam-Klystron, we investigate the feasibility of an IOT (Inductive Output Tube). This is a very compact RF source: The time structure of the beam is produced by a gated emission cathode and the output cavity is directly adjacent to the anode. Unlike IOTs, conventional klystrons lose some of their design efficiency when they are operated below saturation, because only the RF component of the beam is reduced and not the DC beam current. In contrast to this the cathode current of an IOT is controlled by the drive power. In order to keep the gun voltage low, we plan to investigate a device with a hollow beam where the output cavity is excited in a higher order mode (HOM), as was recently suggested by CPI[1].

Computer simulations are carried out with the CAD-system MAFIA. First, an existing Klystrode^{TM} IOT built by CPI is analysed. Simulation results will be shown and compared to experimental data. Based upon this experience, a design strategy is discussed for the HOM IOT.

1 INTRODUCTION

The "TeV Superconducting Linear Accelerator" (TESLA) requires 1.3 ms long RF pulses at the operating frequency 1.3 GHz. The state of the art of klystrons for such long pulses is represented by the TH 2104 Diode-Klystron built by Thomson which can deliver up to 5 MW RF pulses of 2 ms length at a rep. rate of 10 Hz. The efficiency is 45 %, the gun voltage 130 kV.

In view of the estimated 30 MW average RF power consumption of the linear collider efficiency is a major issue. A contract with industry has been signed for the development of an 1.3 GHz 10 MW multibeam klystron with 1.7 ms pulse length and an efficiency of more than 70 %. But even if this challenging goal is reached, the efficiency will be decreased in practical use, since for the operation of the linac, a variation of the output power of at least 10 % must be possible. But reducing the RF drive power has no influence on the average dc electron beam current and hence more energy is wasted in the collector.

In the medium power UHF regime, a new design of RF sources has been successfull which overcomes this drawback. The goal of our investigations is to analyse whether this IOT concept can be applied to the high power L-Band requirements of TESLA.

1.1 *The IOT (Inductive Output Tube)*

IOT's have been used successfully for more than 10 years for TV service at operating frequencies in the UHF regime [2]. The operating principle is briefly described in this section (see Figure 1). The basic components are:

- a gated-emission gun
- a resonator (output cavity)
- and a collector for the spent beam

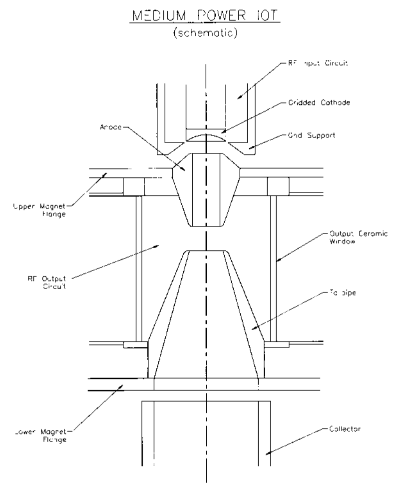

Figure 1: Schematic view of a medium power IOT.

The gun consists of a spherical cathode and a closely spaced spherical grid. The grid support together with the cathode forms a resonant coaxial input cavity which can be used to generate RF voltage at the operating frequency between grid and cathode. A DC bias voltage on the grid shuts off the electrons between bunches and controls the bunch length. The bunched electrons are then accelerated in the anode potential. As they traverse the output resonator gap, they excite the resonator RF and lose energy. The spent beam then enters the collector where the remaining kinetic energy is converted to thermal energy in the collector walls.

Thus, the main advantages as compared to a klystron are

- The beam current is a function of the RF drive. Therefore only as much beam current is produced as is needed to reach the desired output power.
- Since the beam is already bunched at the cathode, the overall design can be very compact.
- Magnetic field requirements are lower, since the beam only travels a short distance.

A disadvantage of the IOT is the relatively low gain of less than 30 dB.

1.2 The HOM IOT

The IOT concept cannot simply be upgraded to TESLA requirements by adjusting the frequency and increasing beam current and gun voltage. Limiting factors are

- breakdown of the gun voltage
- space charge density
- emission density at the cathode
- power density in the output cavity
- thermal stress in the collector

Thus we investigate an IOT with a hollow beam that does not excite the fundamental but a higher order mode (HOM) in the output cavity[3, 1].

