Ph.D THESIS

Grzegorz Kasprowicz, M.Sc.

Methods and Algorithms for Beam Intensity and Position Determination in a Particle Accelerator

Supervisor

Professor Ryszard Romaniuk, Ph.D, D.Sc.

Warsaw, 2010
To Jeroen, Uli, CERN
Contents

1 Introduction
  1.1 The meaning of fundamental research .......................... 1
  1.2 Research area of the thesis - the accelerator science and applications .......................... 2

2 Particle accelerators
  2.1 Definitions, basic concepts ........................................ 7
  2.2 Particle beam parameters and their importance to the experiments .......................... 11
  2.3 Instrumentation for intensity and position measurement .......................... 14
  2.4 The challenges of beam parameters determination .......................... 22

3 The Aim and the scope of the work .......................... 31

4 The methods and algorithms for beam position (trajectory) estimation .......................... 35
  4.1 Requirements of the beam trajectory measurement for PS .......................... 35
  4.2 Existing solutions and limitations .......................... 36
  4.3 Usage of numerical Phase Lock Loop .......................... 39
    4.3.1 The synchronization algorithm .......................... 39
    4.3.2 The PU signal treatment .......................... 42
    4.3.3 Implementation of numerical Phase Lock Loop .......................... 45
    4.3.4 Trajectory Measurement System Architecture .......................... 58
  4.4 The limitations of used method, alternative solutions .......................... 64
  4.5 Usefulness for other accelerators of the method and hardware developed .......................... 64
  4.6 Measurements and tests .......................... 65
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6.1 Computer simulations with real data</td>
<td>65</td>
</tr>
<tr>
<td>4.6.2 Laboratory tests</td>
<td>67</td>
</tr>
<tr>
<td>4.6.3 Real beam signal tests</td>
<td>68</td>
</tr>
<tr>
<td>5 The methods and algorithms for beam intensity estimation</td>
<td>77</td>
</tr>
<tr>
<td>5.1 Requirements of the beam intensity measurement for PS</td>
<td>77</td>
</tr>
<tr>
<td>5.2 Existing solutions and limitations</td>
<td>77</td>
</tr>
<tr>
<td>5.3 Usage of numerical Phase Lock Loop</td>
<td>79</td>
</tr>
<tr>
<td>5.3.1 The synchronization algorithm</td>
<td>79</td>
</tr>
<tr>
<td>5.3.2 The BCT signal treatment</td>
<td>79</td>
</tr>
<tr>
<td>5.3.3 Implementation of numerical Phase Lock Loop</td>
<td>80</td>
</tr>
<tr>
<td>5.3.4 Intensity measurement system control software</td>
<td>84</td>
</tr>
<tr>
<td>5.3.5 Calibration of the measurement system</td>
<td>84</td>
</tr>
<tr>
<td>5.4 The limitations of used method, alternative solutions</td>
<td>89</td>
</tr>
<tr>
<td>5.5 Usefulness for other accelerators of the method and hardware</td>
<td>89</td>
</tr>
<tr>
<td>5.6 Measurements and tests</td>
<td>91</td>
</tr>
<tr>
<td>5.6.1 Laboratory tests</td>
<td>91</td>
</tr>
<tr>
<td>5.6.2 Real beam signal tests</td>
<td>93</td>
</tr>
<tr>
<td>6 Closing remarks</td>
<td>97</td>
</tr>
<tr>
<td>Bibliography</td>
<td>99</td>
</tr>
<tr>
<td>List of Symbols and Abbreviations</td>
<td>103</td>
</tr>
<tr>
<td>List of Figures</td>
<td>105</td>
</tr>
<tr>
<td>List of Tables</td>
<td>108</td>
</tr>
<tr>
<td>Index</td>
<td>109</td>
</tr>
</tbody>
</table>