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Conference Report

APTWG: The 5th Asia-Pacific Transport Working Group Meeting

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Abstract

This conference report gives a summary on the contributed papers and discussions presented at the 5th Asia-Pacific Transport Working Group Meeting held at Dalian, China from 9–12 June 2015. The main goal of the working group is to develop a predictive understanding of the basic mechanisms responsible for particle, momentum and energy transport in magnetically confined plasmas. The topics of the meeting in 2015 were organized under five main headings: (1) turbulence suppression and transport barrier formation, (2) effect of magnetic topology on MHD activity and transport, (3) non-diffusive contribution of momentum and particle transport, (4) non-local transport and turbulence spreading and coupling and (5) energetic particles and instability. The Young Researchers' Forum which was held at this meeting is also described in this report.

Keywords: transport, plasma, turbulence

(Some figures may appear in colour only in the online journal)

1. Introduction

The 5th Asia-Pacific Transport Working Group (APTWG) Meeting was held at Dalian, China from 9–12 June 2015 and is a series of APTWG meetings that started at NIFS Japan in 2011 [1] then at Chengdu, China, in 2012 [2] and at Jeju island, Korea in 2013 [3] and at Kyushu University in 2014 [4]. The main goal of the APTWG is to develop a predictive understanding of the basic transport mechanisms responsible for particle, momentum and energy transport in magnetically confined plasmas. The annual meeting of the APTWG was organized under four or five technical working groups (WG) from the outset of the meeting and aimed to present the progress and discuss the status and the future in each group.

The 5th APTWG Meeting consisted of five sessions: (a) plenary sessions, (b) working group sessions, (c) poster sessions, (d) the Young Researchers' Forum and (e) summary sessions. The purpose of the plenary sessions was to discuss the important topics in transport physics that have not been clarified yet and the scope of this session is intentionally broad. The purpose of the working group sessions was to discuss problems that have not been clarified yet. The five working groups are as follows.

(A) Turbulence suppression and transport barrier formation.
(B) Effect of magnetic topology on MHD activity and transport.
(C) Non-diffusive contribution of momentum and particle transport.
(D) Non-local transport and turbulence spreading and coupling.
(E) Energetic particles and instability.

Each working group includes theory, simulation and experiment, with the ultimate goal of testing theory, simulations and models against experiment. In addition, diagnostic needs and novel diagnostic ideas for a given area are also included in the scope of each working group. Each working group session consisted of three or four invited talks and three to five oral talks and a half hour discussion. Poster sessions of 90 min were arranged after the oral sessions of each working group session. Summary talks of each working group were given on the last day. The purpose of the Young Researchers' Forum (YRF) was to encourage/promote discussions among young researchers. The discussion topics will be anything that is related to the scope of this conference, with emphasis on how to promote future collaboration among young researchers in the Asia-pacific region.

In this report, we summarize the main contributions to and discussions during the 5th APTWG Meeting. Section 2 is devoted to summarizing the plenary sessions. Sections 3–8 describe summaries of the five working groups in this meeting and the YRF. A summary of the meeting is given in section 9.

2. Summary of the plenary session

This year, there were five talks in the plenary sessions: (1) generation and damping mechanism of plasma flow in toroidal plasmas, (2) challenges and opportunities of non-axisymmetric fields in tokamaks, (3) effect of magnetic topology on MHD and transport in magnetic confinement fusion, (4) overview of J-TEXT experimental results and (5) on collisionless zonal flow damping.

Ida presented a talk on the generation and damping mechanisms of plasma flow in toroidal plasmas. In this presentation, he categorized the mechanisms determining the toroidal flow into two parts: torque and Reynolds stress [5]. The torque, including neutral beam injection (NBI) torque, $\mathbf{j} \times \mathbf{B}$ torque, neoclassical viscous damping and neutral particle collision damping, describes the momentum balance in velocity space on the magnetic flux surface. The Reynolds stress has three terms that have different parameter dependence. The first term is the diffusive term proportional to the velocity gradient, the second is the pinch term proportional to the velocity itself and the last is the residual stress term which does not explicitly depend on velocity shear or the velocity. Experimental evidences that the residual stress can produce disparity of toroidal rotation and flip of intrinsic torque were overviewed. The effect of magnetic field stochastization on plasma flow was also discussed. It was found in the LHD experiment that the magnetic field stochastization caused a strong linear damping of toroidal flow which cannot be explained by a pure diffusive process and an additional process was needed [6]. It was pointed out that a possible candidate for the additional process is a residual stress in co-direction.

In presented a talk on the challenges and opportunities of non-axisymmetric fields in tokamaks. Recent KSTAR experiments showed that both intrinsic non-axisymmetric error field ($<\delta B_{m/n=2/1}>/B_0 \sim 10^{-5}$) and toroidal field ripple ($\delta B_{TF}/B_0 = 0.05\%$) would be among the lowest in the world [7]. The observed higher plasma rotation (Mach number up to 0.8) is likely due to both low error field and field ripple. It also shows that the uniqueness of $n = 1$ RMP ELM suppression in KSTAR may be due to the low level $n = 1$ intrinsic error field which makes the plasma less susceptible to kink-resonant mode-locking [7]. A comparative study showed that the midplane RMP strongly influenced the ELMs while two off-midplane RMPs appeared insignificant on ELMs. It was found that the midplane RMP becomes equivalent to the two off-midplane RMPs in terms of stochastic field requirements in KSTAR. It is speculated that the effectiveness of 3D configurations, not just field strengths, needs to be understood possibly in terms of kink-response and neoclassical toroidal viscosity (NTV) physics.

Liang presented a talk on the effect of magnetic topology on MHD and transport in magnetic confinement fusion. The talk first presented experimental results that the magnetic ergodization can produce co-current rotation or positive radial electric field (E_r), leading to lobe structure near the X-point and the strike point splitting. Then the talk focused on the ELM control by using RMP on JET and lower hybrid wave (LHW) on EAST. The two methods could change the edge magnetic topology and impact the ELMs. Type-I ELM suppression was realized using $n = 2$ RMP fields in high collisionality H-mode plasma on JET with ITER-like wall (ILW) [8]. During ELM suppression, the splitting of the outer strike point and a reduction of erosion of the outer tungsten divertor were observed. When LHW was applied to H-mode plasma on EAST, strong ELM mitigation was observed [9]. During the application of LHW, helical current filaments flowing along field lines in the scrape-off layer were observed and believed to change the magnetic topology, leading to the splitting of the outer divertor strike points.

Zhuang presented an overview of transport related studies on J-TEXT at Huazhong University of Science and Technology of China. A 17 chord polarimeter–interferometer system (POLARIS) has been developed [10] and used to study the equilibrium transition during static RMP penetration, perturbations on current density, electron density due to an island and particle transport during sawtooth circles [11]. It has been found that the RMP can increase or decrease plasma density and a detailed research showed that the core density change is directly related to the frequency difference between the RMP and the mode [12]. During the application of RMP, a magnetic island can be formed in the edge and the geodesic acoustic mode (GAM) is reduced in the island region while low frequency zonal flow (LFZF) power is also reduced inside the island but increased at the boundary of the island. The electrode biasing experiment supported the hypothesis that the residual stress is the origin of the intrinsic rotation.

