§1. New ECRH Power Modulation Signals for Identifying Non-linear Component of Electron Heat Transport Measurements

van Berkel, M. (FOM DIFFER),
Kobayashi, T., Igami, H., Tamura, N.

We have developed new ECRH power modulation waveforms in order to detect and quantify non-linearities in perturbative electron heat transport measurements on LHD. For the detection and quantification of non-linearities, unexcited higher harmonics, which are next to excited higher harmonics, are studied as suggested by Inagaki et al.[1] The basic idea is that the higher harmonics will exist in the spectrum of electron temperature measurement, which are originally not part of the perturbation[2], when the perturbative electron heat transport measurement contains non-linear components. Here, two different techniques are developed:

a. Designing and applying new modulation signals based on pseudo random binary three-level signals in which only odd harmonics (3rd, 5th) are excited. Consequently, the 2nd, 4th, and 6th harmonics can be used to detect non-linear components.
b. Using the non-linear interaction between harmonics. To this end, two ECRHs with different periodic block wave modulation are applied (f_1 and f_2). Hence, only multiples of these frequencies should be detected in the presence of the linearity. Although the sum of f_1 and f_2 can be also appeared in the presence of a quadratic non-linearity, its amplitude gives the strength of the non-linear components[3].

Both techniques have been successfully applied in the last 18th experimental campaign of LHD. Figure 1

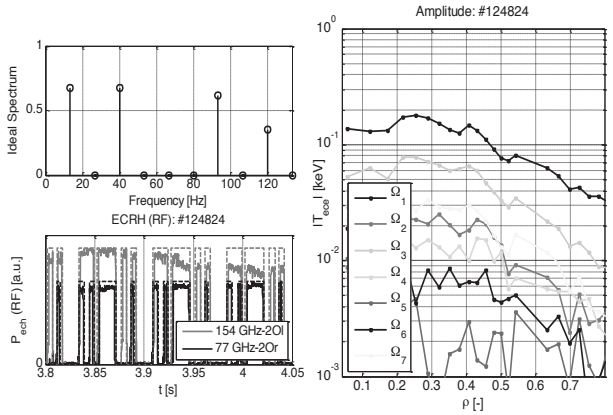

Fig. 1. (Left-top) Ideal spectrum of the perturbation signal. (Left-bottom) Ideal and measured perturbation of the two ECRH beams. Note that the power levels shown are not representable for the true power levels. (Right) Resulting amplitudes for the first seven harmonics at different spatial locations measured with ECE.

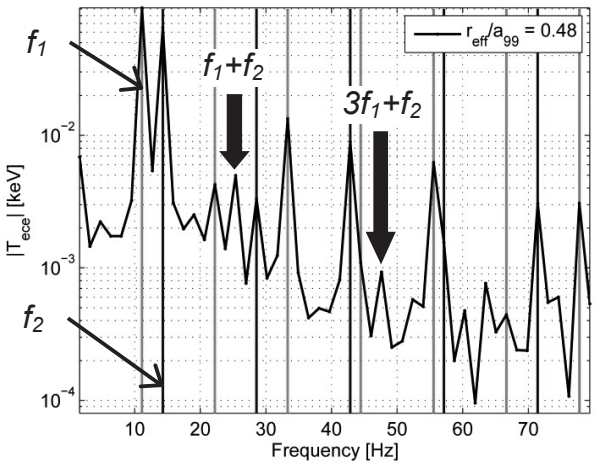

Fig. 2. Amplitude spectrum of ECE data at r_{eff}/a_{99} = 0.48 (LHD #125703). The harmonic components due to 154GHz-2Oll (multiples of f_1 = 11.11 Hz) and 77GHz-Ol2 (multiples of f_2 = 14.3 Hz) are clearly observed.

shows clearly that the newly developed perturbation is successfully applied, indeed only the 1st, 3rd, and 7th are excited. In addition, a weak contribution of the 2nd harmonic is appreciable, which shows that even non-linear contributions are existed. On the other hand, the 5th harmonic is not excited, which suggests clearly that odd non-linearities are negligible.

A similar result has been obtained in the experiment with applying two ECRHs with frequencies of 11.11 Hz and 14.3 Hz. A typical result of this experiment is shown in Fig. 2. As shown in Fig. 2, a strong frequency component with f_1+f_2 = 25.4 Hz is excited, which indicates clearly the presence of the even non-linearity. Figure 2 also shows the frequency component of $3f_1+f_2$ (~47 Hz), which is due to the same non-linearity.

The non-linear components in the electron heat transport should affect the estimation of the transport coefficients[2,4], which should be investigated. The presence of the non-linear components in the perturbative transport measurements in LHD has been clearly indicated by the last 18th LHD experimental campaign.

1) Inagaki, S. et al.: Plasma Fusion Res. **8** (2013) 1202173.
2) Pintelon R. and Schoukens, J.: *System Identification: A Frequency Domain Approach* (2012) Wiley-IEEE Press.
3) Wambacq, P. and Sansen, W.M.: *Distortion analysis of analog integrated circuits* (1998) Springer.
4) van Berkel, M.: Estimation of heat transport coefficients in fusion plasmas (2015) doctoral thesis.