RF Phasing of the Duke Linac*

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Abstract

The injector of Duke storage ring is a 295 MeV S-band linear accelerator (linac) which consists of 3 klystrons and 11 accelerator sections. The phase adjustment between klystrons is achieved by means of 2 commercial coaxial phase shifters in the klystron drive line. The phase between accelerator sections is balanced on the low power level after the waveguide installation. A mechanical high power waveguide phase changer has been developed and installed for each accelerator section. During the high power operation, the waveguide phase can be changed remotely by driving gearmotor to deform the waveguide cross section. The test results and high power performance are reported.

I. INTRODUCTION

A 295 Mev S-band linac has been in operation at Duke University since October 1994 (see [1]). It serves the Duke 1 GeV storage ring as an injector. The linac consists of three ITT 30 MW klystrons, eleven 10-foot long accelerator sections and a RF gun cavity. The RF frequency is 2856.76 MHz. The first klystron feeds the gun cavity and first 3 sections. The other two klystrons each feed four sections. The RF phase adjustment between 3 klystrons is achieved by means of 2 motorized coaxial phase shifters in the klystron drive lines. Only one high power waveguide phase shifter is employed in the gun cavity feed line. The electrical phase length of each waveguide branch was measured and adjusted at low RF level using a double balance mixer. A mechanical high power waveguide phase changer has been developed and installed for each accelerator section. During the operation, the phase between the bunched beam and the RF wave in each individual section can be corrected remotely in the control room. The test results and high power performance are reported. Overall this paper provides a very simple and economical method of RF phasing for short or medium size linac injectors.

II. WAVEGUIDE NETWORK

Aluminum waveguide WR284 pressurized with 26 PSIG of Sulfur Hexafluoride (SF6) are used throughout the

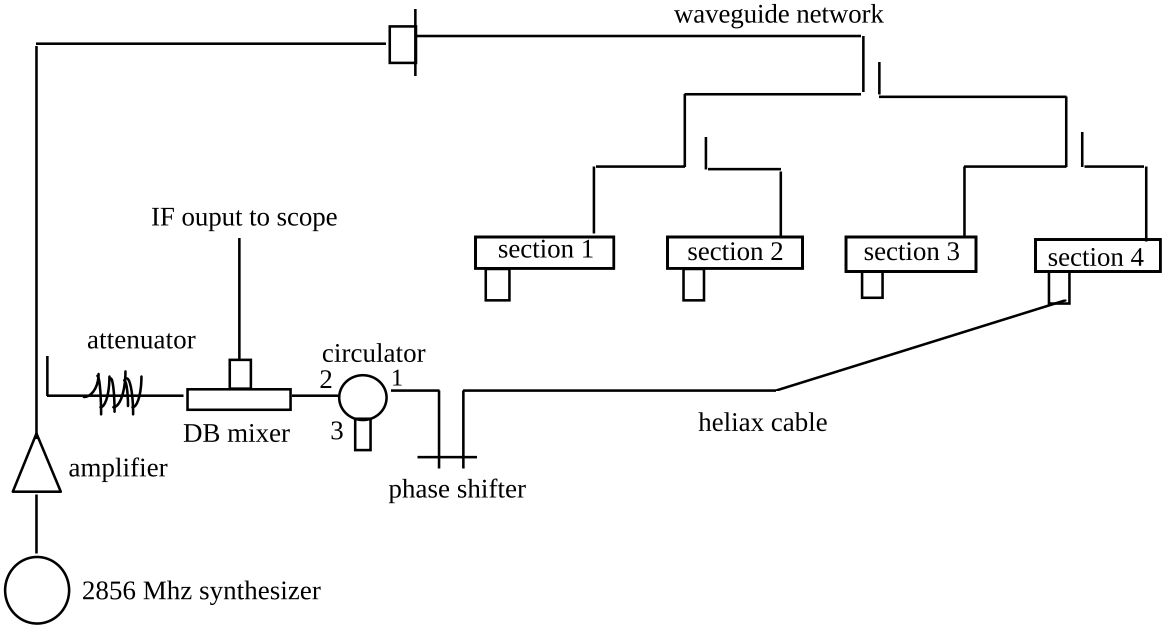

Figure 1. Block diagram of low level RF phase measurement

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whole system. They are carefully designed to have equal electrical phase length among the waveguide network branches. To reduce the phase differentials caused by waveguide temperature or pressure (see [2]), considerable care was also taken to obtain a symmetrical waveguide network design

