# Development of a CW Electron Linac Structure Using a Traveling-Wave Resonant Ring

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*Abstract*

This paper outlines the CW electron linac presently under development at the Power Reactor and Nuclear Fuel Corporation (PNC). We also report on preliminary results concerning a newly developed 1249-MHz CW klystron and low-power tests of an accelerator structure with a traveling-wave resonant ring.

## 1. INTRODUCTION

The PNC facility used to develop a CW electron linac was founded in 1989 as a seven-year program by the Science and Technology Agency of the Japanese government. This facility comprises a 10-MeV, 100-mA, CW electron linac and experimental halls. The linac is under development through collaboration with a group at KEK. Though the motivation for constructing the linac concerns incineration of nuclear-wastes, such as $Cs^{137}$ and $Sr^{90}$, its immediate use will involve such research as nuclear transmutation, as well as the establishment of both engineering and technology regarding the high-power CW linac.

The facility is located at the site of PNC, Oarai Engineering Center, about 100 km north-east of Tokyo. The ground area of this facility is about 20 x 40 m wide. By March, 1992, the linac tunnel has been completed.

A prototype tube of a 1249-MHz CW klystron was fabricated and is presently being tested using the klystron test stand at KEK. Also, a prototype of the accelerator section has been fabricated with a resonant ring.

One subject concerning such high-power CW linacs is the transfer efficiency of the input rf power of the accelerator section to the accelerated beam. The use of a resonant ring with a simple traveling-wave accelerator structure is one candidate for realizing high efficiency. In the usual traveling-wave structure, the residual rf power is wasted through an output coupler in the matched load. On the contrary, in a structure with a resonant ring, it is recirculated for acceleration. The efficiency can thus reach approximately 70%. In this paper, we call it a traveling-wave recirculating accelerator structure (TRAS).

The PNC CW-linac was designed so as to be able to accelerate an electron beam current of 100 mA to 10 MeV with a total rf power of 2 MW. The layout is shown in Figure 1. Seven 1.2-m TRAS regular sections follow a pre-injector with an electron gun and bunchers. The buncher and accelerator sections are fed by two 1.2-MW CW-klystrons. The main parameters of the PNC linac are listed in Table 1.

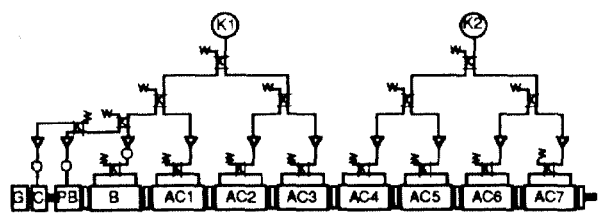


Figure 1. Block diagram of the PNC CW-Linac: G is the electron gun; C, a chopper; PB, a prebuncher; B, a buncher; AC, a regular accelerator section; K, a klystron; x, a directional coupler; w, a dummy load; o, an attenuator; and ∧, a phase-shifter.

Table 1
Parameters of the PNC CW-Linac

| | | |
|---|---|---|
| General | | |
| operation mode | CW-mode | Pulse-mode |
| duty | 100% | 20% |
| pulse width | | 0.8 ms |
| repetition rate | | 250 pps |
| energy | 10 MeV | 18 MeV |
| current | 100 mA | 55 mA |
| Klystron (Target) | | |
| power | 1.2 MW | 4 MW |
| beam voltage | 90 kV | 147 kV |
| beam current | 25 A | 56.5 A |
| micro-perveance | 0.8 | |
| gain | 50 dB | |
| efficiency | 65% | |
| length | 3.4 m | |
| Accelerator section | | |
| type | traveling-wave | |
| operation frequency | 1249 MHz | |
| wavelength | 24 cm | |
| section length | 1.2 m | |
| gain (max) | 1.4 MV/m | 2.5 MeV/m |
| number | 7 | |
| Resonant ring | | |
| transmission (no load) | 0.946 | |
| transmission (load) | 0.850 | |

## 2. PRINCIPLE OF THE TRAS

The TRAS is a traveling-wave resonant ring [1], which includes an accelerator structure used as an insertion device. The concept is illustrated in Figure 2. The resonant ring, itself, is a familiar device used to realize high-power rf in the waveguide. Its function is as follows: The ring is connected to an outside rf source with a directional coupler, the voltage coupling coefficient of which is $C$. The directional coupler divides the input power into two ports by $(1-C^2)P_{in}$ and $C^2P_{in}$, respectively. The power fed into the ring ($C^2P_{in}$) returns to the coupler with a voltage transmission factor of $T$, and is again divided reciprocally; thus, the power of $(1-C^2)T^2C^2P_{in}$ is recirculated. If the ring length is adjusted so that the recirculated waves are continuously superposed in phase, the power contained in the ring builds up. On the basis of the above-mentioned consideration, and assuming that there is no reflection in the ring, the voltage multiplication factor is given by

