COMPARATIVE STUDY OF FAST FOCUS MODE AND SLOW FOCUS MODE IN PLASMA FOCUS DEVICES

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Abstract

In this thesis comparison between Fast Focus Mode (FFM) and Slow Focus Mode (SFM) in plasma focus devices is studied. For INTI PF machine, results of numerical experiments based on Lee Model Code on Deuterium, Neon and Argon in the pressure range of 1Torr to 14 Torr D, 1 Torr to 5.5 Torr Ne and 0.2 Torr to 2.4 Torr Ar show that as a rule-of-thumb, diameter-optimized SFM is considered to occur when fast plasma stream speed generated by pinch column is equal to the peak axial phase speed. Results of speed factor, FIB energy, FPS energy, FIB damage factor, plasma footprint radius for FFM and SFM at different pressures of D, Ne and Ar are presented. These results may be used to predict different applications of both modes: especially in the fields of nuclear fusion reactor first wall materials and its related investigations by time-matched FFM; and thin film nano-material synthesis by diameter-optimized SFM. Design and construction of a PMT-Scintillator diagnostic system for D-D fusion Neutron time-of-flight measurements (TOF) in INTI PF machine are presented. In addition, a fast 50 Ω Faraday Cup was designed and fabricated to enable time-of-flight TOF measurements of pulsed ion beam of INTI PF. The shortest FWHM for ion pulse captured by Faraday Cup was 27 ns. In this research the correlation of the ion beam energy between TOF measurements and Lee Model Code with different kind of filling gases such as D, Ne, Ar, Kr and Xe is presented. The results show there is acceptable correlation between TOF measurements and Lee Model Code. The maximum most common energy for D, Ne, Ar, Kr and Xenon ions generated by pinch column, detected by Faraday Cup were 67 keV, 485 keV, 1.2 MeV, 3.9 MeV and 6 MeV consistent with the values predicted by Lee Model Code. In the cases of Ar, Kr and Xe, Radiative Collapse effect leads to very small pinch radius size which is calculated by Lee Model Code. In order to study the application of INTI plasma focus machine in the field of advanced material sciences, some experiments such as graphite deposition on silicon wafer, hardening by nitriding and also fusion first wall material research by using tungsten targets are presented. Conceptual design of 160 kJ DuPF as a biggest plasma focus facility in the world for material research, by using Lee Model code in both FFM and SFM at different pressures of different kind of filling gases such as D, Ne and Ar is presented. It seems that reliable SFM for all gases occur when the ratio of FPS speed to axial velocity is near to 1. Finally, industrial detail design of DuPF and its parts by using SolidWorks software is presented.

Table of Contents

COPYRIGHT ii
DECLARATION iii
ACKNOWLEDGMENTS iv
Abstract v
Table of Contents vi
List of Tables ix
List of Figures xi
CHAPTER 1 Introduction and Literature Review 1
1.1 Problem Statement 4
1.2 Research Objectives 4
1.3 Continuation of the Literature Review 5
1.3.1 Nano-materials 5
1.3.2 Fusion first wall materials 8
1.3.3 Slow Focus Mode (SFM) 12
1.4 Thesis Outline 15
CHAPTER 2 Plasma Focus Characteristics 17
2.1 Plasma Focus Simulation 17
2.2 The Lee Model Code 20
2.3 Description of the Lee Code 20
2.4 Procedure for Using the Code 24
CHAPTER 3 26
Numerical study of FFM and SFM of INTI PF machine using Lee Model Code 26
3.1 INTI PF Machine 26
3.2 Numerical experiments on INTI PF using Lee Model Code 26
3.2.1 Numerical experiments for operation in Deuterium 27
3.2.2 Operation in Neon and Argon 40
CHAPTER 4 Experimental Set up 52
4.1 INTI PF System 52
4.2 Diagnostics 53
4.3 Faraday Cup 55

4.3.1 Deuterium TOF measurements 71
4.3.2 Neon TOF measurements 79
4.3.3 Argon TOF measurements 85
4.3.4 Krypton TOF measurements 91
4.3.5 Xenon TOF measurements 110
4.4 Photomultiplier-Scintillator System for INTI-PF machine 118
4.5 Set-up for damage studies and results 134
4.5.1 Characterization of samples in damage studies 141
4.6 Experimental set up for deposition experiments and results 146
4.6.1 Results and discussion for the deposition experiments 152
4.6.1.1 Weight 152
4.6.1.2 Thickness 154
4.6.1.3 Chemical Composition 156
4.6.1.4 Surface Morphology 161
4.6.1.5 Summary for Deposition Experiments 172
4.6.1.6 Recommendations 172
4.7 Nitriding by using INTI PF in FFM 173
4.7.1 Sample 1, S1 (10 Shots) 178
4.7.2 Sample 2, S2 (30 Shots) 185
4.7.3 Vickers Micro Hardness Result 191
CHAPTER 5 Numerical experiments on 160 kJ DuPF 193
5.1 FFM operation of DuPF 196
5.1.1 DuPF FFM operation using Deuterium 197
5.1.2 DuPF FFM operation using Neon 199
5.1.3 DuPF FFM operation using Argon 200
5.2 SFM operation of DuPF 201
5.2.1 DuPF SFM operation using Deuterium 201
5.2.2 DuPF SFM operation using Neon 202
5.2.3 DuPF SFM operation using Argon 204
5.3 Comparative study of FFM and SFM in DuPF 205
CHAPTER 6 Industrial detail design of 160 kJ DuPF 225

