Abstract

At the Large Hadron Collider (LHC) experiments, most of silicon detectors use wire bonds to connect front-end chips and sensors to circuit boards for the data and service transmissions. These wire bonds are operated in strong magnetic field environments and if time varying currents pass through them with frequencies close to their mechanical resonance frequency, strong resonant oscillations may occur. Under certain conditions, this effect can lead to fatigue stress and eventually breakage of wire bonds.

During the first LHC Long Shutdown, the ATLAS Pixel Detector has been upgraded with the addition of a fourth innermost layer, the Insertable B-Layer (IBL), which has more than 50000 wire bonds operated in the ATLAS 2 T magnetic field. The results of systematic studies of operating wire bonds under IBL-like conditions are presented. Two different solutions have been investigated to minimize the oscillation amplitude of wire bonds.

Keywords: Wire bonds, magnetic field, resonance frequencies, ATLAS Pixel Detector, Insertable B-Layer.
1 Introduction

A fourth innermost pixel layer, the Insertable B-Layer (IBL) \cite{1}, has been installed in the ATLAS Pixel Detector \cite{2} during the first LHC Long Shutdown. The IBL Detector consists of a cylindrical layer formed by 14 staves arranged around the new ATLAS beam-pipe and tilted by 14° to ensure an azimuthal overlap of the staves and to compensate for the Lorentz angle in the 2 T solenoidal magnetic field of the ATLAS Detector. Each IBL stave holds 32 Front-End (FE-I4) chips \cite{3}, which are bump bonded to silicon sensors. On the module sensors, a flexible Printed Circuit Board (PCB), called module flex, is glued and wire bonds connect it to the front-end chip, allowing data and service transmission.

The IBL wire bonds operated in the 2 T B-field experience a Lorentz force when a current passes through them. Considering a typical wire bond length $l$ of 2 mm and a current $i$ of 100 mA, a wire in a 2 T B-field can experience a maximum force of $4 \cdot 10^{-4}$ N, which is smaller than the minimum force required to break a wire bond ($\sim$0.1 N). However, if the current passing through the wire has an AC component with the frequency close to the wire’s mechanical resonance frequencies, the wire can start to oscillate with a high oscillation amplitude. The oscillation depends on several factors as, for example, wire length and diameter, current, orientation angle with respect to B-field as well as B-field strength. Depending on oscillation amplitude and number of cycles, micro-cracks can develop at the wire’s point of attachment (heel) and, even more, the wire can cross the material elastic limit, both aspects leading to possible failures of the bond \cite{4}.

The case for the IBL Detector has been reviewed to investigate the wire bond behavior under operation in a 2 T magnetic field and to identify potential dangers of resonant wire bond vibrations. Two different solutions for wire bond protection against damages have also been tested.

2 The IBL wire bonds configuration

IBL wire bonds connecting flex and FE-I4 chip are tilted with respect to the B-field at orientation angles between 50° and 90° (Figure 1). Depending on this angle, a wire carrying current experiences a Lorentz force, whose components can be parallel (90° orientation angle) or perpendicular (0° orientation angle).

![Figure 1: (a) ATLAS IBL single chip module. On the bottom of the picture the FE-flex wire bonds are marked. The direction of the ATLAS B-field is indicated. (b) Zoom of a region where the angle between wire and B-field is shown. A 90° orientation angle corresponds to a wire perpendicular to the B-field.](image-url)
to the wire plane\textsuperscript{1}. In the IBL case, the force has both components even if the most dangerous one is the force perpendicular to the wire plane that can cause the wire’s oscillation. A more unsafe case is in the ATLAS Pixel Detector disk region where wire bonds experience only a force perpendicular to the wire plane that therefore has the maximum possible amplitude.

