# Measurement Of Longitudinal Impedance For a KAON Test Pipe Model with TSD-Calibration Method

Y.Yin, C.Oram,TRIUMF, Canada
N.Ilinsky, P.Reinhardt-Nikulin,INR,USSR

*Abstract*

We report measurements of longitudinal impedances for a KAON factory beam pipe model by means of the TSD-calibration method. The experimental method and the results are discussed. The frequency band is from 48 MHz up to 900 MHz, within which range the method produces measured impedances accurate enough to be useful in indicating whether a test pipe will have a suitably low impedance.

## I. Introduction

The coupling impedance of the beam pipe is an important parameter for the accelerator design. Theoretical calculation is not feasible in many cases. So a measurement is necessary. In the KAON Factory Booster and Driver rings the bunch length is about one to two metres, which is much longer than the cut-off wavelength of about 30cm for the KAON Factory pipe. This makes the high-frequency (above the cut-off frequency, 1 GHz) impedance negligible [3]. We use the co-axial wire method [1] [2] for the impedance measurements for a KAON Factory beam pipe model in the low frequency range (below cut-off).

A segment of co-axial pipe can be characterised by S-parameters, the coefficients of the scattering matrix. The error matrices related to all unmatched reflections can be eliminated by mathematically de-embedding the test pipe from the test line. The TSD method is a way of calibrating using Thru pipe, Delay pipe and Short plate, instead of using match, open and short. In this method, the required S-parameters of the beam pipe segment are extracted mathematically, after measuring $S_{12}$, $S_{21}$, $S_{11}$ and $S_{22}$ for the T:Thru pipe, S:Short plates, D:delay pipe and a reference pipe [4].

By de-embedding, TSD can solve the difficulty of the measurement which lies in extracting the transmission and phase changes in an experimental set up where there are transition pieces between the co-axial cable coming from the network analyzer and the beam pipe. These transition pieces cannot be perfectly matched, so there are always reflections present in the measurement.

## II. Measurements on Kaon Test Pipe

Test pipe No.1 is 104 mm wide, 78 mm high and 700 mm long, and made from G-10 board. It is to simulate a section of ceramic chamber in the Booster and Driver rings. The pipe has strips 4mm wide with 1 mm gap between each other pasted on the inner surface of the pipe. The 4 strips in the middle of each plane are cut into 2 sections, forming a 5 mm wide slot with a 5 ohm resistor bridging across the slot externally to make a wall current beam position monitor (BPM) [6]. Test pipe No.2 has the same structure and cross section but is only 25 cm long.

The impedance due to the strips and the slots of the BPM has been measured by the TSD method and by independent measurements using the time domain method [6] [7]. The results from the time domain method are presented for comparison with the TSD method.

### A. *Measurement with 50 Ohm line impedance*

For calibration the TSD method requires, a "through" pipe with length of 370 mm and a "delay" pipe with length of 700 mm, and a "short plate"; all have been used over the frequency range from 48 MHz to 200 MHz [2]. These pipes are made of solid copper with the same cross section as the test pipe, and have a one inch copper pipe passing through them to form a 50 ohm coaxial structure. At both ends there are two cone adapters as transition parts, in order to connect to the 50 ohm coaxial cables. The centre pipe also has two adapters at both ends which are tapered to maintain a 50 ohm impedance. The centre pipe has different lengths, in order to match the length of the"through", "delay" and "short". Every effort has been made to improve the RF contact and the precision of the structure to improve repeatability.

To distinguish the impedance changes caused by the strips, the slots, and the resistors bridging the slot, measurements were done for several different cases. To demonstrate the validity of the calibration, the measurement was also applied to a solid copper reference pipe (with same geometric size as the test pipe) of known impedance. The measurements have been repeated several times for all cases, and the results display good repeatability.

Fig.1 shows that in the resistance spectrum from 48 MHz to 198 MHz of test pipe No.1 there is a resonance at about 170 MHz. The amplitude and the frequency of the peak changed as the slots were patched with copper (case B) or shorted (D) or bridged with 5 ohm resistors (C). The curve "A" is the resistance of the reference pipe. Fig.2 shows the reactance spectrum for the above cases.

### B. *Measurement with line impedance of 180 Ohm*

Both the TSD method and the Time Domain method have been used also for a line impedance of 180 Ohm, as a comparison to the 50 Ohm measurement discussed above. The delay pipe is 10 cm long and the through pipe is 1 cm long, for the frequency range of 180 MHz to 900 MHz.

