Causality Study of MHD Events in LHD Plasmas

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1. Introduction

In some experiments in the Large Helical Device (LHD), partial collapse phenomena in the pofile of the electron temperature are observed[1]. These collapses are led by the growth of the interchange modes. In order to avoid such collapses, it is crucial to investigate the dominant mechanism. In the phenomena, the disappearance of the mode rotation frequency and the beginning of the mode growth look synchronizing. However, the causality of the events has not still been clarified, whether the rotation stopping allows the mode to grow or the mode growth makes the rotation stop. Van Milligan et al. [2] show that the transfer entropy [3] is a useful tool to investigate such causality. They examined the transfer entropy for the causality studies in the fluctuations observed in the TJ-II experiments. Thus, we apply this method to the LHD data of the magnetic fluctuations and the mode frequency in the present study.

2. Transfer Entropy

The transfer entropy $T_{X\to Y}$ is a measure of transferring information between the two events of X and Y in the direction from X to Y, which is defined as

$$T_{X\to Y} = \sum p(x_{n+1}, x_{n-k}, y_{n-k}) \log_2 \frac{p(x_{n+1}|x_{n-k}, y_{n-k})}{p(x_{n+1}|x_{n-k})}. \quad (1)$$

Here x_i and y_j are the time series data of the events X and Y, respectively. The index k means the time-lag index. The functions of $p(a)$ denotes the probability function for the data a, and $p(a|b) = p(a,b)/p(b)$ is the conditional probability of a on b.

3. Causality analysis of collapse events in LHD

In the LHD experiments, the collapse phenomena are observed in two types of discharge condition [1]. One is the ramp-up of the net toroidal current that increases the rotational transform. This condition reduces the magnetic shear, where the stabilizing effect is reduced. The other is the real-time inward shift of the magnetic axis position. This condition enhances the magnetic hill, where the driving force is enhanced. We attempt to analyze the causality in either case between the stopping of the mode rotation and the growth of the perturbed magnetic field by applying eq.(1).

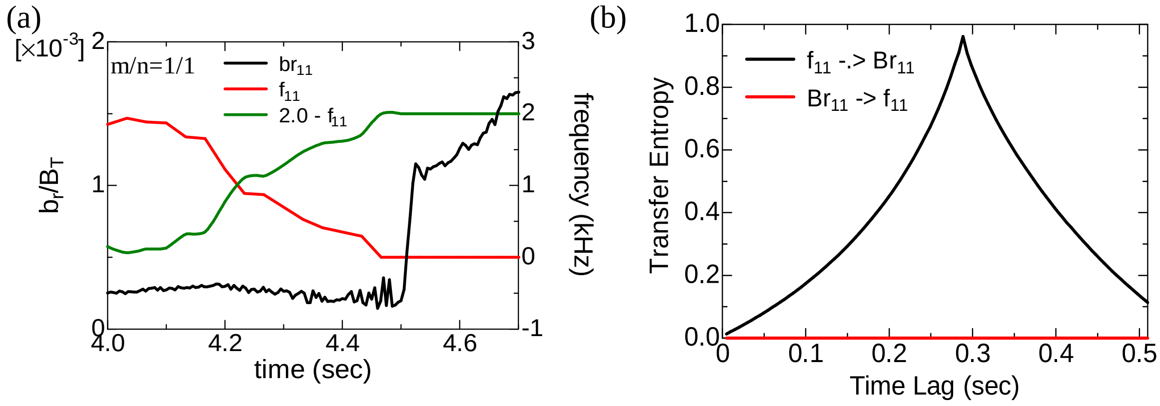

Figure 1: (a) Time evolution of the perturbed magnetic component br_{11} (black), the rotation frequency f_{11} (red) and $2.0 - f_{11}$ (green), and (b) transfer entropy between br_{11} and $2.0 - f_{11}$ in the case of the current ramp-up experiment.

