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X-BAND (11.424 GHz) SLED SYSTEM

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Abstract

This report describes the design and fabrication as well as some test results of an X-band (11.424 GHz) SLED system for high-power use. This system comprises a 3-dB hybrid coupler, two TE015 cavities, and a waveguide system pumped by ion pumps. The unloaded Q-values were measured as being 52000 for each cavity. The results of the first high-power test are presented.

Introduction

A couple of X-band (11.424 GHz) linacs were introduced as the main accelerators in the electron-positron linear collider (JLC) project at KEK, which is one of the post-TRISTAN high energy experiments. An accelerating gradient of over 100 MV/m is required for these linacs to gain a center-of-mass energy of 1.5 TeV, which is the final goal of this project [1]. Two major R&D efforts are under way to build such a high-gradient accelerator. One is an investigation of accelerating structures by which uniform and stable e^+/e^- beams might become available at the colliding point. The other is the development of high-power RF sources to drive the accelerating structures. In this attempt, the development of klystron tubes and windows which could be sustained under a high RF output has been carried out.

Concerning X-band klystron tubes of over 100 MW output with 100 ns duration, the required R&D has been carried out [2]. At the first step, a 30 MW class klystron tube was constructed for the purpose of studying how to produce an RF output of more than 100 MW. A klystron modulator was also designed and constructed. At the present time, a high RF output of almost 20 MW with 100 ns duration is available at the test-bench. Thus, various kinds of waveguides have been successfully examined and a prototype accelerating structure has also been tested. Of course, the system performance during long-term operation has been continuously examined. By applying these test results, a 100 MW class klystron tube has been designed and constructed. However, it seemed to take a lot of time to make the entire RF source, including high-output klystrons for practical use.

For stable operation of the RF system, ceramic windows and waveguides are required to sustain a higher field than that produced by the klystron output. It is very important to find the limit of such waveguides and windows, since they have an affect on developing high-power RF sources and on choosing the accelerator parameters. For this reason, a pulse compression technique, by which the peak RF power is enhanced at the expense of the pulse width, was considered to be useful for testing the components forming the high-power RF transmission line. There were some methods involving pulse compression already operating at worldwide accelerators (for example the SLED, the SLED II, and the BPM). The SLED system was introduced to our attempt, since it had a simple, compact assembly [3].

The SLED system was originally developed with S-band RF for increasing the beam energy of the SLAC [4]. The assembly comprising a couple of high Q cavities and a 3-dB hybrid was inserted into the RF transmission line between the klystron and the accelerator. The cavities were identically made and tuned to resonance. By using this system the klystron output was increased as follows. The klystron output pulse charging the each cavity was reversed in its phase, according to a certain timing. The two waves, that emitted from the cavity and that reflected at the coupling aperture of the cavity, were added so as to provide a high peak power of more than a few times as that of the klystron output. The 3-dB hybrid had a role: the waves from each cavity were combined so as to add at the accelerator port, while they were canceled at the klystron port. In this scheme, however, the pulse width was inevitably shortened, and the peak power decayed away with a time constant determined by the cavity filling time.

The design and measured RF characteristics of the components of the X-band SLED system are described in the following section.

Power enhancement by the SLED

At the high RF power test-bench, the output of 30 MW klystron was increased by the SLED, so as to supply power into a test object inserted between the SLED and the dummy load, as illustrated in Fig.1.

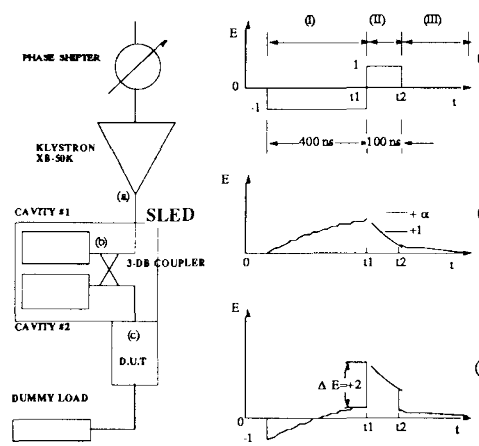

Fig. 1 Schematic diagram of high-power RF test-bench using the SLED. When the klystron output wave (a) is supplied, the emitted wave (b) from the cavity and compressed wave (c) transmitted to the device-under-test (D.U.T) appear as illustrated, respectively.

