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Determination of Cycle, Indexing and Rinsing Time for A Designed Small Scale Industrial Bottle Rinsing System

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Abstract
In the effort to reduce the environmental impact of waste from industrial production, there is an increasing deeply felt need to recover empty glass and plastic containers. The aim of this study was to design and determine parameters of a glass bottle rinsing machine which operates using the Geneva mechanism. A test rig was designed and fabricated. The rig operates on the intermittent rotary motion from a four slot external Geneva mechanism and requires manual loading and unloading of bottles. The bottles are loaded on subsequent indexing part of the rotating table and are washed one after another. The maximum slot contact force, rinsing time and indexing time were measured and analysed. The contact force was found to be between 15 – 29 N while indexing time was between 0.75 – 2.5 seconds. The rinsing time was found to be in the range of 2.43 to 7.84secs for selected speed range, while indexing time was 0.08 to 1.77secs. This work presents a practical application of Geneva mechanism for worktable indexing and bottle rinsing. This is expected would encourage recycling on small scale
Key words: Contact force, Bottle Rinsing, Small scale, Industrial

1.0 Introduction
Glass is created by melting minerals together at high temperatures. Silica, a form of sand, is the main ingredient and is combined with soda ash and limestone melted in a furnace at high temperatures. Other materials and minerals can be added to produce different colours. From our earliest origins, man has been making glass. Archaeologists have found evidence of man-made glass dating back to 4,000BC in the form of coatings on stone beads. Around 1,500 BC the Egyptians made the first glass bottles in a state we would recognise today. Glass containers are impermeable, air-tight, and transparent. You can see the freshness of food and beverages. Glass packaging can handle vacuum or high-pressure sealing, safeguarding against moisture and oxygen. This protects food and beverages from spoilage and bacteria (TGRC, 2015)

1.1 Glass recycling
This is the process of turning waste glass into usable products. Glass waste should be separated by chemical composition, and then, depending on the end use and local processing capabilities, might also have to be separated into different colors. Many recyclers collect different colors of glass separately since glass retains its color after recycling. The most common types used for consumer containers are colorless glass, green glass, and brown/amber glass. Glass makes up a large component of household and industrial waste due to its weight and density. The glass component in municipal waste is usually made up of bottles, broken glassware, light bulbs and other items. Glass recycling uses less energy than manufacturing glass from sand, lime and soda (wasteonline.org).

Glass recycling turns used glass products back into "new" glass products. By some estimates, recycling glass uses 40% less energy than creating new glass from silica sand, lime and soda ash. Recycled glass also creates about 20% less air pollution and 50% less water pollution. Glass recycling is a much more efficient process than plastic recycling, since plastics are usually "down-cycled" into a lower-quality form of plastic. Plastic water bottles, for example, cannot be recycled into new plastic bottles, but glass containers can be recycled indefinitely into new glass containers. In Nigeria, glass recycling is considered to be in its infancy stage as recycling is almost nonexistent. This work aims at developing a machine that would aid reuse of glass bottles through mechanized rinsing. It is expected that this would be beneficial to small scale entrepreneurs who are into production requiring glass bottles are input material.

2.0 Design
The design of the machine is based on the principle of the Geneva mechanism initiated by specifying the crank radius, the roller (pin) diameter and the number of slots. At least three slots are necessary, but most problems can be solved with Geneva wheels having from four to twelve slots. The design procedure is shown in Figure 1 below.

