Two-Stage Mechanical Oscillator As An Energy Input Amplifier

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***Abstract*—** This study aims to analyse and experimentally validate the performance of a two-stage mechanical oscillator as an energy input amplifier. At first glance, the system appears to violate the law of conservation of energy, but this is due to misinterpretation of the energy inputs involved. When measuring the efficiency, the energy used to move the pendulum is regarded as the input energy without considering the pendulum's energy. Because of this omission, the system can appear to defy the aforementioned law. To dispel any doubts, the theory part explains how the pendulum's energy is calculated. Then, both input and output forces are measured using the prototype. It is assumed that the pendulum is already in motion when given energy is applied to maintain its continuous movement. Weight sensors are used in the prototype model, one placed on the pendulum for input readings and another at the end of the lever for output readings. And angle sensor for pendulum movement. When the lever is in equilibrium, the first set of measurements is taken without load, while the second set with a load equal to half of the pendulum's weight. Experimental data confirm that the total system energy remains conserved, validating the theoretical model, and proving that efficiency exceeds 100% with the pendulum.

***Keywords*—** Energy amplifier, Energy coupling, Mechanical oscillator, Mechanical resonance, Pendulum.

I. *INTRODUCTION*

Two-stage mechanical oscillator was founded by Veljko Milkovic [1]. From a few of his patents [2,3], this oscillator can be seen as a mechanical amplifier. Milkovic's two patents ("Mechanical hummer with adjustable pendulum weight" [2] and "Hand water pump with a pendulum" [3]) respectively, represent the basics of this research. Milkovic represents his theory on the water pump model, where he shows how easily water can be pumped with one finger. In many research papers (such as "Design and Fabrication of Pendulum Operated Pump" [4]) researchers claim they used less power to pump water with a two-stage mechanical oscillator instead of using a hand on a regular water pump.

Invention of Veljko Milkovic can be seen as one of the biggest unconventional sources of energy. In his experiment [5] he was able to show that it is possible to pump water with one finger, which clearly indicates that it is possible to achieve this by expending less energy than during the usual method of pumping water. One of the research papers shows the results that "the quick-return mechanism has a capacity of 15.2 liters/min which will require an effort of 102.7 N, whereas the conventional lever lift mechanism has a capacity of 10.65 liters/min and requires an effort of 127 N" [6]. Papers [7-12] are showing the results, design and fabrication for hand water pump using Veljko's idea. Also, that idea is used as a vibration energy harvester in PhD studies [13].

If one looks more closely at the theoretical considerations given in reference [14], it is possible to observe that the pendulum, as the main part of the system, is a key factor in trying to obtain a larger amount of energy at the output than the energy invested in the system input. However, it is not shown anywhere whether the law of conservation of energy is valid for the given case. Since the value of efficiency, i.e. the output power of the system, is calculated by dividing the value of the energy at the output by the value of the input energy, it is obvious that the energy of the pendulum itself is not taken into account in this calculation, which is why the obtained efficiencies are greater than 1. This study is new in this field of study and application of mechanical energy amplification and clean energy production. The same approach is used in nuclear fusion. Namely, the Lawrence Livermore National Laboratory (LLNL) announced that it had achieved fusion ignition [15], where the energy produced by the fusion process exceeded the laser energy input required to initiate it. It can be clearly seen that fusion plays a key role here, just like a pendulum in the system, and the driving laser is like the arm that constantly swings the pendulum.

II. *THEORY OF TWO-STAGE MECHANICAL PENDULUM*

This mechanism relies on a lever. On one side there is a pendulum and on another side is a load or, for an example, a pump from the Veljko's Milkovic experiment. Fig 1 shows that the pendulum has mass M and on another side of the pivot is the weight, whose mass is m. It can be assumed that the lever is in balance and the L2:L1 scale is 1:3. Here L1 and L2 represent the lengths of the lever arms. The oscillator in the picture below turned out to be quite complex to get right mathematical analysis. Mass feedback also added to the complexity lever m which is located on the left side of the lever shaft. There is a scale (L1:L2) in order to reduce energy loss of pendulum (because pendulum tends to lose energy when going up and down), and to increase movement h on left side.

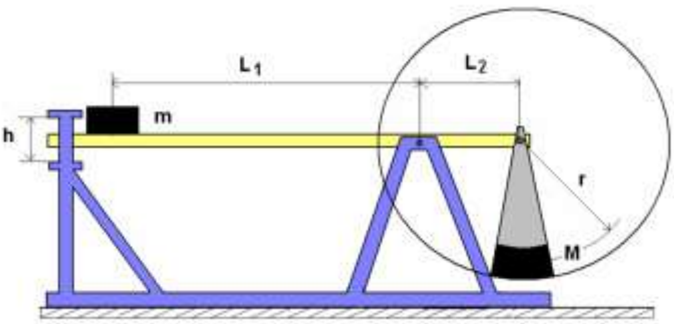


Fig. 1. Principle of functioning two-stage pendulum.

The first step is to find the right formula for calculating the energy of the pendulum and to see which factors cause energy losses. These calculations are based on a few papers of Jovan Marjanovic [16,17,18]. The first one is about mathematical analysis of pendulum [16], the second one is about the influence of pendulum's length and movement of pivot on energy loss [17] and the third one is recommendation on how to build a two-stage pendulum [18].