$$M = C / (1-T(1-C^2)^{1/2}). \quad (1)$$

Thus the maximum multiplication factor is

$$M_{max} = (1-T^2)^{-1/2}, \quad (2)$$

with an optimal coupling coefficient of

$$C_{opt} = (1-T^2)^{1/2}. \quad (3)$$

Naturally, for a better transmission ($T$~1), we can obtain a larger multiplication: we know that under such a condition the smaller coupling is optimum from the simple relation

$$M_{max}C_{opt}=1. \quad (4)$$

In a resonant ring which includes an accelerator structure, the voltage transmission factor is given by the power loss due to not only the wall-loss, such as in the accelerator section, but also to beam loading.

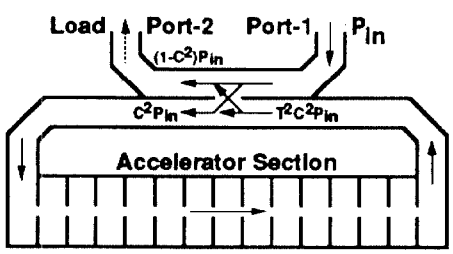


Figure 2. Concept of the traveling-wave recirculating accelerator structure (TRAS).

## 3. DEVELOPMENT OF COMPONENTS

### *3.1 1249-MHz high-power CW-Klystron*

A high-power CW-klystron is under development with Toshiba Corporation. The target values are listed in Table 1. In 1991, a prototype was fabricated, and preliminary high-power test were carried out at Toshiba Corporation, Nasu Works. This tube is presently under high-power testing at the KEK TRISTAN klystron test stand (Figure 3).

So far, a maximum peak power of 780 kW with an efficiency of 46% has been obtained at a beam voltage of 85 kV, a beam current of 20 A, and a micro-perveance of 0.8. Figure 4 shows the characteristics of the klystron output power vs. the drive power. At a drive power of 10 W, the output power is saturated; the gain is 49 dB. The rather low obtained peak power and the efficiency are considered to be due to insufficient adjustments, such as tuning of the beam focusing, since 1.2 MW and 64% at 90 kV had already been obtained using a short-pulse test-tube. The second problem is that the above mentioned performance (780 kW) was obtained at 5% duty, and that a 330-kW output is the limit under CW operation, due to unexpected heating of the output-window.

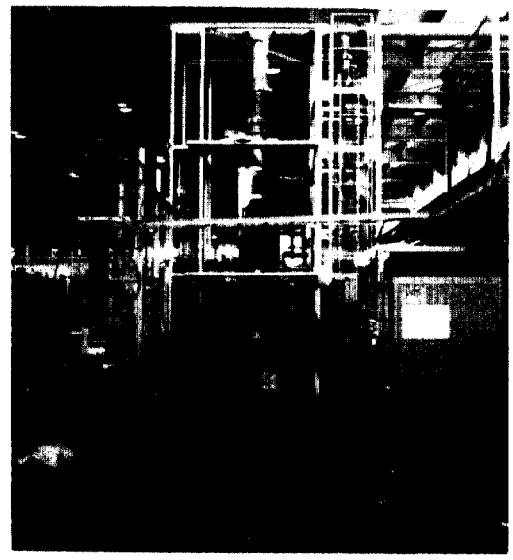

Figure 3. Photo-view of the prototype 1249-MHz high-power CW-klystron under development by PNC and Toshiba Corporation.

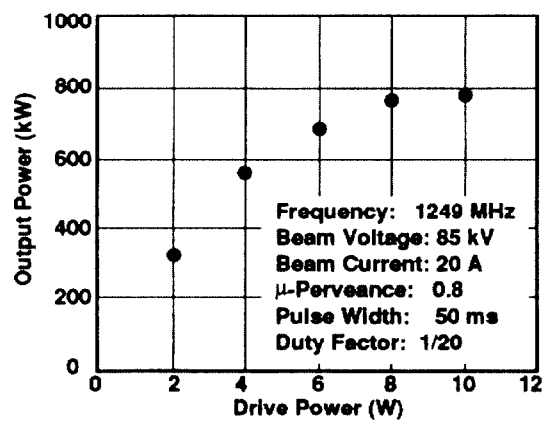


Figure 4. Output vs. drive power, achieved so far.

### *3.2 Accelerator Guides*

The accelerator guide is a $2\pi/3$-mode disk-loaded traveling-wave structure. One accelerator section has two cavity-type couplers and 13 normal cells; the total length is 1.2 m (5 λ) without vacuum flanges. The guide was designed so as to be a quasi-constant gradient structure: the disk aperture, which we call "2a"-dimension, decreases along the structure with two kinds of constant steps (300 μm for the upstream 6 disks, and 400 μm for the downstream 8 disks).