A salient feature of the FE-I4 chip is that all digital (analog) current must pass through the digital (analog) voltage regulator \textsuperscript{[5]}. This means that the voltage regulator wire bonds carry much more current than typical power wire bonds, for which there are multiple pads distributed throughout the chip. For each regulator pad there are 2 or 3 wire bonds, which are the longest and most bended wires on the module. Furthermore, even if there are multiple wire bonds connected, it is a known feature of low resistance parallel connections that the sharing of current among them is not well defined: the worst case is when all current passes through one of the three wires. The digital current varies with configuration and chip activity while the analog current is larger (about 300 mA) but constant. In addition to hit occupancy, triggers produce a digital activity since hits must be transmitted out of the regions. The current raised from triggers depends linearly on the number of consecutive triggers. Nevertheless, the most important digital transients are produced by configuration of the pixel matrix. In this case calibrations scans and abnormal conditions (for example configuration error or a single event upset) can cause a high increase of current. While the frequency of transient during calibration can be managed by modifying the scan parameters, abnormal states cannot be avoided and they can lead to self-sustaining current oscillations. These currents can be dangerous only if their frequency is close to the wire’s mechanical resonance frequency and to the harmonics or sub-harmonics of resonance frequency. Unfortunately, the frequency of power oscillations appears to be a characteristic of each chip and it cannot be predicted. It has been found experimentally that the maximum AC current of digital wire bonds is about 100 mA with a shape in-between a sine and square wave. This last case can be considered the worst for IBL.

3 Experimental set-up

A dedicated set-up has been assembled to reproduce the IBL wire bond operation conditions. Special test boards (Figure 2(a)), able to simulate the 370 µm step present between FE and flex, have been used to bond 25 µm diameter IBL-like FE-flex wires with different lengths\textsuperscript{2} (1.5 mm, 2.0 mm, 2.8 mm) and orientation angles (50°-90°).

The board can be fitted into the two poles of the electromagnet, which produces a 2 T B-field perpendicular to the board (Figure 2(b)). A switch box allows to select a wire bond on the test board and a waveform generator is used to send sine or square waves with an AC current amplitude between 0 and 100 mA. The wires are monitored with a CCD camera and a stroboscope is used to make the wire movement easily visible (Figure 3).

4 Modeling approach for wire bond fatigue

In a simplified view, a wire bond can be considered as a loaded beam that can oscillate in three dimensions. The natural frequencies depend on the wire bond length, diameter and loop height. However several factors can play an important role as for example the wire’s material and the ultrasonic bonding process, which defines the final shape of the wire and the local deformations of the heel region.

A one dimension Finite Element Analysis (FEA) simulation has been performed to address the search of resonance frequencies in the experimental tests for different wire bond lengths (Table 1) \textsuperscript{[6]}. A large

\textsuperscript{1}A Lorentz force perpendicular to the wire plane only occurs because the wire loop moves out of the plane of the sensor and because the ends of the wire are at different heights with respect to the sensor plane.

\textsuperscript{2}IBL shortest and longest wire bonds are about 1.5 mm and 2.8 mm long respectively. A value in between, namely 2.0 mm, has been also used for the test.
Figure 2: (a) On the top a microscope picture of the IBL-like wire bonds with different orientation angles with respect to the B-field and on the bottom a microscope picture of the simulated FE-flex step in the testing board. (b) Test board inserted between the two poles of the magnet. The B-field is indicated.

Figure 3: Schematic view of the experimental set-up used to test IBL-like wire bonds in 2T magnetic field.

number of modes have been found with the FEA simulation and verified in practice. However the experimental analysis of wire bonds oscillation has been focused only on the first mode, having the lowest frequency and requiring the lowest current to drive it to a dangerous oscillation amplitude.

On the contrary, the empirical measurement of the fatigue (i.e. the maximum cyclic load that can be applied so that the wire does not experience fatigue crack growth) threshold is extremely difficult, mainly because it would be a function of the loading conditions and the local stress state (i.e. the geometry of the wire). A numerical analysis is used to determine the vibration amplitude required to increase the
<table>
<thead>
<tr>
<th>Wire Length (mm)</th>
<th>Resonance frequency of the mode (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 mm</td>
<td>23.77  68.94  74.65  145.64  147.12</td>
</tr>
<tr>
<td>2.0 mm</td>
<td>12.75  37.32  40.62  78.72  79.61</td>
</tr>
<tr>
<td>2.8 mm</td>
<td>8.92   24.16  26.61  52.32  52.83</td>
</tr>
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</table>

Table 1: Resonance frequencies for different wire lengths obtained with a 1D FEA model [6].

plastic strain in the heel section of the wires. This simulation is carried out in three steps:

**Simulation of the effects of the ultrasonic bonding process.** Instead of simulating the motion of the bonding tool, a rigid body has been used to compress the ends of the wire with a shape that replicates a deformed profile equivalent to the one observed in IBL-like wire bonds (Figure 4). A special attention has been given to the region of wire’s foot and heel since it is known to be the weakest point during oscillation. The wire geometry has been reproduced by coordinates obtained experimentally from an IBL-like wire bond.