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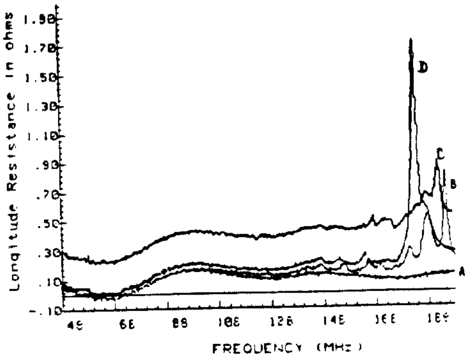


Figure 1: Resistance of Test Pipe No.1 (at 50 ohm)

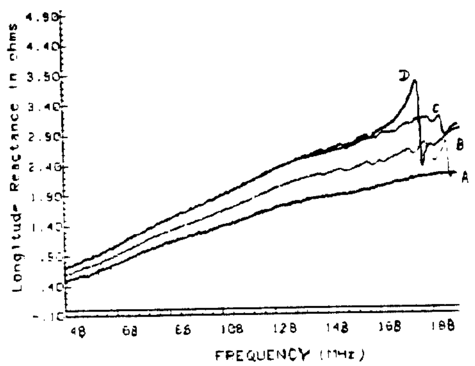


Figure 2: Reactance of Test Pipe No.1 (at 50 ohm)

The centre pipe has diameter of 1/8 inch. The end plates of pipes are 10mm thick and were machined to ensure flatness. The interfacing end of the two adaptors has a 2 mm wide lip to make a good RF contact with the pipes to be attached to it. A special mechanical design was used to keep the centre pipe in tension, to maintain straightness over the 700 mm length of the test pipe. The terminal end of the adaptor has been carefully designed to keep good assembly repeatability. Fig.3 shows results for test pipe No.1: the resistance of the reference pipe(A), the resistance when slots were shorted from externally(B, T1) and when the slots were bridged with 5 ohm resistors(C,T2). T1 and T2 are results from time domain method. Fig. 4 shows the resistance of the pipe with 5 ohm resistors bridging the slots.

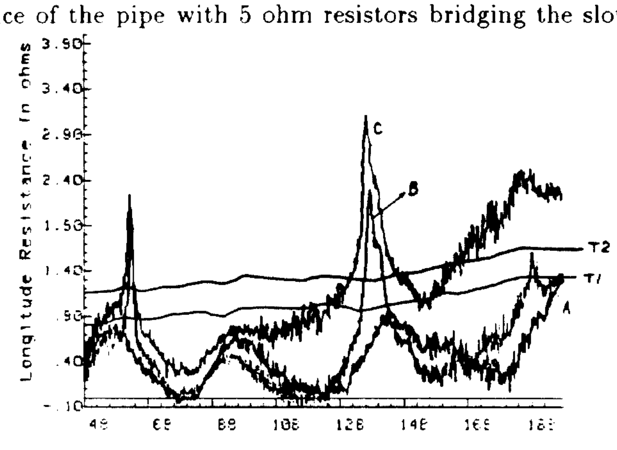


Figure 3: Resistance of test pipe No.1, 48-198 MHz(180 ohm)

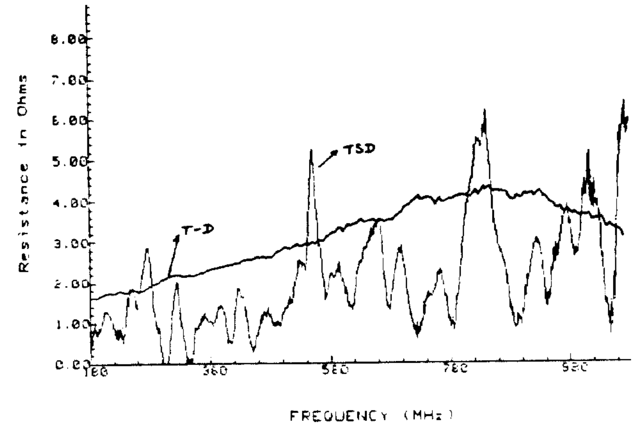


Figure 4: Resistance of pipe No.1, TSD and Time Domain(180 ohm)

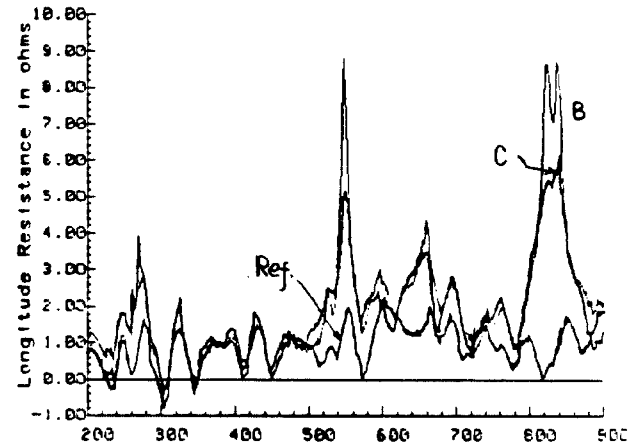


Figure 5: Resistance of test pipe No.1, 200-900 MHz(180 ohm)

The big peaks are due to the slots and the strips. The Time Domain curves T1, T2 are smooth and flat, showing only the trending of the changing impedance. This can also be seen in Fig.4, for the range 180 MHz to 1 GHz. Fig. 5 shows the resistances of test pipe No.1 with 5 ohm resistors(C), and with the slots shorted(B), and the reference pipe.

