# PENGUIN SYNCHRONIZATION CONDITIONS:

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## INTRODUCTION:

A simple demo to demonstrate the effects of a system of driven, coupled oscillators is to place metronomes on a platform set on some round objects so that the system can shift with the ticking of the metronomes. When the demonstration works as planned, metronomes that initially tick out of time with one another are eventually forced to tick in synchronization. Unfortunately, during a recent demonstration this effect could not be shown, which raised a question of what parameters optimized the results.

## DESCRIPTION:

Three or four penguins are placed side-by-side and evenly spaced on a platform. The upper frequency limit on these metronomes is 200 bpm. The platform, which can be various materials, is raised off the ground and allowed to pivot on two (or three) cylindrical objects such as empty soda cans or cylindrical weights.

## TESTS AND ANALYSIS:

The metronomes were first tested to ensure that they were ticking at the frequency they were being set to. Tests at 160 bpm, 120 bpm, 80 bpm generated satisfying results and at this point the metronomes were believed to be working properly.

The demonstration was then set up in the way it had been set up previously with four metronomes on a sturdy foam board raised by empty soda cans. Several tests were conducted varying certain parameters: various frequencies between 80 bpm and 176 bpm were tried, both two and three cans were used, and some metronomes were removed from the system entirely. Unfortunately none of the setups tried generated the desired results. It should be mentioned though that there was evidence that the metronomes were influencing each other. Often patterns could be observed such as all the metronomes being in phase and except for one being exactly out of phase with the others and having the system vary and repeat which metronome this was. Other times the system would sync momentarily but was not able to hold this state for an extended period.

The material of the board was the next to be varied. Due to length, three penguins were used for the metal and wooden platforms. Metronomes were set to 176 bpm were used and the system was raised on two cans. The specifications of the materials as well as the results are as follows:

| Material | Details | Result |
|---|---|---|
| Foam | Mass: 141.2 g<br>60.7 cm x 25.1 cm x 0.7 cm | Results given in the above paragraphs. |
| Plastic | Mass: 561.9g<br>65.0 cm x 13.0 cm x 0.6 cm | Metronomes would tick in phase very briefly before becoming disordered. They would quickly regain synchronization but repeat the behaviour. |
| Metal | Mass: 802.3 g<br>47.1 cm x 20.0 cm x 0.3 cm | The metronomes became synchronised very quickly and remained so for > 2 min. The platform's movement was visible. |
| Wood | 845.8 g<br>38.1 cm x 24.5 cm x 1.6 cm<br>with additional boarder of depth 2.6 cm and adding 0.9 cm to the sides | No synchronization was reached. The board did not move visibly. |

**At this frequency the metal board was the only one to exhibit the metronomes coming into and holding their synchronization for an extended period. Tests were continued using this material, only**. For the first couple of tests the cans were still used and were placed below the two outside penguins. Metronomes are now labelled M1 M2, M3 according to their place on the board. The frequency was varied:

| Frequency | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
|---|---|---|---|---|---|
| 200 bpm | Synced at 52 s. Held synchronisation until 3:00 min when test was stopped. Board moved visibly. | Synced at 1:44 min and held until 2:44 when stopped. Board moved visibly. Some metronomes appeared to 'lag' but did not throw others out of phase. | Synced at 52 s and held phase until 1:59 min. Board moved visibly. | Synced at 1:05 min and held until 2:05 min. Board moved visibly. | Synced at 50 s and held until 2:00 min. Board moved visibly. |
| 192 bpm | Synced at 1:92 min but fell out of phase at 1:43 min. | Synced at 49 s but the first metronome lagged and threw the others out of phase at 3:11 min. | | | |
| 184 bpm | Synced at 1:17. Visible movement of board although it was less prominent at first. M1 out of phase at 2:00. | Not in phase after 3:00 min. | Synced at 57 s. Still in phase at 3:03. M1 seemed to lag but did not throw others off. *** Metronomes were rewound before this test. | Synced at 1:16 min. M1 still appeared to lag. Still in phase at 2:16 | Synced at 1:12 min. M1 is still lagging. Fell out of phase at 2:25. |

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| 176 bpm | Synced at 59 s. M1 out of phase at 1:49 min. | Metronomes would be in phase only briefly (usually with one still lagging) before falling out of phase again. | | | |