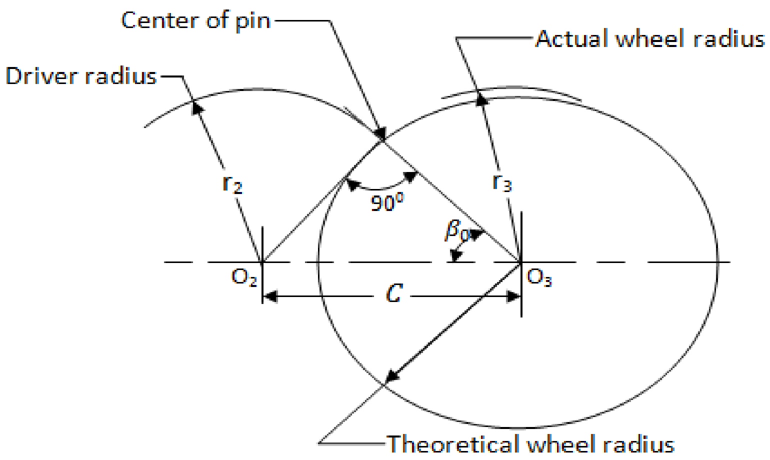


Fig 1: Sketch of Geneva wheel

The angle β_0 is half the angle subtended by adjacent slots, that is

$$\beta_0 = \frac{360^0}{2n} = \frac{360^0}{2\times4} = 45 \quad (1)$$

Where n is the number of slots in the Geneva wheel. Then defining r_2 as the crank radius, we have:

$$C = \frac{r_2}{\sin\beta_0} = \frac{60}{\sin 45} = 84.85\text{mm} \quad (2)$$

Where C is the center distance between the driver shaft and Geneva shaft. The actual Geneva wheel radius is more than that which would be obtained by a zero- diameter roller. This is due to the difference between the sine and the tangent of the angle subtended by the roller measured from the wheel center (Shigley and Uicker, 1995).

2.1 Angular Velocity of the Geneva wheel

After the roller has entered the Geneva wheel slot and is driving the wheel, the geometry is that of Figure 2 below.

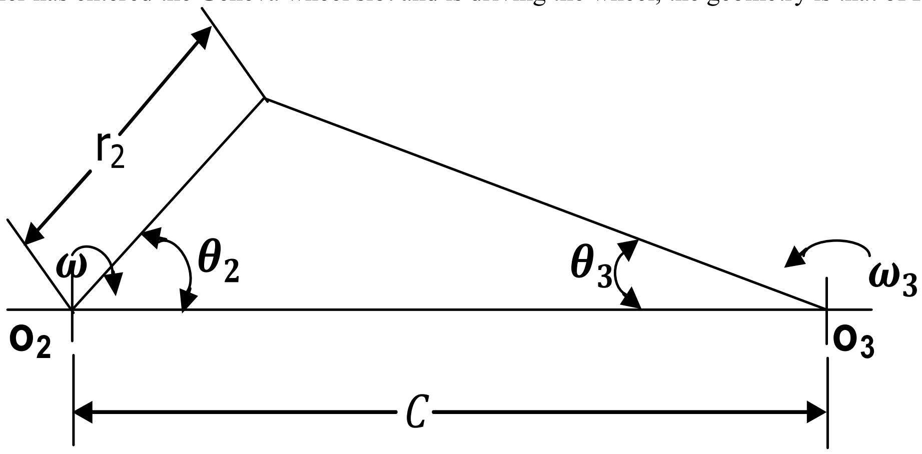


Fig 2: Geneva mechanism analysis

Where O2 is center of driver,
O3 is center of Geneva wheel,
θ_2 is the crank angle and
θ_2 is the Geneva wheel angle.

The angular velocity of the Geneva wheel for any value of value of θ_2 is given by the equation (Shigley and Uicker, 1995)

$$\omega_3 = \omega\frac{\left(C/r_2\right)\cos\theta_2 - 1}{1 + \left(C^2/r_2^2\right) - 2\left(C/r_2\right)\cos\theta_2} \quad (3)$$

Where ω_3 is the angular velocity of the Geneva wheel and ω is the angular velocity of the crank or Driver. The maximum angular velocity of the Geneva wheel occurs when the crank angle is zero (θ_2 =0) and is given by Shigley and Uicker, 1995 as

$$\omega_3 = \omega\frac{r_2}{C - r_2} \quad (4)$$

2.2 Angular acceleration of the Geneva wheel

The maximum wheel velocity occurs when the crank angle is zero (ϴ2 = 0). Substituting gives

$$w_3 = w_2 \frac{r_2}{C - r_2}$$

C = 84.85 mm   r2 = actual driver radius = 70 mm

$$w_2 = \frac{2\,\pi\,N}{60}$$

The angular acceleration of the Geneva wheel is given by the expression (Shigley and Uicker, 1995)

$$\alpha_3 = \omega^2 \frac{(C/r_2)\sin\theta_2\left(1 - C^2/r_2^2\right)}{\left[1 + (C/r_2)^2 - 2(C/r_2)\cos\theta_2\right]^2} \quad (5)$$

