*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, O-2.13 (2004)*

Instabilities in a Dense Cloud of Grown Dust Particles

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1. INTRODUCTION

These experiments have been performed in the PKE-Nefedov reactor [1] which consists in a push-pull rf discharge. Polymer particles deposited on the electrodes are sputtered by the argon plasma ions leading to the nucleation and growth of submicron dust particles [2]. Presented results concern low frequency instabilities appearing in the dense cloud of grown dust particles [3]. The first one appears during the growth phase and evolves as the size and density of dust particles are changing. The second one, called "heartbeat", appearing once the cloud is formed, is characterized by the oscillation of the void size (central dust free region). Electrical (amplitude of the current fundamental harmonic), optical (spatially resolved plasma light) and high-speed camera results, underline the complex structure of these instabilities.

2. GROWTH START INSTABILITIES

These instabilities begin few tens of seconds after the plasma ignition (1.6 mbar, 3.2 W) when the dust cloud is still not visible. Their structure and frequency change with the dust particle size and density evolution. They continue when the dust cloud becomes visible (1-2 minutes after plasma ignition) and can last more than 20 minutes. It seems that these instabilities develop following a well-defined succession of structured phases. Particularly, we can identify 3 phases (P1, P2, P3) at the beginning which correspond to a modification of the instability structure (Fig. 1). These phases are identified in the electrical measurements through the progressive appearance of peaks: one major pattern (P1), growth of intermediate peaks (P2), 3 identical peaks (P3). The duration of each phase varies from one experiment to another (here, P2 is short). They are also observed in the plasma light but with different characteristics. Figure 2 shows the typical light signal recorded near the plasma edge: regular oscillation (P1), amplitude increase (P2), modulated signal (P3). Fourier analysis of similar measurements (with P2 longer) brings out these phases (Fig. 3). Nevertheless, the pattern modification in the electrical signal leads to a threefold increase in frequency when entering in P3 (Fig. 3a), whereas the optical signal keeps on oscillating at the same frequency scale (Fig. 3b). This phenomenon underlines the difference between a signal integrated on the entire plasma volume (discharge current) and a spatially resolved signal (optical signal). The modulation around 3 Hz seems to correspond to a sum of 2 waves with close frequencies (2 peaks around 30Hz). After P3, the instabilities enter suddenly in a chaotic regime P4 where structured oscillations appear in a transient manner [3]. This chaotic phase can last few minutes and either the instability stops or it finds again a structured phase of lower frequency.

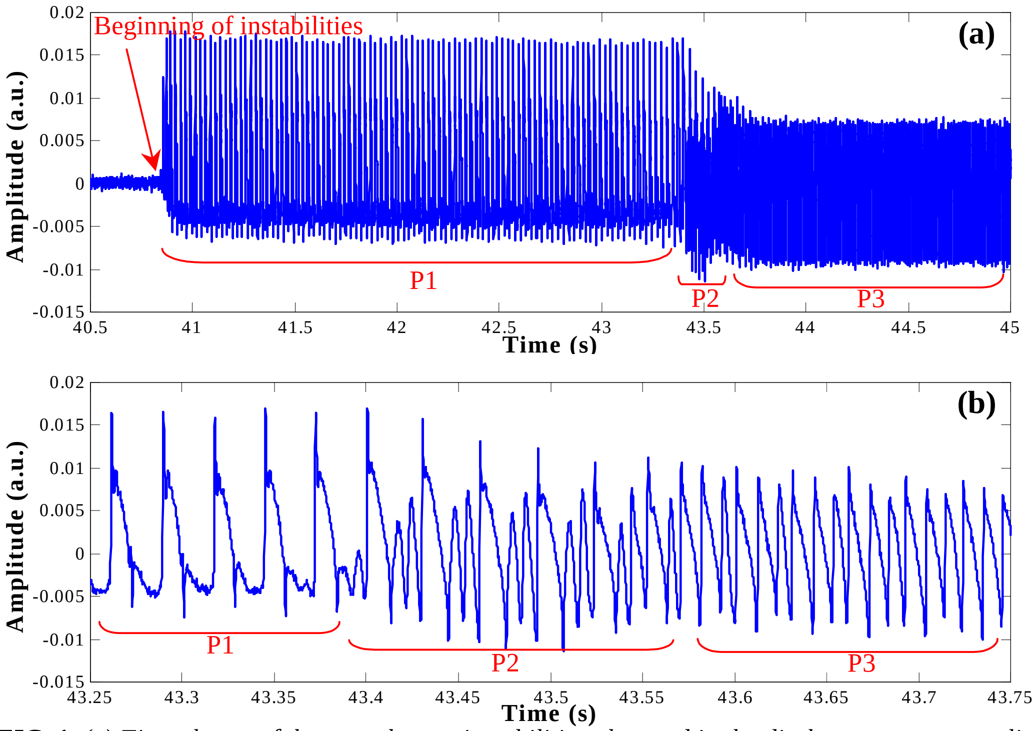

FIG. 1. *(a) First phases of the growth start instabilities observed in the discharge current amplitude (b) zoom of (a) on the phase transitions*

