APPLICATION OF TRL CALIBRATION IN LONGITUDINAL COUPLING IMPEDANCE MEASUREMENT PLATFORM FOR BEPCII *

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Abstract

TRL calibration is one of the standard calibration methods for RF measurement. Applying the TRL calibration method into the longitudinal coupling impedance platform can correct the reflection of the matching section and the RF connector. By using TRL calibration in the platform, the reference pipe of each device under test is no longer required. The concept of the calibration is discussed in this paper and the software based on it is introduced.

INTRODUCTION

Coaxial line impedance measurement is one of the standard methods to measure the longitudinal coupling impedance of the vacuum component of the accelerator[1,2,3]. Coaxial line impedance measurement places an inner conductor at the center of the device under test (DUT). The inner conductor and the DUT itself build up a coaxial line. A short current pulse is propagating through the coaxial line to imitate the behavior of the short bunch as shown in figure 1. The measurement can be implement either in time domain or frequency domain. In frequency domain, the longitudinal coupling impedance measurement is degenerated into the measurement of the S parameter of the coaxial line and normally is carried out by a vector network analyzer (VNA). The connector of a VNA is either SMA or N-type, which is quite different from the coaxial line to be measured geometrically. Some kind of matching section and connector must be used to connect the VNA with the DUT. The matching section and the connector cause extra RF reflection and insertion loss of the measurement system and must be correct.

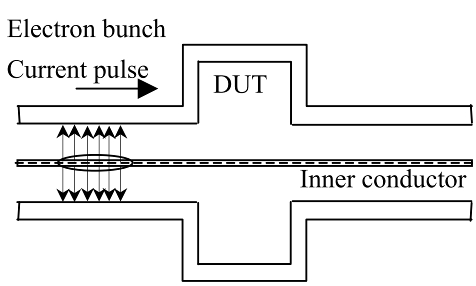

Figure 1: Coaxial line method measure longitudinal impedance.

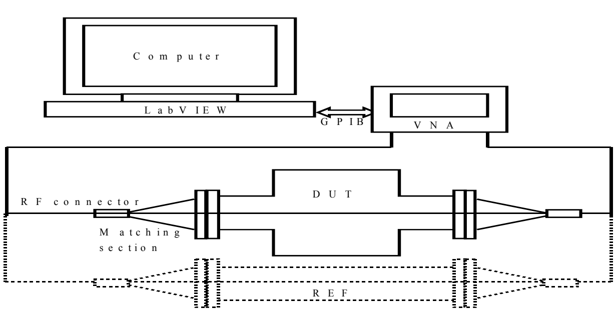

Figure 2: Traditional longitudinal impedance measurement with REF pipe.

Usually the measurement is preceded in two-steps, so called measurement of the DUT and measurement of the reference pipe (REF). And the impedance of the component (DUT) can be extracted form the compare of the S parameters of DUT and REF. In such measurement, a reference pipe of the same length of the DUT is necessary to resolve the mismatching of the whole RF system. Measurements of the impedance is so important that people want to measure the components will be installed in the accelerator as much as possible before they are installed. Then several difference length of reference pipe will be required to carry out the measurements. In order to eliminate the various length of reference pipe, the TRL calibration is applied in the longitudinal impedance measurement platform.

In order to measure the longitudinal impedance of the components of the BEPCII, a longitudinal impedance measurement platform is developed under the collaboration between Tsinghua University and IHEP. The TRL calibration method is applied in the platform.

TRL CALIBRATION

When using a vector network analyzer to measure the S parameter of a RF component, calibration technique is widely applied[4,5]. Figure 3 is a standard error model of measurement. The isolation error (SI_{ij}) is small enough to be omitted in most measurement. The Sl_{ij} and SR_{ij} stand for the error scatter matrix of all components to the left and right of the DUT. A calibration technique performs several measurements on precision standard calibration kits and then calculates the components in the error

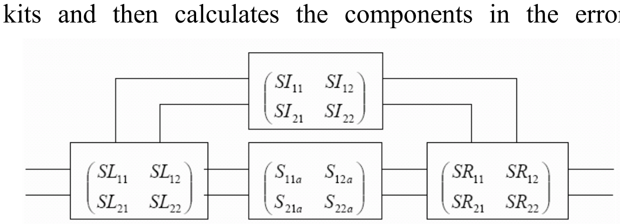

Figure 3: Standard error model for S parameter measurement.

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model. TRL calibration is one of the standard calibration techniques. It performs four standard measurements to calculate the error matrix. The standard measurements are through, reflection of both end and delay line. The matrix TL and TR related to SL and SR and are unknown. After perform the four standard measurements, ten equations can be achieved as shown in the equation above. Then all the ten unknown parameters in the equations, including the components of TR and TL and reflection factor of the reflection calibration kit and the length of the delay line, can be solved. That means the TRL calibration doesn't require the reflection kit to be a perfect reflection and the length of the delay to be known precisely. But because the calculation of the electric length of the delay is a complex data, only when the phase away from 0 or 180 degree, an acceptable result can be achieved. And for the same reason, the reflection calibration kit should have a high reflect but no need to be exact –1, because the method doesn't assume that.

