IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Design of a Flexible Automated Bottle Filling Machine

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ABSTRACT

Over the past years automation has impacted a wide range of industries beyond manufacturingthrough the reduction of production time, improved system performance and process control. Recently Zimbabwe has seen a rise of small scale producers of liquid products which include detergents, liquid soaps, fruit juices, milk products and bottled water. Manual filling methodsbeing used are resulting in low production outputs and losses through spillages. The procurement of state of art bottling systems is cost prohibitive as most systems are designed for large scale industries. This paper describes the design of a low cost flexible automated bottle filling machine capable of filling two different volumes. The machine was designed accordingto the VDI 2206 guidelines for mechatronic systems design. Modelling and simulation was used to determine the most suitable material, transfer system and filling mechanisms for the machine. A conveyor based transfer system was developed coupled to a filling unit which fillsfour bottles at a time. Developed control algorithms were implemented on an Arduino Due microcontroller platform. System integration resulted in a physical prototype being produced.Tests were carried out on the designed machine validating the functionality of the machine. The designed machine could fill 600 bottles in an hour.

Key Words: Automation, Bottle filling machine, VDI 2206, Arduino, Mechatronics

1. INTRODUCTION

From 1900s companies have evolved from regional firms that mainly produced for local markets, to today's corporate giants that make products for international markets. This shift began as companies in the manufacturing sector adopted mass production techniques and processes. In developing countries, the production of beverages, milk, mineral water and

cooking oil is a major support of the entire economy. Despite the tough economic situations Zimbabwe has seen a growth in its liquid handling industry in the past years, for example in the year 2015, 67 bottled water companies were registered (Gumbo, 2015). Statistics also show asteady increase in the number of smallholder milk producers (Chamboko & Mwakiwa, 2016) (Reporter, 2015). An increase in the number of Small to Medium Enterprises (SMEs) that process beverages, post-harvest of fruits and liquid soap has also been observed. SMEs are the engine of economic growth and are essential for a competitive and efficient market with research showing that they are critical for poverty reduction and can play a particularly important role in developing countries (Seda, 2012). However the Zimbabwean liquid handlingindustry still has a low capacity utilization, less than 40% with working capital and antiquatedmachinery and machine breakdowns capacity constrains being 32.3% and 11.4% respectively(CZI, 2013). High costs incurred in the procurement of liquid processing equipment are contributing to these constrains. Equipment for liquid processing includes bottle filling machines. The average cost of procuring a bottle filling machine is beyond the reach of most SMEs with secondhand hand machines averaging USD 20 000. Other SMEs resort to manual methods of filling which are tedious and time consuming (an average of 5 bottles per minute) and are subject to losses due to spillages.

Enormous strides have been made in the last twenty years on the size, speed, quality of performance and complexity of bottle filling machines. One of the key requirements of a fillingmachine is that the containers must be filled as quickly as possible with an accurate quantity of the product (SYSTEMS, 2009).

Different systems and technologies may be used in filling machines though principally these may be divided into three categories: filling by level sensing, using volumetric flow meters andby weight. (Bolzoni, et al., n.d.) Filling systems also exist that makes use of specific period oftime to control a flow of liquid into the respective containers (COCHRAN, et al., 2009). Fillingmachines generally fill bottles at a specified rate however other machines vary production ratesso as to cater for high demand. Such designs introduce challenges in belt speed control and research is being done to introduce variable speed conveyor assemblies (Sagar & Sanjay, 2014).

On the other hand decreasing the belt speed results in energy savings, increase in the lifetime of belt conveyor components such as the conveyor belt and idler rolls (Lodewijks, et al., 2012).Other design constrains for bottling machines include the filling rates, product changeover times and filling accuracies (SYSTEMS, 2009).The design of a bottle filling machines is multidisplinary in nature as aspects that relate to mechanical, electrical and software engineering are synergized. This paper describes the design of a flexible bottle filling machinesaccording to the VDI 2206 design guidelines for mechatronic systems toward constrains suchas higher performance, speed, precision, efficiency and lower costs.

