REPORT

ENHANCING THE QUALITY OF SCIENTIST MOBILITY PROGRAM OF MINISTRY OF RESEARCH, TECHNOLOGY AND HIGER EDUCATION (MRTHE)

By

Prof. Dr. Muhammad Nur DEA

M. Panji Pujasakti

Heri Sulardi

Introduction

The development of innovation in Indonesia is being promoted. Innovation is the blood for the advancement of a nation in the development of Industry 4.0 today. France is one of the countries that has succeeded in developing various high technologies and has become a reference country among other fields of aerospace, transportation, automotive, energy, especially nuclear energy.

The purpose of this visit is to strengthen cooperation in science and technology, especially plasma technology and its application.

Since 1999 plasma technology research and its applications have been carried out at Undip. In 2005 it was agreed by the research group to establish the Center for Plasma Research (CPR) at the Faculty of Science and Mathematics at Diponegoro University. Since then, the CPR has carried out troubles to produce tangible products from research results to commercially viable.

The team incorporated in the Center for Plasma Research has succeeded properly and well in making several plasma technology-based products for the food and environment sector. The environmental sector together with PT Dipo Technology has succeeded in commercializing the air purifier. This product has been marketed and has been installed in several hospitals, offices, smoking rooms, hotels and meeting rooms. CPR products from the application of Dielectric Barrier Discharge Plasma (DBDP) in the form of ozone have been adapted for washing fruit and vegetable agro products and storing grains.

The application of energy from Plasma Physics is very difficult. The application for energy must be through a nuclear fusion reaction. In the world, this research was conducted together with dozens of countries. The research was centered in France. The research center is called ITER is an abbreviation of the International Thermonuclear Experiment Reactor. ITER is being built at Cadarash Aix en Provance close to Aix Marselle University. It was the first nuclear fusion test center in the world and was the center of world research.

Cooperation with Aix Marseille University will be something very strategic to approach plasma research in the field of energy. Indonesia has not participated in this research. Sending students is a strategy that can be done. The mobility of scientists in the field of Plasma and policies driven by the management of the Ministry of Research, Technology and Higher Education is very important.

Visit Aix Marseille University

The visit to Marseille Aix University was carried out to explore the development of Plasma technology in Indonesia that which in the past 20 years has been developed at Diponegoro University. This technology is very generic because it can be applied to various fields including: energy, environment, material science, medicine, biology, agriculture, food. In the field of energy, Aix Marseille University is leading institution in the world. Professor Muhammad Nur has long been in contact with a laboratory at the University. An intern student at the Center for Plasma Research at the University of Diponegoro, Miss Mutia MEIRENI went to the University of Marseille and successfully completed his dissertation. This dissertation is focused in the field Energy, Radiation, Plasma, with titled Spectroscopic diagnostic of magnetic fusion plasmas – application to ITER.

Very strategic research for future energy. The thesis of Dr. MEIRENI focuses on the modeling of the atomic line radiation emitted by magnetic fusion plasmas for diagnostic purposes. An improvement of the accuracy of diagnostics is proposed, in order to have a better characterization of runaway electrons in the context of ITER preparation. In the first chapter, thesis discuss about fusion reaction, about how it is produced in tokamak machines, and we discuss about the disruptions, which are a consequence of instabilities. They are one cause of runaway electrons. In the second chapter, the formalism used in spectral line broadening models is introduced based on quantum mechanics and statistical physics. Numerical calculations are also presented. They are done for applications to synthetic diagnostics in tokamak divertor plasma conditions. Hydrogen Balmer lines with a moderate principal quantum number are considered. In the third chapter, we discuss the physics underlying Langmuir waves. This includes the Landau damping process and its inverse counterpart, the plasma-beam instability mechanism. It is possible to calculate the magnitude of the electric field which is created by a beam of electrons using the quasilinear theory. We present this theory and we present a generalization to strongly nonlinear regimes for which the Langmuir waves are coupled with the ion sound and electromagnetic waves. Finally, we discuss this model and, next, apply the formalism for different beam densities in tokamak edge plasmas and we examine the possibility for making a diagnostic of runaway electrons based on atomic spectroscopy in the fourth chapter.