LONGITUDINAL IMPEDANCE MEASUREMENT WITH TRL CALIBRATION

By applying the TRL calibration into the longitudinal impedance measurement, the impedance measurement platform can precede the measurement of through, reflection and delay line and then calculate the error matrix of platform. Then the platform measure the S

$$\begin{pmatrix} TL_{11} & TL_{12} \\ TL_{21} & TL_{22} \end{pmatrix} \cdot \begin{pmatrix} T_{11a} & T_{12a} \\ T_{21a} & T_{22a} \end{pmatrix} \cdot \begin{pmatrix} TR_{11} & TR_{12} \\ TR_{21} & TR_{22} \end{pmatrix} == \begin{pmatrix} T_{11m} & T_{12m} \\ T_{21m} & T_{22m} \end{pmatrix}$$

$$\frac{TL_{21} + TL_{22}\,k1}{TL_{11} + TL_{12}\,k1} == S^{msl}{}_{11} \qquad \frac{k1\,TR_{22} - TR_{12}}{TR_{11} - k1\,TR_{21}} == S^{msr}{}_{11}$$

$$\begin{pmatrix} TL_{11} & TL_{12} \\ TL_{21} & TL_{22} \end{pmatrix} \cdot \begin{pmatrix} TR_{11} & TR_{12} \\ TR_{21} & TR_{22} \end{pmatrix} == \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}$$

$$\begin{pmatrix} TL_{11} & TL_{12} \\ TL_{21} & TL_{22} \end{pmatrix} \cdot \begin{pmatrix} k2 & 0 \\ 0 & 1/k2 \end{pmatrix} \cdot \begin{pmatrix} TR_{11} & TR_{12} \\ TR_{21} & TR_{22} \end{pmatrix} == \begin{pmatrix} TD_{11} & TD_{12} \\ TD_{21} & TD_{22} \end{pmatrix}$$

matrix of the DUT and calculate the S matrix of a given length delay line. It is possible to takes the place of the measurement of the REF by such a calculation because the S matrix of the uniform reference pipe is theoretically resolvable. The sketch of the longitudinal impedance designed for the BEPCII is shown in figure 4. [6,7]

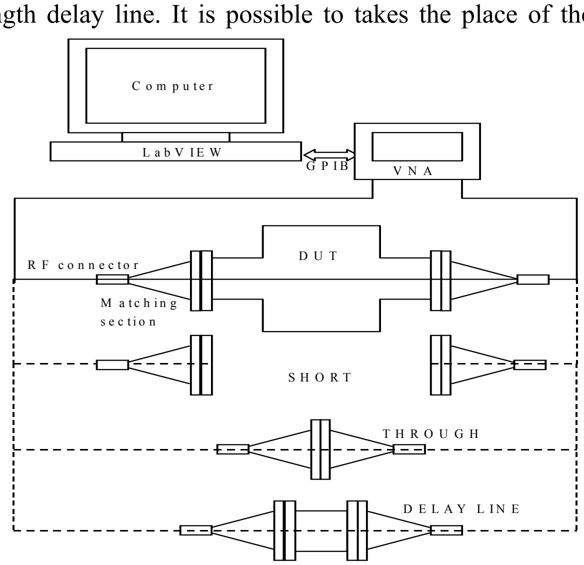

Figure 4: TRL based longitudinal impedance measurement.

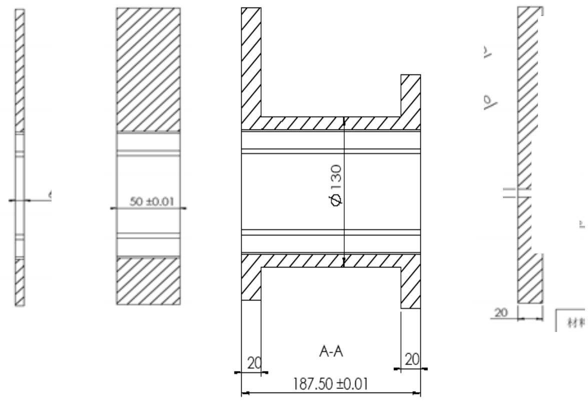

Figure 5 Some calibration kits designed for BEPCII longitudinal impedance measurement platform.

Calibration Kit

In order to apply the TRL calibration method into the longitudinal impedance measurement platform, several calibration kits are designed as shown in figure 5. Because of the advantage of the TRL calibration, the precision control can be loosening a bit. The whole set of calibration kits include a reflection plate and 3 delay line of difference length (short/medium/long). The difference length delay line can be used for difference frequency range.