2.OBJECTIVES

2.1 Main Objective

To design a bottle filling system that fills two different volumes at SME's production rates

2.1.1 Specific Objectives

- To design an automated bottle filling system capable of filling 2 different volumes without reconfiguration
- To design an automated transfer unit for the filled bottles
- To design and integrate control algorithm for the transfer unit and the filling system

3.METHODOLOGY

The design of a bottle filling machine is expected to exhibit synergy and integration towards constrains such as higher performance, speed, precision, efficiency, lower costs. The mechatronic system design process addresses these challenges following an interdisciplinary design procedure, with evaluation, integration, and optimization of the system and all its sub- systems and components as a whole and concurrently with all the design disciplines working in parallel and collaboratively throughout the design and development process to produce an overall optimal design (Farhan, 2013). The VDI 2206 (2003) design methodology for mechatronic systems guideline worked out by the committee of the Association of German Engineers (VDI) which was adopted in the design of the bottle filling machine. The main elements that are presented for the procedural model as a part of the guideline for the VDI 2206are:

- A general cycle of problem solving on the micro-level,
- V-shaped model on the macro-level, (figure 2)
- Macro-cycles according to the degree of maturity
- User specific process modules for recurring operation step

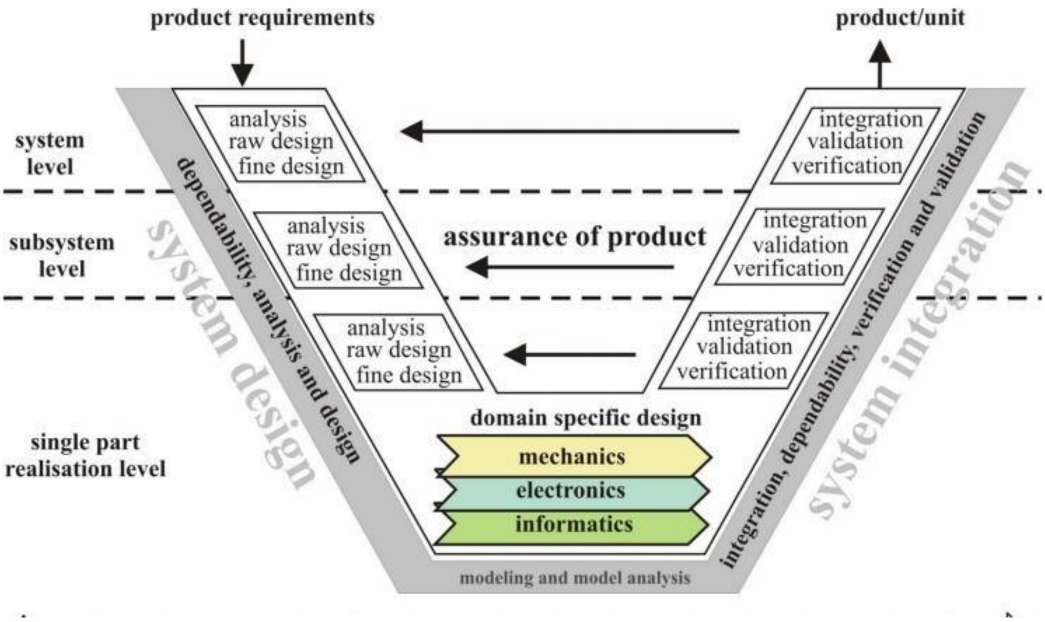


Figure 1 V-shaped model on the macro-level

3.1 Systems Design

In the design of the bottle filling machine the problem was summarized as follows: Liquid processing SMEs are not maximizing profits due to losses from poor filling methods andlow production outputs with the procurement and maintenance of state of art being filling machines being cost prohibitive. The design task was then clarified and described through theuse of requirements. These requirements will also be used in the evaluation of the final product.Table 1 shows the narrative requirements list.