![Figure 4](image)

(a) Simulation of the bond foot obtained with the ultrasonic bonding process. (b) Deformation in the foot region after the bonding simulation [6].

**Thermal loading to account for Joule heating effects.** After the accomplishment of the bonding process, the thermal stresses induced by the Joule heating effect have been included. The total plastic strain accumulated after the first two modeling steps would be equivalent to that obtained in wire operating without the magnetic field (and thus not subject to vibration). Hence, this state was taken as reference for the subsequent fatigue analysis.

**Estimation of the oscillation amplitude to increase the plastic strains.** A static load is finally applied to the wire in small linear increments in the direction perpendicular to the wire’s plane. Whilst the magnitude of this load has no physical meaning for the vibration problem, it would result in a deformation pattern equivalent to that of the first resonance mode (which was assumed to cause fracture). After each increment, the plastic strain at every element within the heel region is compared to that obtained at the end of step 2 (i.e. immediately after applying the thermal load). So as to minimize numerical errors, the plastic strain is assumed to have increased when the difference between both strain values exceeds $10^{-3}$. Similarly, the change in plastic strain is considered effective only when the previous condition is simultaneously met in a minimum of five elements to avoid localized “hot spots” arising from the numerical solution. Once the critical load
increment causing the aforementioned increase in the plastic strain is reached, the corresponding vibration amplitude is obtained by the lateral displacement of the node located at the top of the wire.

Two different wire thicknesses in the foot region have been simulated since wire bonds have not all the same foot shape, which depends on the choice of parameters of the bonding machine as well as the tool quality, bond pad surface quality and the solidity of the support structures during bonding. As typical values, 11 μm and 17 μm thickness have been used. For a wire of 2.8 mm length the lateral vibration amplitudes obtained for the plastic strain limit are 42 μm and 45 μm respectively.

It has to be noticed that the modeling method described provides only an approximation to the fatigue threshold. Indeed it is widely accepted that fatigue failure can occur below the yield strength in metals and several assumptions have been made during the studies, such as the fact that the wire is not pure Al but has 1% Si and that the tempering of the wire has been chosen such that the elasticity has a certain range of values, which are optimum for the wire bonding process and perhaps not optimum for the resistance to vibration damage.

5 Experimental studies of resonant wire bond oscillations

The results obtained from the FEA simulation provide the resonance frequencies depending on the resonant mode and wire’s length (Table [1]). Nevertheless the bonding is not completely reproducible and each wire has small mechanical differences.

The resonance frequencies have been found experimentally on wires of different lengths bonded with the same bonding machine, i.e. using precisely the same machine parameters. The resonance frequency is defined as the frequency at which the oscillation amplitude reaches the maximum value. The first (mode 1) resonance frequencies for 1.5 mm, 2 mm and 2.8 mm are 25740 Hz, 15600 Hz and 9550 Hz respectively while the higher mode resonance frequencies are not visible with the present set-up. The spread of the resonance frequencies obtained testing several wires with the same length is about 1%, revealing a good reproducibility of the bonding machine. The experimental frequencies are not in complete agreement with FEA simulation: a shift of about 10% to higher frequencies is systematically observed. This can be explained by the simplified model used on the simulation where not all wire’s characteristics have been included.

The results obtained confirm the proportionality of the resonance frequency ν to \( l^{-2} \). Indeed the wire bond can be considered as a loaded beam for which the resonant frequency of the first normal mode is

\[
ν = \frac{kd}{l^2}
\]

where \( k \) is a constant depending on the properties of the wire and \( d \) is the wire diameter. During the test the oscillation amplitude is recorded through the CCD camera and, as expected by the theory of loaded beam, the oscillation amplitude results to be proportional to \( l^4 \), implying that longer wires have a larger oscillation amplitude and therefore they can be damaged more easily. The square of the oscillation amplitude is proportional to the power spectrum of oscillations that can be fitted with a Lorentzian line shape [7]:

\[
p = \frac{\left(\frac{(Δν)^2}{4}\right)H}{(ν - ν_0)^2 + \left(\frac{(Δν)^2}{4}\right)}
\]

where \( H \) is the peak height, \( ν_0 \) the resonance frequency and \( Δν \) the full width half maximum (FWHM) of the peak. From the width of power spectrum it is also possible to extract the quality factor of an
oscillation (Q factor) through the formula

\[ Q = \frac{\nu_0}{\Delta \nu} \]  \hspace{1cm} (3)

Figure 5(a) shows the oscillation amplitude as a function of the frequency obtained experimentally for a 2.8 mm wire. The amplitude has its maximum at the resonance frequency and it halves changing the frequency by ±50 Hz. In general, an oscillation is still present changing the frequency of about ±2\% with respect to the resonance frequency.

