Chaos in the Electric Curtain

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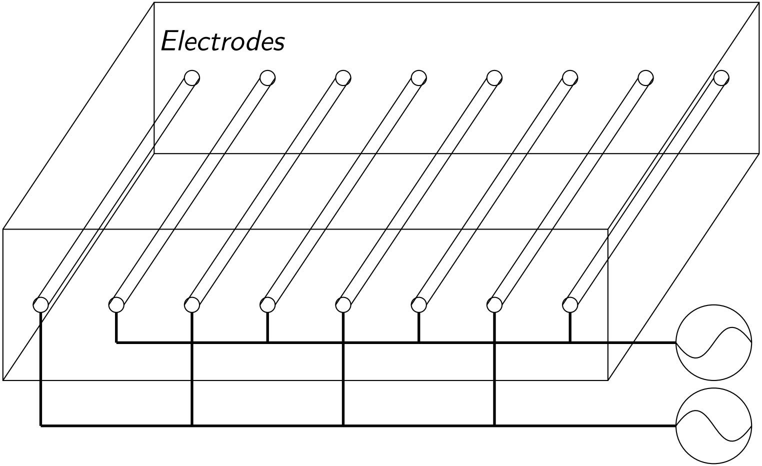
Outline

- What is the Electric Curtain?
- Computational Methods and Simplifications
- The 1D Electric Curtain (surface particle motion)
- The 2D Electric Curtain (off surface motion)

The Electric Curtain

Dielectric Surface



The electric curtain was patented in 1974 by Senichi Masuda for particle manipulation in an electrostatic powder painting booth (Masuda, 1974).
Major application interests include dust mitigation in extraterrestrial environments (Mazumder et al., 2007) and various particulate separation applications including:

- separation of cells in solution (Masuda et al., 1988)
- separation of by-products from agricultural processes (Weiss et al., 1984)
- separation of particles with different charge to mass ratios (Kawamoto, 2008)

Center Line Charge Approximation

Approximate electric field equations (Masuda and Kamimura, 1975):

$$E_x = \frac{kQ}{4\pi\epsilon_0} \sum_{n=0}^{1} \frac{\sin(kx - n\pi)\cos(\omega t - n\pi)}{\cosh(ky) - \cos(kx - n\pi)}$$

$$E_y = \frac{kQ}{4\pi\epsilon_0} \sum_{n=0}^{1} \frac{\sinh(ky)\cos(\omega t - n\pi)}{\cosh(ky) - \cos(kx - n\pi)}$$

Simplifications

1. Primarily investigated single particle motion on the surface of the EC (1D) model.
2. Preliminary work on particle motion above the surface will be shown as well.
3. In both cases the dissipative forces are considered.
   - 1D: Dissipative forces are rolling resistance and viscous fluid force which are both proportional to velocity (Brillianttov and Poschell, 1999).
   - 2D: Just viscous fluid force (non-dissipative collisions)
4. For the center line charge approximation the electrodes are considered as lines with no width. In order to make this approximation valid we put the surface about a third the electrode spacing above the plane of electrodes.

Non-Dimensionalized Parameters

$$t' = \omega t \qquad j = \frac{k^2 qQ}{4\pi\epsilon_0 m^2\omega^2}$$

$$x' = kx \qquad g' = \frac{gk}{\omega^2}$$

$$y' = ky \qquad \beta' = \frac{\beta}{m\omega}$$

j is the dimensionless interaction amplitude.
Dimensionless Equations of Motion:

$$\frac{d^2x'}{dt'^2} + \beta'\frac{dx'}{dt'} = \sum_{n=0}^{1} j\frac{\sin(x'-n\pi)\cos(t'-n\pi)}{\cosh(y')-\cos(x'-n\pi)}$$

$$\frac{d^2y'}{dt'^2} + \beta'\frac{dy'}{dt'} = \sum_{n=0}^{1} j\frac{\sinh(y')\cos(t'-n\pi)}{\cosh(y')-\cos(x'-n\pi)} - g'$$

Setting the Parameters

1. We set $k = 1$. This makes the system periodic in space over $0 \leq x' \leq 2\pi$.
2. For $k = 1$ the electrode spacing is π. We set y' to 1 so the surface is sufficiently far from the electrodes.
3. We set $\omega = 1$. This makes the system periodic in time over $0 \leq t' \leq 2\pi$.

