American J. of Engineering and Applied Sciences 2 (2): 428-437, 2009
ISSN 1941-7020

Design of Garbage Sorting Machine

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Abstract: Problem statement: Domestic waste collection, sorting and disposal are major problems in many developing countries such as Ghana. It is an undeniable fact that the environment has been engulfed in filth. This filth comprises of the garbage and waste generated in homes, workplace and industrial setups. Most of this waste has found its way into the streets, gutters, in and around the homes, dung hills and worst of all, water bodies, many of which are sources of the drinking water treated at high costs or not treated at all. **Approach:** Garbage needs to be sorted into various components and each of such components like textile materials, polythene, foodstuffs, metals and glassware would then have to be handled separately at the disposal or recycling site. Such a process required a certain degree of literacy, discipline and certain basic equipment, for example separate collector bins or sorting bags. In the developed world this is not much a problem because every home has different polythene bags into which the various constituents of domestic waste are put right at the generation point. Separate collection bins were also provided at vantage points for the various types of domestic garbage collection. In the developing countries these arrangements have not been feasible because of the level of literacy, lack of appreciation of the problem, non-availability of the different types of polythene bags and poverty. Currently, most garbage collection in the developing countries is done by depositing every thing into a single container from where they are hauled to be dumped in landfills or burned in incinerators. Refuse disposal by land filling requires a sizeable land for the sole purpose of refuse disposal. This may lead to (1): Encumbering large tracks of prime land, which could not be put to other uses (2): Pollution of ground water by the leachate from the landfills (3): Breeding of leaches, rodents, mosquitoes and (4): Generation of strong stench coming from the landfills, posing health hazards to communities. Incineration also produces strong odour and smoke. **Results:** In both methods no component of the waste was recovered for recycling. This is contrary to the practice in the developed countries where waste recycling is a major undertaking to provide raw materials e.g., glass and metal, for industry and thus reduces the exploitation of natural resources. **Conclusion:** To address the problem in Ghana it is necessary to devise a means of sorting-out the components of domestic waste for recycling into useful components. This study outlined the design and operation of a machine for sorting out garbage into the various components which can be recycled or utilized elsewhere.

Key words: Domestic waste, garbage sorting machine, environment, polythene materials, raw materials, environment

INTRODUCTION

It is an undeniable fact that the environment has been engulfed in filth. This filth comprises of the garbage and waste generated in homes, workplace and industrial setups. Most of this waste has found its way into the streets, gutters, in and around the homes, dung hills and worst of all, water bodies, many of which are sources of drinking water treated at high costs or not treated at all. Some of these wastes are pieces of rotten cloth, polythene materials, peels, leaves, rinds and husks of foodstuff, fruits and vegetables, pieces of all kinds of paper and tissues and all sorts of solid and liquid waste.

This situation has not only worsened the plight of abject poverty, but has contributed immensely to the horrifying scenes in the environment as this filth, some of which has accumulated for ages, is an eye sore to the already sordid environment. It is a source of dreadful diseases threatening our very existence yet it is believed that a lot of this garbage could be processed into very useful materials and utensils. Efforts have been made to

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solve this problem. But is seems Ghana and other countries of the West African sub (Saharan) region, have a peculiar form of this problem, which continues to worsen from day to day.

This write-up sets out to put together a research into identifying some of these problems and to contribute, suggest and provide means of getting rid of this menace by giving the outline and overview of a design of garbage sorting out machine.

Objective: The objective of this research is to design an efficient and cost-effective machine capable of sorting out garbage into the various components which can be recycled or utilized elsewhere.

Justification: Heaps of garbage or domestic wastes, sited at many parts of the communities, need to be sorted to:

- Help get rid of the filth engulfing the environment
- Get the sorted out components like polythene materials as raw materials to feed the recycling plants or to be used to generate energy
- Get rid of breeding grounds for flies, insects and rodents like mosquitoes, tsetse flies, lies and mice which inflict infectious, contagious and communicable diseases on the people
- Create jobs for the unemployed

The cleaning and/or the collection of garbage or rubbish, or in other words, cleaning the environment will become very attractive. This means a lot of the unemployed in the community would be enticed rather than coerced to clean up the garbage they themselves generate. This will not happen on account of appealing to the conscience of the people to clean their environment in which they live (which in so many cases, does not work) but will be a matter of spontaneity to work on competitive basis resulting in creating clean environment and prevention of a lot of dreadful diseases.

According to the Beijing Institute of Domestic Waste Management-the current Beijing municipal solid waste heat value is 2839 kJ kg^{-1}.

