CERN-SPS WIRE SCANNER IMPEDANCE AND WIRE HEATING STUDIES

E. Piselli, O. E. Berrig, F. Caspers, B. Dehning, J. Emery, M. Hamani, J. Kuczerowski, B. Salvant, R. Sautier, R. Veness, C. Vuitton, C. Zannini,
CERN, Geneva, Switzerland

Abstract

This article describes a study performed on one of the CERN-SPS vertical rotational wire scanners in order to investigate the breakage of the wire, which occurred on several occasions during operation in 2012. The thermionic emission current of the wire was measured to evaluate temperature changes, and was observed to rise significantly as the wire approached the ultimate LHC beam in the SPS, indicating the possibility of strong coupling between the beam's electromagnetic field and the wire. Different laboratory measurements, complemented by CST Microwave Studio simulations, have therefore been performed to try and understand the RF modes responsible for this heating. These results are presented here, along with the subsequent modifications adopted on all of the operational SPS wire scanners.

INTRODUCTION

Beam Wire Scanners (BWS) are instruments used for precise transvere profile measurements in the LHC and its injector chain.

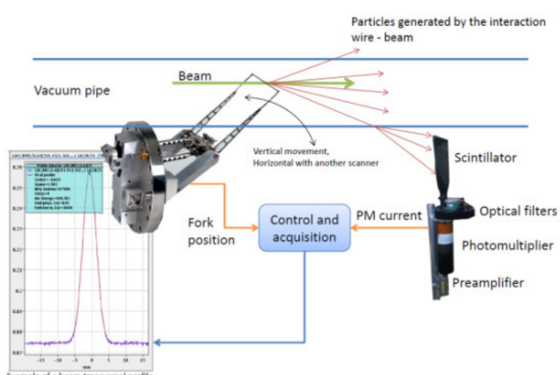

Figure 1: BWS working principle.

During the scan, a thin carbon wire is moved through the beam, with the interaction of beam and wire generating a cascade of secondary particles. For a high energy primary beam these secondary particles are energetic enough to exit the vacuum chamber and can be detected by a scintillator/photomultiplier assembly. With appropriate settings the amplitude of the light produced by the scintillator is proportional to the intercepted beam intensity (Fig. 1).

As the scitillator/photomultiplier signal is fast compared to the revolution frequency, synchronising the acquisition of the wire position and the measured light intensity allows the transverse beam profile to be reconstructed as the wire moves across the beam over multiple turns.

The CERN-SPS is equipped with 6 rotating BWS fitted with a carbon wire of 30µm diameter and which can scan at a maximum speed of 6 ms^{-1}.

SPS WIRE BREAKAGE MECHANISMS

The CERN-SPS rotational wire-scanners are used on a regular basis by machine operators to perform beam size measurements to verify and optimise the beam emittance.

During the run in 2012, there were many more abnormal wire breakages during the use of these scanners compared to previous years. Table 1 summarize these failures. Since the SPS machine was being pushed to provide high intensity beams for LHC, the first suspected cause of these events was due to these higher intensites, as had previously been observed in the high intensity run of 2002 [1]. During this 2002 run, there were observations of a large current induced in the wire, leading to wire breakage, when the scanning fork was in its parking position. This was finally explained by radio-frequency (RF) modes developing in the scanner tanks with the wire acting as an antenna. This was though to be solved by the addition of ferrites to the scanner tanks to damp these modes.

Table 1: BWS SPS Wire Failures During in 2012

Scanner	Beam induced failures	Mechanical failures
416.H	0	0
416.V	2	0
519.H	1	2
519.V	1	0

To try and understand the failures of 2012, the evolution of the wire current of one of the first breakage event observed was plotted as function of the time. Fig. 2 shows four consecutive wire-scans for vertical scanner 416, one before, one during and 2 after wire failure. The first two clearly indicate a current increase in the wire as the wire approaches and then crosses the beam (at 0.008 s as can be seen on the corresponding profile measurements). A current as high as 12 mA is observed when the wire has passed the beam and is close to its IN position. The wire breakage occurs during the second wire-scan (shown in blue). It can be seen that the evolution is similar to the previous wire-scan (in red), until 14 ms where the wire breaks.