It should fill bottles of different volumes (0.5L and 1L) and height (150mm and 300mm) at a rate of 0.083l/s i.e. 1L in 12s.
It should fill 300 bottles of 1L in an hour and 600 bottles of 0.5L in an hour
The system should not operate if the bottle has been removed or fallen during conveyance or filling.
The conveyor should move at 0.10m/s to avoid dynamic instability
Bottle detection and operation of the filling mechanism shall be within 2s-3s
The filling mechanism will have to extend for small bottles and retract for large bottles
It shall be a microcontroller based system
It shall require 12V/24V DC power for operation
It should be able to count the number of filled bottles
It should have a total weight of 20-60Kg
The machine must be portable occupying a volume space of not more than 10m3
It should be below $1500 manufacturing cost

Target market should be small enterprises
To operate with Newtonian fluids only
It should be compatible with PEP, Metal and Glass bottles
It should have a continuous operation for 12 hours.
The system has two position sensorsthat detect the mouth of the bottle in relation to their heights

Table 1: System Requirement

A cross domain solution concepts was then formulated describing the characteristics of the product is shown in Figure 2.

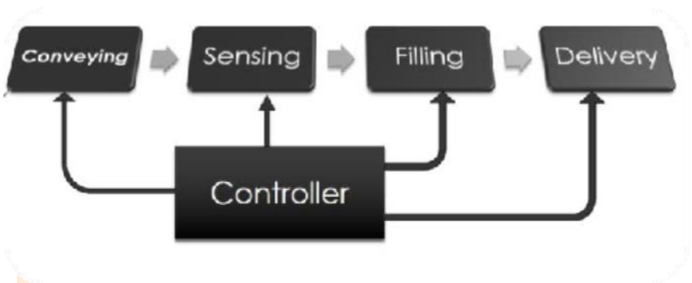


Figure 2 –Solution Concept

The identified subsystems for the machine are the conveyor, sensing, filling, delivery and control unit. In the respective domain suitable solution elements are then assigned to these subfunctions with the overall system context in mind. Design in the mechanical, electrical and software domains was then carried out accompanied by appropriate modelling and simulationactivities.

3.2Mechanical Domain

In this domain the mechanical components were designed the aid of SolidWorks computer- aided-design (CAD) software with appropriate material selection carried out. The design of thesubsystems had to be modular for ease of maintenance. Finite element analysis was used for dynamic tests putting the stability, overall weight and strength of the structure in consideration.SolidWorks was also used in carrying out simulations for evaluation of the possible

configurations for the conveyor and filling systems. A conveyor system driven by DC geared motor was selected with a filling unit which delivers the liquid to four bottles through a distributor being settled for. The working drawings for the mechanical structure are shown in figure 3.

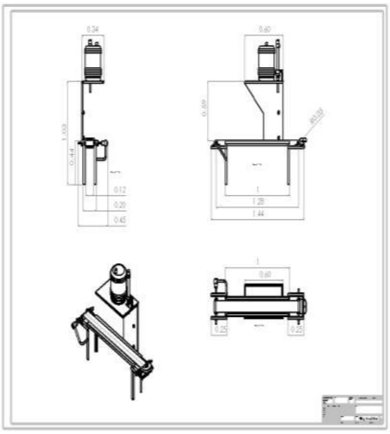


Figure 3-Working Drawings

3.3Electrical Domain

With aid of cross domain communication, appropriate design calculations were carried out so as to determine the appropriate electrical components. Sensor selection, proper sizing and selection of the actuating devices, determination of the interfacing devices between controllersensors and actuators was also done. For example, in order to size the geared motor, the following parameters had to be identified: the speed required to drive the application per its specifications, reflected acceleration torque, reflected friction torque, reflected breakaway torque, reflected gravity torque, continuous torque and horsepower needed for the application outlined in (Admin, 2013). Finally using motor Speed – Torque characteristic curves a 12V DCgear motor, 40 rpm 0.3 horse power, 0.2NM starting torque. The L293N motor driver modulewas selected.

