

6.163 Lecture Notes on Stroboscopy

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Bring to class:

1. Disk of Man Sawing Wood
2. A small motor with a disk
3. Strobotac

Topics for today:

1. Stroboscopy
2. Hand out Lab 2

1. Stroboscopy

Start with a demo using one of the spinning disks and a Strobotac (like the “Dancing Dots” display in Strobe Alley). Demonstrate that

- A. One can find more than one flash rate that makes the image appear to stand still (a Single Stationary Image *SSI*).
- B. One can find flash rates that give multiple stationary images (e.g., double, *DSI*, or triple, *TSI*), and that they are not unique.
- C. At high flash rates only multiple images are seen.

Question: Since the Strobotac tells us the flash rates that gives these various images, can we use this information determine the rotation rate of the motor?

Let us consider a Single Stationary Image (SSI) and ask:

What is the relationship between the period of rotation for the motor (T_{MOTOR}) and the period between flashes for the strobe (T_{FLASH})?

Answer: To obtain an SSI, the motor must make some number of complete rotations between flashes, that is,

$$T_{FLASH} = NT_{MOTOR} . \quad \text{Eq. 1}$$

Now we have one known here (T_{FLASH}) and two unknowns (N , T_{MOTOR}). If we adjust the strobe until we find another SSI at T'_{FLASH} , then we can write

$$T'_{FLASH} = MT_{MOTOR} . \quad \text{Eq. 2}$$

Unfortunately this doesn't seem to help us, because we had to introduce a new variable (M) in Eq. 2. What we need is to know some relationship between M and N .

If we start at the first SSI (T_{FLASH}) and gradually slow the flash rate (i.e., increase T_{FLASH}) until we see the *next* SSI, then we know that $M=N+1$. Making that substitution into Eq. 2 and subtracting Eq. 1 from Eq. 2 gives us

$$T_{MOTOR} = T'_{FLASH} - T_{FLASH} . \quad \text{Eq. 3}$$

Remember that Eq. 3 is valid for successive SSIs only!

Now the frequency f is just 1 over the period T , so

$$\frac{1}{f_{MOTOR}} = \frac{1}{f'_{FLASH}} - \frac{1}{f_{FLASH}}, \quad \text{Eq. 4}$$

and after some manipulation, we obtain

$$f_{MOTOR} = \frac{f_{FLASH} \times f'_{FLASH}}{f_{FLASH} - f'_{FLASH}}, \quad \text{for successive SSIs only!} \quad \text{Eq. 5}$$

Remember that Eq. 5 is valid for successive SSIs only!

Method of multiple subharmonics

This method is quite handy when working with motors that spin faster than the strobe can flash. You start at the highest flash rate, and slowly drop the flash rate slowly, recording each SSI you see. For example, if your strobe went up to 3,000 fpm (our Strobotacs go up to 25,000 fpm) you might find the following SSIs.

Flash Rate	SSI found
3,000	First
2,400	Second
2,000	Third
1,710	Fourth

You can calculate a rotation rate using any pair of these readings. Given two flash rates $Flash_M$ and $Flash_N$ ($Flash_M > Flash_N$) that give SSI's that are N-M apart, then

$$f_{MOTOR} = (N - M) \frac{FLASH_M \times FLASH_N}{FLASH_M - FLASH_N} \quad \text{Eq. 6}$$

Equation 6 is valid for N successive SSIs.

E.g., using the first and fourth readings gives

$$f_{MOTOR} = (4-1) \times (3,000) \times (1,710) / (3,000-1,710) = 11,900 \text{ rpm}, \quad \text{Eq. 7}$$

while using the second and third readings gives

$$f_{MOTOR} = (3-2) \times (2,400) \times (2,000) / (2,400-2,000) = 12,000 \text{ rpm}. \quad \text{Eq. 8}$$

These agree within the precision available.

By taking multiple successive SSIs you can often determine if you made a mistake by missing an SSI. You work out all possible pairings, and if the answers are consistent, you didn't miss any SSIs. If they are inconsistent, you did skip an SSI. With care, you can deduce where the missing SSI had to be and still recover the motor speed!

Multiple Stationary Images

This analysis also works for multiple stationary images (e.g., double or triple images).