The most serious problems posed to the municipality by domestic waste are as follows:

First: Air pollution.

Second: Serious water pollution; garbage dumps corruption process produce pathogenic microorganisms, three sources of heavy metals and organic pollutants. Hydrolysis of the leachate drainage and biological treatments cause serious pollution of surface water and groundwater.

Third:
Biological pollution: There are many pathogenic microorganisms at garbage dumps infested with tiny flies, cockroaches and rats which seriously endanger the physical health of the general public.

Fourth:
Occupation of land: According to the Institute a survey had shown that in 1998 two-thirds of 668 cities in the country (China) had been surrounded by rubbish. National landfill occupied a total of 50 000 depositors.

Fifth: Floodwater refuse explosions occur as the content of organic matter in municipal solid waste.

According to the British Plastics Federation-developed by e-mango.com 203 an average typical value for polymers found commonly in household waste is 38 mega joules kg^{-1} (MJ kg^{-1}) which compares favourably to the equivalent value of 31 MJ for coal. This represents a valuable resource raising the overall calorific value of domestic waste which can then be renewed through controlled combustion and re-used in the form of heat and steam to power electricity generators. Waste containing plastics can also be reprocessed to yield fuel pellets, which have added advantage of being storable. Plastics represent no more than 10-11% of household waste by weight.

Seven million tons of municipal waste can be processed into about 3 millions tons of alternative fuels with a calorific value of about 17 500 KJ Kg^{-1}, which can be used as an important energy source in the following sectors:

- Iron extraction
- Power stations
- Production of the synthesis gas method
- Cement industry

However in the underdeveloped countries like Ghana the waste is accumulated at large refuse damps in every corner of the country. This waste poses the greatest hazards to health, since the refuse damps become the breeding grounds for mosquitoes, rodents and malignant micro-bacteria, aside the odour and stench that emanate from the refuse damps, also causing or adding to the already existing health hazards and threats. This situation has made the surroundings so sordid and abject that apart from being an eyesore and great threat to health, it has been a major topic in the news everyday and has rendered it one of the biggest challenges and problems the cities, municipalities , the metropolises, districts and their authorities have to grapple with.

This waste can be grouped or put into three main categories:

- The type of garbage which has been lying down in heaps for decades and for which most of the components have decomposed, leaving polythene materials, in particular, which will never decompose
- The recently generated garbage, which has been collected in containers or elsewhere
- The refuse which has scattered and can be found in every corner of the surroundings

While the under-developed countries are yet to improve upon their infrastructure and procurement of equipment to tackle or deal with this obnoxious situation efforts have to be made to get rid of the garbage presently engulfing the whole environment. What has aggravated the situation is that most of the garbage finds its way or is intentionally deposited into water bodies which serve as sources of water for use in many different ways for many a people.

MATERIALS AND METHODS

Design of the garbage sorting out machine: Heaps of garbage from typical dumps at various locations in the country were divided into four equal parts and two opposite quadrants of each of the so divided heaps manually sorted out. It was revealed that, on the average, the garbage consists of the following percentage components by volume as indicated in Table 1.

The garbage sorting machine is designed to perform the functions of the manual sorting process, taking into account the approximate percentage compositions of the various components of the heaped-up garbage, as tabulated above.

Table 1: Percentage composition of various components of domestic waste or garbage by volume

Component	Composition by volume (%)
Composite	5.0
Polythene materials	71.0
Pieces of cloth or textile materials	15.5
Paper tissues	3.5
Tins and cans	0.3
Pieces of bottles and glassware	0.5
Earth ware	0.6
Metallic objects	0.9
Leaves, peels, rinds and husks of foodstuffs	2.7

Functions of the components and the general operation of the garbage sorting machine: Rubbish or garbage is collected from the environment and deposited in a skip (1) as shown in Fig. 1. This garbage is fed from the slip into a container that can be vibrated by a vibratory mechanism, the equation of motion which is analyzed from page 9 onwards.

The bottom of the container is also made up of perforated plate (3) through which loose soil (composite) from the garbage can be sieved and collected in another container (2), placed below the first one. When the first container is full of the garbage, a rubbish prickling mechanism (4), the equation of motion of which is also outlined from pages 6-9, is actuated to turn at a definite angle thereby aligning itself with the top of the heaped-up container. The mechanism consists of long and pointed strong metallic thorns. These are pressed into the heaped-up garbage to pick and compress together polythene materials, husks, leaves, pieces of paper and cloth from the heap.