Interaction Amplitude Regimes

Place particle directly above electrode to solve for when the electrostatic force equals the gravitational force.

$$\sum_{n=0}^{1} j \frac{\sinh(y')\cos(t'-n\pi)}{\cosh(y')-\cos(x'-n\pi)} = g'$$

The inequality:

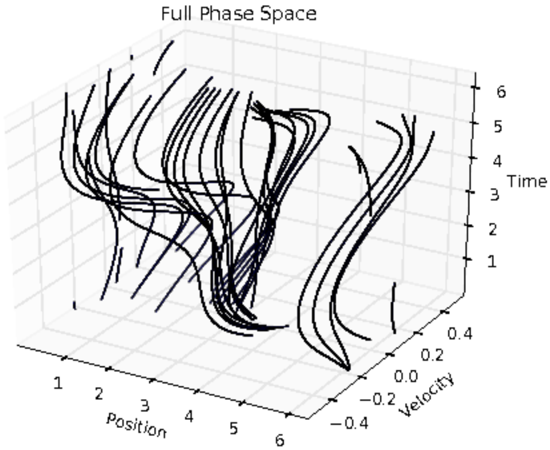
$$\frac{j}{g'} \leq \frac{\cosh^2(y')-1}{2\cos(t')\cosh(y')}$$

needs to be satisfied for the particle to remain on the surface. When we make $\cos(t')$ one and put it $y' = 1$ we find that:

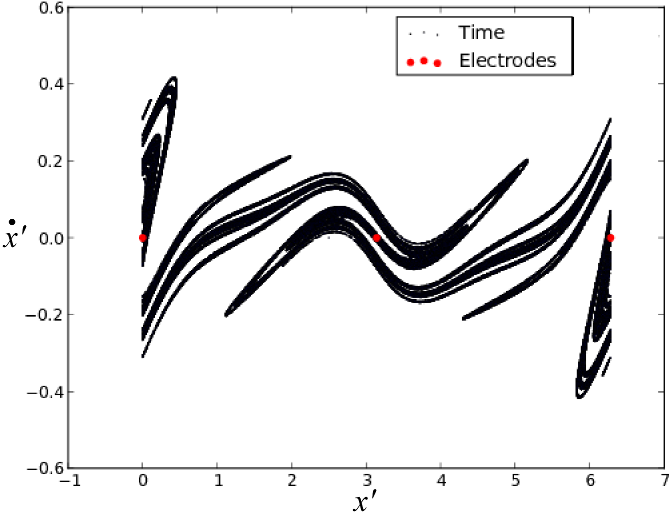
$$\frac{j}{g'} \approx .448$$

is the critical ratio that needs to be considered.