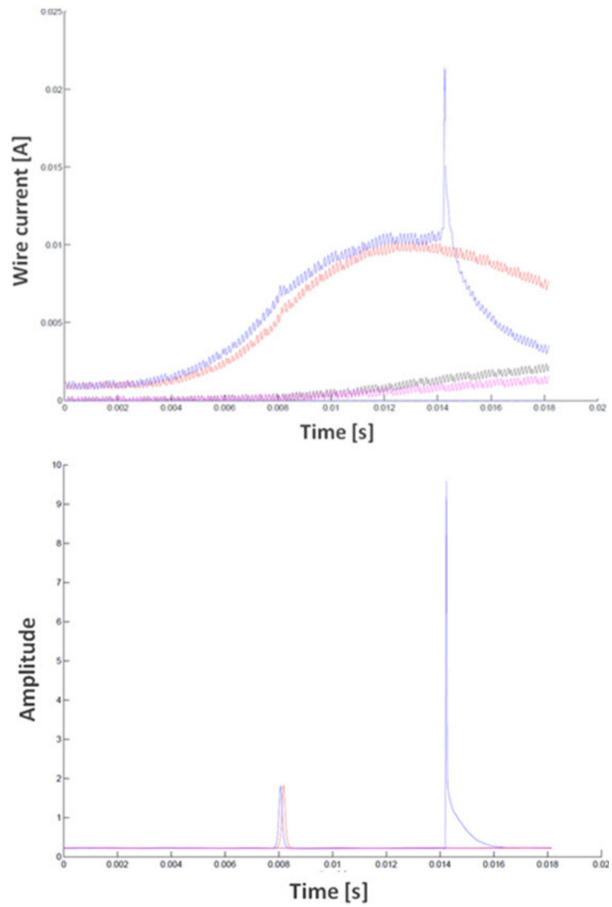

Figure 2: Scanner 416 vertical wire current versus time during four movements around the time of wire breakage (top) and corresponding profile measurement (bottom).

After these first observations, an off-line analysis based on the logged wire-scanner data and beam current transformer (BCT) data was performed for almost all the 2012 run. The goal was to determine the severity of this induced current for the four different scanners (two vertical and two horizontal) in use in the machine.

Fig. 3 shows the results for one of the scanners for all scans performed during the year. The beam intensity during the scan is plotted against the average wire current measured during the 18ms of the scan. The plot shows a correlation between the beam intensity and the induced wire current, with a threshold for the onset at around 2×10^{13} protons.

Table 2 summaries the analysis results for the four operational scanners. The scanner which did not have any wire breakage during the run (416H) is confirmed to not show signs of any beam induced current. All other scanners show induced currents higher than the injected current of 2 mA used for checking the wire integrity.

Observing the mechanical implementation of this scanner (416H), it is found that the main difference is an aperture limit due to inserted field plates. The scanner 416V is the only scanner which shows a clear correlation of the wire current with the beam current and experienced two wire breakages during the run. The other scanners also show a wire current increase without a clear beam intensity dependence. It is suspected that the different behaviour depends on the tank geometry, the subsequent RF modes this can generate and how the wire then samples these modes during a scan.

Table 2: Results of the Off-line Analysis of the Wire Current Versus Beam Current for the Four Scanners

Scanner	Beam aperture [mm]	Current increase	Correlation to Intensity	Peak current [mA]
416.H	461x220x340 plates 100	NO	NO	2
416.V	220x461x318	YES	YES	16
519.H	461x220x455	YES	PARTIAL	16
519.V	220x461x433	YES	PARTIAL	5

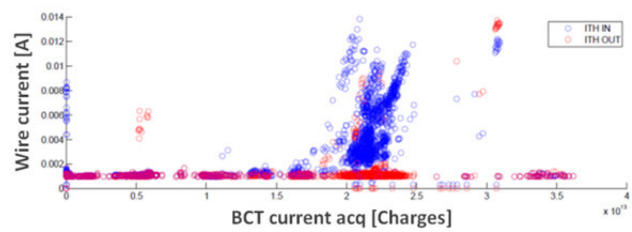

Figure 3: Scanner 416 vertical averaged wire current versus beam current for the whole of the 2012 SPS run.