The mechanism moves up, turns through another large angle anticlockwise and dumps the picked up rubbish into another container (not shown) by means of another mechanism (5). Water is poured into the container of the picked-up polythene materials, husks, leaves, pieces of paper and cloth. The polythene materials will float on top of the water and will be decanted, washed, dried and sent to a plant that converts the polythene materials into plastic goods as that of city waste management in Accra. The husks, leaves, pieces of paper and cloth are strained of the water, dried and sent to a biogas plant.

Fig. 1: The mountainous refuse dump near the Koforidua Railway Station being cleared moments after the `Daily Graphic' publication appeared last Saturday. The refuse dump has been cleared and the 'mountain' has been reduced to an appreciable level. INSET: The refuse dump before it was cleared[3]

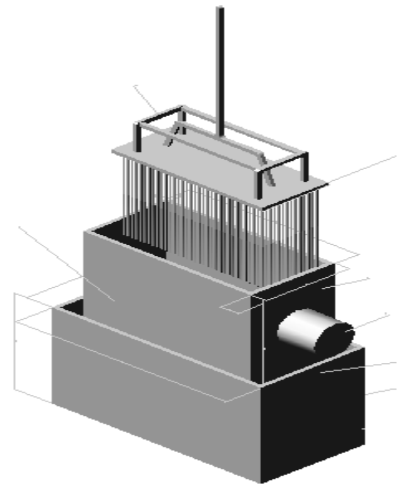


Fig. 2a: Sketch of the rubbish pickling machine (in isometric)

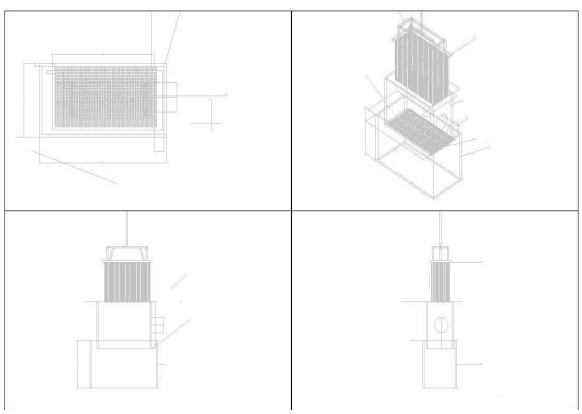


Fig. 2b: Sketch of the Rubbish Pickling Machine (in Three Views and Isometric)

The remainder of the garbage is now made up of pieces of loose soil (silt), stones, broken bottles and cans. The container is vibrated and the loose soil sieves through the perforated plate (3). The cans are picked up by manipulators, the equations of motion of which are similar to or can be derived from that of the prickling mechanism. The broken bottles and glass in the remaining debris are picked in a similar manner and sent to the bottling plant and glass factory respectively for recycling. The broken stones and pebbles can be sent to the construction site.

Equation of motion of the schematic representation of the rubbish prickling mechanism Fig. 2: The rubbish pickling mechanism, shown in Fig. 2a and b, operates on the principles of a manipulator as shown in Fig. 3.

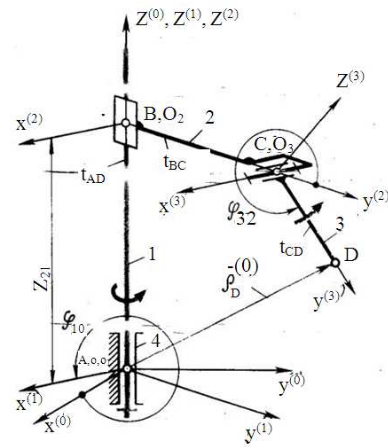


Fig. 3: Schematic representation of the rubbish prickling mechanism[1]

The general equation of such a mechanism is as given by[2]:

$$W = 6n - \left[\sum_{i=1}^{3} (6-i) p_i - q \right] \quad (1)$$

Where:

w = Degree of freedom of movement of the mechanism
n = Overall number of coordinates
pi = Numbering of kinematics pairs $1 \le i \le 5$
q = Number of links (constraints)

In this case n = 3, q = 0, i = 1

$$\sum (6 - i)\ pi = 5.3 = 15$$

The mechanism can be simplified and presented schematically as in Fig. 3.