Calculation for pump selection was carried out according to the following criterion:

3.2.1. What is required/desired flow (GPM)

3.2.2 Determine the Total Dynamic Head TDH

3.2.3 Consult Pump Curve(s)

3.2.4 Select wire size

Required/desired flow = 1.3GPM=5l/min

Now to determine (TDH):

Friction loss = (6.6 ’ X 2.67’/100’) + (2 ’ X 6/100’) Friction loss = 0.176’ + 0.12’Friction loss = 0.296’ Head Pressure

Calculating TDH:

TDH = pumping level + vertical rise + friction lossTDH = 1.98’ + 4.62’ + 0.296’

TDH = 6.896’ (2.09m)

From the TDH and required/desired flow, a pump can be selected from a performance curve.The list of electrical components included:

3.2.1 Arduino Due

3.2.2 IR Sensor Module

3.2.3 L298n Dual H Bridge Module

3.2.4 -Channel Relay Module (5v Coil 12-220vdc)

3.2.5 Water 12v Plastic Solenoid Valve

3.2.6 Submersible Pump 12vdc

3.2.7 5/2 Way Solenoid Electro-pneumatic Valve

3.2.8 Double Acting Cylinder

3.2.9 24vdc 10a Gear Motor

3.2.10 3.2.10 24v 2a Gear Motor

Proteus design suit was then used to develop the circuit schematic for simulation.

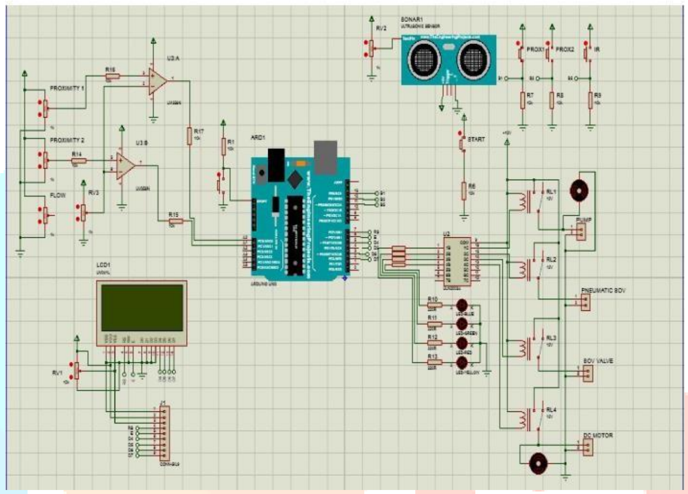


Figure 4-Circuit Schematic

Software Domain

A control algorithm for the system was developed using Arduino Integrated Design Environment (IDE). The algorithm developed followed the flow sequence as show in Figure 4. Development of the algorithm as was also such that it should match the selected electrical components. To properly position the bottles at the filling unit a PID algorithm was incorporated. The control flow chart is shown in figure 5.