The calculations will start from the basic equation of centrifugal force:

$$F_c = M\frac{v^2}{r}. \quad (1)$$

During the movement of this pendulum there is a reduction in the centrifugal force when moving the suspension point down. When the suspension point moves downward, the path of the pendulum weight is no longer perfectly circular, but tends to flatten, i.e. the circle is straightened, which is the same as if the radius of the curvature r_0 is extended by Δr (see the picture below).

Because of the pivot movement there is no longer cylindrical movement like in Fig. *2* (A), but it is going to be like an oval movement Fig. *2* (B). This movement has to be considered and then the new equation is:

$$F_c = M\frac{v^2}{r+\Delta r} \quad (2)$$

The velocity also changes significantly due to the movement of the shaft, so this movement must also be taken into account by increasing the length of the pendulum at the moment when the pendulum passes through the equilibrium position, i.e. when it has maximum velocity, Fig. 2 (C). Namely, extending the pendulum at its lowest point reduces the velocity due to the validity of the law on the conservation of the moment of the amount of movement ($Mv_0r_0 = Mv(r_0 + \Delta r)$), and this is valid only in the vicinity of the lower point, in position 3, because there is no moment of the force of the weight Mg in relation to the suspension point O, and the velocity can be calculated as:

$$v = v_0 \frac{r_0}{r_0+\Delta r} \quad (3)$$

If it has to be considered into (2), equation of centrifugal force looks like:

$$F_c = M\frac{v_0^2 \cdot r_0^2}{(r_0+\Delta r)^3}. \quad (4)$$

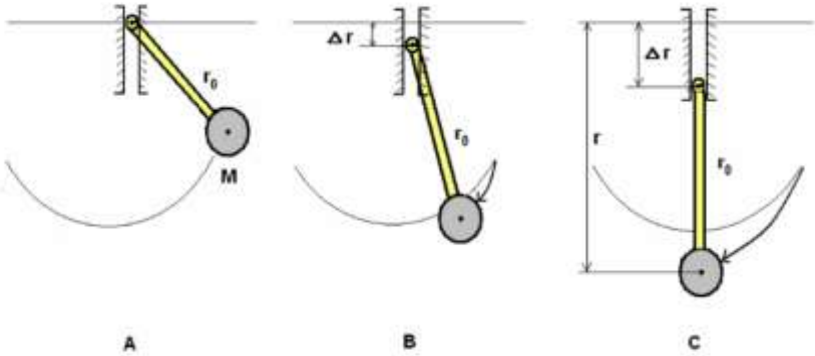


Fig. 2. Movement of pendulum depending on pivot high.

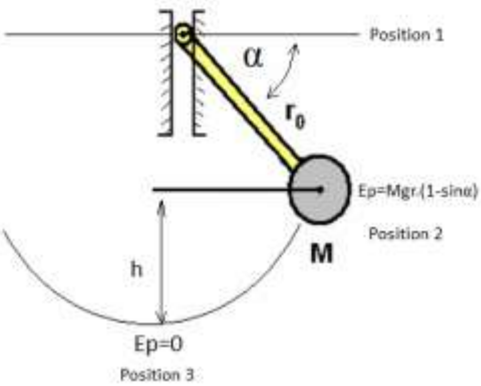


Fig. 3. Potential energy of pendulum.

In order to calculate the speed of the moving pendulum as a function of the angle between pendulum and position 1 (Fig. 3), the kinetic and potential energy must be equated. In order to get the height of pendulum Fig. 3 (Position 2) the value of sinα between Position

1 and Position 2 (Fig. 3) has to be taken from the sin(90°) in Position 3 (Fig. 3) when kinetic energy is the highest. And then the equation for potential energy of pendulum is:

$$E_p = Mgr_0(1 - \sin\alpha) \quad (5)$$

After equating the potential and kinetic energy:

$$Mgr_0(1 - \sin\alpha) = \frac{1}{2}Mv^2 \quad (6)$$

Speed can be found from equation (6):

$$v^2 = 2gr_0(1 - \sin\alpha) \quad (7)$$

And finally, when equation (7) is taken into equation (4), final equation for centrifugal force with included loss of pivot movement is:

$$F_c = 2Mg\frac{(1 - \sin\alpha)\cdot r_0^3}{(r_0 + \Delta r)^3} \quad (8)$$

III. ***PROTOTYPE CONSTRUCTIONS***

The idea of the prototype is to create a working model which will prove the theory above.

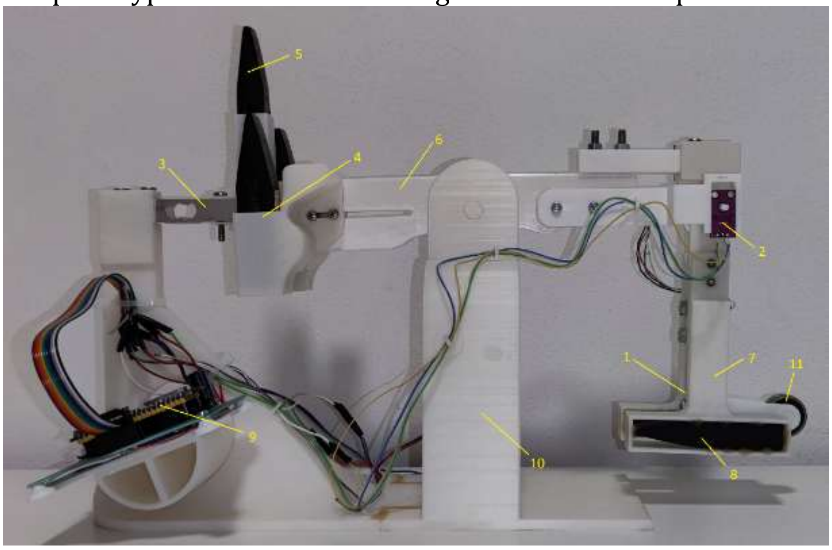


Fig. 4. Prototype model.