6.1 DuPF Electrodes 226

6.1.1 FFM Electrodes 226

6.1.2 SFM Electrodes 228

6.1.3 Electrode Parts 230

6.2 DuPF Vacuum Vessel 254

6.3 DuPF Main Table 267

6.4 DuPF Gas Panel 273

6.5 DuPF Spark Gaps 283

6.6 DuPF Sample Holder 291

CHAPTER 7 Conclusion 298

References 304

List of Tables

Table 1.1 Typical ZaP Flow Z-Pinch operating parameters [23] 14

Table 3.1 Results of numerical experiments based on Lee Model Code on INTI PF operated with Deuterium at different pressures. 29

Table 3.2 Computed FFM and SFM results for 3 Torr and 14 Torr Deuterium based on Lee code in INTI PF 34

Table 3.3 Results of numerical experiments based on Lee Model Code on INTI PF with Neon filling gas at different pressures. 41

Table 3.4 Results of numerical experiments based on Lee Model Code on INTI PF with Argon filling gas at different pressures. 44

Table 4.1 Physical Parameters needed for FC design 58

Table 4.2 Lee Model parameters for different pressures of Deuterium by matching the computed to measured current traces 64

Table 4.3 Summary of Numerical Experiment results generated by FIB Lee Model Code for INTI PF, 12kV, 2-12 Torr Deuterium. Model parameters of each pressure are fitted from measured current traces. 64

Table 4.4 Summary of Experimenal results generated by fast Faraday Cup in INTI PF, 12kV, 2-12 Torr Deuterium. 67

Table 4.5 Deuterium time of flight measurements in INTI PF machine 72

Table 4.6 Neon Time of Flight measurements in correlation with Lee Model Code 80

Table 4.7 Summary of Argon TOF measuremnts in INTI PF machine 86

Table 4.8 Summary of Krypton ions time of flight measurements at 0.5 Torr, 12 kV in INTI PF machine 93

Table 4.9 Summary of Xenon TOF measurements in correlation between Lee Model Code at 12 kV in INTI PF machine 110

Table 4.10 Plastic and Liquid Scintiltators Specifications for Neutron detection [111]. 123

Table 4.11 Voltage divider distribution for 9813QB PMT 128

Table 4.12 Tungsten target samples: experimental set-up 137

Table 4.13 Model and Operational parameters of shot for target sample 1 139

Table 4.14 FIB and FPS data per shot simulated by Lee Code for selected shots of each sample. 139

Table 4.15 Parameters for Deposition Experiment using Neon 148

Table 4.16 Specifications of TM3000 SEM 151

Table 4.17 Specifications of EDX SwiftED3000 152

Table 4.18 Mass of Thin Film Deposited 152

Table 4.19 Chemical Composition at Center of S1, S2, S3, S4, S5 and S6 with 1.5 k Magnification 156

Table 4.20 Chemical Composition at Area Above Center of S1, S2, S3, S4, S5 and S6 with 3.0 k Magnification 156

Table 4.21 Chemical Composition at Center of SG5, SG8 and SG9 with 1.5 k Magnification 157

Table 4.22 Chemical Composition at Area Above Center of SG5, SG8 and SG9 with 3.0 k Magnification 157

Table 5.1 Tube, Model and Operation parameters of DuPF for D, Ne and Ar in FFM state. 197

Table 5.2 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Deuterium at different pressures during FFM operation 198

Table 5.3 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Ne at different pressures during FFM operation. 199

Table 5.4 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Ar at different pressures during FFM operation. 200

Table 5.5 Tube, Model and operational parameters of DuPF for SFM operation of Deuteium, Neon and Argon. 201

Table 5.6 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Deuterium at different pressures during SFM operation 202

Table 5.7 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Ne at different pressures during SFM operation. 203

Table 5.8 Results of numerical experiments based on Lee Model Code on 160 kJ DuPF operated with Ar at different pressures during SFM operation. 204

Table 5.9 Comparative table of SFM and FFM for160 kJ DuPF operated with Deuterium, Ne and Ar based on Lee Model Code 206

List of Figures

Figure 2.1 Schematic of the axial and radial phases. The left section depicts the axial phase, the right section the radial phase. In the left section, z is the effective position of the current sheath-shock front structure. In the right section r_s is the position of the inward moving shock front driven by the piston at position r_p. Between r_s and r_p is the radially imploding slug, elongating with a length z_f. The capacitor, static inductance and switch powering the plasma focus is shown for the axial phase schematic only [60]. 22

Figure 2.2 Schematic of radius versus time trajectories to illustrate the radial inward shock phase when r_s moves radially inwards, the reflected shock (RS) phase when the reflected shock moves radially outwards, until it hits the incoming piston r_p leading to the start of the pinch phase (t_f) and finally the expanded column phase [60]. 22

Figure 3.1 Speed Factor versus Deuterium pressure in INTI PF based on Lee Model Code 30

Figure 3.2 Fast ion energy versus duterium pressure in INTI PF based on Lee Model Code 30

Figure 3.3 FIB damage factor in INTI PF versus Deuterium pressure based on Lee Model Code 32

Figure 3.4 Number of ions per shot in INTI PF versus Deuterium pressure based on Lee Model Code 32

Figure 3.5 Ion current generated by INTI PF pinch column versus Deuterium pressure 33

Figure 3.6 Number of neutrons per shot in INTI PF versus Deuterium pressure based on Lee Model Code 33

Figure 3.7 Computed discharge current of INTI PF versus time based on Lee Model Code at 3 Torr Deuterium, FFM (left) and 14 Torr, SFM (right) 34