The branches from first 3-dB power divider to each section have an about equal physical waveguide length (around 20 feet). This results in a close to equal power dissipation in the accelerator sections and waveguide lines. The installation of our high power waveguide phase changer has eliminated the regulation requirements on waveguide temperature and pressure; therefore, no cooling water for waveguide was required. The pressurized SF6 circulates through a dryer in the waveguide system and is not pressure regulated either. The aluminum waveguide flange CPR284F and gaskets (Parker 5906-284-1) are used throughout the waveguide system. Most of the waveguide components were made in house. Some pieces were made locally to size at the time of installation.

III. RF PHASE ADJUSTMENT

After the installation of waveguides and accelerator sections, the RF phase adjustment was performed. Figure 1 is a block diagram of RF phase measurement set-up. A frequency stable signal generator gives a CW signal at the operation frequency of 2856.76 MHz. The waveguides were pressurized at 26 PSIG and the accelerator sections were cooled at 30.2 degree centigrade which are the normal operation conditions. Four aluminum waveguide spools have been machined to connect the Skarpaas flanges at section's output to the commercial waveguide flanges CPR284F which are used on the waveguide to coaxial adapters. Heliax coaxial cable and semi-rigid coaxial cable are used for the purpose of phase stability.

The phase measurement was made by a double balance mixer (mini-circuit ZEM-4300MH) as a nulling detector. A 20-foot long Heliax coaxial cable is connected to one of the four sections at each time. The RF signal output from each section is compared with the same reference signal at the mixer. First of all, take a rough phase scanning for all of the four sections; then choose one section whose phase error lays in the middle of others as the standard one; adjust the coaxial phase shifter in the RF line to get a zero output from the inter mediate frequency (IF) port of the mixer ; then switch the 20-foot cable to the next section; use a C-clamp to indent the waveguide wall to get the same nulling output of IF port. Bowing in of the narrow wall of waveguide decreases its phase length and bowing in of the broad wall increases its phase length. The waveguide deformation has to be permanent. With 26 PSIG pressure, a hand-operated C-clamp can easily obtain the desired phase adjustments. After the four branches reaching their phase balance, we leave them for overnight and recheck their phase next day. The typical phase difference between branches is around 10 degrees and the maximum one is 35 degrees.

It was found that measurement is reproducible within +/- 1.5 degrees which is caused mainly by reconnecting the 20-foot Heliax cable. Since the zero crossing point of the mixer's IF output is used for phase detecting, the RF signal's amplitude is not a critical issue any more. We set the RF level for the best phase resolution which is 3 mV per degree of phase differential. The four commercial waveguide to coaxial adapters have a phase difference within +/- 1 degree. Assuming the sections are among +/- 2.5 degrees of their design length, the overall accuracy of this method is better than +/- 5 degrees.

IV. WAVEGUIDE PHASE CHANGER

The remotely operable phase changer assembly consists of a flanged 30-inch long piece of aluminum WR284 waveguide suitably equipped with a mechanism for compressing together or pulling apart the broad sides of the waveguide over approximately 80% of its length (see Fig. 2). An aluminum strip .25x.30x24 inch with 14 tapped holes was welded along the centers of each of the broad sides of the waveguide section. To this was fastened with screws a 0.37x2.0x24 inch steel bar which acts as a stiffening rib to distribute a centrally applied compression or tension force along the length. The force is generated by a DC gearmotor driving a shaft with right and left-hand screw threads machined onto its ends. Pivoted nuts riding on these threads move some hinged levers in or out, thereby causing a large deforming force to be applied to the centers of the stiffening ribs. The waveguide walls each move in or out by up to approximately +/- 2 mm (which takes the aluminum in the waveguide well beyond its elastic stress limit), and the phase of the RF wave propagating in the deformed waveguide is changed by about 30 degrees from the fully compressed to fully expanded states (see [3]).

