PS/HI/Note 96-15
December 1996

Impedance Measurements on Booster Pump Manifolds

F. Caspers, H. Schönauer, L. Soby

1. Aim:

Since a number of years a longitudinal instability occuring solely in Ring 4 is observed in the PS Booster. Around 700 MeV appears a fast-growing tail of the bunches above a threshold of ~6.5 10^{12} protons in the ring, causing sometimes loss of a few percent of the beam. The only coherent signals observed on a wideband wall current monitor are short bursts visible on all revolution harmonics above 800 MHz up to 1.5 Ghz. Following a suggestion of M. Chanel, impedance measurements on vacuum pump manifolds were performed in order to determinate whether these cavitiy-like objects could be the culprit, and whether there is a peculiarity on the level of Ring 4. The measurements were subsequently complemented by finite-element wake field computations by M. D'yachkov (TRIUMF), yielding the resonant frequencies.

The effect of damping resonances by inserting ceramic resistors through gauge ports into the cavity has also been investigated.

2. Measurement - Method:

The basic method used was the standard method of measuring the parameter of a wire crossing the test object at the location of the beam with some precautions to assure a good matching at the ports. The impedance of the test object can be calculated from the S_{21} parameters measured [1].

Fig. 1 shows a drawing of a standard pump manifold. A common feature of all manifolds is that the beam is shielded above and below from the cavity by strip-like short-circuits. Ring 4, however, is shielded only from below, probably because it was felt that the proximity of the top wall of the manifold made a proper short-circuit superfluous. For the measurements, 500 mm long standard beam pipes were clamped to the manifold at the ring level under test, and closed with a special flange allowing to solder terminating resistors of 270 ohms to the wire under tension. The resistors were chosen to match the characteristic impedance of ~330 ohms of the wire in the vacuum chamber to 50 ohms. In some cases the closed ends of the vacuum pipes were filled with rubber foam to damp the propagating modes above cutoff.

Another measurement series consists in measuring the S_{21} parameters with only short coupling wires at the ports instead of the wire crossing. From these measurements on expect to find the true resonance frequency and Q values in absence of the perturbing wire.

The S_{21} parameters were measured with a HP 8753C network analyser. Data were dumped via GPIB and Labview software to a Toshiba Laptop.

3. Results:

Three spare manifolds were made available by C. Burnside/LHC/VAC and his team. Nr. 1 and 2 were slightly different from standard, featuring additional lateral ports (closed here) for insertion of pick-up electrodes.

Figs. 2 and 3 show plots of the S_{21} parameters as measured for Ring 3 and Ring 4 levels of Manifold Nr. 3, a standard spare, and the impedances computed from them. Note the marked difference in equivalent shunt impedance between the two levels.

Fig. 4 shows the effect of a ceramic damping resistor inserted into the Ring 4 cavity through one of the gauge ports on top of the manifold on the impedance and the width of the resonance.

Table 1 compiles the impedances and Q values (determined by measuring or interpolating the 3 dB bandwidths of the resonance peaks).

Table 1: Measured Impedances of PSB Pump Manifolds

Mani fold	**Ring**	**Conditions**	**Wire Measurement**					**Probe Measurement** *always without* foam nor damping resistor					100mm couplers	
			fresw MHz	del fw MHz	Qw	Rsw kOhm	Rsw/Qw Ohm	fresp MHz	del fp MHz	Qp	fres2p	del f2p	Rs kOhm	
1	4		1100	0.44	2499	62	24.8	1191	0.601	*1981*	1195	0.385	49.2	*N.B. Qp<Qw!*
	3		1211	0.804	1506	18	12.0	1191	0.474	2512	1195	0.368	30.0	
	2		1225	1.02	1201	9.5	7.9	1195	0.543	2201			17.4	
	1		1220	0.596	2047	19.5	9.5	1196	0.386	3098			29.5	
	1							1137	1.097	*1037*			9.9	*2mm couplers, no chambers*
	4	Foam	1097	0.57	1925	46	23.9	1191	0.601	*1981*	1195	0.385	47.3	*N.B. Qp<Qw!*
	4	Foam+1 long damping res.	1097	18.2	60	1.7	28.2							
	4	Foam+2 res.	1097	56.7	19	0.92	47.5							
	1	Foam	1225	5.25	233	2.55	10.9	1196	0.386	3098			33.9	
2	4	Foam	1090	4	273	7.2	26.4	1091	1.05	1039			27.5	
3	4	Foam	1097	0.69	1590	36	22.6	1196	0.385	3107			70.3	
	3	Foam	1239	1.1	1126	13.6	12.1	1189	0.4	2974			35.9	
	2	Foam	1237	1.8	687	7.7	11.2	1190	0.46	2587			29.0	
	1	Foam	1233	1.6	771	7.8	10.1	1192	0.45	2648			26.8	
	4	Foam+long damp. resist.	1083	18.5	59	1.4	23.9	1196	0.385	3107			74.3	Probe meas'mt. *without* damp.resistor

