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ACCELERATOR STRUCTURE BEAD PULL MEASUREMENT AT SLAC*

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Abstract

Microwave measurement and tuning of accelerator structures are important issues for the current and next generation of high energy physics machines. Application of these measurements both before and after high power processing can reveal information about the structure but may be misinterpreted if measurement conditions are not carefully controlled. For this reason extensive studies to characterize the microwave measurements have been made at SLAC. For the bead pull a reproducible measurement of less than 1 degree of phase accuracy in total phase drift is needed in order to resolve issues such as phase changes due to structure damage during high power testing. Factors contributing to measurement errors include temperature drift, mechanical vibration, and limitations of measurement equipment such as the network analyzer. Results of this continuing effort will be presented

INTRODUCTION

The measurement of an accelerator's internal electric field by the bead pull method is an established and trusted measurement. The bead pull measurement consists of pulling a small metallic bead attached to a string through the accelerator structure while a small amount of rf power is fed into the structure at the frequency of the mode you wish to investigate. Real and imaginary S_{11} data is acquired by a network analyzer as the bead moves through the accelerator structure. The electric field amplitude and phase is then calculated for each bead position in the structure.

At SLAC the measurement serves several roles: it is used to quantitatively judge engineering and fabrication issues, to tune newly fabricated accelerator structures and also to characterize any differences that might arise from high power processing by comparing pre and post processing bead pull measurements.

For the purpose of tuning the measurement is well established and its accuracy is trusted. When the measurement is used to investigate changes due to high power processing, which can be on the order of 1° degree of phase integrated across the structure, understanding errors with the measurement becomes essential. At this level there are many things that may contribute to the accuracy of the measurement including: temperature of the room and structure, stability of RF source in the network analyzer, data analysis techniques,[1] atmospheric pressure, and water vapor content of the air. This paper will address issues of temperature, mechanical vibration and network analyzer stability by using statistical analysis of multiple bead pull's with the goal of quantifying a phase measurement error that can be generalized for future measurements. Atmospheric pressure and humidity will not be addressed since a dry nitrogen purge is used during the measurements.

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TEMPERATURE CONSIDERATIONS

At SLAC we have introduced a commercial water temperature control system to stabilize the structure temperature during the measurement. The system consists of a Thermo Haake DC-30 circulator and temperature control unit along with the Themo Haake K-20 Chiller. The DC-30 is specified to control the water temperature to 0.1° Celcius.

The bead pull measurement is performed with the controller temperature set near the ambient room temperature typically around 20°C. Though the controller is specified to regulate the water temperature to $.1^{\circ}$C, temperature excursions during the measurement on this scale can occur due to the control algorithm of the DC-30. The consequence of the temperature control is a sawtooth variation in temperature data during the bead pull scan. S_{11} data for a non moving bead centered in the last cell of the structure is presented. Phase data is sampled at 5 Hz while temperature data is sampled at 1 Hz.

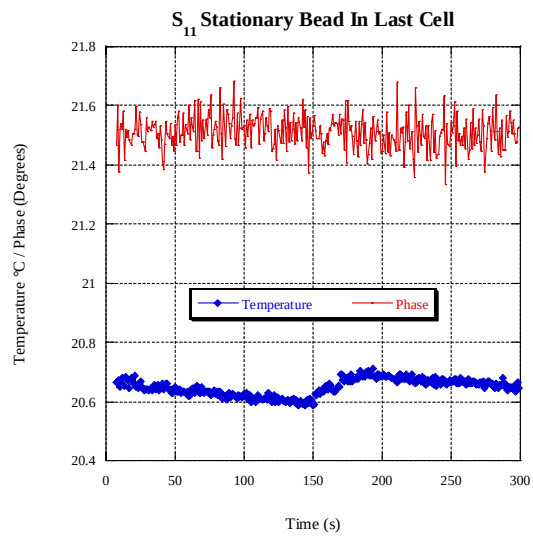

Figure 1:S_{11} phase measurement of a stationary bead in last cell for 5 minute scan.

The Figure 1 data address the phase stability of the bead measurement with the bead in the position where it is most sensitive to temperature and frequency variations. A

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typical bead pull scan takes on the order of 3 minutes where the presented data scan is around 5 minutes. The small ramp in temperature is evidence of the control algorithm turning on the heater element. There seems to be no immediate reaction in the phase data.

Room Temperature

The ambient room temperature where the measurement is performed can also have an effect and is the reason for implementing the closed loop water circulation system. There may still be a correlation between the room air temperature and the structure temperature during the measurement even with the water regulation.