For a Double Stationary Image (DSI) the motor spins an integer number of rotations plus (or minus) a half rotation between flashes, so

$$T_{FLASH} = (N \pm 1/2)T_{MOTOR} . \quad \text{Eq. 9}$$

For Triple Stationary Images (TSIs), replace 1/2 with 1/3, and for a quadruple stationary image replace 1/2 with 1/4. Beyond that it is not possible to generalize.

At this point, you should be able to solve a problem such as:

You send an assistant to measure the rotation rate of a motor with a Strobotac. Your assistant returns and tells you that they found a DSI at 5,000 fpm, and that the next slower SSI occurred at 3,750 fpm. What is the speed of the motor?

Final Comments

This process of using a flashing lamp to determine the rate of a repeating phenomenon is known as *stroboscopy*. In general, flashing lamps used for this purpose are called *stroboscopes*. In this subject we will almost always use a *Strobotac*—a particular unit designed by Edgerton and his colleagues for the General Radio Corporation. They are now made by IET Labs, (<http://www.ietlabs.com>). A new unit costs over \$4,000. You can buy used units on eBay for \$150 to \$300. In your write-ups, please be specific and write “Strobotac” instead of “stroboscope” (unless, of course, you used a different kind of strobe).

The flash duration of the Strobotac (for certain settings) is less than 1 microsecond (μs), and thus is short enough to do bullet photography. However, the BCPS is quite low, and the hot spot is quite small (i.e., the beam is narrow), so we will use a different unit for the bullet lab later this term.

Finally, note the units— f_{MOTOR} is a rotation rate usually specified in revolutions per minute (RPM), while f_{FLASH} is a flash rate usually specified in flashes per minute (fpm).

2. Lab 2, Stroboscopy

Hand out assignment. Make these comments on Lab 2.

1. There is a lot of work to be done in this lab. It can be completed in the time allotted, but you must be on time for the lab session, and your team must work in a coordinated, efficient, manner.
2. In this lab you will use the procedure laid out in the sample memo to measure the BCPS of the Strobotac. When you write up your procedure, it is OK to simply refer to the sample memo (e.g., “To measure the BCPS of the Strobotac, we used the procedure laid out in Dr. Bales memo, IMxx. The distance from the strobe to Dotty was xx feet, and the load resistor was set at xx Ohms.” where you fill in the xx’s.)

Your oscilloscope readings must go into the results. Your calculation of the BCPS must appear in the discussion. In the procedure, you may need to refer to the calculated BCPS. Just write along these lines: "Given that the calculated BCPS

(shown in the Discussion section) was XX, we chose a strobe-to-subject distance of XX ft, and an aperture of f/N."

3. This tends to be the longest lab write up of the term., because you will conduct five different experiments. Each experiment needs its own subsection in your procedure, results, and discussion.
4. In your background, don't forget to tell us what stroboscopy is! Your answer to the first pre-lab question will help.

The Man Sawing Wood

Show the disk of the man sawing wood. Note that it has 16 images that, when viewed in sequence, form an animation. The images are placed sequentially in a clockwise manner about the disk (Figure 1), and the disk spins in a clockwise manner as well.

You will use this information to answer the second pre-lab question, which asks you to determine the flash rates required to animate these images in a forward and backwards manner. Your analysis will be similar to that used above in the first part of the lecture.

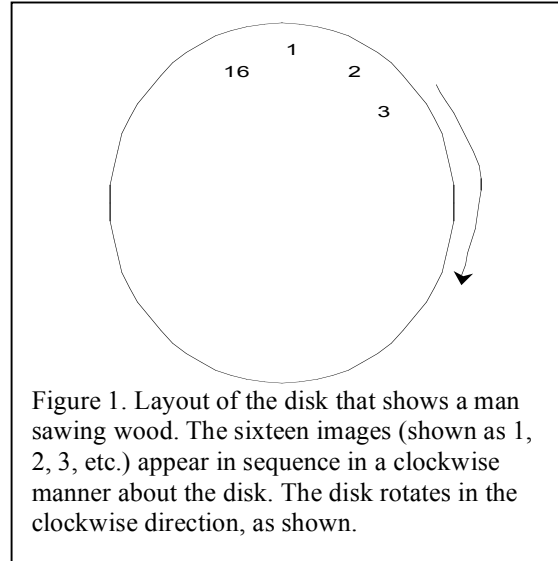


Figure 1. Layout of the disk that shows a man sawing wood. The sixteen images (shown as 1, 2, 3, etc.) appear in sequence in a clockwise manner about the disk. The disk rotates in the clockwise direction, as shown.