For that reason, the model from Fig. *4* has three sensors, marked with numbers 1, 2, 3. The first sensor (position 1) is for measuring the input force applied to the pendulum, which will be done manually by hand. The second sensor (position 2) is for angle measurement of pendulum's movement, and the third sensor (position 3) is for measuring the output force which will be the sum of input energy used to set the pendulum in motion and the pendulum's own energy. Pendulum's weight is 317g in total (position 7). It consists of two weights of 100g from each side (marked place 8) and with the sensor in the middle (position 1). Extended part (position 11) is for transferring the contact energy to the sensor. Angle sensor (position 2) is fixed on the lever and extended part, which is connected to the pivot of the pendulum, goes through the sensor and measures the movement of a pendulum. Opposite weight (position 4) is for making the lever (position 6) in balance. It can move as well, so it can be easily adjusted. At the end of the lever is the load (position 5) which can be removed for different measurement purposes. The whole process of measuring and sending the data to the PC through USB cable is done by ESP32-S3 (position 9) fixed on the housing of prototype (position 10).

Fig. 5. Notch at the end of the level.

At the end of the lever, a notch (Fig. 5) is made for the sensor (marked place 3) so that the lever can impact the sensor from both directions, from above and below. Ceramic bearing is used for joining the pendulum and the lever as well as the lever and the housing, to reduce friction.

The first sensor has a maximum load of 1 kg and the second one has 10 kg of maximum loads.

Sensor Calibration

1) Weight sensor

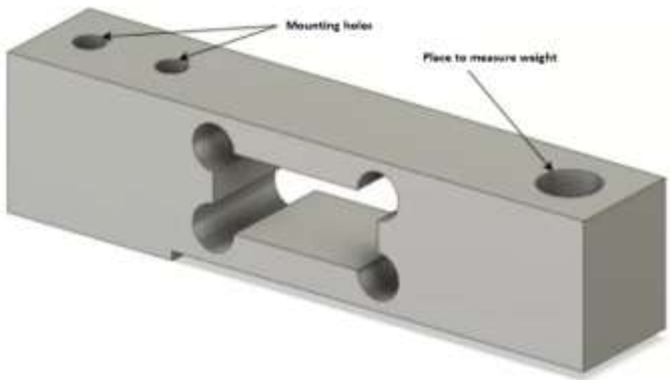


Fig. 6. Weight sensor.

The weight sensor, Fig. 6, is designed to measure the pressure applied to it, which is then transformed into grams. This is done by drilling the holes at the edges of the rectangle in the middle of the sensor. Variable resistors are placed on top of those holes (Fig. 7, marked places 1 and 2) and their resistance changes when one side of the sensor moves.

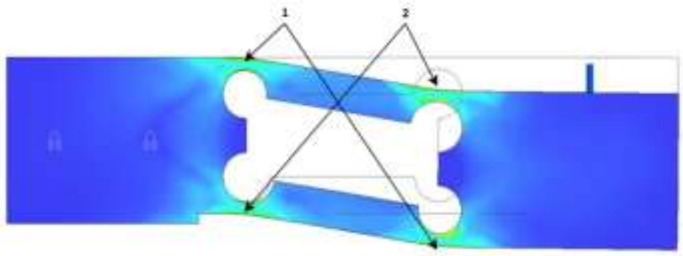


Fig. 7. Places where variable resistors are placed on sensor.

This formation is creating a Wheatstone bridge, and it is connected with module HX711 which is later connected to the ESP32-S3, Fig. 8.

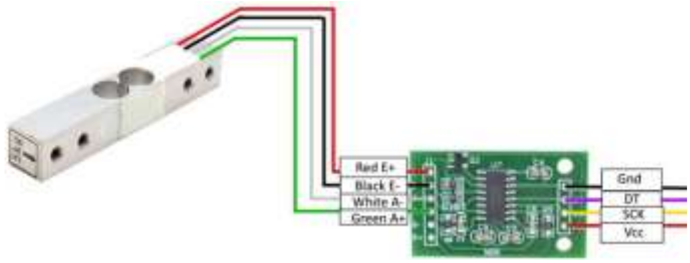


Fig. 8. Connecting load cell with HX711 module.

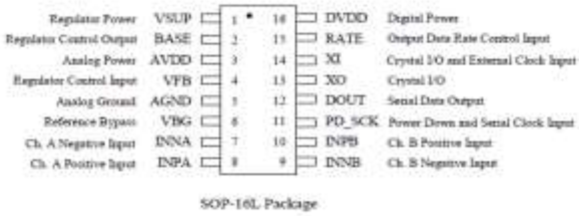
In order to obtain accurate reading from the sensors, the calculation is done when there is no weight on the load cell and when 200 g is applied to the cell. The first one is done on a cell with 1 kg of maximum load. Reading without weight was around 42568 +/- 50 and that number can be called offset. Then with 200 g load reading was from 266337 to 267127. That value will be reduced by the offset and then divided by 200 which represents the weight applied to the cell.

$$1gr = \frac{266736(middle\ value) - 42568(offset)}{200(weight\ in\ grams)} = 1120 \qquad (9)$$

The same procedure is done for a load cell of 10 kg maximum load, and for that sensor is 221 for 1g.