Measurements with foam damping of propagating modes are more easily to interpret because the 'baseline' is easy to identify. For the probe measurement of the same structures the foam was removed. However it turned out that the probe coupling was probably too strong (~100 mm long wires) and thus these measurements are not very reliable. This may explain the fact that the Q-factors measured for the probe are below the wire-loaded Q-value in some cases.

One notices the outstanding differences between Ring 4 level and the other three:

1. Wire mesurements show resonance frequencies of 1225 - 1230 Mhz for the Ring 1-3 cavities and of 1100 Mhz for Ring 4.
2. Equivalent shunt impedances are of the order of 40 kohms for Ring 4 and of 8-18 kohms for the other rings. Q-values scatter considerably between 700 and 2000, but
3. Rs/Q values are more consistently distributed around 24 ohms for Ring 4 and around 11 ohms for the Rings 1 - 3.

Probe measurements show resonances around 1190 Mhz regardless of the ring. If the probe measurements give the correct resonance frequencies this would imply that the wire shifts the resonance downwards by ~100 Mhz in Ring 4 and by about 30-50 Mhz upwards in the other rings.

It appears from Table 1 that in certain cases (notably Ring 4) the attribution of resonance frequencies between probe and wire measurements might be questionable. Note that normally the presence of the wire should increase the resonance frequency of the mode under consideration. In some cases (e.g. Manifold 3 ring 4) the wire measurement was done with a damping resistor while the probe measurement were always made without damping resistor which can partially explain this unusual behavior. In another case (Manifold 1, Ring 4) the Q value of the wire measurement was higher than that of the probe which is most likely due to too strong coupling of the probe which should be checked again via an S11 measurement on the probes (too strong coupling of the probes also leads to detuning).

The only exception of Manifold 1, Ring 1 with a resonance at 1137 Mhz corresponds in fact to a different probe geometry: Very short wires of ~2mm length were used directly at the beam ports *without* the 500 mm long beam pipes clamped to the beam ports in *all other* measurement configurations.

The Table also includes the impedances of Ring 4 cavities damped by insertion of a ceramic tube coated with a resistive layer. Indeed the shunt impedance is knocked down by a factor of >25. The R/Q values, being essentially a geometry factor, remains practically unchanged.

4. Numerical computations

The coupling impedances of resonant structures can be approximately calculated from the numerical computation of the wakefield of a short bunch (e.g. 5 cm long) with a finite element method. This has been done by M. D'yachkov (TRIUMF) [2]. These longitudinal impedances are shown on Figs. 5 and 6 for

(a) Ring 1-3 cavities with two short-circuit strips,
(b) Ring 4 cavity with only short-circuit strip.

Their main features are:

1. The cut-off frequencies (and the resonance frequencies) for the structures are slightly different (frequency of the Ring 4 cavity = 1.0 GHz, and of the Ring 1-3 cavity = 1.15 GHz)

2. Impedance at the resonance frequencies are significantly different (Z_Ring 4/Z_Ring1-3 = approx 2.5), it looks that R/Q (which should be proportional to the integral of $\int R(\omega)d\omega$ of the Ring 4 cavity approx 2.5 times higher than the R/Q for the Ring 1-3 cavity.

3. There is also a big difference in transverse impedances of the structures (not shown here).

5. Conclusions:

Both wire measurements of longitudinal coupling impedance and wakefield calculations agree that the pump manifolds act as individual high-Q resonators for each ring, where

1. Ring 4 stands out by a factor ~2.5 w.r.t. the other rings both in R_s (~50 kohm) and R_s/Q (~25). Q values vary over the measurements but can reach values up to 2000.
2. Resonance frequencies (measured: 1.097 GHz and calculated: 1 GHz) for the Ring 4 cavities are also lower by about 130 Mhz w.r.t. the other levels. There is a difference of 100 Mhz between calculations and wire measurements.

Recently, the instantaneous bunch spectrum above 900 MHz of the instability was measured with a 5 Gsample/s scope with FFT processor and found to be centered around 1 Ghz.