Though the room temperature is specified to be controlled to ±0.5°C larger fluctuations may occur. Figure 2 shows that the regulation system seems to adequately control the structure temperature.

The temperature measurement was performed with a J-type thermocouple attached midway in the structure at cell 27. Though Figure 1 suggests the phase does not immediately respond to the temperature changes, the phase of the sawtooth pattern a sequence of scans will not be constant with the measurement and may contribute to the random phase error in the measurement over many scans.

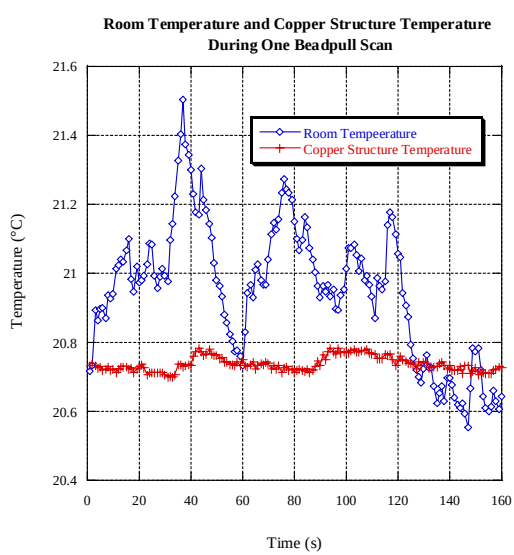

Figure 2: Room temperature vs. regulated structure temperature during bead pull scan.

Phase Sensitivity with Temperature

Structure damage due to high power processing and breakdown has been characterized by looking at pre and post processing bead pull scans. Data from the differences in these scans has been viewed as revealing an overall change to the structure due to the damage.

From a sampling of 20 bead pull scans, the data was grouped according to temperature. The phase is calculated from S_{11} data where the electric field peaks within each cell. The data from scans with two different temperature values might be misinterpreted as structure damage if careful temperature measurements are not taken during the scans.

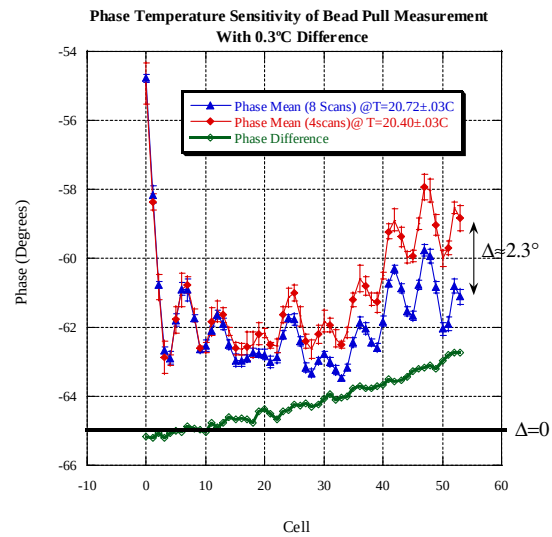

Figure 3: Phase sensitivity as a function of temperature. Error bars represent phase error for number of scans. Temperature standard deviation calculated from a sum of data for all scans in group.

The difference of 2.3° phase in Figure 3 agrees well with equation (1),

$$\Delta\phi = 2\pi\Delta T(df\,/\,dT)T_f\,. \qquad (1)$$

Where: ΔT is structure temperature difference of the scan, T_f is the fill time and $df/dT \approx 0.19$MHz/C°, a constant depending on the thermal expansion coefficient of copper and our working frequency of 11.424MHz.

NETWORK ANALYZER COMPARISON 8510 VS. 8720

A comparison of data taken with two different models of network analyzers, the HP 8510 NWA and the newer Agilent 8720 NWA, was performed. The 8510 is a modular system whose production began in the 1980's but is still a trusted instrument for its accuracy and stability, while the 8720 is a newer more compact and economical model. Bead pull measurements are made with the S_{11} parameter continuously as the bead moves through the structure. Data update rates vary between the 8510 and 8720 and methods of data collection can take two separate forms for the 8510. Both NWA's can acquire data in a mode that utilizes internal triggering, while the 8510 has an option to use an external trigger with varying trigger rates. The base internal trigger rate for the 8720 is much faster than that of the 8510 and more data can be collected during the same time period. The amount of data collected during a scan can have a significant effect on the measurement repeatability and accuracy due to data analysis techniques.