SOLUTION PROPOSED

Following the results of the studies on 2012 data it is again believed that these wire breakages are related to RF coupling between the beam and the wirescanner, but this time due to RF modes sampled during the actual wire scans as opposed to those sampled in the wire parking position. Solutions to the problem have therefore concentrated on this phenomenon.

A charged particle beam circulating in the accelerator generates an electromagnetic field with a frequency spectrum which, in the case fo the SPS may extend up to several GHz. If the resonating modes of the wirescanner tank are within this beam spectrum, RF power can be transmitted from the beam to the wire.

The first modification adopted to try and reduce the power coupled to the wire was the installation of a tungsten wire of 0.5mm diameter placed across the fork at a distance of 40mm from the shaft (Fig. 4).

The idea behind this thicker, more robust tungsten wire was to try use this as an additional coupling antenna to “deviate and absorb” some of the higher RF modes generated in the tank cavity and dissipate the energy in the body of the fork/shaft structure. This would then reduce the RF coupling to the carbon measurement wire, leading to a lower induced current.

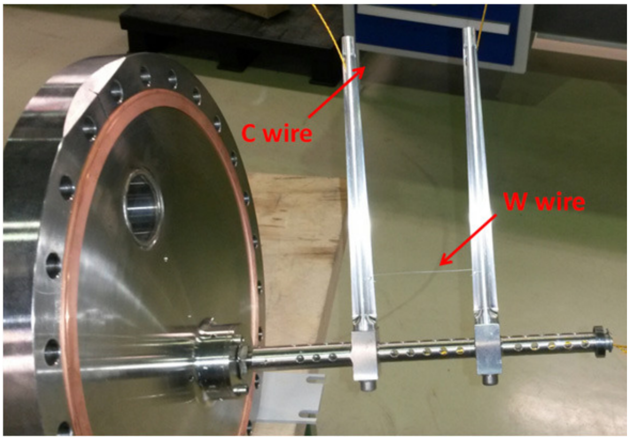

Figure 4: SPS BWS with additional tungsten wire.

The second modification adopted was intended to decrease the overall RF power building up in the vacuum tank. Two vertical, aluminium plates were installed to avoid discontinuities and reduce the volume of the tank seen by the beam. (Figs. 5,6).

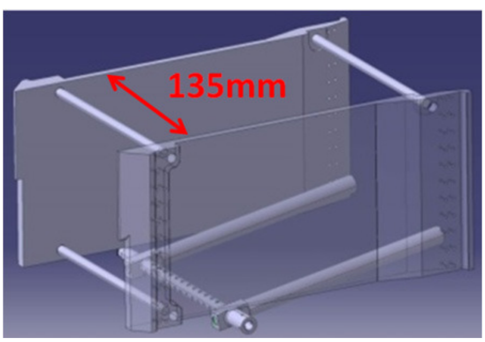

Figure 5: New vertical insertion plate drawing.

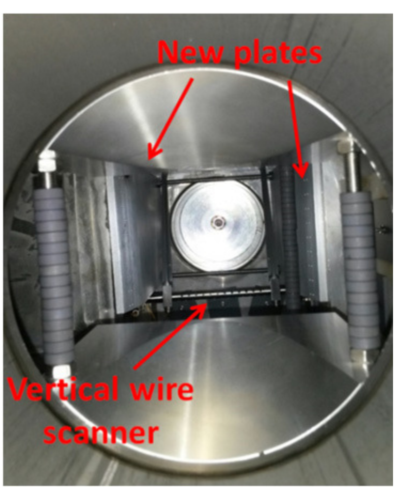

Figure 6: New vertical insertion plate.

LABORATORY MEASUREMENTS

Both the above modifications were applied to the SPS 416V scanner for tests in the laboratory. The scanner was also equipped with a probe antenna powered by a Vector Network Analyzer (VNA) in order to excite the high frequency modes in the beam spectrum (Fig. 7). The two ends of the carbon wire were connected to a Δ-Σ RF hybrid coupler [2], with the resulting sum (Σ) and difference (Δ) signals measured by the VNA. The difference signal being the eventual signal that would generate a current in the carbon measurement wire.