These results suggest that the pump manifolds might indeed be the driving impedance of the 'Ring 4 Instability', explaining why this ring distinguishes itself amongst the otherwise nearly identical brothers. This is in apparent contradiction with the fact, that adding 10 manifolds in 1993 has not changed neither the threshold of the instability nor the ensuing blow-up.

Straightforward application of the Keil-Schnell-Boussard criterion for stability yields for the observed threshold intensity an impedance of the order of 30 kohms. This would fit the measurements if there were only one manifold in the ring or if the resonances of the present 42 manifolds don't overlap.

Measurements are neither precise nor complete enough to decide this. But the insensitivity of the threshold to the number of manifolds may be explained by assuming non-overlapping resonances.

An efficient measure to reduce the coupling impedance of the manifolds would be the insertion of flexible, perforated sleeves into all beam ports. Since the manifolds with their pumps have to be taken out, this would entail a major and labourious vacuum operation. In the meanwhile insertion of damping resistors, which can be done in situ, should lower the impedance below threshold and could be tackled during the next shut-down.

6. Acknowledgement:

The numerical calculations decribed in Sec. 4 have been performed by M. D'yachkov (TRIUMF).

7. References:

1. F. Caspers in "RF Engineering for Particle Accelerators", CERN Accelerator School Proceedings CERN 92-03, p.128.
2. More complete results can be consulted on the Web: http://decu10.triumf.ca:8080/psb/

