

## THE ENERGY SWITCH IN A 20 MeV MULTI-ENERGY ON-AXIS COUPLED SW GUIDE

Tao Xiaokui, Tong Dechun, Jin Qingxiu, Lin Yuzheng, Jing Gang, Hu Shaoguang, Sheng Wei  
 Department of Engineering Physics, Tsinghua University, Beijing 100084  
 Chen Bingyi Li Yuezeng, Sun Baoyu, Zou Yang  
 Beijing Institute of Electronics & Vacuum Technology, Beijing 100016

### Abstract

A 20MeV S-band on-axis coupled SW guide with “Energy Switch” has been developed for the high-energy medical accelerator. Since the guide is on-axis coupled and operated in the  $\pi/2$  mode at 2856MHz, the axial size of the coupling cells is so small that the existing technology of energy switch in side coupled accelerators is difficult to use. Consequently a new type of energy switch is developed to fit the on-axis coupled structure. This paper presents the microwave properties of the energy switch under cold and high power tests.

Commissioning test has been completed by the end of year 2000. The beam test results show that the energy switch performs well, meeting the design criteria.

### 1. INTRODUCTION

Multi-energy medical electron linacs that can produce both low and high energy x-rays (6MV/15MV or 6MV/18MV) together with a wide range of electron energies are widely used all over the world. Such multi-energy accelerators are mostly manufactured by several companies outside of China, such as Varian, NEC and Siemens. They are the main part of medical electron linacs of China imports. However, no organization in China could manufacture such linacs before. So this kind of multi-energy electron linacs must be developed to meet the demand in radiotherapy.

Supported by the Major Research Project of the Ninth-Five Plan (1996-2000) of China, we began development of multi-energy electron linac structures for the domestic market. Based on our past works, we still use the on-axis coupled structure, which is compact, easy to machining, welding and cooling due to the axial (circular) symmetry.

The key problem for multi-energy electron linacs is how to varying beam energy over a wide range without degrading the energy spectrum. There are several “Energy Switch” techniques in side-coupled structures. Based on these techniques, we developed a new type of energy switch for on-axis coupled structures. This energy switch has been successfully used in a 20 MeV S-band SW guide. And this new technique is protected by a patent.

### 2. GENERAL DESCRIPTIONS OF ENERGY SWITCHES IN SW GUIDE

The simplest method of varying the output energy is either to vary the RF power into the accelerator or vary the injected beam current. However, this approach will provide only a narrow range of energy variation beyond

which the energy spectrum will very rapidly degrade. The output electron energy spectrum is determined by the first section of the accelerator, the “buncher”. Since the optimum bunching conditions are uniquely determined, the independent variation of one of the conditions, for example varying the input RF power or injected current, will degrade the energy spectrum (i.e. results in a wide energy spectrum). So, the function of energy switch is to vary the output electron energy over a wide range without degradation of the output electron energy spectrum.

There are several types of SW linac structures operating in the  $\pi/2$  mode, such as side coupled structure, on-axis coupled structure, coaxial coupled structure and annular coupled structure. In all these biperiodic structures, the coupling cavity is unexcited at  $\pi/2$  mode. However, the existing techniques on the energy switch just utilize this unexcited coupling cavity to vary the relative magnitude and /or sign of the fields in adjacent accelerating cavities.

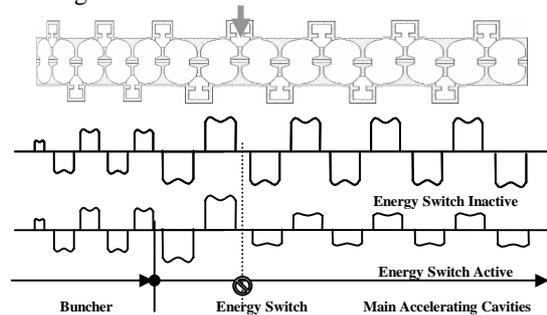


Fig.1 Energy Switch

As shown in fig. 1, so-called energy switch technique is to introduce a special coupling cavity at a particular location behind the buncher along the accelerator. By disturbing the boundary, one can change the electromagnetic field of this coupling cavity so as to detune this cavity, to shift the phase or to vary the coupling between this cavity and the adjacent accelerating cavities. According to the theoretic analysis<sup>[5]</sup>, this perturbation can produce a step in the accelerating field of the structure while preserving the  $\pi/2$  mode resonant conditions. Furthermore, by controlling the RF power, one can vary the output energy while maintaining the accelerating electric field within the buncher.

