Pressure gradient driven core-localized electromagnetic instability in the plasma with a weak magnetic shear on HL-2A tokamak

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Electromagnetic instability driven by pressure gradient in the core region is more and more critical in the present and future fusion devices, especially for which operate with reactor-relevant parameters. As two typical examples, kinetic ballooning modes (KBMs) and Alfvenic ion temperature gradient (AITG) modes, have become major concerns and captured much more attentions. To deal with unresolved issues on those electromagnetic instability, a series of experiments related to AITG modes have been carried out on HL-2A tokamak [1]. It is found that only when ECRH and NBI are simultaneously injected into the low density plasma, those modes are driven unstable [2]. Moreover, decline in density fluctuation induced by AITG modes is observed during high power heating. Experimental evidences suggest that ECRH enhances AITG modes by causing a drop in electron density and an increase in Te/Ti, here Te and Ti are electron and ion temperature, respectively. Besides, high-power ECRH may also change safety factor or magnetic shear and then contribute to mitigation of AITG modes. Further analysis based on general fishbone-liked dispersion relation indicates that there are three thresholds of η_i, Te/Ti and S for the excitation of AITG mode, here S is the second derivative of safety factor. The theoretical results given in Fig.2 provide a rational explanation for the experimental observations and are confirmed by the linear simulation of GENE code. Turbulent transport and zonal flow (ZF) dynamics due to AITG modes are also analysed by gyrokinetic simulations [3]. Numerical results have shown that AITG modes and ITG turbulence are the main candidates for turbulent transport. Moreover, the inclusion of fast ions (FIs) can destabilize both instabilities, which is resulted by the decrease of ballooning parameter α hence reduced Shafranov shift stabilization due to the negative FI density gradient, making them more unstable according to the s-α diagram. In addition, the ITGs are suppressed by both dilution and finite-β stabilization effects caused by FIs. Nonlinear simulations excluding the effects of FIs indicate that the transport level become lower as the turbulence predominated by ITGs is strongly suppressed by the nonlinear electromagnetic (EM) stabilization and enhancement of ZFs. However, the transport is further increased although the ZFs become stronger due to the transition from ITG to KBM dominated turbulence state. The presence of FIs can modify the relation between ZF shearing rate and beta. The transport level is insensitive to plasma beta but increases significantly because of the KBM destabilization. Meanwhile, the ZF amplitude reaches maximum when it suffers an erosion at higher value.