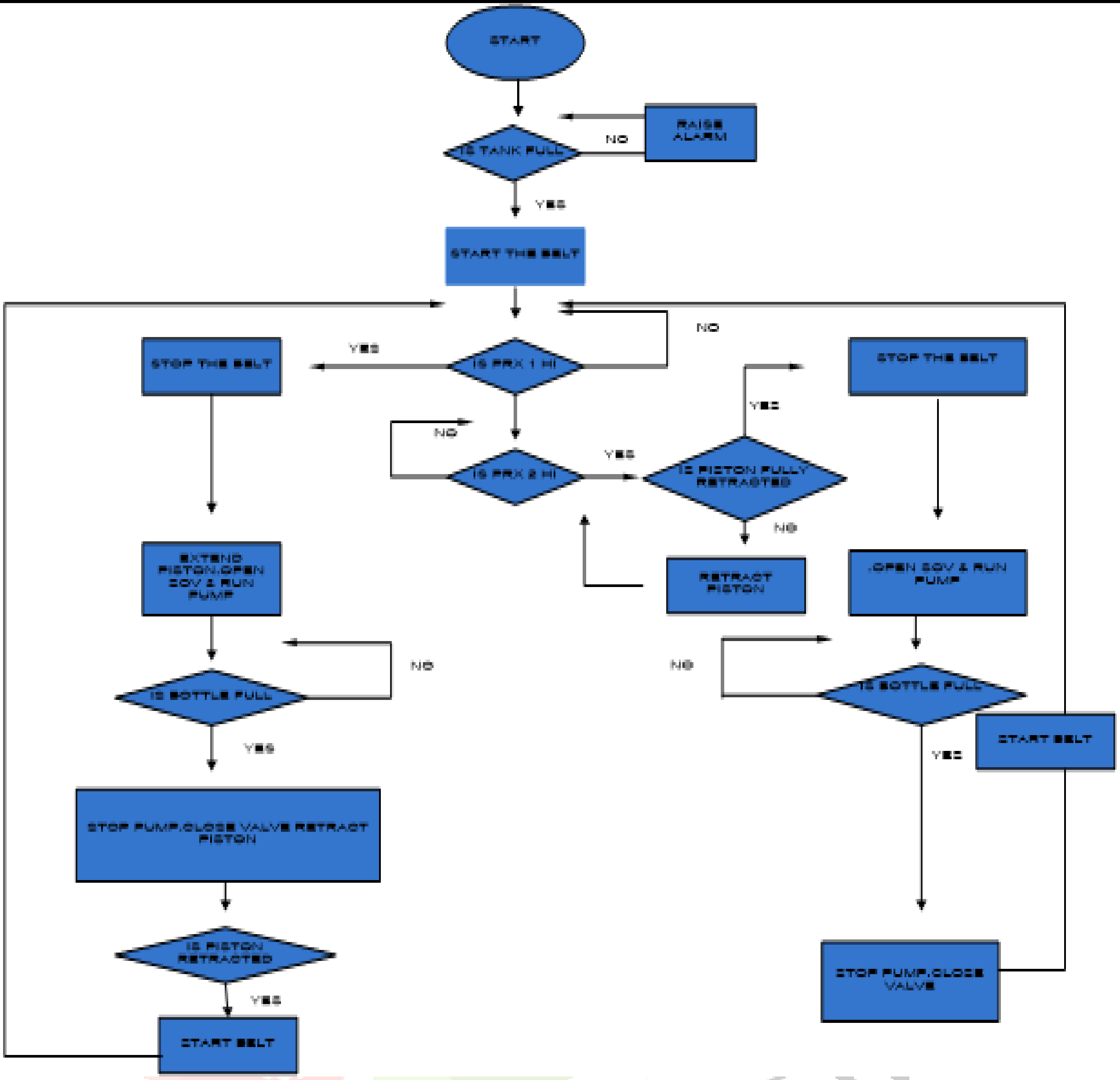


Figure 5-Control Flow Chart

4. RESULTS

4.1 Deflection Test

Deflection tests were carried out for both aluminum and steel as shown in figure 6 and 7respectively. The steel proved that it has a less deflection than aluminum alloy. Steel: 5.8mm maximumdeflection. Aluminum: 16 mm maximum deflection.