For side coupled structure, mechanical or electrical perturbations are easier to apply since the coupling cavity is located off the beam axis. So the existing energy switch techniques are all on side coupled structure<sup>[1] [2] [3] [4]</sup>.

### 3. ENERGY SWITCH FOR ON-AXIS COUPLED STRUCTURE

In on-axis coupled structure, coupling cavities are located on the beam axis. Since the beam hole is cut-off to the input RF power, the on-axis coupling cavity is magnetically coupled to the adjacent accelerating cavity through a pair of coupling slots (so called kidney-shaped slot) 180° apart cut into the wall between them. The slots are rotated 90° about the beam axis at the opposite side of each wall at each cell. Fig. 2 shows this relationships.

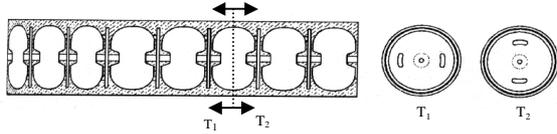


Fig. 2 On-axis coupled structure

In order to obtain higher shunt impedance, the axial size of the coupling cavities is usually small (i.e. about 3mm in S-band). So the energy switch techniques used in side coupled structure are no longer applicable. Consequently we have to develop new energy switch techniques that can be used in on-axis coupled structure.

#### 3.1 The Insertion of the Energy Switch Pole

The coupling cavity in on-axis coupled structure is so small that it is easy to be perturbed. So we can use relatively smaller perturbation object. On the other hand, it is neither convenient to the mechanism nor easy to keep stable. After a series of experiments on model cavities, we decided to place a metal pole into the coupling slot between a coupling cavity and the adjacent accelerating cavity (see fig. 3).

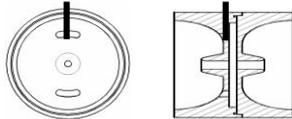


Fig.3 Insertion position of the pole

While the pole inserted and pulled out, the effective area of the slot will be varied. Consequently we can change the ratio of the coupling factors between the coupling cavity and the adjacent accelerating cavity. So the ratio of the field in the accelerating cavities adjacent to this coupling cavity can be varied.

#### 3.2 The optimization of the energy switch cavity

As an applied technique, the energy switch in on-axis coupled structure must meet these requests: a) good electrical contact to keep the stability under high microwave power conditions; b) good gas-tight performance to keep vacuum; c) proper size of the metal pole and the coupling slot to meet the design of particle dynamics; d) more than 10,000 times reciprocating actions capability for the whole energy switch system.

Consequently the optimized “switch cavity” has following features (see fig. 4): 1) use choke structure to support the metal pole; 2) thicken the wall where to insert

the metal pole and change the adjacent accelerating cavities to asymmetry about the centre line of the cavity; 3) change the adjacent coupling slots from pair to single to increase the influence of the metal pole; 4) the radial dimensions of the “switch cavities” varied according to the length of the choke structure( $\lambda/4$ ); 5) use bellows with good baking properties to ensure the whole system working under high vacuum; 6) for the distinctive outline, water wall inside the cavity is used instead of outside water jacket.

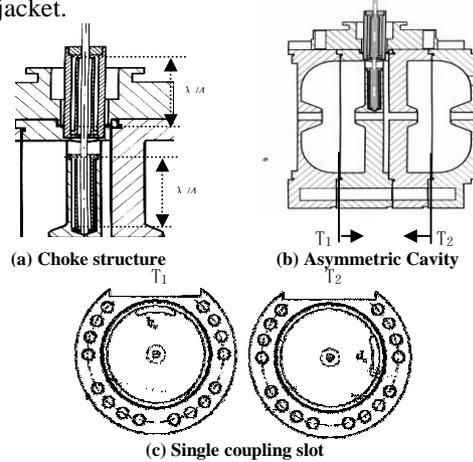


Fig.4 Optimization of the energy switch cavity

### 4. COOL AND HIGH POWER TESTS ON A PROTOTYPE GUIDE

In order to gather experiences for the high energy guide, we first rebuild a 6MeV SW guide operating at 2998MHz. As shown in fig.5, the guide is made up of 8 accelerating cavities and 7 coupling cavities, among which a special designed energy switch section is inserted. On this prototype guide, experiments about microwave properties and high power reproducibility tests are operated.

