Pendulum Wave

Project Hands on Physics

July 5, 2018

1 Operation

The structural part of the instrument is based on mere mechanical laws
and it consists of a set of pendulums of different lengths, hanging from a lintel
supported by two side supports and connected to a tuning system, and
in an array of lasers and sensors. The mechanical apparatus is to
send electrical signals as input to an Arduino board and, simultaneously,
be pleasing to the eye while it is running.

1.1 Local Operation Pendulum-Laser-Sensor

To build and materially so and? Cient the structure is indispensable
focus on the local operation of each set of three laser-Pendulum-sensor.
The laser beam is directed perpendicularly to the ground, so hit the sensor
in the absence of the ball. When the pendulum, during its motion, passes through the
rest position, the mass placed in the bottom of it intercepts the laser beam. The
sensor (or more precisely photoresistor) detects this change in light
that strikes it and sends the input signal to the Arduino.

1.2 Preparation of the instrument

Every time that the entire apparatus is used, some are necessary opera-
tions to make sure everything is in order, to? ven total functions
no significant errors.
The steps (in order) are as follows:

- Stabilization of the structure
- Alignment Laser-Pendulum and Laser-Sensors
- General Wave test of pendulums
- Local tuning of pendulums
- Calibration of the sensors and startup

The following explains in more detail all actions to be followed in order
to obtain an excellent operation.

Stabilization of the structure

To stabilize the structure is necessary to mount the first thing the supports
triangular.

They are? Xed by a cockerel lintel on which are mounted pendulums
and laser. Following should be opened so that the base rests completely
land. In? It is? Xed the mobile base using another rooster.
Although not strictly necessary, as you will see below, it may be
convenient to adjust the inclination of the lintel (for example to put it into bol-
there). To do so, loosen the wing nuts that hold it? Xed to the side bolsters,
ways? loved his inclination and retighten the wing nuts for? secure it again.

Warning! Is crucial make sure that the lintel
NOT is free to rotate once completed the stabilization phase. The
risk of not? ettuare this most important task is that during the func-
tioning apparatus ways it? Who his inclination (compromising
oscillation of pendulums) or even worse fall off the side bolsters and drop!

To perform the operations of stabilization is better to work in pairs,
so that during assembly of the first support a person can maintain
the lintel parallel to the ground, avoiding in this way that is damaged or broken
during the process.
Working in pairs also brings the advantage of having a double check on
This very important part of the preparation.

Alignment Laser-Pendulum and Laser-Sensors

These two arrays, if executed properly, also ensure that the archi-
beam is level.
To be able to implement it is necessary to feed the diodes (in our case with a ten-
Board of 4.5V), so you can see where point. If you want to observe
Also the laser beam can be humid? care of the air with steam in order to see
a solid line instead of a single point on a super? cie. This last one
operation is not essential but it allows to identify any deviations of the
laser beam due to an LED failure.

To align the laser with the pendulums is necessary that they do not wobble, remained
Nendo firm in their rest position. Laser and pendulums are aligned when
all the beams are intercepted by the balls, hitting at best hypo-
dissertation their center.
After this, since the act as pendulums? Him to lead, the archi-
beam should be in a bubble.

The alignment between laser and sensors starts by fitting the sensor bar between
Horizontal End-Suction bases of the lateral supports of the structure. Then just adjust
its position in such a way that all the laser hit the respective photoresistor.
At this stage we must do everything possible to make sure that each laser points
in the center of the photo-resistor, to avoid problems sending input to the board
Arduino.

General Wave test of pendulums

At this point you have to act on the length of the pendulum, in order to adjust
the frequency.

Given that the tuning of the pendulums, as described below, is a process
that may take a long time, it is necessary to identify quickly which
pendulums are to be adjusted.
To do this we use a wooden rod that allows us to move all
balls at a same amplitude, and then to begin all of their respective motions
osccilatori simultaneously. Observing the oscillations total
we can easily notice such pendulums move faster or slower
they should.
Once the pendulums identified to be adjusted we can focus on them
and grant them properly.

Local tuning of pendulums

Now that we know what pendulums are ways? Think about how to care grant them.

A chief? each of the pendulum is connected to a mechanism accordatu-
ra, as described in section Pendulums and tuning mechanism; we see
Now how do you use.
To shorten? lo (ie increase the frequency of the pendulum) is necessary gi-
The rare guitar key counter clockwise looking from above. Consequently
to stretch? lo (ie decrease the frequency of the pendulum) just turn it
counterclockwise, always looking from above.

To achieve the desired frequency you need to run local tests
the pendulum that you want to tune.
Using a stopwatch begins to measure the instant $t_{the,}$ and they begin to
counting the pendulum swings.
Warning! Remember that a full swing of a pendulum? Nes
when it performs twice the same arc of circumference, returning
in the initial position.
Once the ' n- th pendulum has made or_n fluctuations (consult the TA
beautiful section Formulas and laws to determine $or_{n)}$ stop the stopwatch
the instant $t_{f.}$

The frequency of the pendulum is now much closer to that desired because the
time indicated on the chronometer display $\Delta\ t = t_f - t_{the}$ approaches $T_{tot\,(}$ you see
section Formulas and laws).

Council! To determine more accurately the actual frequency of the pendulum
examined is advised that most people measure the time $\Delta\ t$ Contemporary-
mind, so that errors due to reaction times too retarded or
Early every observer compensate the average of the measured times.

