A NEW HIGH POWER KLYSTRON FOR THE SLAC B-FACTORY

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Abstract

A new klystron for driving the SLAC B-Factory is currently under development at Philips. Detailed numerical analysis has been carried out in order to meet all the requirements. Particular attention is paid to the bandwidth and phase behavior of the tube because the upper limit in group delay is given by the control system of the B-Factory. Although bandwidth and efficiency are competing demands - not easily met by the same design - the simulation predicts very high efficiency. Another important aspect which is being taken into account for the design is operational stability of the tube. The design concept and numerical as well as measurement results will be presented.

1 DESIGN CONCEPT

The main requirements for the operational parameters of the tube are listed below:

- operating frequency 476 MHz,
- output power 1.2 MW,
- micro perveance 0.83 - 1.3,
- gain > 43 dB,
- bandwidth (-1 dB) +/- 1.5 MHz,
- group delay (+/- 0.5 MHz) < 150 nsec,
- efficiency > 0.6 .
- stable operation with load VSWR of up to 1.2.

The tube is equipped with a diode gun for beam generation and an electromagnetic focusing system. Two possible rf systems have been investigated. A structure with six fundamental cavities and a seven cavity structure including one second-harmonic cavity. The latter one was finally realized. No external cavity loading was required to achieve the specified bandwidth. The collector is able to dissipate 1.4 MW static beam power and full static power for 1 second.

2 BEAM GENERATION

Because no modulating anode is required for tube operation a diode gun was chosen for beam generation. The gun was not only designed to give excellent beam quality but also to ensure stable and long life operation. An impregnated tungsten cathode with Os/Ru coating is used for low operating temperature[1]. Conservative values have been chosen for electric field strength and cathode loading. The gun produces a very laminar beam and the low beam compression ratio leads to very homogeneous distribution of current density on the cathode surface. The ratio of current density between edge and center of the cathode is 1.18 and the maximum current density is 0.63 A/cm^2.

The numerical design of the gun has been carried out with the SUPERSAM code from INP[2]. The simulation results are shown below (Fig. 1).

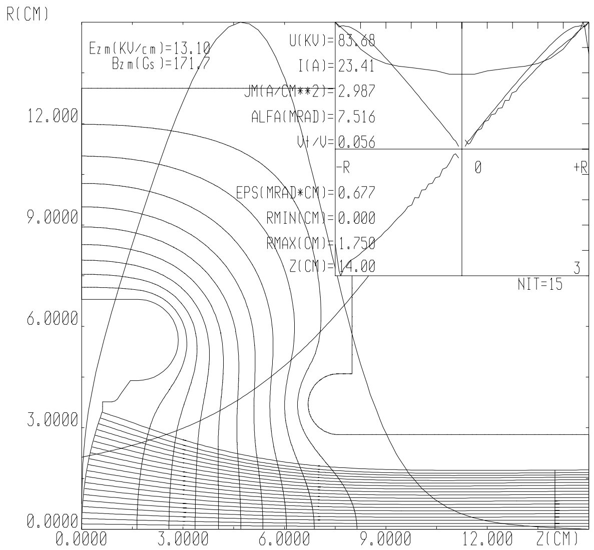

Figure 1: gun simulation

3 NON-LINEAR SIMULATIONS

In the following two different approaches to the tube design are discussed. The non-linear simulations of the tube performance have been carried out with the FCI code[3].

3.1 RF-Section with 6 Cavities

In order to study the behavior of the tube with respect to bandwidth and group delay a more conservative design with six fundamental cavities was investigated first. For this purpose a constant magnetic focusing field of 250 Gauss which is about two times the Brillouin field was assumed. After optimization the simulation showed that the specifications regarding bandwidth, group delay and efficiency can be met by the 6-cavity design. The calculated output parameters of the tube at saturation are:

- output power 1.205 MW,
- efficiency 0.62,
- gain 50 dB,
- group delay (+/-0.5 MHz) max. 135 nsec,

- bandwidth (-1 dB) > +/- 2 MHz.

The dependence of output power versus drive power and the bandwidth for two different drive levels are shown in Fig. 2 and Fig. 3, respectively.

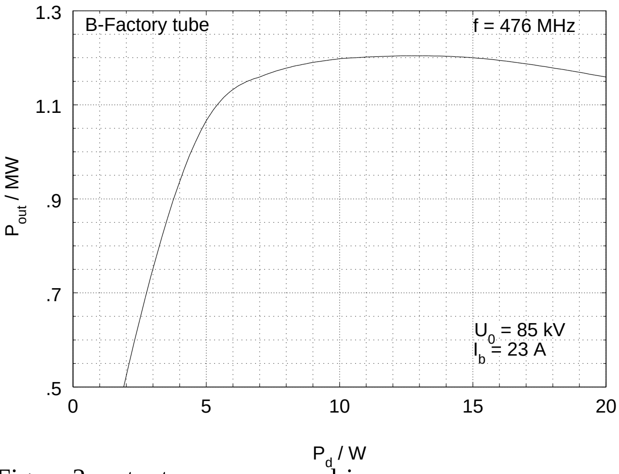

Figure 2: output power versus drive power.