A prototype accelerator section was fabricated during 1991 FY by Mitsubishi Heavy Industries, Ltd., Mihara Machinery Works. The normal cell dimensions were determined by those of the predecessors (6-cell reference cavities). The coupler cavity dimensions were determined on the basis of Kyhl-Method in an iteration manner of measurement-and-machining, starting at a dimension scaled up from an s-band structure. Water-cooling is one of the most severe subjects for such high-power CW-machines. This was simulated using a three-dimension computation program. This section was made by means of an usual brazing method under a vacuum.

### *3.3 Resonant Ring*

The actual resonant ring (Figure 5) comprises a directional coupler used for power-feeding, two Bethe-hole couplers for monitoring the accumulated power (both forward and backward), a phase-shifter, a stub-tuner, vacuum ports, and an accelerator section. According to a calculated transmission factor, the coupling coefficient ($C$) was chosen to be 0.324. The remote-controlled phase-shifter is used for fine adjustments (max. ±10°) in order to compensate for the phase-shift due to a temperature change between no-rf-feed (28°C) and full-rf-feed (31°C) in the accelerator section.

Using a network analyzer, a low-power test was carried out. The ring length was first adjusted so that the operation frequency would coincide with the resonant frequency, by an $S_{21}$-measurement at port 1 (input) and port 2 (output) of the directional coupler (Figure 2). Then, by measuring both the forward-wave and backward-wave signals from the Bethe hole coupler, the reflection was reduced. As shown Figure 6, after an adjustment, -52.7 and -81 dB were obtained for the forward and backward wave amplitudes, respectively. Since the coupling of the Bethe-hole coupler is -60 dB, the gain was 7.3 dB in this case. The expected gain by the calculation is 9.8 dB. The difference between them was found to be due to attenuation at the phase-shifter. This will soon be improved.

## 4. FUTURE

Heating of the klystron output window is the most important problem to be solved. The prototype TRAS section will soon be tested under high rf power.

## 5. REFERENCES

[1] L.J. Milosevic, et al., Trans. I.R.E. Vol. MTT-6 (1958), pp.136.

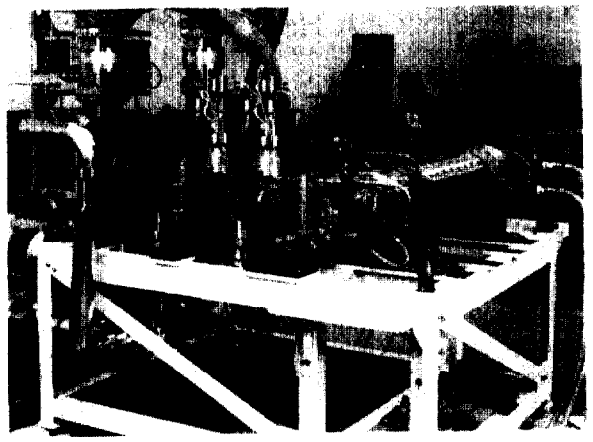

Figure 5. Photo-view of the prototype TRAS resonant ring.

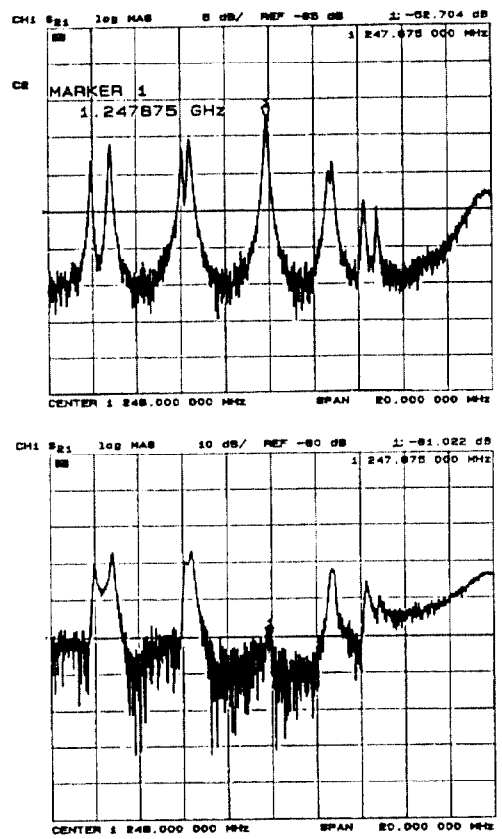


Figure 6. $S_{21}$-measurement at port 1 of the input directional coupler and the Bethe hole coupler output. Upper: forward-wave; lower: backward-wave (reflection) .