HIGH SPEED RESONANT FREQUENCY DETERMINATION APPLIED TO FIELD MAPPING USING PERTURBATION TECHNIQUES

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Abstract

Perturbation techniques are commonly used for measuring electric and magnetic field distributions in resonant structures. A field measurement system has been assembled using a Hewlett Packard Model 8753C Network Analyzer interfaced via an HPIB Bus to a personal computer to form an accurate, rapid and very flexible system for data acquisition, control, and analysis of such measurements. Characterization of long linac structures (up to 3 m) is accomplished in about three minutes, minimizing thermal drift effects. This paper describes the system, its application and its extension to applications such as confirming the presence of weak, off-axis quadrupole fields in an on-axis coupled linac.

Introduction

Characterization of electric and magnetic field distributions in resonant structures is commonly accomplished using the "beadpull" technique. A piece of material (often spherical) of known dielectric and magnetic properties is passed through the resonant structure and the variation of resonant frequency is measured as a function of the "bead" position. The influence of the dielectric perturber on the resonant frequency of the structure is proportional to the square of the relative field strength at the position of the bead [1].

Traditional methods of measuring this frequency variation include phase-locked loop and frequency-modulation techniques. However, the apparatus described here measures the resonant frequency directly for a discrete set of field locations along the bead path. A network analyzer drives the resonant structure with a periodic, swept-frequency pulse while the bead passes through the structure. The advanced features of the 8753C network analyzer enable it to measure the resonant frequency in as little as 150 ms. In addition, computer control enhances system flexibility, allowing the same generic measurement technique to be applied quickly and without difficulty to a host of related experiments, three of which are described in this paper.

Description of Measurement Apparatus

The present measurement system evolved from the apparatus and control codes assembled to study the dielectric properties of materials [2]. The system consists of a Hewlett Packard Network Analyzer model 8753C, an IBM PC XT or AT with HPIB interface, and a small synchronous motor.

Figure 1 illustrates a setup for a typical beadpull, in this case in a Radio Frequency Quadrupole (RFQ) structure. The perturber is initially located outside of the cavity, and is supported on a monofilament line which is selected for its good strength-to-weight ratio and low perturbation contribution. The network analyzer is then fully configured by the PC and the "bead out" resonant frequency is measured (using the built-in resonant-peak-finding capabilities of the analyzer) and set as a reference frequency in the analyzer. At this point, the analyzer is switched to phase-measurement mode and the reference phase is arbitrarily set to zero. The bead is moved at a constant speed through the cavity and the analyzer determines the resonant frequency by determining the frequency at the zero degree phase shift for the selected number of positions of the bead. Measurements with this technique yield a resonant frequency with a typical reproducibility of $\pm$ 150 Hz on a resonance having a bandwidth (3 dB points) of 500 kHz; i.e., a resonant frequency reproducibility of 0.03% of bandwidth. This implies that a 1% accuracy on field amplitude measurements can be achieved using a perturbation of less than 10% of cavity bandwidth.

The difference in frequency from the established reference is transferred to the PC and logged, along with the time of each measurement. This data set is then analyzed off-line to determine the field distributions in the cavity, and can be output to a plotter or printer. There is no direct indicator of position, and position references are therefore taken from salient features in the frequency-shift plot.

The data acquisition code running on the PC is written in QuickBASIC [3] and communication with the network

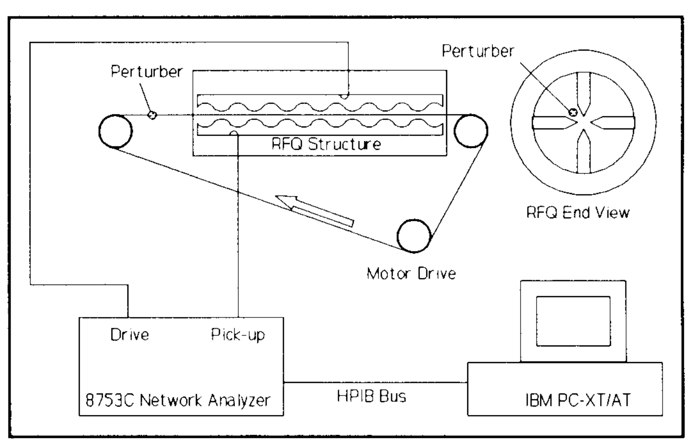

Fig. 1 Apparatus layout.

analyzer over the HPIB Bus is achieved using the HPIB interface software module supplied by Hewlett Packard with their HPIB interface card [4]. This software presents one problem: data transfers to the PC are done in single-precision real format, causing significant data truncation under some conditions. Our measurement technique bypasses this problem, however, by using the analyzer in a frequency difference mode.