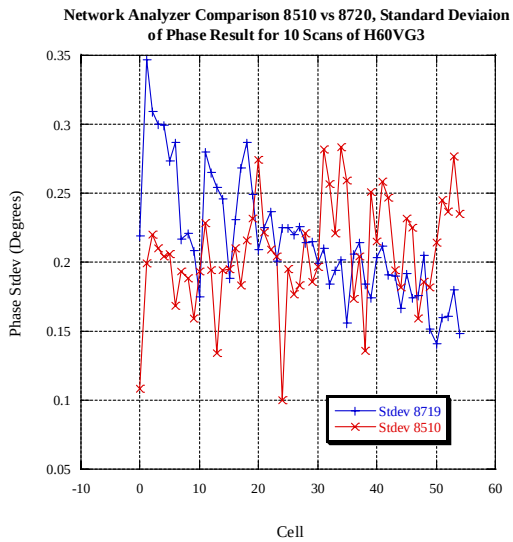

Figure 4: Standard Deviation of Phase for 10 Scans with different network analyzers.

A systematic error seems to dominate in the beginning cells for the 8720 network analyzer. This is most likely not due to the instrument but some unknown factor.

MECHANICAL AND MOTION CONSIDERATIONS

Since the measurement is made with a moving bead/string, motion related errors may be introduced into the data.

Vibration

One source of this motion is mechanical vibration transferred from the stepper motor system to the structure and bead/string system. Mechanically the structure strongback is separated from the bead pull tower that houses the stepper motor system. A considerable amount of noise can be transferred to the measurement if mechanical contact is established between the tower and accelerator structure.

The graph in Figure 5 compares the difference between having the input waveguide arms supported and unsupported during the scan with the previously mentioned tower contact eliminated. Measurement jitter that is visually observed on the network analyzer marker can be reduced by supporting the cable and input waveguide assembly. But when measured, figure 5 shows that this effect is only seen in the second and last cells. This should not lead one ignore the observed jitter, waveguide arms will continue to be supported to reduce observed noise.

String Position Reproducibility

Measurements performed after high power testing challenge us to mechanically reproduce the previous settings for the measurement. The string position within the structure should be accurately reproduced for a good comparison. This can be accomplished by visual inspection. Data for one such realignment is given in Figure 6 and gives confidence in the reproducibility of string alignment.

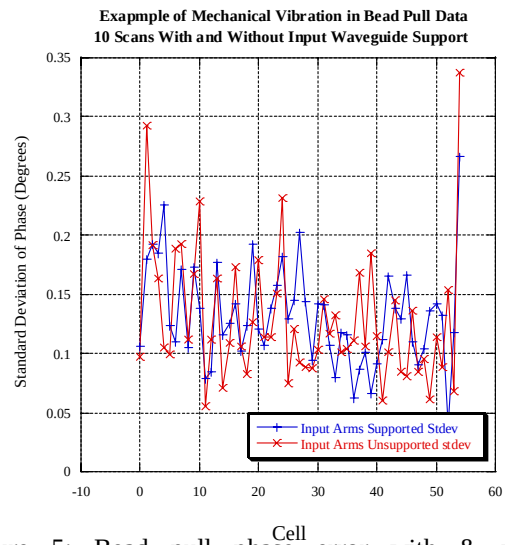

Figure 5: Bead pull phase error with & without mechanical vibration isolation.

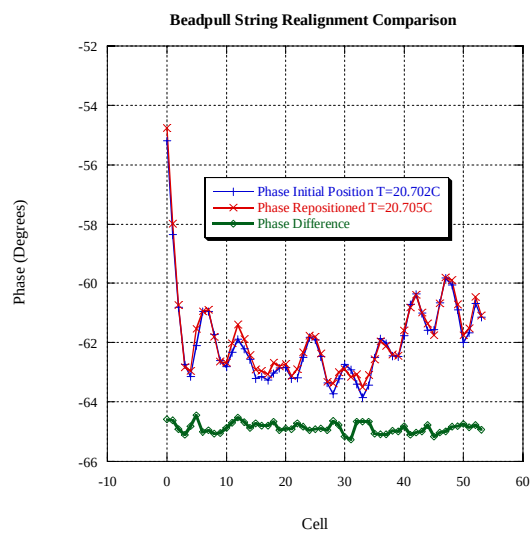

Figure 6: String replacement and realignment.

CONCLUSIONS

It seems we can trust the bead pull to produce an accurate measurement of internal structure fields. If we are to compare these measurements with previous results to extract meaningful information, close attention should be paid to the structure temperature during the scan and corrected with equation (1) if necessary. While investigations into vibrations and network analyzer model didn't reveal any great problems, a constant attention to detail is necessary for all aspects of the bead pull measurement to ensure consistent results.

REFERENCES

[1] T. Khabiboulline et al, "A New Tuning Method For Traveling Wave Structures," PAC 95