The dependence of the oscillation amplitude with respect to the wire orientation angle in the B-field has been tested. Figure 5(b) shows experimental results on how the amplitude decreases with the increase of the orientation angle. The best configuration is therefore the wire’s plane perpendicular to the B-field while the worst case is 0°, which corresponds to the wire’s plane parallel to the B-field (and force perpendicular to wire’s plane).

Systematic studies have been conducted changing duty cycle and rise time of the AC current square wave passing across the wire. Indeed the electrical signal passing through the digital regulator wire bonds of an IBL module has a relatively long rise time and it can have a duty cycle of about 5\%. In this situation the power transmitted to the wire bond is different and consequently the oscillation amplitude changes. Figure 6(a) shows the oscillation amplitude and the root mean square (RMS) of the current as a function of the duty cycle for a 2.8 mm wire in the 2 T B field with a square wave current of 20 mA peak to peak. The maximum amplitude is obtained with a 50\% duty cycle while it clearly decreases following the reduction of the RMS current. A drop of 75\% of the initial amplitude is obtained at very low duty cycles. Figure 6(b) shows the variation of the oscillation amplitude as a function of rise time obtained testing 2.8 mm wire bonds at a resonance frequency of 9800 Hz. A rise time equal to 0\,\mu s means a perfect square wave while 50\,\mu s is equivalent to a triangular wave. In the latter case, a decrease of the oscillation amplitude of about 35\% is visible.

Since the IBL current passing through regulator wire bonds can be a mix of sine and square wave, the Fourier harmonics play an important role in identifying the range of frequencies at which the wire bond oscillates in a B-field. The square wave can be developed as a Fourier series:

\[ x(t) = \frac{4A}{\pi} \left( \sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \ldots \right) \]  \hspace{1cm} (4)
Figure 6: (a) Oscillation amplitude at the resonance frequency and RMS current as a function of duty cycle sending a square wave to a 2.8 mm wire bond in a 2 T B-field (orientation angle \( \sim 30^\circ \)). (b) Oscillation amplitude at the resonance frequency as a function of rise time. The rise time on the x-axis takes into account only the leading edge (trailing edge has the same value).

being \( A \) the square wave amplitude and \( \omega = 2\pi\nu \). Equation 4 shows how the harmonics amplitude depends on \( n \). As a consequence, the current amplitude changes according to the harmonics amplitude. Indeed the oscillation amplitude at the resonance frequency is higher for a sine wave with respect to a square wave of the same current amplitude since the sine wave can be considered as the first harmonics of the square wave with consequently a higher current amplitude (about 1.3 times). At the frequency of the third harmonic the wire bond oscillates with an amplitude about three times smaller than at the resonance frequency, in agreement with theory. At higher harmonics, the wire bond still oscillates but its oscillation amplitude is negligible being proportional to the current amplitude obtained by equation 4. An inverse study can be performed considering the wave at the resonance frequency as one of the \( n \) harmonics of a square wave with frequencies of one third, one fifth, etc. of the resonance frequency. The oscillation amplitude diminishes with the decrease of the frequency since the square wave with frequency \( 1/n \) times the resonance frequency contains the resonance frequency only as the \( n \) harmonics, whose amplitude is given by equation 4. In the case of 2.8 mm wires with an AC current of 100 mA peak to peak, a frequency of \( \nu/3 \) or \( \nu/5 \) still generates an oscillation amplitude quite large (about 3-4 times the wire diameter) that could cause damage to the wire (Figure 7). When the frequency is reduced by at least a factor nine, the amplitude starts to be relatively small. In case of wires with smaller lengths, the amplitude is lower \( (a \propto l^4) \) and, consequently, also the oscillation amplitude at the harmonics frequencies are lower with less possibility of damaging the wires.