Diamond presented a talk on the collisionless damping and saturation of zonal flows. The dual cascade of enstrophy and energy in quasi-2D turbulence strongly suggests that a viscous but otherwise potential vorticity (PV) conserving system decays selectively toward a state of minimum potential enstrophy. They derive a nonperturbative mean field theory for the dynamics of minimum enstrophy relaxation by constructing an expression for PV flux during the relaxation process. The theory is used to elucidate the structure of anisotropic flows emerging from the selective decay process. This structural analysis of PV flux is based on the requirements that the mean flux of PV dissipates total potential enstrophy but conserves total fluid kinetic energy. Their results show that the structure of PV flux has the form of a sum of a positive definite hyperviscous and a negative or positive viscous transport of PV. Transport parameters depend on zonal flow and turbulence intensity. Turbulence spreading is shown to be related to PV mixing via the link of turbulence energy flux to PV flux. In the relaxed state, the ratio of the PV gradient to zonal flow velocity is homogenized. This homogenized quantity sets a constraint on the amplitudes of PV and zonal flow in the relaxed state. A characteristic scale is defined by the homogenized quantity and is related to a variant of the Rhines scale. This relaxation model predicts a relaxed state with a structure which is consistent with PV staircases, namely, the proportionality between mean PV gradient and zonal flow strength. At the end of the presentation, the L-H threshold of low collisionality was also discussed.

3. Turbulence suppression and transport barrier formation

This working group focused on the investigation of the behavior of turbulence and explored the physics of transport barrier formation. A total of 19 papers including four invited, five orals and ten posters were presented. Based on the physics topics we categorize the session into four subgroups: (1) experimental observations and numerical study during the mode transition, (2) edge structure and behavior, (3) turbulence structure and behavior and (4) others. Here, we provide a summary of the presentations.

3.1. Experimental observations and numerical study during the mode transitions

In this subgroup, we had six presentations (four invited, one oral and one poster) discussing how plasma behaves during L-H/H-L transitions, L-I-H transition or ELMy H-mode to QH mode transition.

Kobayashi presented edge dynamics of the L-H transition observed with the Heavy Ion Beam Probe (HIBP) in the JFT-2M tokamak. The HIBP can measure plasma potential and density with high temporal and spatial resolutions. As the time derivative of the radial electric field $\boldsymbol{E}_{\mathrm{r}}$ can be expressed in terms of the total radial current J_{r} which consists of loss-cone loss J_i^{lc}, neoclassical viscosity J_i^{bv}, turbulent Reynolds stress $J_i^{v\nabla v}$, wave convection J_{e-i}^{wave}, charge exchange J_i^{cx} and other terms [13], the author compares the measured J_{r} estimated by the plasma potential measurements using the HIBP with the theoretical expressions of the sum of J_i^{lc} [14, 15], J_i^{bv} [15, 16] and $J_i^{v\nabla v}$ [17]. Note that the theoretical expressions of these three terms allow one to estimate them based on the experimentally obtained plasma parameters, and it is found that the Reynolds stress term is much smaller than the first two terms within the Nyquist frequency of the HIBP system. Estimated J_{r} is zero during the L-mode and shows a peak at the L-H transition and another, but smaller, peak (secondary peak) after about 3 ms of the transition. This J_{r} is compared with the sum of the three terms ($J_i^{\mathrm{lc}} + J_i^{\mathrm{bv}} + J_i^{v\nabla v}$) and it shows that the theoretical model (1) is in good agreement with the observation in the order of magnitude and (2) is missing the secondary peak and a stationary negative current during the L-mode, i.e. $J_i^{\mathrm{lc}} + J_i^{\mathrm{bv}} + J_i^{v\nabla v}$ has a finite positive value during the L-mode. For the missing parts, the author makes comments on the necessity of improving understanding of the momentum balance during the L-mode and precise measurements of high k turbulence.

Xu presented experimental observation from the HL-2A tokamak on triggering the L-I and I-H transitions by MHD crashes with the reduced threshold power [18]. When the NBI with 1 MW power is applied to the plasma, the author finds that a kink-type MHD mode and its crash are routinely observed prior to both L-I and I-H transitions; while without such a crash, the mode transition does not occur. Such an observation is explained by the author stating that the MHD mode crash releases a substantial amount of energy from the core to the edge causing the increase of pressure gradient, thereby creating sufficient E_{r} shear to suppress the turbulence. This, then, leads the plasma to enter a higher confinement mode. The author also finds that if electron cyclotron resonance heating (ECRH) power (0.4–1.6 MW) is provided in addition to the NBI heated plasma, then the MHD mode disappears, and the plasma enters into the H-mode at higher power threshold. Approximately 30–40% of power reduction is achieved to trigger the L-H transition when the MHD crash is observed at HL-2A. At fixed NBI heating power, the larger the plasma density, the bigger (in magnitude) the MHD mode is required to trigger the I-H transition.

Dong presented characteristics of turbulence, zonal and diamagnetic flow in L-I-H transitions of HL-2A tokamak in connection with the limit cycle oscillations (LCOs). An existing physical model that includes three loops of zonal flow versus turbulence and turbulence versus pressure gradient is presented to explain the two observed types of LCOs, i.e. Type-J where E_{r} shear increase leads the turbulence suppression and Type-Y where turbulence leads E_{r}, and the author states that the experimental observations supports the model. Type-J LCOs are routinely observed during I-H transitions, while Type-Y LCOs are observed in L-I-L and the early phase of L-I-H (note: right before I-H transition Type-J is observed). During the I-phase in H-I-H transition, Type-Y is not observed. Further, the author states that diamagnetic flows in the late I-phase and I-H transition play a dominant role in addition to the zonal flows driven by the turbulent Reynolds stress. Based on the experimental observations, three conditions for the I-H transitions are identified: (1) the I-phase has Type-J LCOs, (2) the pressure gradient scale length L_{p} is less than a critical value (~1.7 cm for the invested cases), and the E_r shearing rate is higher than the critical values (~10^6 s^{-1} for the invested cases), and (3) the growth rate of the diamagnetic flow is equal to or higher than the ion–ion collision frequency.

Huang reported a L-H transition study with the lower hybrid wave (LHW) as an auxiliary heating on EAST. The density roll-over dependence of L-H transition power threshold was observed in the plasma with $B_t = 2.35$ T and the minimum power threshold accessing the H-mode is with a density normalized by Greenwald limit density at about 0.38. Furthermore, the author has categorized H-mode discharges into three groups as (1) single L-H transition, (2) the first of multiple L-H transitions and (3) followed multiple L-H transitions, and finds that confinement time is inversely proportional to the plasma current regardless of the categories; while the single L-H transition tends to have better confinement time. The author also finds that dithering length (in time) is smaller for a faster increase of plasma energy and slower increase of plasma density.

Park presented a numerical simulation work [19] with the aim of determining the key parameter causing the L-H transition and the sequence of the transition based on the 3D fluid model BOUT ++ with resistive ballooning turbulence. The author finds that the key parameter in L-H transition is R_T defined as the ratio of energy transfer rate from turbulence to zonal flow to the total turbulence input power, i.e. if $R_T > 1$, then the edge transport barrier (ETB) is formed. A detailed study on the evolution of ETB formation shows that R_T first becomes greater than 1 which causes the turbulence-driven flow shear to increase. This, in turn, increases the pressure gradient at the edge generating even higher E_r shearing rate. Once the E_r shearing rate becomes larger than the linear growth rate of the unstable modes, then the sustained H-mode is created. The author comments that this numerical observation occurs only if the input power is larger than a threshold power.