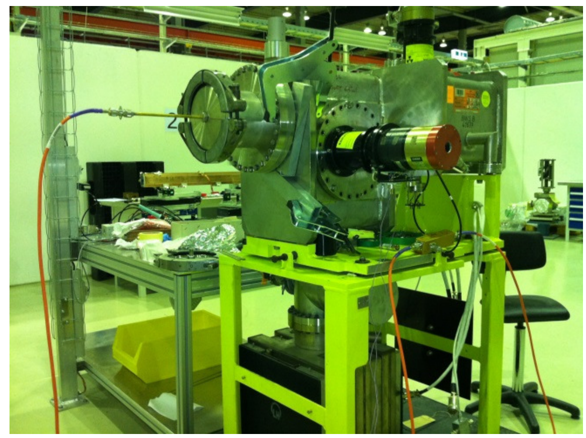
Figure 7: SPS BWS tank with the probe and the hybrid system.

Measurements were performed for three different configurations:

1) the original unmodified wirescanner
2) with a tungsten wire added to the fork
3) with a tungsten wire added and vertical plates incorporated

Measurements were taken in all configurations with the fork in both the IN and the OUT (parking) positions.

We assume that the delta signal gives a signal proportional to the induced current on the carbon wire. Figs. 8 and 9 show the measured delta signals in the IN and OUT position respectively, for the frequency range from 300 kHz to 2 GHz. Two regions of high coupling can be identified, one between 200 MHz and 400 MHz and the other between 600 MHz and 800 MHz.

Figs. 10 and 11 show the difference in the measured Δ signal between the original configuration, that with only the additional tungsten wire and the configuration with both tungsten wire and side plates, for the two different frequency ranges of interest.

This is plotted at various wire positions for two different probe positions, one with the 40 cm long probe inserted by 15 cm in the tank and the other with the probe inserted by 25 cm (conf1 and conf 2 respectively in Figs.10 and 11).

ISBN 978-3-95450-141-0

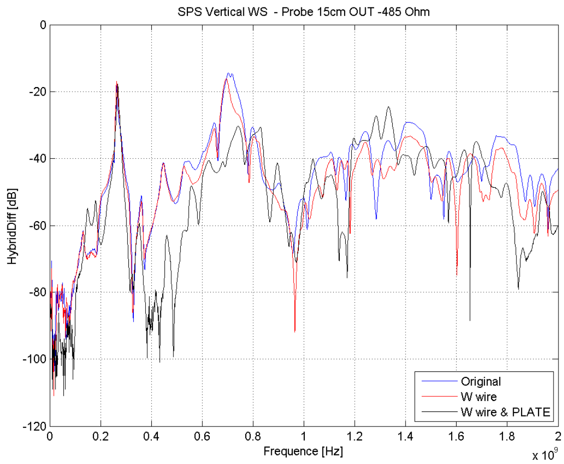

Figure 8: Δ signal on the fork for the IN position.

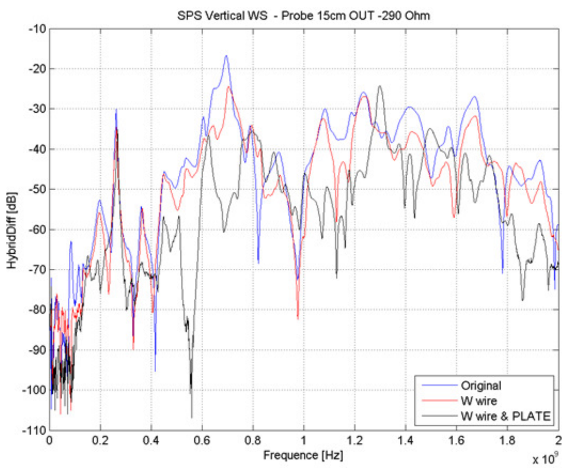

Figure 9: Δ signal on the fork for the OUT position.

The angular position of the fork where it would normally meet the beam is marked with a red line.

