Sound and vibration measurements at the collimator robustness test

G. Spiezia, O. Aberle, R. Assmann, A. Masi, S. Redaelli
Acknowledgments

From Universita’di Napoli FEDERICO II

Prof. F. Cennamo, Eng. U. Cesaro

AB/ATB

AB/BDI

AB/OP

TS/MME

AT/MTM

AB/ABP

R. Perret
A. Bertarelli
A. Dallocchio
B. Dehning
P. Sievers
L. Bottura
G. Arduini
J. Wenninger

AB/OP
Overview

• Motivation
• Experimental Setup
• Software
• Analysis Data
• Conclusions
Motivation

- Detect impacts of high intensity, high energy proton beams is an issue for other operating machines!
- How can we detect beam impacts (→ damage) on the LHC collimators??
- Sound and vibration measurements proposed to achieve this goal.
- System developed and implemented in the collimator prototype for the robustness test at TT40 (November 2004)

Goals:

1. Detect impacts of proton beams on the LHC collimator
2. Possibly reveal damage of the mechanical structure (Not done because the collimator survived!)
**Available Sensors**

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>N.</th>
<th>Sensitivity</th>
<th>Freq. range</th>
</tr>
</thead>
<tbody>
<tr>
<td>B&amp;K 2273AM1</td>
<td>1</td>
<td>1.1 pC/ms²</td>
<td>1Hz-6kHz</td>
</tr>
<tr>
<td>B&amp;K 2273A</td>
<td>2</td>
<td>0.38 pC/ms²</td>
<td>1Hz-10kHz</td>
</tr>
<tr>
<td>AP40</td>
<td>2</td>
<td>2.1 pC/ms²</td>
<td>0.5Hz-10kHz</td>
</tr>
<tr>
<td>AP37</td>
<td>2</td>
<td>1 pC/ms²</td>
<td>0.5 Hz-20kHz</td>
</tr>
<tr>
<td>Mic. B&amp;K4189</td>
<td>1</td>
<td>41.6 mV/Pa</td>
<td>6.3 Hz-20kHz</td>
</tr>
</tbody>
</table>

Piezoelectric accelerometers usable over a wide frequency range measurement (radiation hard)

Free field microphone for sound measurements
Robustness Test: TT40 Installation

Technical Challenges
• High radiation environment
• Long cables for installation
• High frequency acquisition
• Short time
  (Beginning of the project in August,
   First measurement in October)

Remote control of the hardware placed in the tunnel
System Architecture

Data Board Acquisition

Preamplifiers

Sensors

Special cables for accelerometers
Coaxial cable for the microphone

RS 232 programmable
Preamplifiers

**Working principle**: Charge-voltage conversion of the accelerometer signals

4-Channel Nexus Preamplifier for the B&K accelerometers and the microphone
- Setting sensor sensitivity
- Setting low and high pass filter for each channel
- Setting gain for each channel (6 orders of magnitude)
- Automatic test to check the correct installation of the accelerometers
- **RS-232 Programmable**

**Lower cost solution**
4 AP-5000 line drive preamplifiers for the AP accelerometers
- Fixed gain
- No control is possible
- Powered by a constant current source provided by the data acquisition board
**Data Acquisition Board NI 4472**