Figure 3.8 Computed radial trajectories of INTI PF based on Lee Model Code for 3 Torr (left) and 14 Torr (right) Deuterium; FFM (left), SFM (right) 35

Figure 3.9 Plasma footprint radius versus Deuterium pressure in INTI PF 36

Figure 3.10 FPS energy per ion versus Deuterium pressure in INTI PF 37

Figure 3.11 Plasma Stream energy versus pressure for Deuterium in INTI PF 37

Figure 3.12 The ratio of plasma stream energy to FIB beam energy versus Deuterium pressure in INTI PF 38

Figure 3.13 Computed discharge current of INTI PF versus time based on Lee Model Code at 2 torr Neon, FFM (left) and 5.5 torr, SFM (right) 40

Figure 3.14 Computed radial trajectories of INTI PF based on Lee Model Code for 2 Torr (left) and 5.5 Torr (right) Neon; FFM (left), SFM (right) 42

Figure 3.15 Computed discharge current of INTI PF versus time based on Lee Model Code at 0.4 Torr Argon, FFM (left) and 2.5 Torr Ar, SFM (right) 43

Figure 3.16 Computed radial trajectories of INTI PF based on Lee Model Code for 3 Torr (left) and 14 Torr (right) Deuterium; FFM (left), SFM (right) 43

Figure 3.17 Speed Factor versus Neon and Argon pressure in INTI PF based on Lee Model Code 45

Figure 3.18 Fast ion beam energy (per ion) versus Neon and Argon pressure in INTI PF based on Lee Model Code 45

Figure 3.19 FIB damage factor for Neon and Argon versus pressure in INTI PF based on Lee Model Code 46

Figure 3.20 computed number of ions per shot in INTI PF based on Lee Model Code for Neon and Argon versus pressure 47

Figure 3.21 Plasma footprint radius generated from pinch column versus Ne and Ar pressure in INTI PF 47

Figure 3.22 Ion current generated by pinch column versus Ne and Ar pressure in INTI PF 48

Figure 3.23 FPS energy per ion versus Ne and Ar pressure in INTI PF 48

Figure 3.24 FPS energy %E0 versus Neon and Argon pressure in INTI PF 49

Figure 3.25 The ratio of plasma stream energy to FIB energy versus Ne and Ar pressure in INTI PF 50

Figure 4.1 Schematic diagram of INTI PF machine, Center for Plasma Research, INTI International University 53

Figure 4.2 SXR measurement in INTI PF Machine 55

Figure 4.3 Biasing circuit fot INTI-PF Faraday Cup 59

Figure 4.4 Assembled INTI-PF Faraday Cup 60

Figure 4.5 Deuteron's energy versus time of flight during 4cm flight length 62

Figure 4.6 Axial peak velocity, Speed factor and Ion current expected from FC with variation of Deuterium pressure in INTI PF, based on Lee Code. The model parameters f_m, f_c, f_{mr}, f_{cr} for each shot are fitted by matching the computed current trace to the measured current trace of that shot. 63

Figure 4.7 Experimental current fitted by Lee Code including XR, FC and Voltage probe signals, 12kV, Deuterium, INTI PF, Fast Focus Mode (3 Torr and 37 ns FWHM, left side) and Slow Focus Mode (12 Torr and > 2μs FWHM,right side). The fitted model parameters (fm, fc, fmr, fcr) of the FFM shot are: 0.07, 0.7, 0.2, 0.7. 65

Figure 4.8 dN/dE and Number of Ions versus energy achieved by Faraday Cup signals for INTI PF at FFM (right) and SFM (left) operations. 66

Figure 4.9 Numerical experiments based on Lee Code show that plasma footprint area of SFM (right, 12 Torr) is at least 10 times more than its FFM (left, 3 Torr) in INTI PF 67

Figure 4.10 Ion Flux correlation between Lee Code (red trace, RHS scale) and Faraday Cup (blue trace, LHS scale) 68

Figure 4.11 Number of fast ions (1keV) from Faraday Cup and Damage Factor from Lee Model Code 69

Figure 4.12 Slow Ions Number ratio to Fast Ions Number and FWHM measured by Faraday Cup in different pressures of Deuterium at 12 kV discharge voltage in INTI PF. 70

Figure 4.13 Mean Ion energy measured by FC and FPS energy per ion calculated by Lee Model Code, decreasing by increasing of Deuterium pressure 70

Figure 4.14 Current fitting of Test 446, 3 Torr, D, 12 kV 73

Figure 4.15 FC and TOF signal for Test 446, 3 Torr, D, 12 kV in INTI PF machine 73

Figure 4.16 Radial trajectories for Test 446, 3 Torr D, 12 kV, predicted by Lee Model Code during proper current fitting 74

Figure 4.17 Current fitting of test 445, 3 Torr, D at 12 kV in INTI PF machine 74

Figure 4.18 FC and TOF signal for test 445, 3 Torr, D, 12 kV in INTI PF machine 75

Figure 4.19 Radial trajectories for Test 445, 3 Torr D, 12 kV, predicted by Lee Model Code during proper current fitting 75

Figure 4.20 Current fitting for test 416, 8 Torr, D at 12 kV using Lee Model Code 76

Figure 4.21 FC TOF signal for test 416, 8 Torr, D at 12 kV in INTI PF machine 76

Figure 4.22 Radial trajectories of test 416, 8 Torr, D at 12 kV during proper current fitting 77

Figure 4.23 Deuterium Ion energy versus presure from FC and Lee Model Code 77

Figure 4.24 Current fitting of test 883, 3Torr, Ne at 12 kV in INTI PF machine 81