Guo presented his theoretical work on how phase dynamics can explain the ELMy → QH mode transition. This work shows that $E \times B$ shear governs the dynamics of the cross-phase of the peeling-ballooning (PB)-mode-driven heat flux, and so determines the evolution from the ELMy H-mode to the quiescent H (QH) mode. The mode transition is found to follow from the conversion from a phase locked state to a phase slip state, where the higher $E \times B$ shearing rate corresponds to a higher phase slip frequency. PB modes are pumped continuously in the phase locked state, while in the phase slip state the PB activity is a coherent oscillation. The author also provides the experimentally verifiable scaling of the critical $E \times B$ shearing rate, i.e. ELMy H-mode if the $E \times B$ shearing rate is smaller than the critical value (phased locked state), and QH-mode otherwise (phase slip state).

3.2. Edge structure and behavior

In this subgroup, we had four presentations (one oral and three posters) discussing the experimental, numerical and analytical results on the structure and behavior of edge plasmas and their connection to pedestal turbulence.

Zhang presented characteristics of pedestal turbulence, specifically coherent mode (CM) and broadband fluctuations (BB) during the ELM free phase [20], measured with the reflectometry on EAST. As for how the small scale fluctuations correlate with the equilibrium profile evolution, the author finds that the both CM and BB reduce the increasing rate of the pedestal pressure. Thus, the author states that both modes have an effect on outward pedestal transport. The CM typically appears during the ELM free phase just after the L-H transition for about 10 ms, and as the CM disappears the BB fluctuations start to be observed. The CM rotates in the electron diamagnetic direction in the lab frame with a poloidal wavenumber of 0.5–0.7 cm^{-1}, and its frequency chirps down from 80–100 kHz to 40–50 kHz as the pedestal evolves. During the inter-ELM phase, the pedestal turbulence is typically dominated by the BB fluctuations with the poloidal wavenumber of 0–3 cm^{-1} rotating, in the lab frame, in the electron diamagnetic direction in the pedestal and the ion direction in the pedestal shoulder.

Wang presented the effects of magnetic perturbations (MPs) on density fluctuation in the pedestal region via reflectometry on EAST [21, 22]. When the non-resonant MPs are applied during the H-mode, fluctuation amplitudes of the low frequency component are observed to be increased, and the spectrum broadening occurs after the H-L back transition. On the other hand, if the resonant MPs are applied during the H-mode, the spectrum broadening is observed within the H-mode. Reduction of pedestal density gradient is observed in both cases. If the rotating resonant MPs are applied during the H-mode, spectrum of the fluctuation changes with the rotating phase, and reduction of edge temperature is observed. For all three cases, density pump-out is observed.

Zhu presented three different methods to estimate the SMBI (supersonic molecular beam injection) fuelling efficiency based on the electron density profile measurement on EAST. The fuelling efficiency is defined as the ratio of an increased number of plasma ions to the injected total number of particles by SMBI. The injected total number of particles by SMBI is estimated by assuming that the total number is linearly proportional to the SMBI pulse width in time. To estimate the increased number of plasma ions, the author uses three different methods. The first one is that the line averaged density is obtained from the interferometer signals, and the change of the averaged density is multiplied by the plasma volume. The second method is utilizing the multi channel polarimeter–interferometer (POINT) to get the increased number of plasma ions. The third one is adding the microwave reflectometry system to the POINT. The author finds that all three methods provide similar results, while the second and third methods tend to be a bit more accurate over the first method. Since the third method is computationally heavier than the second one, the author concludes to use the second method. Using the second method, the author finds that injected particles are mostly deposited in the edge region, and fuelling efficiency drops as the pulse width (in time) increases.

Itoh presented his theoretical work on the spatial structure of solitary radial electric field at the plasma edge in toroidal confinement devices [23]. In order to investigate the importance of the radial current due to the neoclassical transport process, the author reported a scaling relation for the solitary structure of radial electric field and the dependence of the electric field structure on the plasma parameters and geometrical factors. The order of magnitude estimations based on the proposed theoretical work are found to be not far from the experimentally observed ones. Furthermore, the author discussed the difference between the tokamak and helical plasmas and the implication of the results to the limit of achievable gradient in the H-mode pedestal.

3.3. Turbulence structure and behaviour

In this subgroup, we had six presentations (one oral and five posters) on the general structures and behavior of turbulence.

Kishimoto presented his work, carried by a global flux-driven gyro-kinetic simulation GKNET [24], on the spatio-temporal structure and dynamics of turbulence in a toroidal system. The author reports that the turbulence is dominated by three different spatio-temporal scales which are (1) fast time scale avalanches, (2) global intermittent bursts resulting from the instantaneous formation of radially extended global mode and (3) slow time scale avalanches coupled with the dynamical evolution of $E \times B$ staircase [25]. The global intermittent bursts are caused by a quasi-ballooning structure with meso- to macro-scale radial correlation length. This structure grows once small scale potential vortices excited in different radial locations are in phase, but the mode quickly disintegrates as the zonal flow and/or geodesic acoustic modes (GAMs) are generated. The author also finds that the dynamical evolution of the $E \times B$ staircase takes place in the outer region and leads to a break in the stiffness.

Li presented his work on the collisional damping rate and real frequency of GAMs as a function of the ion collision rate based on a drift kinetic model with five different collision operators [26]: (1) Lorentz operator independent of energy, (2) Lorentz operator with an energy dependent collision frequency, (3) full Hirshman–Sigmar–Flarke form collision operator, (4) Krook operator with number and energy conservation term and (5) Krook operator with number conservation term. Overall trends of the damping rate of the GAMs are found to increase at low ion collision rate but decrease at high ion collision rate regardless of the choice of the collision operator models. However, it is found that the damping rate is much higher for the number-conserving-only Krook operator compared to using other operators. The real frequency of GAMs always decreases as the ion collision rate increases. Again, the number-conserving-only Krook operator asymptotes to a different value compared to other operators. Based on this study, the author concludes that the property of both conservations of energy and number density is important to study the dynamics of the GAMs.

Kim presented his work on the reliability of turbulence correlation length measurement. The main question he finds an answer to is that how reliably one can measure the correlation length of the turbulence using only two spatial points. To find an answer to this question he generates a set of synthetic data with many random Gaussian events in a 3D toroidal geometry for which the author knows the true correlation length. Then, by using the data from only two spatial points, the author generates the correlation function from which the correlation length is estimated. The author concludes that if the separation distance between the two measurement points is approximately greater than half and less than four times the true correlation length, the measurements can be reliable. This finding is applicable for the 50% noise level.

Miwa presented the spatiotemporal structures of the mode that propagates in the ion diamagnetic direction in a linear device. The author had shown that it is possible to excite the ion temperature gradient (ITG) mode in the linear device, by using a fluid model [27]. The mode that propagates in the ion diamagnetic direction was observed by an azimuthal multi probe-array, which is consistent with ITG modes. The author also evaluated the axial mode-number by using a novel cross-correlation technique with an axial probe-array. The obtained axial mode-number is 0 ~ 0.5, whose ambiguity is caused by how to assume the axial plasma boundary. This circumstantial evidence supports that the observed mode here is a kind of ITG mode. The author remarked that more investigations such as direct measurement of the ion temperature fluctuation should be carried out to further vindicate the observation of ITG modes.

Yu presented his theoretical work on nonlinear excitation of zonal flow by drift waves in tokamak plasmas with toroidal rotation [28] using the ideal MHD equations. The author finds that the radial wave-number and the nonlinear growth rate of the driven GAM increase with the speed of the toroidal rotation. The frequency shift of the GAM due to the toroidal rotation is also captured. The growth rate of the zonal flow is decreased by the frequency shift of the GAM and increased by the additional nonlinear terms with the toroidal rotation velocity. If the amplitude of the pump drift wave is greater than the threshold value, which is a function of the Mach number of the toroidal rotation, the nonlinear growth rate increases with the toroidal rotation; otherwise, the nonlinear growth rate decreases.