The readback of phase information is provided by an LVDT displacement transducer mounted on one of the two stiffening ribs and activated by a rigid arm which is mounted on the opposite rib. The LVDT signal is thus a direct measure of changes in the wall-to-wall dimension in the center of the broad walls of the waveguide. As measured using a slotted line attached to one end of this waveguide section, the phase shift is a very linear and reproducible over many cycles function of the LVDT signal.

V. SYSTEM PERFORMANCE

The described system has been in operation for six months and has functioned very well. Two energy spectrometers are employed for monitoring the phase relationships between RF traveling wave and electron beam. The low energy spectrometer is located after first accelerator section and the high energy spectrometer is at the end of linac. Phasing is performed manually in the control room. The phasing criteria are to maximize the beam energy and minimize the energy spectrum width.

The availability of phase adjusting for each individual accelerator section has proven valuable. After installation it was found that the beam line length between first and second accelerator sections was mistakenly manufactured 1.074 inch shorter than the designed 69-wavelengths. We shortened the waveguide length to that section correspondingly and performed a phase measurement similar to the low power one but operated at a high power level. The phase measurement accuracy performed at high power level is around +/- 10 degrees. The fine phase adjustment for these two sections was made by their waveguide phase changers.

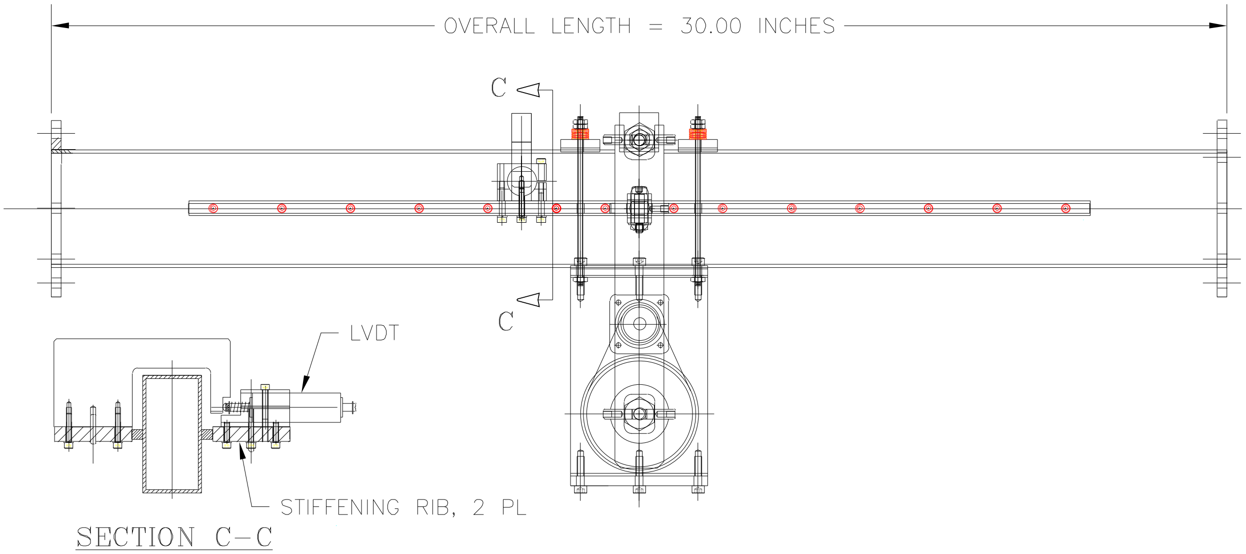

Figure 2: Waveguide Phase Changer

Each waveguide phase changer has a phase adjusting range of +/- 15 degrees. But the actual phase range is not limited by it. If one of the phase changes reaches its limits, it is possible to indent the waveguide wall adjacent to it to bring the phase to its middle. The waveguide phase changer can be used like a phase indicator during the high power operation which gives the phase direction needed for the phase adjustment.

The current phasing system accuracy is limited by our high energy spectrometer which has a sensitivity of 0.2%. The further improvement is to have a more sensitive spectrometer or using the beam induced signal as phase measurement.

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