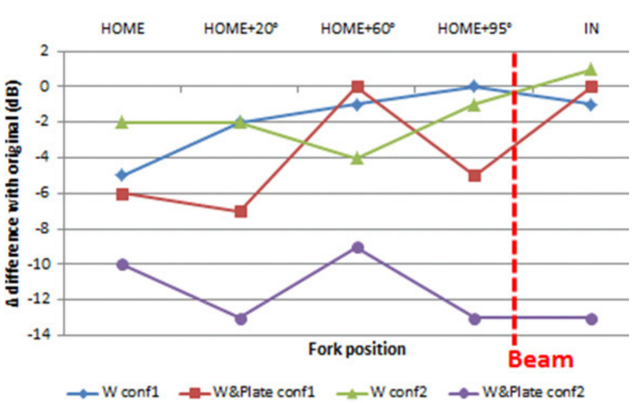

Figure 10: Δ signal difference in the range 200-400MHz.

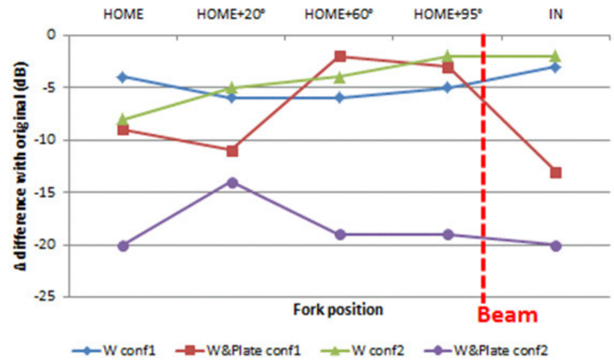

Figure 11: Δ signal difference in the range 600-800MHz.

It is clear that with both modifications in place there is a reduction in the coupling in both frequency ranges of interest over the whole fork range. However the degree of reduction achieved depends heavily on the probe position with respect to the tank.

CST SIMULATION

The measurement set-up was also simulated using the CST STUDIO SUITE [3], with the 3D model used for the simulation shown in Fig. 12.

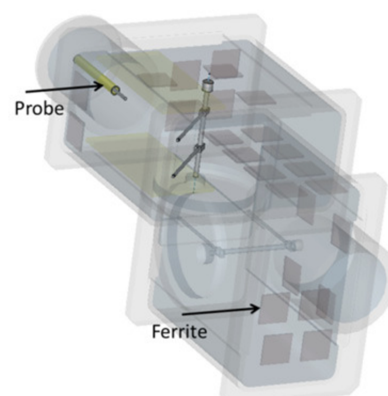

Figure 12: CST 3D model of the SPS BWS.

The model contains all the main features of the device, including the measurement probe and the carbon wire with its connecting wires with the fork. The sum and difference signals were simulated using the frequency domain solver of CST Microwave STUDIO with tetrahedral mesh cells. The results show two resonant peaks in the 200-400MHz range and a broader resonance in the 600-800MHz range in good agreement with the measurements (Figs. 13,14,15,16).

The solution "wire and plates" and "plates" both show significant improvement over the original design.

ISBN 978-3-95450-141-0

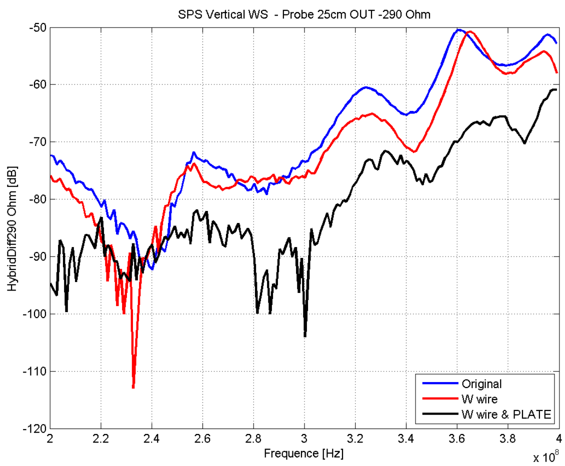

Figure 13: Measured Δ signal on the fork for the OUT position in the range 200-400MHz.