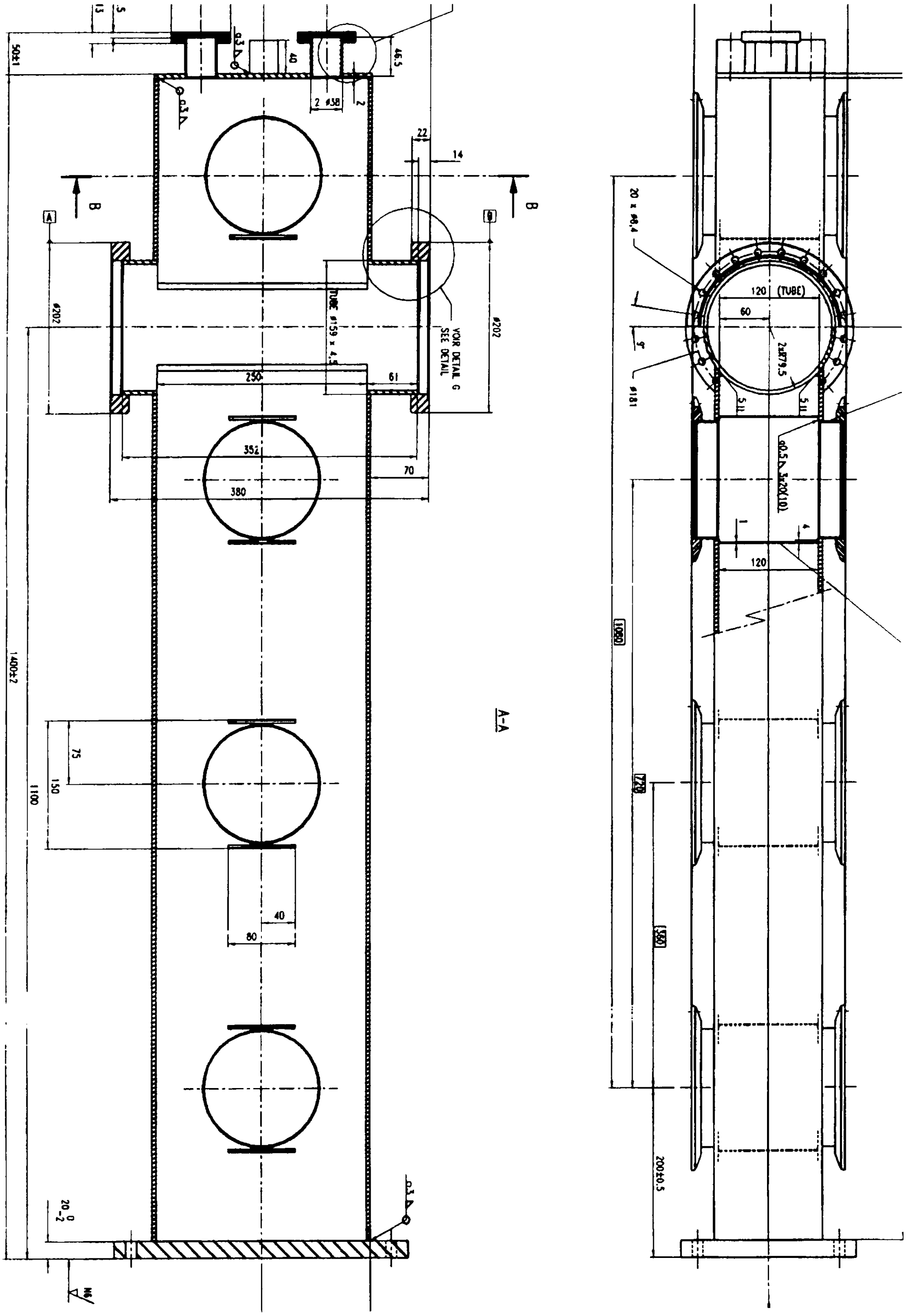

Fig. 1: PSB Vacuum Manifold. Note that level 4 has only on short-circuit strip.

Wire Impedance Measurements on PSB Pump Manifolds

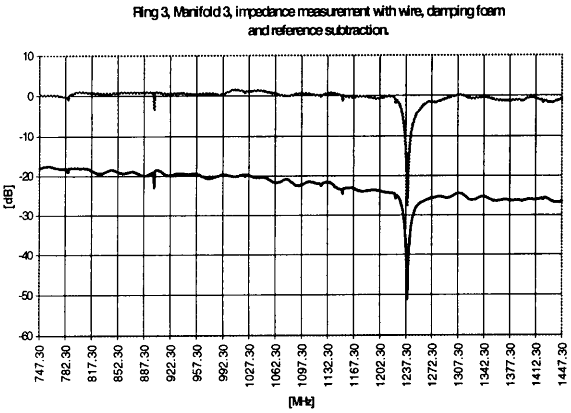

Fig.2a: Manifold Nr. 3, Ring 3, S21 Response

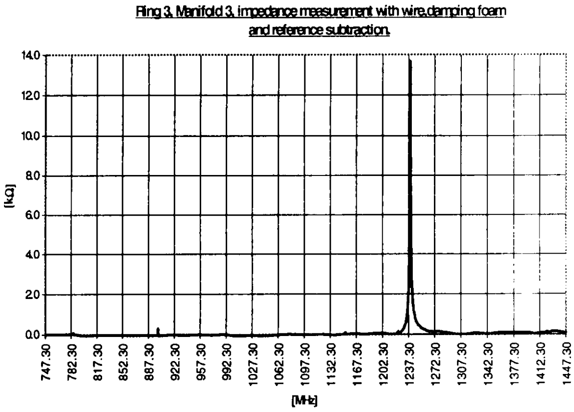

Fig.2a: Manifold Nr. 3, Ring 3, Impedance (real part)

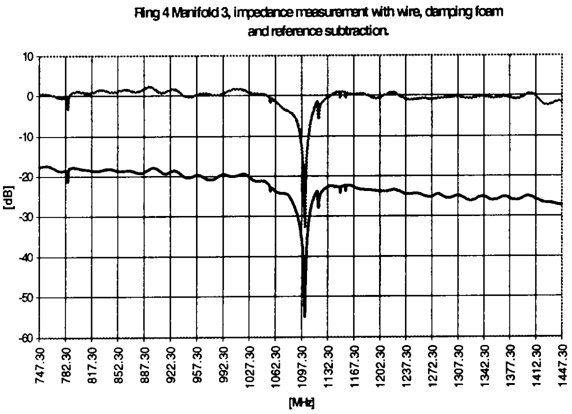

Fig.3a: Manifold Nr. 3, Ring 4, S21 Response

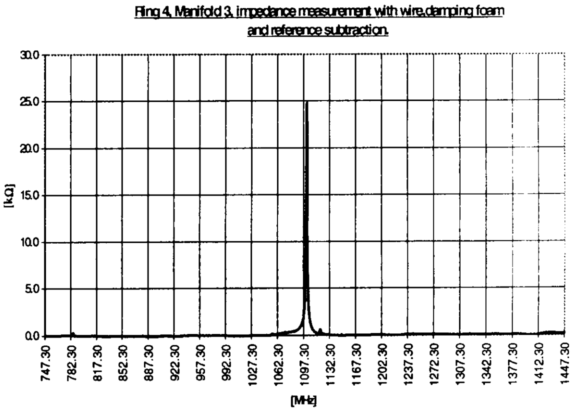

Fig.3a: Manifold Nr. 3, Ring 4, Impedance (real part)