1.3 Design Tools

Existing design tools including fast-running, one-dimensional optimizing codes, cannot simply be employed to study the HOM IOT. Although they are well tested for existing IOTs, they are based on approximations which are valid only near the beam axis for solid beams.

We plan to use the MAFIA[4, 5] package for our analysis. This package offers modules for the RF investigation of the resonant cavities as well as PIC modules for the self-consistent calculation of the electron motion. It has been used successfully for klystron design[6] before.

2 SIMULATION

In a first step, we used MAFIA to analyse an existing medium power Klystrode^{TM} IOT. The working frequency for the analysis was chosen to be 700 MHz, the design output power is 60 kW.

2.1 Parameters and Assumptions

The whole device is rotationally symmetric and can be simulated in rz-Geometry. In practice, the RF power is extracted through a cavity coupling loop. In order to maintain the rotational symmetry, this was replaced by a layer of lossy material at the outer boundary of the cavity. The geometry of the cavity and material constants of this artificial load were chosen such that the impedance R and the quality factor Q correspond to experimental data: R=12.8 kΩ, R/Q=95.4Ω, Q=134.

For the HOM IOT, the output cavity will be designed using 3D resonator codes which include waveguide boundaries to simulate the RF extraction. 2D resonator as well as time domain codes will be used to investigate the input circuit and determine the bunch shape.

For the analysis of the existing IOT, we assumed that the gridded gun workes perfectly and yields a bunched electron beam with the time structure shown in figure 2. The gun voltage was 32 kV and the corresponding electrostatic field was also calculated in MAFIA. Whereas for a beam current of 1 A no magnetic field is necessary to focus the beam, for higher currents we assumed a solenoid field of 250 Gauss between the flanges and less than 15 Gauss at the cathode surface.

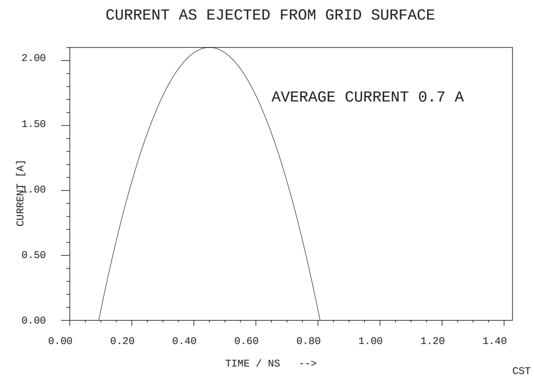

Figure 2: Time structure of the current. This pattern repeats every 1.43 ns.

2.2 Typical Results

Some simulation results are shown in figures 3 and 4.

Due to the high quality factor Q=134 of the output cavity the time to reach the steady state of the excitated mode amounts to a few hundred RF-periods. It is not possible to simulate the complete build-up process until the system reaches steady state, because it would take too much CPU-time and noise would increase to intolarable values. The port approximation[7] cannot be used for the HOM case. Therefore we calculate the mode pattern and preload the cavity with the excited mode. A good guess for the amplitude and phase can be drawn from a simulation of the first 20 RF-periods of the build-up process.

In steady state, the RF output power is replaced by the beam in every period. The rest energy of the beam is dissipated in the collector walls a few periods later. Thus, steady state can be identified through the fact, that the average beam energy loss is equal to the RF power loss in the artificial load. The efficiency is determined in different ways which agree only in steady state (see table 1).

Initial RF power	Efficiency calculated from: RF cavity field	dissipated power
32.5 kW	51.4 %	55.6 %
40.0 kW	57.3 %	57.9 %
42.0 kW	57.3 %	56.4 %

Table 1: Identification of steady state. Average beam current 2 A, bunch length 180°. The efficiency in steady state is 57.3 %.

For three different cases, we compared our results for the efficiency with the results of a simple one-dimensional program which usually yields good results for medium power IOT's but cannot be extended for the calculation of the HOM IOT (see table 2).