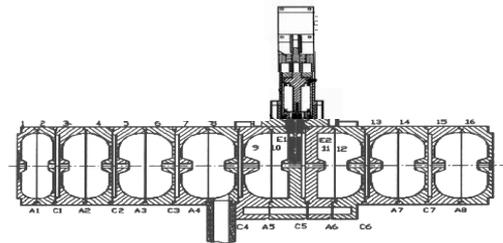


Fig.5 Prototype guide with the Energy Switch

#### 4.1 microwave properties under cool tests

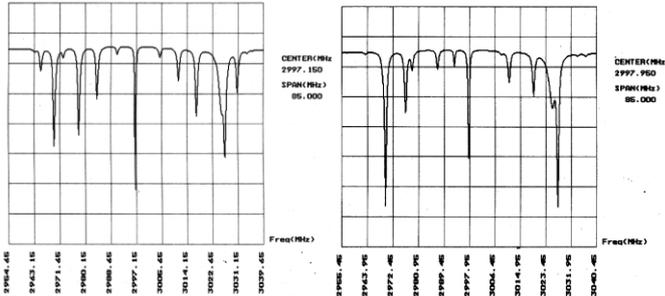
##### ➤ Measurement of $f$ , $k$ and $Q_0$ (Table 1)

Properties	Energy Switch Inactive	Energy Switch Active
$K_{(A5-C5)}$	0.0247	0.0125
$K_{(C5-A6)}$	0.0247	0.0253
$f(A_5)$ (MHz)	2996.90	3001.15
$f(C_5)$ (MHz)	2996.95	3022.00
$f(A_6)$ (MHz)	2996.10	2996.05
$Q(A_5)$	12045	12046
$Q(C_5)$	2298	1976
$Q(A_6)$	12084	11944

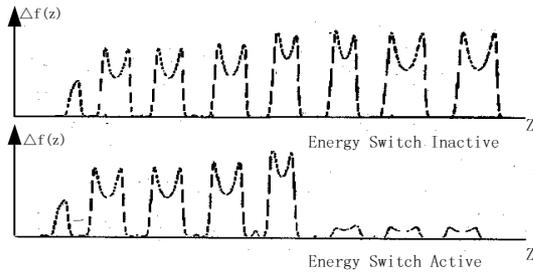
➤ **Table 2 Measurement of dispersion frequency**

Properties	Energy Switch Inactive	Energy Switch Active
$f_0$ (MHz)	2996.86	2997.81
$\beta$	1.35	1.74
$Q_0$	15700	13200

➤ **Fig. 6 Pass band performance with Energy Switch inactive and active**



➤ **Fig. 7 Change of the axial electric field distribution**



➤ **Reproducibility test**

After 5,000 times insertion and pulling out of the metal pole, we get the reproducibility result as follows (Table 3):

Properties	Energy Switch Inactive	Energy Switch Active
$f_0$ (MHz)	$2996.80 \pm 0.15$	$2997.80 \pm 0.20$
$\beta$	$1.30 \pm 0.05$	$1.65 \pm 0.10$
$Q_0$	$13000 \pm 300$	$11500 \pm 300$

**4.2 microwave properties under high power tests**

The energy switch is proved feasible under cool tests. However, the high power test is more important. The welded, vacuum-tight prototype guide is shown in fig. 8. Driven by a 2.0MW magnetron, the guide worked stably during 6,000 times operations of the energy switch.



Fig. 8 Prototype guide

**5. BEAM TESTS ON A 20MEV SW GUIDE**



Fig. 9 The completed 20MeV SW guide

Beam tests of the 20 MeV SW guide were held in early 2001. The following table (Table 4) gives the main results which show that the energy switch performs well, meeting the design criteria. [6]

Beam Energy (Measured) (MeV)	Beam Energy (Designed) (MeV)	Peak Beam Current (Measured) (mA)	Peak Beam Current (Designed) (mA)	Energy Switch Status
6.6	6.0	100	90	Active
18.09	18.0	20	15	Inactive
20.4	20.0	6.7	2	Inactive

**6. CONCLUSIONS**

A new type of energy switch has been successfully developed for constructing an on-axis coupled, multi-energy, single-section, SW linac structure in response to the need for more versatile, but simple and reliable techniques for varying the output electron energy over a wide range for medical accelerators. The basic concept, which utilizes the coupling slot to vary the nearest neighbour couplings, provides the capability of varying the electron energy from minimum to maximum energy without degrading the energy spectrum. This technique has been experimentally demonstrated and is now utilized in a 20 MeV multi-energy SW guide.

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