Figure 4.25 Faraday Cup and TOF signal for test 883, 3 Torr, Ne at 12 kV 82

Figure 4.26 Radial trajectories for test 883, 3 Torr, Ne at 12 kV, predicted by Lee Model Code during proper fitting 82

Figure 4.27 Faraday Cup and TOF signal for test 872, 2 Torr, Ne at 12 kV 83

Figure 4.28 Current fitting of test 872, 2 Torr, Ne at 12 kV in INTI PF machine 83

Figure 4.29 Radial trajectories for test 872, 2 Torr, Ne at 12 kV, predicted by Lee Model Code during proper fitting 84

Figure 4.30 Correlation between Lee Model Code and FC TOF results for 2 Torr - 4 Torr Neon at 12 kV in INTI PF machine 84

Figure 4.31 TOF measurements of test 859, 0.9 Torr Srgon at 12 kV in INTI PF machine 87

Figure 4.32 Current fitting of test 859, 0.9 Torr, Argon at 12 kV in INTI PF machine 88

Figure 4.33 TOF measurements of test 859, 0.9 Torr Argon at 12 kV in INTI PF machine, 150 MHz bandwidth limit 88

Figure 4.34 Radial trajectories of test 859, 0.9 Torr, Argon at 12 kV including radiative collapse in INTI PF machine 89

Figure 4.35 Original TOF signal of test 852, 0.8 Torr Argon at 12 kV in INTI PF machine 89

Figure 4.36 Current fitting of test 852, 0.8 Torr, Argon at 12 kV in INTI PF machine 90

Figure 4.37 Magnified FC TOF signal for test 852, 0.8 Torr Argon at 12 kV 90

Figure 4.38 Correlation between Lee Model Code and FC TOF measurements results for Argon in INTI PF machine 91

Figure 4.39 Original TOF signal of test 897, 0.5 Torr, Krypton at 12 kV in INTI PF machine 94

Figure 4.40 Current fitting of test 897, 0.5 Torr Krypton at 12 kV in INTI PF machine 95

Figure 4.41 Magnified FC, Current, Voltage and pin-diode signals for test 897, 0.5 Torr Krypton at 12 kV in INTI PF machine 95

Figure 4.42 Radial trajectories of test 897, 0.5 Torr Krypton at 12 kV in INTI PF machine; Radiative Collapse effect is clear at the end of radial piston trajectory in pink color 96

Figure 4.43 Oroginal TOF signal of test 901, 0.5 Torr Krypton at 12 kV in INTI PF machine 97

Figure 4.44 Current fitting of test 901, 0.5 Torr, Krypton at 12 kV in INTI PF machine 98

Figure 4.45 Magnified FC, Current, Voltage and pin-diode signals of test 901, 0.5 Torr Krypton at 12 kV in INTI PF machine 98

Figure 4.46 Radial trajectories of test 901, 0.5 Torr, Krypton at 12 kV in INTI PF machine calculated by Lee Model Code 99

Figure 4.47 Original signal of test 902, 0.5 Torr, Krypton at 12 kV in INTI PF machine 100

Figure 4.48 Current fitting of test 902, 0.5 Torr, Krypton at 12 kV in INTI PF machin 101

Figure 4.49 Magnified FC, Current, Voltage and pin-diode signals of test 902, 0.5Torr Krypton at 12 kV in INTI PF machine 101

Figure 4.50 Computed radial trajectories of test 902, 0.5 Torr krypton at 12 kV in INTI PF machine including its radiative collapse effect at the end of radial phase 102

Figure 4.51 Original signal of test 905, 0.5 Torr Krypton at 12 kV in INTI PF machine 103

Figure 4.52 Current fitting of test 905, 0.5 Torr Krypton at 12 kV in INTI PF machine 104

Figure 4.53 Magnified FC, Current, Voltage and pin-diode signals of test 905, 0.5 Torr Krypton at 12 kV 104

Figure 4.54 Radial trajectories of test 905, 0.5 Torr Krypton at 12 kV in INTI PF machine including its radiative collapse effect at the end of radial phase 105

Figure 4.55 Original signal of test 906, 0.5 Torr Krypton at 12 kV in INTI PF machine 106

Figure 4.56 Current fitting of test 906, 0.5 Torr Krypton at 12 kV in INTI PF machine 107

Figure 4.57 Magnified FC, Currrent, Voltage and pin-diode signals for test 906, 0.5 Torr Krypton at 12 kV 107

Figure 4.58 Radial trajectories of test 906, 0.5 Torr Krypton at 12 kV in INTI PF machine including its radiative collapse effect at the end of radial phase 108

Figure 4.59 Correlation between Lee Model Code and FC TOF measurements results for 0.5 Torr Krypton at 12 kV for each of 10 shots in INTI PF machine 109

Figure 4.60 Original signals of test 887, 0.33 Torr Xenon at 12 kV in INTI PF machine 111

Figure 4.61 Current fitting of test 887, 0.33 Torr Xenon at 12 kV in INTI PF machine 112

Figure 4.62 Magnified FC, Current, Voltage and pin-diode signals of test 887, 0.33 Torr Xenon at 12 kV in INTI PF machine 112

Figure 4.63 Radial trajectories of test 887, 0.33 Torr Xenon at 12 kV in INTI PF machine including radiative collapse effect at the end of radial phase 113

Figure 4.64 Original signals of test 894, 0.33 Torr Xenon at 12 kV in INTI PF machine 114