Itoh presented work on hysteresis in gradient-flux relation of core plasmas. This hysteresis is ubiquitous in the plasma [29], so that the change at the edge propagates to the core, and vice versa. This way of thinking provides a new insight into the fast response of the edge transport barrier in responding to the control parameters in the core.

3.4. Others

In this subgroup, we had three presentations (one invited, one oral and one poster) discussing scenario development and considering diagnostics for a fusion power plant.

Xu presented how one may achieve high performance plasma with low-torque and large q, i.e. $q_{\rm min} > 2$, where q is the safety factor. The author notes that large q is preferred to avoid disruption. The author has performed the experiment on DIII-D and reports that high confinement ($H_{89\rm p} = 3.5$ or $H_{98\rm y2} = 2.1$ at $\beta_{\rm N}$ ~ 3) is sustained for about 150 ms. The author associates such a high confinement with the formation of an ITB (internal transport barrier) at large minor radius, i.e. ρ ~ 0.6–0.7, mainly in the electron channel. The key to achieving good confinement from the beginning of the discharge is to achieve a high pedestal by strong gas puff.

Yu presented the experimental observation of the ion ITB on HL-2A [30]. The ion ITB is observed during the NBI heated discharges, where the ion temperature is measured using the charge exchange recombination spectroscopy. The position of the ITB foot is located at the $q = 1$ surface. The experimental observations show that the maximum normalized gradients of ion temperature with the long lived modes or the fishbone instabilities are larger than those with strong sawtooth osscillations. Simulations indicate that the ion thermal diffusivity inside the ITB can reach the neoclassical level.

Li presented work on what needs to be considered for preparing diagnostic systems at the China Fusion Engineering Test Reactor (CFETR). The author states that once the measurement requirements and their justifications are provided, diagnostic systems must be selected based on technical consideration and integration to the tokamak with other diagnostics while the radiation effects are taken into account.

Besides our intellectual curiosity on turbulence and its behavior in an anisotropic toroidal geometry, we have a practical goal: suppress the transport level to realize a fusion power plant. In this working group, we have a nice distribution of experimental, numerical and theoretical works. On the other hand, only a few cases attempt to compare experimental and numerical/theoretical results quantitatively. It is important to acquire predictive capability so that we can develop plasma scenarios which provide a good enough tokamak performance to generate a reasonable amount of electricity without performing expensive experimental parameter scans. Therefore, we believe that it is necessary to enhance our activities further on quantitative comparisons between experimental observation and numerical/theoretical works.

4. Effect of magnetic topology on MHD activity and transport

The effect of magnetic topology on MHD and transport has been recognized to be crucial in ELM suppression by resonant magnetic perturbations (RMP). Common capabilities in RMP related studies on EAST, J-TEXT, KSTAR and LHD etc make it possible to address key issues and emphasize the studies in this important new area in the Asia-pacific region. In this session, there were 17 presentations including 3 invited talks, 3 oral talks and 9 posters. They covered topics including MHD instabilities, RMP and its application for ELM control, the interaction between MHD and turbulence, and some other MHD modeling etc. Main progress in these topics is summarized in the following.

4.1. Progress in MHD instabilities studies

Ohdachi presented the observation of localized mode in the bad curvature region at the core-density-collapse event in the Large Helical Device (LHD). In LHD, a peaked pressure profile is formed during so-called internal diffusion barrier (IDB) plasmas [31] when the preset magnetic axis is shifted outward. The pressure gradient in this kind of discharge is one of the largest in LHD. The limit of the profile peaking is determined by a large-scale collapse event, called 'core density collapse' (CDC) [32]. It was reported that magnetic configuration of the IDB plasma having CDC is unstable for the ideal ballooning mode [33]. Pre-cursor like oscillations just before the CDC was observed only in the outboard side of the plasma. By a newly developed 2D soft x-ray array system [34], having 6(poloidal) $\times$ 8 (toroidal) channels, plasmas at the outboard side of the horizontally elongated section are observed. Pre-cursor like oscillations are found to be localized at the local bad-curvature region. This localized structure is consistent with other fluctuation measurements, e.g. CO_2 laser imaging interferometer.

Liu presented the observations of instability-induced L-H transition in the HL-2 A. Recently, some new results that may clarify the nature of L-H transition and the mechanisms that trigger their onset, has been evidenced. The new feature, the coupling of the fishbone mode with the edge plasma parameters during high-β discharges, is found. Such strong fishbone driven by energetic ions routinely occurs and crashes rapidly just prior to the L-H transition. Measurements form reflectometry also suggest that the fishbone could provide a locally enhanced shear in the plasma flow due to fast ion redistribution, and act as a trigger for the L-I or L-H transition. Investigating the mechanism behind this new phenomenon is of great interest in order to understand the transport mechanism, which remains an open issue in tokamaks.

4.2. Progress in RMP and ELM physics studies

Sun presented the recent observations of ELM mitigation by magnetic perturbations (MPs) on EAST. A flexible RMP system [35] has been commissioned and initial results about ELM mitigation with toroidal mode numbers $n = 1$ and $n = 2$ RMP have been observed in the 2014 campaign. ELM mitigation during the application of an $n = 1$ even (up down symmetry) coil configuration with an amplitude of coil current 10kAt (each coil consists of four turns and the current supply is 2.5 kA) has been observed in type-I ELMy H mode plasmas heated by 2 MW NBI with a moderate normalized collisionality around 1. The ELM frequency increases from around a factor of 5 and the crash amplitude and the particle flux on the divertor are reduced by a similar factor. Clear density pump-out and magnetic braking effects have been observed during the application of RMP. Footprint splitting is observed in both static and rotating field cases and agrees well with vacuum modeling. Internal magnetic field perturbation measurement with POINT diagnostics on EAST has been presented by Yang. It can be applied for plasma response studies and compared with the MHD response modeling in the future.

Jhang presented a mechanism for magnetic field line stochastization during an edge pedestal collapse. On the basis of 3D nonlinear magneto-hydrodynamic simulations using BOUT++ code, it is proposed that the nonlinear energy transfer among ballooning and tearing will lead to the field line stochastization during an edge pedestal collapse. The stochastization is found to occur due to the growth of tearing modes by extracting kinetic energy of unstable ballooning modes, eventually leading to the island overlap. This energy conversion between disparate parity happens via secondary tearing modes which are generated through a coherent nonlinear interaction between adjacent ballooning modes. The secondary tearing mode may be a candidate for the precursor mode observed in experiments.

4.3. Progress in interaction between MHD and turbulence and others

Hu presented the nonlinear mutual destabilization of tearing mode and ITG mode. Effect of shear flow on multi-scale nonlinear interaction in plasmas is numerically investigated by using a self-consistent Landau-fluid model. Unexpected dual roles of shear flow in the process are discovered, significantly suppressing micro-scale fluctuations and dramatically promoting macro-scale fluctuations. Furthermore, its similar dual roles in turbulent transport are also demonstrated. The theoretical prediction on the threshold of shear flow based on an analytical modeling is verified via the numerical simulations. Since the new underlying mechanism for the nonlinear promotion is identified as the formation of a large vortex flow inside magnetic island, it can be applied to understand complicated processes of critical events in both space and magnetic fusion plasmas.