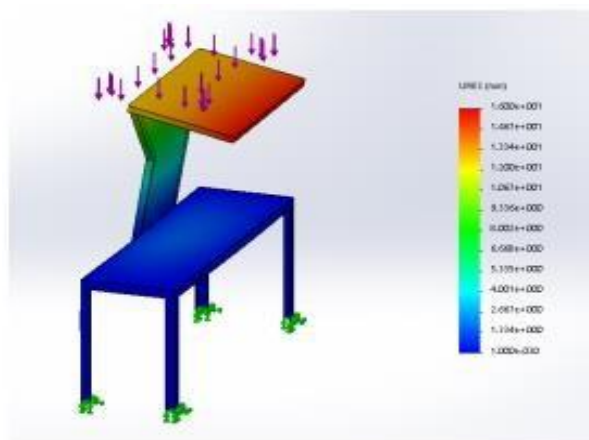
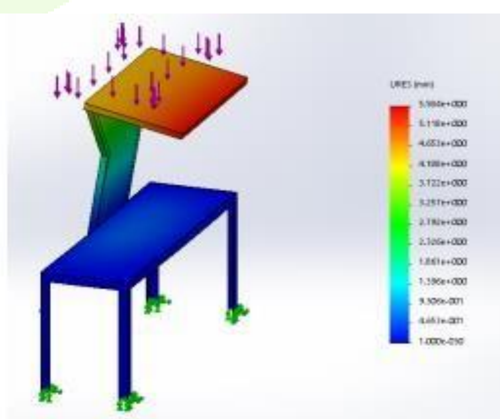


Figure 6-Aluminium 1060 under deflection

4.2 von Mises



5 Figure 7-Steel under deflection

von Mises yield criterion to predict yielding of was carried on both the aluminum and steel as shown in figure 8 and 9respectively.

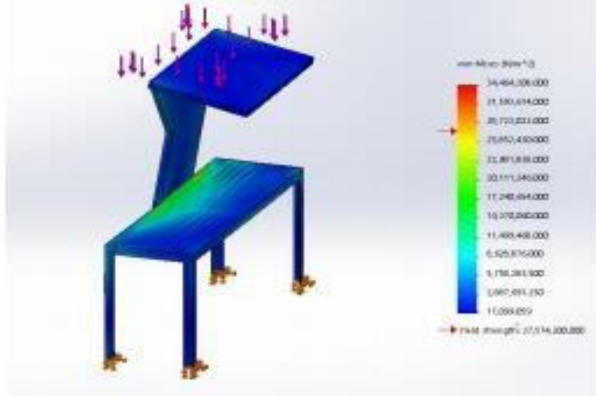


Figure 8-von Mises for Aluminum Alloy 1060

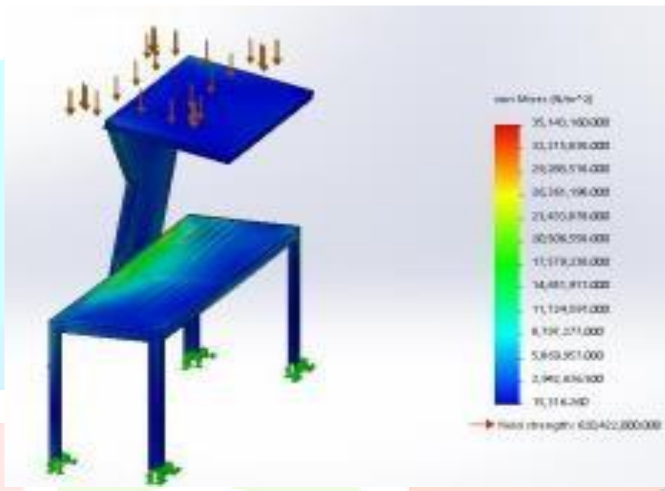


Figure 9-Von Mises for Steel

The von Mises shows good results for all the materials.Steel: 34 000 000 N/m^2

Aluminium: 35 000 000 N/m^2

For both the deflection and von Mises tests steel had a better score therefore it was used in thedesign of the frame