Calibration of the sensors and startup

The final step before the start of the instrument calibration
of photoresistors.

To calibrate the sensors appropriately is first necessary to create an environment
dark and feeding the LED with a voltage of 4.5V. As a result, maintaining

the masses of the pendulums move by laser beams, start calibration from the computer, wait a few seconds since the program? herm that calibration is
It was completed, once again illuminate the environment and? ne release pendulums.

If these instructions have been followed correctly now nothing remains
Enjoy the show.

2 Construction

To build the structure we have taken into account some points to be observed to? conditions so that such whole apparatus functions properly, ie:

- The distance traveled by the laser beam must not be excessive
- The structure must be easily removable and transportable
- The structure must be as stable as possible
- The pendulums they do not twist on themselves
- The length of the pendulums must be adjustable
- Lasers and sensors must be mounted and oriented along a perfectly RET-
ta perpendicular to the ground

On the basis of these demands to be met we have measured, using calculations trigonometric, the various measures that we needed to create a structure how much more e? cient as possible.
Each part was made according to specific needs? That inquiries. Below
They show various stages of assembly for each piece of the structure.

2.1 lateral supports

To make sure that the lintel does not collapse we realized that supports 2 satis? no the first 3 items mentioned above. On the basis of the maximum flow rate of laser to be transposed by the sensors, we decided to build two triangles disas-tabili and leaflets, with a fairly wide base to prevent the structure of shake.
The angle at the upper vertex, therefore, had to be chosen adequately in Mo-do that the oblique axes exercised a restraining reaction on the lintel more large as possible, while maintaining an opening that would ensure the greatest balance.

2.2 Pendulums and tuning mechanism

To meet the fourth and fifth point mentioned above were taken some precautions.
To have that? them of the pendulums do not twist their (and decreasing? ectively their length) we had to make sure that the 2 points? ssi of each? the
They are fairly spaced between them, while maintaining a lintel dimensions do not overdo it.

The mechanism that allows to adjust in a very precise manner the length
Pendulum is based on the operation of the mechanical guitar: provisions

tive that allow to turn around a pin a? it, without limitations and
regardless of its length.
The end result? Consists of the following with? Configuration for each pendulum:

The? the part knotted to an eyelet, is connected to ground via a anel-
flax, passes through the second eyelet (without being in any way? xed) and then
knotted at mechanics for guitar.

2.3 Laser and sensors

These two elements are those that have requested greater accuracy. Of-
facts, even a minimum of the laser displacement from its ideal position has a
great impact on the functioning of the device.

To allow an alignment as accurate as possible, it was decided to drill
the axis of the sensors and laser one above the other, as if they were a single
axis. However this was not enough to ensure that the laser beam hit
perfectly the sensor, then it is resorted to for the quick setting glue
secure it more adequately.
Each diode has been in? Ne, connected in parallel to the other two copper strips
with an adhesive side attached to the lintel.

3 Formulas and laws

To realize the entire structural basis we relied on a multiplicity of
laws? physical and mathematical formulas.
The lengths of the pendulums, for example, have been determined on the basis of
frequencies that we wanted to obtain, according to the law:

$$f_n = \frac{1}{2\pi} \sqrt{\frac{g}{THE_n}}$$

hence, making explicit THE_n you get:

$$THE_n = \frac{g}{4\pi^2} \frac{1}{f_n^2} \qquad (1)$$

Staring now the time T_{tot} that elapses between the phase shift and the ria? a-
Samento of pendulums, because we know what happens every pendulum will com-
piere a whole number of oscillations or_n at that particular period of time, in
so that a time lapse of the period T_{tot} all return to their pendulums
initial position.
The frequency of ' n- th pendulum will, therefore, the relationship between or_n is $T_{tot.}$ replaced
tuendo in (1) is obtained:

$$THE_n = \frac{g}{4\pi^2} \left(\frac{T_{tot}}{or_n} \right)^2 \qquad (2)$$

For example we have? Xed $T_{tot} = 30$ s, and we decided that the pendulum
with greater frequency must have a number of oscillations or_{max} equal to 33
fluctuations.

The pendulum immediately adjacent to it must fulfill at the same time **an oscillation in less, then $or_{max} - 1$ fluctuations. In general, the ' n- th pendulum will have to make $or_{max} - n + 1$ fluctuations.**
Substituting in (2) we obtain a longer way in which we calculated the distance that each ball must have architrave:

$$THE_n = g \frac{}{4\pi^2} \left(\frac{T_{tot}}{or_{max} - n + 1} \right)^2 \qquad (3)$$

The following table lists the measures used in our device.

n- th pendulum or_n		f_n	THE_n
1	33 1.	1 Hz	0.215 m
2	1:07	32 Hz 0.218 m	
3	31 3.	1 Hz 0.232 m	
4	30 1:	00 Hz 0.248 m	
5	29 H	z 0.97 0.266 m	
6	28 H	z 0.93 0.285 m	
7	27 H	z 0.90 0.307 m	
8	26 H	z 0.87 0.331 m	
9	25 H	z 0.83 0.358 m	
10	24 H	z 0.80 0.388 m	
11	23 H	z 0.77 0.422 m	
12	22 H	z 0.73 0.462 m	