At first, the current ramp-up case is analyzed. Figure 1(a) shows the time evolution of the dominant component of the radial perturbed magnetic field and the corresponding mode rotation frequency. The $m = 1/n = 1$ component is dominant in this collapse. In this case, the stopping of the rotation is observed as the decreasing and the following disappearing of the frequency. However, in the present analysis in eq.(1), the probability must increase and reach the maximum value at the zero frequency. Thus, we employ the value of the difference from 2.0kHz instead of the frequency itself, as shown in Fig.1(a). The transfer entropy is shown in Fig.1(b). The information seems transferred from the frequency to the magnetic perturbation. This result indicates that the rotation stopping occurs firstly and it causes the mode growth. However, the maximum $T_{f \to B_r}$ is obtained at the time lag of about 0.3 sec, while $T_{B_r \to f}$ is completely zero for the entire time region. These values probably mean that the transfer entropy between the maximum frequency difference at t=4.4sec and the largest value of b_{r11} at t=4.7sec is mainly detected. Therefore, this result does not provide the causality desired here, because the onset of the sudden growth of b_{r11} occurs around t=4.5sec. Thus, as the next step, we utilize only the data between 4.4sec $\leq t \leq$ 4.6sec in order to focus on the onset region, as shown in Fig.2 (a). The transfer entropy of $T_{f \to B_r}$ has the maximum value at the time lag of 0.06 sec. This time lag may correspond to the time difference between t=4.46 sec when the frequency reach the maximum value and t=4.52 sec when b_{r11} growth is saturated. In this case, the transfer entropy seems to indicate the desired causality.

Next, the axis shift case is examined as shown in Fig.3. In this case, the $m = 2/n = 1$ component is dominant. The growth and the decay of b_{r21} are observed repeatedly, and each b_{r21}

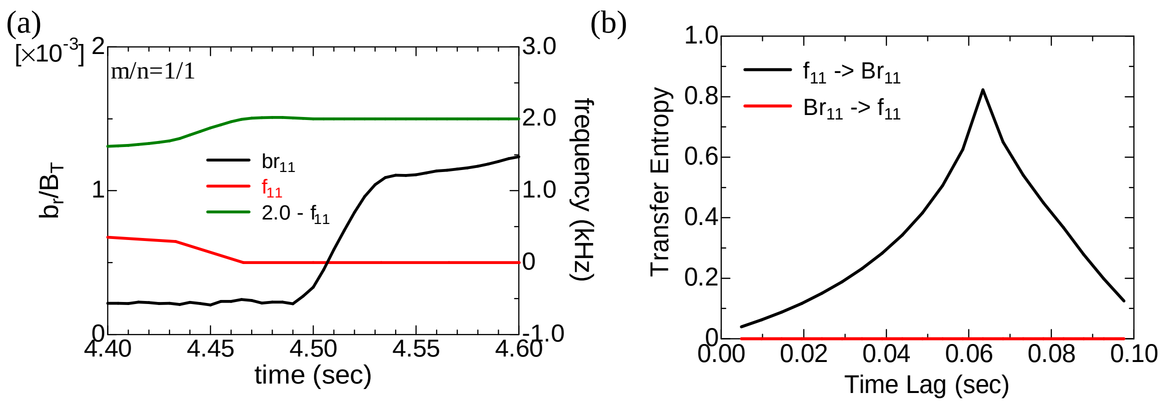

Figure 2: (a) Time evolution of the perturbed magnetic component br_{11} (black), the rotation frequency f_{11} (red) and $2.0 - f_{11}$ (green), in the time region $4.4 \leq t \leq 4.6$ and (b) transfer entropy between br_{11} and $2.0 - f_{11}$ in the case of the current ramp-up experiment.

growth corresponds to the partial collapse. As in the current ramp-up case, the frequency is zero during b_r has large values. Therefore, we also utilize the value of $f_{max} - f_{21}$ instead of f_{21} itself. As shown in the Fig.3(b), the dominant values of the transfer entropy are shown in the result of $T_{f \to B_r}$ at about the time lags of 0.2sec and 0.3sec. Since we need the results for much smaller time lag, we utilize only the data in 3.35 sec $\leq t \leq$ 3.37 sec again, as shown in Fig.4 (a). The dominant transfer entropy is $T_{B_r \to f}$ at the time lag = 0.003 sec, as shown in Fig.4 (b). This may reflect the precursor before the dominant growth in b_{r21}, and indicate the causality opposite to that in the current ramp-up case, although the corresponding values in in the experimental data is not clear in this case.