The effect of toroidal rotation anisotropy on GAM using gyro-kinetic equations has been presented by Ren. Dispersion relation in the presence of arbitrary Mach number M, anisotropy strength σ, and the temperature ration τ is analytically derived. It is shown that when σ is less than $3 + 2\tau$, the increased electron temperature with fixed ion parallel temperature increases the normalized GAM frequency. When σ is larger than $3 + 2\tau$, the increasing of electron temperature decreases the GAM frequency. The anisotropy σ always tends to enlarge the GAM frequency. The Landau damping rate is dramatically decreased by the increasing τ or σ.

Other presentations like the simulation of the stabilization of neoclassical tearing mode (NTM) by electron cyclotron current drive (ECCD), simulation of tearing and Kelvin–Helmholtz instabilities in a rotating cylindrical plasma, and other MHD simulations for the next generation tokamak CFETR etc have also been reported at the conference. The validation of those modelings via experiments will be valuable for the understanding of those basic MHD instabilities. There were also many discussions during the conference focused on the magnetic topology under RMP. Key questions should be answered in the near future, including

- Can we confirm experimentally that magnetic islands are really there in RMP experiments?
- What kinds of measurement do we need to confirm the stochastization?
- Could the nonlinear response to the magnetic perturbations be important?
- Are there any theory/simulations that can explain the effects of stochastic fields on plasma rotation?

5. Non-diffusive contribution of momentum and particle transport

This working group covers several topics related to momentum transport and particle transport. At this conference, there are 22 presentations in this working group, including three invited talks, three regular oral talks and fourteen poster presentations. In this section, we will summarize the presentations of this working group at this conference.

5.1. Plasma rotation generation and modeling

Some new ideas on plasma rotation generation and prediction were discussed at this conference. Wang introduced the concept of turbulent acceleration. The equations for gyrocenter density and parallel momentum were obtained by taking the moments of the electrostatic gyrokinetic equations [36]. When subtracting the density equation from the momentum equation, a new term, named the turbulent acceleration term [37] appears in the equation of the ion velocity. A quasi-linear estimate for electrostatic ITG turbulence shows the turbulent acceleration is quantitatively comparable to the divergence of residual stress. When the electromagnetic effect is considered, the turbulent acceleration can be enhanced with the increase of β. The talk also reported the estimation of flow drive by the divergence of nonlinear flux. It was found the nonlinear residual stress can be comparable to the quasi-linear residual stress and, also for nonlinear residual stress the asymmetric parallel fluctuation spectrum is not required for flow drive [38].

On flow drive by quasi-linear residual stress, the parallel symmetry breaking is usually due to the $E \times B$ flow shear, such as zonal flow. However, two possible mechanisms of symmetry breaking were reported at the conference. Kaang discussed the symmetry breaking of stress in electromagnetic ITG mode. By analyzing the mode structure of ITG instability, it was found that mode asymmetries in parallel velocity and parallel vector potential are enhanced by synergy between β and $E \times B$ flow shear and, then, parallel Reynolds stress and kinetic stress increase due to this enhance asymmetry. In particular, with the increase of β, the dominant mode can be changed from the $l = 0$ mode with even parity to the $l = 1$ mode with parity [39, 40]. In this case, the EM-Reynolds stress can significantly increase. Also based on the mode structure analysis, Xie introduced another possibility of inducing a seed residual Reynolds stress by ITG mode with up-down asymmetric mode structure. It was reported that the ITG mode from the vertical ballooning theory [41] and that from the weak asymmetric ballooning theory [42] contributes opposite torque. These two contributions compete with each other and may induce the reversal of rotation direction.

Gao discussed the effect of rf waves on flow drive from the point of view of the generalized ponderomotive force [43]. The local rf force can induce torque from asymmetric k-spectrum or asymmetric absorption, or, even the total torque is zero, the local force can generate net drive effect from momentum redistribution [44]. In other words, local rf force can provide a local momentum source and then direct drive the toroidal flow, which is possibly responsible for explaining the flows observed in lower hybrid wave current drive (LHCD) and mode conversion ion cyclotron wave heated (MC-ICH) plasmas [45]. This talk also pointed out that the effect of rf on momentum transport (diffusion and pinch) is of the same importance as the momentum source provided by rf.

The plasma rotation due to collisionless ion orbit loss was estimated in Ou's presentation with different magnetic configurations [46]. A peak of the averaged ion orbit loss (IOL) momentum fraction was found very near inside the separatrix region in a double null divertor (DND) configuration; but not found inside the last closed flux surface (LCFS) in an outer limiter configuration. For the DND configuration, the intrinsic rotation due to IOL depends on the plasma shape. With the increase in elongation and triangularity, the peak of the averaged IOL momentum fraction increases and it moves inward for the lower plasma current. The toroidal and poloidal flow with NBI on EAST had been simulated by using ONETWO and NUBEAM, which was reported in Wang's poster. It was found that the torque due to the counter-NBI is flat comparing with the co-NBI since the $J \times B$ torque is more important for counter-NBI than co-NBI due to the increase of the fast ion with banana orbits

5.2. Rotation measurement and analysis

Three presentations on experimental studies of plasma rotation were given at this conference, all of which were on the EAST tokamak.

Lyu introduced recent experimental results on RF-heated plasma rotation. Experimental results indicated that substantial co-current core rotation increase was observed at RF injection and L-H transition. Central rotation increase over L-H transition was linearly correlated with the increase in plasma stored energy for both ELM-free and ELMy plasmas, with larger slope observed for ELM-free ones. Although the Rice-scalings [47] are roughly satisfied, there are still large uncertainties in the relation of the change of rotation to the ratio of the stored energy to plasma current. It may imply the effect of rf-plasma interaction. Plasma parameters, such as plasma current, resonance location, plasma shape, were scanned to study their effects on plasma rotation. Momentum transport analysis indicates diffusion might be dominant. Preliminary results of impurity (high Z) and particle transport coefficients were introduced in this talk as well.

Zhao discussed the rotation and momentum transport in the scrape-off layer (SOL) of EAST. Co-current toroidal rotation in the SOL among L- (about 18 km s^{-1}) and ELM-free H-mode (about 45 km s^{-1}) are measured using Mach probes. Further analyses showed that the convective term play a leading role in total toroidal momentum in L-mode, while the Reynolds stress term had a really significant effect on the total toroidal momentum in H-mode. It was also found that there are the net inward momentum fluxes inside separatrix and in pedestal in L-mode. This momentum pinch was thought to be responsible to generate the intrinsic rotation.

Qu reported the measurement of poloidal flow in NBI EAST plasmas by using the correlation reflectometry. It was found that the flow velocity was reversed by the beam injection in L-mode and the shear of perpendicular velocity became stronger in the edge of H-mode plasma.

5.3. Particle and impurity transport

Tamura reported the investigation of the dynamic characteristic of the impurity transport in response to a change in heating on the LHD device by employing the method of tracer-encapsulated solid pellet [48]. Emission intensity from the highly ionized V tracer impurity was found to quickly respond to ECH switching-off. This observation cannot be explained by a simple modification of the charge state distribution of V ions and may suggest that plasma heating affect the impurity transport directly.