The angular acceleration reaches a maximum where

$$\theta_2 = \cos^{-1}\left\{ \pm \sqrt{\left[\frac{1 + \left(C^2/r_2^2\right)}{4(C/r_2)}\right]^2 + 2} - \frac{1 + (C/r_2)^2}{4(C/r_2)} \right\} \quad (6)$$

$$\theta_2 = 6.3642^0$$

This occurs when the roller has advanced about 30 percent into the slot (Shigley and Uicker, 1995)

2.3 Drive-pin Contact stress

Drive-pin contact stress is given by Hertz equation and cited by Johnson, 1956 as:

$$S_{max} = K_1 \sqrt{\frac{F_{max}}{td}} \quad (7)$$

Where $k_1 = 0.798 \sqrt{\frac{1}{\left(\frac{1 - v_1^2}{E_1}\right) + \left(\frac{1 - v_2^2}{E_2}\right)}}$

S_{max} = Contact compressive stress between Geneva drive-pin and wheel slot at maximum angular acceleration of Geneva wheel (N/m^2)

Fmax = Force between the Geneva drive pin and Geneva wheel slot at instant when the angular acceleration of the wheel is a maximum (N)

t = Thickness of Geneva wheel (m) = 10mm = 0.01m

d = Diameter of Geneva wheel (m) = 12mm = 0.012m

k_1 = constant

v = Poisson's ratio for steel = 0.25 to 0.33

E = Modulus of elasticity of steel = 200 to 220 Gpa

Frictional moment acting on Geneva wheel,

$$M_f = 2\ ib - in = 0.226\ Nm$$

Diameter of table (load) = 300mm,

RL = 150mm = 0.15m

Thickness of Table (load), t = 4mm = 0.004m

Mass moment of inertia of a thin disc or a solid cylinder of radius RL about its axis, (Khurmi and Gupta, 2004)

$$J_L = M_L \frac{R_L^2}{2}$$

Where ML = mass = weight/g

$$M_L = \frac{w}{g} = \frac{wv}{g} = \frac{w(\pi r^2 t)}{g}$$

$$w = \text{specific wgt} = \frac{\text{wgt}}{\text{value}} = \frac{mg}{v} = \rho g$$

$$V = \text{volume} = \text{area x length} = \pi r^2 t$$

$$J_L = M_L \frac{R_L^2}{2} = \frac{\pi R_L^2\,wt}{g}\left(\frac{R_L^2}{2}\right)$$

g = acceleration due to gravity = 9.81m/s2   density of steel, ρ = 7850kg/m3

$$w_{steel} = \rho g = 7850 \times 9.81 = 77008.5\ N/m^3$$

$$J_L = \frac{\pi R_L^2\,wt}{g}\left(\frac{R_L^2}{2}\right) = 2.497 \times 10^{-2} kgm^2$$

Mass moment of inertia of the Geneva wheel about axis of rotation, (Johnson, 1956)

$$J_G = \frac{K_5\,w\,D^5}{g}$$

K5 = 0.00506 for four slot Geneva wheel   D= diameter of Geneva wheel = 120mm = 0.12m

$$J_G = 9.884 \times 10^{-4} kgm^2$$

Force between the Geneva drive pin and wheel slot at instant when the angular acceleration of Geneva wheel is a maximum

$$F_{max} = \frac{(J_G + J_L)\, a_{max} + M_f}{KD}$$

K = 0.2384 for four slot Geneva wheel (Johnson, 1956)

$$F_{max} = \frac{0.02596\, a_{max} + 0.226}{0.028608}$$

3.0 Methodology:

A small scale industrial bottle rinsing system with four slot Geneva mechanism was designed, fabricated and assembled. The assembly drawing is shown in the appendix. The experimental methods consists of the determination of maximum pin-slot contact force, cycle time, indexing time and rinsing time of the test rig at different selected speeds.

3.1 Maximum Pin-slot Contact force

SolidWorks 2010 software was used to carry out a motion study of the drive mechanism of the test rig at 4rpm, 8rpm, 12rpm, 16rpm and 20rpm. The pin-slot contact force was calculated and a plot of pin-slot contact force against Driver cycle time at each selected speed generated using the software. The Maximum pin-slot contact force was taken from the graphs and recorded.