Although it was possible to have the metronomes synchronize for an extended period of time the effect became uncertain at 192 bpm. The cans were then replaced by 500 g metal cylindrical weights and the frequencies at this set-up were varied. More or less tests were conducted depending on need with the goal being to see what the lowest effective frequency was:

| **Frequency** | **Test 1** | **Test 2** | **Test 3** | **Test 4** | **Test 5** | **Test 6** |
|---|---|---|---|---|---|---|
| 200 bpm | Synced at 38 s and held phase until 1:38 min. Board moved well although it would alternate between strong swings and weaker swings. | Synced at 24 s and held phase until 1:00 min. Board moved visibly and evenly. | | | | |
| 192 bpm | Synced at 50 s and held phase until 2:00 min. M1 lagged but did not throw others off. | | | | | |
| 184 bpm | Synced at 2:00 min but was thrown quickly out of phase again. No visible movement of board.<br><br>Possible issue of platform resting on an uneven | Synced at 23 s. No visible movement of board.<br><br>Platform was repositioned to a more sturdy spot | Synced at 20 s and held phase until 2:00 min. Visible movement of board. | Synced at 12 sec and held phase until 2:00 min. Visible movement of the board. | Synced at 20 s with some metronomes lagging. The lag disappeared by 30 s. Phase was held until 2:00 min. Visible movement of the board. | Synced at 51 s and held phase until 2:00. Visible movement of platform. |

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| 176 bpm | Synced at 10s and held phase until 2:00 min. Some minor lag was observed. | Synced at 19 s. M1 lagged occasionally. Lagged seemed to clear by 1:00 min. held phase until 2:00 min. | Synced at 36 s. M1 lagged on occasion but did not throw others out of phase. Visible movement of platform. | Did not fully synchronize after 3:00 min. System alternated between M2 or M3 being antiphase while the other two metronomes were in phase. Very little motion of the board.<br><br>It's possible that something was displaced when the penguins were would prior to this test. | Synced at 55 s but M1 was out of phase at 1:41 min. Little motion of board. | Same patterns observed as Test 5. |
| 168 bpm | Synced at 20 s. Minor lag observed in M1. Held phase until 1:53. | Synced at 30 s. but was out of phase at 47 s. Regained phase around 3:00 min but quickly fell out of phase again. | | | | |
| 160 bpm | Synced at 6 s but was out of phase at 33 s.<br>Some visible movement of the board initially. Not fully in phase again after 3:00 min. | | | | | |

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|---|---|---|---|---|---|---|
| | System alternated between two in phase and outside one out of phase. | | | | | |

The 500 g weights allowed the system to work effectively at lower frequencies. Synchronization becomes particularly uncertain at 176 bpm. To test a system of four metronomes a longer, but slimmer, platform made of the same metal material as before was used. The cylinders were placed between M1 and M2 and M3 and M4.

| **Frequency** | **Test 1** | **Test 2** | **Test 3** | **Test 4** |
|---|---|---|---|---|
| 200 bpm | Synced at 18 s. Did not hold phase (although this was due to neglecting to wind the metronomes). | Synced at 11 s and held phase until 2:00 min. | | |
| 192 bpm | Synced at 1:12 min and held phase until 2:00 min. | Synced at 22 s and held phase until 2:00 min. | | |
| 184 bpm | Not synced after 5 min.<br>No visible movement of board | Not fully synced after 3 min.<br>Various patterns were observed. | Noticed metronomes had been pushed slightly to the back of the board, when recentred the system moved better.<br>Still not fully synced after 5 min. | Synced at 22 sec and held phase until 1:00 min.<br><br>** The penguins were wound to their maximum for this test. |
| 176 bpm | Synced at 16 and held until 1:00 min. | | | |
| 168 bpm | Synced at 34 s and held for 1:00 min. | | | |
| 160 bpm | Not synced after 2:30 min. | | | |
| 152 bpm | Not synced after 3:30 min. | | | |

Although less tests were performed this set-up demonstrated similar behavior to the three metronome set-up. Some issues were encountered at 184 bpm although this was likely due to neglecting to wind the metronomes fully. 176 bpm is the suggested lower limit for this set-up as it was for the previous set-up.

## CONCLUSIONS:

Whether or not all of the metronomes synchronize in this demonstration depends on a multitude of factors, most of which were unable to be tested extensively. However, a few other things of note that were noticed while testing should be mentioned here to ensure an effective demo. All metronomes should be wound fully before the test begins to prevent one or more from slowing down during a demonstration. The system should be placed in a location where the weights can shift easily but the platform does not tend to roll off the table. A platform which rocks back and forth visibly is a good indication that the system is in a good position (although this visible movement will not always lead to the desired result).

The length of time which the metronomes take to synchronize largely depends on how out of phase they were to begin with. Starting with perhaps half the metronomes in phase and the other anti-phase will lead to a longer synchronization time and make the process more visible.

*Although it may be possible to exhibit the desired effect using the platforms made of other materials either of the metal platforms improves upon the chances of this happening. Additionally, using solid metal cylinders instead of empty soda cans also lower frequencies to be exhibited. Whether using the four penguin or the three penguin set-up using frequencies above 176 bpm is recommended. Systems at or below this setting become less likely to synchronize and hold this effect.*

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