Effects of flow shear and meso-scale structures can influence the particle transport. Three presentations were focused on this topic at this conference. In Kosuga's talk, an inward particle flux driven by parallel flow shear driven instability was reported [49]. When the parallel flow shear becomes strong enough, this inward particle flux may dominance the outward diffusive flux and then the flux reversal occurs. Sasaki reported a similar work, where the role of perpendicular flow shear on turbulent transport was investigated. The bifurcation between drift wave (DW) dominant state and flow-driven-mode dominant state was found. The streamer structure is formed in the DW dominant state, and the improvement of the particle confinement is observed when the externally induced flow shear enhances the spontaneously generated flow shear. Kin introduced the end-plate biasing experiment in the linear plasma device, PANTA [50]. It was found that the outward particle flux by DW decreases 70% during biasing, while the Inward flux driven by mediator ($m = -1$ mode) reversed its direction to outward during biasing due to the change in the phase relation between density and potential fluctuations

On the HL-2A and EAST tokamak, various diagnostic systems and analyzing methods were developed. Zhang introduced preliminary results from particle transport studied by using modulated SMBI and fast sweep FMCW reflectometer on HL-2A. Shi and Liu reported the particle transport studies in a density modulation experiment by using polarimeter/interferometer on EAST, where the singular value decomposition (SVD) together with the generalized cross-validation (GCV) reconstruction method [51] and the fast date processing method were introduced in these two presentations, respectively. Zhang reported the status of impurity transport studies on HL-2A by virtue of laser blow-off (LBO) and SMBI techniques for metal and gaseous impurity injection and impurity transport code STRAHL with a derivative χ^2 minimization method for analyzing.

Fueling and exhaust are key issues for reactors, which is related to particle transport, but strongly influenced by many factors, such as geometry, plasma–wall interaction, fueling methods and techniques, and so on. Deng reported that the divertor plasma detachment with multifaceted asymmetric radiation from the edge (MARFE) events directly by pellet injection was observed in the EAST. The observation that the plasma detachment can be modulated periodically by multi-pellet injection may provide a promising access to active control of divertor power load.

A discussion was carried out during the group session and the summary session. On plasma rotation, more experimental activities, especially on the analyses of momentum transport, were suggested. The physics beyond the conversion between ITG and trapped electron mode (TEM) should be considered. The effects of momentum transport on plasma flow are of the same importance as the driving mechanisms. The phenomenon of rotation reversal at ITB might include interesting physics. On particle/impurity transport, similarly, the pinch/convention reversal should be paid more attention. The connections between core transport, SOL flow and edge flux are discussed. Considering the ITER case, the study of impurity accumulation and exhaust should be further considered.

6. Non-local transport and turbulence spreading and coupling

Experimental evidences for the breakdown of a 'local expression' of transport, in which the fluxes are proportional to gradients of macroscopic variables at the same location, have been accumulated both in tokamak and helical plasmas [52–57]. To enhance the predictive capability of the dynamics of burning plasmas, physical mechanism of 'violation of local closure' should be verified. Some models, which explain how the turbulences generate global responses of radial profiles to the spontaneous and/or external perturbations, are proposed. Evaluation of such 'fast front propagation' and 'intrinsically-coupling' models is ongoing [58–61]. Because of this situation, this section covered the following topics:

- Turbulence spreading.
- Turbulence with long-range correlation.
- Interaction between micro-, meso- and macro-scale turbulences.
- Core-edge coupling in transport.

At this conference, there were 11 presentations in this working group, including three invited talks, five regular oral talks and four poster presentations. At this conference, we discussed (1) co-existence of multi-scale fluctuations and non-linear interactions between them, and (2) new experimental approaches for more comprehensive understanding of the turbulence transport. In this section, we will summarize the presentations of this working group based on these points.

6.1. Co-existence of multi-scale fluctuations

Fluctuations with various spatial scales co-exist in the magnetized inhomogeneous plasma. The micro-turbulence, e.g. the drift waves, had been considered to be excited by the pressure gradient. Now it is widely recognized that micro-turbulence is determined on interactions with meso/macro-scale fluctuations [17]. The multi-scale physics is therefore important to understand the turbulence transport. Recently, the meso/macro-scale structures, e.g. zonal flows and long-range fluctuation, and their non-linear couplings with micro-turbulences have been identified experimentally [62, 63]. Present experimental study of turbulence is focused on the observation of meso/macro-scale structures. Ohshima reported observation of the long-distance correlation of low frequency ($<$20 kHz) radial electric field fluctuations along the magnetic field line in the Heliotron-J, which is considered to be an index of the existence of zonal flow. Radial wavelengths of these fluctuations are found to be longer than those reported [64, 65], thus these components are considered to be a meso-scale structure. While the multi-scale coupling of fluctuations plays an important role on determination of the turbulence structures, the transport in magnetized plasma is still driven by micro-turbulence. Thus, observation of micro-turbulence is foremost issue today. Sun developed a multi-channel CO_2 laser collective scattering diagnostics in EAST, which can detect microscopic density fluctuations with radial wavenumbers of 10, 18, 26 cm^{-1}. In addition, ability to detect coherent modes such as kink mode and tearing mode through modulation of micro-fluctuations is discussed. Inagaki presented new microwave frequency comb Doppler reflectometer, which is succeeded to measure density and poloidal flow fluctuations at many different radii in the edge region of LHD plasma. The microwave frequency comb and advanced microwave detection system, i.e. ultra fast digital storage oscilloscope (80 Gs s^{-1}), are considered to be very powerful tools. Gyro-kinetic simulations for real tokamak plasma shape and profiles are very useful to understand experimental observations. Xiao developed the gyro-kinetic GTC code and compared with recent experiments in EAST and HL-2A tokamaks. Novel mode structures are found in the pedestal region.

6.2. Non-linear interactions between multi-scale fluctuations

Turbulence spreading and avalanche related to self-organized criticality (SOC) models are considered to be typical phenomena associated with disparate-scale coupling of fluctuations in the turbulent plasma. Simulation works are performing the role of the driving force to solve this issue. Kasuya found that turbulence spreading is a fundamental mechanism of the fast energy transfer. Yi indicated turbulence spreading can increase turbulent transport to a level exceeding the predictions of the local theories. This is considered to be one of the non-local mechanisms of the global confinement degradation. Wang observed the fast avalanche phenomena by a flux-driven GKNET simulation. A flux-driven system with heat source and sink is recognized as a key modeling in studying the non-local transport. The localization of $E \times B$ flow shear, so-called 'staircase' [66], and intermittent propagation of flux associated with SOC dynamics are also indicated numerically. Experimental verification of the 'staircase' is one of the targets for verification of avalanche related to the SOC models. Inagaki and Wang presented experimental challenges to observe turbulence spreading and an avalanche process of turbulence. Observation of the staircase by the microwave frequency comb Doppler reflectometer has just begun. At this conference, the two-point two-time correlation technique is considered to be a very powerful tool to detect non-linear coupling between multi-scale fluctuations. Yan and Ou reported observations of the ballistic fast radial propagation of fluctuation wave front, which is considered to be evidence of enhanced SOC dynamics.

Interactions between micro-turbulence and meso-scale MHD modes (NTMs and fishbone) were newly observed by Yan and Ou. The NTM is excited during the non-local transport phenomena (abrupt central temperature rise) and the radial propagation of turbulence due to avalanche is blocked by the NTM. In addition, Yan demonstrated that fishbone bursts trigger the non-local transport phenomena. The interplay between the electromagnetic instability and the non-local transport was discussed. Equilibrium profiles of pressure and flows are now considered to be one of global structures dynamically coupling with turbulences. Wu, Wei and Wang studied radial profiles of rotations and density. Hysteresis in flux-gradient relation observed in heating power modulation experiment is a good target to test non-local transport models and thus Kasuya attempted a numerical reconstruction of the hysteresis.