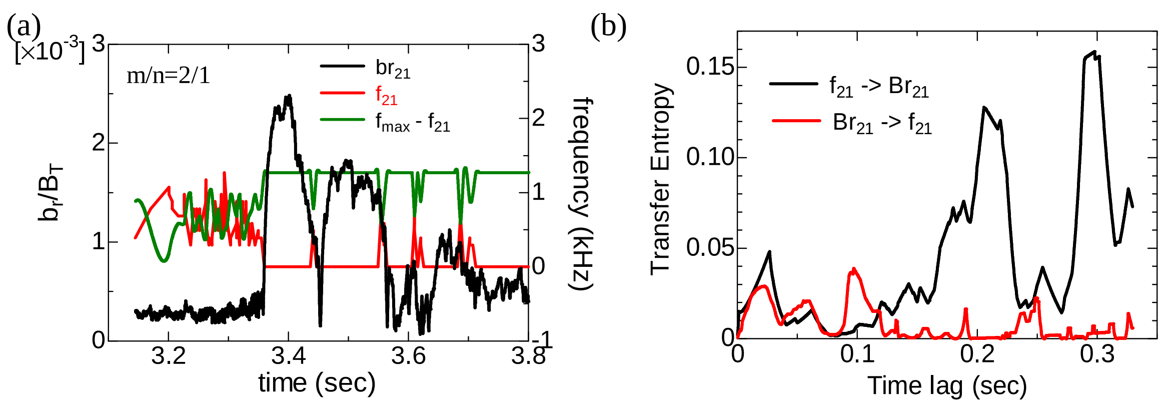

Figure 3: (a) Time evolution of the perturbed magnetic component br_{21} (black), the rotation frequency f_{21} (red) and $f_{max} - f_{21}$ (green), and (b) transfer entropy between br_{21} and $f_{max} - f_{21}$ in the case of the axis shift experiment.

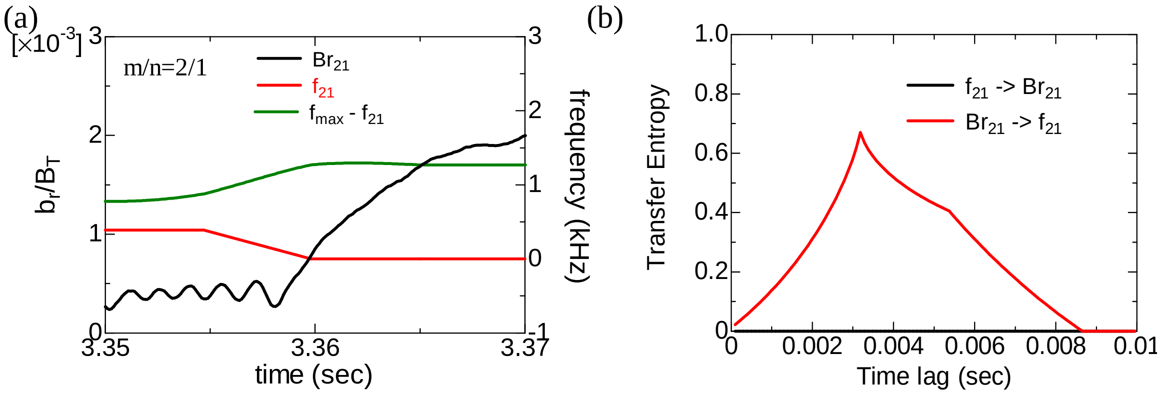

Figure 4: (a) Time evolution of the perturbed magnetic component br_{21} (black), the rotation frequency f_{21} (red) and $f_{max} - f_{21}$ (green), in the time region $3.35 \le t \le 3.37$ and (b) transfer entropy between br_{21} and $f_{max} - f_{21}$ in the case of the axis shift experiment.

4. Summary

To determine the causality in the collapse phenomena observed in the LHD experiments, we utilize the transfer entropy. We obtain the preliminary result that the rotation stopping causes the mode growth in the current ramp-up case while the mode growth causes the rotation stopping in the axis shift case In these analyses, we shorten the time range of the data to obtain the desired results so that only the events to be analyzed should be involved in the range. Since this study is the first attempt of the transfer entropy, the interpretation of the results should be discussed more precisely. As the future work, the reason of the opposite causality between the current ramp-up and the axis shift cases should be investigated. Then, the similarity and the difference in the collapse property between the cases of the hill enhancement and the shear reduction should be analyzed in the aspect of the causality.

Acknowledgments

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