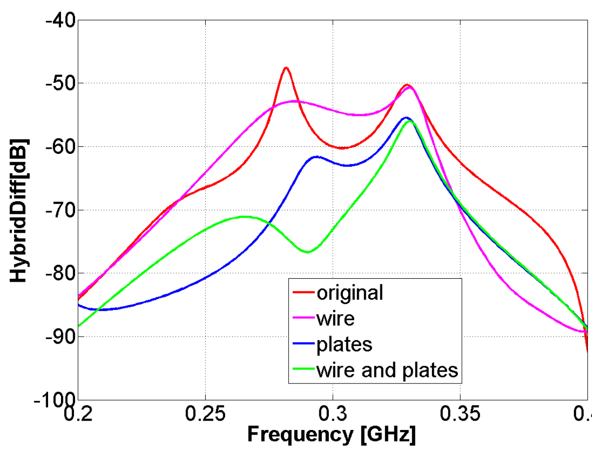

Figure 14: Simulated Δ signal on the fork for the OUT position in the range 200-400MHz.

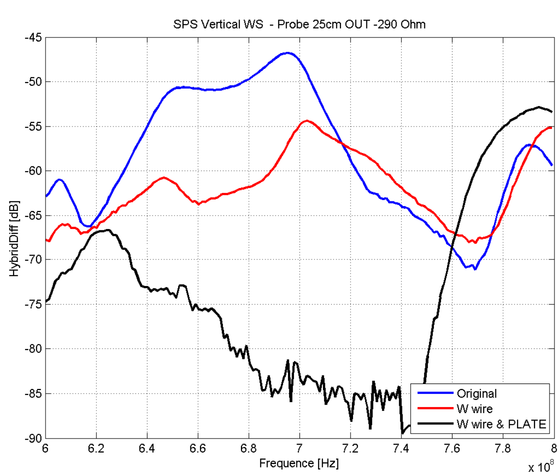

Figure 15: Measured Δ signal on the fork for the OUT position in the range 600-800MHz.

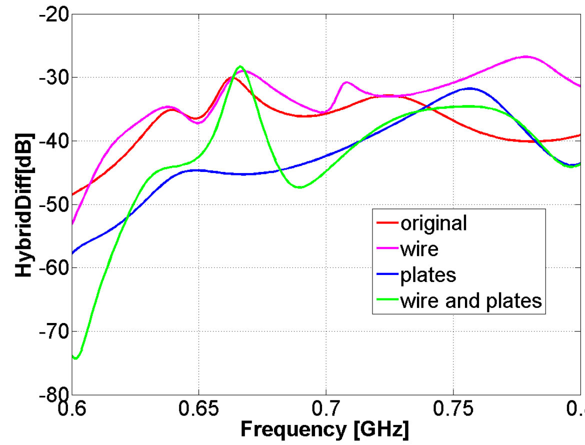

Figure 16: Simulated Δ signal on the fork for the OUT position in the range 600-800MHz.

CONCLUSIONS AND PERSPECTIVES

Laboratory measurements and simulations have been performed to try and understand the wire breakage of the SPS wirescanners during high intensity operation, thought to be linked to beam induced currents in the measurement wire. A good agreement is observed, with significant RF coupling expected in the case of the original tank set-up. A marked reduction in the RF power absorbed by the structure is also seen by both measurement and simulation when adding a tungsten wire to the fork and vertical shields to the tank. Both modifications have now been carried out on the installed SPS scanner 416 vertical and the tungsten wire on all the wire scanners. The effect on wire lifetime will be investigated during the 2014 and 2015 SPS runs.

REFERENCES

[1] F. Caspers, B. Dehning, E. Jensen, J. Koopman, J.F. Malo, Roncarolo F., "Cavity mode related wire breaking of the SPS Wire Scanners and loss measurements of wire materials", Proc. DIPAC 2003, Mainz, Germany.

[2] F. Roncarolo, "Accuracy of the Transverse Emittance Measurements of the CERN Large Hadron Collider", PhD Thesis (2005), http://lphe.epfl.ch/publications/theses/these.fr.pdf

[3] CST Microwave Studio, http://www.cst.com