2) Time delays and measurement accuracy

According to the datasheet for HX711[19], there are two types of measurement speed (RATE), one is 10Hz and another is 80Hz. Fig. 9 shows that pin 15 has output data rate control for selecting speed measurement, 0V for 10Hz and 5V for 80Hz. The difference between those two speeds is that for 10Hz the measurements are much more accurate, and noise filtration is done, but for another option noise reduction has to be done by software and it is not that accurate.



Pin #	Name	Function	Description
1	VSUP	Power	Regulator supply: 2.7 ~ 5.5V
2	BASE	Analog Output	Regulator control output（NC when not used）
3	AVDD	Power	Analog supply: 2.6 ~ 5.5V
4	VFB	Analog Input	Regulator control input（connect to AGND when not used）
5	AGND	Ground	Analog Ground
6	VBG	Analog Output	Reference bypass output
7	INA-	Analog Input	Channel A negative input
8	INA+	Analog Input	Channel A positive input
9	INB-	Analog Input	Channel B negative input
10	INB+	Analog Input	Channel B positive input
11	PD_SCK	Digital Input	Power down control (high active) and serial clock input
12	DOUT	Digital Output	Serial data output
13	XO	Digital I/O	Crystal I/O (NC when not used）
14	XI	Digital Input	Crystal I/O or external clock input, 0: use on-chip oscillator
15	RATE	Digital Input	Output data rate control, 0: 10Hz; 1: 80Hz
16	DVDD	Power	Digital supply: 2.6 ~ 5.5V

Fig. 9. Pin descriptions of HX711.

The sensor board used in the prototype has a default measurement speed of 10Hz achieved by connecting the pin 15 to the ground, as shown in Fig. 10 taken from datasheet.

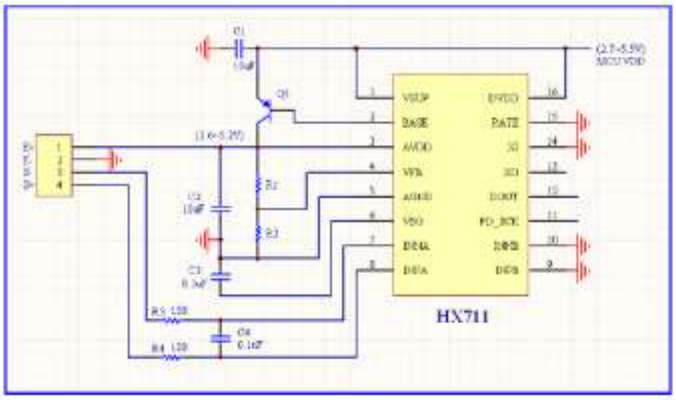


Fig. 10. Schematic of HX711 board.

This speed measurement means that there is a 100ms delay in sending data to the microcontroller which causes the final angle measured by the angle sensor under applied force to be inaccurate. In addition to 100ms, the time required for processing data in the microcontroller and subsequently sending it to the PC must also be considered.

In order to keep things simple, a rough estimate of the angle will be calculated for a delay of 100ms. The maximum speed of pendulum taken from equation (7) is about 2.4m/s. By using the simple equation for speed distance can be calculated:

$$v = \frac{s}{t} => s = v \cdot t = 0.24m \tag{10}$$

Now that distance will represent the arc of circle where angle can be calculated, by knowing that the length of pendulum is 0.12m:

$$s = r \cdot \theta_{rad} => \theta_{rad} = \frac{s}{r} = \frac{0.24}{0.12} = 2\, rad \quad (11)$$

Next thing is to calculate degrees from radians:

$$\theta_{deg} = 2\frac{180}{\pi} \approx 114.59° \quad (12)$$

This means that if applied force to the sensor is done when the pendulum is at 45° the measurements will be seen only when the pendulum reaches around 160°. It is not very realistic for two reasons. When the force is applied to the sensor, the pendulum will not move immediately in the opposite direction, but it will take some time to move in the direction of applying force. Another reason is that the pendulum slowing down due to gravity and other forces is not taken into account. That will reduce the delay time by half or more and the expected input force in results can be seen shifted by 30-50°.

3) Rotation angle sensor

The rotation angle sensor is HW-526 which is very cheap and has low resistance while angle reading. The potentiometer has a reading angle from 0 - 333.3°. Reading the voltage of potentiometer is done by an AD converter of ESP32-S3 microcontroller with 12-bit resolution and values from 0 to 4095. The voltage on the pin is read by software which knows how many degrees each value has. It is done by dividing the maximum angle by the maximum values of ADC (13).

$$\text{Angle per value} = \frac{333.3}{4095} = 0.0814° \quad (13)$$

The sensor testing is done by taking a physical angle measurer and moving the sensor by a certain angle, Fig. *11*11. Subsequently, that angle is observed on the PC, checking the match with the reading on physical angle measurer as well.