The maximum amplitude and decay time depend on both the Q-value and the coupling coefficient β of the cavity, as described theoretically in reference [4]. According to reference [4], the emitted wave E_e from the coupling aperture of the cavity is related to the incident wave E_k from the klystron, as expressed in following equation:

$$T_c(dE_e/dt) + E_e = -\alpha Ek, \qquad (1)$$

where $T_c=2Q_0/\omega(1+\beta)$ and $\alpha=2\beta/(1+\beta)$. Equation (1) can be solved for the klystron output shown at the top-right in Fig. 1. By using the results obtained by solving equation (1), and $E_L=E_k+E_e$, the following expressions for the load field in the three time intervals (I), (II) and (III) are obtained:

$$E(I) = -\alpha e^{-\tau}+(\alpha-1), \qquad (2a)$$

$$E(II) = \gamma e^{-(\tau-\tau 1)}-(\alpha-1), \qquad (2b)$$

$$\text{and} \quad E(III)= [\gamma e^{-(\tau 2-\tau 1)}-\alpha]e^{-(\tau-\tau 2)}, \qquad (2c)$$

where $\tau=t/T_c$ and $\gamma=\alpha(2-e^{-\tau 1})$. The peak voltage is obtained at time t_1 (Fig. 1), and the calculated value for the case (β=4.5, Q_0=52000, t_1=400 ns and t_2=500 ns) is 2.28-times as high as the klystron output voltage (5.2-times as high as the power).

Components

The 3-dB coupler The Riblet short-slot coupler is used as the 3-dB hybrid through which the output of the klystron is guided to a couple of cavities; waves from each cavity are combined so as to add and be transmitted to the load. This coupler comprises two adjacent rectangular waveguides (WR-90), as shown in Fig. 2, in which wave coupling is provided at an opening of the common wall.

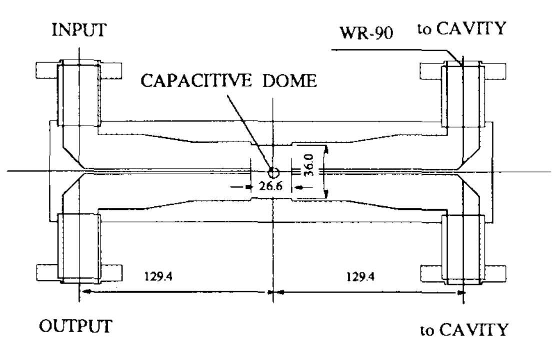

Fig. 2 Cross-section view of the 3-dB coupler.

This type of 3-dB coupler has been widely used in high-power RF transmission lines, since the structure is simple enough to sustain a high electric stress.

The value of coupling depends on both the width and length of the coupling region. For 3-dB coupling, they were designed to be 36.0 and 26.6 mm, respectively. Two posts (called the capacitive dome) were attached for fine tuning at the center of the top and bottom walls of the coupling region. The measured characteristics of the coupler are listed in Table 1.

Table 1
Measured characteristics of the 3-dB coupler

COUPLING (MAIN LINE)	-3.16 DB
(SUB LINE)	-3.14 DB
PHASE DIFFERENCE	96.1 DEG
ISOLATION	-25.0 DB
INPUT VSWR	1.09
OUTPUT VSWR	1.15

The cavities Room-temperature cavities made of copper (OFHC) are used as pillbox cavities for the assembly. The TE015 mode was chosen as the S-band SLED system of the SLAC. The Q-value of the each cavity was measured as 52000 and 52300, respectively. To lower the resonant frequency of the TM115 mode, which is normally degenerate with the TE015 mode, a groove was circularly cut in one end-plate (also following the model of the SLAC). This groove (1.5 mm in width and 1.5 mm in depth) shifted the TM115 mode by nearly 450 MHz while having no influence on the TE015 mode. A coupling aperture was drilled through the other end-plate (9.1 mm in diameter with 1.5 mm thick, roundly finished to avoid breakdown). The measured coupling coefficient β of each cavity was 4.55 and 4.57, respectively. Illustrated in Fig. 3 is a cross-section view of the cavity.

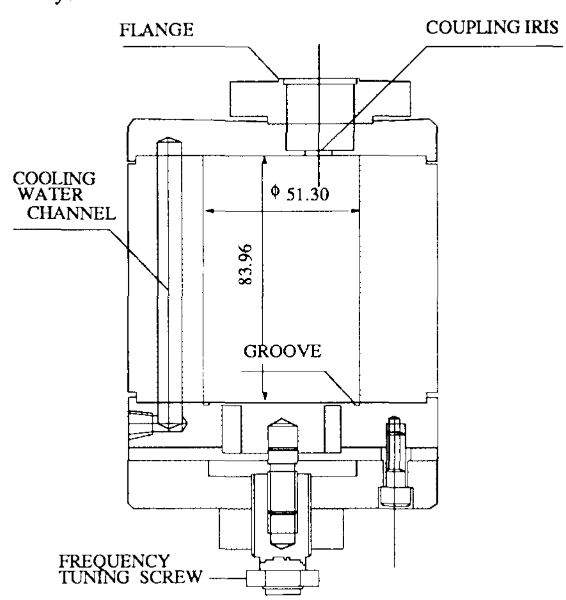

Fig. 3 Cross-section view of the cavity.