The examination to defend dissertation was carried out on July 23, 2019. Prof. Nur was one of the foreign reviewers who got the chance. The specific field needed is still occupied by Prof. Nur and his colleagues at Grenoble INP, France and High Temperature Physics in Moscow.

Along with the dissertation exam event was also held cooperation talks between institutions. On that occasion the education attaché of the Indonesian Embassy in Paris could also be present in Marseille. Discussion in the framework of exploratory further collaboration was carried out when it was amicable after the dissertation exam.

Joint discussions with the education attaché of the Indonesian Embassy in Paris, the Ministry of Research, Technology and Higher Education, Prof. Nur from CPR Diponegoro University and researchers from Laboratoire Physiques des Interactions Ioniques et Moleculaires resulted in the decision that cooperation would continue. Sending talented students in the field of Plasma Physics for nuclear fusion from Indonesia will continue to be pursued.

In September 2019, **Achmad Fajar Putranto** was admitted to Doctoral School of Physique et Sciences de la Matière, Faculté des Sciences d'Aix-Marseille Université. Scholarships are given by the French government.

Visit to Grenoble

After visiting Aix Marseiile University, after the test defended dissertation Dr. MEIRENI, Prof. Dr. Muhammad Nur DEA, M. Panji Pujasakti and Heri Sulardi visited Grenoble INP ENSE³. Grenoble INP, it is a center for innovation in energy use and renewable resource research which prioritizes international collaboration and engagement. It brings together key players in research and training disciplines who have expertise in new energy technology. The GreEn-ER building hosts the Grenoble INP-Ense³ engineering school, bachelor's and master's courses for the Université Grenoble Alpes (PhiTEM), and the G2ELab laboratory.

Figure 1: The GreEn-ER building hosts the Grenoble INP-Ense³ engineering school.

Ense³ is in contact with a large number of research facilities which work on key domains such as Energy, Water and Environment. Laboratories are involved in the training of our engineers offering research projects, internships, a research based-course or a job. At Ense³ teacher-researchers work in one of 9 research laboratories.

Ense³ students are active participants in imagining and implementing new spaces for their peers to live, participate in sports, and engage in local culture while benefiting from the proximity of residential housing.

In Gre En ER Grenoble INP, the team discussed with Dr. Nelly Bonifaci is a senior researcher. Dr. Bonifaci was a partner of Prof. Nur more than twenty-five years ago. They work together with 13 international papers has been published. The visit to the innovation center is expected to support a new start of cooperation related to innovation in various fields at Ministry of Research, Technology and Higher Education.

Figure 2: Prof Nur and Mr. Pujasakti in front of the Gre En-ER Grenoble INP ENSE3 building

Grenoble is the Heart of a Global Scientific Project

Located inside the GIANT scientific campus that hosts 30,000 researchers and students, Grenoble INP - Ense³ is part of a community focused on creating strong ties between training, research and industry. The objective of GIANT is to respond to major issues facing our society: renewable energy and environmental issues, information and communication technologies, as well as topics in biosciences and health. Every day, new ideas, partnerships, and advancement are created on scientific and societal levels. Students not only study here, but are trained on research platforms, as well as with laboratories that have established partnerships with the school. Ense³ students have the opportunity to take ownership of key roles in scientific and engineering projects alongside their studies. In addition, many students take leadership roles in student associations and junior council that further enhance the integration of study, collaborative relationships, and research

Figure 3. Polygon Scientific of the Grenoble

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GIANT brings together the best minds in a coherent environment to foster interdisciplinary solutions, confrontation of ideas, responsiveness, exchange and diffusion of knowledge and synthesis of professional skills.