6.3. New experimental approaches

New experimental and theoretical approaches will offer new insight into the paradigms of non-locality of turbulence. Ou performed Hurst exponent analysis to characterize the fundamental process of transport. A large Hurst exponent (>0.5) is the key ingredient of the SOC behavior in addition to identification of long-range correlations and self-similarity of fluctuations, the f^{-s} $(0 < s < 1)$ frequency dependence. An enhanced SOC behavior is found during the non-local transport phenomena in HL-2A. Yi proposed cross bi-coherence of micro-turbulences at distant locations, so-called 'non-local bi-coherence analysis', to analyze the turbulence spreading and avalanche process of turbulence. Inagaki reported the first trial of the non-local bi-coherence analysis and tri-coherence analysis in LHD.

6.4. Summary in this section

The current status of our understanding may be summarized as follows. (i) Non-linear coupling between disparate-scale structures, especially, turbulence spreading and avalanche process is investigated theoretically and experimental verification has started. (ii) Proposal for new turbulence analysis method will provide new hints for making a prospective non-local transport model. Topics discussed in this working group link closely with other topics e.g. non-locality can contribute to the turbulent suppression and transport barrier formation (Group A) and it usually generates non-diffusive transport (Group C).

7. Energetic particles and instability

This WG provided a forum for recent research progress of theory, simulation and experiment related to the physics of energetic particles (EP). The contents covered the following several aspects: (I) stability of Alfvenic modes; (II) EP loss and transport; (III) effect of RF heating on MHD instabilities. Three invited talks, three oral talks, and seven posters were presented.

7.1. Theory and simulation

Cao presented the transport theory for passing energetic ions in the presence of Landau resonances with rotating magnetic islands. The resonance between passing energetic ions (EIs) and rotating islands can lead to the formation of a resonant flux surface, which overlaps with the magnetic flux surfaces. New transport channels responsible for the EI transport enhancement, corresponding to the three radial drift motions of EIs due to the interaction between EIs and islands, are discovered. And three drift velocities are also formulated. And contributions of the three motions to the EI flux are also calculated.

Pei presented simulation of the ion fishbone using kinetic-MHD hybrid simulations using MEGA code in the EAST discharge. The results indicated that the threshold of β_{h0} for the excitation of the fishbone instability is about 0.5%, where β_{h0} is the ratio of the pressure of EIs to the pressure of the bulk plasma at the magnetic axis. The mode frequency in the simulation depended on the pitch angle λ and EI maximum energy E_{max}. For the NBI EIs with $\lambda = 114°$ and $E_{max} =$ 60 keV, the mode frequency in the simulation was around 6 kHz, which agreed with the experimentally observed frequencies (4 kHz–10 kHz). The simulation results indicated the mode was dominant by the $m = 1$ harmonic and the radial location was within the $q = 1$ surface.

Yang reported simulation of toroidal Alfven eigenmodes (TAEs) instabilities by NOVA/NOVA-K in the CFETR. For the different safety factor profiles, Alfven continuum and eigenmode structures of TAEs and reversed shear Alfven eigenmodes (RSAEs) were calculated using NOVA, then NOVA-K analyzed in TAE damping mechanism for different toroidal mode numbers. The numerical results suggested that if the safety factor profiles were chosen appropriately in CFETR, then all the TAEs could be stable.

7.2. Experiment

Kim presented the experimental observations of fast-ion loss dynamics in KSTAR. At present, the EP diagnostics such as fast ion loss detector (FILD), compact neutral particle analyzer (NPA) and so on had been used to reveal the fast-ion loss mechanism on KSTAR. Several factors, affecting fast-ion loss, such as ELMs, edge magnetic perturbations, tearing modes, energetic particle modes (EPMs) had been observed. Various experimental instances of the fast-ion losses on KSTAR were introduced. The clearest response on the fast-ion loss was the ELM-induced one, and it had been found that the edge magnetic perturbations having various field spectra could cause the non-axisymmetric loss patterns. To understand the change in fast-ion behavior responding to the non-axisymmetric magnetic perturbations, full 3D orbit simulations using LORBIT and F3D-OFMC were carried out and the calculated change in the pitch-angle distribution based on the vacuum field was matched well with the FILD measurements. In contrast to the edge-activity cases, fast-ion loss correlated with core activities seemed to be case-sensitive since the interplay of the fast-ion orbit with the rotating modes may have to be synchronized, leading to the resonant interaction and loss.

Chen reported the core-localized Alfvenic modes (CLAMs) driven by EIs in the HL-2A NBI plasmas with weak magnetic shears. Two types of CLAMs had been observed and identified on HL-2A, i.e. high frequency gap mode (HFGM) and resonant KBM (rKBM). The HFGMs with 100 kHz $< f <$ 500 kHz and $n = 3$–7 were often observed with the increasing of the edge safety factor, q_a. The measured frequency of them is more than that of the TAEs, and $f_{\min} \sim f_{\mathrm{TAE}}$. The analysis suggested that the modes localized inside the high-order RSAE gap of the Alfvenic continuum, and their eigen-frequencies depended on the minimum q ($q_{\min}$) and the characterization of the modes were similar to that of the conventional RSAEs. When the core plasma density was more than 3.0×10^{19} m^{-3} and the impurity or SMBI entered into the bulk plasma, the profiles of the plasma density/pressure was peaked, and the magnetic shear was weak so far as to be negative. In that case, the rKBMs with 30 kHz $< f <$ 150 kHz and $n = 2$–9 were observed by the many kinds of core diagnostics. It was found that the HFGMs often transit into the rKBMs when the density profile suddenly peaked. The neutron monitoring in the vacuum-chamber outside demonstrates that the HFGM and rKBM both degraded the confinement of the energetic-ions, and the rKBMs were related to the beta-collapse of plasmas.

Akiyama reported the ion cyclotron harmonic waves measured with an RF spectrometer in LHD. The RF radiation measurements in the range of the ion cyclotron harmonics had been conducted and installed on LHD. The measured RF spectrum revealed multiple high harmonics with a difference of 25 MHz when the trapped Eis were injected. The frequency spacing approximately corresponded to the ion cyclotron frequency of the outboard edge region. This observation suggested that the prompt loss of the NBI-produced EIs was causing the ion cyclotron harmonic waves (ICHW). In addition, responses to the ripple-trapped-EP driven interchange modes (EICs) and ELMs, were also observed.

Hu gave an introduction to the activities of EP study on EAST. With the development and improvement of the auxiliary heating and current drive systems on EAST, the fast-ion related physical issues became essential elements of the EAST project, and also crucial for achieving EAST scientific objectives. Several new fast-ion diagnostics have been developed and tested, e.g. fast ion D_α (FIDA), solid state neutral particle analyzers (ssNPA), FILD, gamma camera and neutron camera, etc. In 2014, with one available neutral beam injection, which can produce 2–4 MW beam power with 50–80 keV beam energy, NBI blip experiments were applied to study the fast-ion slowing-down behavior. Repetitive fishbones near the trapped ion processional frequency were first observed. It was found that this ion fishbone could trigger core sawtooth crash, and could lead to a fishbone long-lived saturated kink mode (LLM)-fishbone transition. Kinetic-MHD hybrid simulations using MEGA code were carried out to investigate the fishbone and AE on EAST.