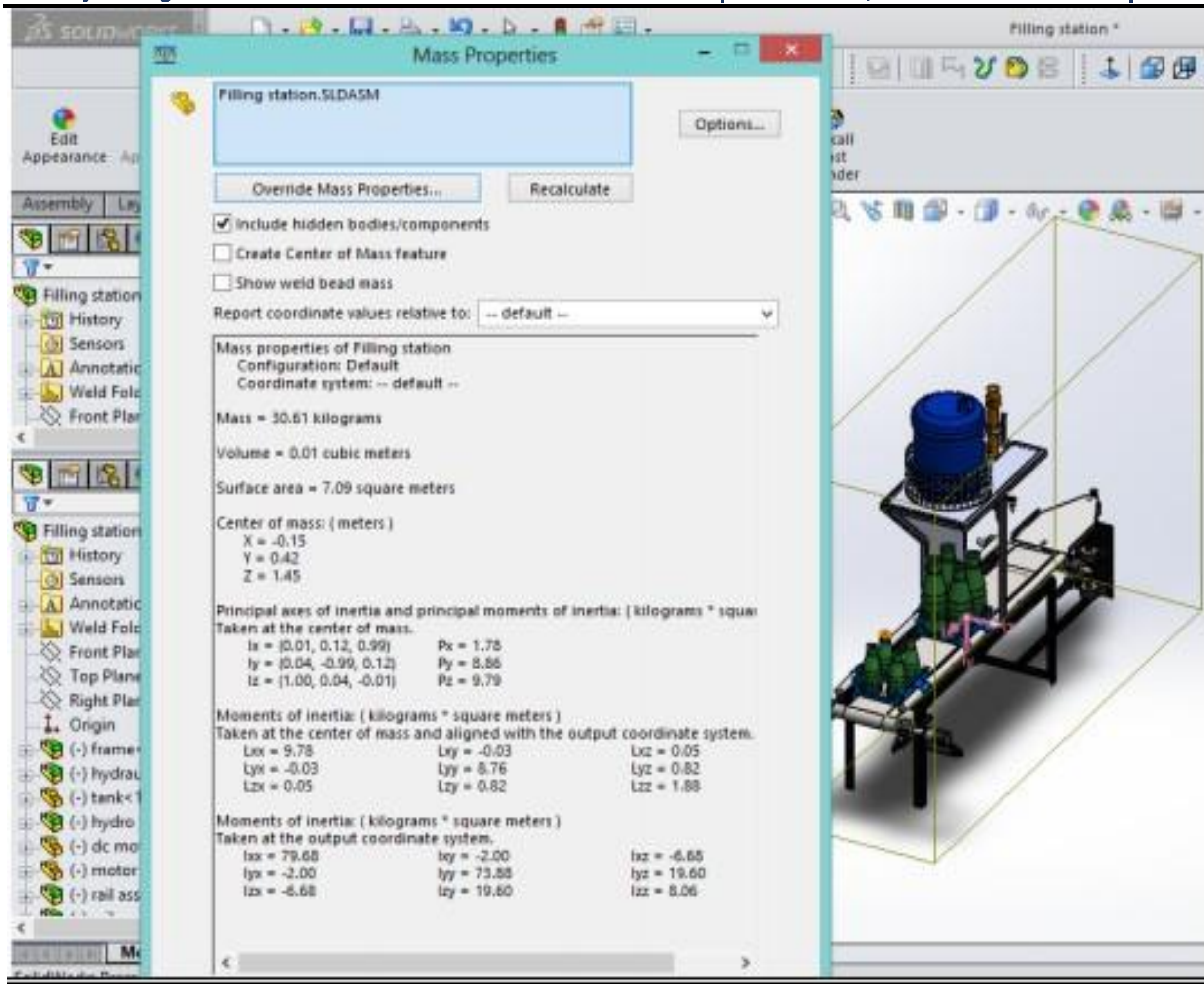


Figure 11-Mass properties analysis

The mass properties analysis shown in figure 10 showed that the machine weighs 50Kg whichis within the acceptable range according to the design requirements

CONCLUSION

The main objective of the project was to develop a low cost bottle filling system capable fillingtwo different volumes and this was achieved. The machine was designed using locally availablematerials adding value to them and which allows ease commercialization and development forthe Zimbabwean SMEs. The modularized design allows ease in maintainability of the machine.The machine is also portable and occupies a small volume space thus can be accommodated in

the work space of SMEs without need for larges industrial structures. According to the VDI 2206 other design cycle can be carried out so as to mitigate deviations observed from the testscarried out.

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