Figure 4.65 Current fitting of test 894, 0.33 Torr Xenon at 12 kV in INTI PF machine 115

Figure 4.66 Magnified FC, Current, Voltage and pin-diode signals of test 894, 0.33 Torr Xenon at 12 kV in INTI PF machine 115

Figure 4.67 Radial trajectories of test 894, 0.33 Torr Xenon at 12 kV in INTI PF machine including its radiative collapse effect at the end of radial phase 116

Figure 4.68 Correlation between Lee Model Code and FC TOF results for Xenon at 12 kV in INTI PF machine 117

Figure 4.69 9813QB PMT tube 122

Figure 4.70 A NE102A plastic scintillator 123

Figure 4.71 NE102 scintillator coupling to PMT window by means of thin layer of clear silicone 124

Figure 4.72 9813QB PMT Voltage-divider circuit with consideration of pulse output linearity and to minimize ringing and high-voltage power supply noise is designed for INTI PF device. 125

Figure 4.73 Typical voltage gain characteristics for 9813QB PMT 128

Figure 4.74 INTI PF PMT Voltage Divider 129

Figure 4.75 INTI PMT up to ±5 kV, 2 mA Power Supply 130

Figure 4.76 INTI PF PMT-Scintillator Galvanized iron housing 130

Figure 4.77 12kV, 2.5 Torr Deuterium signals, dI/dt (Yellow), PMT-Scintillator (Blue), Faraday Cup (Pink), XR pin-diode (Green). 132

Figure 4.78 2.4541 MeV D-D neutron detecting from PMT-Scintillator detector in INTI PF, 12 kV, 2.5 Torr, 134

Figure 4.79 Experimental set up, adjustable sample holder and shutter for INTI PF 136

Figure 4.80 INTI plasma focus adjustable sample holder 136

Figure 4.81 tungsten target samples 1, 2, 4 and 3 (right to left) after plasma focus firing 138

Figure 4.82 INTI PF measured signals at 12kV, 2.5 Torr Deuterium accompanied by Lee Code fitting (shot 295- Sample 1) 138

Figure 4.83 INTI PF measured signals at 12kV, 2.5 Torr Deuterium accompanied by Lee Code fitting (shot 300- Sample 2) 140

Figure 4.84 INTI PF recorded signals at 12kV, 2.5 Torr Deuterium accompanied by Lee Code fitting (shot 310- Sample 3) 141

Figure 4.85 INTI PF measured signals at 12kV, 2.5 Torr Deuterium accompanied by Lee Code fitting (shot 312- Sample 4) 141

Figure 4.86 SEM image of tungsten target sample 1. Single shot without shutter. 12kV, 2.5 Torr, D. 142

Figure 4.87 EDX analyzes for Tungsten target sample 1 142

Figure 4.88 SEM image of tungsten target sample 2. 5 shots, 12kV, 2.5 Torr, D. 143

Figure 4.89 XRD results for Tungsten target sample 2. 143

Figure 4.90 SEM image of tungsten target sample 3 placed at 8 cm. Holes and cracks are much less than other samples. 10 shots, 12kV, 2.5 Torr, D. 144

Figure 4.91 SEM image of tungsten target sample 4 placed at 6 cm from anode tip. Exposure is 10 shots, at 12kV, 2.5 Torr, D. 145

Figure 4.92 Graphite Target Fixed on Anode Tip 147
Figure 4.93 Silicon Substrate Fixed on Sample holder 147
Figure 4.94 Areas on Samples That Are to Be Analyzed 148
Figure 4.95 Silicon Wafer (left), Silicon Substrates (right) 148
Figure 4.96 Acetone, Iso-propanol, DI-water, Hotplate Stirrer (From left to right) 149
Figure 4.97 Hitachi TM3000 SEM Tabletop 150
Figure 4.98 Graph of Mass of Thin Film Deposited (1 shot) on S1, S2, S3 and S4 as a function of pressure 153
Figure 4.99 Graph of Mass of Thin Film Deposited (5 shots) on S5 and S6 as a function of pressure 153
Figure 4.100 Average Thickness of S1, S2, S3 and S4 over respective Gas Pressure 155
Figure 4.101 Average Thickness of S5 and S6 over respective Gas Pressure 155
Figure 4.102 Average Thickness of SG5, SG8 and SG9 over respective Gas Pressure 155
Figure 4.103 Chemical Composition at Center of S1, S2, S3 and S4 over respective Gas Pressure 158
Figure 4.104 Chemical Composition at Center of S5 and S6 over respective Gas Pressure 159
Figure 4.105 Chemical Composition at Area above Center of S1, S2, S3 and S4 over respective Gas Pressure 159
Figure 4.106 Chemical Composition at Area Above Center of S5 and S6 over respective Gas Pressure 160
Figure 4.107 Chemical Composition at Center of SG5, SG8 and SG9 over respective Gas Pressure 160
Figure 4.108 Chemical Composition at Area Above Center of SG5, SG8 and SG9 over respective Gas Pressure 160
Figure 4.109 Center of S1 162
Figure 4.110 Center of S2 162
Figure 4.111 Center of S3 163
Figure 4.112 Center of S4 163
Figure 4.113 Area above Center of S1 164