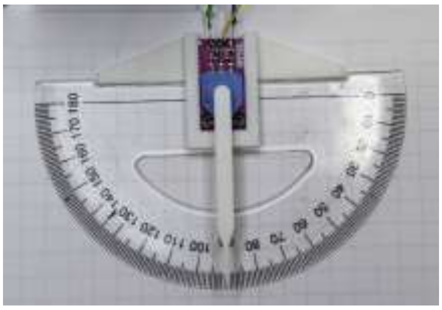


Fig. 11. Testing angle sensor.

When the pendulum is not moving and the lever is in balance it means that the pendulum is at 90°. In the calibration part, which is at the beginning of the software, value received from the angle sensor is taken as 90°. After moving the pendulum, measured angles are subtracted or added depending on the direction of the movement of the pendulum.

IV. *RESULTS*

These results are taken from the mentioned sensors which are placed on the prototype device. Two types of measurements will be done, one without load and another with load of 106g while the pendulum is moving by hand. Also, in both measurements, two values of Δr — 1mm and 5mm — will be considered.

In the first part calculations of pendulum's energy will be shown with loss by ceramic frictions and proven by reading the data after letting the pendulum swing from that angle. Later on, measurement without load for Δr = 1mm and Δr = 5mm will be measured, and after that with load for the same Δr. At the end, measurements will be compared and efficiency calculated.

The Δr is determined by adding the correct wrapper around the sensor in Fig. 5. The gap on the lever is 10mm, and if Δr is 5mm the wrapper will have a thickness of 5mm.

At first the pendulum was in a state of rest. When it was pushed by hand, data had been sent to the PC. It must be noted that data is sent to the PC only when a weight sensor detects something, otherwise no data is sent.

In order to understand the readings when the pendulum crosses 90° to 120° and above, the output sensor will detect negative weight and vice versa.

Calculating the force of pendulum

Pendulum force will be measured with two Δr, one will be with minimum loss of 1mm and second with 5mm. Firstly, pendulum force will be measured by using formula for centrifugal force (8). The following parameters are considered:

-Pendulum mass: 0.317 kg

-g (Acceleration due to gravity): 9.81 $\frac{m}{S^2}$

-Sin(45°) = 0.707

-L (pendulum length from pivot) = 0.12 m

-Δr = 0.001 m

By changing these parameters in equation (8), centrifugal force becomes equal to:

$$F_c = 2Mg\,\frac{(1-sin\alpha)\cdot r_0^3}{(r_0+\Delta r)^3} = 2\cdot 0.317\cdot 9.81\cdot\frac{(1-sin\,(45))(0.12)^3}{(0.12+0.001)^3} \quad (14)$$

$$F_c = 1.77686\text{ N}. \quad (15)$$

Now in order to be more precise with calculated data, the friction of ceramic bearing will be taken into account. In order to do that, the gravitational force acting on pendulum needs to be calculated:

$$F_{gravity} = \text{mg}. \quad (16)$$

Then the force due to gravity acting tangentially to the arc of the pendulum's swing needs to be calculated:

$$F_{tangentially} = F_{gravity}\ \text{sin(starting angle)} \quad (17)$$

$$F_{tangentially} = 0.317\cdot 9.81\cdot \sin(45) \quad (18)$$

$$F_{tangentially} = 2.1986\text{ N}. \quad (19)$$

Then, the friction force of ceramic bearing at the pivot will be:

$$F_{friction} = \text{Coefficient of friction} \cdot F_{tangentially} \tag{20}$$

$$F_{friction} = 0.1 \cdot 2.1986 \tag{21}$$

$$F_{friction} = 0.21986 \tag{22}$$

Loss during friction is represented as:

$$L_{loss} = F_{friction} \cdot \text{L} = 0.21986\ [\text{N}] \cdot 0.12\ [\text{m}] = 0.02638\ [\text{J}] \tag{23}$$

In order to show loss in Newtons instead of Joules, it needs to be divided by the distance travelled by the pendulum during one oscillation. Next equation will be used to calculate the distance:

$$\text{d} = 2\ \text{L} \sin(45°) = 2 \cdot 0.12 \cdot 0.707 = 0.16968\ \text{m}. \tag{24}$$

Now the loss from equation (19) will be divided by the distance from equation (20):

$$F_{loss} = \frac{L_{loss}}{d} = 0.15546\ \text{N} \tag{25}$$

Finally, the total force will be reduced by friction force and then the pendulum force is:

$$F_{c_{tottal}}(\Delta r\ =\ 1mm) = 1.6214\ \text{N} \tag{26}$$

Using the same calculations value of F centrifugal with Δr=5mm will be:

$$F_{c_{tottal}}(\Delta r\ =\ 5mm) = 1.45622\ \text{N} \tag{27}$$

Measuring the force of pendulum released from 45° with Δr of 5mm

As it is mentioned, the pendulum was released from 45° with Δr = 5mm and allowed to swing freely. Fig. 12 shows part of the results from the output sensor where data can be seen in grams.

	A	B	C
1	Angle	gr_in	gr_out
2	106	0	88
3	121	-2	0
4	126	0	-53
5	129	-3	0
6	126	0	-147
7	115	-1	0
8	103	0	108
9	84	-1	0
10	69.2	0	94
11	59.4	-2	0
12	53.6	0	-34
13	52.4	-2	0
14	54.7	0	-130
15	72.5	0	85
16	96.5	0	92
17	116	0	-6
18	119	-1	0
19	119	0	-131
20	119	-2	0
21	105	0	49
22	101	-1	0
23	75.7	0	79
24	74.2	-1	0
25	58.3	0	-1
26	58.7	-1	0
27	61.8	-1	0

Fig. 12. Results from the output sensor after releasing pendulum from 45°.