<table>
<thead>
<tr>
<th><strong>N° channels</strong></th>
<th>8- simultaneously sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling rate</strong></td>
<td>102.4 kS/s down to 1.0 kS/s</td>
</tr>
<tr>
<td><strong>ADC type</strong></td>
<td>Sigma-delta converter</td>
</tr>
<tr>
<td><strong>ADC modulator oversample rate</strong></td>
<td>64 f_s for 51.2kS/s&lt;s≤102.4kS/s&lt;br&gt;128fs for 1.0 kS/s&lt;s≤51.2kS/s</td>
</tr>
<tr>
<td><strong>Idle channel noise</strong></td>
<td>110 dB min 1.0 kS/s&lt;s≤51.2kS/s&lt;br&gt;105 dB min for 51.2kS/s&lt;s≤102.4kS/s</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>24 bit</td>
</tr>
<tr>
<td><strong>Input Range</strong></td>
<td>±10 Volt</td>
</tr>
<tr>
<td><strong>Input Configuration</strong></td>
<td>Pseudo-differential</td>
</tr>
<tr>
<td><strong>Input Coupling</strong></td>
<td>AC or DC software selectable</td>
</tr>
<tr>
<td><strong>Input current source</strong></td>
<td>0 or 4 mA each channel independently software-selectable</td>
</tr>
</tbody>
</table>

- 24 bit resolution ensures an acceptable quantization noise level even for no full scale signal.
- 8- Simultaneously-sampled channels (up to 100 kHz)
Software

Applications developed in Labwindows 7.0

- Acquisition and saving Data
- Preliminary analysis off line
- Remote control of the NEXUS preamplifier.
Acquisition Data

1. Setting of the software selectable parameters of the board.
2. Check of the writing operations on the disk.
3. Conversion operations from binary to text format.
4. Reproduction of the microphone data.
5. Setting for an automatic continuous acquisition.

60 sec Acquisition at 51.2 kS/s

\[ \text{Size Ring Buffer} = 10 \times \text{nb\_channel} \times \text{nb\_samples} \]

1/10 buffer full → Event trigger

Conversion and saving

~ 200MB Data
Preliminary Analysis

Frequency Domain

Detailed off line analysis performed with Matlab 7.0.1

Time Domain
B&K Preamplifier

1. Setting RS232 parameter
2. Setting input output parameters
3. Check status device
4. Resonance test
5. Setting parameters for microphone
Measurement Conditions

- For each jaw, collision at the maximum proton beam intensity (4 x 72 bunches) for different transverse impact depth (~1 mm up to ~6 mm)

- For each jaw, collision at increasing proton beam intensity for a specific transverse impact depth (~5 mm)

- Bump on the TED (target 5 m distant from the collimator) at increasing proton beam intensity
Measurement results

TED

We can distinguish between impact on the Ted and on the collimator

Detection of the impact on the collimator for TT40 test achieved
Data Analysis

The shape peak is mainly noise (neglected in the Fourier analysis)

Frequency analysis focused on the comparison of the signal before the peak with the signal after the exponential decay

Radiations??
Comparison with Sound spectrum of TED

The excited frequency components change when the beam hits the TED
Frequency Analysis

The main frequency components are the same for different beam intensities. This is in accordance with mechanical inspection of the jaws.
Comparisons with Lab Test

TT40 TEST

LAB TEST: Vacuum Tank

LAB TEST: Bellow
Dependence on beam intensity and depth

Good correlation of the microphone signal with the beam intensity and the impact depth on the jaw.
Accelerometers
As for the microphone, “saturation” peak and the consequent exponential decay

BUT vibration signal decays earlier (less precise Fourier analysis) Not clear which is the part of the instrumentation (cables, sensor or preamplifier) more influenced by the critical measurement conditions

Accelerometer signals evaluated in the time interval individualized with the microphone
Frequency Analysis

- Some frequency components come out after the impact
- Comparisons with the expected vibrations of the mechanical structure is ongoing
Conclusions

• Successful detection of beam impacts on the collimator with sound/vibration measurements achieved at TT40!
• This is a powerful tool that can in principle be used for the LHC.
• Dependence on beam intensity and impact depth were measured with the microphone and are in qualitative agreement with expectations
• Frequency analysis showed vibrations of the whole collimator mechanical structure after beam impact (confirmed by laboratory measurements)
• Effect of the radiations under investigation with the manufacturer (more important for accelerometer signals)
Sound and vibration measurements at the collimator robustness test

G. Spiezia, O. Aberle, R. Assmann, A. Masi, S. Redaelli