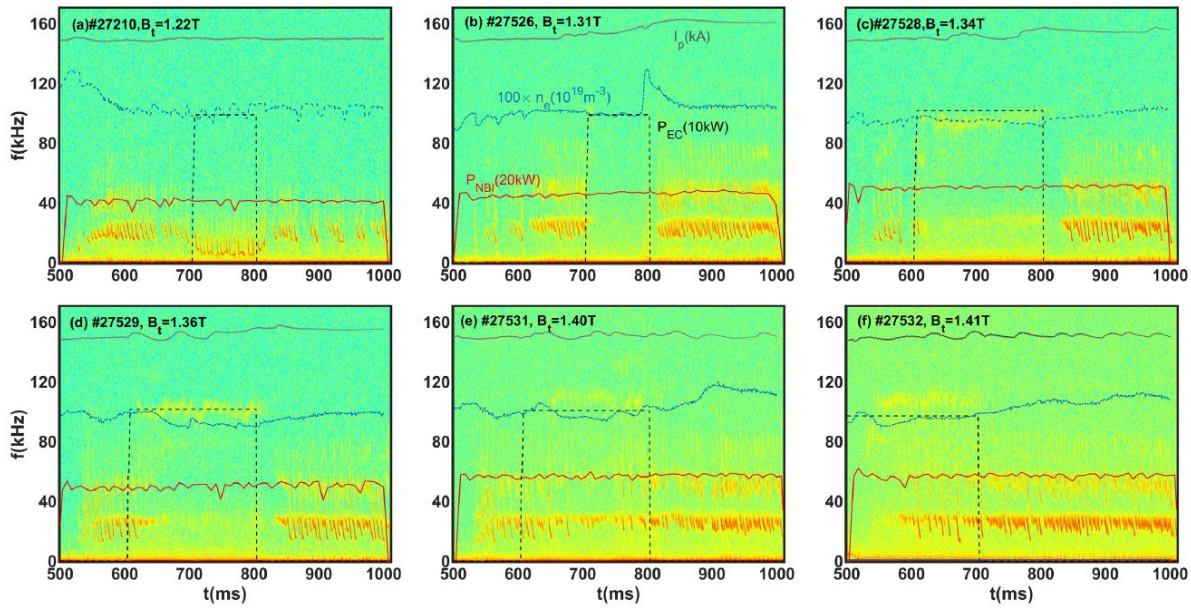

Figure 1. Dependence of AITG modes on deposition location of ECRH on HL-2A tokamak. The magnetic field Bt, plasma current Ip, line-averaged density ne, injected powers of NBI and ECRH, are also given in the figure.

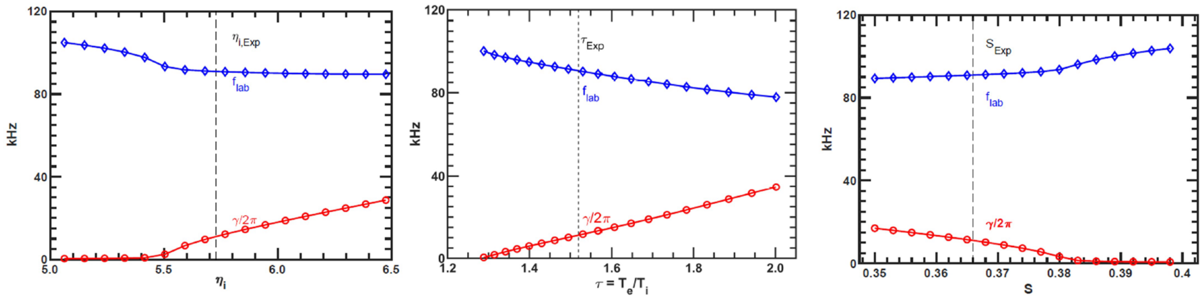

Figure 2. Dependence of real frequency and growth rate of AITG modes on η_i, Te/Ti and S. Three thresholds of η_i, Te/Ti and S are suggested by general fishbone-liked dispersion relation.

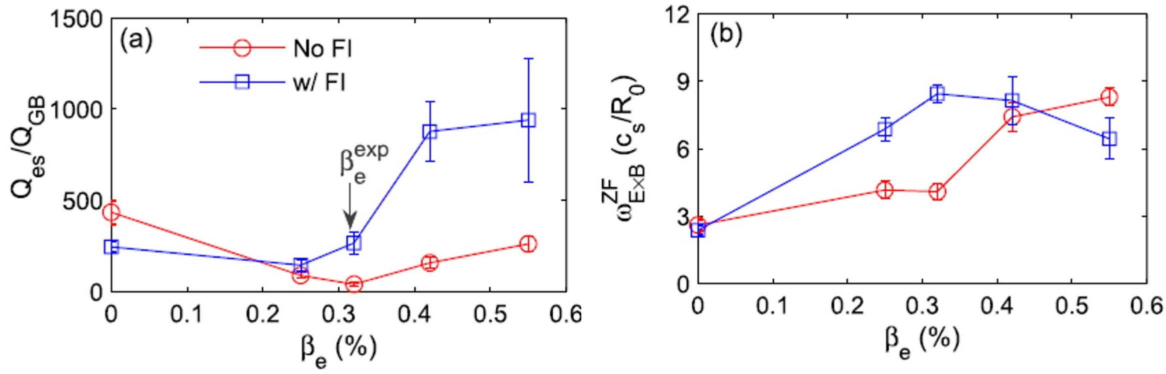

Figure 3. Ion heat flux induced by AITG/ITG and (b) ZF shearing rate versus βe. The results without and with FI contributions are donated by red and blue curves, respectively.

In summary, the new findings can not only enrich experimental knowledge for pressure gradient driven instability, but also be beneficial to active control of core-localized electromagnetic modes in the future burning plasma. Last but not least, it also provides a new perspective for relationship among pressure gradient driven instability, ZFs and fast ions.

References

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