The vacuum pumps This SLED system, including the waveguides and the load, was pumped by four 20 l/s ion pumps distributed along the waveguides. For measuring the pressure, four cold cathode gauges (CCG) were installed near to each ion pump.

Test results

An experiment concerning the X-band SLED system with low-level RF was successfully carried out after being assembled. The peak RF power enhanced by the SLED reached to almost five-times as high as the input RF power, the pulse width was 500 ns with 100 ns phase reversal in the rear. Since that was nearly 90% of the calculated value, it was found that the assembly was well fabricated for practical use at the test-bench. The phase-control system of the klystron input pulse was also successfully made for practical use. The design and fabrication of this circuit are described in detail in reference [5]. Shown in Figs. 5 and 6 are pictures of the phase of the input pulse and the output of the SLED in the low-level experiment, respectively.

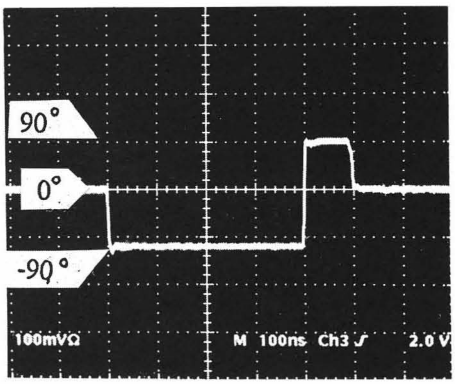

Fig. 5 Observed input pulse phase (low-level).

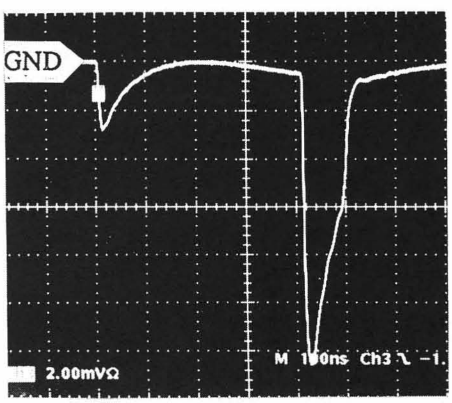

Fig. 6 Observed output of the SLED (low-level).

In the high-power RF test-bench, the SLED system was pumped by ion pumps and the vacuum pressure obtained 10^{-6} Pa range within three days. A high RF output of 2.5 MW has been successfully obtained with a klystron output of 800 KW (a repetition rate of 2 Hz) during the first seven hours of an aging run. In this run, due to RF discharge, the vacuum pressure frequently rose up to 1×10^{-5} Pa which was set as the threshold value to stop the klystron output. While continuing the conditioning process of the SLED, the vacuum pressure at the same RF input became lower. It seems that a required high RF output can be obtained with proceeding the conditioning process. The peak power obtained during high-power operation was lower than that of the test result with low level, since the output pulse width of the klystron was shortened so as to make the best for an experiment with short pulse (100 ns). Frequency trimming and/or RF input parameter adjustment are still needed. Observed output signal at 2.5 MW is shown in Fig. 7.

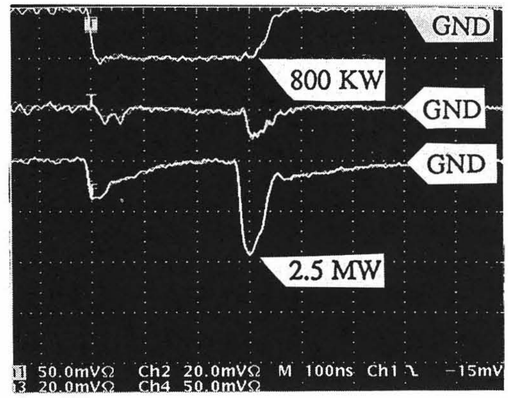

Fig. 7 Observed output signal of the SLED in the high - power test. Klystron output (top), reflected power to the klystron (middle) and output of the SLED (bottom) are shown.

Summary

The construction of an X-band SLED for high power use was successfully completed. The result of SLED operation with low-level RF showed good agreement with a value obtained by a theoretical calculation in the case of β=4.5,Q_0=52000, t_1=400 ns and t_2=500 ns. This shows the cavities and the 3-dB coupler has been well fabricated for practical use. During seven hours of a high-power aging process, a 2.5 MW peak output became available with no serious problems. The conditioning of this system is continuing.

Acknowledgement

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