3.2 Cycle, Indexing and Rinsing time

For one complete cycle of the driver, the table travels through 900. Thus, one complete cycle of the table is equal to driver cycle time multiplied by four (4). The dwell time of the Geneva wheel is the rinsing time of the test rig. The Driver cycle time, indexing time and rinsing time of the rig were calculated using equations 8 to 10 (Groover, 2009) and the table cycle time calculated from the driver cycle time. The test rig cycle time, indexing time and rinsing time were verified using a stopwatch.

$$T_c = \frac{1}{N} \quad (8)$$

Where T_c= cycle time, min   N = rotational speed of driver, rev/min

$$T_s = \frac{(180+2\beta_0)}{360N} \quad (9)$$

where T_s = Dwell time, ,min

$2\beta_0$ = angle between adjacent slots of the Geneva wheel, degrees

$$T_r = \frac{(180-2\beta_0)}{360N} \quad (10)$$

Where T_r = indexing time, min and other terms are defined above.

4.0 Results

The maximum pin-slot contact force at different selected speeds from the graphs of pin-slot contact force against driver cycle time generated using SolidWorks 2010 is shown in table 4.1.

Table 4.1: Results for Maximum Pin-slot Contact force

S/No	Speed (rpm)	Max. Pin slot contact force (N)
1	4	15
2	8	17
3	12	22
4	16	25
5	20	29

Table 4.2: Results for Angular Acceleration

N(rpm)	W2 (rad/s)	W3 (rad/s)	α3 (rad/s)
8	0.8378	3.9490	-12.3158
12	1.2566	5.9236	-27.7106
16	1.6755	7.8981	-49.2632
20	2.0944	9.8726	-76.9738

4.1 Results for speed verification using a Tachometer

The selected speeds to be used in the experiment were verified using a tachometer (model: ATH6, Lucas Industrial Measurements). The result is shown in the table 4.2. The pulley speeds when verified with the tachometer were found to be very close to expected selected speeds with negligible difference.

Table 4.3: Pulley Diameter, Calculated speed and Tachometer readings

S/N	Diameter (mm)	Calculated speed (rpm)	Tachometer reading (rpm)
1	587.50	4	5
2	293.75	8	7
3	195.833	12	12
4	146.875	16	15
5	117.5	20	19

4.2 Results of Cycle time, Indexing time, rinsing time verification using a stopwatch

The cycle time, indexing time and rinsing time of the test rig were verified using a handheld digital stopwatch. The result is shown in the table 4.4 and 4.5. The cycle time, washing time and indexing time of the test rig when verified with the stopwatch were found to be very close to expected calculated values with differences of ± 2seconds, ± 0.344 seconds and $\pm$ 0.7475 seconds respectively.

Table 4.4: Verification of Cycle time

S/N	SPEED (rpm)	DRIVER CYCLE TIME (secs)	CALCULATED CYCLE TIME (secs)	CYCLE TIME (STOPWATCH READING)
1	4	15.00	60.00	38.060
2	8	7.50	30.00	28.112
3	12	5.00	20.00	18.330
4	16	3.75	15.00	13.430
5	20	3.00	12.00	10.638

Table 4.5:Verification of Rinsing and Indexing time

S/N	SPEED (rpm)	CALCULATED RINSING TIME (secs)	RINSING TIME (STOPWATCH READING)	CALCULATED INDEXING TIME (secs)	INDEXING TIME (STOPWATCH READING)
1	4	7.500	7.844	2.500	1.772
2	8	5.625	5.938	1.875	1.248
3	12	3.750	3.904	1.250	0.566
4	16	2.813	3.022	0.938	0.190
5	20	2.250	2.434	0.750	0.078