The coordinate system $O_1x^{(1)}y^{(1)}z^{(1)}$ constraining link 1 rotates around $z^{(1)}$ axis, the system $O_2x^{(2)}y^{(2)}z^{(2)}$ constraining link 2 moves collinearly relative to link 1; the system $O_3x^{(3)}y^{(3)}z^{(3)}$ constraining link 3 rotates around the $x^{(1)}$- axis. The axes $z^{(0)}$ $z^{(1)}$and $z^{(2)}$ coincide, while the axes $x^{(1)}$, $x^{(2)}$, $x^{(3)}$ are parallel. The position function:

$$\rho^{-(0)} = \rho_D^{(0)} (\wp_{10}, Z_{21}, \wp_{32}) \quad (2)$$

n matrix form assumes the following type or form:

$$\rho^{(0)} = T_{10} T_{21} T_{32} \rho_D^{(3)} \quad (3)$$

Where:

$$P_D^{(0)} = \begin{Bmatrix} x_D^{(0)} \\ y_D^{(0)} \\ z_D^{(0)} \\ 1 \end{Bmatrix}$$

$$T_{10} = \begin{Bmatrix} \cos\wp_{10} & -\sin\wp_{10} & 0 & 0 \\ \sin\wp_{10} & \cos\wp_{10} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{Bmatrix}$$

$$T_{21} = \begin{Bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & z_{21} \\ 0 & 0 & 0 & 1 \end{Bmatrix}$$

$$T_{32} = \begin{Bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\wp_{32} & -\sin\wp_{32} & l_{BC} \\ 0 & \sin\wp_{32} & \cos\wp_{32} & 0 \\ 0 & 0 & 0 & 1 \end{Bmatrix}$$

$$P_D = \begin{Bmatrix} 0 \\ l_{CD} \\ 1 \end{Bmatrix}$$

The quadruple, (0 0 0 1),in the matrices T_{10}, T_{c1}, T_{32} and unity (one) (1) in the columns of the matrices transformed into an identical form (≡) and are added in order that the matrices become quadratic and can be inter multiplied. The matrices are multiplied on the basis of the known multiplication rule for matrices; row on columns. Consequently the product of the matrices results in the equation:

$$\begin{Bmatrix} x_D^{(0)} \\ y_D^{(0)} \\ z_D^{(0)} \\ 1 \end{Bmatrix} = \begin{Bmatrix} -l_{BC}\ \text{Sin}\,\phi_{10} - l_{CD}\text{Sin}\phi\text{Cos}\phi_{32} \\ l_{BC}\ \text{Cos}\,\phi_{10} + l_{CD}\text{Cos}\phi_{10}\text{Cos}\phi_{32} \\ Z_{21} + l_{CD}\ \text{Sin}\,\phi_{32} \\ 1 \end{Bmatrix}$$

and subsequently the required or the desired coordinates of the point D (we are seeking for) in the stationary system $O^{(o)}X^{(o)}Y^{(o)}Z^{(o)}$ are:

$$\begin{aligned} x_D^{(O)} &= -l_{BC}\text{Sin}\phi_{10} - l_{CD}\text{Sin}\phi_{10}\text{Cos}\phi_{32} \\ y_D^{(O)} &= l_{BC}\text{Cos}\phi_{10} + l_{CD}\text{Cos}\phi_{10}\text{Cos}\phi_{32} \\ z_D^{(O)} &= z_{21} + l_{CD}\text{Sin}\phi_{32} \end{aligned} \qquad (4)$$

It is important that we verify in some simple general terms the values of coordinates corresponding to the above formulae and the kinematical diagram of the mechanism shown in Fig. 1. F or example for:

$\varphi_{10} = \varphi_{32} = 0$:
$x_D^{(0)} = 0$; $y_D^{(0)} = l_{BC} + l_{CD}$; $z_D^{(0)} = z_2$
$\varphi_{10} = \varphi_{32} = 270^0$:
$x_D^{(o)} = l_{BC;}$;$y_D^{(O)} = 0$; $z_D^{(o)} = z_{21} - l_{CD}$

With the help of dependencies of Eq. 3 having the given range of coordinates of the point D, we can select the relevant values of the lengths of the links l_{BC} l_{CD} and the ranges for the generalized coordinates φ_{10}, z_{21} and φ_{32}.

An important technical index called Velocity of Motion of Gripper and Separable Links of the Manipulator has many uses; by this the maximum velocity can be defined not only by the behaviour of the working process of the manipulator and power of the drives, but also by the condition of safety of the operating personnel.