The focus is on column C, which represents the output force measured in grams. The value must be negative, because the lever is pushing the sensor from bottom to top, due to the pendulum exerting a force in the opposite direction.

When the maximum negative value is multiplied by gravitational force (equation (28)) it has the force almost identical to the calculated force from equation (27). It can be concluded that the calculations of pendulum's force are correct.

$$F_{out} = 0.147[Kg] \cdot 9.81[^{m}/_{s^2}] = 1{,}44207\ N \quad (28)$$

Measurements for Δr=1mm with no load

The wrapper from Fig. 5 must be 9mm thick in order to get Δr=1mm. At first, the pendulum was in a state of rest. Then the pendulum was set into motion by hand and continued to swing as a force was applied at each cycle.

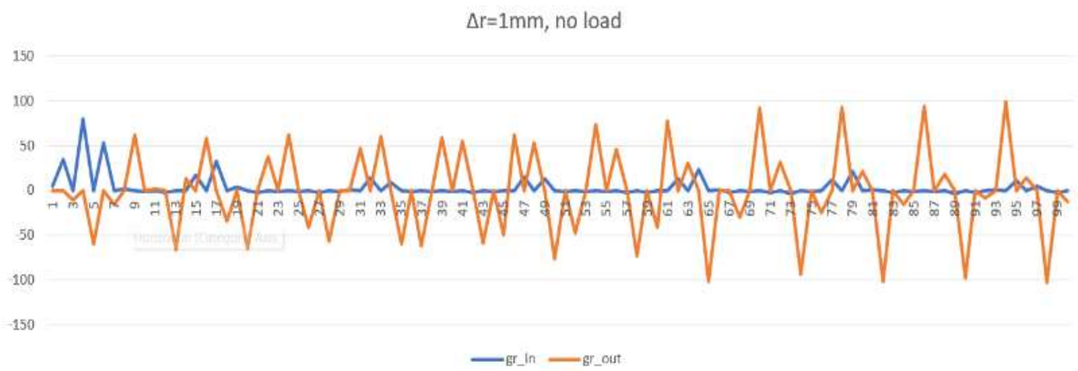


Fig. 13. Received data from sensors with no load at Δr=1mm.

Two lines can be seen in Fig. 13, the blue line represents the input sensor and the orange line represents the output sensor. The measured data are expressed in grams which can easily be converted to force. The first ten samples show that the input force is higher because this is the phase when the swinging begins. Later it can be observed that the input force decreases because it keeps the pendulum's motion. On the other hand, the output force is several times greater than the input force. Observing sample 64 for the input sensor and sample 65 for the output sensor, it can be seen that input measurement is 24g and output measurement is -101g. This means that output force is:

$$F_{out}=0.101 \cdot 9.81 = 0.99N \quad (29)$$

And input force:

$$F_{in}=0.024 \cdot 9.81 = 0.23N \quad (30)$$

This extra output force is from the pendulum itself, and angle from raw data will be used in order to calculate pendulum's force. However, because of delaying data which is explained in section 3.1.2 the minimum angle will be considered. This minimum angle represents the maximum potential energy when energy by hand has been added.

In Fig. 14 the first column represents the angle, the second input sensor and the third output sensor. The numbered samples are shown on the left. It needs to be mentioned that samples are shifted by one because, in Excel, the first row is occupied by the column names. Thus, sample 64 in Fig. 13 corresponds to sample 65 in Fig. 14, and so on.

55	99.93	0	74
56	88.37	-1	0
57	69.98	0	46
58	63.46	-2	0
59	55.57	0	-73
60	53.21	-2	0
61	56.95	0	-41
62	84.14	0	78
63	88.62	13	0
64	115.72	0	31
65	117.51	24	0
66	130.29	0	-101

Fig. 14. Raw data from sensor for Δr =1mm, no load.

The minimal angle is 53.21 and using the same steps as in equation (26), the calculated force is 1.052N. Adding the input force to this value results in:

$$F_{outCalculated}=F_{in} + F_{(53,21°)}= 0.23 + 1.052 = 1.282N \quad (31)$$

It can be seen that the calculated output force and the given output force from the sensor are not the same. They differ by about 0.3N, which can be attributed to additional losses that were not considered.

Utilization rate for this example is:

$$\eta=\frac{F_{out}}{F_{in}}\cdot 100\% = \frac{0.99}{0.23}\cdot 100\% = 430\% \quad (32)$$

Measurements for Δr=5mm with no load

For this measurement, the wrapper around the output sensor was replaced with one having a thickness of 5mm in order to get Δr=5mm. The same procedure as in previous section was done and the results are shown in Fig. 15.