Figure 4.114 Area above Center of S2 165
Figure 4.115 Area above Center of S3 165
Figure 4.116 Area above Center of S4 166
Figure 4.117 Center of S5 167
Figure 4.118 Center of S6 167
Figure 4.119 Area above Center of S5 168
Figure 4.120 Area above Center of S6 168
Figure 4.121 Center of SG5 169
Figure 4.122 Center of SG8 169
Figure 4.123 Center of SG9 170
Figure 4.124 Area above Center of SG5 170
Figure 4.125 Area above Center of SG8 171
Figure 4.126 Area above Center of SG9 171
Figure 4.127 The surface of the Low Carbon Steel 173
Figure 4.128 Comparison of the Sample 0, Sample 1 and Sample 2 174
Figure 4.129 Sample 0 which remains untreated 174
Figure 4.130 Sample 1 (a) Before Nitriding (b) After Nitriding 175
Figure 4.131 Sample 2 (a) Before Nitriding (b) After Nitriding 175
Figure 4.132 Sample 0 at the magnifications of X150 at the spot 176
Figure 4.133 Sample 0 at the magnifications of x1000 at the spot 176
Figure 4.134 Sample 0 at the magnifications of X150 at the periphery 177
Figure 4.135 Sample 0 at the magnifications of X1000 at the periphery 177
Figure 4.136 Area Selection of the Sample 0 for EDX 178
Figure 4.137 EDX Elemental Analysis of the Sample 0 178
Figure 4.138 Sample 1 at the magnifications of X150 at spot 180
Figure 4.139 Sample 1 at the magnifications of X500 at spot 181
Figure 4.140 Sample 1 at the magnifications of X1000 at spot 181
Figure 4.141 Sample 1 at the magnifications of x150 at periphery 182
Figure 4.142 Sample 1 at the magnifications of x500 at periphery 182
Figure 4.143 Sample 1 at the magnifications of x1000 at periphery 183

Figure 4.144 Cross Sectional View of Sample 1 184
Figure 4.145 Magnified Cross Sectional View of Sample 1 184
Figure 4.146 Area Selection of the Sample 1 for the EDX 185
Figure 4.147 EDX Elemental Analysis of the Sample 1 185
Figure 4.148 Sample 2 at the magnifications of X150 at spot 187
Figure 4.149 Sample 2 at the magnifications of X500 at spot 187
Figure 4.150 Sample 2 at the magnifications of X1000 at spot 188
Figure 4.151 Sample 2 at the magnifications of x150 at periphery 188
Figure 4.152 Sample 2 at the magnifications of x500 at periphery 189
Figure 4.153 Sample at the magnifications of x1000 at periphery 189
Figure 4.154 Cross Sectional View of Sample 2 190
Figure 4.155 Magnified Cross Sectional View of Sample 2 190
Figure 4.156 Area Selection of the Sample 2 for the EDX 191
Figure 4.157 EDX Elemental Analysis of the Sample 2 191
Figure 4.158 EDX Elemental Analysis of the Sample 2 192
Figure 5.1 Outward appearance of the DPF devices; a- PF6 device; b- PF10 device; c- 3 kJ DPF device [65] 194
Figure 5.2 Large DPF facilities; middle level of the three-floor PF-1000 installation [65] 194
Figure 5.3 Vertical section of DPF chambers optimized for SXR production; MPS [65] 195
Figure 5.4 Computed tube current and radial trajectories of 160 kJ DuPF based on Lee Model Code for 3 Torr (left) and 14 Torr (right) Deuterium; FFM (left), SFM (right) 208
Figure 5.5 Computed tube current and radial trajectories of 160 kJ DuPF based on Lee Model Code for 2 Torr (left) and 2.7 Torr (right) Neon; FFM (left), SFM (right) 209
Figure 5.6 Computed tube current and radial trajectories of 160 kJ DuPF based on Lee Model Code for 1 Torr (left) and 1.5 Torr (right) Argon; FFM (left), SFM (right); the radiative collapse compression in the case of 1 Torr Argon is considerable at the end of radial phase 210
Figure 5.7 Number of neutrons per shot for FFM and SFM at 160 kJ DuPF using Deuterium 211

Figure 5.8 Speed Factor versus pressure in DuPF for FFM and SFM using D, Ne and Ar. 212

Figure 5.9 FIB damage factor of FFM and SFM of DuPF for D, Ne and Ar 214

Figure 5.10 FPS Speed at the exit point versus pressure in DuPF using D, Ne and argon 215

Figure 5.11 Plasma footprint radius at DuPF for its FFM and SFM operation using D, Ne and Ar 216

Figure 5.12 Energy into plasma in % of E_0 versus Pressure for FFM and SFM configuration of DuPF using D, Ne and Ar 217

Figure 5.13 Number of ions per shot for FFM (5cm anode radius) and SFM (10 cm anode radius) operation of DuPF in D, Ne and Ar 219

Figure 5.14 FIB Energy versus pressure in DuPF during FFM and FFM using D, Ne and Ar 220

Figure 5.15 FPS energy to FIB energy ratio during FFM and SFM operations of DuPF using D, Ne and Ar 221

Figure 5.16 FPS energy per ion in DuPF during FFM and SFM run using D, Ne and Ar 222

Figure 5.17 Ratio of FPS speed to axial velocity in DuPF for FFM (5 cm anode radius) and SFM (10 cm anode radius) using D, Ne and Ar 223

Figure 6.1 DuPF-FFM electrodes 226

Figure 6.2 Cross section view of DuPF-FFM electrodes 227

Figure 6.3 2-D and 3-D drawings of DuPF-FFM electrodes 228

Figure 6.4 DuPF-SFM electrodes 229

Figure 6.5 Cross section view of DuPF-SFM electrodes 229

Figure 6.6 2-D and 3-D views of DuPF-SFM 230

Figure 6.7 Different parts of DuPF electrodes 231

Figure 6.8 Main cathode base plate 233

Figure 6.9 Cathode bars, 24 pieces for SFM and 12 pieces for FFM 234

Figure 6.10 DuPF-SFM Cathode bars ring 235

Figure 6.11 DuPF-SFM PTFE Insulator which insulates anode from cathode at the back of electrodes 236