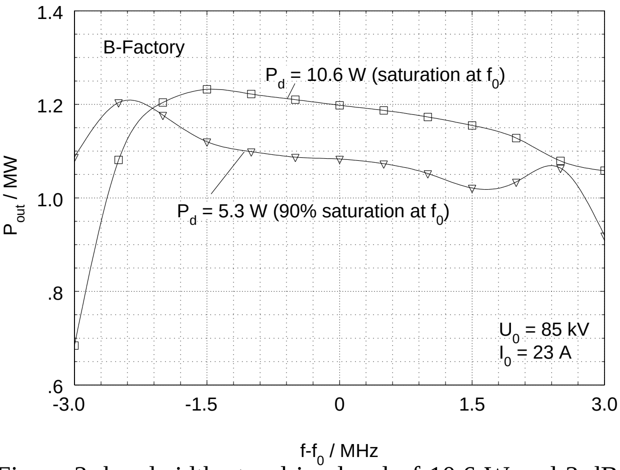

Figure 3: bandwidth at a drive level of 10.6 W and 3 dB below.

It turned out that the first cavity contributes significantly to the group delay. In order to achieve the required low group delay while maintaining a high efficiency the input cavity has to be highly overcoupled. Despite the large coupling factor this tube design showed a high gain of 50 dB.

As mentioned earlier a very important point is the operational stability of the tube. When looking at the simulation results one has to keep in mind two facts. First, the simulation assumes a perfectly matched load and second, the optimization was carried out in order to have maximum efficiency. In general, a tube which is designed for maximum efficiency will not be stable for all phases of a load reflection. So, one has to consider a certain safety margin for the efficiency with respect to load reflections. In order to achieve an efficiency above 0.6 the external quality factor of the output cavity has to be quite high. Although a numerical analysis of instabilities is not yet possible the calculation shows some returning particles from the output gap which at least indicates the possibility of an instability.

In order to realize a reliable tube which operates stable at all phases of the maximum specified load VSWR it was decided to improve the performance by adding a further cavity.

3.2 RF-Section with 6 +1 Cavities

In order not only to improve the bunch length in the output gap but also the energy distribution within the bunch a second-harmonic cavity was inserted into the rf structure of the tube. For the final optimization the assumption of a constant magnetic field was no longer made. The calculated field of the magnet foreseen for tube operation was used in the simulations. Output power versus drive power, bandwidth and group delay are shown in Fig. 4, Fig. 5 and Fig. 6, respectively.

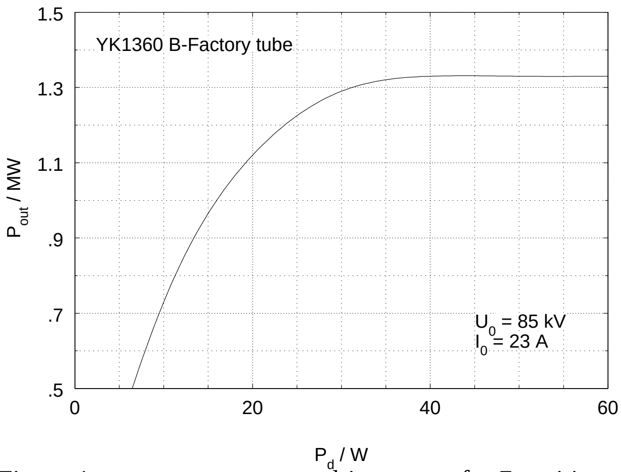

Figure 4: output power versus drive power for 7 cavities.

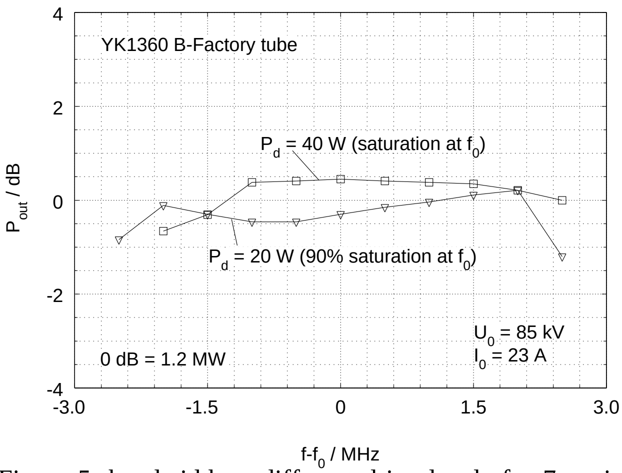

Figure 5: bandwidth at different drive levels for 7 cavities.

With the additional second-harmonic cavity the performance could be increased significantly. The large coupling factor for the first cavity is no longer necessary.