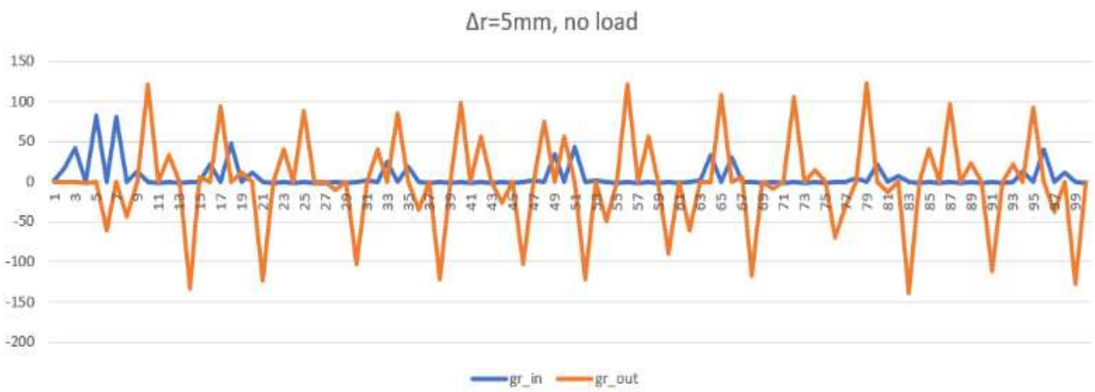


Fig. 15. Received data from sensors with no load at Δr=5mm.

With a larger Δr, the pendulum loses power much faster than with a smaller Δr, which is expected. This can be seen in the graph (Fig. 15), where the blue line shows higher values every second or third cycle. It can be seen that between samples 18 and 51 there is one smaller peak at sample 33, and between samples 51 and 96 there are two smaller peaks at samples 66 and 80. In terms of losing power, it means that it is losing its potential energy and that every second swing starts from an angle closer to 90° than to 45°.

For this measurement samples 51 and 52 will be considered because there are more samples with higher input than the samples with lower input like sample 80. The sample 51 represents input force, and it has 43g, while the sample 52 which represents output force has -122g.

$$F_{in}=0.043 \cdot 9.81 = 0.42N \quad (33)$$

$$F_{out}=0.122 \cdot 9.81 = 1.19N \quad (34)$$

From the raw data, the minimal angle for those samples is 58°, Fig. 16, and the force is calculated in the same way as previus.

42	83.5	-1	0
43	69.1	0	57
44	62.7	-2	0
45	58	0	-26
46	58.7	-1	0
47	62.3	0	-103
48	72.1	2	0
49	86.2	0	75
50	98.1	35	0
51	115	0	56
52	123	43	0
53	128	0	-122

Fig. 16. Raw data from sensor for Δr =5mm, no load.

$$F_{outCalculated}=F_{in} + F_{(58°)}= 0.42 + 0.68 = 1.1N \quad (35)$$

When comparing two equations (34) and (35), the error calculated is 0.1N. Then the utilization rate for this example is:

$$\eta=\frac{F_{out}}{F_{in}} \cdot 100\% = \frac{1.19}{0.42} \cdot 100\% = 283.3\% \quad (36)$$

Measurements for Δr=1mm with load

Using the same configuration as in previous section, the load has been placed at the end of the lever which can be seen in Fig. 4 (marked place 5). The same measurement procedure is used as in the previous two cases.

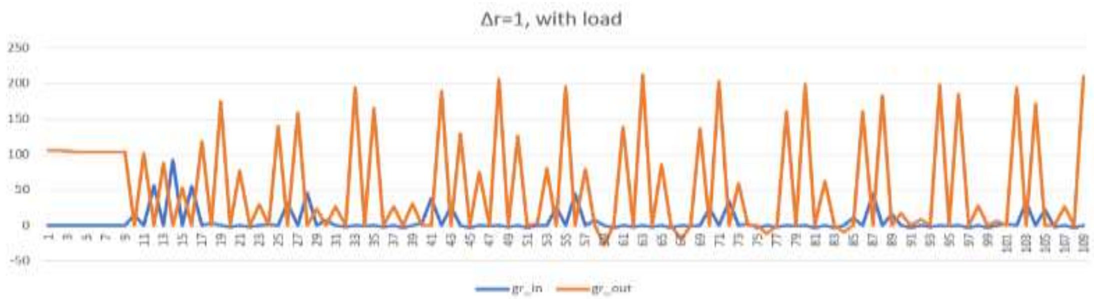


Fig. 17. Received data from sensors with load at Δr=1mm.

The first nine samples show that the sensor is reading the weight of load before the swinging begins. The results of interest, as before, are the lowest values. This means that the pendulum has lifted the weight, and the sensor will detect the corresponding force. A sample that is one of the most interesting ones is 56, because its output value becomes negative which means that the pendulum has enough energy to overcome gravitational energy and lift the load. Therefore, that sample will be considered. The sample 56 from the input sensor is 44g and sample 59 for output sensor is -27g. Since the pendulum was able to overcome the weight of the load and lift it, the given reading will be added to the read value of the load.

$$gr\_out(new) = |gr\_out| + load\_weight = |-27| + 106 = 133g \quad (37)$$

Next calculations will be the same as in previous sections.

$$F_{in}=0.044 \cdot 9.81 = 0.43N \quad (38)$$

$$F_{out}=0.133 \cdot 9.81 = 1.3N \quad (39)$$

From raw data, Fig. 18, the minimum angle is 48.6°.

46	127	-3	0
47	124	0	75
48	101	-1	0
49	93.7	0	206
50	68.5	-2	0
51	60.4	0	126
52	51.6	-3	0
53	48.6	0	3
54	61.4	0	80
55	80.6	25	0
56	97.8	0	196
57	114	44	0
58	128	0	79
59	133	8	0
60	134	0	-27
61	132	-3	0
62	120	0	139
63	109	-2	0

Fig. 18 Raw data from sensor for Δr =1mm, with load.

$$F_{outCalculated}=F_{in} + F_{(48.6°)}= 0.43 + 1.36 = 1.79N \quad (40)$$

The difference between given and calculated output force is 0.49N. The utilization rate is:

$$\eta=\frac{F_{out}}{F_{in}}\cdot 100\% = \frac{1.3}{0.43}\cdot 100\% = 302.32\% \quad (41)$$

Measurements for Δr=5mm with load

The last measurement gives the following results in Fig. 19.