Wires bonded on the same strip and spaced by about 50 \( \mu \)m has been tested to simulate some of the wire bonds in the IBL FE-flex region that are bonded on the same pad. The test reveals that these “twin wire bonds” can oscillate together at the same resonance frequency or they can oscillate at two different frequencies, which are by the way very close (in a range of about 5%). If they oscillate together, the oscillation amplitude is larger with respect to the case of two wires oscillating at two different frequencies since they are coupled together. In both situations, the oscillation amplitude is lower than having a single wire since the current is shared and therefore multiple wire bonds per pad are preferable.
Figure 7: Oscillation amplitude expressed in wire diameter (25 µm) for frequencies of $1/3$, $1/5$, $1/7$, $1/9$ of the resonance frequency $\nu_0$ for a wire of 2.8 mm length. A square wave has been used. The resonance frequency $\nu_0$ for this particular wire is 10030 Hz.

6 Methods to minimize wire bond oscillations and failures

The most critical and weak point of a wire bond is the heel and foot region of the first bond. Indeed the Al wire is extremely stressed during the cold welding bonding process since it is compressed and bent about 45° in the process of moving to and making the second bond. This wire bond weakness is demonstrated by the fact that wire bonds usually break in the heel region (in general on the side where the first bond is done) when they are exposed to mechanical strains as, for example, oscillation.

One method to protect wire bonds against breakage is to encapsulate their feet and heels. The ATLAS Semiconductor Tracker (SCT) and Pixel Detector applied the encapsulant “Dymax 9001-E-V.3.1” (called Dymax in the following) on their wire bonds [8]. The same product has been tested on IBL-like wire bonds by encapsulating both foot heels. The encapsulation height at the foot region varies from 35 µm to 50 µm, being the application done manually. A second solution has been proposed to protect the whole wire against water contact or contaminants since it has been demonstrated that IBL wire bonds can be corroded in a high humidity environment. Urethan sprays are often used for standard PCBs to create a shield against dust, moisture and contaminants. The polyurethan “CellPack Urethan D9201PU” (called Urethan in the following) has been tested for the IBL case. The wire bond coating is done spraying manually the Urethan from the canister. The consequence is a non-uniform coating with Urethan drops along the wire and some areas not well covered.

Figure 8 shows the mean resonance frequency as a function of the wire bond length for the three cases (bare, encapsulated wire bond feet and coated wire bond) where the dependence of the resonance frequency to $l^{-2}$ is visible. The resonance frequency of encapsulated wire bonds is about 10% higher than bare case and, on equal terms, a higher current is necessary to get them oscillating. This behavior leads to the assumption that the wire bond feet are protected by Dymax, which shortens the wire’s length, Lessens the heels movement and reduces the local stress in the foot region attenuating the crack nucleation and ultimate failure. On the contrary the resonance frequency of coated wire bonds is lower (between 2% and 10%) than the bare case since the wire mass is higher. The larger error bars are just due to a large spread of resonance frequencies because of a different amount of Urethan covering the tested wires. In general, a higher current is required to get the same oscillation amplitude with a Urethan coated wire as for a bare wire and even higher current is needed for the case of a Dymax encapsulated wire. This means that the

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3For both protections (Dymax and Urethan) the application was performed manually with the risk of breaking wires. In case of real detectors, an automatic and more safe procedure needs to be developed.
Urethan coating offers some vibration protection, but the best protection is with the Dymax encapsulation at the bond feet.

Figure 8: (a) Resonance frequency as a function of wire bond length for bare, Urethan coated and Dymax encapsulated wire bond. (b) Resonance frequency shift after the application of Urethan or Dymax to bare wire bonds.

7 Wire bonds resistance against oscillation

The amplitude at which the wire oscillates is of fundamental importance since, depending on it and on number of cycles, the wire can overcome the material elastic limit and micro-cracks can develop at the heel. If the wire is left in oscillation mode at these conditions, the cracks can further propagate until the wire breaks.

A symptom of wire’s weakening is the drop of oscillation amplitude after a certain number of oscillation cycles. This drop is caused by the developing of micro-cracks at the heel region that reduce the rigidity of the bond to the point that it acts as if it is hinged. Furthermore the crack absorbs energy from the mechanical vibrations while it is growing and it does not allow the complete transmission of the current. The amplitude drop is also reflected by a change of the resonance frequency to lower values. At this new resonance frequency, the wire vibrates with a lower amplitude than the first one. After a certain number of cycles, the amplitude decreases further and a new resonance frequency can be observed. This procedure can be repeated several times causing further damages to the heel until the wire breaks. Clearly the process of damaging or breaking the wire is more easily achieved with high oscillation amplitudes, which can be obtained with longer wires as well as with higher AC current and B-field strength. The decrease of oscillation amplitude, and consequently the shift in the resonance frequency, can be used as parameters to monitor the wire resistance to oscillations.