Liu presented the study of MHD behaviors during minor disruptions in SUNIST plasmas. During the precursor stage of minor disruptions on SUNIST it was found that $m/n = 3/1$ mode grew rapidly in the early stage and subsequently there existed mode locking which led to minor disruptions eventually. In particular, it was observed that each minor disruption was accompanied by a runaway plateau, where a kind of high-frequency (HF) MHD instability occurs. The characteristics of this HF MHD mode mainly include that: the frequency was between 150 kHz and 300 kHz; a mode with toroidal mode number $n = 1$ propagates in the direction of the electron diamagnetic drift direction; the poloidal magnetic field perturbation exhibits a ballooning mode feature; there was a strong nonlinear coupling between $m = 3$ and $m = 4$ mode. By scanning the toroidal field and electron density, this HF MHD mode might be identified as TAE, which was driven by runaway electrons generated during minor disruptions.

Yu reported the effects of ECRH/ECCD on internal kink modes (IKMs) during plasma current ramp-up on HL-2A. During high-power ECRH or ECRH + ECCD ($P \sim 1.0$ MW), the multi-harmonics IKMs were excited, and their frequencies were slow downward sweeping with the current increasing. The mode structure was measured by the electron cyclotron emission imaging (ECEI) and tomography technology of soft x-ray arrays. It was found that the IKMs can be driven when ECRH or ECRH+ECCD power deposits inside or near $q = 1$ surface. The IKMs can be excited more easily in the pure ECRH or ECRH+ECCD$^-$ (driven-electron in the opposite IP direction) conditions than on the ECRH+ECCD$^+$ (driven-electron in the IP direction) conditions.

Jiang presented the dynamics of the double e-fishbone instability in HL-2A ECCD plasmas. The double e-fishbone localized near two $q = 1$ flux surfaces with the weak/negative magnetic shear configuration. The mode features had been shown firstly by the advanced 2D ECEI system. From ECEI, two $m/n = 1/1$ modes propagating in the opposite directions poloidally had been observed clearly. From the 2D k-spectrum of the ECEI signals, there were two dominant k_{p} with different signs, which was in accordance with the opposite precessional directions. The modes only can be found in low density discharge and their frequencies were close to the precessional frequency of the trapped fast electrons. Moreover, the thermal energy transfer between the two modes can be revealed by the ECEI, which seemed to be related to the nonlinear interaction between the two modes and local heat transport during the MHD activity.

In the EP-WG, there were three other presentations all from EAST. They were: (i) study of fast ion transport by short beam pulses (by Hao); (ii) fast electron flux driven by lower hybrid wave in the SOL (by Li); (iii) analysis of the anisotropic energy by lower hybrid waves heating (by Huang).

The researches primary focused on linear physics problems related with SAW and EP, and provided better understanding. However the cognition for the nonlinear is not enough, especially many-mode induced EP transport and EP induced collective effects in burning plasmas. The future research emphasis included the following: EP transport and losses due to instabilities; control of EP driven instabilities; 3D effects on EP transport; nonlinear behavior (avalanche, mode-mode coupling, phase-space dynamics); effect of EP induced ER on confinement/transport; decay of EP instabilities and relevant effects.

8. Young Researchers' Forum

In order to encourage and promote discussions and further collaboration among young researchers in the Asia-pacific region, a specific session, the Young Researchers' Forum (YRF), dedicated to students and researchers at early stages of their careers, started from the 3rd APTWG meeting in 2013 [3]. In the 2014 APTWG meeting [4], an opportunity was given to several students to present their own work in the YRF. This year, more time was scheduled for the YRF and three invited talks and six orals were presented in this session. We will briefly summarize these presentations.

Zang presented the measurement of pedestal parameters (including height and width) using the Thomson scattering on EAST and also showed the preliminary tests of pedestal width scaling. Qiu showed the importance of the plasma non-uniformity for the excitation of geodesic acoustic modes by drift wave turbulence and especially that the non-uniform diamagnetic frequency played a dominant role and would render the convective instability into quasi-exponentially growing absolute instability [67]. Wu presented a 1D modeling of L-H transition by applying the quenching effect of turbulence via $E \times B$ flow shear rate exceeding the shear suppression threshold [68]. The L-H transition with an I-phase characterized by limit cycle oscillations was observed by slightly ramping up the heating power in the modeling and specifically two different oscillation relationships between $E \times B$ flow and the turbulence intensity were found.

Banerjee presented the poloidal flow driven by electron cyclotron wave and the simultaneous observation of a mode at 781 Hz with long range radial and poloidal correlation on QUEST. Chen showed that the diver configuration and the ion $B \times \nabla B$ drift direction play important roles on L-H transition power threshold and transition behavior. Cai showed that ELM frequency is more sensitive to edge safety factor (q_a) in the plasma with lower edge current density based on a current relaxation model of ELMs [69] and explained the observations on EAST that the ELM frequency is much more irregular for the plasma with lower edge current density. Wang presented simulations of the mode penetration by resonant magnetic perturbations based on a reduced MHD model with neoclassical poloidal viscosity (NPV). The simulation showed that the penetration threshold increases with the NPV when the value of NPV is high and this has been attributed to the screening effect of NPV on the RMPs by trying to restore the velocity profile. Zhou presented numerical simulations of plasma fuelling using gas puffing (GP) and supersonic molecular beam injection (SMBI) based on the BOUT++ framework. The results showed that the SMBI generally has a deeper penetration depth compared to GP. A comparison with different SMBI intensities showed that SMBI penetrated deeper with larger injection and lower injection density. Liu showed that the particle flux during type I and III ELMs favors the inner divertor in normal field direction, while it favors the outer divertor in the reversed field in LSN configuration on EAST.

This year we had more slots allocated for talks by young researchers. The session was successful and served as a place for training young folks. For improvement, we note that a flexible program depending on the nature of participants might be beneficial. Namely, this year we had more students compared to previous meetings. In this respect, there was some discussion on having introductory talks on the topic in the workshop, etc. These might be a useful lesson for future YRFs.

9. Summary

The 5th APTWG Meeting was organized under five working groups: (A) turbulence suppression and transport barrier formation, (B) effect of magnetic topology on MHD activity and transport, (C) non-diffusive contribution of momentum and particle transport, (D) non-local transport and turbulence spreading and coupling, (E) energetic particles and instability. There were a total of 1 1 1 people from six countries participating in this meeting and 49 orals and 96 posters were presented. In the working group session, active discussions were dedicated to the present status/understanding and also future plan. In addition, the relations between these five topics were also discussed. We have reached a consensus that the five working groups are closely related. For example, non-locality discussed in Group C can contribute to the turbulent suppression and transport barrier formation (Group A) and it usually generates non-diffusive transport (Group C); the MHD and magnetic topology effect discussed in Group B can contribute to the turbulence suppression and barrier formation (Group A) and can induce energy particle transport (Group E); the E_r due to energy particle (Group E) can have an effect on plasma turbulence and transport (Group A and C).

In addition to the other scientific working groups, the APTWG Meeting includes a Young Researchers' Forum, which is dedicated to students and young researchers in the Asia-Pacific region and encourages them to promote the discussions and enhance further collaboration. This year, more time was scheduled for the YRF and more orals have been presented in this session. In addition, the poster prize was given to a young researcher, Min Jiang (SWIP in China), who presented an outstanding poster 'Dynamics of the double e-fishbone instability in HL-2A ECCD plasmas'.

The 5th APTWG Meeting provided a place for fruitful discussions among scientists in the fields of (1) turbulence and transport, (2) MHD and magnetic topology and (3) energetic particles and instability and new insight for the interaction between turbulence, magnetic topology, and energetic particle driven instability. The next meeting will be held in Korea in 2016.

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