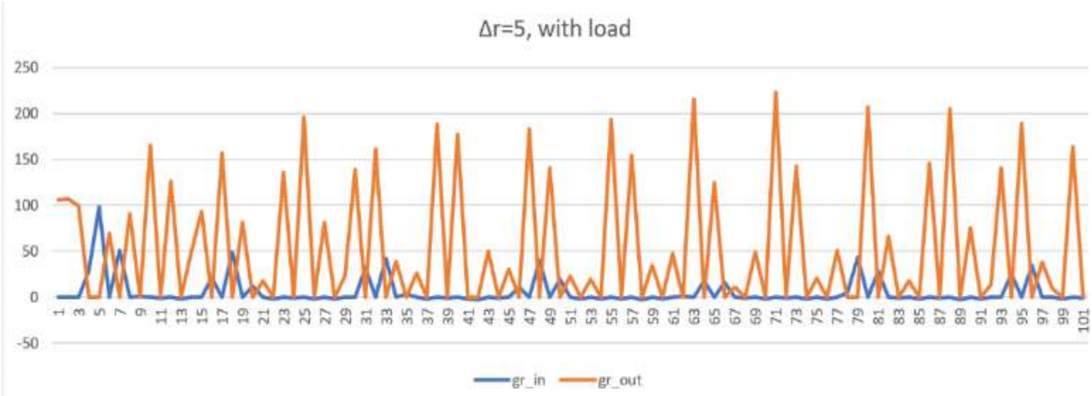


Fig. 19. Received data from sensors with load at Δr=5mm.

The main problem with the readings was that the software in the microcontroller was set to send the data only if one of the input or output sensors detected some weight. Since the Δr is 5mm, the data will not be sent if load is lifted and reading is zero, because then, in order to read negative values, it must travel an additional 5mm. And with the usual force of pushing the pendulum, the lever never touches the sensor from the opposite side, which leads to not having the negative data on the graph. Even though there was negative reading, it would not give accurate results. Since negative data is not available, the lowest reading output data will be used. For the sample 33, the input reading is 42g, and for sample 36, the output reading is 26g. The output reading must be corrected because it reflects the lifting of the load, and the current reading load must be subtracted from previous reading of load. Thus, the new value gives the actual output force.

$$gr\_out(new) = load\_weight - gr\_out = 106 - 26 = 80g \quad (42)$$

23	123	-2	0
24	113	0	136
25	101	-1	0
26	116	0	196
27	70.8	-2	0
28	58.8	0	81
29	55	-2	0
30	54.8	0	23
31	78.6	0	139
32	87.5	32	0
33	112	0	161
34	118	42	0
35	129	0	39
36	132	3	0
37	151	0	26

Fig. 20. Raw data from sensor for Δr =5mm, with load.

$$F_{outCalculated} = F_{in} + F_{(54.8°)} = 0.41 + 0.85 = 1.26N \quad (41)$$

The difference between the given and the calculated output force is 0.48N. The utilization rate is:

$$\eta = \frac{F_{out}}{F_{in}} \cdot 100\% = \frac{0.78}{0.41} \cdot 100\% = 190.24\% \quad (42)$$

V. *CONCLUSIONS*

The initial assumption that the output energy is the sum of the pendulum's energy and the input energy can be seen as valid, as seen from the given results, even though the calculated output energy was higher than the data obtained from the sensor. Typically, the difference is around 0.3N and that error can be attributed to a problem with instant angle reading. As it was mentioned during the calculations, the angle of pendulum was taken from the data, and assumed to be the lowest. This was based on the assumption that the pendulum was pushed at the moment it reached its maximum potential energy. However, this was not always the case. Usually, the pendulum was pushed when it started returning from the point of maximum potential energy. The calculated output energy would be more accurate if there was a sensor that would instantly provide the data of the impact force on the pendulum. When the pendulum was released from the desired angle of 45°, the output sensor detected the same number as calculated. From this, it can be concluded that the error was due to the timing of sensing the impact force and capturing the corresponding angle.

Another problem with the measurement arose when a load was added, particularly when Δr was 5mm. During all four data collection trials, the pendulum was pushed in the same manner as before. As a result, the lever never touches the output sensor from the opposite side as in the previous three experiments. When the sensor is touched from the opposite side, it gives a negative value, representing the impact force of the pendulum. However, with the added load, the pendulum must first overcome the weight of the load to do the additional 5mm until touching the sensor and registering the impact force. In both cases with added load, an additional path of 1mm or 5mm was not considered since it represents one more measurement of the actual energy. The solution for that is to modify the prototype for measurement with added load, and instead of measuring the impact on the sensor, another weight should be placed and the amount it is lifted should be measured.

In future, the next paper will follow this approach with additional weight added at the end. Measurement will be divided into two parts, first, measuring the energy required to lift the weight without the pendulum, and second, measuring the energy with the pendulum. This approach will reveal the real benefit of the pendulum and the lever.

For now, this paper can prove that two-stage oscillators indeed act as a force amplifier, as indicated by the utilization rate shown in each measurement.

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