Figure 6.12 DuPF-SFM anode base plate 237

Figure 6.13 DuPF-SFM Pyrex insulator 238

Figure 6.14 DuPF-SFM anode tube end disc 239

Figure 6.15 DuPF-SFM anode tube, 20 cm diameter and 70 cm height 240

Figure 6.16 DuPF-FFM minor cathode plate, additional component for FFM which can be assembled on main cathode plate to change FFM radius 241

Figure 6.17 DuPF-FFM cathode bars ring 242

Figure 6.18 DuPF-FFM PTFE Insulator which insulate anode from cathode at the back of electrodes 243

Figure 6.19 DuPF-FFM anode base 244

Figure 6.20 DuPF-FFM Pyrex insulator 245

Figure 6.21 DuPF-FFM anode tube end-disc 246

Figure 6.22 DuPF-FFM anode tube 247

Figure 6.23 DuPF anode back glass 248

Figure 6.24 DuPF anode high voltage disc 249

Figure 6.25 DuPF main electrodes insulator made from PTFE 250

Figure 6.26 DuPF Aluminum disc for earth 251

Figure 6.27 DuPF main cathode collector grounded cylinder 252

Figure 6.28 DuPF cathode grounded plugin tube 253

Figure 6.29 DuPF stainless steel vacuum vessel 254

Figure 6.30 DuPF stainless steel vacuum cylinder 255

Figure 6.31 DuPF vacuum cylinder down flange 256

Figure 6.32 DuPF vacuum cylinder upper flange 257

Figure 6.33 DuPF vacuum vessel gate 258

Figure 6.34 DuPF vacuum vessel stainless steel window tube 259

Figure 6.35 DuPF vacuum vessel feedthrough tube 260

Figure 6.36 DuPF vacuum vessel stainless steel window flange 261

Figure 6.37 DN10 vacuum flange 262

Figure 6.38 DN25 flange 263

Figure 6.39 DN40 vacuum flange 264

Figure 6.40 DuPF vacuum vessel window glass 265

Figure 6.41 DuPF vacuum vessel assembling 266

Figure 6.42 DuPF electrodes and vacuum vessel assembling 267
Figure 6.43 DuPF main table made of stainless steel 267
Figure 6.44 DuPF main table stainless steel base 268
Figure 6.45 DuPF main table cone which is installed on its stainless steel base 269
Figure 6.46 DuPF main table sheet 270
Figure 6.47 DuPF main table stainless steel tube 271
Figure 6.48 DuPF main table 272
Figure 6.49 DuPF electrodes, vacuum vessel and main table assembly 273
Figure 6.50 DuPF gas panel 274
Figure 6.51 DuPF main gas cylinder 275
Figure 6.52 DuPF gas panel side flange 276
Figure 6.53 DuPF gas panel main cylinder side flange 277
Figure 6.54 DuPF gas panel minor cylinder 278
Figure 6.55 DuPF gas panel minor cylinder side flange 279
Figure 6.56 DuPF gas panel junction tube 280
Figure 6.57 DuPF gas panel stand plate 281
Figure 6.58 DuPF gas panel 3-D 282
Figure 6.59 DuPF electrodes, vacuum vessel and gas panel assembly 283
Figure 6.60 DuPF spark gap set up 284
Figure 6.61 DuPF spark gap cylinder 285
Figure 6.62 DuPF spark gap high voltage semi-sphere 286
Figure 6.63 DuPF spark gap triggering semi-sphere 287
Figure 6.64 DuPF spark gap PTFE box 288
Figure 6.65 DuPF spark gap gas inlet-outlet tube 289
Figure 6.66 DuPF spark gap assembly 290
Figure 6.67 DuPF electrodes, vacuum vessel, main table, gas panel and spark gap assembling 290
Figure 6.68 DuPF stainless steel sample holder 291
Figure 6.69 DuPF sample holder part 292
Figure 6.70 DuPF sample holder vacuum fixer 293
Figure 6.71 DuPF sample holder disc 294

Figure 6.72 DuPF sample holder handle 295
Figure 6.73 DuPF sample holder rod 296
Figure 6.74 DuPF sample holder shutter 297

CHAPTER 1

Introduction and Literature Review

The plasma focus is typically operated in a coaxial geometry with an intense pinch mode. The dynamics comprises an axial acceleration phase, followed by a radial phase consisting of a fast compression, a pinch and an explosive pinch disruption phase. During these two last phases intense radiations are emitted including x-rays and powerful axially directed beams of ions and electrons. The break-up of the pinch also launches axially propagating fast plasma streams. This intense pinch mode is the subject of many studies and much research documentation. The intense radiations and beams and plasma emissions have many applications including fusion neutron generation and more recently the fabrication and deposition of advanced materials and the testing of potential wall materials in fusion-relevant situations.

The DPF facility acts as a type of plasma accelerator [1, 2] that produces directed hot ($T_{pl} \sim 1$ keV) fast ($v_{pl} > 10^7$ cm/s) dense ($n_{pl} \approx 10^{16}$ to 10^{19} cm^{-3}) plasma streams, high energy ion ($E_i \approx 0.01$ to 100 MeV) and electron ($E_e \approx 0.01$ to 1.0 MeV) beams in addition to soft ($E_{hv} \sim 0.1$ to 10 keV) and hard ($E_{hv} \sim 10$ to 1000 keV) X rays and fusion neutrons ($E_n \sim 2.45$ and 14 MeV).