8 Innovation Institutions within GIANT

Higher education institutions:

1. Grenoble INP (Institut Polytechnique de Grenoble)
2. Grenoble Ecole de Management (GEM)
3. Université Grenoble Alpes (UGA)

Major French institution:

1. le Commissariat à l’Energie Atomique et aux Energies Alternatives (CEA)
2. le Centre National de Recherche Scientifique (CNRS)

State-of- the-art European laboratories:

1. l'EMBL pour la biologie moléculaire (European Molecular Biology Laboratory).
2. la source de lumière de l'ESRF (European Synchrotron Radiation Facility)
3. la source de neutrons de l'ILL (Institut Laue-Langevin)

Figure 4. Polygon Scientific of the Grenoble with European Molecular Biology Laboratory, European Synchrotron Radiation Facility and Institute Laue-Langevin

Attachment

Review of Thesis

By: Prof Muhammad Nur

I. Information about the work

1. **Title** : Spectroscopic diagnostic of magnetic fusion plasmas – application to ITER

2. **Author** : Mutia MEIRENI

3. **University** : Aix-Marseille University

Doctoral School 352 : Physique et Sciences de la Matière

Speciality: Energy, Radiation, Plasma

4. **Statement of topic and purpose**

The statement on the topic and the proposed problem to be resolved in this dissertation has been very clearly described in the general introduction. Doctoral candidates have explained how to use spectroscopic techniques to diagnose plasma. In this dissertation, modelling of radiation emitted by plasma magnetic fusion has been proposed as an instrument used. The shape and intensity of the line is calculated taking into account the existence of a fluctuating electric field (Stark effect) because of the collective motion of charged particles. Modelling is tailored to the conditions expected in ITER

In this dissertation, it has also been suggested that passive spectroscopic methods may be used based on direct observations of radiation emitted by plasma. This method allows one to get information about relevant parameters (Ne, Te etc.). In this dissertation, it is explained that the main topic is the calculation of the Stark profile for different atoms and ions found in TOKAMAK, links with runaways' electrons. It was also explained that plasma instability in TOKAMAK was considered by using a statistical model for fluctuations in plasma parameters and taking into account the contribution of strong Langmuir wave turbulence.

II. Description of the Thesis

Thesis with title "Spectroscopic diagnostic of magnetic fusion plasmas – application to ITER" has been described in the general introduction. This thesis is a model of radiation emitted by plasma magnetic fusion for diagnostic purposes. The shape and intensity of the line is calculated by observing the existence of a fluctuating electric field (Stark effect) because the particles are individually charged, or because of their collective movements. In this thesis a discussion of diagnostic spectroscopic magnetic fusion devices has been carried out. This discussion emphasizes the expected conditions in ITER, which is currently being built in Cadarache (France). The method by utilizing the Stark profile is proposed to be a passive spectroscopic method, which is based on direct observation of radiation emitted by plasma. This method allows us to get information about relevant plasma parameters such as electron density (Ne) and electronic temperature (Te). With Stark Effect these runaways electrons are tried to be detected or observed.

The basic principles of broadening the spectrum are discussed using quantum mechanics and statistical physics. Broadening the spectrum of hydrogen atoms especially Balmer series has been obtained by numerical simulations. Broadening provides very meaningful information which means the dependence of the Stark Effect on electron density and can be used as a basis for detecting runaways electrons

In the third chapter, this thesis explain underlying Langmuir waves. This includes the Landau damping process and its inverse counterpart, the plasma-beam instability mechanism. The magnitude of the electric field which is created by a beam of electrons using the quasi-linear theory can be calculated. Finally, this thesis discuss spectroscopy passive method for different beam densities in TOKAMAK edge plasmas to examine the possibility for making a diagnostic of runaway electrons.