If the dependence of generalized coordinates and time is known then the velocities can be determined by differentiating w.r.t time for the position functions. Thus, for example, for the type of mechanism, operating in the form of a manipulator under consideration, with 3° of freedom under the given relationships $\varphi_n(t)$, $z_2(t)$ and $\varphi_{32}(t)$ projections of the velocity vector of point D of the gripper on the coordinates axes can be found by differentiating Eq. 4 w.r.t time:

$$\begin{aligned} V_{D_x} &= \dot{X}_D^{(O)} = -\omega_1\text{Cos}\phi_{10}\left(l_{BC} + l_{CD}\text{Cos}_{32}\right) + \omega_{32}l_{CD}\text{Sin}\phi_{10}\text{Sin}\phi_{32} \\ V_{D_y} &= \dot{y}_D^{(O)} = -\omega_1\text{Sin}\phi_{10}\left(l_{BC} + l_{CD}\text{Cos}\phi_{32}\right) - \omega_{32}l_{CD}\text{Cos}\phi_{10}\text{Sin}\phi_{32} \\ V_{D_z} &= \dot{Z}_D^{(O)} = V_{21} + \omega_{32}l_{CD}\text{Cos}\phi_{32} \end{aligned} \qquad (5)$$

The magnitude and direction of the velocity vector of point D can be found as:

$$\left.\begin{aligned} &V_D = \sqrt{V_{D_x}^2 + V_{D_y}^2 + V_{D_z}^2} \\ &\text{Cos}\alpha = \frac{V_{D_x}}{V_D};\text{Cos}\beta = \frac{V_{D_Y}}{V_D};\text{Cos}\gamma = \frac{V_{D_{zZ}}}{V_D} \end{aligned}\right\} \qquad (6)$$

where, α, β, γ are directional angles of the velocity vector.

Computing by the formulae of Eq. 5 and 6 for concrete number of values makes it possible to evaluate the behaviour of change and maximum velocity of point D of the gripper.

In the general case for each point of the working zone of a manipulator there exists some telex angle ψ-

Service angle within which the gripper can operate up to this point. As already known the value of this angle is defined as the ratio of the area of the sphere enclosed by the telex-angle, to the square of the radius of sphere and so the maximum value of the telex-angle $\psi = 4\pi r^2/r^2 = 4\pi$ (radians).

The ratio, θ, of the service angle, ψ, to its maximum value ψ_{max}, $\theta = \frac{\psi}{\psi_{max}} = \frac{\psi}{4\pi}$ is called Service Coefficient of the given point.

The value of θ varies from zero for points on the periphery of the working volume where the gripper can be oriented to one (1) unique direction, to unity, one (1), for points of the zone of full service, where the gripper can be oriented to any direction.

Determination of the service coefficient, θ, relates to, or depends on the analysis of the movement of the links of the mechanism of the manipulator for various fixed positions of the centre of the gripper.

The equation of motion of the heaped container shown can be formulated in general as:

The motion of the heaped container as described above can be taken as that of a mechanism under forced vibration of single degree of freedom. A source of external energy is provided to maintain oscillation of fixed amplitude[3].

Let as consider the simple damped system with a harmonic force F = Fo sin ωt acting on the container:

Where:

Fo = Initial externally applied force (N)
ω = Angular velocity (rev min^{-1})
t = Time (sec^{-1})

The equation of motion for such a system is given by (Newton's second law in the positive displacement x of the container):

$$m\ddot{x} + c\dot{x} + kx = FoSin\omega t$$

Where:

m = Mass of the heaped container
x = Distance displacement of the container from its equilibrium position
$\dot{x}$ = Velocity of the system (m sec^{-1})
$\ddot{x}$ = Acceleration of the system m sec^{-2}
c = Retarding force that is frictional retardation termed as viscous damping force.
k = A constant of the system (spring(s)) obeying Hook's Law

$\tau = 2\pi (m\ k^{-1})^{1/2}$ a period of oscillation of the system and $f = 1/\tau = 1/2\pi(k\ m^{-1})^{1/2}$ frequency.

The solution of such an equation is given in two parts: partial Xp and the complementary:

$$Xp = A \sin \omega t + B \cos \omega t$$

We now attempt to find the values of A and B. Consider the two equations:

$$X_p = A\omega Cost - B\omega Sin\omega t$$

and

$$X_p = (-A\omega^2 Sin\omega t - B\omega Cos\omega t)$$

By substitution:

$$m(-A\omega^2 Sin\omega t - B\omega^2 Cos\omega t) + C(A\omega Cos\omega t - B\omega Sint) + k(A sin\omega t + B cos\omega t) = F_o Sin\omega t$$