All HPIB interface overhead (handshaking, arbitration, etc.) is transparent to the programmer, allowing short code structures comprised of simple command-response sequences. The data is not displayed deliberately, to maintain the code simplicity. The beadpull program output file is loaded into an analysis code in MathCAD [5], where reasonable calculation, display, and plotting/printing facilities abound.

Examples of Resonant Cavity Field Measurements

Axial Fields in an On-Axis-Coupled Electron Linac

The on-axis electric fields of a multicell, three metre-long 1.3 GHz electron accelerating structure, built by AECL, have been characterized with this measurement system. Beadpulls on the graded-beta sub-section and the power-coupling sub-section of the structure are shown in Fig. 2. With the analyzer doing a frequency determination every 150 ms, and at a beadpull speed chosen to give a measurement every one mm, the data in each plot was acquired in 90 seconds.

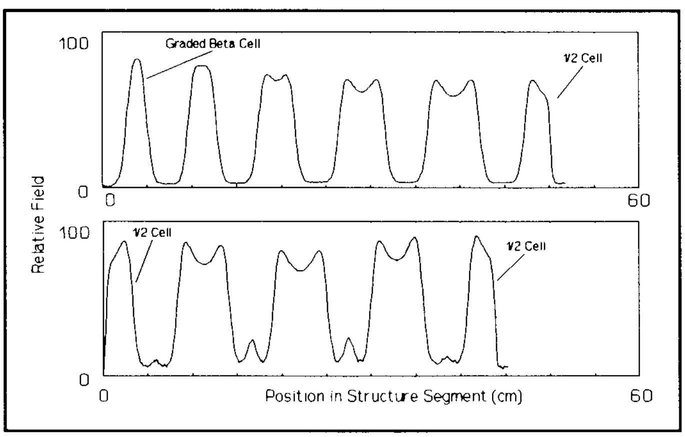

Fig. 2 Graded-beta and coupling sections of linac.

Quadrupole Harmonics in Coupled Cavity Linac Cells

Recently, it has been suggested [6] that, in on-axis-coupled multi-cell linac structures, coupling-slot orientation may influence the beam shape and focusing via quadrupole spatial harmonics induced by the coupling slots. MAFIA analysis [7] predicts that these fields are present and that they are of the order of 10^{-3} to 10^{-4} times the magnitude of the accelerating field. It is very difficult to measure such weak field components with traditional perturbation techniques and a new approach has been attempted. A two vane propeller-like dielectric perturber was located in the coupling cells of an on-axis coupled structure and was rotated about the beam axis. The structure had been assembled with the "conventional" coupling-slot orientation which creates the maximum quadrupole field component. The beadpull code and hardware were modified to turn the perturber with a small dc stepping motor (1.8 degrees per step). Rudimentary step control was effected by switching individual motor phases via the PC parallel port and a power-driver translation board. Resonant frequency measurements were taken at 3.6 degree increments over six full revolutions. Figure 3 shows the mainly quadrupole nature of the field over two complete rotations. The presence of the fields, at the levels expected, was confirmed without difficulty [8].

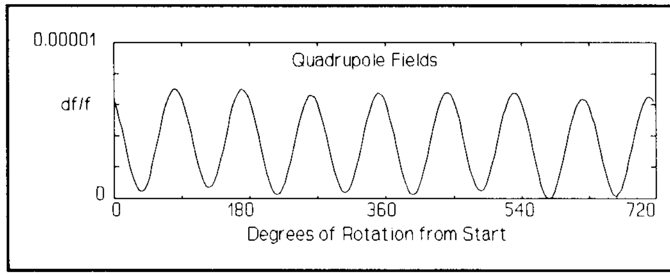

Fig. 3 Quadrupole field measurement.