III. Interpretation and/or evaluation

A. The first chapter

This chapter has explained in general the basics of nuclear fusion and TOKAMAK including plasma TOKAMAK and TOKAMAK confinement. Specifically this chapter also briefly explains about ITER. Regarding the topic of this PhD Thesis, this chapter describes runaway electrons in the TOKAMAK. The mechanism of the occurrence of runaway electrons is also well reviewed. The interesting thing in this chapter is the diagnostic of runaway electrons

It has been explained that runaway electrons can cause massive damage to the TOKAMAK wall. There are seven identified study topics that have been carried out to monitor electron runaway, including: Infrared Camera; Laser Inverse Compton Scattering; Synchrotron Emission; X-ray Emission; Electron Cyclotron Emission; Radial and Vertical Neutron Camera; Gamma Ray Spectrometers

All of the above techniques use a broad electromagnetic spectrum and each has certain limitations. This dissertation tries to look at diagnostic accuracy by stoking the Stark effect on hydrogen atom emissions due to the effect of runaways' electrons.

Very important and very interesting from chapter 1 is an explanation of passive spectroscopy to be an alternative tool for detecting runaways electrons.

Which is still a big question mark in chapter 1 is that there is no clear information about the validation of this simulation model. The results shown in chapter 2 also cannot provide information about the validation of the model. The validation in question is a comparison between the broadening synthetic spectrum and the real spectrum obtained from the emission of H atoms in the tokamak. Is this possible to do, or a real spectrum of related emissions has not been experimented on.

B. The second chapter

In chapter two, this dissertation has explained well fundamental l concepts such as quantum mechanics and statistical mechanics. The basic principle of the occurrence of the Stark Effect through perturbation theory of quantum mechanics has been used to describe the broadening of spectral lines. The shape of the spectral line is explained strictly from the energy emitted by spontaneous emission of photons by atoms. Some mechanisms contribute to broadening lines.

It has also been explained that the Stark effect is more important than broadening of Doppler Effect when the plasma density is high or when the main quantum number from the initial level is high.

The statement that the broadening of the line spectrum is directly proportional to the density of particles around the emitter, and therefore, can be used as a diagnostic measurement parameter of TOKAMAK Plasma. It is possible to create a FWHM graph as function of Ne for the same B, Te and θ. This graph is very helpful in showing that the broadening line spectrum is strongly influenced by electron density.

The use of code by applying Ne, Te, B and θ into the code will give the results of widening the spectrum of the line with the dominant Stark Effect assumption. Validation of this model from plasma TOKAMAK spectrum emissions is still awaited. This validation can provide support for passive spectroscopy diagnostics in the plasma ((especially for N_e and T_e) TOKAMAK edge region in ITER operations. In defence of this dissertation, the comments or explanation about this opinion can be conveyed.

C. The third chapter

The discussion in the third chapter on Langmuir waves and the process of attenuation of Landau damping process and its inverse counterpart, has been able to explain well the mechanism of plasma-beam instability. This discussion has also been able to explain the magnitude of the electric field made by a beam of electrons. Very nonlinear Langmuir waves are also found in this chapter. What is still lacking is that the link between instability of the plasma beam has not been well discussed with runaway electrons.

We know that, Vlasov uses a consistent collective field generated by charged plasma particles from kinetic-based collision descriptions for the interaction of charged particles in the plasma. Vlasov describes the use of different distribution functions between electrons and plasma positive ions. The equations are used separately specifically for ions and specifically for electrons, even though the equation forms are the same. This type of plasma that has not included hot plasma. In this dissertation, we do not find the reason for using the Vlasov-Poisson equation and do not use the Vlasov-Maxwell equation as an approach.

Another thing that needs to be stated here and obtained clarification is that the broadening calculation of simulated line spectrum $D\alpha$, D_{β}, and $D\gamma$ has been carried out using the Stark broadening model and assuming that the values $T_e = T_{at} \equiv T$. Assume that the temperature of electrons, ions, and atoms are the same and close to plasma temperatures show the type of hot plasma and thermodynamic equilibrium has occurred.