Equating coefficients of the sine and cosine terms separately:

$$A(k - m\omega^2) + B(-c\omega) = F_o$$
$$A(c\omega) + B(k - m\omega^2) = 0$$

$$A = \frac{F_o(k - m\omega^2)}{(k - m\omega^2)^2 + c\omega^2}$$

$$B = -\frac{F_o(c\omega)}{(k - m\omega^2)^2 + (c\omega^2)}$$

We now display X_p as a pair of rotating vectors. (Fig. 4) Since B<0 (negative) it lags A by π/2:

$$\text{Now } X_p = R Sin(\omega t - \varphi)$$

Where:

$R = (A^2+B^2)^{1/2}$ and $\tan\varphi = -\frac{B}{A}$

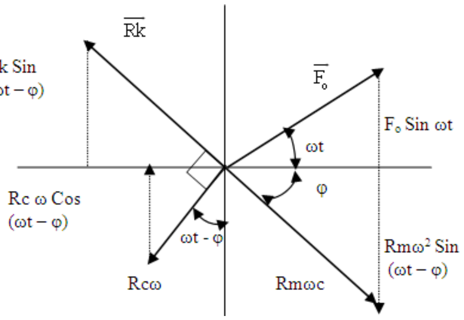


Fig. 4: Display of X_P as a pair of rotating vectors

From the values of A and B:

$$R = \frac{F_o}{\left\{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2\right\}^{1/2}}$$

and

$$\tan\varphi = \frac{cw}{k - m\omega^2}$$

The general solution for X where damping is critical is given by the equation:

$$X = e^{-\lambda t}\left(C_1 \mathrm{Sin}qt + C_2 \mathrm{Cos}qt\right) + \frac{F_o \mathrm{Sin}\left(\omega t - \phi\right)}{\left\{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2\right\}}$$

Where:

$$\lambda = \left(c / 2m\right)$$

and

$$q = \left\{\left(\frac{k}{m}\right)^2 - \left(\frac{c}{2m}\right)^2\right\}$$

C_1 and C_2 are constants related to A and B as:

C_1 = A+B and C_2 = (A-B) i, I = $(-1)^{1/2}$

Consider:

RSinφ = A+B = C_1 and RCosφ = (A-B) I = C_2

Then the first part of the equation can be expressed in the form:

$$X_1 = e^{-\lambda t}\left(C_1 \mathrm{Cos}qt + C_2 \mathrm{Sin}qt\right) = e^{-\lambda t}\left(R\mathrm{Sin}\phi \mathrm{Cos}qt + R\mathrm{Cos}\phi \mathrm{Sin}qt\right)$$

$$\frac{C_1}{C_2} = \frac{A + B}{\left(A - B\right)i} = \frac{R\mathrm{Sin}\phi}{R\mathrm{Cos}\phi} = \tan\phi$$

and

$$\left(A + B\right)^2 + \left\{\left(A - B\right)i\right\}^2 = R^2\left(\mathrm{Sin}^2\phi + \mathrm{Cos}^2\phi\right) = R^2$$

or

$$C_1^2 + C_2^2 = R^2 \text{ or } R = \left(C_1^2 + C_2^2\right)^{1/2}$$

and the equation can be written in the form:

$$X_1 = e^{-\lambda t} R\mathrm{Sin}\left(qt + \phi\right) = e^{-\lambda t}\left(C_1^2 + C_2^2\right)^{1/2} \mathrm{Sin}\left(qt + \phi\right)$$

and the general solution of the equation is:

$$X = e^{-\lambda t}\left(C_1^2 + C_2^2\right)^{1/2} \mathrm{Sin}\left(qt + \phi\right) + \frac{F_o \mathrm{Sin}\left(\omega t + \phi\right)}{\left\{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2\right\}^{1/2}}$$

The first term of the equation is the transient function and the second term is the complementary function. The transient solution will, for practical purposes vanish in finite time. Now we get back to the original differential equation where:

$$m\ddot{x} + c\dot{x} + kx = F_o \mathrm{Sin}\omega t \Rightarrow F_o \mathrm{Sin}\omega t - m\ddot{x} - c\dot{x} - kx = 0$$

Also:

$$x = R\mathrm{Sin}\left(\omega t - \phi\right)$$
$$\Rightarrow \dot{x} = \omega R\mathrm{Cos}\left(\omega t - \phi\right)$$
$$\ddot{x} = -\omega^2 R\mathrm{Sin}\left(\omega t - \phi\right)$$

We know that in equilibrium:

$F_o \mathrm{Sin}\omega t \rightarrow$ Disturbing Force

$-m\ddot{x} = Rm\omega^2 \mathrm{Sin}\left(\omega t - \omega\right) \rightarrow$ Inertia Force

$-c\dot{x} = -Rc\omega \mathrm{Cos}\left(\omega t - \phi\right) \rightarrow$ Dumping Force

$-kx = -Rk\mathrm{Sin}\left(\omega t - \phi\right) \rightarrow$ Spring Force

All the forces as they exist in equilibrium can be displayed as a set of rotating vectors (Fig. 5).