Dense Plasma Focus devices, compared with other thermonuclear devices, have a number of important applications [3, 2]:

- These devices provide an opportunity to expose different materials and objects to pulsed radiations of various types – ion, electron, plasma, X ray, neutron and shock wave of high-power flux density (up to 10^{13} W/cm^2 for fast electrons, 10^{12} W/cm^2 for fast ions, plasma streams and X ray photons and up to 10^9 n/cm^2 for neutrons) with pulse duration in the range 10^{-9} to 10^{-6} s. Thermal loads in these devices produced by the above-mentioned streams and a discharge current may reach magnitudes up to 10^{10} MW/m^2 with the characteristic time of action up to about 10^{-4} s.

- Because most types of radiation generated by DPF are of penetrating nature these devices can produce important volumetric effects (in contrast to lasers).
- They enable the experimenter to choose the specific distribution of pulsed energy between all the above-mentioned types of ionizing radiation – soft and hard X rays, neutrons, electron, ion and plasma beams. This is possible because energy flux density may be significantly different for each type of radiation depending on the mode of operation of the device.
- These streams in DPF devices can be separated in time due to different velocities of their (quasi-)particles.
- These beams in DPF devices can also be separated in space due to different angular distributions and by application of a magnetic field or by using their dissimilar Linear Energy Transfer (LET).

These intense and varied radiations give important opportunities for new and sometimes unusual applications in pulsed radiation physics and chemistry in general, and in different branches of material sciences (radiation material science, nanotechnologies, dynamic quality control of machines and mechanisms during their operation, neutron activation analysis, etc.) in particular.

The physics of interaction of high-power pulses of radiation generated in different fusion devices with materials is especially important for study of damage produced in elements of these installations including the discharge chamber of the DPF itself, but specifically the plasma-facing walls of thermonuclear fusion installations with inertial (laser, wire-array Z-pinches and heavy ion fusion) and magnetic (Tokamak and Stellarator) plasma confinements. In the latter case DPF devices can simulate radiation sources, which are typical for the stressed regimes of the reactor's operation (ELMs, VDEs, disruption instability, etc.).

More recently it has become apparent that for the purpose of materials deposition and fabrication of nano-materials, the intensity of the radiation and beams may need to be controlled. It has been suggested that it may even be beneficial for some situations to eliminate or greatly reduce charged particle beams; for example for the deposition of certain nano-materials, especially from the point of view of spatial homogeneity. Thus the reduction of the intensity of the pinch or even the elimination of the pinch sub-phase may be of use for such situations [4].

In order to extend the usefulness of the plasma focus for applications, it is important to better understand the fundamental processes in hot plasmas, so as to be able to optimize a certain device for a specific application. The aim of this project is to collate known behavior of the Fast Focus Mode (FFM) and investigate the behavior of Slow Focus Mode (SFM) of dense plasma focus [4] and compare their properties with a view to improve performance for material science applications.

In existing plasma focus facilities it is the established practice to maximize the yield in the production of any desired radiation. This in almost all cases means adjusting the plasma focus for intense compression [5] in a selected gas; for example for fusion neutrons, Deuterium is selected; for SXR lithography, neon is selected [6] , for micro-machining, argon or a Deuterium-argon or argon-krypton mixture [7]. On the other hand for good deposition conditions it may be necessary to reduce focus intensity; using the focusing not so much for its explosive emission of intense radiation but for its storage of plasma energy and a subsequent release of the stored energy into streaming plasma. Using Lee Model code it has been recently developed the first modeling tool for the computation of plasma ion beams and high-speed plasma streams from the plasma focus [8, 9]. One of the results shows that a low-voltage, high-energy plasma focus has big advantages as a source of fast ion beams and high-speed plasma streams. In addition its dynamics could also be slowed down and its high energy be used to produce a longer more uniform pulse for materials fabrication. The SFM may thus be most useful in producing fast plasma stream FPS for nano-materials Fabrication [10, 11].

As part of this research we will explore the use of a single plasma focus device with two interchangeable anodes to produce two contrasting modes for:

I. Intense ion beam and streaming plasma pulses for damage studies of potential fusion reactor wall materials, particularly of plasma-facing walls.
II. High power long duration uniform flow of plasma ions and streaming plasma pulses for synthesis of nano-materials

Before continuing with the Introduction and Literature Review we first specify our Problem Statement and Objectives as follows.

1.1 Problem Statement

What is predicted by Lee Model Code for FFM and SFM states in INTI PF machine? What are the neutron time of flight measurements in INTI PF machine during FFM? Is there any correlation between Lee Model Code and ion time of flight measurements in INTI PF machine? What are the applications of FFM and SFM in INTI PF machine? What are the FFM and SFM results for high energy plasma focus device using Lee Model Code? Is it possible to design a 160 kJ DuPF for material applications?

1.2 Research Objectives

The objectives of this project are to conduct numerical and experimental studies of FFM and SFM of INTI PF machine using Lee Code, then to conduct numerical experiments and parameter design of the 160 kJ Dual plasma focus and finally to produce the complete industrial detail design and drawing of the Dual plasma focus with interchangeable electrodes by SolidWorks Software. Subsidiary objectives are to improve diagnostic capabilities by designing and constructing a photomultiplier-plastic scintillator system for D-D fusion neutrons and Hard X-Ray TOF measurements and a Fast Faraday Cup for ion beam measurements.