D. The fourth chapter

In chapter 4 of this dissertation, passive spectroscopy is further developed, in the context of ITER preparation. Development is carried out to improve diagnostic accuracy to get better characterization of runaway electrons. This chapter also describes that the runaway electron beam energy is sufficiently high, an electric field is generated through the plasma-beam instability. If it is comparable to the thermal plasma (Holtsmark) micro-field, it can be observable in the spectra through the Stark effect.

Broadening spectrum line through calculations of Lyman α in TOKAMAK edge plasma conditions, under the influence of a beam of energetic electrons. If the beam energy is high enough, this electric field is comparable to the thermal microfield and it can induce an additional broadening of spectral lines observed in passive spectroscopy due to Stark effect.

In figure 4.2, we find the graph of dipole autocorrelation function (DAF) as function of time. Formula 4.3 shows that DAF depends on n, l and m. We also know that Lyman α is a transition from n = 2 2p) to n = 1 (1s). In this thesis, it has not been explained how to take the values of l and m.

In the introduction to this chapter it has been mentioned that in TOKAMAK, runaways electron has a speed close to the speed of light. This speed requires a relativistic approach. Is the effect of wave collapse on radiating emitters in the use of the Vlasov Poison kinetic approach? Why is this approach done, why not Vlasov Maxwell's approach?

The important and very interesting thing about this thesis is that it has obtained the broadening spectrum line through calculations of Lyman α in TOKAMAK edge plasma conditions, under the influence of a beam of energetic electrons. This is very possible to use as passive spectroscopy. In Figure 4.11 the Lyman α line spectrum is shown for N_e, N_{beam}, ∆Ek, T_e and T_o, but it has not been explained why this value is taken, for example $T_e = 10\ T_o$.

For the result in Figure 4.11, we can create a FWHM graph as function of N_e, N_{beam}, for the same, T_e and T_o. This graph is very helpful in showing that the broadening line spectrum is strongly influenced by electron density in plasma and electron density in beam of runaways electrons.

Another question that can still be asked is why the treatment used in chapter 4 is only for Lyman α line spectrum. What if it is also used for Balmer series? Are there limitations to the database?

E. General evaluation and conclusion

This thesis will be very interesting if there is a general discussion. This discussion strongly supports the big idea which is the hypothesis of this dissertation, passive spectroscopy can be used to detect electron beams that emerge from confining plasma in tokomak. Runaways electrons will damage the TOKAMAK wall. The general discussion will provide interrelationships between chapters, so that "the red thread" of this dissertation is well illustrated.

Finally from all that I did a review of **Miss Mutia Meureini's dissertation**, I found that a new breakthrough had been made to support ITER's reliability. **In my opinion, this dissertation extremely the feasibility of being presented in front of the jury of Doctoral Desertion Defense of Doctoral School 352: *Physique et Sciences de la Matière* with Speciality on Energy, Radiation and Plasma.**

This review has been done by:

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Your title : Prof. Dr

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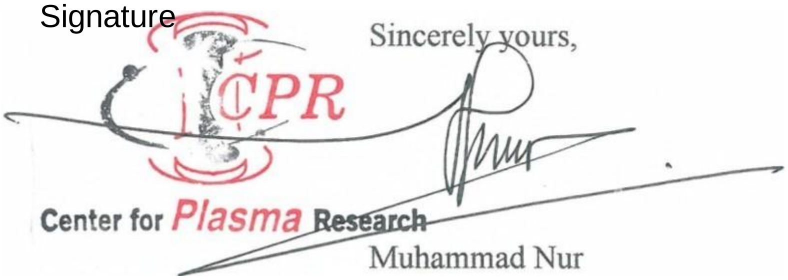
Date: 7th July 2019

Signature



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Date: 7th July 2019

Signature

Sincerely yours,

CPR

Center for Plasma Research

Muhammad Nur