## III. The Analysis of the Measurement

The longitudinal coupling impedance is a description of the coupling between the beam and vacuum chamber. The theory is that the energy lost by a short current pulse on a central wire is the same as that lost by a bunch of particles having equal time shape. But the presence of the wire obviously modifies the time evolution of the fields after the pulse [8]. So usually a thin wire is preferred for the impedance measurement.

The test pipe we measured has discontinuities: the break in the strips, which will interrupt the wall current. The reflected wall current will superpose with the input signal. When both signals are in phase periodic peaks will appear in the results. The frequencies of the peaks are related to the length from the break to the end of the test line. For the 50 ohm line impedance measurement, the cone adapters are 10 cm long, the total test line is 90 cm, and so the lowest resonant frequency is 170 MHz. The same phenomenon applies to the 180 ohm measurement. The 60 MHz reso-

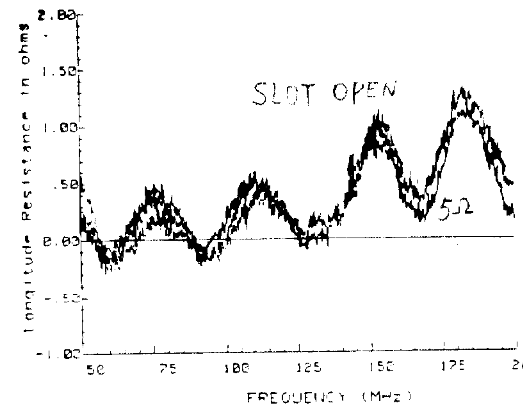


Figure 6: Rsistance, test pipe No.2 (180 ohm)

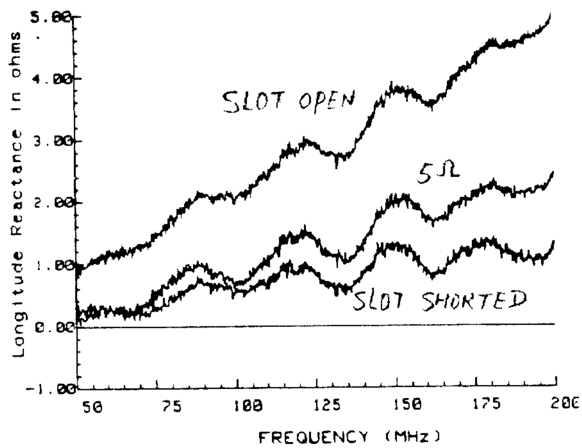


Figure 7: Reactance, test pipe No.2 (180 ohm)

nance is due to the field leakage from the gap between the 2 sides of the G-10 pipe. However, these resonances do not exist in the real machine since the vacuum pipe is a ring. Thus the peaks do not represent the impedance of the pipe in the working condition. But the other parts of the curve do show the real impedance. In order to measure the impedance close to the real situation, the resonances should be eliminated or avoided, because they can not be cancelled by de-embedding. If we ignore the resonances, the impedances of the various cases should have little difference over the frequency range of the measurement. This is more clear in the 180 ohm line impedance measurement, because the big centre pipe of the 50 ohm line impedance changes the field pattern.

Test pipe No.2 is only 25 cm long, this moves the resonances to a frequency of 230 MHz; so in the low frequency range, there are no resonances. The measurement shows in Fig.6,7 that the impedance is as small as from 0.5 to 1 ohm, close to the reference pipe. This is consistent with theory.

## IV. Conclusion

The stretched wire method is a useful way to measure the longitudinal impedance; but, since a thin wire is needed to improve the accuracy of the measurement, the high reflections will cause the resonances to be related to the length of the test line set up if there is a discontinuity.

The TSD method requires very careful mechanical design and implementation to ensure good RF signal contact and repeatability of mechanical assembly. Also several measurements with different mechanical setups are necessary, unlike the time domain method. However the TSD method can show narrow resonances, and other detailed structure in the impedance curve (although one has to be careful to analyse it ), providing additional information to the time domain method.

Time domain measurements of the same structure do not display the peaks, because the network analyzer simulates the time domain response to an impulse input and mathematically transforms the frequency domain data into the impulse response. [9] The first pulse is kept. The reflection signals which contain the resonance information are therefore gated out. To reduce the sidelobes and improve the dynamic range of a time domain measurement, the windowing filters the frequency domain data prior to converting it to the time domain. This also smeare out the resonance.

The G-10 board model is different from a real ceramic one with no capacitors at the end, a smaller slot will be used to pick up the beam position signal because of the high beam intensity. Hence the impedance will be different in the real situation. However, the measurement shows that Z/n for the whole ring is still small. For instance, at 150 MHz, for the Booster, it is less than 1 ohm.

## V. Acknowledgments

The authors give their thanks to Linda Walling, for use of her TSD measurement program and to Walling and Dr. B. Zotter for the many helpful discussions leading to an understanding of the results and of the method.

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