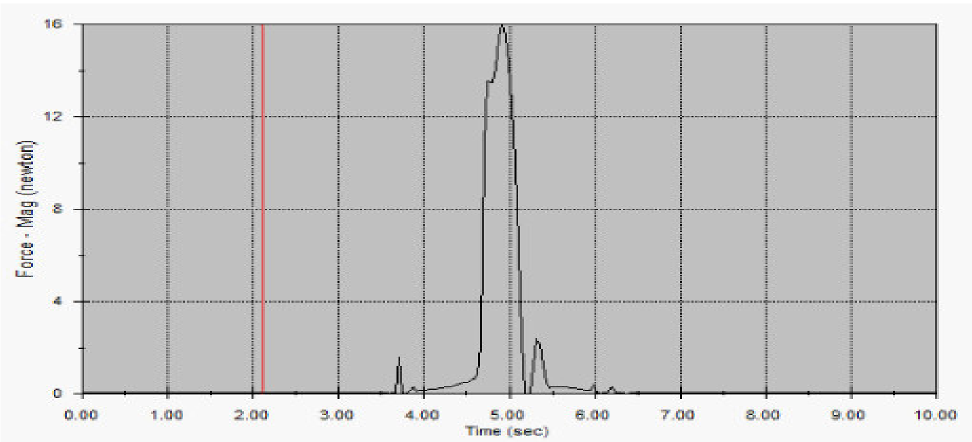


Fig. 3: Plot of Pin-slot Contact force against Driver Cycle time for 4 rpm

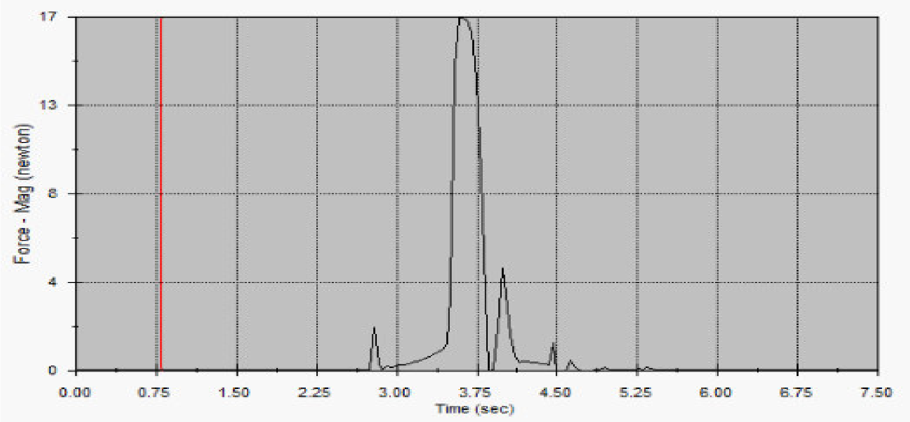


Fig. 4: Plot of Pin-slot Contact force against Driver Cycle time for 8 rpm

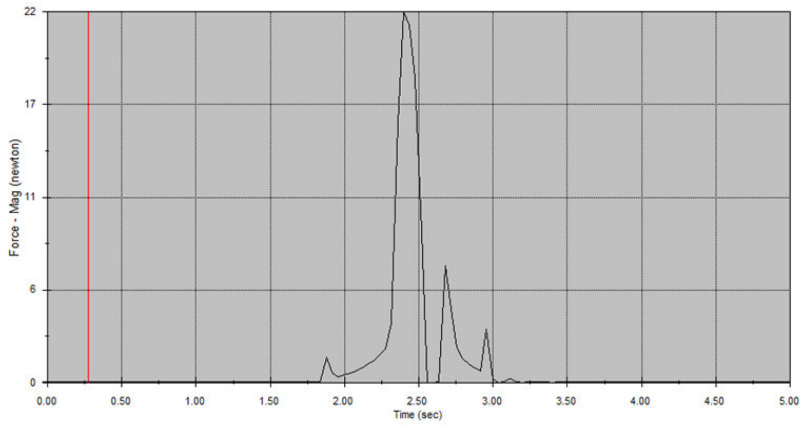


Fig. 5: Plot of Pin-slot Contact force against Driver Cycle time for 12 rpm

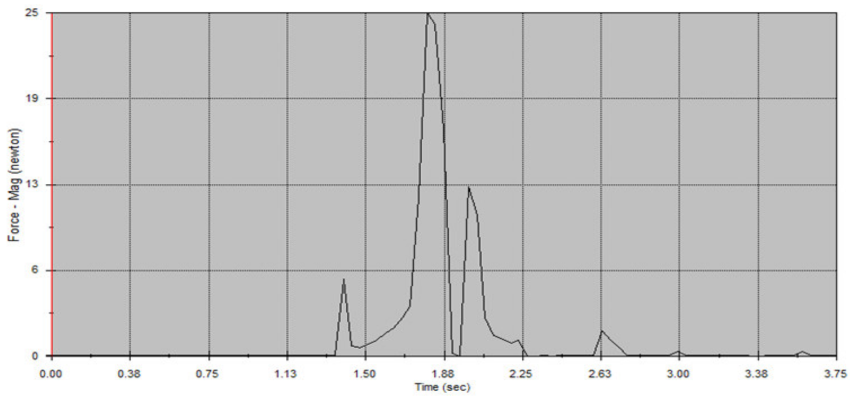


Fig. 6: Plot of Pin-slot Contact force against Driver Cycle time for 16 rpm

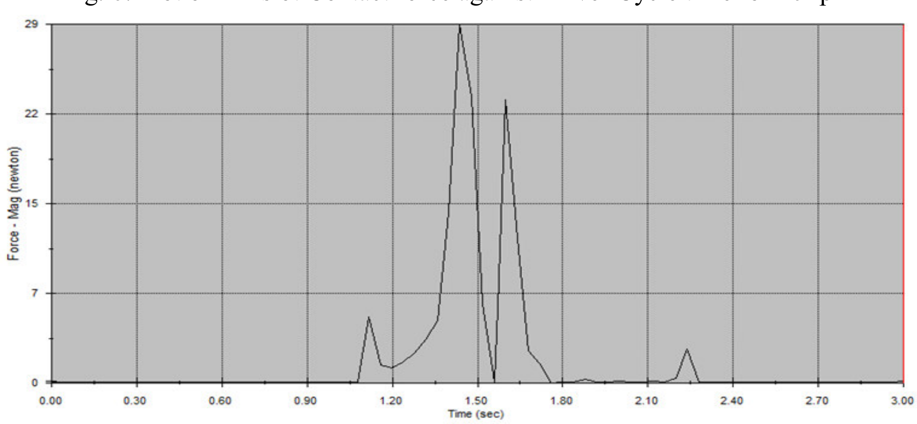


Fig. 7: Plot of Pin-slot Contact force against Driver Cycle time for 20 rpm

Figs 3 – 7 show the plots of the motion study conducted with the SolidWorks 2010 software. From the plots the maximum pin slot contact force for each selected speed was obtained and this was similar to what was obtained by calculation. Fig 8 shows the plot of contact force against selected speeds. It was observed that a linear relationship exists between contact force and speed with R^2 value of 0.987.