RFQ Azimuthal and Longitudinal Field Measurements

This measurement system has been used to simplify structure tuning and field levelling on RFQ1 [9], which has recently had its vanes replaced to increase the beam energy from 600 keV to 1.25 MeV [10]. For these measurements a metal perturber was inserted a fixed distance through the cavity wall successively in each quadrant through symmetric holes located along the length of the structure. In each case, the frequency shift produced was measured relative to the cavity frequency without the perturber. By doing so, a good comparison of azimuthal field symmetry is obtained, along with some indications of longitudinal symmetry. Figure 4 shows the normalized field strengths obtained for a tuning change (a single vane movement in this case). Effects are seen in all four quadrants.

Access for this test method is not available over the total length of the structure, so an automated beadpull was performed on one quadrant. In an RFQ, the electric field undergoes a sinusoidal variation in the region of the modulated vane tips. This variation is localized in the tip region and is not important when characterizing longitudinal vane-to-vane voltage distributions. The field on the shoulder of the vane is not influenced by tip profiles. The fields are purely azimuthal and reflect local vane-to-vane voltages. Hence, the beadpull was done as illustrated in Fig. 1.

The beadpull results, displaying field distributions along the length of the RFQ, are shown in Fig. 5. Measurements were made at 1600 points along the 1.5 m structure in 190 seconds. The three small dips in the plot are due to 3.18 cm

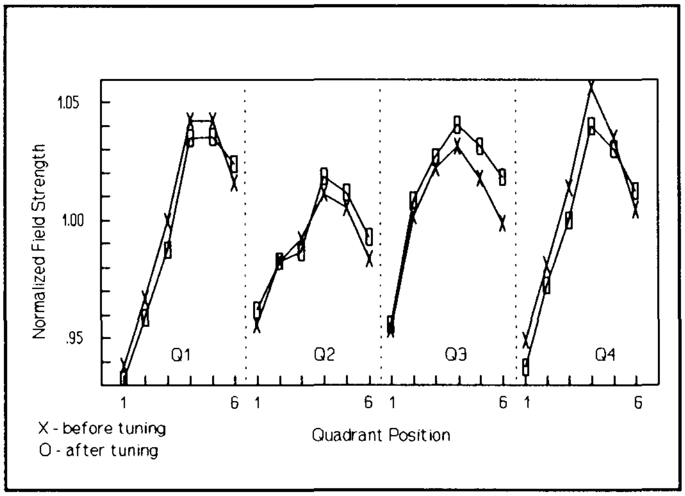

Fig. 4 Azimuthal field measurements in an RFQ.

flat sections, machined into the shoulder of the vane, separated by 98.6 cm. These sections are used as reference sites during telescopic vane alignment. While affecting the localized field to a small extent (<3%), these flats have no effect on the axial field and conveniently provide a solid position calibration for the beadpull.

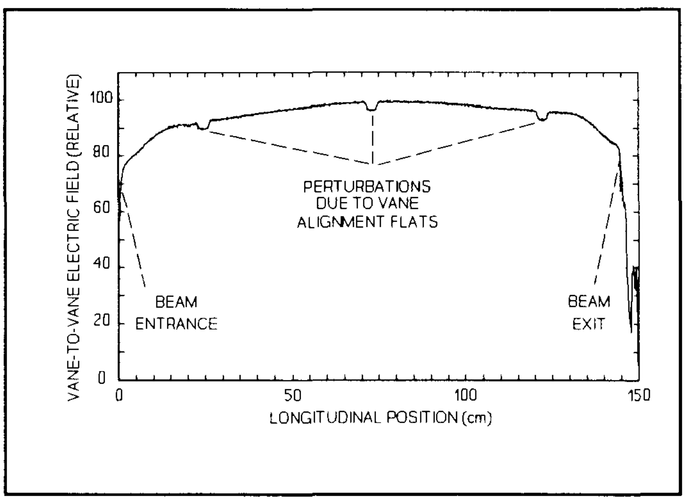

Fig. 5 RFQ longitudinal field distribution.

Summary

The flexibility of control and sophisticated data analysis features of the HP 8753C Network Analyzer combine to simplify field measurements immensely. In addition, the phase measurement technique, made feasible by the stability of this instrument, yields good qualitative data for comparison of tuning changes in rf structures.

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