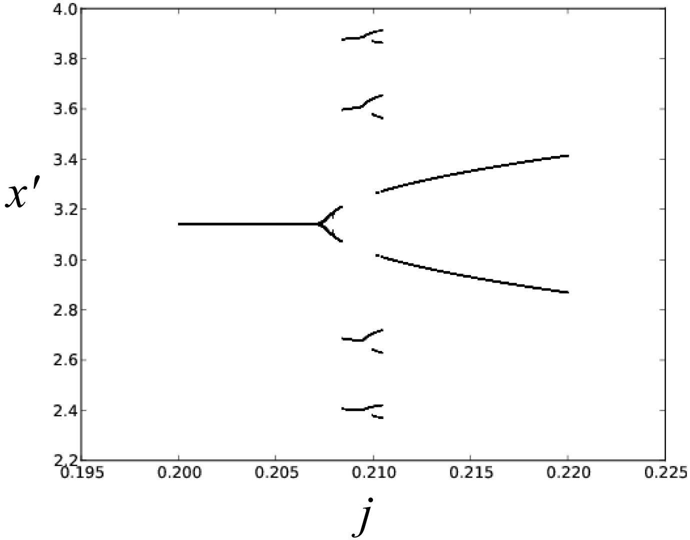
The full periodic phase space



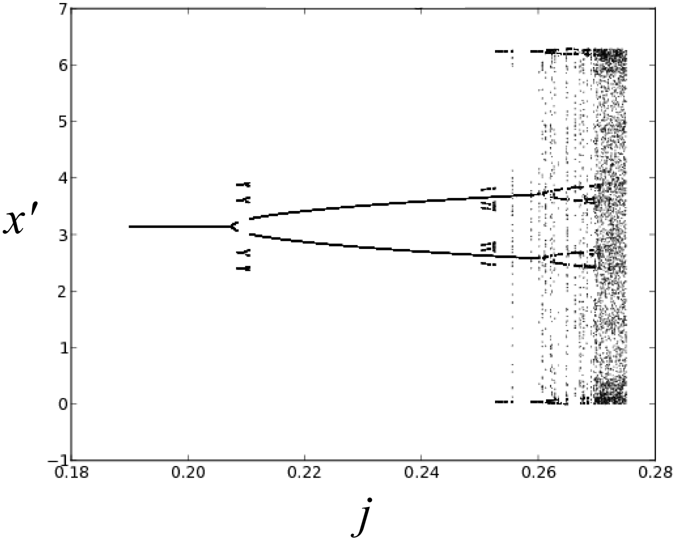
Full phase space time sliced

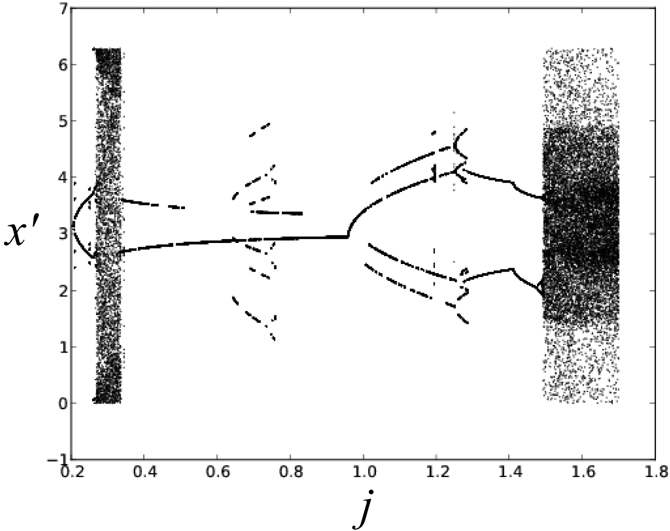


Period doubling?

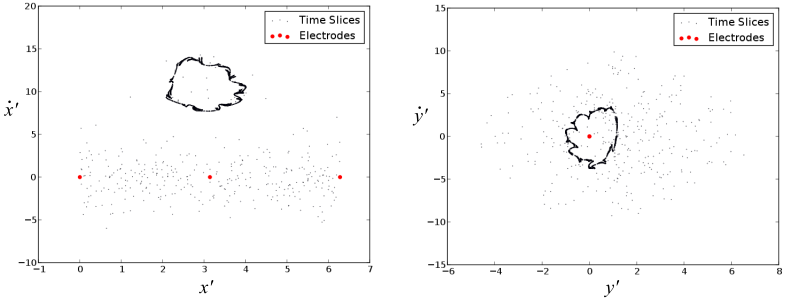


A unique period doubling rout to chaos




7
6
5
4
3
2
1
0
−1
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
x'
j

Preliminarly 2D Work



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Bibliography

S. Masuda, "Booth for electrostatic powder painting with contact type electric field curtain," USA Patent 3801869, April, 1974.

M. Mazumder, R. Sharma, A. Biris, J. Zhang, C. Calle, and M. Zahn, "Self-cleaning transparent dust shields for protecting solar panels and other devices," *Particulate Science and Technology*, vol. 25, pp. 5-20, May 2007.

S. Masuda, M. Washizu, and I. Kawabata, "Movement of blood cells in liquid by nonuniform traveling field," *IEEE Transactions on Industry Applications*, vol. 24, pp. 217-222, Mar/Apr 1998.

L.C. Weiss and D.P. Thibodeaux, "Separation of seed by-products by an AC electric field," *JAOCS*, vol. 61, no. 5, pp. 886-890, May 1984.

H. Kawamoto, "Some techniques on electrostatic separation of particle size utilizing electrostatic traveling-wave field," *Journal of Electrostatics*, vol. 66, pp. 220-228, 2008.

S. Masuda and T. Kamimura "Approximate methods for calculating a non-uniform traveling field," *Journal of Electrostatics*, vol. 1, pp. 351-370, January 1975.