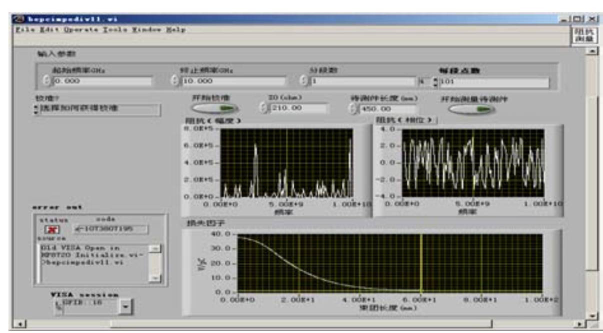

Figure 6: User interface written by LabVIEW.

Software

The procedure of TRL calibration can be controlled by an application written in Labview. And the user interface is shown in figure 6. The measurement frequency range can be set and the impedance and loss factor of the components can be shown. The raw data of the S parameters of each measurements can also be saved in a separate sheet.

RESULT

In order to check the availability of the TRL calibration based coaxial impedance measurement platform, a

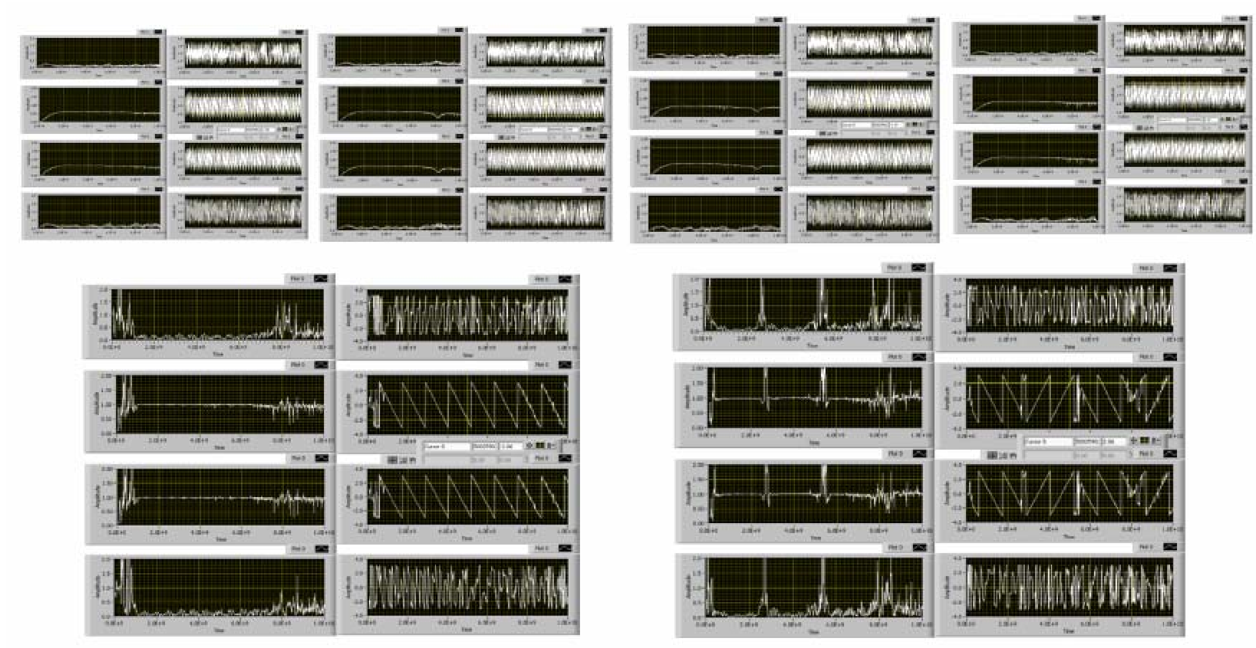

Figure 7: Calibration of measurement of different length.

measurement of the calibrated delay line is performed. Which using a short delay line to perform the calibration and using the data to calibrate the measurement of a longer line.

As shown in figure 7, the upper are the S parameter of through and short/medium/long delay line. Obviously, the reflection mass everything up. The lower left one is the calibrated long delay line, and using the short delay line as delay line does the calibration. The lower right is using the medium delay line as delay line to calibrate the long delay line. The calibrated S parameters are nice in relative frequency. A short delay line can be used for relative wide frequency range but the lower frequency range is not good enough. While a longer delay line can be used for lower frequency. The frequency range of availability of the delay line is related to the length of it. In order to make the measurement be available in a wider range of frequency, a multiple line calibration can be performed.

CONCLUSION

Coaxial line impedance measurement is important to evaluate the impedance of vacuum components during the design stage of a storage ring. TRL calibration can be applied in the longitudinal coupling impedance platform. By applying the TRL calibration, the requirement of reference pipe can be eliminated.

The longitudinal coupling impedance measurement platform is designed fabricated by Tsinghua University under a collaboration with IHEP and is delivered to IHEP last MAY.

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