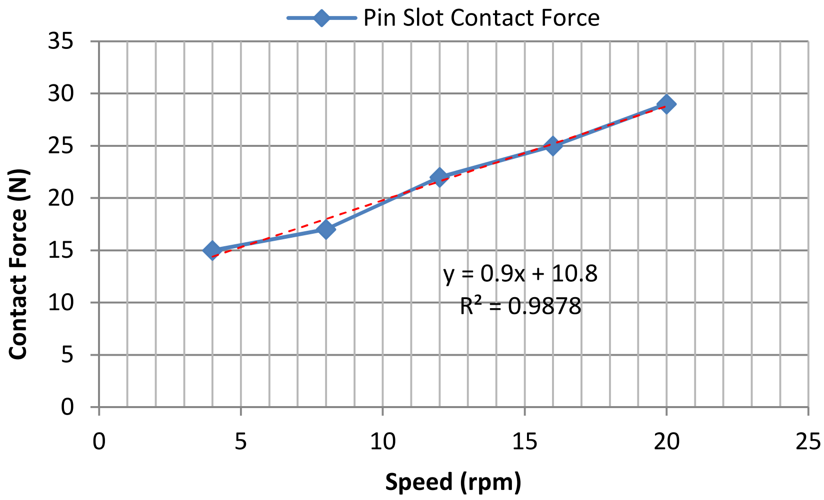


Fig. 8: Plot of Contact force against speed

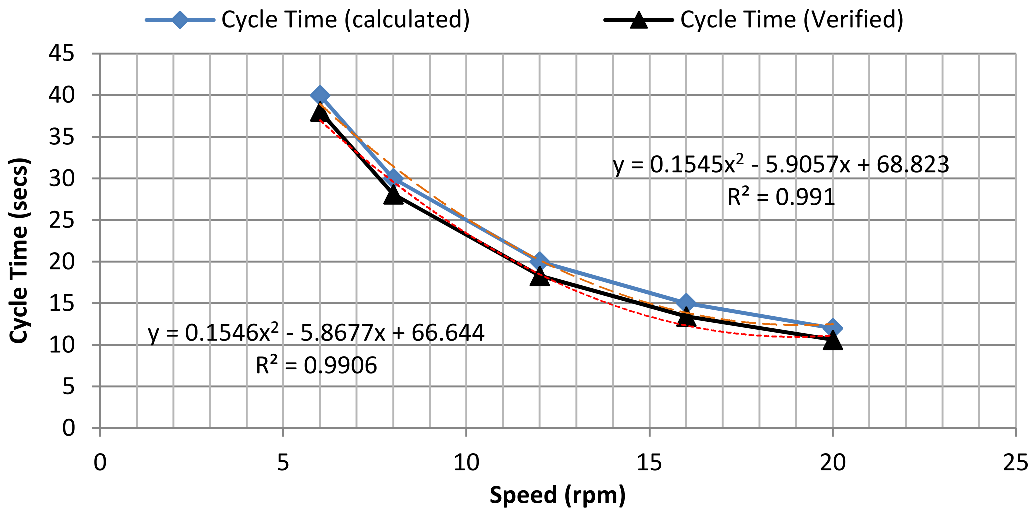


Fig. 9: Plot of Cycle Time versus Speed

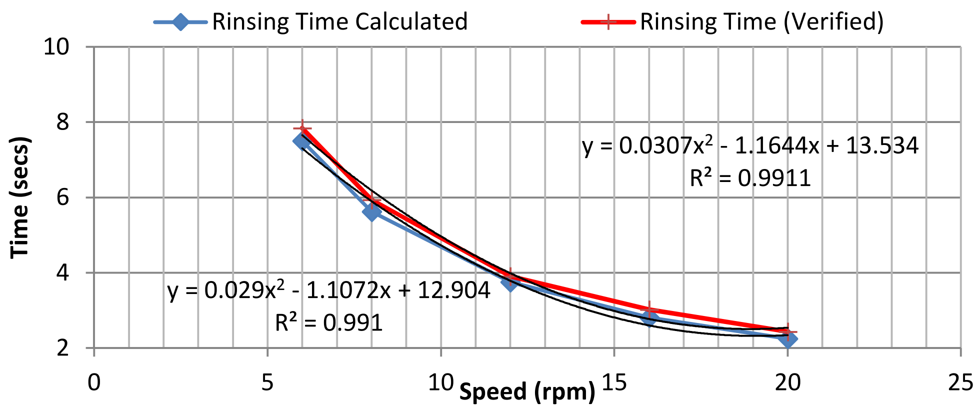


Fig. 10: Plot of Rinsing Time versus speeds

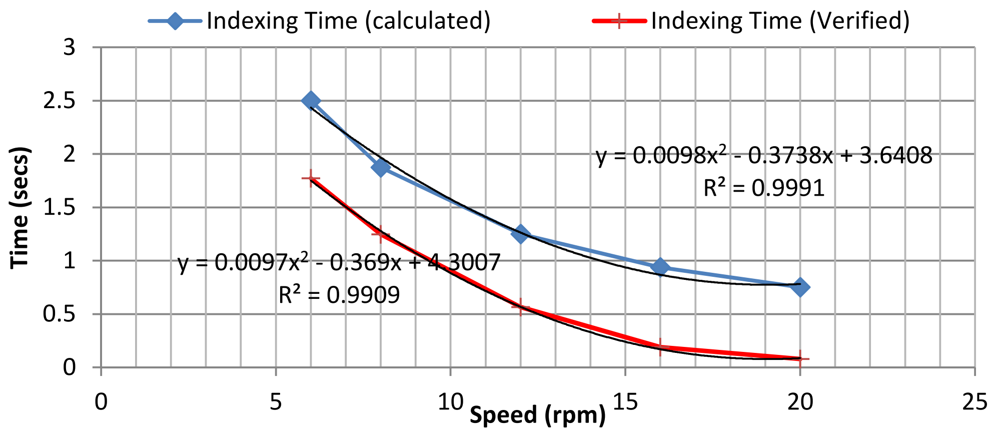


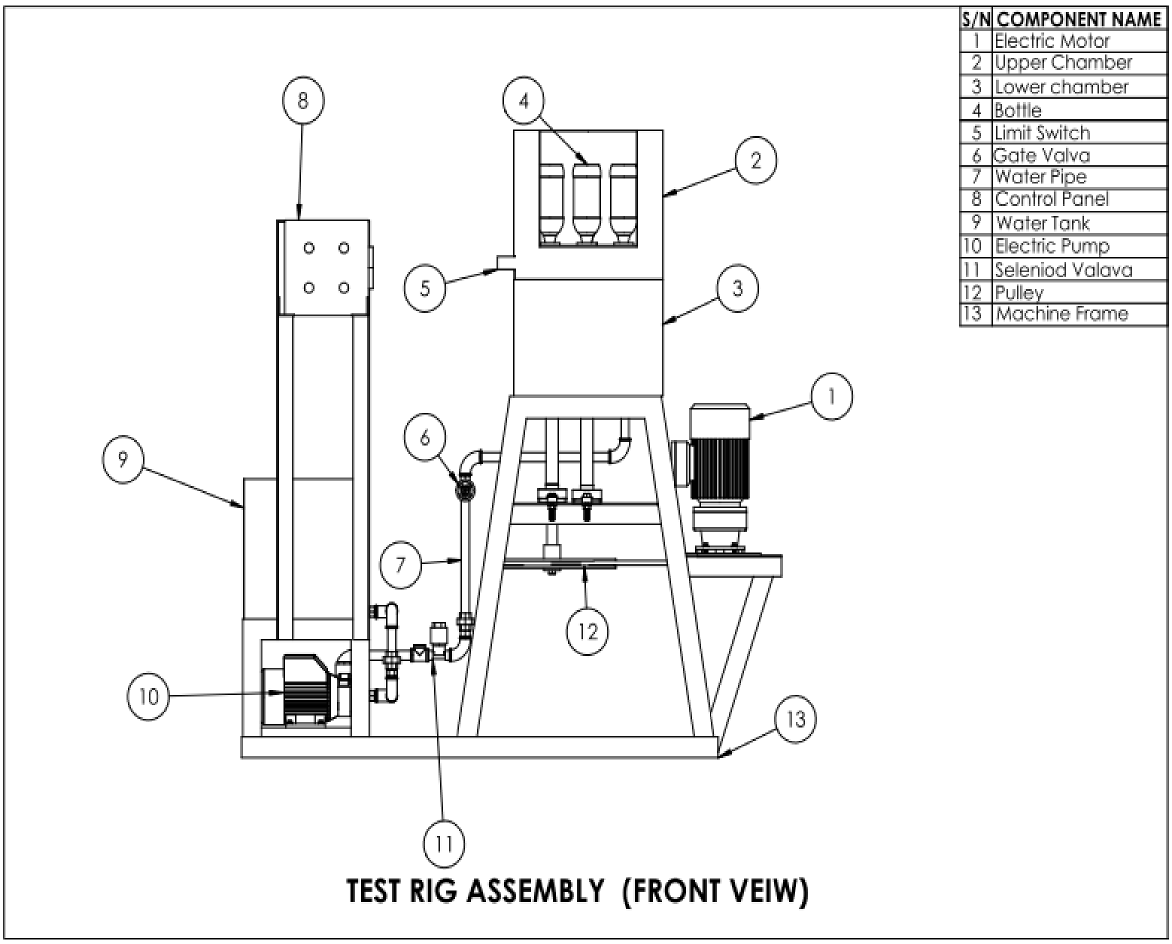
Fig. 11: Plot of Indexing Time versus speed

Fig 9 – 11 showed plots of cycle time, indexing time and rinsing time versus selected speeds. It was observed that both calculated cycle and rinsing times were close to their experimental values. They were also seen to have very similar R^2 values. The indexing time however showed significant difference between calculated and experimental values. These three parameters all had quadratic equations as their best fit mathematical models.

5.0 Conclusion:

Form the results, we can conclude that maximum force is adequate and would ensure that bottles are not damaged during operation. The values obtained from calculated and experimental data can be seen as an indication of the workability of the designed machine.

APPENDIX



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