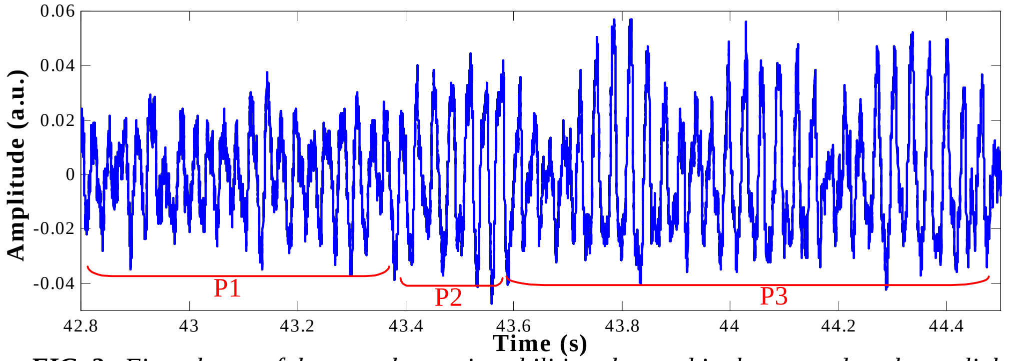

FIG. 2. *First phases of the growth start instabilities observed in the near edge plasma light*

Until now, it is not clear if these oscillations are similar to the ones observed in Ref. [4]. The correlation between these phases and the dust particle cloud characteristics is actually under investigations. The apparent frequency increase in the electrical signal in P3 which corresponds to a modulation of the optical signal is an interesting feature to understand. Furthermore, the optical signal recorded near the plasma edge is roughly symmetric to the one recorded in the center [5] and can give insights on wave propagation or void rotation.

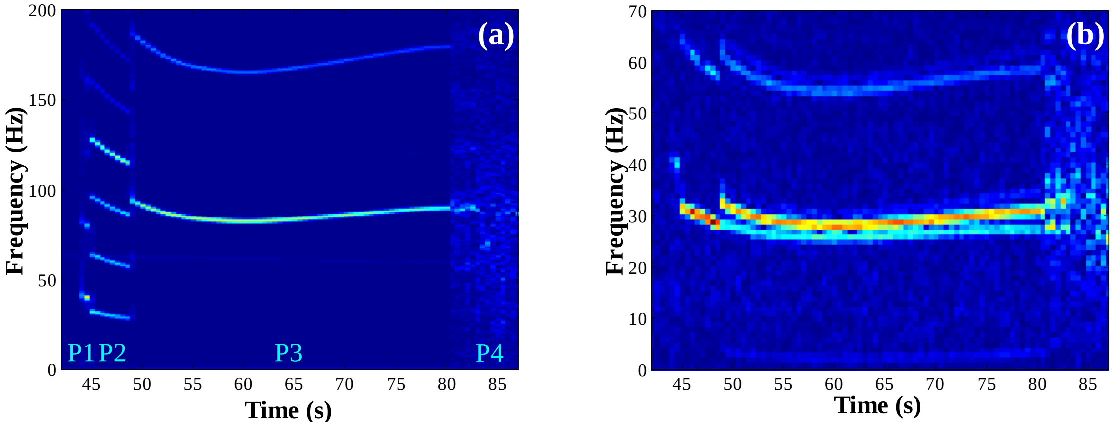

***FIG. 3.** Fourier analysis of the growth start instabilities observed (a) in the discharge current amplitude (b) in the optical signal recorded near the plasma edge*

3. HEARTBEAT INSTABILITY

Once the dense cloud is completely formed, the heartbeat instability can arise in the void. It consists in successive expansions and contractions of the void size. It can appear spontaneously or be generated by lowering the pressure or increasing the rf power. A typical electrical signal during the instability, is shown in Fig. 4 and a more complete analysis can be found in Ref. [5]. Simultaneously, the total plasma light in the void center has been recorded and oscillates in phase with the electrical signal. Nevertheless, the optical signal seems to drop just before the sharp peak [5] often observed on electrical signals (insert in Fig. 4) and is minimum at the peak top. This behavior confirms that the sharp peak traduces a modification in plasma parameters but its origin is still not clear.

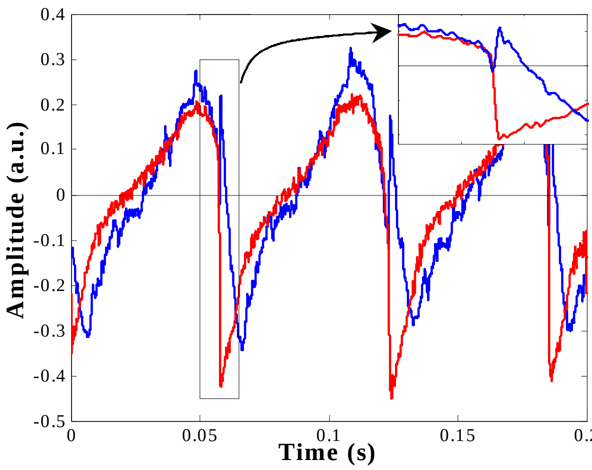

***FIG. 4.** Discharge current (blue) and total plasma light inside the void (red)*

Near the instability threshold or just before it stops, a transition regime characterized by failed peaks on both electrical and optical signals can be observed. The signal increases, crosses zero and instead of raising faster to its maximum value as in Fig.4, it drops and the maximum value is delayed (Fig. 5). This phenomenon is repeated with more and more failed peaks and finishes by the instability stop. Figure 5 shows a transition between 1 and 2 failed peaks in the optical signal. We observed instability stops beginning with 1 failed peak, getting one more failed peak after the other to more than 10. It underlines the threshold dependence of this instability and explains the sudden frequency decrease observed at low power [5].