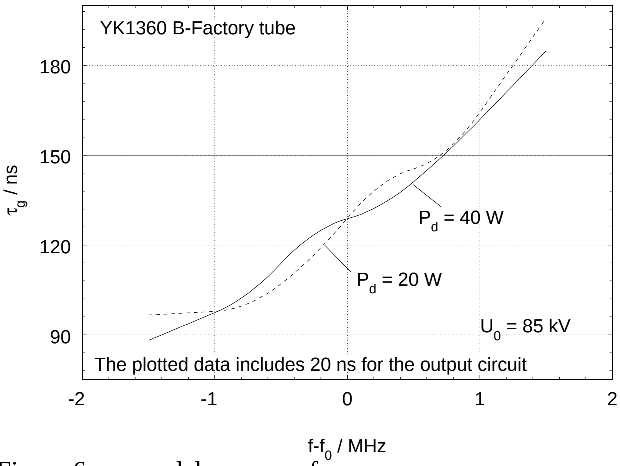

Figure 6: group delay versus frequency.

The calculated values are as follows:

- output power 1.33 MW,
- efficiency 0.67,
- gain 45.2 dB,
- group delay (+/-0.5 MHz) max. 138 nsec,
- bandwidth (-1 dB) > +/- 2 MHz.

While maintaining the bandwidth of the tube the efficiency and output power could be increased. The group delay is also slightly increased but still below 150 nsec. Concerning the stability the gain is decreased to a more moderate value and the simulation does not show any backstreaming particles even at maximum efficiency. Still, the simulation assumes a matched load but the safety margin which has to be paid for stable operation at a load VSWR of 1.2 is now considered to be large enough.

4 MEASUREMENT RESULTS

The tube has been built according to the design parameters obtained by the calculations described in section 3.2. The measurements of bandwidth and group delay are shown in Fig. 7 and Fig. 8, respectively, together with the calculated values. The agreement is quite good except that the bandwidth characteristic is shifted upwards by 1 MHz. The tube has shown a maximum efficiency of 0.63 at 85 kV beam voltage and 1.32 MW output power. A further increase was limited by increasing losses on the drift tube following the output gap. This behavior is connected with a too high perveance of the gun which turned out to be 6% higher than the design value. The final tube settings and output parameters at saturation are listed below:

- beam voltage 84 kV,
- micro perveance 1,
- gain 45 dB,
- output power 1.25 MW,
- efficiency 0.61,
- group delay (+/-0.5 MHz) max. 136 nsec,
- bandwidth (-1 dB) > +/- 2 MHz.

With the above setting the tube runs very stable. No instabilities have been observed up to a load VSWR of 1.2 at all phases.

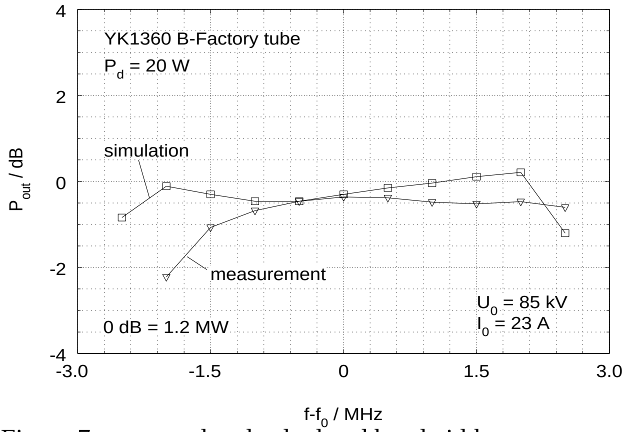

Figure 7: measured and calculated bandwidth.

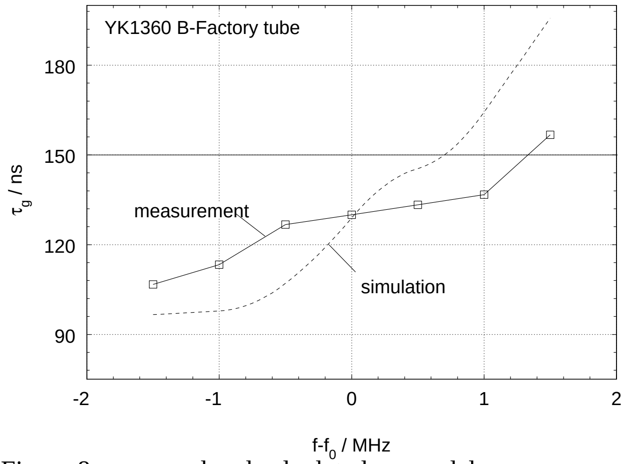

Figure 8: measured and calculated group delay.

5 CONCLUSION

A new klystron for the SLAC B-Factory has been successfully designed, built and tested with the help of numerical simulations. The measurements agree well with the calculations. The tube shows very high operational stability up to a load VSWR of 1.2. The perveance which is 6% above the design value will be corrected with the next tube and may lead to further improvement of performance.

REFERENCES

[1] 'Lifetime Experience with low Temperature Cathodes equipped in Super Power Klystrons', R. Bachmor, PAC '95, Dallas, Texas, 1995.

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[3] 'FCI - Field Charge Interaction Program for High Power Klystron Simulations', T. Shintake, PAC '89, March 20-23, 1989, Chicago, USA.