Both calculations show that the efficiency η increases for higher output power even for gap voltages well above the

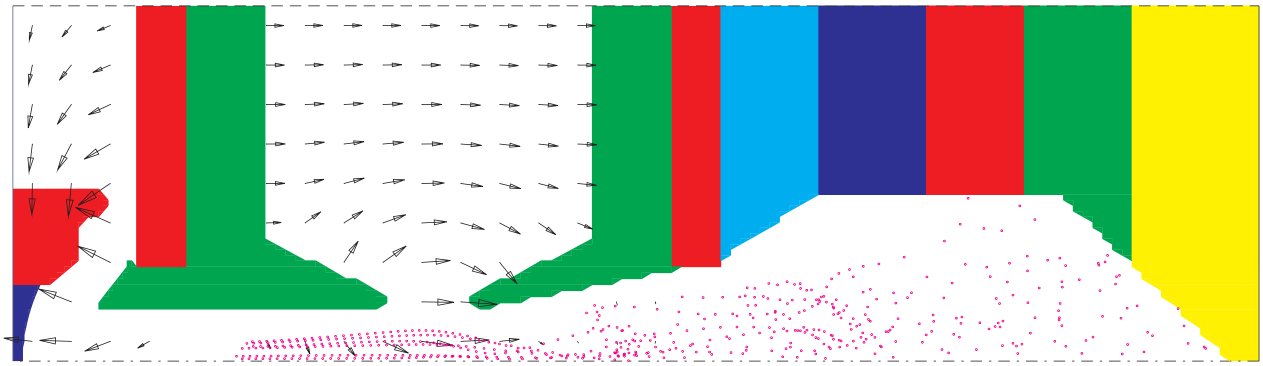

Figure 3: Typical simulation output. Electrons move from left to right. They are emitted from the surface of the grid and accelerated in a static electric field. Passing the output cavity, electron bunches excite an RF field. The spent beam is dumped into the collector.

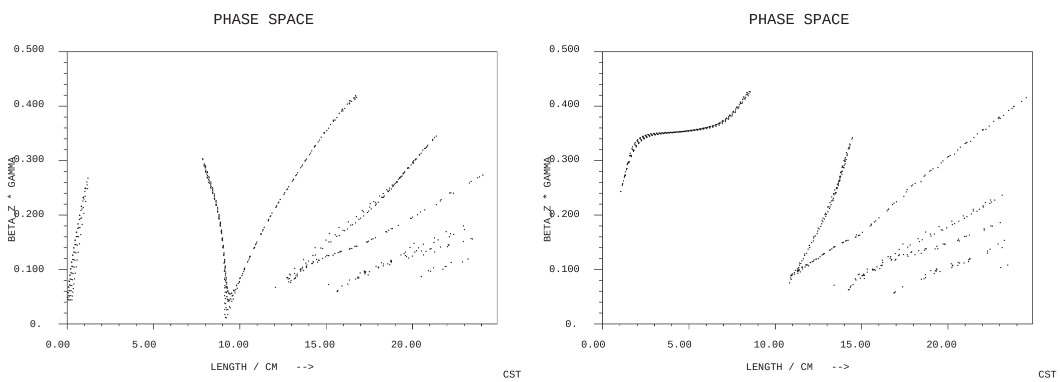

Figure 4: The momentum $\beta_z * \gamma$ is plotted against the longitudinal position for $t = t_0$, and $t = t_0 + T/2$. The average beam current is I_{ave} =2.93 A, the gap voltage is V_{gap} =40.8 kV.

	Reference results			MAFIA results		
I_{ave} [A]	2.93	2.03	1.10	2.93	2.03	1.10
I_{max} [A]	11.36	7.89	4.32	8.79	6.09	3.30
P_{out} [kW]	61.0	29.7	8.7	65.0	36.7	11.1
η [%]	64.9	45.7	24.8	69.3	56.5	31.5
$\hat{V}_{gap}$ [kV]	37.0	25.6	13.9	40.8	30.7	16.9

Table 2: Comparison of Results to a Reference Calculation

gun voltage V_{gun} =32 kV. Figure 4 shows that even for this case no particles move back to the gun region.

MAFIA yields higher absolute values for the efficiency because of the higher harmonic content of the simplified bunch shape used (see figure 2). We expect lower values for η when the realistic bunch shape is considered.

3 ACKNOWLEDGEMENTS

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