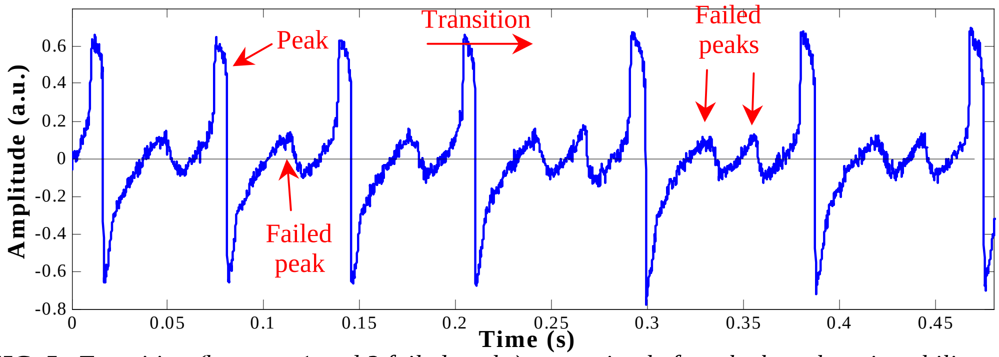

FIG. 5. *Transition (between 1 and 2 failed peaks) appearing before the heartbeat instability stops.*

High-speed camera recordings (up to 9000 images/s) have been performed to observe and understand the motion of the dust cloud during the heartbeat instability. Due to the high dust density, the images are not well contrasted. However, void opening and closure have been correlated with electrical signals (Fig. 6) and it seems that these motions are slightly delayed along the vertical axis of the void that seems to behave like a bubble.

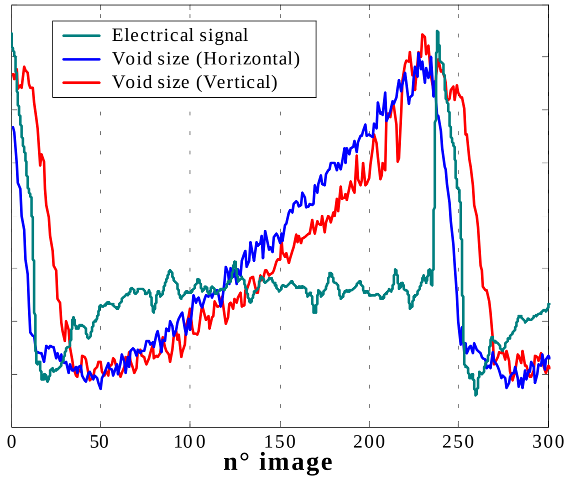

FIG. 6. *Electrical signal and void size evolution*

4. CONCLUSION

This paper reveals the complex structure of different instabilities related to dust particle growth. In particular, the growth start instability structure can give indication on the evolution of dust particle characteristics. Local and global measurements underline different aspects of the instabilities and must be correlated to fully understand their origin.

ACKNOWLEDGMENTS

The PKE-Nefedov chamber has been made available by the Max-Planck-Institute for Extraterrestrial Physics (Germany), under the funding of DLR/BMBF under grants No.50WM9852. This work was supported by CNES under contract No.03/CNES/4800000132.

REFERENCES

1. G.E. Morfill, H.M. Thomas, U. Konopka, H. Rothermel, M. Zuzic, A. Ivlev and J. Goree, Phys. Rev. Lett. **83**, 1598 (1999)
2. M. Mikikian, L. Boufendi, A. Bouchoule, H.M. Thomas, G.E. Morfill, A.P. Nefedov, V.E. Fortov and the PKE-Nefedov team, New J. Phys. **5**, 19.1 (2003), http://www.iop.org/EJ/abstract/1367-2630/5/1/319
3. M. Mikikian, L. Boufendi and A. Bouchoule, *Proc. 30th EPS Conf. on Contr. Fusion and Plasma Phys.*, St. Petersburg, 7-11 July 2003, ECA **27A**, O-3.1B, http://epsppd.epfl.ch/StPetersburg/PDF/O3_001B.PDF
4. G. Praburam, J. Goree, Phys. Plasmas **3**, 1212 (1996); D. Samsonov, J. Goree, Phys. Rev. E **59**, 1047 (1999)
5. M. Mikikian and L. Boufendi, Phys. Plasmas **11**, 3733 (2004)