The worst possible IBL scenario, which is a wire bond with an AC current of 100 mA peak to peak with a y close to the mechanical resonance frequency in the 2 T B-field, has been tested on bare, coated and encapsulated wires of different lengths and with several orientation angles with respect to the B-field. The wires are left in oscillation mode for 5 minutes. This duration has been chosen after the observation that most of the effects appears within this time. After this time the number of broken wires as well as the quantification of the possible shift of resonance frequency are recorded. Table 2 summarizes the results obtained without considering the wire orientation angles. The 1.5 mm wires are not affected by any decrease of amplitude and none of them break in the three configurations. On the contrary, the
2.8 mm wires are subject to considerable damages: all wires have a decrease of amplitude both in bare and coating cases and 30% of them suffer an amplitude decrease in case of encapsulation. Furthermore about 15% and 10% of wires break in the bare and coating case, respectively. Despite that, 2.8 mm wires do not break if their feet are encapsulated, remarking the effectiveness of the Dymax. For the 2.8 mm wires, the resonance frequency shift has been estimated to be 4.6%, 3.4% and 0.3% for bare, coated and encapsulated wires respectively. The coating solution provides an improvement in term of protection with respect to bare wire bonds but it is not good as the encapsulation. This disadvantage might be overcome if a better coating method covering completely and uniformly the wire bond length is developed.

<table>
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<tr>
<th>Wire’s length</th>
<th>Type of test</th>
<th>Wires affected (%)</th>
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</thead>
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<tr>
<td></td>
<td>Bare</td>
<td>Coated</td>
</tr>
<tr>
<td>1.5 mm</td>
<td>Decrease of amplitude</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Broken wires</td>
<td>0</td>
</tr>
<tr>
<td>2.0 mm</td>
<td>Decrease of amplitude</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Broken wires</td>
<td>9</td>
</tr>
<tr>
<td>2.8 mm</td>
<td>Decrease of amplitude</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Broken wires</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 2: Percentages of wires affected by an amplitude decrease or broken after 5 min in oscillation mode at 100 mA AC current in the IBL configuration. The test has been performed with wires of different lengths and in different conditions (bare, coated and encapsulated wire bonds). A total of about 60 wire bonds have been tested.

Wire bonds have been tested also with the wire plane parallel to the B-field direction (in this case the maximum B-field reachable in the set-up is 1.1 T). This is the worst case since the force applied to the wire is perpendicular to the wire bond plane and has the possible maximum value. In this condition, also wires of 1.5 mm can break with generally a lower AC current than the one used for the IBL case.

8 Conclusions

An experimental set-up has been built to simulate as much as possible the operation conditions of IBL wire bonds in the ATLAS magnetic field. The results provide useful information for the comprehension of the IBL wire bonds behavior, owing to have the real conditions well reproduced in the experimental set-up. The worst IBL case is a 2.8 mm wire with an AC current of 100 mA at a frequency close to the wire’s mechanical resonance frequency and with lower orientation angles with respect to the 2 T B-field. It has been demonstrated that in this case, as well as in other possible cases, the wire gets irreparably damaged after a small number of oscillation cycles and it can easily break. Furthermore it has been proven that the frequency range of risk for square wave AC currents goes from mode 1 resonant frequency down to 1/3, 1/5, 1/7 of that frequency (and even lower) if the amplitude is high enough. Two types of wire bond protections have been investigated: the classical encapsulation of the wire feet and the coating of the whole wire. The last method is also useful to protect the wire against humidity or other possible contaminants. Even if the encapsulation remains the best solution for oscillation protection, it has not been implemented for IBL. This decision is due to the fact that at the time of the studies most of the staves were already produced and the application of the Dymax or Urehtan was considered too risky for the modules safety. The alternative solution against oscillations consists in avoiding the currents with the frequencies at which wire bonds can oscillate. For the IBL detector a Fixed Frequency Trigger Veto
(FFTV) has been implemented for excluding the potentially dangerous frequencies identified in these studies.

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References