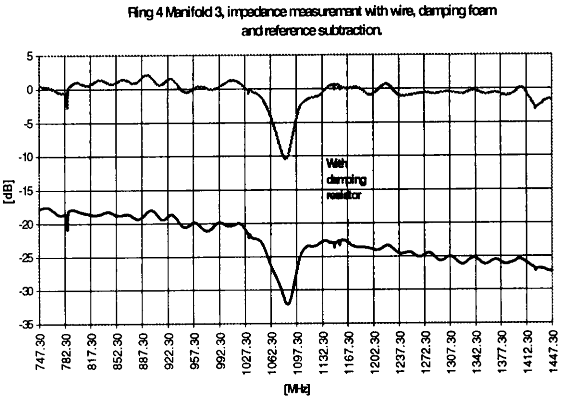

Fig.4a: Manifold Nr. 3, Ring 4 damped, S21 Response

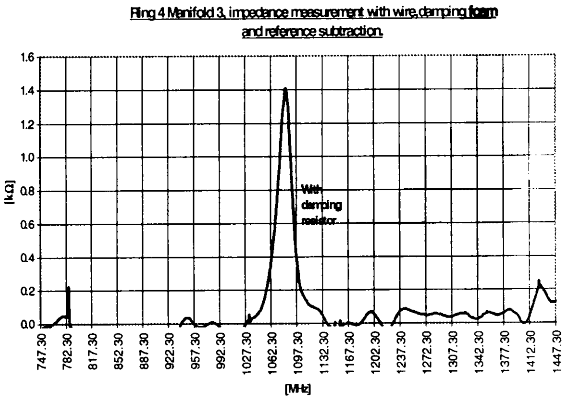

Fig.4a: Manifold Nr. 3, Ring 4 damped, Impedance (real part)

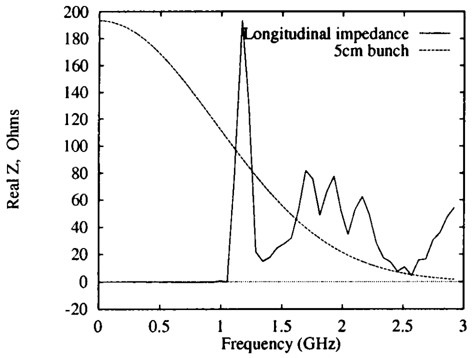

Figure 5: Real part of longitudinal impedance

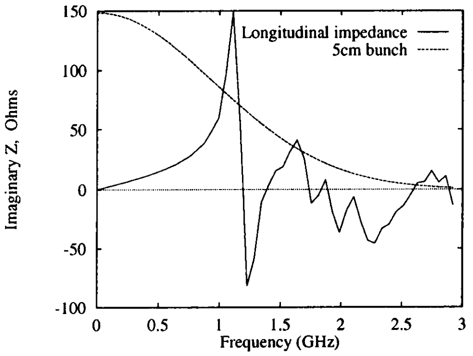

Figure 6: Imaginary part of longitudinal impedance

Fig. 5: Computed Impedance of Ring 1 - 3 Geometry

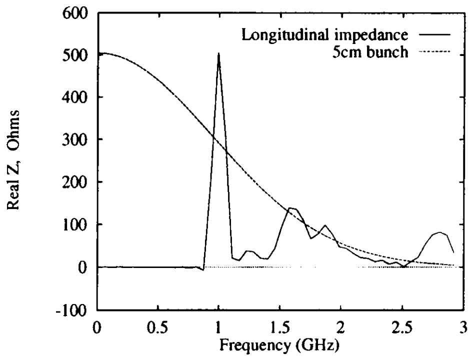

Figure 5: Real part of longitudinal impedance

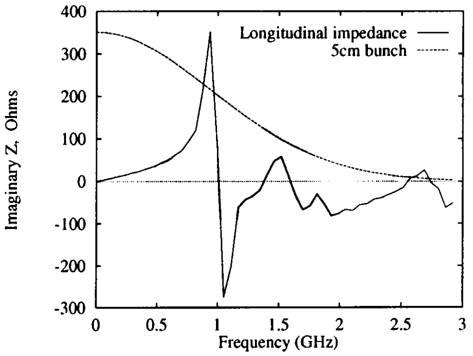

Figure 6: Imaginary part of longitudinal impedance

Fig. 6: Computed Impedance of Ring 4 Geometry