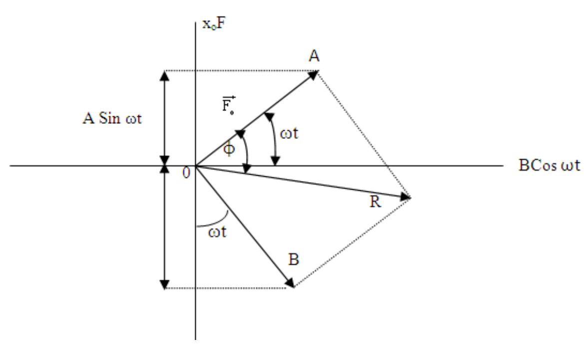
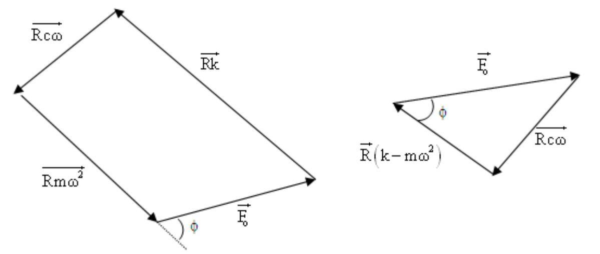


Fig. 5: Display of the forces in equilibr\ium



(a) (b)

Fig. 6: (a): A closed polygon of the forces; (b): Their resultant

The forces can be considered as a set of concurrent forces in equilibrium rotating with a constant angular velocity ω. We may draw a force polygon as shown below. The force polygon must close. (Fig. 6, a) The lower force polygon is the result of combing the collinear terms Rk and $Rm\omega^2$ (Fig. 6. b) and:

$$\Rightarrow R = \frac{F_O}{\left\{\left(k - m\omega^2\right)^2 + \left(c\omega\right)^2\right\}^{1/2}}$$

and

$$\tan\phi = \frac{c\omega}{k - m\omega^2}$$

Now returning to R, let us divide numerator and denominator by k from which we can say:

$$R = \frac{\frac{F_o}{k}}{\left\{\left(\frac{k - m\omega^2}{k}\right)^2 + \left(\frac{c\omega}{k}\right)^2\right\}^{1/2}}$$

Also for tanφ, let us divide the numerator and the denominator by ω_n-the natural frequency of the un-damped system from which we can also say:

$$\tan\phi = \frac{c\left(\frac{\omega}{\omega_n}\right)}{\frac{k}{\omega_n} - \frac{m\omega^2}{\omega_n}}$$

We now define a few quantities:

$\delta = \frac{F_o}{k}$ = Deflection of the spring under a static force F_o

$\omega^2_n = \frac{k}{m}$ = The square of the natural frequency of the undamped system

$c_c = 2m\omega_n$ = Critical damping constant for free oscillation

Then $k = m\omega^2_n$ and $m = \frac{c_c}{2\omega_n}$. Therefore,

$$k = \left(\frac{c_c}{2\omega_n}\right) \bullet \omega^2 = \frac{c_c\omega_n}{2} \quad \text{Also } \delta = \frac{F_o}{k}$$

Substituting these values into the equation for R:

$$R = \frac{\delta}{\left\{\left(\frac{k - m\omega^2}{k}\right)^2 + \left(\frac{c\omega}{k}\right)^2\right\}^{1/2}} = \frac{\delta}{\left\{\left(1 - \frac{m\omega^2}{k}\right)^2 + \left(\frac{c\omega}{k}\right)^2\right\}^{1/2}}$$

or

$$R = \frac{\delta}{\left[\left\{1 - \left(\frac{\omega}{\omega_N}\right)^2\right\}^2 + \left\{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega_n}\right)\right\}^2\right]^{1/2}}$$

Also

$$\tan\phi = \frac{c\omega}{k - m\omega^2} = \frac{c\omega}{m\omega^2{}_n - m\omega^2}$$

Dividing both numerator and denominator by $m\omega^2_n$ we have:

$$\tan\varphi = \frac{\frac{c\omega}{m\omega_n^2}}{1 - \left(\frac{\omega}{\omega_n}\right)^2} = \frac{\left(\frac{c}{m\omega_n}\right)\left(\frac{\omega}{\omega_n}\right)}{1 - \left(\frac{\omega}{\omega_n}\right)}$$

$$\text{But } c_c = 2m\omega_n \Rightarrow \omega = \frac{c_c}{2m}$$

$$\therefore \tan\phi = \frac{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega_n}\right)}{1 - \left(\frac{\omega}{\omega_n}\right)^2}$$

We can regroup our main equation and say that:

$$\frac{R}{\delta}=\frac{1}{\left[\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}^2+\left\{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega}\right)\right\}^2\right]^{1/2}}$$

and

$$\tan\phi=\frac{c\omega}{k-m\omega^2}$$

The term R/δ is defined as the amplification factor. Both equations show that R/δ and φ are functions of ω/ω_n and damping ratio c/c_c

Also consider a resonance instance or state where $\omega = \omega_n$. It can be recognized that this results in infinite amplitudes for a system with no damping. However with damping present, maximum amplitudes occur at values of $\omega/\omega_n<1.0$. We employ calculus to find out when R/δ is maximum i.e., by differentiating R/δ with respect to ω/ω_n and equate to zero:

$$\frac{R}{\delta}=\frac{1}{\left[\left\{1-\left(\frac{\omega}{\omega_N}\right)^2\right\}^2+\left\{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega_n}\right)\right\}^2\right]^{1/2}}$$

$$\frac{d}{d\left(\frac{\omega}{\omega_n}\right)}\left\{\frac{R}{\delta}\right\}=-\frac{2\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}(-2)\left(\frac{\omega}{\omega_n}\right)+8\left(\frac{c}{c_c}\right)^2\left(\frac{\omega}{\omega_n}\right)}{2\left[\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}+\left\{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega_n}\right)\right\}^2\right]^{\frac{3}{2}}}=0$$

$$\Rightarrow\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}\left(\frac{\omega}{\omega_n}\right)=2\left(\frac{c}{c_c}\right)^2\left(\frac{\omega}{\omega_n}\right)$$

or

$$\frac{\omega}{\omega_n}=\left\{1-2\left(\frac{c}{c_c}\right)^2\right\}^{1/2}$$

RESULTS

Evidence has shown from our findings that in both methods, no component of the waste is recovered for recycling. This is contrary to the practice in the developed countries where waste recycling is a major undertaking to provide raw materials e.g. glass and metal for industries and thus reduces the exploitation of natural resources. To address the problem in Ghana it is necessary to devise a means of sorting-out the components of domestic waste for recycling into useful components.

DISCUSSION

As indicated in the abstract and the introduction the problem of disposal of domestic waste or garbage among other types of waste has been a pertinent problem in Ghana and other developing or so called third counting. Aside rubbish scattered everywhere in the entire environment, one can locate heaps of the garbage situated everywhere in the communities. This has been a major problem the district, municipal and the metropolitan authorities as well as the central government have to grabble with. The best being done so far is to mobilize a few waste equipment, which are already under stress or engage some private agencies to clear the heaps out of town and take them to destinations, where even worse problems associated with the waste, are rather created. This is evident with the fact that the issue of domestic waste or garbage disposal has been an issue which always crop up in mass, print and electronic media every day.

Research has shown that there are already existing machines which can generate energy from domestic waste. There are others which can produce utensils from polythene materials. However three are no machines which can sort out such non-degradable polythene and other materials from the heaps of the domestic waste which have been lying down there for decades. These heaps of domestic waste or garbage do not only remain an eyesore in the communities, but have been a great threat to the health of everybody in the communities who are vulnerable to dreadful diseases. The design of a simple machine which gas been outline in this study is believed to solve this problem. It is designed on the basis of manual sorting of this domestic waste or garbage into the various components in percentage by volume as indicated in Table 1. It will be a very cost-effective, efficient and reliable, simple machine which can be manufactured and maintained by local artisans. It will only require a simple prime mover as a two-stroke engine to power its mechanisms which will perform some motions of a few degrees of freedom and vibration, as analyzed in the text. We recommend the manufacture of the this machine to investors and entrepreneurs, but we ourselves will attempt to carry out this manufacture of this machines first as a prototype on pilot basis and later on duplicate and/or improve upon it.

CONCLUSION

This study considered the design of an efficient and cost-effective machine, which is capable of sorting out garbage into the various components which can be recycled or used in generating energy.

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